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Valuing the Benefits of Nature-Based Solutions

A Manual for Integrated Urban Flood Management in China

Marcus Wishart, Tony Wong, Ben Furmage, Xiawei Liao,
David Pannell, and Jianbin Wang



Contributors

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A Manual for Integrated Urban Flood Management in China

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Executive Summary



Floods are the most frequent of all natural hazards and responsible for causing more damages than any other disasters. Globally, floods are estimated to have affected more than 2 billion people between 1998 and 2018, accounting for 45 percent of all people affected by disasters during that period with an estimated 142,088 fatalities. The immediate impacts of flooding include the loss of human life, livelihoods, damage to property, destruction of crops, loss of livestock, disruption of services, and deterioration of health conditions owing to waterborne diseases, among others. The direct economic losses caused by flooding over the last decade are estimated at US$ 656 billion, although these are systematically under-reported and actual values are likely much higher. When accounting for intangible impacts on human well-being, natural disasters are thought to cost the global economy in excess of US$ 520 billion a year.

Increasing exposure to floods and changing climate conditions are expected to result in increasing damages. This increase in exposure is being driven by continued population growth and urbanization, sustained economic growth and growing prosperity, compounded by the effects of a changing climate. Changes in climate are expected to alter water regimes, both in terms of availability and variability, as well as many of the factors that affect the frequency and severity of flood events, such as precipitation and run-off, and sea levels. It is estimated that approximately 1.3 billion people (or 15 percent of the global population) will live in flood-prone areas by 2050. Given the substantial uncertainties embodied in climate change projections there is increasing recognition of the need for more robust approaches, reflected in the increasing use of scenario planning and more holistic resilient approaches to flood management compared to more traditional control and reduction approaches. An Integrated Urban Flood Management (IUFM) approach takes a whole catchment perspective that considers a broad range of social economic and environmental objectives. It values the full range of direct and indirect costs and benefits from blue, green, and grey solutions and balances actions before, during and after the flood event across retreat, adapt and defend strategies.

China is among the world's most highly exposed countries to floods, which is expected to worsen under future climate change. More than 67 percent of the population is located in flood-prone areas. Recorded flood losses in China have more than tripled from about US$ 7 billion per year in the 1980s to approximately US$ 24 billion per year in the 2000s, with the largest annual damage recorded in 2010, amounting to a total loss of US$ 51 billion. On average, floods are estimated to result in losses equalling to 1 percent of Chinese GDP every year. According to the Global Climate Risk Index for 2017, China is ranked high as the 31st most affected country in the world by climate-related disasters. Preliminary estimates suggest that the most recent floods in southern China during the summer of 2020 have caused direct economic losses of US$ 25.87 billion, without accounting for the secondary cascading effects on the economic flows and outputs. Under different climate change scenarios, precipitation associated with a maximum five-day rainfall event is projected to increase in the Central, Southern, and Eastern regions of China. Without large-scale structural adaptation, China is expected to suffer the highest direct economic losses globally over the next 20 years, increasing by 82 percent above current levels.

Rapid urbanization and associated land use changes are driving increasing risks of urban floods in China. Urbanization typically increases impermeable land surface areas, which reduces infiltration and increase surface runoffs and peak discharges during storm events. Urban microclimate and urban heat island effects are likely to cause more thunderstorms. Meanwhile, increasing numbers of people and assets are being exposed to flood risks due to continued migration to densely concentrated urban areas. From 1978 to 2018, China's urbanization rate increased from 17.9 to 59.6 percent, with the number of people living in urban areas growing from 172.45 million to 831.37 million. By 2030, the urban population is expected to account for 70 percent of the total population. Flooding is already a regular occurrence in 641 of China's 654 largest cities and a survey by the Chinese National Statistic Bureau shows that 62 percent of Chinese cities experienced floods from 2011 to 2014 with the direct economic losses amounting to as much as US$ 100 billion. Preliminary estimates suggested that severe flooding in Hubei Province in July 2020, where the COVID-19 outbreak started, have caused economic losses of over US$ 3 billion.

In response to the challenges of urban flooding, China introduced the Sponge City Initiative in 2014. This approach integrates nature-based solutions (NbS) in combination with, and as complementary to, traditional grey infrastructure and non-structural approaches to urban flood management. This approach leverages the use of 'blue' and 'green' spaces in the urban environment to address surface-water flooding, attenuate peak run-off, improve purification of urban runoff, and enhance water conservation. Sponge City interventions use natural or semi-natural measures to mimic natural water cycles, such as soil percolation and bio-filtration, to mitigate the effects of human development. Such interventions include permeable roads and parking lots, vegetated rain gardens, green roofs, constructed wetlands, among others. By 2030, China aims to have 80 percent of urban areas across the country sponge-like, in line with the objective of SDG 11 to "make cities and human settlements inclusive, safe, resilient and sustainable". Thirty pilot cities were selected in 2015 and 2016 by a working group from the ministries of Finance (MoF), Housing and Rural-Urban Development (MoHURD) and Water Resources (MWR) to pilot the construction of Sponge Cities.

The Sponge City Initiative reflects a global transition toward integrated urban flood management approaches that increasingly leverage nature based solutions. The IUFM approach combines both structural and non-structural solutions, leveraging both grey and green infrastructure to mitigate the impacts of urban flood and inundation risks. Many global practices have emerged that support the concept of IUFM, including Water Sensitive Cities (WSC) in Australia; Low Impact Development (LID) in the US and Canada; Sustainable Drainage Systems (SuDS) and the Blue-Green Cities (BGCs) approach in the UK; Active, Beautiful, Clean Waters (ABC Waters) programme in Singapore; and the Room for the River approach in the Netherlands. The common element across all these is the integration and adoption of NbS to complement the traditional engineering approaches. The 2018 United Nations World Water Development Report called on countries to scale up the adoption of NbS to mitigate water-related risks, especially under the prospects of a changing climate. The Global Commission on Adaptation's landmark report, *Adapt Now*, also calls for governments and companies to significantly accelerate action and investment in NbS.

The incorporation of NbS to IUFM provides the opportunity to realise a broader range of tangible and intangible social, economic and environmental cobenefits. By absorbing, filtering and slowing stormwater runoff, NbS can help mitigate urban floods and improve water quality. Furthermore, NbS provide a range of additional tangible and intangible benefits by enhancing natural ecosystems and improving the aesthetics of the urban environment for the people that live and work in them. Those benefits include, but are not limited to, enhanced resilience to future climate change, increased amenity values and increased utility and social values through providing urban green spaces and increased asset values. NbS often require lower capital investments than traditional grey infrastructure approaches and have substantially lower operating expenses. While there are significant uncertainties in predicting future climate change and their impacts in urban landscapes, NbS offers the potential to increase resilience and cope with future changes in climate through adaptive management. They are considered 'no-regrets' measures as they provide benefits even without climate change.

One of the main challenges in realizing the potential of NbS for IUFM at scale is effectively monetizing the range of cobenefits and internalizing future returns to leverage sustainable financing. While the technical solutions are relatively well established their implementation at scale has been limited by the inability to realize the values associated with the full range of benefits derived from NbS. These challenges are accentuated by the difficulties in attributing the derived benefits and allocating the cost of financing among an often-wide range of beneficiaries. Every IUFM context faces different issues, involves different solutions, has different sources of funding and access to different financing options. Furthermore, it is possible that the range of financing and funding options will increase over time as technologies advance, governments undertake policy, institutional and industry reforms, and local capability increases. It is therefore important to have strategies for ensuring: (i) a broad range of possible finance sources is considered; (ii) the chosen financing approach responds to the unique attributes of NbS; (iii) benefits and costs are allocated equitably and activities are funded fairly; (iv) that the decision making process is transparent; and (v) funding is efficient, effective and delivers project benefits over time.

While there are a range of potential sources of financing to support the integration of NbS for urban flood management, such investments continue to rely heavily on public funding. China's Sponge Cities have primarily been financed through central government transfers, with each pilot estimated to be receiving between US$ 57 and US$ 86 million per year for three consecutive years. The investment needed to scale up the program has been estimated at US$ 302 billion by 2020 and US$ 1 trillion by 2030, with the financing gap expected to be financed by provincial and local governments, financial institutions, together with the private sector and local communities. Achieving such scale requires a range of innovative financing options. While some conventional approaches, such as land and property taxes generate limited revenues, many of the fundamental elements for other innovative sources of financing are in place, with China having established the world's largest green bond market and a range of potential avenues for mainstreaming NbS.

This report outlines a comprehensive framework for valuing the benefits associated with NbS for IUFM in order to facilitate the identification of appropriate and sustainable financing mechanisms to realize those values. Traditional approaches of assessing the benefits of urban flood management have been focused on avoided losses due to reductions in the probability of flooding. A benefit to this approach is that it is simple to calculate and to explain to decision makers. It can also provide information regarding the optimal level of flood risk reduction associated to the direct intervention cost. However, such traditional approaches do not reflect the full range of social, environmental and economic benefits that can be realized by NbS for IUFM. Broader recognition of these benefits, and an evaluation of their value under different circumstances, provides the foundation for capturing non-market values and leveraging private sector and community financing options. The approach described herein builds on the "Principles for Valuing Water" articulated by the High-Level Panel on Water convened by the United Nations and the World Bank Group and includes three common types of flooding (i.e. fluvial, pluvial and coastal) through a five step process.

The first step is to understand the broader urban social-economic context within which flooding occurs, including the objectives and challenges faced by the specific location. Decision makers need to consider the social, economic and environmental impacts at multiple scales, including local, urban and catchment. The impacts need to be first determined by a flood risk assessment, combining both flood hazard assessment and flood vulnerability assessment. The primary outputs of a flood hazard assessment are the probability or frequency of occurrence, the magnitude and intensity of occurrence, and the average time between flood occurrence. Flood vulnerability is characterized as exposure and damage, quantifying the degree to which a system (in this case, people or assets) is susceptible to the adverse effects of floods and the resultant damage costs. Based on the flood risk assessment, a three-tiered IUFM framework is used based to inform appropriate strategies based on the principles of: (i) retreat, (ii) adapt, and (iii) defend.

The second step is aimed at systematically identifying the full range of flood management and mitigation interventions in the urban landscape. This includes the spectrum of 'grey' to 'green' to 'blue' infrastructure solutions, along with other non-structural measures. Traditional approaches to flood management promote flood defence and mitigation. They primarily address flood hazards through flood control infrastructure that largely involves conventional engineering structures, often referred to as "hard" engineering or "grey" infrastructure. Examples include dikes, levees, dams, pumping stations, diversion channels, stormwater sewer and drainage and related infrastructure. Integrated approaches are intended to complement grey infrastructure, increasingly leveraging a wide range of green or blue solutions, together with non-structural measures, including land use zoning, water-sensitive urban planning, flood management capacity building, community flood awareness raising, flood preparedness, early warning and response systems, among others.

The third step is to systematically identify the full range of potential social, economic and environmental benefits associated with the identified interventions. Twenty broad categories covering a wide range of environmental, social and economic benefits that can be derived from NbS for IUFM have been identified. Among these, environmental cobenefits of NbS include improvement in natural habitat, enhancing urban

biodiversity, improved water and air quality, reduction of heat-island effects and reductions in sediment and nutrient transport as well as eutrophication. Social cobenefits can include more active and connected communities, control noise pollution, improved psychological benefits and mental wellbeing, increased employment opportunities, including those jobs that are directly linked to the implementation of the NbS themselves. Economic cobenefits include improved local land and property values, increased tourism values, avoided losses and so forth. NbS can also contribute to the reduction of social inequalities, with urban floods often disproportionately affecting women, disadvantaged and marginalized groups, as well as the poor because of where they are located, the way floods disrupt their normal lives and the level of resilience they have to cope with and recover from flood events.

The fourth step evaluates the values associated with the benefits from NbS through a more comprehensive Benefit-Cost Analyses (BCA). IUFM practices provide tangible benefits that are easily quantifiable (e.g. avoiding flood losses). However, they also produce a range of tangible and intangible effects that can be difficult to quantify or monetize (e.g. biodiversity, the amenity benefits of having access to public green and blue spaces). While many studies have attempted to quantify a wide range of non-market values, these studies can be both expensive and time consuming. An alternative way is to apply the benefit transfer method to reasonably approximate values associated with certain benefits based on the existing literature. The Investment Framework For Economics of Water Sensitive cities (INFFEWS) valuation tool draws on a database of values to generate monetary values for non-market benefits. The current version of the tool contains more than 2,000 non-market benefit values across 20 different benefit types. The INFFEWS BCA Tool has been developed to provide a robust BCA based on sound economics, transparency, consistency and quality assurance mechanisms.

The fifth and final step is to identify appropriate financing options that can be used to realize the values associated with NbS for IUFM. The principle sources of funding are based on sustainable revenues derived from tariffs, taxes and or transfers that determine how investment costs are repaid over time while also supporting project life-cycle costs. Government has traditionally played a key role in providing economic and social infrastructure both as financier and by establishing the enabling polices and regulations. However, public investments alone are often not sufficient given the size of investment required to meet future challenges relating to managing urban floods. By facilitating the identification and valuation of a broader range of benefits, beyond only those of traditional flood management measures, the tools are able to better capture improvements in the urban landscape and provide opportunities to leverage a wider array of financing options that can help promote the application of nature based solutions and continuous improvements in the quality of life and urban landscape. Based on the nature of the potential benefits and beneficiaries identified, different financing mechanisms and sources can be adopted and leveraged. Private sector partners and community co-investment have the potential to unlock additional project value and revenue streams, increase the pool of potentially available fund and improve project efficiency.

The range of financing options to support NbS for IUFM are informed by the value of the direct and indirect benefits. These values are typically context specific and informed by the level of social and economic development, as well as the exposure to floods. Given the diversity of urban conditions in China, the realization of these values and the appropriate financing instruments will be further informed by both the affordability and collectability of the associated revenue streams. Where these are limited, government funding will continue to be important in promoting NbS for IUFM, particularly in lower income urban areas. However, government funding can be better deployed through targeted performance-based subsidies and conditional transfers. Such incentives can be used to shift expenditures from post-disaster responses to more cost-effective preventative measures, such as incorporating NbS into integrated urban planning and integrated spatial planning at the catchment scale. In higher income, well resourced urban areas a range of policy instruments can be used to encourage investments in NbS projects. Conventional revenues streams associated with property taxes remain limited to a few pilot cities and there is a need to explore other measures for generating local revenues in support of NbS for IUFM. These can include the establishment of special project vehicles

that can issue dedicated bonds that are marketed to institutional investors, the establishment of flood risk insurance facilities that can be used to develop a nationwide flood disaster risk pool, among other measures. Municipal governments can also use a range of policy instruments to encourage investments in NbS projects, particularly where land developers are identified as the major beneficiaries, such as specific requirements linking higher floor area ratios to commitments by developers to contribute to investing in NbS. Blended financing options can be deployed for middle income municipalities to facilitate the transition toward greener development models.



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Abbreviations

ATP	Adaptation Tipping Points
ABC Waters	Active, Beautiful, Clean Waters
API	Australian Property Institute
ARI	Annual Recurrence Interval
BCA	Benefit Cost Analysis
BCR	Benefit Cost Ratio
BID	Business Improvement District
BGCs	Blue-Green Cities
CRCWSC	The Cooperative Research Centre for Water Sensitive Cities
CoI	Cost of illness
CBRC	China Banking Regulatory Commission
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GAVP	Generally Accepted Valuation Principles
HSDRRS	Hurricane & Storm Damage Risk Reduction System
IUFM	Integrated Urban Flood Management
IPCC	Intergovernmental Panel on Climate Change
IUWM	Integrated Urban Water Management
INFFEWS	Investment Framework for Economics of Water Sensitive cities
KPI	Key Performance Indicator
LID	Low Impact Development
MoHURD	Ministry of Housing and Urban-Rural Development
MDBs	Multilateral Development Banks
NbS	Nature-Based Solutions
NPV	Net Present Value
NGO	Non-Government Organization
OECD	Organization for Economic Co-operation and Development
PPPs	Public Private Partnerships
PTSD	Posttraumatic Stress Disorder
RMB	Renminbi
SDG	Sustainable Development Goals.
SuDS	Sustainable Drainage Systems
SCP	Sponge City Program
USD	United States Dollar
USA	United States of America
UK	United Kingdom
UNEP	United Nations Environment Programme
USPAP	Uniform Standards of Professional Appraisal Practice
WSC	Water Sensitive City
WTP	Willing to Pay

1 The Challenge of Urban Flood Management



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This chapter provides an overview of the global challenge of urban floods, including those faced by China, and it introduces the transition toward integrated urban flood management and China's Sponge City Initiative.

1.1 The Global Challenge

Floods occur more frequently than any other natural disaster and cause more damage than any other weather- or non-weather-related phenomenon (see figure 1.1). The effects associated with floods have significant social and economic consequences for communities and individuals. Immediate effects include loss of human lives and livelihoods, damage to property, destruction of crops, demise of livestock, disruption of services, and deterioration of health because of waterborne diseases, in addition to numerous intangible effects. The magnitude of these effects depend on location, frequency, and duration of flooding; depth and speed of flood waters; vulnerability and value of the affected environments, both natural and constructed; and the resiliency, or capability of communities to recover quickly.

Globally, floods affected more than 2 billion people between 1998 and 2018, with 95 percent of these people living in Asia (CRED and UNISDR 2015). During this period, floods accounted for 45 percent of all people affected by disasters and caused an estimated 142,088 fatalities. Poor and marginalized people are typically more severely affected. They face greater exposure by living in marginal or unsafe areas such as those on floodplains or along riverbanks, and they have greater vulnerability because they are more likely to live in substandard housing and have uncertain landownership rights that provide no incentives for investing in risk reduction. Poor and marginalized households are also less able to absorb and recover from disasters; they rely on suboptimal coping mechanisms, have minimal savings, and lack access to formal credit mechanisms.

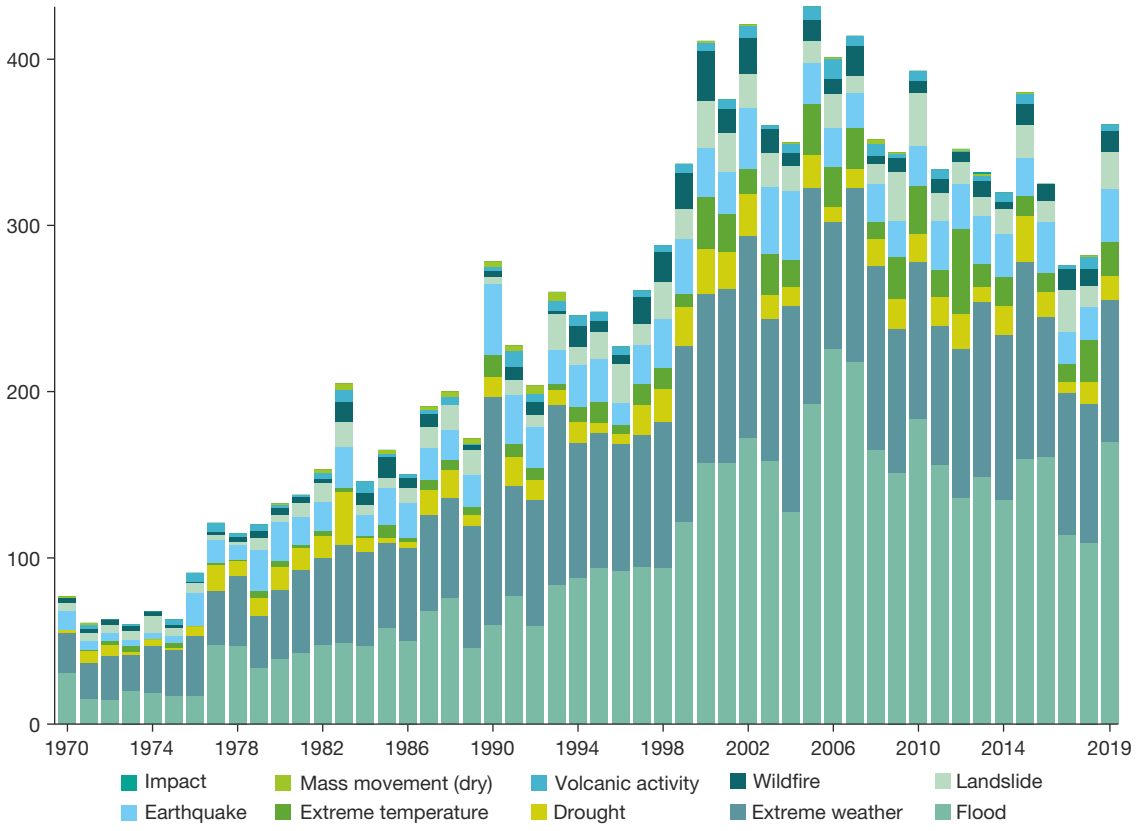
Estimates place the economic losses caused by flooding over the past decade at US$656 billion. However, the direct economic costs are systematically underreported, and the actual losses are likely to be much higher. The data on economic losses are only available for 37 percent of registered disasters; the direct cost of most disasters (63 percent) is unknown or not well documented. In China, economic losses are estimated to have reached over US$30 billion in 2017 alone; furthermore, the highest estimate of annual damage caused by flooding was recorded in China in 2010, with reported losses of US$51 billion (Kundzewicz et al. 2014). When accounting for effects on well-being, natural disasters cost the global economy an estimated US$520 billion per year (World Bank 2017), with vulnerable countries - and particularly their most disadvantaged communities - experiencing the heaviest burden.

The costs associated with flood-related damages are expected to grow, given increasing exposure to loss, changes in land use and climate uncertainties (figure 1.2). Increasing exposure to flood-related losses is being driven by continued population growth and economic expansion, along with growing prosperity and levels of development. Rapid urbanization and economic development have exposed larger numbers of people and assets to flood hazards, increasing vulnerabilities and the levels of risk. By 2050, it is estimated that approximately 1.3 billion people (or 15 percent of the global population) will live in flood-prone areas (Verwey, Kerblat, and Brendan 2017). As the number of people and the number and value of assets in flood-prone areas increase, so, too, does the exposure to loss, which will increase the economic damages from flood events. Short-term projections indicate that

the extent of urban areas exposed to flood hazards will increase 2.7 times by 2030 compared to 2000 (Güneralp, Güneralp, and Liu 2015). This suggests that the socioeconomic processes driving urban expansion are sufficient alone to increase the exposure of urban areas to existing flood hazards, without accounting for the effects of climate change. Long-term projections present a more dire picture. For example, it is suggested that the number of people affected by 100-year return period floods will increase in a warmer future; specifically, the number of people affected in China by high-end flood risks is expected to grow from 24 million in 2035 to 55 million in 2044 (Willner et al. 2018). This forecast highlights the need for significant flood protection to keep high-end fluvial flood risk at constant levels.

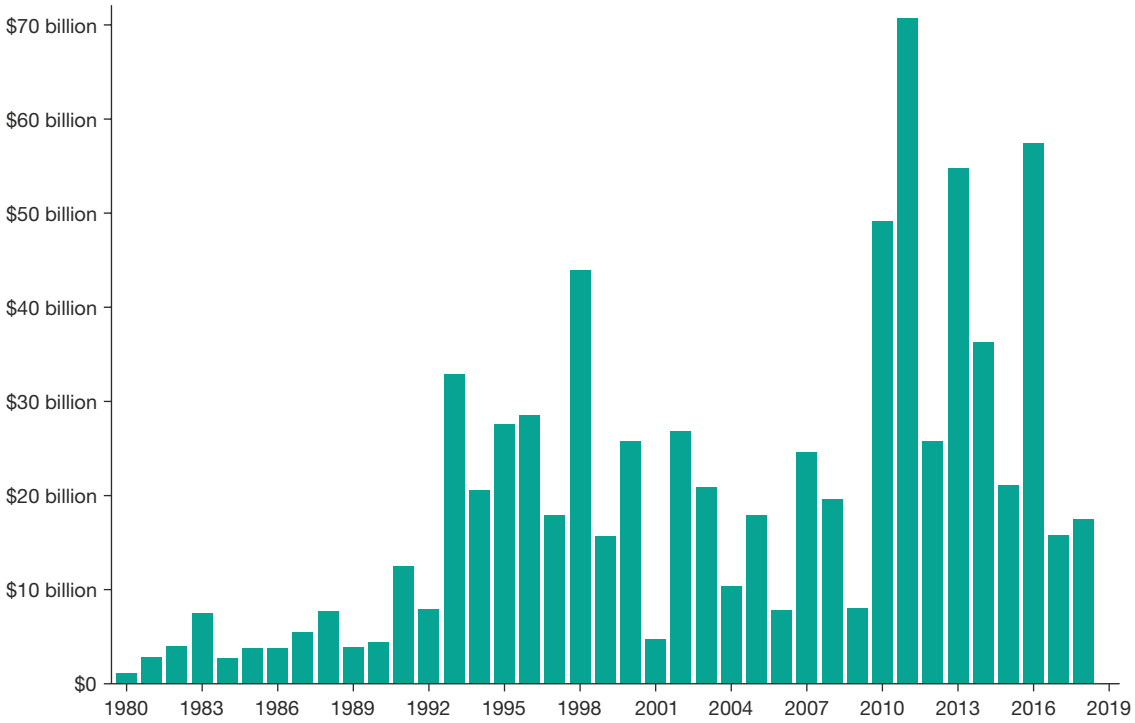
Rapid urbanization and associated land use changes are driving an increase in urban floods risks in China. Land use changes can significantly alter local processes driving the hydrological system, including modifications to flood characteristics, with urbanization resulting in a loss of drainage capacity caused by catchment hardening and increased flooding in urban areas. Urban microclimate and urban heat island effects are likely to cause more thunderstorms. Catchment hardening also increases the frequency, volume and peak discharge of storm runoff events. As urban areas expand, typically at the expense of forests and vegetated areas, the proportion of impermeable surfaces increases, which reduces infiltration and increases surface runoff. These landscape changes potentially increase peak discharges and flood magnitudes. In addition, urban development in flood-prone areas,

Figure 1.1: **GLOBAL REPORTED NATURAL DISASTERS BY TYPE, 1970 TO 2019**



Source: EM-DAT (OFDA/CRED International Disaster Database), Université Catholique de Louvain, Brussels (accessed 2020, OurWorldinData.org/natural-disasters).
Note: In 2018, 109 flooding disasters were reported, the most of any disaster type reported in 2018.

Figure 1.2: **DAMAGES AS A RESULT OF GLOBAL FLOODING DISASTERS, 1980 TO 2019, MEASURED IN CURRENT US$**



Source: EM-DAT (OFDA/CRED International Disaster Database), Université Catholique de Louvain, Brussels, Belgium (accessed 2020), OurWorldinData.org/natural-disasters.

particularly in informal settlements, often lacks adequate drainage, leading to regular flooding with disruptive consequences for local residents.

Changes in climate have the potential to alter many of the factors that affect the frequency and severity of flood events. These factors include precipitation, surface water levels, and sea levels. The Intergovernmental Panel on Climate Change's (IPCC's) assessments of global and regional climate changes and associated hazards indicated that many of these factors have changed and will continue to change (see table 1.1). These changes contribute to modifications in the frequency and intensity of flooding events (Hoegh-Guldberg et al. 2018). More extreme precipitation events, sea level rise, and cyclone intensification are likely to increase riverine, coastal, and urban flooding. This in turn can lead to widespread damage to infrastructure, settlements, and livelihoods, and to flood-related deaths, diseases, and injuries (Hijioka et al. 2018). More significantly, climate change and consequential increases in uncertainty in the estimation of flood probabilities have led to the development of flood mitigation strategies with emphasis on scenario planning and a broader city resilience approach compared with the traditional economic risk approach. Such scenario planning should include different development scenarios, including social, economic, and demographic changes within the catchment.

1.2 The Challenge in China

China is among the countries whose economy is most highly exposed to flood risks (map 1.1). More than 67 percent of the national population is estimated to live in flood-prone areas (World Bank 2019), which include

90 percent of China's large- and medium-size cities. In addition, about 35 percent of farmland and 80 percent of agricultural and industrial-added value are thought to be located in flood-prone areas (World Bank 2019). Rapid urbanization has facilitated an unprecedented economic transformation and a shift in the structure and expectations of Chinese society, with over 60 percent of the population, or more than 840 million people, living in cities in 2019 compared with less than 20 percent in the 1970s. A global flood risk assessment in 2013 pointed out that potential urban damages, affected population and agricultural values associated with flood risks in China made up significant shares of the global total (Ward et al. 2013). These figures are projected to increase; an additional 300 million people are expected to live in cities by 2030, placing the proportion of people living in cities at 70 percent. A similar relative increase in the urban population in Europe took place over more than 120 years. As a result of the high levels of exposure, flooding in China is estimated to cost on average about 1 percent of the gross domestic product (GDP) per year (Kobayashi and Porter 2012). Of the 654 cities in China, 641 were reported to be exposed to frequent flooding, with direct flood damage in more than 150 of these cities estimated in 2015 at US$22.5 billion (RMB 160 billion). A survey by the National Bureau of Statistics in China shows that 62 percent of the country's cities experienced floods from 2011–14, with the direct economic losses amounting to as much as US$100 billion (National Bureau of Statistics of China 2015).

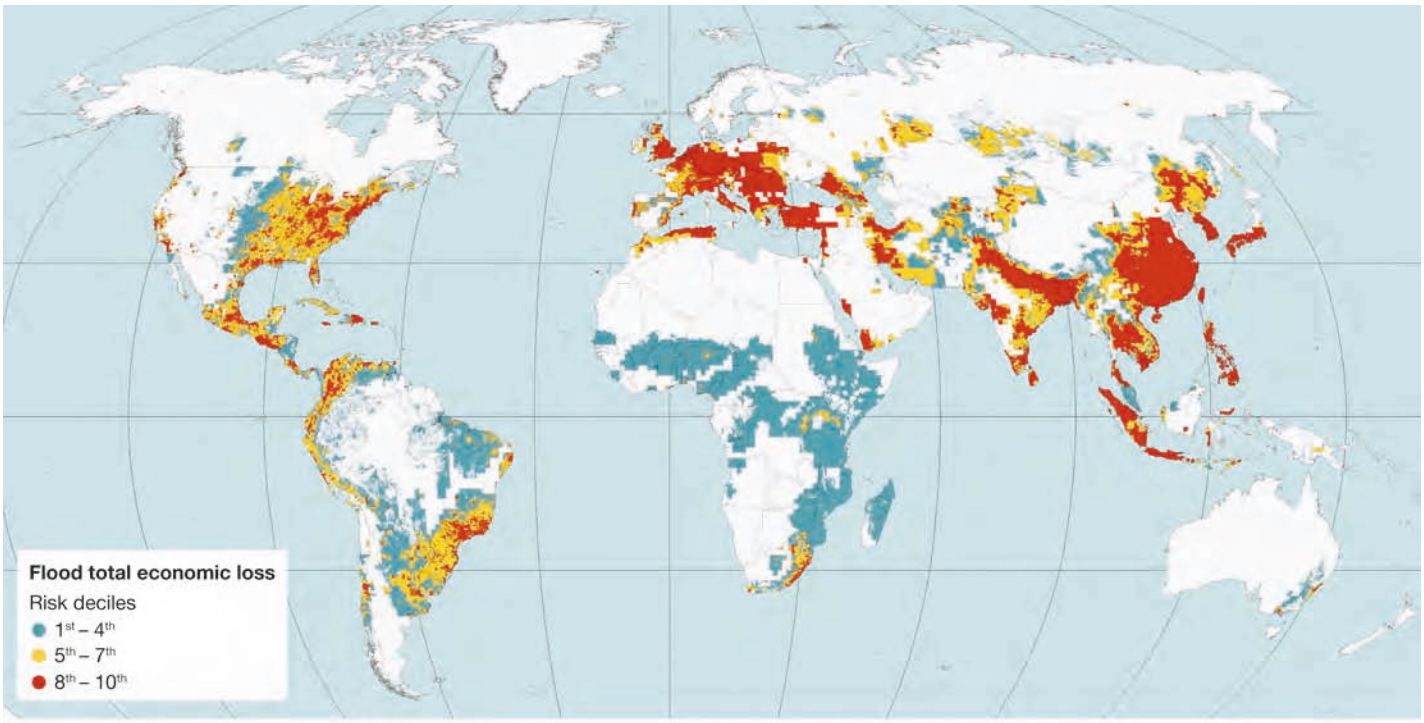
Historically, rapid urbanization and associated land-use changes have failed to consider the cumulative and integrated effects of reduced infiltration on urban water cycles. In the absence of large-scale structural adaptation, the direct economic losses caused by flooding could increase by 82 percent in China over the next 20 years (Willner, Otto, and Levermann. 2018). These losses are expected to increase because of a warming climate with the outcomes having global implications, affecting markets and industries around the world. Having provided the foundation for flood mitigation through traditional infrastructure approaches, China is now investing in new high-quality, integrated green infrastructure embodied in the Sponge Cities approach.

Flood management has a long history in China and efforts to strengthen resilience have had considerable success in reducing the exposure to flood hazards. The evolution in flood protection, management, and mitigation has historically been linked to major flood events (see figure 1.3) (Liu 2016). After the founding of the People's Republic of China in 1949, flooding was largely addressed through a "build-and-protect" approach that sought to harness major rivers and subdue nature. This philosophy of control and defend led to the construction of extensive systems of flood control infrastructure, such as dikes, dams, and flood detention areas (Kobayashi and Porter 2012). Over the past 70 years, about 47 million hectares of land area and 500 million people have been protected from flooding. More than 413,679 kilometers of flood control structures have been built in all of the major river basins, and China has more dams today than any other country in the world, storing more than 800 billion cubic meters of water. This represents a five-fold increase from when the People's Republic of China was established. Overall investment in flood control infrastructure increased by more than four times just from the 1990s to the early 2000s, and the average annual number of deaths from flooding fell from about 9,000 in the 1950s to 1,500 by the early 2000s.

A more comprehensive integrated flood-management approach was developed after devastating flood events that exposed limitations in the control-and-defend approach. Notably, the deadly Great Flood of the Huaihe River in 1975 caused by heavy rainstorms and dam failures triggered a transition toward a broader, comprehensive flood-management approach (Liu 2016). The emphasis shifted from traditional structural engineering efforts to embrace a broader portfolio of measures that included both structural and nonstructural interventions designed to increase resilience and improve safety. While this progression toward a comprehensive flood-control system built on the infrastructure foundations it included the improvements in early warning and forecasting systems, preparation of disaster response plans, as well as strengthening institutional systems to provide a closely coordinated flood response structure with headquarters at central, river basin, provincial, municipal, and county levels.

Flood risk management and increasing resilience have become key components of China's approach to flood management over the past two decades (Kobayashi and Porter 2012). This concept was introduced after the devastating floods along the Yangtze River and other major rivers in 1998 that claimed the lives of 4,150 people, affected 223 million people across 29 provinces, and cost 2.28 percent of GDP (Caijing News 2020). This evolution

Map 1.1: **GLOBAL FLOOD TOTAL ECONOMIC LOSS RISK DISTRIBUTION**



Total Economic Loss is found by weighting the value of GDP exposure to floods for each grid cell by a vulnerability coefficient to obtain an estimate of risk. The vulnerability weights are based on historical economic losses in previous disasters. The economic loss risks are applied to GDP per unit area exposure to obtain economic loss risks. The weights are an aggregate index relative to losses within each region and country wealth class (classifications based on 2000 GDP) over the 20-year period from 1981–2000.

Source: Dilley et al. 2005.
Note: GDP = gross domestic product.

Table 1.1: **TYPES OF FLOODING IN CHINA**

Cause of flooding	Urban and rural areas	Flood detention areas	Mountainous areas	Coastal areas
Fluvial flooding (inundation from rivers and/or lakes)				
Pluvial flooding (local stormwater runoff, limited drainage)				
Flash flooding				
Coastal flooding (storms, high tide)				

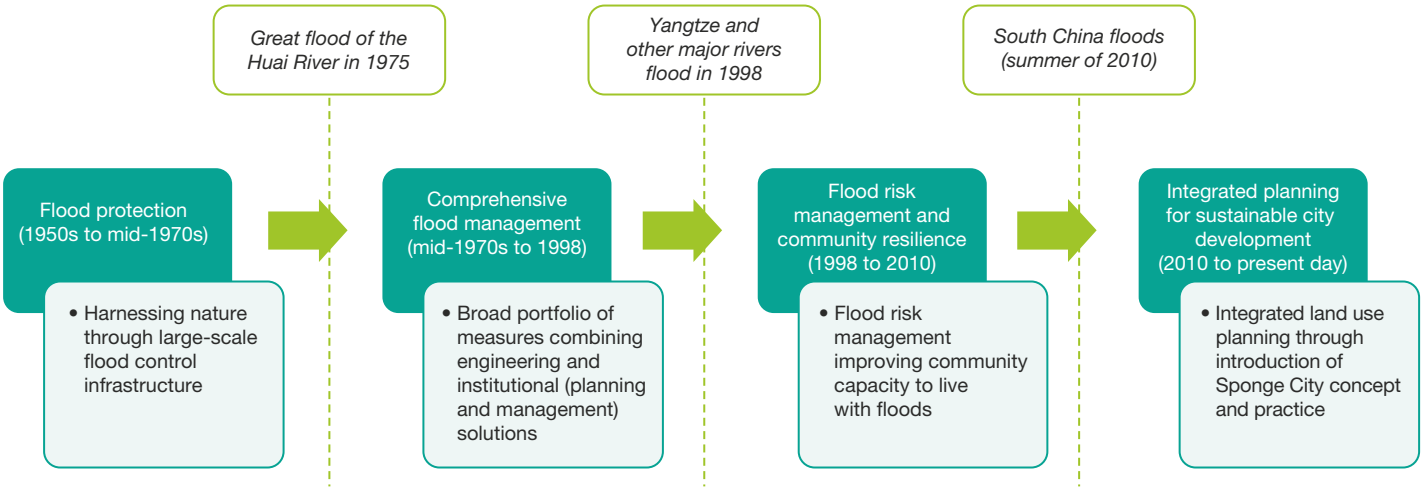
Source: Based on Kobayashi and Porter 2012.

marks a further shift away from flood control toward building community resilience to tolerate floods with certain degrees of risk (Liu 2016). Systems thinking is also evident, with water policies and planning seeking to tackle both flooding and drought. China's 1997 Flood Control Law, amended in 2007, designates certain regions as flood prone and requires authorities to develop appropriate flood-management plans at the basin and watershed levels with land use controlled according to flood risk. Consequently, an area of focus is the integration of weather prediction and forecasting into decision support systems to allow local officials to respond more quickly to predicted flood emergencies, helping further improve the capacity of the flood and drought control headquarters. Full dam and reservoir operation and evacuation plans have also been developed for 98 areas designated as national flood storage and detention zones. Such efforts helped minimize the social and economic impacts associated with severe storms events that resulted in extensive flooding across southern China in 2020 (Box 1.1).

The concept of integrated urban flood management lies within the broader framework of integrated urban water management. This aims to promote coordinated management of water resources in the urban landscape, including flood and drought management, water supply and sanitation, and water environment and ecology, among others, to optimize economic and social gains derived from water resources without compromising the sustainability of water resources and ecosystems. Meanwhile, planning for the water sector should be integrated and coordinated with other urban sectors, such as land use, housing, energy, and transportation, as part of a broader urban planning framework to overcome fragmentation in public policy formulation and decision-making processes.

The evolution of flood management in China follows the concept of the urban water transitions framework (see figure 1.4). This is a heuristic tool identifying six developmental states for cities as they progress toward increased water sensitivity (Brown, Keath, and Wong 2009). The framework reflects a global transition toward more integrated approaches to water management that recognize the importance of water in supporting urban livability, sustainability, and resilience for a city's long-term prosperity. Although progress at the local level varies significantly across the country, the overall evolution in flood management practices showcases a transition from the Drained City state toward the Water Sensitive City state. The first phase of the evolution, flood protection (1950s to mid-1970s), reflects the *Drained City* state, featuring large-scale flood control infrastructure as the primary approach to dealing with flooding. The latter phases reflect aspects of the *Water Sensitive City* state, particularly as flood management approaches began to apply a more integrated systems approach by combining structural

Figure 1.3: **EVOLUTION OF FLOOD MANAGEMENT IN CHINA**



Box 1.1: **FLOODS IN SOUTHERN CHINA IN 2020**

In 2020, China experienced extreme rainfall and flood events comparable to the major floods in 1998. From early June to mid-August, accumulated precipitation was estimated to be 1.7 times the long-term average and the highest on record since 1961.[1] Intense rains resulted in unusually high-water levels of major rivers and lakes, concentrated in the Yangtze River Basin, Huai River Basin, Lake Tai Basin, Lake Dongting Basin and Lake Poyang Basin in the southern China. The Three Georges Dam in the Yangtze River received 76,000 cubic meters per second at its peak level, the highest ever inflow since the dam was built and at its maximum capacity.[2] By mid-August, floods in 27 provinces had reportedly disrupted the lives of over 63.5 million people, with more than four million residents having to evacuate from their homes, and 219 people had been reported missing or dead. The number of casualties was considered relatively modest considering the severity and magnitude of rains and subsequent flooding[3, 4] owing to the comprehensive and integrated flood management system developed over the past few decades. This approach is built on an infrastructure platform with improvements in flood forecasting and early warning, coupled with improved coordination and flood response mechanisms. According to the State Council Policy Briefing on August 13, the floods caused direct economic losses of US$25.87 billion (RMB178.96 billion),[5] which does not account for the secondary cascading effects on the economic flows and outputs.

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Source: Original figure for this publication.

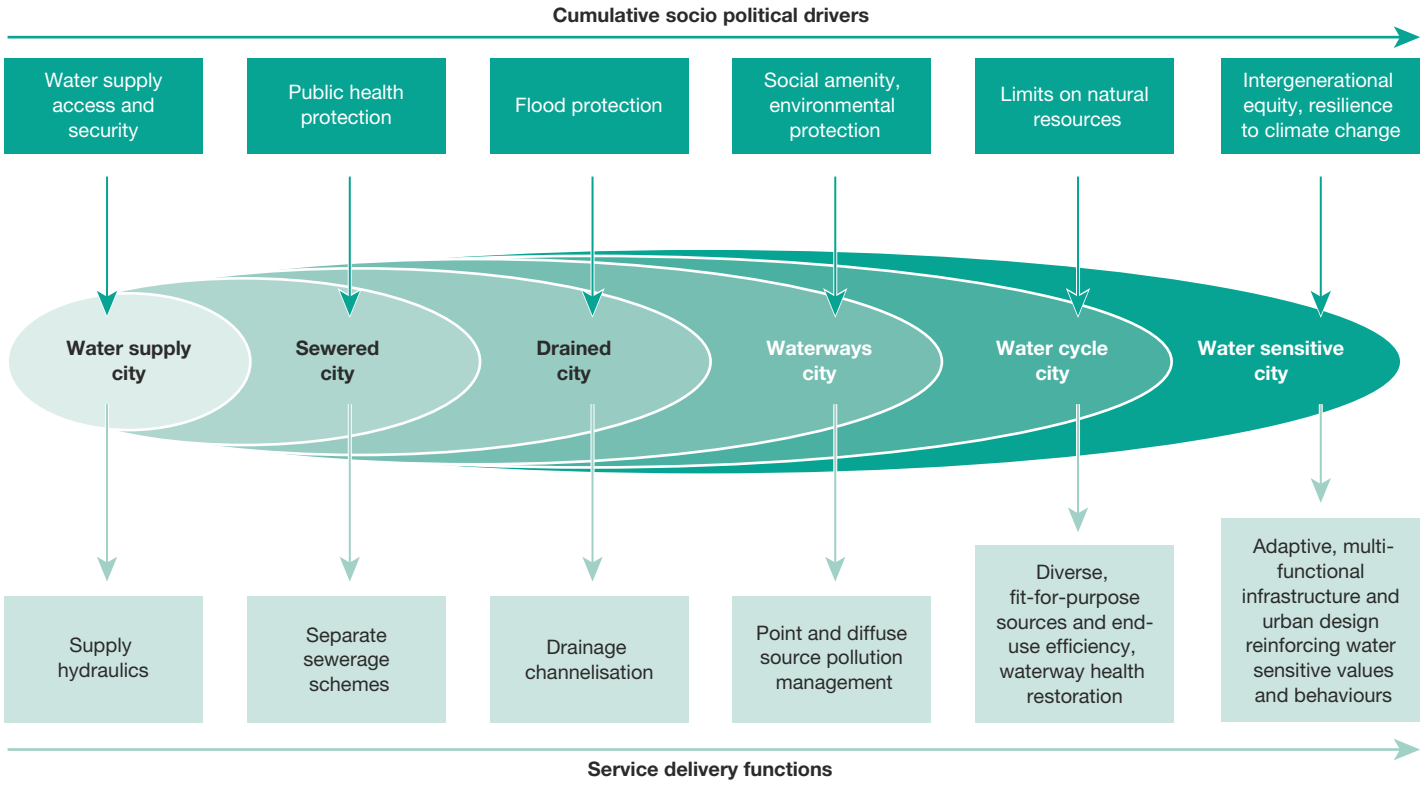
engineering solutions with nonstructural institutional interventions on a variety of scales. These have culminated in the incorporation of concepts around "flood risk" embedded within the "Sponge City" approach that integrate nature-based solutions to improve community resilience and ensure a harmonious coexistence between humans and water. These efforts will help to further bolster flood resilience and adaptation to increasing flood risk caused by climate change, urbanization, and other macroscale changes.

Integrated urban water management increasingly focuses on leveraging nature-based solutions, or green infrastructure. Such approaches use natural or seminatural measures to mimic natural water cycles and thereby mitigate the effects of human development. Typical interventions include permeable roads and parking lots, vegetated rain gardens, green roofs, and constructed wetlands, among others. Nature-based solutions that strategically conserve, restore, and use natural systems such as forests, floodplains, and soils can help improve resilience against water-related disasters, including floods and drought, in addition to providing water supplies and improving water environment at the same time, often at lower costs, especially in developing countries.

1.3 Developing Sponge Cities

Globally, a range of approaches have emerged that support the concept of integrated urban water management (IUWM). For example, in Australia, the vision of the water sensitive city (WSC) represents an aspirational concept in which water has a central role in shaping a city. In a WSC, people are not disrupted by flooding; rather, they enjoy reliable water supplies, effective sanitation, healthy ecosystems, cool green landscapes, efficient use of

Figure 1.4: **URBAN WATER TRANSITIONS FRAMEWORK**



Source: Brown, Keath, and Wong 2009.

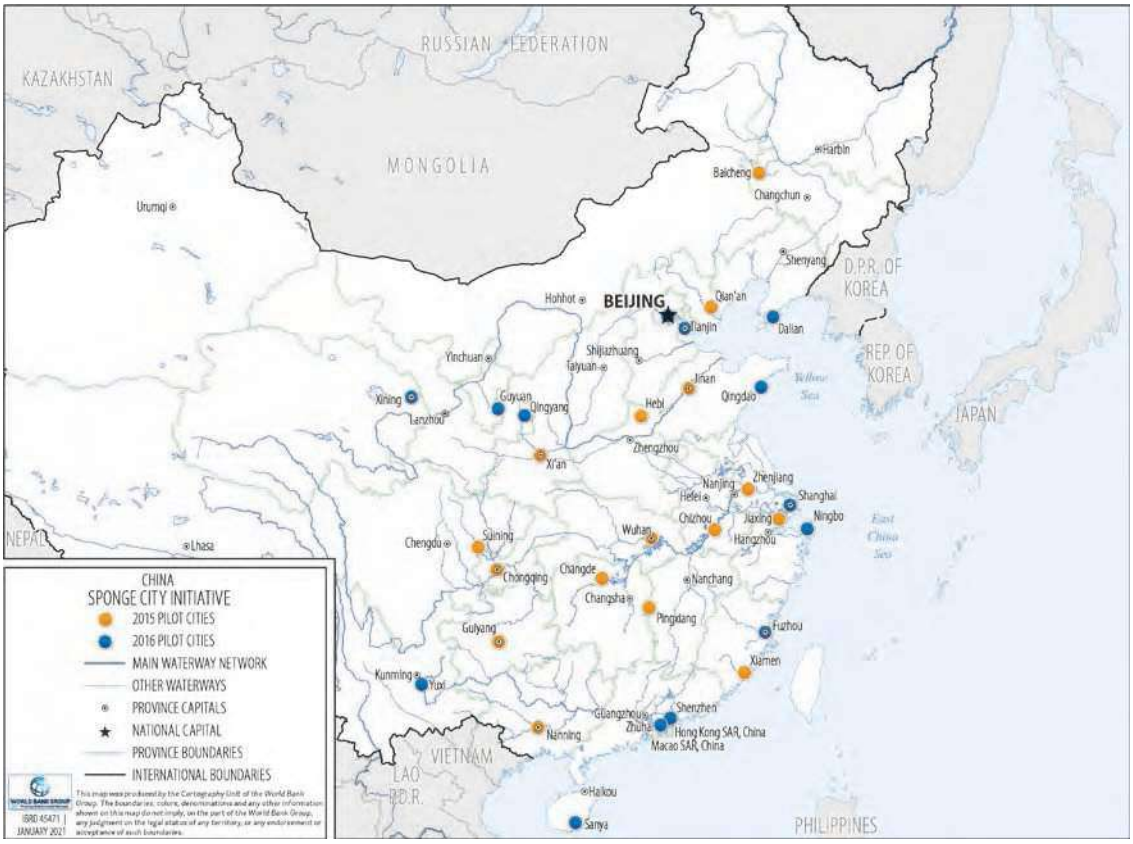
resources, and beautiful urban spaces that feature water and bring the community together. Similar initiatives include low-impact developments (LIDs) in the United States and Canada that includes systems and practices that use or mimic natural processes to manage stormwater runoff to protect water quality and associated aquatic habitats. These practices can yield multiple benefits and build city resilience by maintaining or restoring a watershed's hydrological and ecological functions. In the United Kingdom, sustainable drainage systems (SuDS)[1] and blue-green cities (BGCs) involve water management practices that aim to align modern drainage systems with natural water processes and recognize surface water as a valuable resource that should be managed for maximum benefit in the urban landscape. In Singapore, the Active, Beautiful, Clean Waters Programme (ABC Waters Programme) strives to improve the quality of the city-state's waterways and improve urban livability by integrating water management into the urban landscape through nature-based solutions that harness water's full potential. In the Netherlands, the Room for the River intends to address flood protection, master landscaping, and environmental improvement in areas surrounding rivers. These initiatives reflect the increasing recognition of broader benefits derived from integrating water management with urban development to improve the quality of the urban environment. Such approaches increasingly combine built infrastructure with solutions that harness natural systems to deliver a range of cobenefits beyond traditional flood measures, providing opportunities to engage with a wider range of stakeholders.

[1] https://www.susdrain.org/delivering-suds/using-suds/background/sustainable-drainage.html.

The Sponge City Initiative launched in China in 2014 reflects this transition. It is an important contribution to the Government's broader ambition and policy of realizing the construction of an ecological civilization. The initiative seeks to address flooding by integrating several ideas and practices, such as nature-based solutions, community and environmental well-being, and adaptation to climate change, within urban land use planning processes (Chan et al. 2018). This approach builds on earlier concepts of flood risk management and community resilience to promote sustainable city development through more integrated planning approaches. The Sponge City Initiative followed the 2010 floods in southern China in which exceptionally heavy summer rains caused major rivers, including the Yangtze, Yellow, and Songhua, to reach catastrophic levels.

The objective of the Sponge City Initiative is to address surface water flooding, attenuate peak runoff, improve purification of urban runoff, and enhance water conservation. Sixteen pilot cities were selected in 2015 with another 14 cities included in the subsequent year (map 1.2). By 2030, China aims to have 80 percent of urban areas across the country sponge-like in line with Sustainable Development Goal (SDG) 11: "Make cities and human settlements inclusive, safe, resilient, and sustainable." In support of these efforts, cumulative investments in sponge city projects in Beijing, Shanghai, Shenzhen, Wuhan, and other areas are projected to reach RMB

Map 1.2: **THE 30 SPONGE CITY PILOTS IN CHINA**



Source: Zevenbergen, Fu, and Pathirana 2018.

1.9 trillion (US$300 billion) by the end of 2020. This endeavor has relied in large majority on government programs to provide financial support in fostering implementation in a selection of pilot cities. Given the substantial investment gaps, secure and sustainable financing mechanisms are needed.

The sponge city approach leverages nature-based solutions and "blue" and "green" spaces in the urban environment for flood management and mitigation. Nature-based solutions are increasingly recognized as cost-effective measures that can leverage natural systems to provide critical services, such as wetlands used for flood retention and mitigation (Browder et al. 2019). Such approaches can generate a wide range of other tangible and intangible cobenefits that contribute to broader environmental, economic, and social improvements in the urban landscape. There are also a broader range of benefits and a complex set of interrelationships between the value of those benefits associated with water and flood management measures. However, these benefits are often coincidental and not optimized within design considerations. This integrated planning approach reflects, in part, the changing nature of society and efforts to meet increasing expectations for improved environmental quality and water security.

Sponge cities have already reaped considerable benefits. It is reported that during a rainstorm on May 25, 2018, in Shanghai, ponding issues were successfully eliminated in residential pilot areas because of a combination of interventions including permeable pavements and parking lots, green roofs, and constructed wetlands. Interventions in Shenzhen's Futian River have raised the flood protection standard from a 20- to a 100-year return period while also enhancing resilience to future changes in climate; increasing amenity, utility, and social values; and increasing asset values. In Kunshan, the ecosystem services embedded in the cityscape have improved water quality, enhanced landscape connectivity, promoted increased biodiversity, allowed for food production, and influenced the urban microclimate, reducing the amount of pollution entering regional waterways and mitigating flood risks for downstream cities. Through a unique blend of structural and nonstructural initiatives, the Sponge City Initiative has the potential to strengthen resilience to the many challenges of urban water security and urban livability.

Ultimately, becoming a water sensitive city requires significant changes in practice and policy as cities develop and transition through different city-states. A successful transition, therefore, needs to rely on commitment and alignment from many different stakeholders as well as recognition of the various benefits of water sensitive cities and the changing nature of their value as society evolves. There are a number of challenges to realizing this transition, including technical and physical concerns, legal and regulatory issues, and social and institutional considerations, among others. However, financial challenges have been identified as one of the main constraints, given the substantial costs in implementing the Sponge City Initiative and the broad range of tangible and intangible cobenefits. The Ministry of Housing and Urban-Rural Development (MoHURD) estimates that the required investments could reach about RMB 100 million to 150 million (approximately US$15 million to US$22 million) per square kilometer or higher in more economically developed areas, such as Beijing and Shanghai. For the 16 pilot cities included in the first phase, the MoHURD invested about RMB 6.9 billion (approximately US$985 million), while the total investment required is estimated at RMB 86.5 billion (US$12.26 billion).

The broad range of cobenefits that can be derived from nature-based solutions advocate for an important role for government in addressing urban flood risks. This role would ideally incorporate public sector financing and responsibility for setting policies that enable the mobilization of private sector investments and social capital contributions; in addition, the government would facilitate multisector approaches. However, there is a need for better recognition of the range and diversity of environmental and social cobenefits as well as the values of resilience and reversibility. The values associated with these benefits need to be incorporated into economic assessments and to be linked to appropriate financing models and funding options. Successful realization and continuous improvement require better performance monitoring and improved scientific knowledge and tools to assess the value of these benefits. The objective of this manual is to contribute to this process of continuous improvement in the valuation of benefits associated with nature-based solutions for integrated urban flood management.

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2

Leveraging Nature-Based Solutions for Integrated Urban Flood Management



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This chapter outlines key steps in identifying the full range of flood management and mitigation interventions in urban landscapes—from the spectrum of "gray" to "green" infrastructure solutions to nonstructural measures.

The methodology described here is intended to inform the valuation of benefits associated with nature-based solutions (NbS) for integrated urban flood management. The methodology provides the following:

- **High-level guidance for policymakers in the form of an overarching framework and an overview of strategic issues to consider in evaluating flood management options**
- **Practical information for managers reviewing the results of benefit-cost analysis (BCA) and ensuring a fit-for-purpose approach**
- **A consistent methodology for practitioners wishing to undertake a BCA, together with worked examples, more technical references, and access to supporting tools, guidelines, and templates.**

The methodological approach focuses on five steps for identifying the range of benefits associated with the array of appropriate flood management interventions and for assessing their values based on the particular context. Given the diversity of socioeconomic conditions in China's urban centers, this manual is supported by a series of case studies to provide reference points along the urban development continuum.

The methodology examines three of the four common types of flooding: fluvial, pluvial, and coastal. Although groundwater flooding is important in many parts of the world, it is often difficult to distinguish from surface flooding in many cases. An increase in impermeable surfaces and rising water tables result in more water flowing into rivers, causing fluvial flooding. Rising water tables also limit the ability of drainage and sewage networks to move water, preventing surface water from escaping and subsequently causing groundwater flooding. The following definitions have been adopted from *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* (Jha, Bloch, and Lamond 2012, 71–72).

Fluvial flooding occurs when a watercourse's capacity is exceeded by flows from rainfall, snow melt in the upper catchment area, and/or rising sea levels and storm surges in the lower catchment area and delta. Watercourse elevation and flows depend on natural factors, such as the amount and timing of rainfall, as well as human factors, such as deforestation and the presence of embankments (also known as *levees* or *dikes*). Excess flows raise the water level in the watercourse and any flood management channels, overflowing the banks and spilling out into the adjacent floodplain and low-lying areas. The severity of fluvial flooding events is exacerbated by increased rainfall and rising sea levels attributed to climate change.

Pluvial flooding occurs when rainwater runoff exceeds drainage system capacity and the ground does not allow water to drain through pervious areas, such as soil, sand, and vegetated spaces. These pervious drainage areas are typically developed, making them impervious and trapping water above ground. Pluvial floods are often caused by localized summer storms or by weather conditions related to unusually large low-pressure areas; furthermore, the shorter time scale makes pluvial flooding hard to predict. It usually occurs before water enters downstream

waterways, and it happens particularly in tropical climates. The floodwater drains quickly, but flooding happens frequently, even daily, during the rainy season. The severity of pluvial flooding is exacerbated by urban expansion and increasing rainfall intensity attributed to climate change.

Coastal flooding occurs when ocean or seawater inundates typically low-lying coastal areas because of storm surges, major tidal events, and rising sea levels. Seismic activities and tsunamis can cause extreme events. Coastal flooding differs from cyclic high tides because it is primarily driven by unexpected and discrete events. In extreme cases, coastal flooding can affect areas far from the coast, and elevated sea levels can persist for six to eight hours after the event.

Groundwater flooding occurs in areas with seasonally high groundwater. It occurs when the water table level of the underlying aquifer rises until it reaches the surface level. Groundwater levels typically rise during the wet seasons and fall during dry periods. These rising water levels may cause flooding on normally dry land and reactivate flows in bourns (streams that flow for only part of the year). In rainy seasons, water from these reactivated bourns flows into perennial watercourses, overwhelming urban and low-lying areas. Groundwater flooding can also occur when aquifers used for drinking water are no longer used. The resulting rising water table can overwhelm water and sewerage infrastructure, causing flooding.

A series of steps is outlined for identifying, valuing, and choosing an appropriate mix of flood management interventions for the particular system context (see figure 2.1). The steps reflect the organization of this manual, with relevant sections or chapters identified in the right column. Steps 1 and 2 are key to understanding the nature of the problem and the magnitude of potential effects, but this manual focuses primarily on steps 3, 4, and 5. The ability to identify appropriate and sustainable financing mechanisms should feed into the decision process determining the appropriate mix of interventions. These steps are critical to ensuring on-the-ground delivery through a range of tools and guidance to comprehensively value and finance the optimal solution.

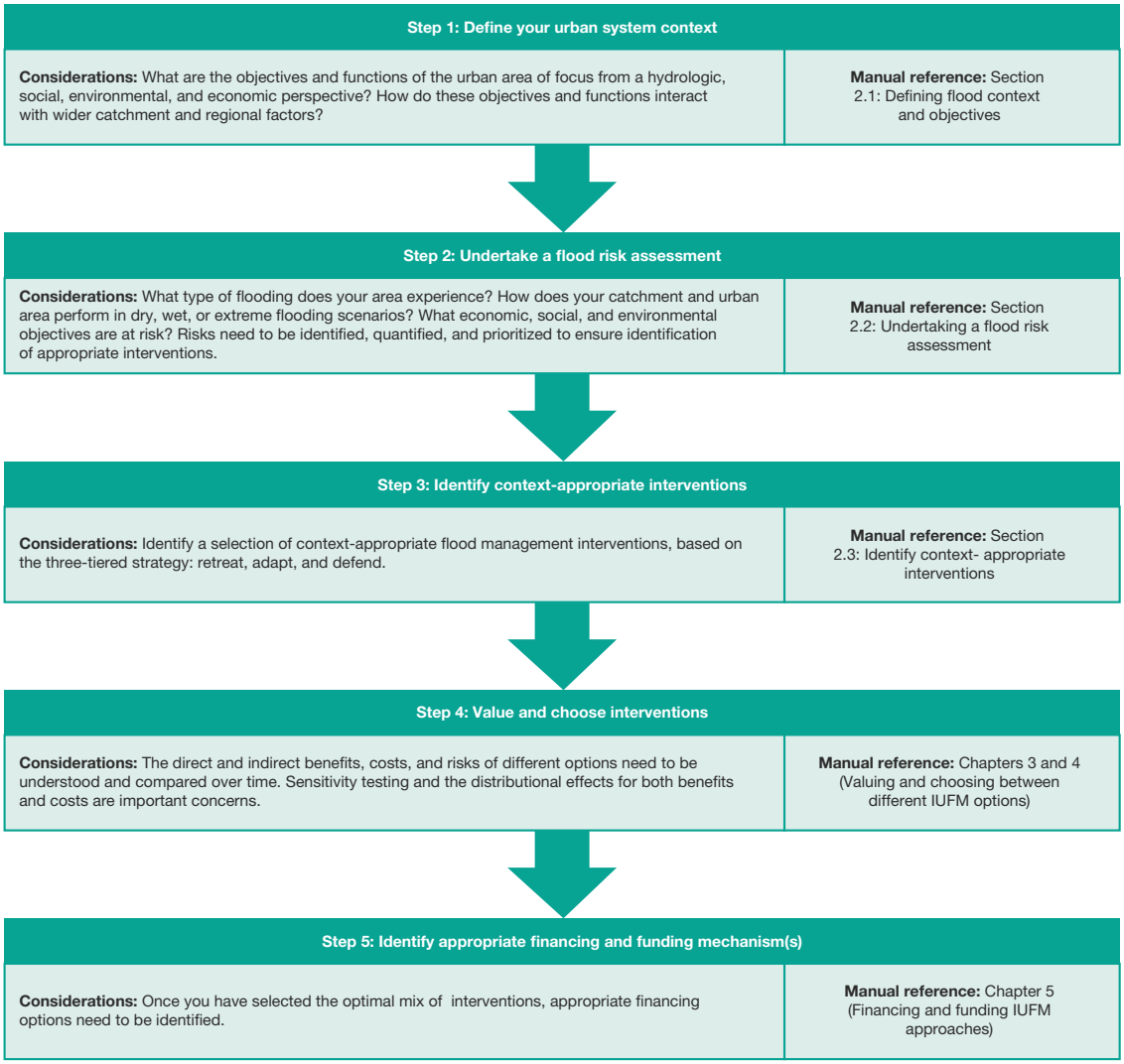
2.1 Defining Flood Context and Objectives

The first step toward defining appropriate NbS for integrated urban flood management (IUFM) is to define the catchment that affects the urban area being examined. “Catchment to coast” is a way of understanding various types of flooding along a continuum (see figure 2.2). Flooding can occur along any point of the system. Usually this system follows a river although flooding can occur at any point of depression along the continuum from catchment to coast (pseudo-river). The system is broken into three primary components. First is the catchment area, where water falls and/or is collected. Second is the intermediate urban context, which exists in various forms between the catchment and the coast. Most urban development occurs in this zone. Third is the coast, the boundary between the land and an ocean, a sea, or another large body of water. The coastal zone can also exist along a river, and it is also a zone for urban development. Many large cities are located in coastal areas where the combination of different types of flooding exacerbates the effect. Water flows along this continuum, and flooding can occur at various locations because of a variety of drivers and factors.

To determine which flood management interventions are appropriate, decision makers must consider the benefits, costs, and risks of high-water flows in an area as well as the possible variations along a water system and within an urban system. In data-poor environments, community knowledge can be used in addition to freely available modelling software to create representative flood risk maps. Community knowledge can be gathered through workshops moderated by risk experts; during these workshops, knowledge and experiences of locals can be systematically recorded in a structured way (Jha, Bloch, and Lamond 2012, 74).

Decision makers need to have clear objectives and to consider the social, economic, and environmental effects on multiple scales (local, urban, and catchment). Establishing an agreed desired state that supports a region’s broader development objectives can highlight gaps and prioritize actions, especially when resources are limited. For example, protecting a highly urbanized and growing economic center may be given a higher priority than protecting a regional agricultural area. Decision makers also need to recognize that actions in one part of the system may

Figure 2.1: **STEPS FOR IDENTIFYING, VALUING, AND CHOOSING FLOOD MANAGEMENT INTERVENTIONS**



Source: Original figure for this publication.
Note: IUFM = integrated urban flood management.

affect another and that these effects may be both positive and negative. Maximizing an outcome for one urban center may not be optimal for the region and catchment as a whole.

Many flood management interventions are available, each with its own costs, risks, and benefits. The right mix of measures depends on the context. For example, what suits a densely populated, well-established urban community may not suit a greenfield development. What might be appropriate for an area with extensive flooding records, a deep understanding of its river systems and urban form, and well-maintained flood protection assets may not suit a data-poor area with limited existing infrastructure.

Figure 2.2: **CITY WATER RESILIENCE APPROACH**



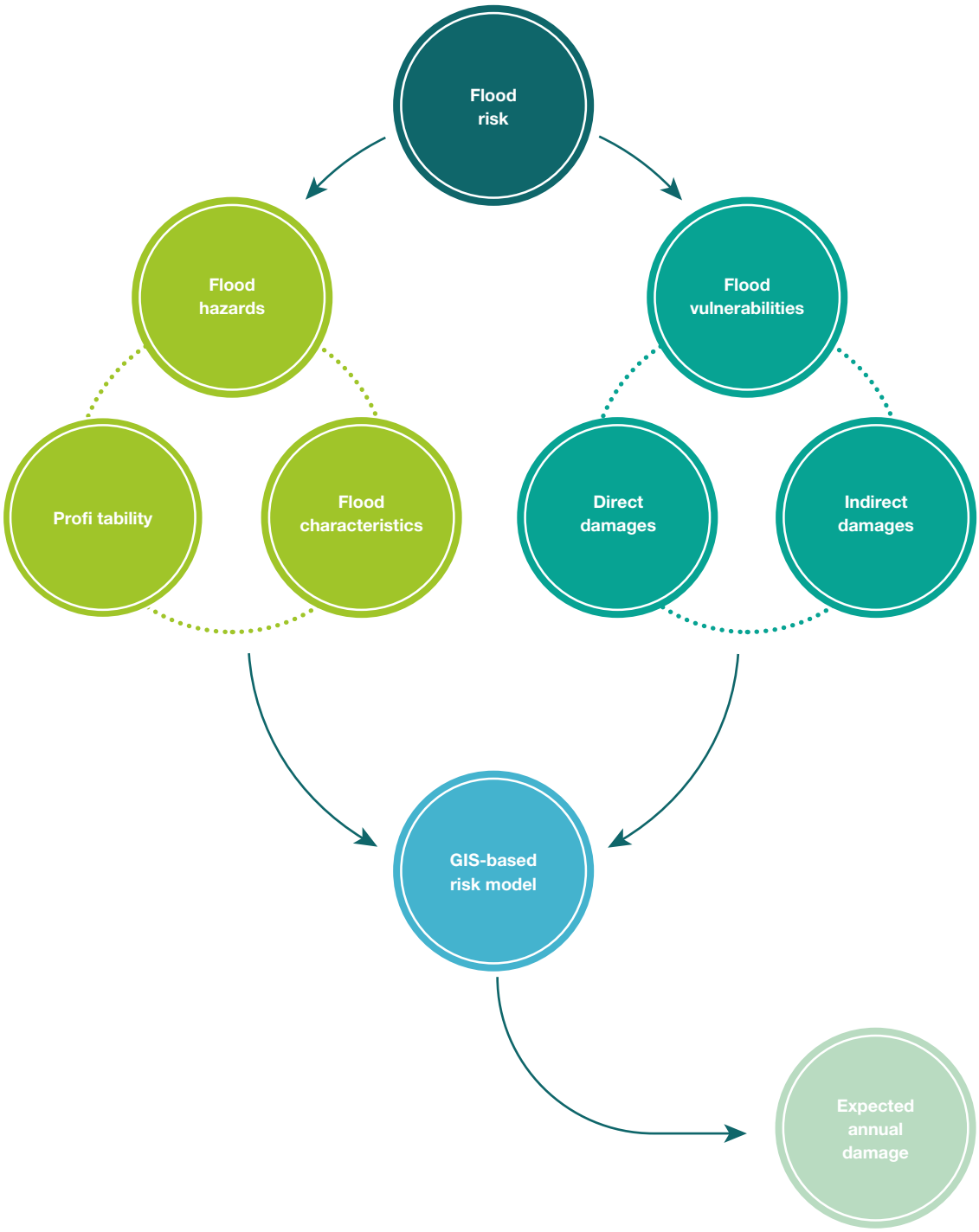
Source: The Resilience Shift | The Rockefeller Foundation | Arup 2019.

2.2 Undertaking a Flood Risk Assessment

Assessment of flood risk is an essential tool for evaluating the potential consequences of a flood. Subsequently, it is used in a variety of analytical methods and metrics from floodplain management to benefit-cost analyses and urban planning outcomes. According to a common definition, flood risk is determined by a flood hazard assessment and a flood vulnerability assessment. Flood hazard assessment is "the quantification of amount, extent, and location of flooding expected to occur with a given return period," and vulnerability is "the susceptibility of the area subjected to the flooding" (Olesen, Löwe and Arnbjerg-Nielsen 2017, 4). Flood hazard can be spatially represented, based on a calculated flood depth and return period whereas flood vulnerability can be quantified by a damage cost assessment (see figure 2.3). However, there is a variety of other flood risk methodologies, such as the one used by the Intergovernmental Panel on Climate Change (IPCC), which denotes flood risk as "the cost of flooding given flooding occurs," thus combining the effects of vulnerability and exposure (Field et al. 2012).

The determination of risk, quantified through a combination of hazard, exposure, and vulnerability, varies considerably between organizations and contexts. This is particularly true for damage cost estimation, and there is no universally accepted model or method to ascertain flood damage. However, there are several good industry practices recognized nationally (Olesen, Löwe and Arnbjerg-Nielsen 2017, 12). A comparison of flood damage cost methods used in Australia, Denmark, Germany, and the United Kingdom shows that only direct damages attributable directly to flooding are quantified. However, there is an increasing recognition of the need to include indirect or intangible damages. Although it's not essential to include indirect and intangible damages - they are difficult to quantify - excluding indirect and intangible damages from flood risk analyses leads to a systematic underestimation of the overall costs of flooding (Olesen, Löwe and Arnbjerg-Nielsen 2017, 22). It is, therefore, important to clearly identify damage classes the methods by which they're quantified and to consider if they effectively describe the given context (Olesen, Löwe and Arnbjerg-Nielsen 2017).

Figure 2.3: **COMMON FLOOD RISK ASSESSMENT STRUCTURE**



Source: Olesen, Löwe, and Arnbjerg-Nielsen 2017, based on Zhou et al. 2012.

2.2.1 Flood Hazard Assessment

The primary outputs of a flood hazard assessment are the probability, or frequency, of occurrence; the magnitude and intensity of occurrence; and the expected time of the next future occurrence (Jha, Bloch, and Lamond 2012, 55–72).

2.2.1.1 Compound Events

Urban flooding is a growing development challenge; it is typically the result of a complex combination of meteorological and hydrological causes. Increasing impermeability and intensifying rainfall exacerbate the pluvial flood risk in urban areas, resulting in compound urban pluvial flooding. Urban expansion has increased the hardness of surface areas, amplifying the need for infrastructural drainage solutions. However, compound events increasingly overwhelm these infrastructural solutions because of the size of floods. To become more resilient, urban areas must seek new alternatives by building stronger social flood resilience, decreasing urban hardness, and designing infrastructure that better manages flood risks associated with compound flooding.

The result of compound events highlights why it is important to consider urban flooding within a catchment. The most effective response to an urban flooding issue may lay outside (up- or downstream) of the urban area.

2.2.1.2 Flood Hazard Maps

A flood hazard map is the first step in defining a catchment's flood risk. It catalogues the potentially damaging physical events, phenomena, and human activities that may affect the system both directly and indirectly. Each system should have a flood hazard map, which is then modified to stakeholder requirements. Ideally, maps can be easily understood by both technical and nontechnical stakeholders. They can use a range of data sources (from technical data to community data). Flood hazard maps are generally characterized by flooding type, and they define flooding depth, velocity, extent, and direction. They can also be prepared for specific frequency or return periods.

The steps involved in preparing flood hazard maps are described in table 2.1. Ideally, expert simulation software will provide spatial information on flood area and depth for a given event. More information on how to prepare a flood hazard map and conduct flood assessments for different types of floods appears in section 1.4.3 of *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* (Jha, Bloch, and Lamond 2012, 78–88).

2.2.2 Flood Vulnerability Assessment

Vulnerability is the degree to which a system (in this case, people or assets) is susceptible to or unable to cope with the adverse effects of natural disasters. The two critical factors of vulnerability assessments are the location of elements at risk and the vulnerability of those elements to different aspects of flooding. This vulnerability is characterized as exposure and damage. Importantly, exposure of an element does not necessarily mean it is vulnerable, but an element must be exposed to be considered vulnerable.

Elements can have varying levels of exposure, ranging from acute to chronic. Elements that experience extreme conditions over a short time frame are acutely exposed whereas elements experiencing moderate conditions over the long term are chronically exposed. The interaction between elements and their degrees of exposure influences their vulnerability.

Understanding vulnerability also involves quantifying direct and indirect damage costs of a given hazard (via a damage cost assessment). Table 2.2 contains examples of flood vulnerability.

Further reading:

FLOODsite. 2008. "Review of Flood Hazard Mapping." Integrated Flood Risk Analysis and Methodologies, No.T03–07–01, Wallingford, United Kingdom.

Neelz, S., and G. Pender. 2010. Benchmarking of 2D Hydraulic Modeling Packages. Bristol, United Kingdom: Environment Agency.

World Meteorological Organization. 1999. Comprehensive Risk Assessment for Natural Hazards. WMO/TD No. 955. Geneva

Table 2.1: **PROCESSES FOR PREPARING FLOOD HAZARD MAPS**

How to prepare a riverine flood hazard map[40]	How to prepare a coastal flood hazard map[41]
1. Collect and integrate data from digital elevation and surface models.	1. Collect data to characterize coastal domain and to generate the digital terrain model.
2. Calculate return period of flooding.	2. Characterize morphology and bathymetry of coastal fringe.
3. Model flood scenarios, using various hydraulic models (1D, 2D,1D2D).	3. Generate data that reflect water levels of different probabilities of occurrence.
4. Validate model.	4. Model event in coastal zone (numeric and analytical models) and validate and calibrate the model.
5. Prepare flood maps, using validated model, and distribute to user groups.	5. Generate and distribute coastal hazard maps.
6. Monitor, evaluate, and update maps regularly.	6. Monitor, evaluate, and update maps.

Source: Modeled after World Bank publication *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* 2012.

Vulnerability assessments also use other characteristics to determine how vulnerable an element or system is to a flooding event or scenario. These additional characteristics include magnitude, frequency, degree of potential damage (sensitivity), and ability to adapt, mitigate, and thrive (resilience).

Total vulnerability of an asset or system is assessed on a scale of 0 to 1, with 0 indicating no vulnerability and 1 indicating the highest level of vulnerability. In most cases, a vulnerability assessment and a damage assessment are combined to generate a risk model, which calculates the expected annual damage relating to the probability of the flooding event (Olesen, Löwe and Arnbjerg-Nielsen 2017).

The flood risk maps generated from the models allow policy makers and managers to identify areas of high flood susceptibility and impact and to decide on priorities and interventions. These flood risk maps should give locations, resources under threat (both population and physical elements), levels of technology available, lead times for warnings, and residents' perceptions about hazard awareness. The incidence of damage can be illustrated in a stage damage curve, based on either data from an event damage survey or on a hypothetical scenario of an event (Jha, Bloch, and Lamond 2012, 173–5).

Identifying a system's most vulnerable elements and prioritizing resources and assistance reduce vulnerability and enhance capacity. The following chapters of this manual explain how to determine and fund a context-specific response to identified flooding "hot spots."

Further reading:

Jha, K., R. Bloch, and J. Lamond. 2012. Cities, and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century. pp. 134–169. Washington, DC: World Bank.

Olesen, L., P. Löwe, and K. Arnbjerg-Nielsen. 2017. Flood Damage Assessment: Literature Review and Recommended Procedure. Melbourne, Australia: Cooperative Research Center for Water Sensitive Cities.

Dutta, D., S. Herath, and K. Musiake. 2001. "Direct Flood Damage Modeling toward Urban Flood Risk Management." Joint Workshop on Urban Safety Engineering, 127–143.

Cutter, S. L., 2006. Hazards, Vulnerability, and Environmental Justice. p. 163. Abingdon, UK: Earthscan.

Tobin, et al. 2011. "The Role of Individual Well-Being in Risk Perception and Evacuation for Chronic Versus Acute Natural Hazards in Mexico." Applied Geography 31 (2): 700–11.

Table 2.2: **EXAMPLES OF FLOOD VULNERABILITY**

	Chronic	Acute
Direct	• Frequent minor inundation • Ponding • Structural damage • Erosion	• Urban damage • Rural damage • Infrastructure damage • Environmental damage
Indirect	• Planning failures • Development in flood-prone areas • Loss of land value • Falling tax revenue • Decreasing community health • Decreasing community amenities • Deteriorating economic conditions	• Business loss • Loss of production • Loss of confidence in government • Supply chain disruption (localized and global) • Increased prevalence and severity of depression, anxiety, and posttraumatic stress disorder

Source: Original table for this publication.

2.3 Identify Context-Appropriate Interventions

Flood risk management generally involves measures in the following aspects:

1. **Risk aversion: urban development and planning should consider the difference of temporal and spatial distribution of flood risk to avoid high-risk areas as much as possible; and try to permanently or temporarily place valuables that are vulnerable to flooding above the highest possible flood level, or move them out of the range that may be flooded.**
2. **Risk reduction: planning and engineering measures can be implemented to reduce the probability and area prone to inundation, reduce the depth of inundation, shorten the duration of inundation, and therefore weaken the destructive capacity of flood.**
3. **Risk sharing: through the institutionalization of insurance, disaster relief savings, mutual insurance, social donation, benefit compensation, government relief or disaster relief loans and other forms, the unavoidable and unbearable risks can be dispersed in time or space and reduced to the acceptable levels,.**
4. **Improving flood resilience: according to the characteristics of flood risk, deal with or adjust the structure, materials and layout of buildings and assets, enhance the ability of flood resistance, and reduce the losses caused by flood.**
5. **Improving risk predictions: due to the change of geographical environment and engineering conditions, the regional flood risk distribution characteristics may change. The predicting ability of risks includes the ability to identify the statistical characteristics of risks, to predict the real-time hazards, and to**

evaluate the losses and impacts. The improvement of risk prediction ability is reliant on the development of modern monitoring, communication and information systems for hydrological, meteorological and social-economic conditions.

6. **Improving the capacity for emergency response: an integrated and effective emergency response system should be built with careful emergency planning, early warning, community participation and coordination between different sector and levels of governments. The application process for emergency funding should also be streamlined.**
7. **Improving the capacity for post-disaster recovery: the post-disaster recovery should be supported with sufficient and accessible funds, sound technical measures and comprehensive plans to help communities to recovery in a fast, inclusive and sustainable manner.**
8. **Avoiding artificially increased risks: actions that may increase flood risks should be avoided, such as encroachment into floodplain and waterways; dumping garbage into the rivers, crossing levees and so forth.**

2.3.1 Traditional Approach to Flood Management

Traditional approaches to flood management promote flood defense and mitigation. They primarily address flood hazards through flood control infrastructure that largely involves conventional engineering structures, often referred to as "hard" engineering or "gray" infrastructure (see table 2.3). Examples include dikes, levees, dams, pumping stations, diversion channels, and related infrastructure.

Although such measures have reduced flood frequency and enabled urban and economic development within floodplains, the costs of building and maintaining extensive flood control systems are significant, and they continue to increase. These measures can also lead to a false sense of security**.** In addition, modifying landscapes to redirect water flows often has severe negative effects on natural habitats and natural processes (Smith et al. 2017). This outcome, in turn, contributes to the ecological decline of urban rivers and limits the benefits of ecological restoration. Furthermore, climate change and increasing uncertainties have led to greater costs of flood defense to overcome the need for greater design tolerances for these uncertainties.

Globally, billions of dollars are spent each year to reinforce flood control systems (Soz, Kryspin-Watson, and Stanton-Geddes 2016). Despite increased technical capacity and availability of resources, maintaining and periodically upgrading flood control infrastructure present ongoing challenges for responsible agencies. Without proper maintenance, structures are prone to failure, which can lead to catastrophic events. For example, the devastation caused by Hurricane Katrina in 2005 was attributed in part to inadequate design, construction, and maintenance of the flood protection system - a shortcoming that contributed to multiple levee and floodwall breaches.[1] Since then, New Orleans, United States, has spent about US$14 billion to strengthen its levee system (Soz, Kryspin-Watson, and Stanton-Geddes 2016) serving to "lock -in" investment in advanced technologies to keep water out.

Reliance on traditional flood protection infrastructure has resulted in large-scale and technically complex centralized systems that have limited capacity to adapt to varying conditions. Climate change and other global drivers of change have helped increase the realization that urban water management needs to be more flexible and adaptive to handle future shocks and uncertainties (Pahl-Wostl 2008). Flood managers need to consider alternative and complementary measures, such as decentralized, multifunctional nature-based systems, which are often more flexible and beneficial. Not only do these nature-based systems protect local waterways, but

[1] Interagency Performance Evaluation Taskforce, Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System, US Army Corps of Engineers, 2009.

Table 2.3: **FOUR EXAMPLES OF FLOOD MANAGEMENT INFRASTRUCTURE INTERVENTIONS**

Intervention	Definition	Pros	Cons
Drains	A formal flood conveyance mechanism that transports water from sources to sinks	• Improvements to local water conditions • Improvements to local revenue and economy • Direct conveyance • Simple solution to complex urban drainage issues	• Significant preconstruction • Sociocultural tension through resettlement • High capital cost • Inability to withstand high stormwater flows, which results in solid waste discharge
Levee or Dike	Flood embankments that generally consist of earthen materials and may have a clay core to reduce seepage	• Permanent structure • High level of research • Ease of building from a variety of materials • Decease in risk of damage and contamination in urban context (Resistance & Avoidance) • Favored by residents	• "Levee effect" in which seemingly protected infrastructure is catastrophically damaged • Movement of flood risk down the river, typically to lower socioeconomic groups • Possibility of occupying valuable land with no option for alternative use • High level of workmanship
Sea walls	• Passive defense mechanism of coastal environments and infrastructure • Consisting of many types, their primary purpose is to limit coastal erosion and flooding	• Effective stabilizer of coastal environments and infrastructure in the short term • Visible protection of coastal areas from inundation	• Ineffectiveness in long term • High cost of construction and maintenance
Diversion channels	Gated channels above dense urban centers that can open in periods of high flow to inundate sparsely populated areas upstream	• Conditional flood management strategy that can be deployed when conditions warrant • Provision of upstream conveyance and storage to reduce flood risk downstream	• High incident of damage in upper catchment urban areas when gates are opened and flooded • Possibility of flooding in downstream regions despite opening of channels
Dam or Reservoir	A barrier that stops or restricts the flow of water or underground streams	• Provision of ancillary benefits, such as drinking water storage and hydroelectric power • Reduction in magnitude of flooding through partial capture of a catchment's flows	• Dam failure that results in high volumes of water discharged at high pressure • Overtopping that damages the dam and results in uncontrolled release of water downstream • Sometimes need to balance conflicting objectives of drought and flood protection

Source: Adapted from World Bank publication *Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century* 2012.

they also improve microclimates, biodiversity, and the livability of urban landscapes (Deletic et al. 2018). Gray infrastructure solutions are needed in many situations, but they are not a panacea and should be considered in conjunction with NbS.

2.3.2 The Role of Nature-Based Solutions

NbS synthesize ecosystem-related approaches, including restoration and issue-specific infrastructure, management, and protection (Cohen-Shacham et al. 2016). Such solutions are analogous to ecosystem-based adaptations, ecodisaster risk reduction, and green infrastructure - all of which have emerged as alternatives or complementary actions to traditional gray infrastructure approaches. Introducing and using NbS involve designing, constructing, and maintaining natural or seminatural measures to mimic natural water systems to mitigate the effects of human development. These systems are characterized as "network[s] of natural or semi-natural features that [have] the same objectives as gray [built] infrastructure… [and are] created by human design, engineering, and construction to provide specific services such as [flood risk management and] coastal risk reduction." (Sutton-Grier et al. 2018) NbS typically adapt target ecosystems and conditions by manipulating natural components, such as soil, water, and vegetation, to form wetlands, reforest river catchments, build urban parks, and to rejuvenate coastal dunes (see table 2.4 and figure 2.4 for examples). Like gray infrastructure, NbS require societal and institutional knowledge to ensure optimal effectiveness as well as careful maintenance of the NbS to ensure a healthy environment for all.

Table 2.4: **FIVE EXAMPLES OF NATURE-BASED SOLUTIONS**

Intervention	Definition	Pros	Cons
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. Wetlands can be used to address coastal, pluvial, and fluvial flooding, depending on their location.	• Provide extensive flood storage • Have low cost to implement and manage • Improve ecosystem's health • Reduce pollution loads in water	• May be politically difficult • Require buy-back of developable or developed land for renaturification
Mangroves	Group of trees or shrubs in coastal areas. Restoration of mangroves can help create a natural barrier to reduce risk of coastal flooding. These natural defenses trap sediment, block wave action, and absorb waves that would otherwise inundate coastal areas.	• Reduce coastal erosion • Have low cost to implement and manage • Improve ecosystem health • Produce long-term environmental and flood mitigation outcomes	• May be politically difficult • Require buy-back of coastal land, taking land away from alternative uses • May sustain damage from storms, necessitating repair • Require knowledge of botany to ensure planting of appropriate species in suitable areas

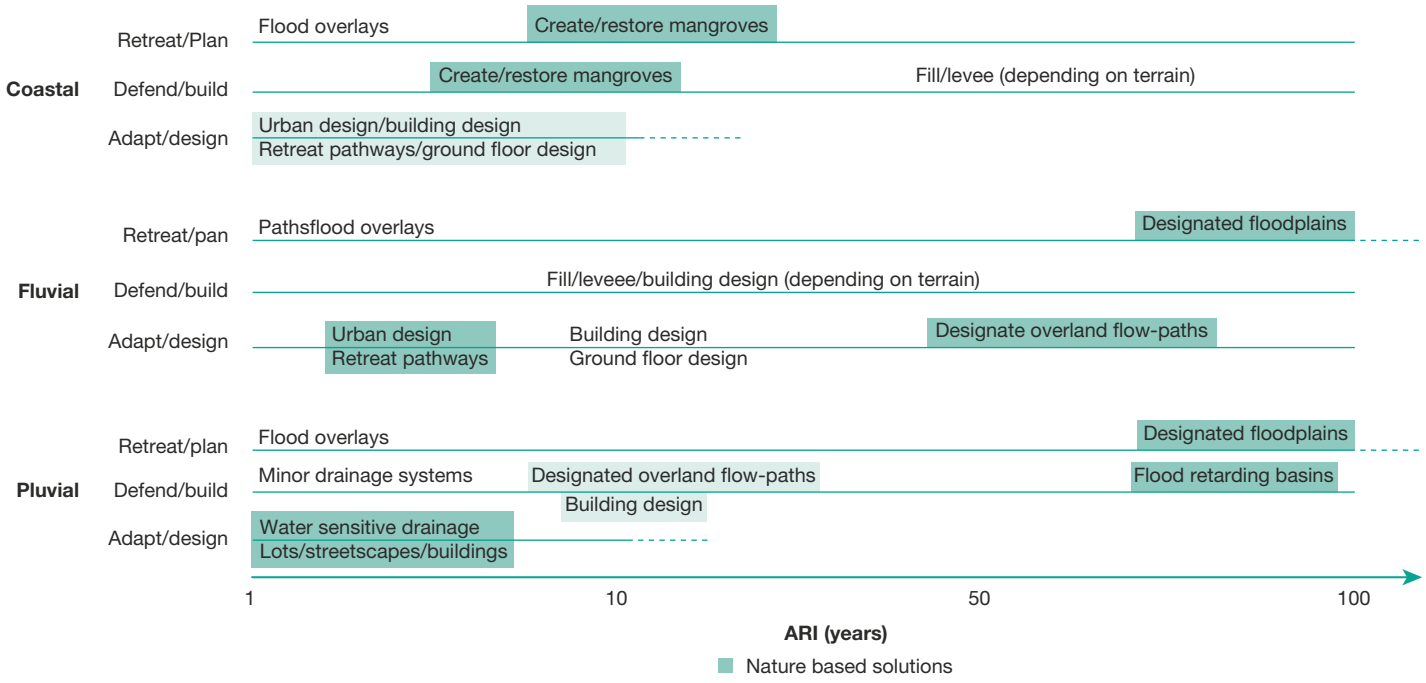
Continued

Table 2.4: **FIVE EXAMPLES OF NATURE-BASED SOLUTIONS (*Continued*)**

Intervention	Definition	Pros	Cons
Floodable Parks	Artificial flood storage that can strategically flood permeable, sparsely populated areas	• Strategically floods permeable, sparsely populated areas • Provide multiple services for public amenities, biological health, and flood management • Have low development cost	• May experience flooding for some time, rendering the area inaccessible for amenities and activities • May increase pollution in the area because urban runoff flows into park areas • Sometimes lead to concern that urban wetlands and parks with retention areas will experience an increase in the number of rodents and snakes and will become breeding grounds for mosquitoes and other insects
Coastal Dunes	Sand dune ecosystem that borders the coast and acts as natural defense of coastal flooding	• Protect coast adjacent to infrastructure from storm surges by acting as a barrier • Provide sand for beach restoration • Have low development cost	• May require substantial restoration because of high level of degradation in most dune ecosystems • May sustain damage from sand mining, agricultural grazing, and development
Daylighting Culverts	Efforts that include widening streams, roughening banks, and reopening culverts to form natural rivers	• Slow down river flows • Reduce the likelihood of flow blockage • Provide easier access for maintenance • Increase biodiversity, water quality, and amenities	• Require land above culverts to be returned to stream habitat, possibly requiring buy-back and relocation • May be complex, time consuming, and expensive, depending on the culvert and land use conditions
Bioswales	Broad and shallow vegetated, mulched, or landscaped channels that provide stormwater treatment and retention	• Is a localized flood prevention mechanism • Is relatively easy to install and maintain • Has low cost of installation • Demonstrate high level of effectiveness compared with the scale of the intervention	• May be blocked by urban waste and runoff, requiring regular cleaning of the swale surface, and if chronically affected, necessitating restoration of the subsurface drainage medium • Require careful consideration of the biological species placed in the swale surface

Source: *Adapted from World Bank publication* Cities and Flooding: A Guide to Integrated Urban Flood Risk Management for the 21st Century 2012.

Figure 2.4: **IMPLEMENTATION OF NATURE-BASED AND TRADITIONAL INFRASTRUCTURE SOLUTIONS**



Source:
Note: ARI = Average Recurrence Interval; Light green indicates situations where both nature-based solutions and traditional grey infrastructure may be applied

NbS have several discrete benefits over traditional gray infrastructure, particularly in the realm of flood management (see table 2.5). These alternatives offer an extensive view of the flooding risk, giving managers an in-depth look at the hydrological, biological, and social characteristics of a system or catchment. Consequently, these solutions can be multifunctional, with direct benefits to flood management, in addition to ancillary benefits for health, environment, and economy. Particularly important are ancillary benefits for agency budgets, poverty reduction, and pollution management. NbS are typically more cost effective than hard infrastructure solutions, so they free up funds for other projects (OECD 2020; World Bank 2019). Furthermore, improving flood management through nature-driven concepts in poverty-stricken areas fosters increased investment by reducing the risk and severity of flood damage. Lastly, the multifunctionality of NbS allows for projects to address flood management as well as environmental concerns and goals, such as water pollution, air pollution, climate change, and reforestation.

Importantly, traditional infrastructure depreciates in value when infrastructure deteriorates or sustains damage between and during flooding events. By contrast, NbS can appreciate in value between flooding events, building up the adjacent natural systems over time. However, both types of infrastructure, traditional, and nature based, depreciate following successive extreme flooding events.

The potential benefits of NbS are broad, illustrating their adaptability and multifunctionality. Unfortunately, the benefits - particularly positive community outcomes and improvements in livability - are not effectually represented in traditional benefit-cost analyses for flood management infrastructure. Yet these “nonmarket” values need to be incorporated because they are important components of nature-based interventions. Including these nonmarket values in future analyses will demonstrate the effectiveness of NbS and their multifunctionality (see box 2.1 for an example) (Gunawardena et al. 2017).

Table 2.5: **OPPORTUNITIES AND CHALLENGES PRESENTED BY NATURE-BASED SOLUTIONS**

Opportunities	Challenges
Increased knowledge[1, 2]: Projects provide extensive knowledge of catchment function, ecology, and flood risk elements.	**Absence of design and management guidelines**[2]: Design and testing protocols for ecosystems and their roles in risk mitigation are not yet fully evaluated and standardized.
Multifunctionality[1,2]: These solutions provide complementary, multifunctional approaches for flood risk management.	**Lack of demand**[4]: Limited awareness exists of flood resilient design and its benefits.
Positive social outcomes1: Projects provide areas for community gathering, relaxation, and leisure.	**Optional**[4]: No mandate exists to use flood resilient design, and the incentives for using these projects are few to nonexistent.
Positive health and well-being[1]: Multifunctional projects can save energy and sequester air and water pollution, increasing positive health benefits and reducing negative ones.	**Lack of or gap in skills**[4]: Implementation of flood resilient design is superseded by like-for-like, lot-scale rebuilding after a flood. Thus, opportunity to educate residents about nature-based solutions falls by the wayside.
Reduced urban poverty and opportunity to address poverty urbanization[1,3]: Addressing flood risks for urban poor provides tangible security benefits and allows communities and governments to invest in these areas.	**Operation or maintenance costs**[1, 2, 5]: Periodic investments are needed to maintain these projects, potentially remediating the biological components of the system.
Positive economic outcomes[1]: Projects augment service industry, attracting high-value businesses and successful professionals.	**Transaction costs**[2, 5]: Developing and implementing these solutions come with a cost associated with educating professionals and local residents to effectively use and manage them.
Opportunities to supplement income[1, 3]: Nature-based solutions can increase the agricultural areas of communities, leading to more agricultural output for consumption or selling.	**Location**[6]: Nature-based solutions require particular environmental conditions to function properly, limiting their effectiveness as a "catch all" answer.
Reduce urban pollutants[1]: Better air and water quality result from nature-inspired projects.	**Space requirements in high density areas**[5]: It can be difficult to convince residents that nature-based solutions can be effective in highly valuable, dense urban spaces.
Freeing of funds[1]: Reduced costs for nature-based solutions allow more funding for other projects, such as poverty alleviation.	

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Source: *Original table for this publication*

Box 2.1: **COST COMPARISON OF TRADITIONAL AND NATURE-BASED SOLUTIONS FOR COASTAL DEFENSE**

Comparing the cost of traditional infrastructure approaches and nature-based solutions reveals a distinct difference in upfront costs, maintenance costs, and compounding benefit values. Constructing coastal defense infrastructure, such as seawalls, typically costs US$6,500 to US$9,800 per meter; however, it can be as high as US$32,800 per meter. Conversely, installing nature-based solutions, such as living shorelines, costs US$0 to US$6,562 per meter, representing a potential saving of US$3,238 to US$9,800 per meter. Assuming structures are not replaced over a 50-year lifespan, the annual maintenance and repair costs are up to US$1,710 per meter per year and US$328 per meter per year respectively, an additional saving of US$382 to US$1,710 per meter per year. Furthermore, the ancillary benefits of a living shoreline on water quality and fish production are valued between US$1 and US$7 per meter per year.

Source: Sutton-Grier et al. 2018.

Despite the demonstrated benefits of NbS, decision makers are reluctant to implement them as extensively as gray infrastructure. The key barriers are primarily administrative, particularly the lack of established guidelines, development incentives, revenue streams, financing options, and skilled professionals able to design, implement, and manage nature-based projects. The perception of NbS as costly, complicated, and unverified is an additional barrier, particularly in developed countries in which established development and funding paradigms are extensively embedded and publicly supported. Reflexive implementation of like-for-like, lot-scale rebuilding in the wake of a flooding event highlights the lack of efforts to incentivize adaptive reconstruction and retrofitting, particularly by insurance providers and policy makers.

Furthermore, technical components of NbS can detract from their effectiveness as alternatives to all gray infrastructure solutions. Traditional infrastructure solutions have fully developed protocols and standards, and emerging nature-based approaches lack an equal measure of scrutiny. Yet, the potential benefits of NbS are immense, and while there are a number of toolkits and guidelines available, there is a need for policymakers to better understand the potential role of these endeavors.

Comprehensively analyzing the effectiveness of NbS and developing a standardized approach to implementation and evaluation address barriers to widespread adoption, positioning NbS as viable complements, even alternatives, to traditional infrastructure solutions. Integrated management approaches could address these technical barriers, using traditional structural and alternative nonstructural measures to demonstrate the multifunctionality of NbS and develop effective implementation guidelines.

2.3.3 A More Integrated Approach to Urban Flood Management

Contemporary flood management practices are social-technical endeavors involving hybrid solutions of gray and green (nature-based) infrastructure underpinned by appropriate investments in the building and maintenance of social (community and institutional) flood resilience. This approach to urban flood management integrates a range of structural and nonstructural measures to effectively reduce flood risk (see box 2.2 for examples). Traditional and NbS each have their strengths and weaknesses, so they should be considered as complementary, rather than distinct, measures. This approach would result in flood risk management strategies that support an integrated, efficient, effective, and value-driven response to flood hazards by creating hybrid systems that merge conventional infrastructure with NbS.

This manual proposes a three-tiered framework for designing an integrated flood risk management strategy (see table 2.6), laying the foundation for identifying appropriate nature-based interventions that offer a wide range of benefits. The framework outlines three complementary approaches to managing flood risk:

BOX 2.2: **DEFINING STRUCTURAL AND NONSTRUCTURAL MEASURES**

Structural measures reduce flood risk by controlling the flow of water. They include hard-engineered structures, such as flood defenses and drainage channels, as well as more nature-based measures, including wetlands and natural buffers.

Nonstructural measures keep people safe from flooding through better planning and management of urban development. These measures include emergency planning and management (for example, early warning systems); increased awareness and preparedness; flood avoidance through land use planning; and increased community resilience through improved building design and construction and appropriate risk financing.

Source: Jha et al. 2012

- **Retreat: reexamining land use zoning and redefining its use in highly vulnerable areas to transition to more appropriate use for land, for example, the Dutch concept of "making room for the river"**
- **Adapt: through urban design, spatial planning and adapting built forms to accommodate flood characteristics of the subject city, an effort that includes establishment of preferential flood pathways (green and gray corridors) and designated flood inundation areas and use of flood resilient building designs**
- **Defend: investing in flood defense provided by traditional engineering approaches toward flood levees, flow diversions, pumps, gates, and so on.**

The three approaches are not mutually exclusive; in fact, they are often combined on a range of scales. They involve a range of constructed and nature-based **structural** measures, together with **nonstructural** initiatives, including:

- **Determining and planning compatible uses of flood vulnerable areas and buildings within these areas**
- **Building community flood literacy**
- **Strengthening and maintaining individual and institutional capacities for flood preparedness, response, and recovery.**

Any given flood management strategy would include a mix of retreat, adapt, and defend approaches tailored to the particular outcomes, objectives, context, and type of flooding being addressed. For example, fluvial flooding could be addressed by making room for the river through the following three-tiered plan involving **retreat**—development of ecological landscapes; **adapt**—adoption of new built forms (for example, higher floor levels), strengthening of social resilience through increased community awareness and preparedness (for example, insurance of infrastructure and other assets against flooding; see box 2.3); and defend - construction of flood protection infrastructures, such as levees, dams, pumps, and so on. Similarly, managing pluvial flooding could involve **retreat**—remediating urban waterways; **adapt**—creating green corridors and dealing with water when and where it falls (source control) through green buildings and smart infrastructure; and **defend**—using pumps. Often the combined approach can deliver a broader range of benefits, and greater benefit-cost ratios while maintaining a core level of flood protection.

The mix of interventions should span multiple spatial scales to limit ripple effects and to improve the robustness of the broader system (Zevenbergen et al. 2008). By understanding the interactions among spatial levels, policy

Table 2.6: **THREE-TIERED FRAMEWORK (STRUCTURAL AND NONSTRUCTURAL OPTIONS) FOR MANAGING FLOOD RISK WITH EXAMPLES**

Approach	Structural options	Nonstructural options	Case study example
Retreat *options* reduce exposure to the hazard through land use planning. They involve moving people and associated infrastructure away from vulnerable areas to less exposed areas.	• Relocation or abandonment of threatened assets	• Land use restrictions • Setbacks • Rolling easements • Revised settlement patterns • Socioeconomic transition strategies • Cultural needs assessment	**Room for the River** (Netherlands) focuses on restoration of natural floodplains through a range of measures (for example, lowering and broadening floodplains, river diversions, temporary water storage areas, depoldering, and dike relocation) at more than 30 strategic locations along the river.
Adapt options reduce the effects of the hazard by increasing the flexibility of vulnerable communities so that they may cope with change and continue using the land.	• Building on pilings • Adaptation of drainage and emergency flood shelters	• Anticipatory building codes • Early warning and evacuation systems • Risk-based hazard insurance	Active, Beautiful, Clean (ABC) Waters Programme (Singapore) is a strategic initiative to improve water quality and livability by integrating stormwater management into the urban landscape. The initiative promotes the creation of multifunctional spaces (that is, flood protection, recreational spaces, and biodiversity) through blue-green infrastructure, such as floating wetlands, rain gardens, naturalized canal edges, and detention ponds.
Defend *options* reduce the likelihood of the hazard through preventive or defensive measures.	• Dikes • Levees • Floodwalls • Seawalls • Bulkheads • Groins	• Dune restoration • Beach nourishment • Afforestation	Hurricane & Storm Damage Risk Reduction System (HSDRRS, New Orleans, United States) After Hurricane Katrina, the levees, floodwalls, gated structures, and pump stations that make up the 133-mile Greater New Orleans perimeter system were strengthened (with higher and more resistant levees and flood walls, emergency pumps, and so on). The HSDRRS is now capable of defending against a 100-year storm surge event.

Source: *Original table for this publication*

Box 2.3: **INSURANCE AS PART OF A HOLISTIC RESPONSE TO FLOOD MANAGEMENT**

Insurance against flooding is a nonstructural solution for helping communities acclimate their mindset and adapt their behavior toward flooding. Insurance is a key pillar in any comprehensive strategy of adaptation to natural hazards because it

- Increases resilience against residual risks that cannot be prevented or mitigated
- Can incentivize engagement and investment in risk mitigation measures
- Reduces pressure on the fiscal budget from natural disasters.

For insurance to be an affordable and effective contributor to flood management:

- **Insurers** need to understand, quantify, and price the risk, which requires good flood mapping, enforced standards for infrastructure and development, and confidence in the overall flood management system.
- **Households and businesses** need to be able to purchase the right level of insurance; therefore, they need to be able to understand risk, to mitigate, and to access insurance products that provide their preferred coverage.
- **Governments** need to ensure availability of information about flood risk and flood effects; effectiveness of mitigation measures (planning and construction standards must be clear); and confidence in flood management systems. When the risk pool is not deep enough (for example, extreme climate events) or the access is not wide enough (for example, diminished ability to pay) there may be a role for government provision.

Sources: White 2011; Jha et al. 2012.

makers can design a comprehensive flood management strategy that takes advantage of interventions at different scales. For example, at the household level, residents benefit from a flood-proof house. However, multiple flood-proof buildings strategically located throughout an urban area benefit the entire city by improving its capacity to cope with flooding and by reducing its dependency on primary flood defense structures. The retreat-adapt-defend strategy supports scale- and context-appropriate solutions. Hybrid solutions can be tailored to the flood management environment (pluvial, fluvial, and coastal) and cut across all scales if considered at the appropriate time in the project.

2.3.4 Mitigation Strategy Framework for Flooding Scenarios

This section outlines a range of structural and nonstructural mitigation strategies for three different flooding scenarios: pluvial flooding (section 2.4.1), coastal flooding (section 2.4.2), and fluvial flooding (section 2.4.3). For each flooding scenario, the mitigation strategies are organized in relation to the retreat-adapt-defend framework. Each strategy is numbered according to the flood type (for example, P for pluvial) and management approach (for example, A for adapt), and this numbering is consistently applied throughout this manual and its appendixes. After the description of mitigation strategies, a series of graphical representations of select strategies are provided to illustrate the differences in the urban landscape before and after intervention.

1.3.4.1 Mitigation Strategies for Pluvial Flooding

A range of structural and nonstructural mitigation strategies that could be applied in pluvial flooding zones (Table 2.7). The strategies include a mix of retreat, adapt, and defend approaches. The benefits and beneficiaries for each pluvial flooding strategy appear in appendix A.

Table 2.7: **MITIGATION STRATEGIES FOR PLUVIAL FLOODING COMPARING STRUCTURAL AND NONSTRUCTURAL SOLUTIONS**

Mitigation Strategies for Pluvial Flooding				
		Retreat	**Adapt**	**Defend**
Structural	Hybrid green and gray intervention	PR1. Conversion of low-lying land and flood-prone area to parks and public open spaces	PA1. Building design that is adaptive to rising water level (for example, bedrooms above water level, waterproof housing, building on podiums, minimum floor levels, critical services located above water level) PA2. Modified street profile to reduce flooding into buildings (for example, protection for doors and basement car parks) PA3. Designated flood conveyance for above-design events (for example, overland flow pathway management) PA4. Flood detention in parks and public open spaces PA5. Naturalization of drainage canal PA6. Increase in green area and soakage catchment wide PA7. Rainwater and stormwater harvesting system for flood detention and for reuse catchment wide	PD1. Upgrade of existing drainage infrastructure (for example, capacity increase, pumping stations, emergency storage) PD2. Local defend (for example, pumps, water guards, and sandbags)
Nonstructural	Community engagement, effective governance, planning, and land use policy	PR2. Land use policy (for example, flood mapping, risk-based approach, and land use rezone and relocation)	PA8. Development control and building regulation (for example, to mainstream adaptive building design and promote stormwater harvesting and reuse) PA9. Adaptation tipping points (ATPs) and adaptation pathway approach PA10. Coordinated planning approach (for example, catchment-wide strategy) PA11. Development of social resilience through community preparedness, flood response, and flood recovery (for example, early warning, evacuation, and emergency services)	

Source: *Original table for this publication*

Figure 2.5 illustrates the application of select mitigation strategies, focusing on the appropriate positioning of interventions within the urban landscape. The top image depicts a typical urban development transect in a pluvial flooding zone. This image contrasts with the bottom urban development transect, which depicts a strategic mix of select retreat, adapt, and defend approaches implemented at appropriate points in the landscape.

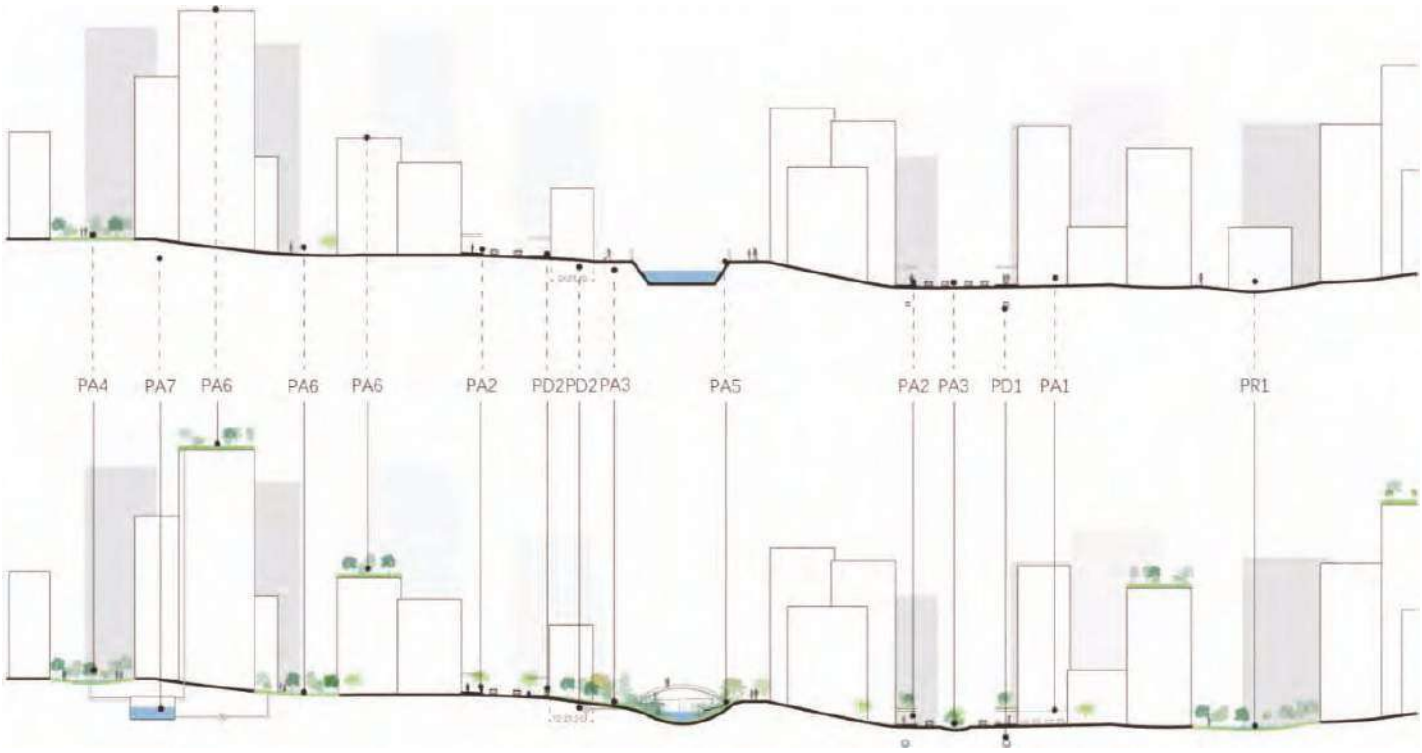
The next set of illustrations (figure 2.6) showcases the look and feel of each intervention depicted in the transect in figure 2.5. The pictures show the urban landscape before and after particular strategies.

2.3.4.2 Mitigation Strategy for Coastal Flooding

Table 2.8 outlines the structural and nonstructural mitigation strategies that could be applied in coastal flooding zones. The strategies include a mix of retreat, adapt, and defend approaches. The benefits and beneficiaries for each coastal flooding strategy appear in appendix A.

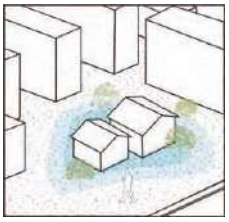
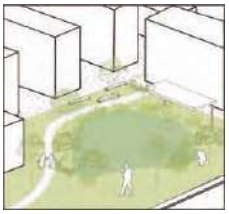
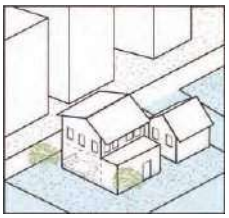
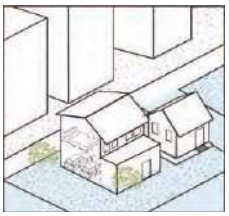
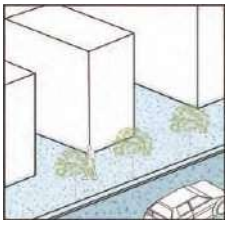
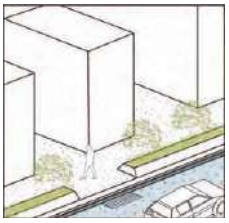
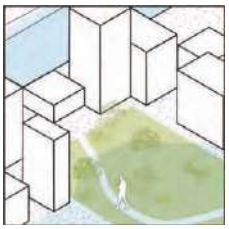
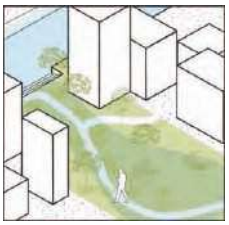
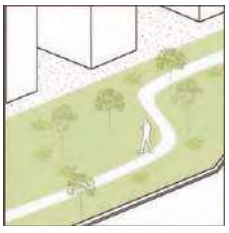
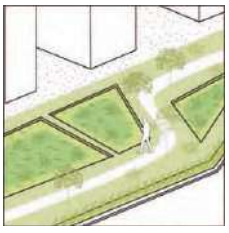
Figure 2.7 illustrates the application of select mitigation strategies, focusing on the appropriate positioning of interventions within the urban landscape. The top image depicts a typical urban development transect in a coastal flooding zone. This contrasts with the bottom urban development transect, which depicts a strategic mix of select retreat, adapt, and defend strategies implemented at appropriate points in the landscape.

Figure 2.5: **PLUVIAL FLOODING MITIGATION STRATEGIES**



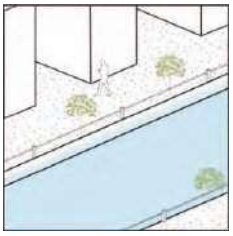
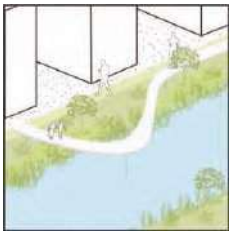
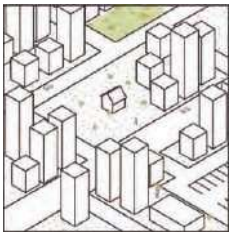
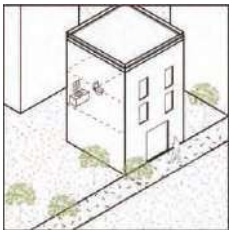
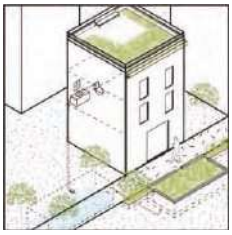
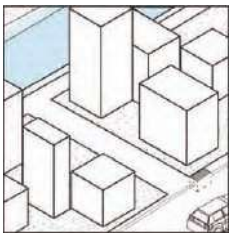
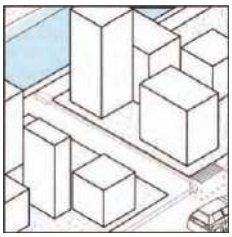
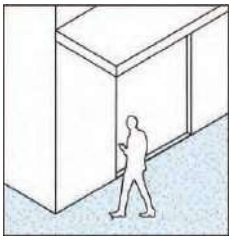
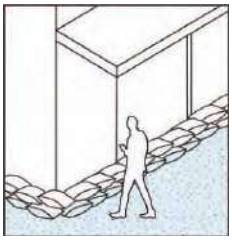
Source: Original figure for this publication
Note: *Specific strategies are detailed in Figure 2.6.*

Figure 2.6: **PLUVIAL FLOODING SCENARIOS BEFORE AND AFTER INTERVENTION**

Strategy	Before	After
PR1: Conversion of low-lying land and flood-prone area to parks and public open space		
PA1: Building design adaptive to rising water level (for example, bedrooms above water level, waterproof housing, building on podiums, minimum floor levels, and critical services located above water level)		
PA2: Modified street profile to reduce flooding into buildings (for example, protection for doors and basement car parks)		
PA3: Designated flood conveyance for above-design events (for example, overland flow pathway management)		
PA4: Flood detention in parks and public open space		

(Continued)

Figure 2.6: **PLUVIAL FLOODING SCENARIOS BEFORE AND AFTER INTERVENTION (*Continued*)**

Strategy	Before	After
PA5: Naturalizing drainage canal		
PA6: Increasing green area and soakage catchment wide		
PA7: Rainwater and stormwater harvesting system for flood detention and reuse catchment wide		
PD1: Upgrading of existing drainage infrastructure (for example, capacity increase, pumping stations, and emergency storage)		
PD2: Local defend (for example, pumps, water guards and sandbags)		

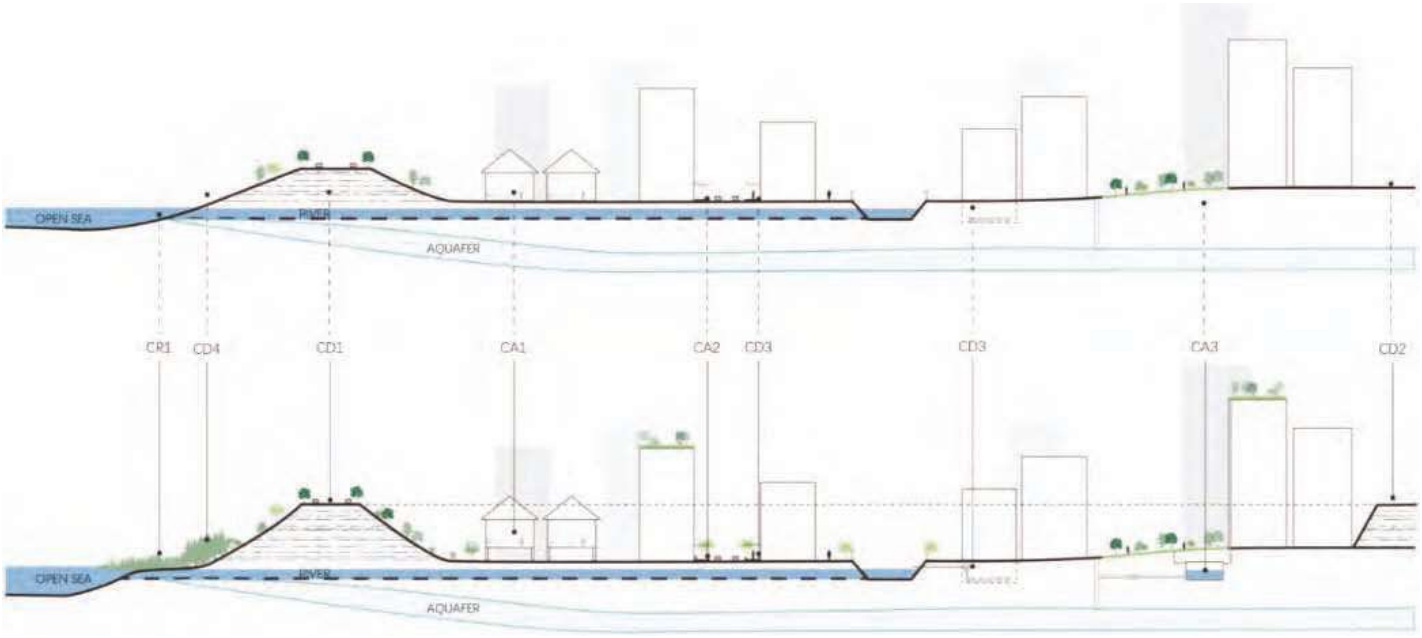
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Table 2.8: **MITIGATION STRATEGIES FOR COASTAL FLOODING COMPARING STRUCTURAL AND NONSTRUCTURAL SOLUTIONS**

Mitigation Strategy for Coastal Flooding				
		Retreat	**Adapt**	**Defend**
Structural	Hybrid green and gray intervention	CR1. Conversion of coastal low-lying land to ecological landscape (for example, mangrove, marsh, and wetlands, allowing them to migrate as level of sea water rises) and protecting and enhancing coastal life	CA1. Building design adaptive to rising water level (for example, floating house, bedrooms above water level, waterproof housing, building on podium, minimum floor levels, critical services located above water level) CA2. Modified street profile to reduce flooding into buildings (for example, doors and basement car park) CA3. Stormwater harvesting system for flood detention and reuse (for such services as alternative water supply, groundwater recharge to geohydrology, countering of sea water intrusion, and countering of land subsidence)	CD1. Levees and embankments (for example, increase in road along foreshore and sea gates) CD2. Localized polder formation CD3. Local defend (for example, sandbags, flood guards, and pumps) CD4. Mangrove forest belt in front of defense infrastructure to reduce wave attack and run-up and overtopping height
Nonstructural	• Community engagement • Effective governance, planning, and land use policy	CR2. Land use policy (for example, flood mapping, risk-based approach, and land use rezone and relocation)	CA4. Development control and building regulation (for example, to mainstream adaptive building design and to promote stormwater harvesting and reuse) CA5. Adaptation tipping points (ATP) and adaptation pathway approach CA6. Building of social resilience through community preparedness, flood response, and flood recovery (for example, early warning, evacuation, and emergency services)	

Source: *Original table for this publication*

Figure 2.7: **COASTAL FLOODING SCENARIO WITH AND WITHOUT INTERVENTION**



Source: Original figure for this publication
Note: Specific strategies are detailed in Figure 2.8.

The next set of illustrations (figure 2.8) highlights the look and feel of each intervention depicted in the transect in figure 2.7. The illustration demonstrates how a particular intervention will transform the urban landscape by using two pictures that show localized differences in the urban landscape before and after intervention.

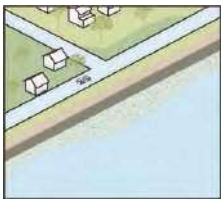
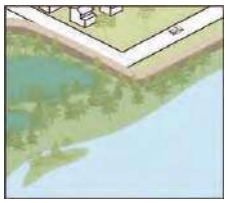
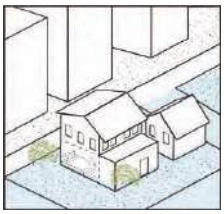
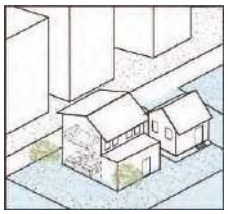
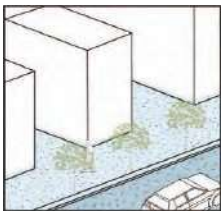
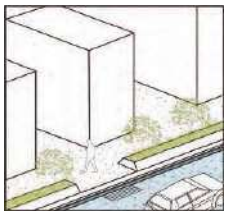
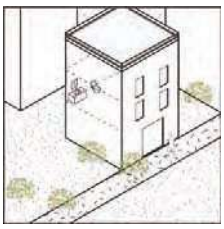
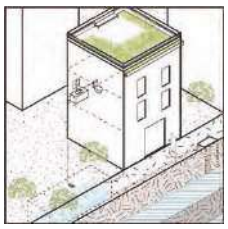
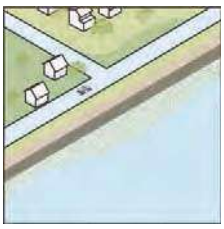
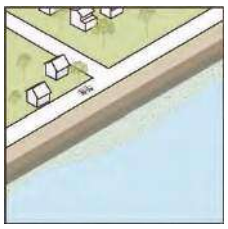
1.3.4.3 MITIGATION STRATEGY FOR FLUVIAL FLOODING

Table 2.9 outlines a range of structural and nonstructural mitigation strategies that could be applied in fluvial flooding zones. The strategies include a mix of retreat, adapt, and defend approaches. The benefits and beneficiaries for each fluvial flooding strategy appear in appendix A.

Figure 2.9 illustrates the application of select mitigation strategies, focusing on the appropriate positioning of interventions within the urban landscape. The top image depicts a typical urban development transect in a fluvial flooding zone. This contrasts with the bottom urban development transect, which depicts a strategic mix of select retreat, adapt, and defend strategies implemented at appropriate points in the landscape.

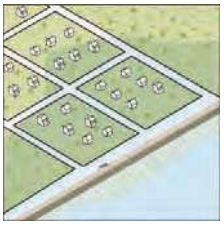
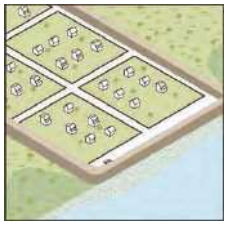
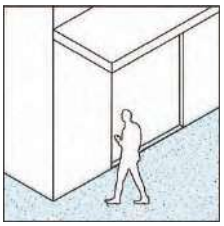
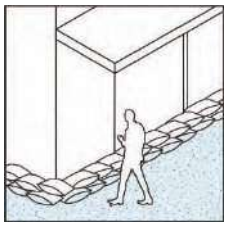
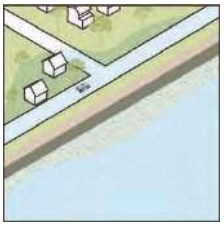
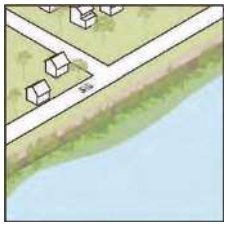
The next set of illustrations (figure 2.10) showcases the look and feel of each intervention highlighted in the transect in figure 2.9. The illustrations demonstrate how a particular intervention will transform the urban landscape, using two visual aids that show localized differences in the urban landscape before and after intervention.

Figure 2.8: **COASTAL FLOODING MITIGATION STRATEGIES**

Strategy	Before	After
CR1. Conversion of coastal low-lying land to ecological landscape (for example, mangrove, marsh, and wetlands, allowing them to migrate as sea water level rises) and protecting and enhancing coastal life		
CA1. Adaptive building design to rising water level (for example, floating house, bedrooms above water level, waterproof housing, building on podium, minimum floor levels, critical services located above water level)		
CA2. Modified street profile to reduce flooding into buildings (for example, doors andbasement car park)		
CA3. Stormwater harvesting system for flood detention and reuse (for example, for alternative water supply, groundwater recharge to geohydrology, countering of sea water intrusion, and countering of land subsidence)		
CD1. Levees and embankments (for example, road elevation increase along foreshore and sea gates)		

(Continued)

Figure 2.8: **COASTAL FLOODING MITIGATION STRATEGIES (*Continued*)**

Strategy	Before	After
CD2. Localized polder formation		
CD3. Local defend (for example, sandbags, flood guards, and pumps)		
CD4. Mangrove forest belt in front of defense infrastructure to reduce wave attack and run-up and overtopping height		

Source: Original figure for this publication

Table 2.9: **MITIGATION STRATEGIES FOR FLUVIAL FLOODING COMPARING STRUCTURAL AND NONSTRUCTURAL SOLUTIONS**

Mitigation Strategy for Fluvial Flooding				
		Retreat	**Adapt**	**Defend**
Structural	Hybrid green and gray intervention	FR1. Return of occupied floodplain to wetlands and parks as ecological landscape and public open space	FA1. Building design adaptive to rising water level (for example, floating house, bedrooms above water level, waterproof housing, building on podium, minimum floor levels, critical services located above water level) FA2. Modified street profile to reduce flooding into buildings (for example, doors and basement car park) FA3. Designated flood conveyance (for example, major flood corridors)	FD1. Attenuation at upstream (for example, dams, reservoirs, and diversion structures) FD2. Flood levee and embankments FD3. Localized polder formation FD4. Local defend (for example, flood guards and sandbags and pumps)

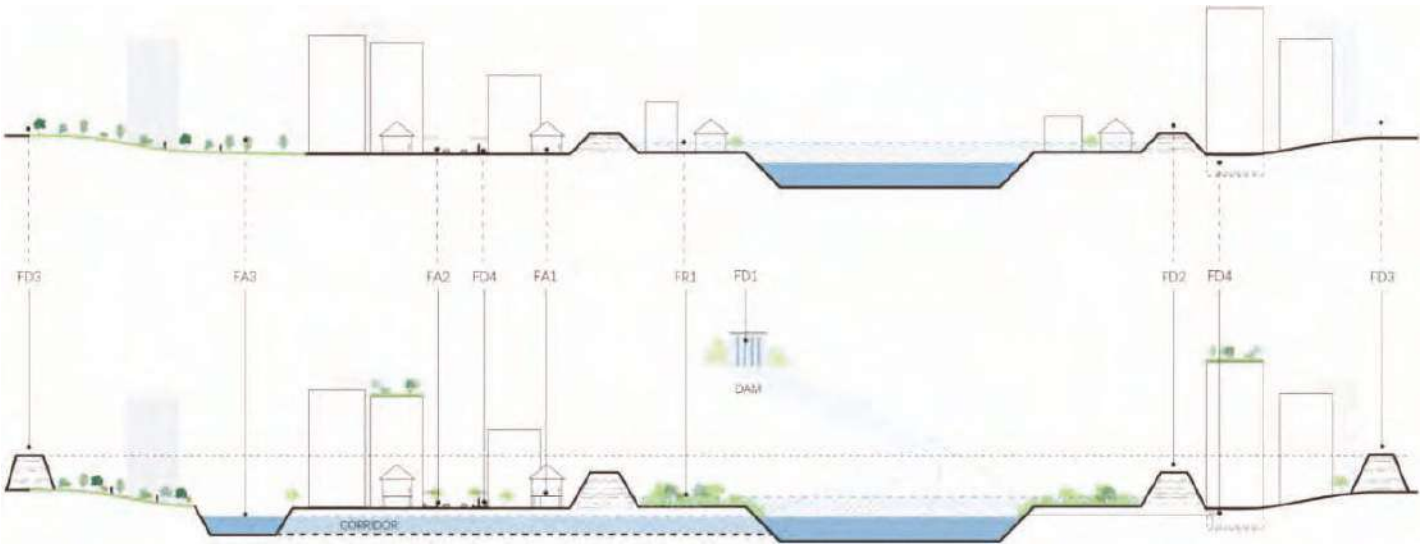
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Table 2.9: **MITIGATION STRATEGIES FOR FLUVIAL FLOODING COMPARING STRUCTURAL AND NONSTRUCTURAL SOLUTIONS (*Continued*)**

Mitigation Strategy for Fluvial Flooding				
		Retreat	**Adapt**	**Defend**
Nonstructural	Community engagement, effective governance, planning, and land use policy	FR2. Land use policy (for example, flood mapping, risk-based approach, and land use rezone and relocation)	FA4. Development control and building regulation (for example, to mainstream adaptive building design) FA5. Adaptation tipping points (ATP) and adaptation pathway approach FA6. Strengthening of social resilience through community preparedness and improved flood response and flood recovery (for example, early warning, evacuation, and emergency services)	FD5. Coordinated upstream and downstream catchment strategy approach (for example, dam and diversion operation)

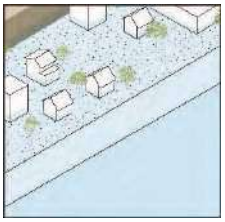
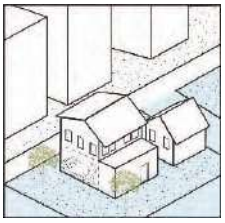
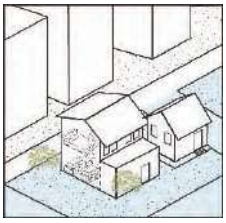
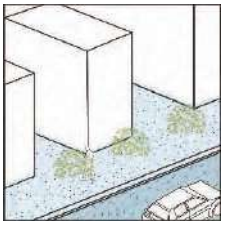
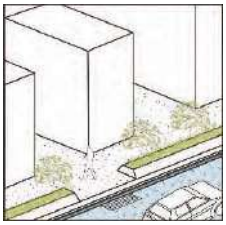
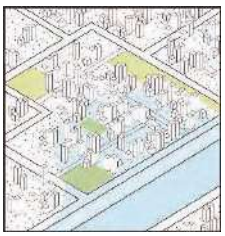
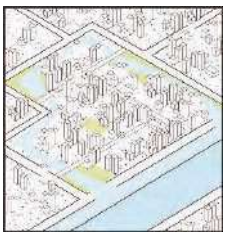
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Figure 2.9: **FLUVIAL FLOODING SCENARIO WITH AND WITHOUT INTERVENTION**



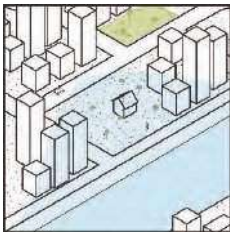
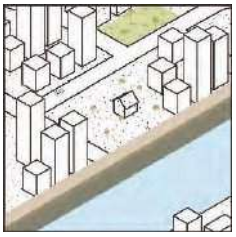
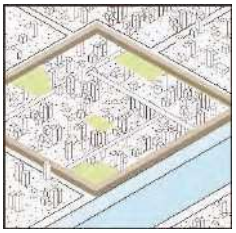
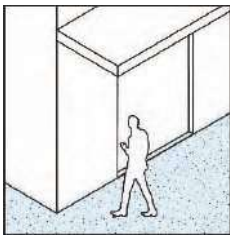
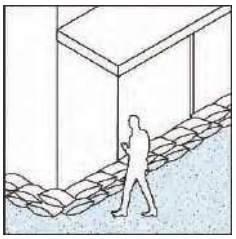
Source: Original figure for this publication
Note: Specific strategies are detailed in Figure 2.10.

Figure 2.10: **FLUVIAL FLOODING MITIGATION STRATEGIES**

Strategy	Before	After
FR1. Return of occupied floodplain to wetlands and parks as ecological landscape and public open space		
FA1. Building design adaptive to rising water level (for example, floating house, bedrooms above water level, waterproof housing, building on podium, minimum floor levels, and critical services located above water level)		
FA2. Modified street profile to reduce flooding into buildings (for example, doors and basement car park)		
FA3. Designated flood conveyance (for example, major flood corridors)		
FD1. Attenuation upstream (for example, dams, reservoirs, and diversion structures)		

Continued

Figure 2.10: **FLUVIAL FLOODING MITIGATION STRATEGIES (*Continued*)**

Strategy	Before	After
FD2. Flood levee and embankments		
FD3. Localized polder formation		
FD4. Local defend (for example, flood guards and sandbags, pumps)		

Source: *Original figure for this publication*

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3 Valuing the Benefits of Nature-Based Solutions for Integrated Urban Flood Management



This chapter explores some of the methodologies and challenges associated with the process of identifying and valuing benefits and the implications for nature-based solutions.

3.1 Capturing the Benefits of Integrated Urban Flood Management

A key feature of integrated urban flood management (IUFM) involves striking an appropriate mix of structural and nonstructural solutions. Options vary in terms of scale, timing, the types of benefits and costs, the degree of certainty and associated risks, and the distribution across locations, time, and stakeholder groups. Traditionally, "gray" or "hard" structural solutions have dominated efforts to develop the capacity, resilience, and adaptability of urban communities in response to urban floods. However, nature-based green infrastructure solutions are increasingly integrated into urban planning to provide a cost-effective and flexible approach for urban flood management. Such integrated solutions often provide multiple tangible and intangible cobenefits in urban landscapes, such as human well-being and biodiversity, in addition to flood management.

Benefit-cost analysis (BCA) provides a means of comparing different options to ensure the right mix of interventions to address the specific challenges. To apply BCA effectively, the benefits and costs associated with different options need to be described and, ideally, assigned a monetary value. Traditional approaches to determining monetary values have focused on avoided losses due to reductions in the probability of flooding (table 3.1). A benefit to this approach is that it is simple to calculate and to explain to decision makers. It can also provide information regarding the optimal level of flood risk reduction relative to the direct intervention cost. However, such approaches do not reflect the full range and diversity of environmental and social cobenefits and the values of resilience and reversibility that can be realized through integrated approaches to urban flood management. Such innovations require new approaches to facilitate the identification and assessment of the full range of benefits to be derived from IUFM.

Table 3.1: **TYPES OF LOSS FROM FLOODS**

Can the loss be monetized?	Direct loss: Loss from contact with flood water	Indirect loss: No contact—loss as a consequence of flood water
Yes—monetary (tangible)	For example, buildings and contents, vehicles, livestock, crops, infrastructure	For example, disruption to transport for people and goods, loss of value because of interruptions to commerce and business, legal costs associated with lawsuits
No—nonmonetary (intangible)	For example, lives and injuries, loss of memorabilia, damage to cultural or heritage sites, ecological damage	For example, stress and anxiety, disruption to living, loss of community, loss of cultural and environmental sites, ecosystem resource loss

Source: Modified from "Disaster Loss Assessment Guidelines," Emergency Management Australia 2002.

3.2 Identifying the Benefits of IUFM

Combining green and gray infrastructure approaches to IUFM can lead to cost savings and greatly improved overall risk reduction in addition to generating additional social, economic, and environmental cobenefits (photo 3.1 and figure 3.1). In addition to the direct benefits of avoided losses due to improved flood management, environmental cobenefits of nature-based solutions (NbS) can include the following:

- **Improvements in natural habitat**
- **Protection and enhancement of biodiversity**
- **Reduction or reversal of the trend toward loss and degradation of terrestrial ecosystems and their services**
- **Reduction or reversal of the trend toward loss and degradation of aquatic ecosystems and their services**
- **Reduced greenhouse gas (GHG) emissions and increased carbon sequestration**
- **Improved air quality**
- **Reduced temperature fluctuations**
- **Reductions in nutrient transport and eutrophication**
- **Soil stabilization and nutrient cycling**
- **Groundwater recharging**
- **Other improvements to catchment processes**
- **Support in improving health of marine environments**

There are also substantial socioeconomic benefits to be derived from NbS in association with flood management in the urban environment. These include increased access to green space; aesthetic benefits derived through ecosystems being considered beautiful, appealing, or visually appreciated; increasing local land and property values; improvements in local multimodal transportation; more active and connected communities; improved tourism and recreation opportunities, including sports (for example, recreational fishing, boating, and so on); reduced public health risks; and employment opportunities, including those jobs that are directly linked to the implementation of the NbS themselves. There are also a range of nonmaterial benefits (WWAP 2018) associated with spiritual, religious, and totemic values as well as with improved cognitive development; the reduction of social inequalities that often disproportionately affect women, disadvantaged groups, and the poor; and life satisfaction and aspirations, among others.

The distribution of these benefits may differ significantly, depending on the mix of options and local conditions. Different projects can also generate benefits at different times for a range of reasons, including the following:

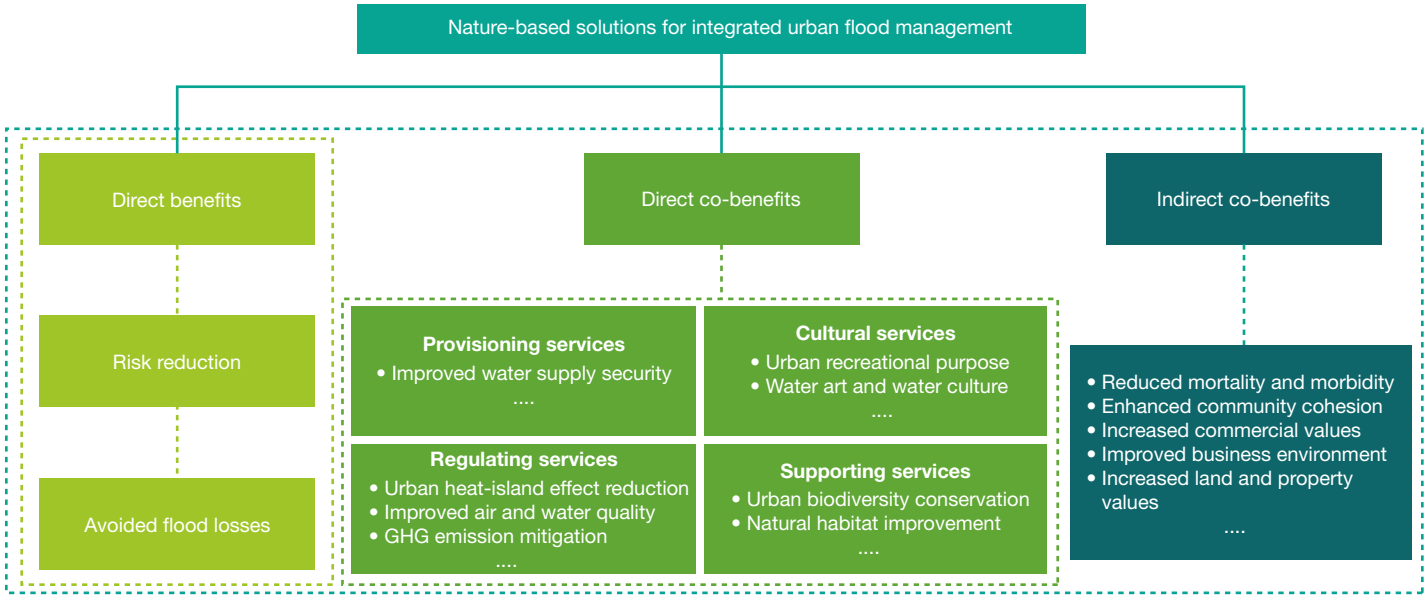
- **Lag time associated with implementation. For example, if a project relies on new research, it could take several years before results are available, while large assets take time to build.**
- **Lag time for physical implementation to take effect and start generating benefits. For example, plants and trees require time to grow.**
- **Lag time associated with projects addressing threats that have not yet occurred but are expected to, or may intensify, in the future. Examples include climate change and population growth.**
- **Lag time for adoption. A project may require people to change their behavior or management approaches, which can take time.**
- **Issues associated with educational programs. Benefits from such projects decline over time if not reinforced or if a new law or regulation is not enforced.**

Photo 3.1: **BENEFITS ASSOCIATED WITH A NATURE-BASED PROJECT IN FLOOD MANAGEMENT**



Source: original figure for this publication, photo from Kunshan Urban Development InvestmentCompany

FIgure 3.1: **TYPES OF BENEFITS POTENTIALLY DERIVED FROM NATURE-BASED SOLUTIONS FOR IUFM**



Source: Original figure for this publication.

Adoption lags and the decline of benefits associated with educational programs are particularly relevant factors associated with nonstructural solutions. Often involving measures that aim to change behavior, these projects include community education programs and laws that limit property development in flood-prone areas, among others. Typically, not everybody adopts the behavior being promoted; in fact, the degree of adoption varies from project to project, and assessments of projects need to account for this variation. Failing this, there is a risk in giving funds to projects that have great potential but little benefit in practice.

3.3 Valuing the Benefits of NbS for IUFM

Assessing the best mix of options for IUFM involves presenting as many benefits and costs in monetary terms (or monetary-equivalent terms) as possible. Beyond the direct flood loss estimates, information detailing social and environmental values are important to include because the importance to the community of different social and environmental outcomes varies enormously. Ignoring these values likely will result in poor decisions about how to spend public resources, which can result in reduced social support and create potential problems during implementation.

The practices involved in IUFM provide tangible effects that are easily quantifiable (for example, avoiding the cost of repairing flood-damaged infrastructure and determining the market value of hydroelectricity from a dam that provides both energy and flood-management benefits). However, they also produce intangible effects that can be difficult to quantify and monetize (for example, the amenity benefits of having access to public green space). Due to the fact that they are difficult to quantify and monetize, these intangible benefits are often not included in formal economic and financial assessments of project value.

Intangible benefits and costs can sometimes be valued through preexisting markets, such as markets for houses. However, that's not always the case. Some of the common cost savings and market and nonmarket benefits associated with many flood-management projects are illustrated in table 3.2, and figure 3.2 illustrates some of the benefits associated with an NbS project to improve flood management (see also appendix A for a map of the benefits and beneficiaries associated with each of the mitigation strategies outlined in section 2.4).

Nonmarket benefits are generated by goods that are not bought and sold in markets. Some benefits have both market and nonmarket aspects (for example, improved health and recreation). An absence of information about market prices and changes in supply and demand as prices fluctuate make it more difficult to monetize these benefits. Some nonmarket values are "nonexcludable goods" (for example, lower ambient temperatures in a region as a result of urban greening); it is not possible to charge a price, so there is no market for them.

Some nonmarket goods relate to externalities - effects on third parties not involved in the economic activity that generates the externalities. The downstream flooding effects of forested catchment clearing is one example. There may not be a market in flood abatement because of high transaction costs of negotiating between those benefiting from catchment deforestation and victims, for example, or because of the absence of well-defined rights (such as a public right to flood protection).

Estimating the nonmarket benefits of a project requires two types of information: the additional quantity of the benefit that results from the project and the monetary-equivalent value of that additional quantity of the benefit. Information about the additional quantity of the benefit from NbS may come from technical experts (such as scientists and engineers) or from community members (for example, through a survey or focus group). The appropriate technical experts will vary depending on the benefit. Estimating improvements in biodiversity may need input from ecologists, estimating reduced morbidity may need input from public health researchers, and estimating increased vegetation may need input from plant scientists.

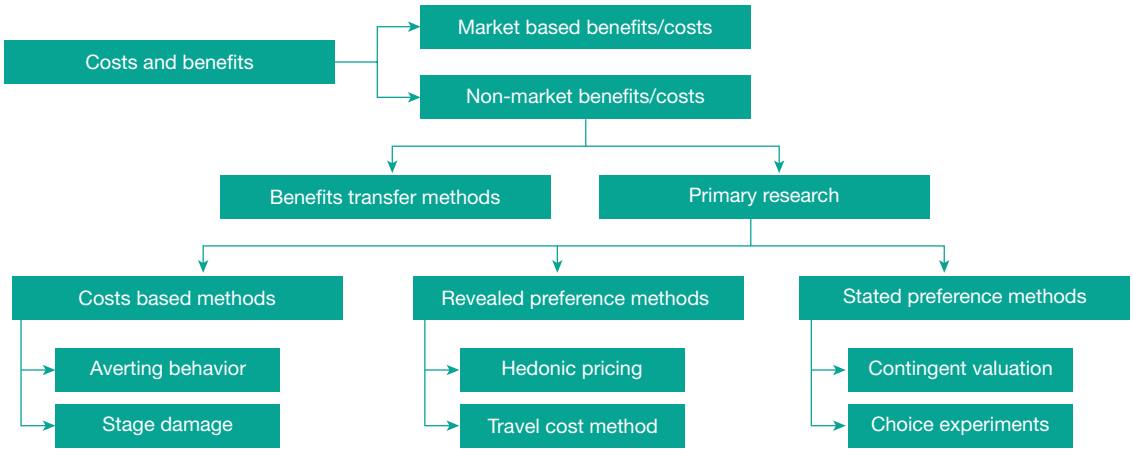
Placing a monetary-equivalent value on the benefits is often challenging. There are several well-tested techniques for monetizing nonmarket values. Ideally, the process involves conducting a primary nonmarket valuation study.

Table 3.2: **COMMON FLOOD MANAGEMENT BENEFITS AND METHODS FOR THEIR VALUATION**

	Benefit	Benefits valued by
B1	Reduced water consumption	Market or cost saving
B2	Reduced or delayed investment in infrastructure (for example, water treatment plant)	Cost savings
B3	Reduced recurring costs (for example, energy for cooling)	Cost savings
B4	Improved management of wastewater	Market or cost savings
B5	Increased business profits (for example, from sewer mining)	Market
B6	Increased work productivity (for example, from less extreme heat)	Market
B7	Increased tourism	Market and nonmarket
B8	Improved aesthetics	Nonmarket
B9	Improved opportunities for recreation	Market and nonmarket
B10	Reduced crime and increased community cohesion	Market and nonmarket
B11	Reduced mortality (for example, from reduction in extreme heat)	Nonmarket and market (health system costs)
B12	Reduced morbidity and improved health (for example, from reduction in extreme heat)	Nonmarket and market (health system costs)
B13	Reduced greenhouse gas emissions and increased carbon dioxide sequestration	Market and nonmarket
B14	Groundwater recharge (for example, for potable extraction or wetland enhancement)	Market and nonmarket
B15	Ecological improvement and biodiversity	Nonmarket
B16	Improved air quality	Nonmarket
B17	Reduced water pollution load to receiving water body	Market and nonmarket
B18	Reduced flood risk	Risk reduction
B19	Increased productivity of aquatic and terrestrial ecosystem (aquaculture, water resources, and land produce)	Risk reduction
B20	Improved security of water supply	Nonmarket

Source: Original table for this publication.

FIgure 3.2: **EXAMPLES OF METHODOLOGIES FOR VALUING COSTS AND BENEFITS**



Source: Original figure for this publication.

*Box 3.*1: **VALUATION TOOL FOR NONMARKET BENEFITS OF WATER SENSITIVE SYSTEMS, PRACTICES**

The Cooperative Research Centre for Water Sensitive Cities (CRCWSC) has developed a database tool known as the Investment Framework for Economics of Water Sensitive Cities (INFFEWS) Value tool. The core of the tool is a comprehensive database of Australian nonmarket valuation studies. Each study in the database contains a dollar value estimate of the nonmarket benefits generated by water sensitive systems and practices. To populate the database, a comprehensive search-and-review process was used. The design of this tool has been informed by industry stakeholder consultation, and industry experts have provided feedback on the design and functionality of the tool.

The INFFEWS Value tool contains more than 2000 nonmarket benefit values covering all benefit types (table 3.2) from 76 Australian studies specifically related to investment in water sensitive systems and practices.

The INFFEWS Value tool consists of the following components:

- Excel-based spreadsheets that constitute a comprehensive set of information about nonmarket valuation studies with useful filter and search options.
- Guidelines that outline the features and functions of the value tool and provides demonstrated examples on how to conduct benefit transfer using values from the database.
- The INFFEWS Benefit-Cost Analysis (BCA) tool (see box 4.2) is another tool developed to support balanced and systematic decision making about water sensitive investments and to provide evidence for use in business cases.
- Values from the INFFEWS Value tool can be used as inputs to the INFFEWS BCA tool.
- For more information, including access to the tool, please visit the CRCWSC website: https://watersensitivecities.org.au

Source: Cooperative Research Center for Water Sensitive Cities. https://watersensitivecities.org.au (accessed in September 2020)

Appendix C and figure 3.2 summarize some of the different primary research methodologies. These studies can be both expensive and time consuming, but they may be justified for very large projects or for those with significant consequences because of poor choices.

An alternative is to apply the benefit transfer method to reasonably approximate the nonmarket benefits associated with the proposed investment.[1] This approach can also be used as part of an initial assessment of options or for decisions in which the size or risks of the investment decision are low. The Investment Framework For Economics of Water Sensitive Cities (INFFEWS) Value tool uses a database of values drawn from other studies to generate monetary values for nonmarket benefits. Guidelines explain how to conduct benefit transfer, including how to choose appropriate adjustment methods when relevant (see box 3.1). Appendix B applies the benefit transfer method to two hypothetical examples.

[1] Appendix C summarizes common non-market valuation techniques. Understanding the strengths and weakness of each approach is important in considering either primary research or applying the value transfer approach.

3.4 Understanding the Size, Timing, and Certainty of Project Costs and Benefits

The costs of different options for IUFM may vary significantly (see figure 3.3). Large structural solutions (such as drains, levees, and seawalls) often require sizeable upfront capital costs, and take time to build. However, they can deliver the full value of their flood protection benefits immediately upon completion. Furthermore, if accountability for delivery and maintenance is well defined, the accountable party has a high level of control over whether the effort translates into action and has any effect. y contrast, NbS can avoid large upfront capital investments, while nonstructural solutions may involve no capital investment. The benefits of smaller scale NbS may accumulate over time. Furthermore, because they are scalable, NbS projects and nonstructural solutions provide opportunities to learn and change the approach as conditions change and more information becomes available. This is particularly advantageous in data-poor environments. However, NbS can also involve considerable ongoing operating costs and high levels of uncertainty because they often encompass natural processes in open systems.

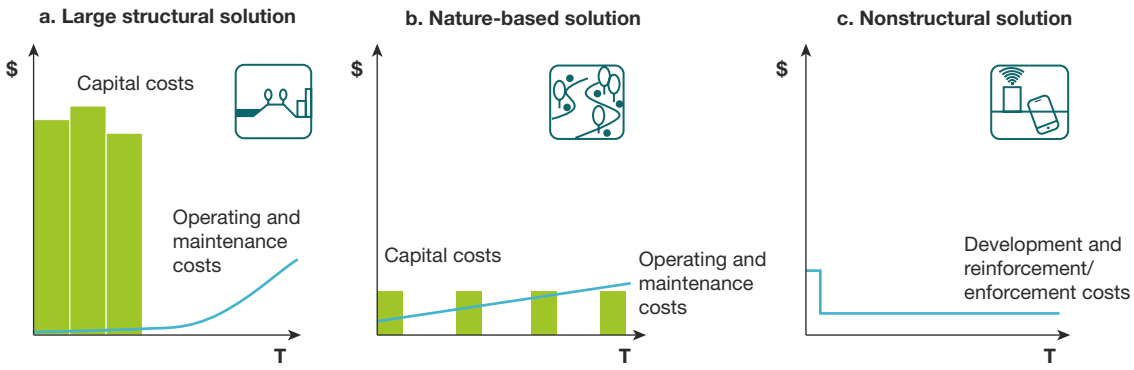
Many factors can affect adoption of new practices and technologies, such as NbS and nonstructural solutions, and their importance can vary substantially from case to case (Pannell 2015; Rogers 2003). Factors influencing the attractiveness of a new practice include its costs, its financial benefits, its riskiness, its complexity, and its compatibility with existing practices and systems as well as social pressures for or against the practice and the attractiveness of the existing practice that the new practice would replace. The strength of community networks, community attitudes, and community knowledge or awareness can also play a role. Generally, the more a practice requires people to change their behavior, the less likely people are to find the practice attractive as a solution unless the changes themselves are highly attractive to people. Furthermore, changes that may be attractive if adopted on a small scale can be highly unattractive if they have to be adopted on a large scale.

Quantifying adoption levels involves considering evidence and opinions about adoption of the desired practices, including the current levels of adoption, the extent to which that adoption has already been encouraged by awareness programs or similar; track record of past efforts to promote adoption; and the private economic costs and benefits of the practice. For some projects, the organization responsible for the project relies on another organization to deliver part of it. If this relationship is managed via an enforceable contractual agreement, confidence that the other organization will deliver can be reasonably high. However, if the arrangement is less formal, the probability that the project will fail because the partner organization failed to deliver should be taken into account.

When uncertainty about the uptake of NbS or nonstructural options is significant, or the consequences of a poor choice large, it may be important to experiment with different scenarios through sensitivity analysis. It is also important to make sufficient provision for future costs of reinforcement and or enforcement to realize anticipated benefits. In practice, there is much uncertainty about how benefits will accrue over time, so the precise shape of the “benefit curve” will be context specific (figure 3.4).

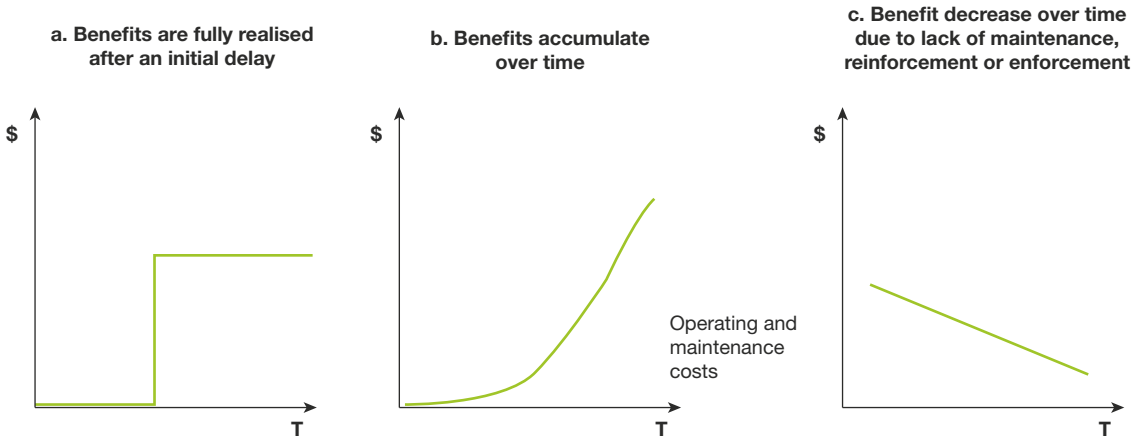
Understanding the profile of costs, benefits, and risks or uncertainties over time is important for comparing options (chapter 4) and financing (chapter 5) the preferred portfolio of actions. For example, time lags matter in a BCA because future benefits and costs are discounted and expressed in present value terms (see chapter 4). The further in the future a benefit occurs, the smaller its value in present value terms.

Figure 3.3: **ILLUSTRATIVE EXAMPLES OF COST PROFILES ASSOCIATED WITH IUFM OPTIONS**



Source: Original figure for this publication.
Note: T = time.

Figure 3.4: **ILLUSTRATIVE EXAMPLES OF BENEFIT PROFILES ASSOCIATED WITH IUFM OPTIONS**



Source: Original figure for this publication.
Note: T = time.

3.5 Addressing Equity

A core objective of IUFM is to improve the lives of flood-affected people. However, floods affect different parts of the catchment differently, and IUFM responses deliver different benefits to different groups of people over time. It is, therefore, important to understand how costs and benefits are traded among parts of the community and over time. Understanding these trade-offs requires a meaningful engagement process. This engagement has several advantages:

- **It increases information and data available (important in data-poor environments, local knowledge).**
- **It improves the authorizing environment and consequently reduces implementation and maintenance costs.**
- **It may increase the range of funding sources available.**

As well as considering the effects on different groups of people, it may also be appropriate to consider (but not double-count) the institutions affected by the costs and benefits of different options. This step may be important in working through who should finance and fund implementation of different IUFM options (see chapter 5). Appendix B provides two worked examples illustrating distributions and effects of different solutions.

Traditional BCA focuses on the overall merits of a project or policy, based on whether the benefits attributable to the project outweigh its costs. The costs and benefits to all people are added without regard to the individuals to whom they accrue: a one dollar gain to one person cancels a one dollar loss to another. This "a dollar is a dollar" assumption separates resource allocation from distribution effects—or efficiency from equity effects. It does not mean that distributional considerations are unimportant or should be neglected. Rather, they should be considered a separate part of the analysis.[2]

Some BCA specialists advocate weighting the various benefits generated by a project, depending on the groups to whom they accrue and judging how appropriate or important it is for those groups to receive benefits. That approach is not advocated in this manual.

If the information is available, a BCA can identify potential winners and losers and the magnitude of their gains and losses. It is then up to decision makers to decide whether distributional effects or equity issues are important and need to be addressed.[3] Based on the nature of potential benefits and beneficiaries identified, different financing mechanisms could be adopted. For instance, if the benefits are retained locally, land value capture vehicles may be considered. If the benefits are generated somewhere else other than the location of the NbS interventions, arrangements of inter-jurisdictional compensation may be explored.Chapter 5 discusses some of the issues to consider when determining how to fund IUFM investments and how to distribute costs so that projects deliver the best overall community benefit. Appendix B presents two worked examples that demonstrate how information from a BCA can help identify the winners and losers from IUFM projects and help decision makers determine how to fund/finance those projects, i.e. linking beneficiary identification to financing mechanisms.

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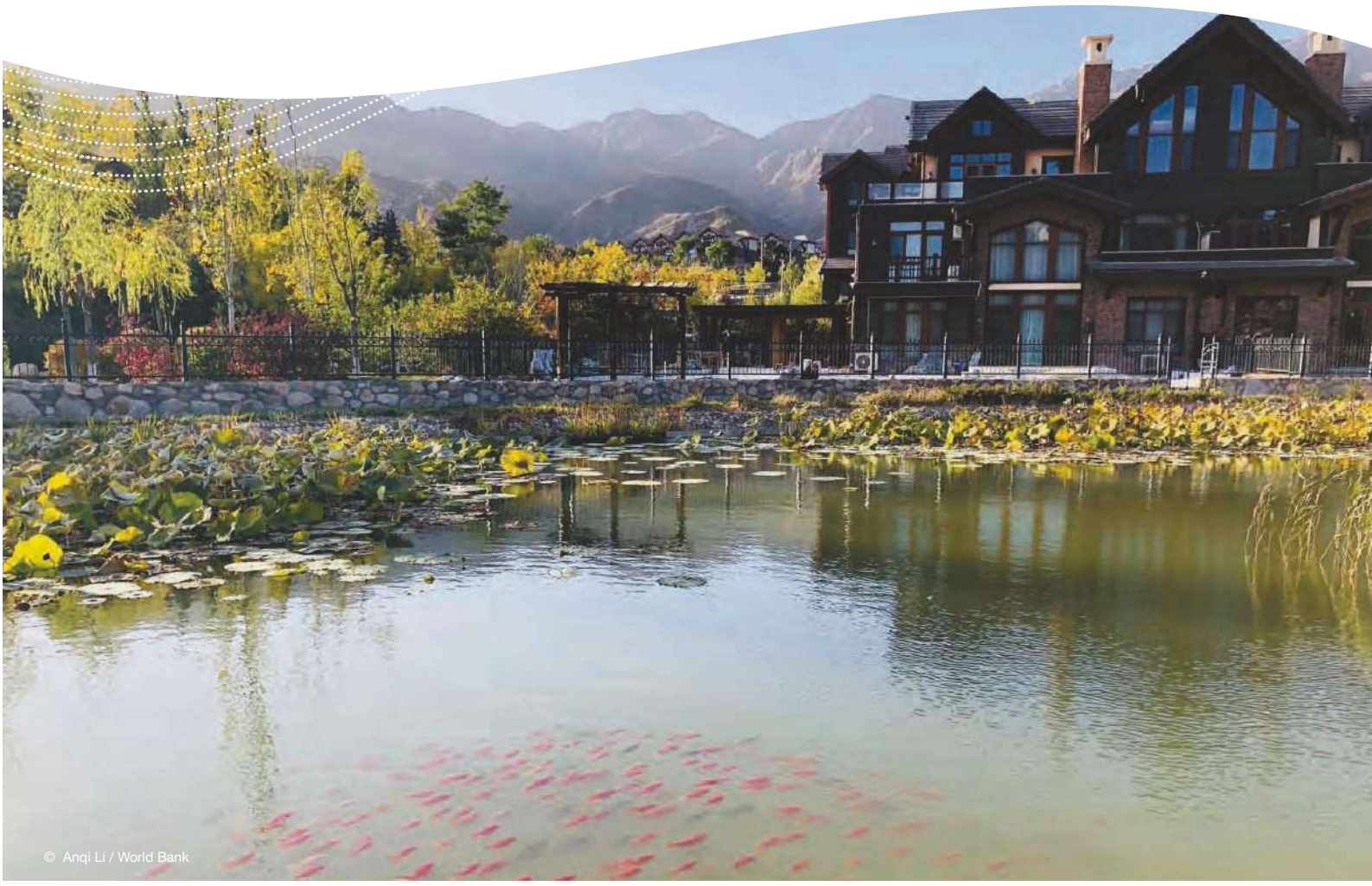
WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris: UNESCO.

[2] Office of Best Practice Regulation, Guidance Note: Cost-Benefit Analysis. Canberra, Australia, Department of the Prime Minister and Cabinet, Australian Government, 2016, p. 5.

[3] Office of Best Practice Regulation, 'Guidance Note: Cost-Benefit Analysis', p. 13.

4

Choosing from Integrated Urban Flood Management Options



This chapter briefly introduces benefit-cost analysis, outlines issues to consider when using BCA as part of integrated urban flood management, and provides advice on what to do in the face of data, time, and budget constraints.

4.1 Introduction

A key challenge for flood managers is making a sound long-term decision that benefits the community overall, best uses the available information, and makes transparent any assumptions and uncertainties. The funding available for integrated urban flood management (IUFM) is almost always much less than the funding required to implement the appropriate combination of projects to realize the intended objectives. Therefore, decision makers must compare and prioritize options. The costs, risks, and benefits of different IUFM options vary significantly across time, location, and stakeholders. Incomplete information and uncertain outcomes also require flood managers to make assumptions, which can materially affect the analysis. Good decision making typically acknowledges the following principles (adapted from Kinrade et al. 2012):

- **Focus on objectives: Decisions should meet clear, measurable, and prioritized objectives.**
- **Effectiveness: Chosen options should make a difference and demonstrate efficacy.**
- **Efficient use of resources: Chosen options should deliver objectives in the most cost-effective manner.**
- **Avoidance of adverse side effects: Decision makers should avoid options that adversely affect or increase the vulnerability of other systems, sectors, or social groups.**
- **Adaptation: Chosen options should encourage adaptation strategies that are flexible and reversible or modifiable.**
- **Relevance: Decision makers should use appropriate data, methods, criteria, and assumptions that meet stakeholders' expectations and requirements.**
- **Completeness: Decision makers should consider all direct and indirect benefits and costs as well as all winners and losers. They should also consider a wide range of options.**
- **Consistency: Data, methods, criteria, and assumptions should allow for meaningful and valid comparisons with similar decisions.**
- **Consultation: Decision makers should undertake meaningful consultation and engagement so that decisions reflect stakeholder and community values and preferences. The level of engagement should reflect the significance of the decision.**
- **Collaboration: Decisions should be collaborative: they should involve close cooperation with other relevant decision makers.**
- **Transparency: Analysis should provide clear and sufficient information for reviewers to assess the decision's credibility and reliability.**
- **Compliancy: Decisions should comply with relevant national and state legislation, policies, and guidelines.**

4.2 Reasoning behind Benefit-Cost Analysis

There are a range of common methodologies for evaluating flood and disaster risk management policy scenarios. These include benefit-cost analysis (BCA), multicriteria analysis (MCA), and robust decision-making approaches, among others (UNISDR 2017). Each needs to be considered within the proper context and complexity by reviewing the data and resources available and the degree of consensus among stakeholders.

BCA is a flexible and proven conceptual framework that can help decision makers better understand the distribution of those who gain and those who do not. It supports an initial assessment of project feasibility; it is not a detailed engineering or economic assessment. The BCA framework for decision making is consistent with the principles outlined earlier, and it is used widely to inform policy, business cases, and investment decisions (Brent 2006). Examples of its application include managing wastewater in Sri Lanka, constructing the Three Gorges Dam in China, hosting the Beijing Olympics, preserving the Amazon rainforest, assessing an immunization program for avian influenza, and building the Jamuna Bridge in Bangladesh (Quah and Toh 2011).

The concept behind BCA is simple: compare the benefits of a project or policy with its costs to assess whether it is worthwhile. A BCA "is primarily about organizing available information in a logical and methodical way" (New Zealand Government Treasury 2015). A BCA usually prioritizes three decision criteria: the net present value (NPV), the benefit-cost ratio (BCR), and the economic rate of return (ERR). Furthermore, BCA can be conducted through a participatory process enabling stakeholder involvement and consultation on cost-benefit identification and valuation. In this way, the process of BCA can be as useful as the outcomes. However, putting this simple idea into practice can be challenging because it involves collecting and integrating many types of information.

In contrast, multicriteria analysis offers an assessment of options against a broad set of criteria that encompass different dimensions and have different units (both quantitative and qualitative). It can be useful to incorporate and reflect the wide range of social, cultural, and environment benefits that can come from nature-based solutions (NbS) for integrated urban flood management (Box 4.1) (Browder et al. 2019). In practice, because the MCA approach involves more time, money, and complexity, it is usually used in conjunction with BCA, particularly in situations with lower levels of public support or a high degree of uncertainty and for cases in which the benefits that are difficult to value in monetary terms are of the greatest interest and relevance to stakeholders affected by the policy decision.

Most government guidance on appraisal for flood management investments suggests a simpler BCA as a more realistic starting point. Therefore, BCA has been the primary approach for prioritizing among ways to reduce risk while investing in developed countries (Price 2018). This is reflected in China through the "Economic Evaluation Guidelines for Water Conservancy Construction Projects"[1] and in other countries, such as the United Kingdom, which provides guidance for flood management project appraisal.[2]

4.3 Differences between Economic and Financial Evaluations

Economic and financial evaluations of a project compare costs and benefits in present value terms. People often expect that for any given project, a financial evaluation should reach broadly the same conclusion as an economic evaluation. However, this is not the case; there are significant differences between the two approaches.

The primary difference between them is the frame, or perspective, used for the analysis. A financial analysis uses an individual enterprise or agency as its frame. By contrast, an economic evaluation uses the whole society as its frame, so it has a wider scope of benefits and costs. As a result, a project benefit or cost can differ across financial and economic evaluations.

[1] Ministry of Water Resources of China (1996) Water Conservancy Construction Project Economic Evaluation Guidelines. SL72-94.

[2] Defra Flood and Coastal Defence Appraisal Guidance https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/181441/risktopeople.pdf

*Box 4.*1: **MULTI-CRITERIA APPROACH FOR SELECTING GREEN AND GREY INFRASTRUCTURE TO REDUCE FLOOD RISKS AND INCREASE COBENEFITS**

A multicriteria decision tool was used to evaluate flood reduction investments as part of efforts to develop adaptive, sociotechnical risk management measures and strategies for coastal communities against extreme hydro-meteorological events. These measures and strategies are aimed at minimizing social, economic and environmental impacts and increasing the resilience as part of the "Preparing for Extreme And Rare events in coastaL regions" (PEARL) project funded through the European Commission (http://www.pearl-fp7.eu/). The tool was developed to evaluate different types of measures for floods (fluvial, pluvial, costal, flash, groundwater) and different site characteristics (soil type, urban land use and so forth) in three case studies: Marbella, a coastal city in south Spain; Ayutthaya, located 80 km north of Bangkok; and, Sukhumvit, a business district in eastern Bangkok.

The overall performance matrix of the flood management measures is dependent on the scores and weights of different flood management measures. Scoring is based on a qualitative assessment of the effects of different measures on each criterion, which was developed based on data collection through literature review. The relative importance of criteria, i.e. weighting, is defined by the users and reflects local preferences. The final ranking of all different measures is calculated as the weighted average of scores of all criteria considered. More than 25 criteria are included, including flood reduction reliability, cost reduction and multiple co-benefits, including water quality, environment, social and cultural aspects.

Source: Alves, A., Gersonius, B., Sanchez, A., Vojinovic, Z. and Kapelan, Z. (2018) Multicriteria approach for selection of green and grey infrastructure to reduce flood risk and increase co-benefits. Water Resources Management. 32, 2505-2522.

Unlike a financial evaluation, an economic evaluation measures nonmarket benefits and costs as well as externalities, which are particularly important for IUFM projects. An economic evaluation also treats such factors as depreciation and taxes differently. There are various references dealing with the difference between an economic evaluation and a financial evaluation with the World Meteorological Organization providing a useful guide to the context of integrated water management (World Meteorological Organization n.d.).

4.4 Main Steps in a BCA

The BCA process aligns with the general principles of good decision making and provides a clear mechanism to demonstrate that World Bank–funded projects have raised living standards. Specifically, a benefit-cost ratio greater than 1 indicates that a project's benefits outweigh its costs. The World Bank, an early adopter of BCA, identifies six characteristics of a good BCA:

- Use of expected benefits and expected costs
- Comparison between the with- and without-project scenarios to assess benefits and costs
- Comparison of proposed projects against alternatives, including the "do nothing" option
- Use of sensitivity analysis to understand risks and uncertainties
- Consideration of whether the project delivers against World Bank's goal of poverty reduction
- Consideration of externalities.[3]

[3] IEG World Bank, Cost-Benefit Analysis in World Bank Projects, Washington DC, USA, The International Bank for Reconstruction and Development/The World Bank, 2010.

Table 4.1: **KEY STEPS IN A BENEFIT-COST ANALYSIS**

Step	Description
1	Understand the context, objectives, and risks.
2	Define project-based case and alternatives involving integrated urban flood management (IUFM).
3	Identify and quantify benefits, costs, and risks.
4	Identify who benefits and who bears the costs over time.
5	Discount future costs and benefits to obtain present values and adjust benefits to account for risk of project failure.
6	Compute decision metrics (for example, benefit-cost ratio).
7	Address uncertainty, by including among others a sensitivity analysis.
8	Compare and rank alternatives and make recommendations.

Source: Original table for this publication

There are eight commonly accepted steps in conducting a BCA (table 4.1).[4]

Once the project is defined, the BCA helps ensure that it is logically consistent. This means that in the field, specified actions coincide with the project goal, project mechanisms bring about the onground actions, and costs accurately reflect the project mechanisms. Internal consistency is crucial to accurately and fairly assess the project objectives. However, a comprehensive BCA can be data-demanding and requires substantial time and resources, and so an abridged BCA tool may be appropriate to carry out a simplified BCA under data limitations (Box 4.2).

4.5 BCA Checklist

Although a BCA for integrated urban flood management (IUFM) can present challenges, many of the general principles and potential pitfalls as well as the applications for IUFM are the same for all BCA assessments. There are generally five categories of issues for conducting a robust BCA (Figure 4.1).

[4] For example, see New Zealand Government Treasury Guide to Social Cost Benefit Analysis, New Zealand, 2015; Commonwealth of Australia, Handbook of Cost-Benefit Analysis (archived), Canberra, Australia, Department of Finance and Administration, 2006.

Box 4.2: SUPPORTING PRACTICAL APPLICATION OF PRINCIPLES OF BENEFIT-COST ANALYSIS

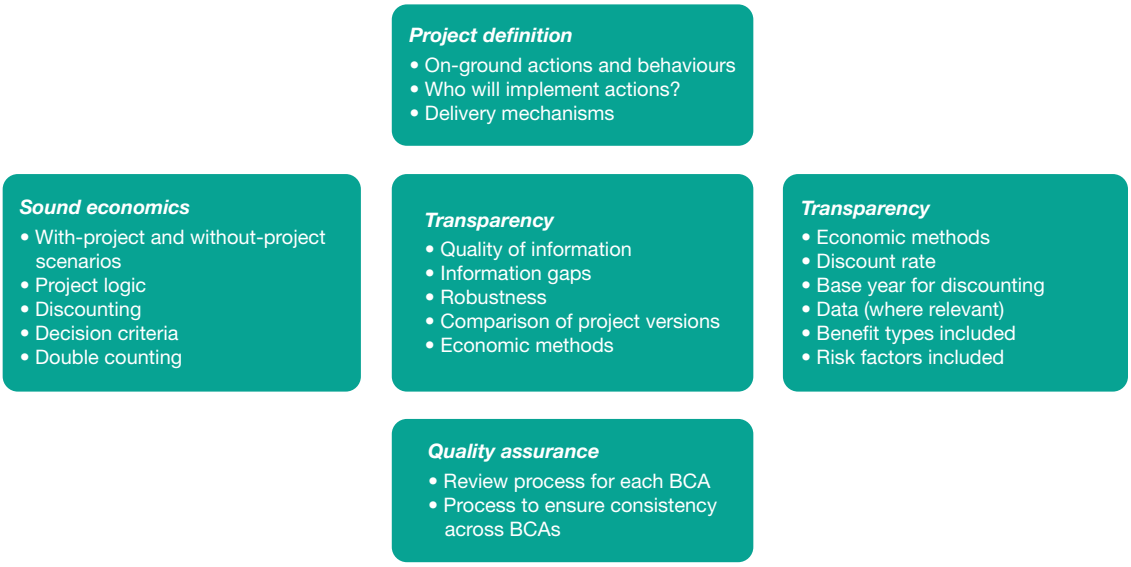
Many tools and resources support practical application of the principles of benefit-cost analysis (BCA). After extensively reviewing existing BCA tools in Australia, the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) developed a user-friendly BCA tool tailored to water sensitive cities' investments. The Investment Framework for Economics of Water Sensitive Cities (INFFEWS) BCA Tool was developed in close consultation with stakeholders and tested by developers in case studies. A number of trials ensure that its usability and features align with industry needs. Updated versions will be released as the tool develops.

The INFFEWS BCA Tool consists of the following components:

- *BCA Tool and Guidelines*—a multisheet Excel spreadsheet and a detailed user guide
- *Rough BCA Tool*—a simplified spreadsheet and set of guidelines to enable a quick and rough BCA
- *BCA Comparison Tool*—a spreadsheet to compare and rank BCA results from multiple projects or different versions of the same project
- *BCA for Strategic Decision Making*—a document outlining the BCA basics, guidance on strategic issues related to BCAs, and use of economic information in strategic decision making.

Source: Cooperative Research Center for Water Sensitive Cities (https://watersensitivecities.org.au/)

Figure 4.1: **CHECKLIST FOR A BENEFIT-COST ANALYSIS**



Source: Original figure for this publication.
Note: BCA = benefit-cost analysis.

4.5.1 Project Definition

A BCA evaluates a project or policy that consists of actions and interventions, so these actions and interventions must be clearly defined. A BCA cannot be used to evaluate general issues such as water pollution or provision of green infrastructure, but it can be used to evaluate a particular project that would improve water pollution or provide green infrastructure within a defined project boundary. When defining the BCA for a project, it is important to be explicit about the following:

- Onground actions and behaviors. What changes in management actions or behavior are envisioned to deliver the benefits?
- Implementation. Who will implement actions? These could be undertaken as part of the project itself or by somebody else (for example, private citizens, businesses, or other organizations). If it is somebody else, the project's role is to influence that party's decisions and, subsequently, the new actions or behaviors.
- Delivery mechanisms. What will this project actually do? Is it undertaking the actions itself? If so, what are they? Is it attempting to influence decisions by others about what actions they will undertake? If so, what will the project do to influence them?

Understanding the base case

An essential step for any BCA is understanding the base case, which is the "without" project scenario. The benefits "with" the project are measured relative to the benefits "without" the project. Most important, comparing values "with" and "without" the project is not the same as comparing values "before" and "after" the project. For example, an environmental asset may degrade without the project, but the project would improve its condition relative to its current condition (see figure 4.2).

On the other hand, a project that appears to generate substantial benefits may not, because those benefits would have become reality even without the project. In other words, the benefits are not "additional" to what would have happened anyway. The without-project trajectory for benefits would be almost the same as the with-project trajectory, so the difference between them and, hence, the benefits of the project would be small (see figure 4.3).

The "with versus without" principle

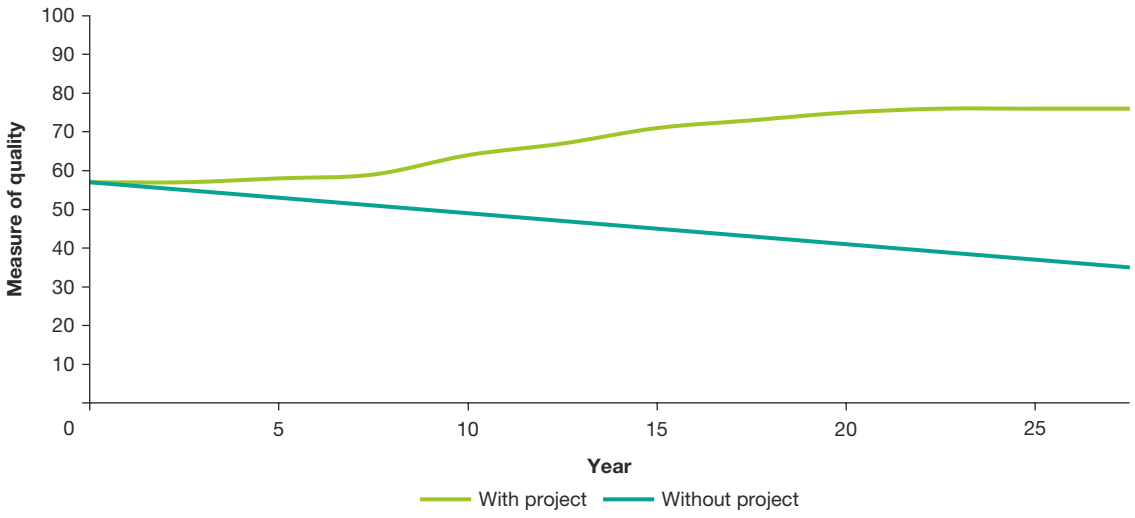
The "with versus without" principle is possibly the most important idea behind BCA. Applying it incorrectly results in worthless BCA results. The benefit of a project is the change in values generated only by the project. It is the difference between the welfare generated with the project and without the project.

Usually, a project is evaluated before it is implemented, so the results have to be predicted for both scenarios (with and without the project). Neither set of results can be observed because each one is in a hypothetical future different from the other.

Because of the "with versus without" principle, a project can generate benefits even if it does not completely prevent a decline in values (such as environmental degradation). As long as it slows or reduces degradation, the result is measured as a benefit.

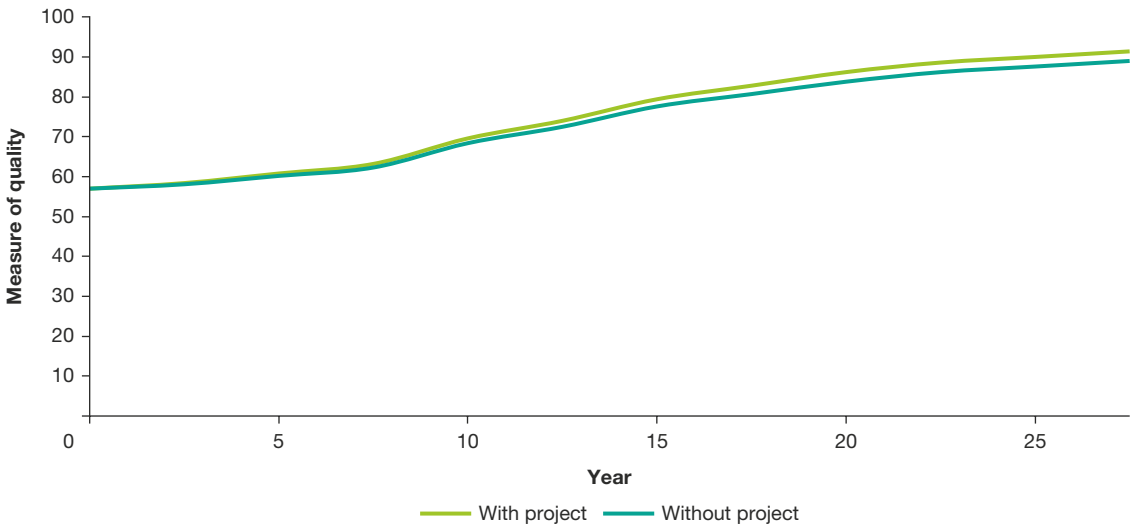
Making good predictions about the "without-project" scenario can be difficult. The process requires good knowledge of the issue, the context, the proposed management practices, and the people whose behavior matter. Inaccurate or insufficient thinking about the "without" scenario exaggerates the estimates of benefits. The BCA Tool user guide includes a checklist of issues to consider when thinking about the with- and without-project scenarios (see box 4.3).

Figure 4.2: **ESTIMATES OF VALUES WITH PROJECT VERSUS VALUES WITHOUT IT WHEN A PREDICTED DECLINE TURNS INTO A RISE**



Source: Original figure for this publication

Figure 4.3: **ESTIMATES OF VALUES WITH PROJECT VERSUS VALUES WITHOUT IT WHEN VALUES WOULD INCREASE EVEN WITHOUT PROJECT**



Source: Original figure for this publication.

Box 4.3: **CHECKLIST FOR CONSIDERING SCENARIOS WITH AND WITHOUT PROJECT**

This list of questions can help practitioners of benefit-cost analysis (BCA) determine whether their deliberations of the with- and without-project scenarios are sufficiently clear and comprehensive. Practitioners can think about the questions on this checklist before quantifying the project's benefits on the *benefit parameters* sheet or the *custom benefits* sheet.

1. Types of effects

- What conditions or outcomes are likely to change because of the project? (Examples include availability of a public good, sale of a commercial product, probability of a risky event, severity of a risky event if it does occur, and delay or reduction in a cost.)
- What is the chain of events from the project to the outcomes?

2. Effectiveness of project at delivering changes in behavior or management

- What barriers prevent the desired changes in behavior or management? To what extent does the project address these barriers?
- Given the mechanisms used in the project (for example, education, information, subsidies, and regulation), how many people or businesses will adopt the desired changes in behavior or management?
- What is the chance that the desired behavior change will occur anyway, without the project?
- To what extent will essential partner organizations come on board with the project?

3. Effectiveness of changes in behavior or management at delivering benefits

- What difference will the actions resulting from the project (including changes in behavior or management) make to the desired outcomes?
- How responsive is the benefit to the actions being promoted? (For example, if one of the benefits is increased urban wildlife making use of new habitat, to what extent will the new habitat result in increased populations of wildlife?)
- Would the project generate new benefits that would not have otherwise occurred, or does it propel forward in time benefits that would have occurred eventually? Or some combination thereof?
- Will conditions worsen before the benefits from the project start to emerge?

4. Effects in second round

- Will the project create incentives or opportunities that lead to effects in the second round?

5. Without-project scenario

- What is the current trajectory of change, and how would that evolve without the project? Would it stay on the same trajectory or not? Things that may change in the without-project scenario include income, population, government policy, technology, other facilities or infrastructure, climate, developments, demand for recreation, and demand for water.

(Continued)

*Box 4.*3: **CHECKLIST FOR CONSIDERING SCENARIOS WITH AND WITHOUT PROJECT (continued)**

- To what extent would the desired changes happen anyway, even without the project? The extent to which changes would have happened anyway need to be specified as part of the without-project scenario.
- What would people do without the project? How does this affect the benefits of the project?

Source: Investment Framework for Economics of Water Sensitive Cities Tool for benefit-cost analysis, Cooperative Research Centre for Water Sensitive Cities (https://watersensitivecities.org.au/)

4.5.2 Project Risks

Avoiding over optimism about projects involves explicitly understanding the risk that the project may be implemented but may fail to deliver its intended benefits.

"Risk" is used in many different ways, so it is important to be clear about what it means here. In this context, risks are things that might stop the project from delivering its intended benefits. These risks do not refer to hazards to the environmental, human health, or to the economy, for example. There are various types of project risks, including technical risk, sociopolitical risk, financial risk, and management risk (see box 4.4). All can be important, and they should all be considered.

Risk refers to an unpredictable outcome about which it is possible to specify a probability, at least subjectively. Uncertainty—in which probabilities cannot be specified—is also relevant and can be usefully addressed using sensitivity analysis[5]

4.5.3 Sound Economics

The analysis should be consistent with the following accepted economic principles:

- With-project and without-project scenario. A without-project scenario is clearly defined and used as the baseline. Benefits are calculated based on a comparison of with-project and without-project scenarios, not a comparison of before-project and after-project scenarios (see section 4.5.1).
- Project logic. The project is logically defined and internally consistent. The defined delivery mechanisms can reasonably be expected to cause the desired actions and behaviors on the required scale. The defined actions and behavior changes can reasonably be expected to deliver the goal of the project. The budgeted costs are sufficient to fully cover the project actions.
- Discounting. Has the analysis been done in real terms or in nominal terms? What approach to discounting has been used and what discount rates have been used? Often, each organization has its own policy about discount rates. It is recommended that sensitivity analysis be conducted to understand how different discount rates will affect the BCA results. For projects with very long life cycles and lasting effects, which is often the case with NbS for IUFM, discount rates can be reduced over time to account for uncertainty about future growth. For instance, in France, the official social discount rate is 4 percent for the first 30 years, and then it decreases toward 2 percent beyond 30 years.
- Decision criteria. Standard decision criteria for BCA are reported by including net present value and benefit-cost ratio (BCR). In calculating the BCR, the costs consist only of short-term project costs and operating or

Box 4.4: **TYPES OF RISK**

Technical risk: The project may fail to deliver outcomes for technical reasons—something breaks, newly planted trees die, a miscalculation occurs during the design phase, or a natural event makes the actions ineffective. This risk may be estimated through discussions with experts who understand the technical issues or with people who are experienced in implementing similar projects.

Sociopolitical risk: In some cases, social or political factors will prevent project success. For example, a project might rely on another government agency to enforce existing regulations, but that agency does not enforce them because of the likelihood of a political controversy. There might be community protests, perhaps even legal action, to stop the project.

Estimating this risk is subjective. It involves considering whether the project will be supported or obstructed by social, administrative, or political factors. It involves weighing whether the project will garner support or opposition from local community groups and networks, local government bodies, bureaucratic entities, and so on. What is the probability that the project will fail to reach its goal due to one or more of these factors? If legal approvals are required, what is the probability that they will not be forthcoming?

The project may generate social or political controversy with adverse consequences for the responsible agency. This controversy may result from the failure of the project to deliver its intended benefits, or it may result from completely unrelated factors. For example, the project may fully deliver its intended benefits, but it also may have unintended adverse consequences, which could generate political criticism or controversy.

Either way, this sociopolitical risk should be considered as a separate, and additional, negative factor on top of any risk to the project benefits themselves. The adverse consequences that could be relevant to this risk include reprimands, suspensions, loss of promotion, demotion, or termination of employment contracts for individuals in the project organization.

Spin-offs such as this can be considered subjectively by decision makers when they are looking at the quantitative results of benefit-cost analysis (BCA). Qualitative information about the risks would be presented to decision makers along with the quantitative results.

Financial risk: Most projects require some level of ongoing funding after the initial project phase. For example, this could be for maintenance and repairs, operational costs, or ongoing public education and awareness raising. Without funding for maintenance and operations, benefits generated during the initial project phase may be compromised or even lost entirely.

Because this risk (lack of maintenance funding) reduces the expected benefits of some projects, it should be considered part of the BCA. Estimating the risk involves knowing who will be responsible for funding ongoing maintenance and operations and how decisions to provide that funding will be made.

The risk of maintenance funding not being provided also has a positive aspect: it means there is a cost saving. If benefits are scaled down because of this type of financial risk, maintenance costs should be scaled down by the same probability.

This discussion relates to the risk that a project's benefits will not be delivered. There is also risk regarding cost; although the BCA is based on the best estimate of the project costs, once the project is implemented, the actual costs may be higher or lower. This issue is included as a sensitivity analysis on cost. On the sensitivity sheet, the user specifies how total project cost may fluctuate relative to the

(*Continued*)

Box 4.4: **TYPES OF RISK (*Continued*)**

default level, and this range is included as part of three types of sensitivity analysis: robustness of results to changing variables, sensitivity of results to individual factors, and break-even analysis for individual factors.

There could potentially be higher-than-expected costs associated with the base case. This would be captured in sensitivity analysis of the project's benefits.

Managerial risk: If different projects will be managed by different organizations, then differences in the risk of failure related to management are likely. These risks might include poor governance arrangements; poor relationships with partners; poor capacity of staff in the organization; poor specification of targets, milestones, and timelines; and poor project leadership.

Estimating the risk requires knowing the organization(s) that will be responsible for project delivery and their track record for successfully managing similar projects.

Source: Investment Framework for Economics of Water Sensitive Cities BCA Tool, Cooperative Research Centre for Water Sensitive Cities (https://watersensitivecities.org.au/)

maintenance costs. Other costs (such as compliance costs or costs to other stakeholders) are deducted from the benefits rather than including them in the denominator of the BCR.

- Multiplier effects. Advocates for projects sometimes argue the projects will generate additional benefits through economic multiplier effects, as the benefits flow through the economy. However, this argument ignores the likelihood of negative (offsetting) multiplier effects from the imposition of taxes to fund the project. The new activity may also displace other activity. In most cases, "multiplier effects should be ignored" (New Zealand Government Treasury 2015, 16).
- Double-counting benefits. Benefits should not be counted twice. Double-counting most often occurs when benefits are reflected in land and house prices. For example, an investment in green infrastructure in a particular location generates recreational and aesthetic benefits, which are estimated using a choice experiment. A secondary effect is that house prices in the area rise, which may be estimated using hedonic pricing. However, the BCA should not include both the choice experiment and the hedonic pricing results because they capture the same benefits. House prices are rising because purchasers anticipate their access to the new green infrastructure, perceive the extra benefits that they will receive, and raise the price they are willing to pay for the house. To include both the choice experiment results and the hedonic pricing results would be double-counting. Guarding against double-counting cannot readily be automated, but thinking through the issue is part of the decision flow with this process.

4.5.4 Transparency

To judge how much confidence decision makers can have in the BCA results, the analysts should report on the following items:

- Quality of information. How reliable is the information that was used to conduct the analysis? For example, was it based on peer-reviewed research, expert advice, or informed judgments made by the analyst?

- Information gaps. Which information items were lacking and may be candidates for further investigation?
- Robustness. Given realistic variations in the numbers used in the analysis, can a firm conclusion be reached about the project's performance? For example, is it clearly a good project with favorable results even when more pessimistic assumptions are used? Or is there a 50:50 chance that the BCR is greater than 1?
- Economic methods. The economics community does not agree about some aspects of BCA practice. Three examples are (1) the choice to weigh the benefits, depending on which groups within society capture them; (2) the choice to include the excess burden of taxation in the calculation of costs; and (3) the choice to consider discount rates and to select them. The BCA report should state clearly which economic methods were used.
- Optimism bias. Research shows that people who develop projects often overestimate the benefits and underestimate the costs (Kahneman 2011). In its guidelines, the Australian government notes that "Optimism bias … is an endemic problem in [benefit-cost] analysis" (Commonwealth of Australia 2006). This bias, known as the "planning fallacy," stems from the natural human tendency to get excited about a potential project, and it leads people to overlook risks or problems, underestimate costs, and exaggerate how many people will benefit or how much they will benefit. This happens unintentionally and unwittingly, even among people who are aware of the risks of overoptimism.

It is important to try to counter the planning fallacy to reduce the risk of approving ineffective or unworthy projects. Various strategies can be used to address this tendency (see box 4.5).

4.5.5 Consistency

In many cases, BCA results must be compared. When organizations must prioritize among competing projects, BCAs integrate most of the relevant information in a way that facilitates comparison. However, to make valid comparisons, the different BCAs need consistent assumptions for the following:

- Economic methods (as outlined earlier)
- Discounting and the same discount rate. Future benefits and costs must be discounted to the same base year, and the number of years included in the analysis must be consistent.
- Circumstances in which the same variable is relevant to multiple BCAs (for example, the marginal value of a life saved). The same values should be used in each BCA unless there are clear reasons to vary them.
- The range of benefit types included. A study that included only benefits related to market goods cannot be compared with another study that included both market and nonmarket benefits.
- The risk types being assessed (for example, technical, sociopolitical, financial, and managerial).

Achieving consistency across BCAs entails effort, requiring the organization using analyses to be explicit about efforts to delivery consistency and to check on its delivery.

4.5.6 Quality assurance

Peer review of draft BCAs before they are finalized is crucial but often overlooked. Most guides to BCA mention peer review only in passing, if at all.

Agencies that commission or undertake BCAs should require a peer review of the completed first version of every BCA. Experience with many different users of BCA has revealed that peer review can often make a major difference in the quality and comparability of BCAs. Common problems that an independent expert reviewer may pick up

Box 4.5: **TACKLING OPTIMISM BIAS AND SELF-SERVING BIAS**

A range of measures can reduce the potential impacts of optimism and self-serving bias. For example, the Investment Framework for Economics of Water Sensitive Cities (INFFEWS) Tool for benefit-cost analysis includes:

- Explicit questions about negative factors that tend to be ignored. The tool for benefit-cost analysis (BCA) asks the user to quantify the project risks—the probability that the intended benefits will not be delivered. Reasons for nondelivery could include technical failures, sociopolitical factors, insufficient funding for maintenance, and poor management. The estimated risk factors are used to scale down the expected benefits.
- Logical consistency checks. In the tool's user guide, users are asked to check if answers to some later questions in the spreadsheet logically coincide with their answers to specific earlier questions. This helps flush out some biased responses.
- Transparency about the assumptions used. All information used in the BCA can be viewed in the spreadsheet, which has the capacity to record the sources for each item of data.
- Review of assumptions by independent experts. Kahneman (2011) found people are much more realistic about judging other people's projects than their own. Peer review of the numbers included in a BCA is recommended best practice. The BCA Tool includes a facility for reviewers to comment on each part of the analysis and for the analyst to respond.
- Sensitivity analysis. The spreadsheet automatically generates sensitivity analysis results. Users or decision makers can look to see if the project is still attractive when relatively pessimistic assumptions are used. For example, if costs are higher than expected, is the project still worthwhile?

Another strategy, especially for large projects, is to conduct a feasibility assessment or pilot test for the first phase of a project. Approvals for later stages depend on the results of the feasibility assessment. Project managers should collect additional information about the aspects of the project that were most uncertain in the project-assessment phase and then revise the original assessment accordingly. Decision makers use this revised assessment to decide if the project should proceed.

Source: INFFEWS BCA Tool, Cooperative Research Centre for Water Sensitive Cities (https://watersensitivecities.org.au/).

include (but are not limited to) overoptimism in the assumptions used (as discussed earlier), lack of awareness by the original analyst of improved or more recent data sources, weaknesses in the without-project scenario, and errors in or omissions from the economic methods.

4.6 When Data, Time, and Budget Are Limited

There is limited advice available on how to conduct a simplified BCA. However, a good decision maker does a mental BCA to weigh the benefits and costs of different decision options. These are codified in the New Zealand Treasury Guide and the INFFER model (Pannell et al. 2012). The New Zealand Treasury recognizes this reality and argues for systematizing and organizing this mental BCA, putting it down on paper to produce a "rough" BCA. That is, "A rough [BCA] is better than no [BCA]" (New Zealand Government Treasury 2015, 6). The INFFER process uses

Table 4.2: **SUGGESTED STEPS FOR CONDUCTING A "ROUGH" BENEFIT-COST ANALYSIS**

	Description
1	Understand the issues and context.
2	Define project alternatives (one or more with-project scenarios) and baseline (the without-project scenario).
3	Complete a rough benefit-cost analysis (BCA) for each project scenario.
4	Identify types of benefits and costs, the entity that benefits, and the entity that loses. Prepare a table that lists the benefits and costs, describing them, and if possible, with the available information. Benefits and costs need to be thought of as the difference between a with-project scenario and a without-project scenario.

Source: Original table for this publication

a set of simple criteria (based on BCA criteria) to filter out less attractive project options before selecting projects for full BCAs. Table 4.2 presents suggested steps for conducting a rough BCA, combining aspects of these two sources.

Conducting a highly simplified or "rough" BCA can be good for several reasons:

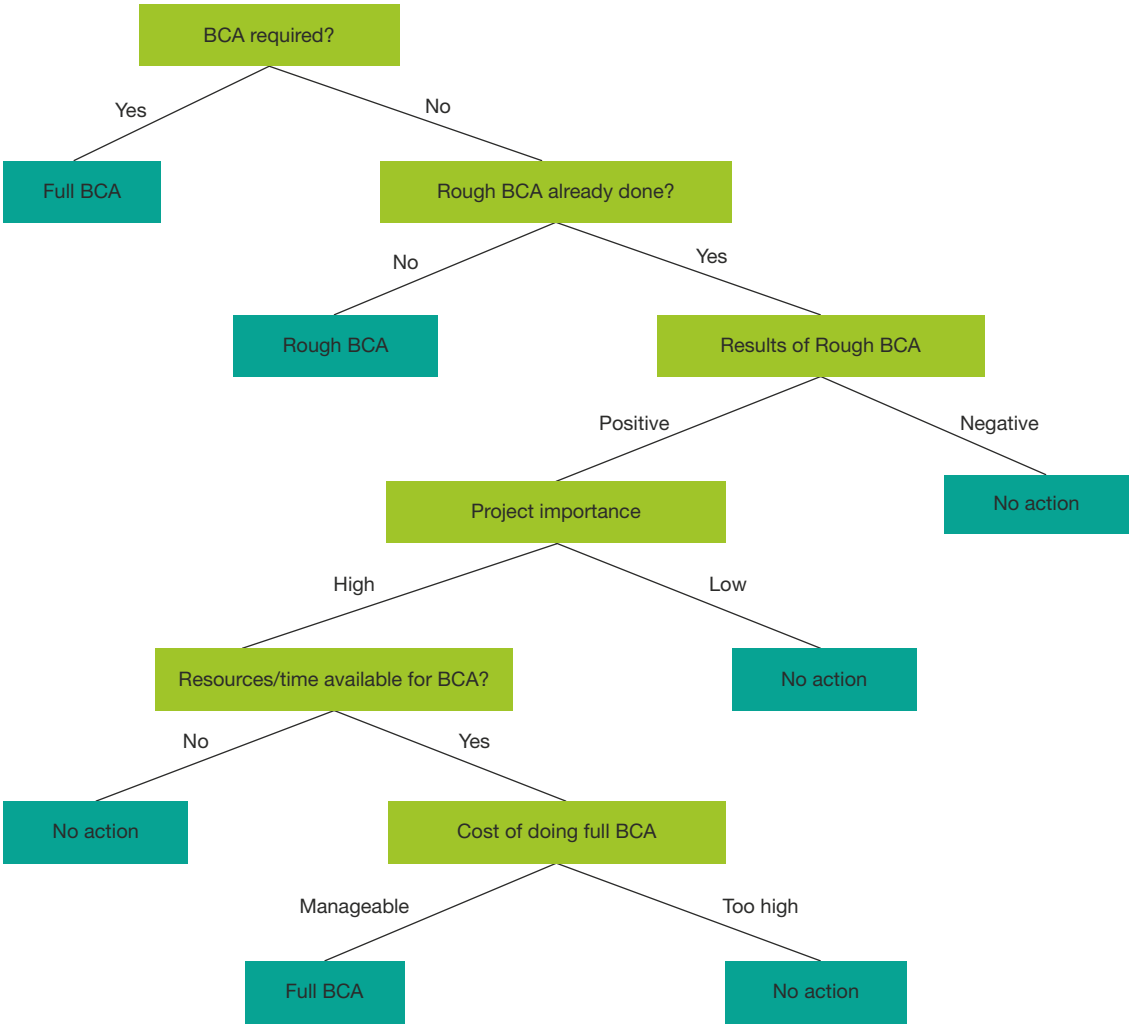
- A rough BCA may be sufficient. The results may be so clear that a full BCA is not needed. Doing full BCAs on many project options may not be sensible if sufficient resources are available for only a few. Rough BCAs could help select the projects that should be evaluated with a full BCA.
- A rough BCA could be a good first step in organizing thoughts for a full BCA.
- A rough BCA may be the best option when little data are available and a decision is needed quickly.
- An organization without the resources or expertise to do a full BCA may be able to do a rough BCA.
- A rough BCA may help identify the information requirements for a full BCA.

Figure 4.4 summarizes the decision-making process for deciding whether to progress beyond a rough BCA to a full BCA.

4.7 Sensitivity Analysis

Sensitivity analysis is the formal term for "what if" analysis, and is a strength of economic models. The benefit and cost estimates used in any BCA are uncertain, and factors affecting those estimates will likely vary over time. Thus, sensitivity analysis can be used to get useful information and insights from the analysis (box 4.6). The possible uses of sensitivity analysis include:

Figure 4.4: **SUMMARIZES THE DECISION-MAKING PROCESS FOR DECIDING WHETHER TO PROGRESS BEYOND A ROUGH BCA TO A FULL BCA.**



Source: Original figure for this publication.
Note: BCA = benefit-cost analysis.

- Testing the robustness of an optimal solution. Sensitivity analysis can test the stability of results. For realistic changes in the parameters, how widely do the results—NPV and BCR—change?
- Identifying sensitive or important variables. By comparing the sensitivity analysis results for different individual variables, the analyst can determine which variables have the biggest influence on results. The analyst can then focus on those variables and collect the best available data about them.

Box 4.6: **SENSITIVITY ANALYSES BUILT INTO THE TOOL FOR BENEFIT-COST ANALYSIS**

Sensitivity analysis can be conducted differently for different purposes. The tool for benefit-cost analysis (BCA) includes five sensitivity analysis functions on the sensitivity sheet:

- Robustness of results to changing variables. The first function (known as a "Monte Carlo analysis") tests the robustness of results, based on 1,000 simulations that change key variables up or down or leave them at their default levels. The user specifies changes up or down at the bottom of the sensitivity sheet. To use this function, the user requests a "range for sensitivity analysis" for each benefit category on the benefit sheet. This request provides a lower value than the default value and a higher value, much like a "confidence interval" for the variable. (For example, the user could select a range for which there is a 75 percent chance that the true value lies within that range.) A table at the bottom of the sensitivity sheet specifies the probabilities of the different values for the variable (low, default, and high). The tool assumes these three values represent the full range of possible values for the variable and, thus, represent a discrete probability distribution for that variable. The tool also assumes the distributions are independent of each other, making it easy to draw random samples from the joint probability distribution of all the variables. The tool does this 1,000 times to generate the results on the sensitivity sheet. These simulations include variations in all the variables at once, not one at a time.

- The sensitivity sheet presents the minimum and maximum values for net present value (NPV) from the 1,000 simulations; the probability that NPV > 0; and the probability distribution of NPV results, shown as a discrete distribution with five levels.

- The same test is available for the benefits-cost ratio (BCR), and results for both the NPV and the BCR can be provided for the project organization alone and for the overall community.

- Sensitivity of results to individual factors. The tool provides a "sensitivity index" for each main variable, again based on 1,000 simulations. This index is the average BCR for high values of the variable (from 1,000 simulations) minus the average BCR for low values of the variable, all divided by the BCR for the base case. A positive sensitivity index value indicates that an increase in the variable increases the BCR; a negative value indicates that an increase in the variable decreases the BCR. The larger the absolute value of the sensitivity Index, the greater the variable's influence over the range specified. The sensitivity index accounts for both the slope of the relationship and the specified range of values. For example, a variable might have a big impact on the BCR per unit change in the variable, but if the realistic range for that variable is narrow, then its sensitivity index will not be high.

- Break-even analysis for individual factors. For each variable, this function shows the break-even values at which the BCA results change. Based on 1,000 simulations, the tool calculates the rate of change of the BCR per unit change in the variable to calculate the percentage change in the variable needed to change the overall BCR to 1. If the base case BCR is above 1, the break-even analysis provides the percentage changes needed to drop the BCR to 1; if the base-case BCR is less than 1, the break-even analysis provides the percentage changes needed to increase the BCR to 1. If the required percentage changes are small enough, this analysis suggests that plausible changes in the variable could change the BCA result. It provides further evidence about the robustness of the BCA results and indicates which variables are likely to affect the BCA results and, therefore, may require additional information. These variables are shaded red if the break-even value falls within the range specified for sensitivity

(*Continued*)

*Box 4.*6: SENSITIVITY ANALYSES BUILT INTO THE TOOL FOR BENEFIT-COST ANALYSIS (*Continued*)

analysis. If the break-even value is greater than 100 percent or less than –100 percent, this is indicated with a text message rather than showing the actual number. Changes in these variables are extremely unlikely to alter the BCA result.

- Sensitivity to discount rate. This function also assesses the robustness of BCA results.
- Sensitivity to excluding the excess burden of taxation. This function demonstrates how including or excluding the excess burden of taxation affects the BCA results. Users can include this variable by selecting a non-zero value for marginal excess burden on the General sheet.

Source: Pannell 1997

- Identifying critical values, thresholds, and break-even values. Sensitivity analysis can help answer questions about how much a variable can change before it affects the outcomes of a BCA (for example, changing the results from favorable [BCR > 1] to unfavorable [BCR < 1]). It is particularly useful for assessing if the threshold value of the variable (the point at which the BCA result changes) falls within a range of reasonable values. A break-even value within the reasonable range may justify collecting additional information to predict the variable's actual value.
- Making recommendations more credible, understandable, compelling, and persuasive. Decision makers can use sensitivity analysis to judge how much faith they can place in the BCA results. A BCR greater than 1 in almost all cases, despite wide variations in the assumptions, provides confidence in supporting the project. Similarly, a BCR less than 1 in almost all cases provides confidence in rejecting the project (Pannell 1997).

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5

Funding and Financing Nature-Based Solutions for Integrated Urban Flood Management



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This chapter provides an overview of financing and funding options and principles, along with a matrix of options, pros and cons, and examples of their application.

5.1 Introduction

Ensuring sustainable revenue streams that can be used to mobilize sufficient financing in support of nature-based solutions (NbS) for integrated urban flood management remains the biggest challenge in realizing their potential. Although the technical solutions are well established, their implementation at scale has been limited by the inability to realize the values associated with the full range of benefits derived from NbS.

Once a suitable portfolio of nature-based, nonstructural, and structural solutions has been identified, the next step is to secure financing and funding. In particular, it is important to have strategies for ensuring that

- **a broad range of possible financing sources are considered;**
- **the chosen financing approach responds to the unique attributes of nature-based and nonstructural solutions;**
- **benefits and costs are allocated equitably, and activities are funded fairly;**
- **the decision-making process is transparent; and**
- **funding is efficient and effective, and it delivers project benefits over time.**

Every context for integrated urban flood management (IUFM) faces different issues, involves different solutions, has different sources of funding, and has access to different financing options. Furthermore, it is possible that the range of financing and funding options will increase over time as technologies advance; governments undertake policy, institutional, and sectoral reforms; and local capability increases. Such considerations will influence the revenue streams that can fund NbS and enable new forms of financing and new partnerships among government, the private sector, and communities. This chapter provides a menu of options rather than a prescriptive approach.

All infrastructure requires secure and sustainable sources of funding. These are revenue streams that determine how investment costs are repaid over time, compensating those who provide the debt or equity capital for the project investments while also supporting project life-cycle costs, which include those associated with ongoing operation and maintenance and capacity-building necessary to deliver the service and realize benefits over time. Including life-cycle costs minimizes the total project cost that must be financed and maximizes value.

Financing is about mobilizing the money required up front to pay for the design, construction, and early operational phases of an infrastructure asset through debt or equity instruments of a public or private nature. The role of financing is to bridge the intertemporal gap between the often large up-front costs of an infrastructure investment and the revenue streams accruing over its lifetime (Poole, Toohey, and Harris 2014, 106).

For example, the party who provides the initial loan (finance) to construct a dam may be different from those who repay (fund) the financing over time. An international bank or private sector organization may fund construction of an asset, but the beneficiaries of the asset may repay the investment over the life of the asset through service charges, user fees, or taxes. Service providers that operate in a commercial manner, such as water utilities or hydropower companies, typically refer to these finance streams as revenues, while government entities, such as flood management agencies, typically refer to them as budgets.

5.2 Sources of Funding for NbS

There are three main sources of funding for water-related infrastructure, including both gray and green solutions for urban flood management. Differentiating among these three sources provides a useful tool in helping unlock an understanding of the funding sources generating the cash flows that can be used to leverage repayable sources of financing. This differentiation also helps distinguish among sources of direct funding by end users, indirect funding from governments or their agencies, and funding from private sources of finance. The three main sources are as follows:

- **Tariffs: A source that comes from users paying for a specific service. For example, power companies charge customers for the amount of electricity used, or water companies charge for the quantity of water provided.**
- **Taxes: A source that comes from the government through the general budget or a dedicated tax to help pay for a service within its jurisdiction. For example, a municipal or state government may provide funding to a department to provide flood-management services.**
- **Transfers: A source that comes from outside the government that is providing the service. For example, a state government may receive a grant from the federal government or an international development agency.**

Examples of the different types of funding sources and their potential application to IUFM are summarized in figure 5.1 and table 5.1.

5.2.1 Understanding the distribution of benefits derived from NbS can inform the funding mix.

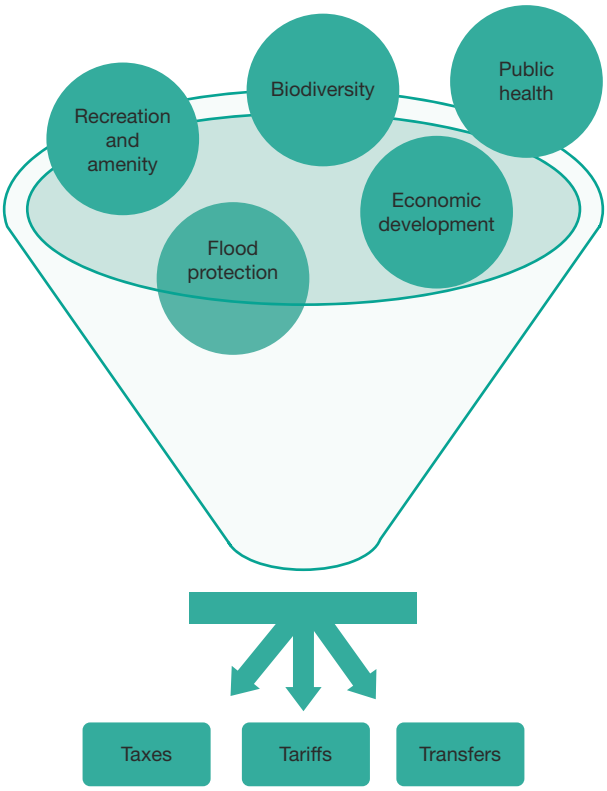
The suitability of the funding options for various NbS and nonstructural solutions differs, and each option has its own relative merits (table 5.1). The costs and benefits associated with various IUFM interventions are distributed across stakeholders, geography, and time. Consequently, questions of who should pay, how they should pay, and when they should pay are all relevant considerations for establishing a fair, sustainable, and efficient means of paying for IUFM strategies. More sophisticated financing and funding strategies can more closely reflect the distribution of costs and benefits, but they are also more expensive to establish and administer. Some parties may also not have the capacity to pay their fair share, particularly when the costs are up-front and large.

Benefit-cost analysis (BCA) can provide insights into the most efficient means of achieving an outcome from a community perspective. It can also provide transparency about the distribution of costs and benefits among different stakeholders, but it cannot judge if that distribution is fair. A range of factors can be considered in working through the options, including the following:

5.2.2 Distribution of the causes of the flooding risk (polluter pays)

When increased flooding risk is largely attributable to a particular action or event (for example, land clearing) by a party, it may be appropriate that the party contribute to the mitigation and management of those risks. A key practical question asks whether the “polluters” are concentrated and easily identifiable (for example, a property developer or farmers clearing upstream land) or diffuse (a large informal settlement reducing water quality and increasing impervious area). A direct tax or charge that reflects the size of the impact may be more cost effective in

Figure 5.1: **CONSIDERING PROJECT FUNDING OPTIONS**



Distribution of costs and benefits:
Understand project direct and indirect benefits and costs across time, geography and stakeholders

Who should pay:
Establish const/benefits allocation principle (e.g. polluter pays, beneficiary pay capacity to pay)

How should they pay?:
Determine appropriate funding mix

Source: Original figure for this publication.

the former case rather than in the latter, particularly if the aim is to change behavior. Other approaches to behavior change, such as capacity-building and incentive programs, may be more cost effective for diffuse polluters.

5.2.3 Distribution of the benefits arising from the IUFM interventions (beneficiary pays)

When beneficiaries can be identified and the benefits can ideally be quantified, having the beneficiary pay may be an appropriate basis for sharing the costs of the interventions (for example, the downstream residents of a new dam providing flood protection, hydroelectricity, and water for drinking and industry). If these benefits are largely public goods or if they are uniform across different groups, a fixed charge or tax may be appropriate. Alternatively, tailored charges, taxes, and tolls may be more suitable if benefits are excludable, diverse, and quantifiable among different individuals or groups. Cost-allocation models, such as the "separable cost and remaining benefits" approach, can be used to link costs and financiers to benefits and beneficiaries and to allocate the costs among beneficiaries in proportion to the benefits remaining after separable costs are removed.

5.2.4 Intergenerational equity

Large structural IUFM investments often involve significant up-front capital investment but deliver benefits over many years. For example, the useful life of a well-maintained levee or dam could be greater than 100 years. Consequently, spreading the funding of these construction costs over the life of the asset better aligns these costs with the beneficiaries.

5.2.5 Capacity to pay

Levels of wealth and disposable income can vary significantly across a community, yet for public goods in particular, each person or entity should contribute according to individual means. This principle is sometimes used as a secondary guide. For example, beneficiary pays might be adopted subject to people being able to pay for their shares of the benefits. Determining who can pay and how much they should pay can be a sensitive issue.

The size of the flood event and the extent of the damage are also relevant for capacity to pay. After a small event that causes little damage, households or businesses may take behavioral or building-specific actions to mitigate the effects. By contrast, for large events that result in significant damage, large structural public-good infrastructure may play a bigger role. Government-funded disaster response or private insurance may cover catastrophic events.

The Investment Framework For Economics of Water Sensitive Cities (INFFEWS) BCA tool can provide a starting point for funding discussions. The tool's stakeholder sheet breaks down benefits for each benefit type, across the lead organization, and for up to eight other stakeholders. The stakeholder sheet shows the aggregate present values of benefits and costs and the net present value (NPV) for each group. Identifying beneficiary distribution, the sheet provides a first pass of who received the benefits and who incurs the costs of the project relative to a do-nothing scenario. (Appendix B provides an illustration of the outputs of the tool). Ultimately, the distribution of costs and benefits and the question of who should pay are decisions for the community concerned (or their representatives).

Table 5.1: **SOURCES OF FUNDING**

Type of funding	Examples	Pros	Cons	Potential applications for IUFM
Taxes				
Broad-based taxes	Income taxes that go into national consolidated revenue Property taxes charged by state, city, or municipal governments Special purpose taxes or charges (for example, in Australia, the Temporary Flood and Cyclone Reconstruction Levy applied to the 2011–12 tax year)	Can be efficient when broad based Can address equity objectives (for example, progressive income tax or tax that is proportional to property value) Suitable for public goods that deliver widespread, nonexcludable benefits Taxes set by public officials accountable to the community	Administration can be costly, particularly if complex Tax base may not align with beneficiaries or polluters Intergenerational equity may be an issue (for example, short-term increase in taxes to fund long-lived assets with long-term benefits)	Solutions that deliver significant broad (non-excludable) public good benefits Situations in which tax base and beneficiaries align Extreme events that have regional or national implications Localized tax for community-based IUFM investment (Box 5.1) Government subsidies for NBS investment for IUFM (Box 5.2)

(Continued)

Table 5.1: **SOURCES OF FUNDING** ***(Continued)***

Type of funding	Examples	Pros	Cons	Potential applications for IUFM
Value capture	Taxes and charges imposed on property owners near new infrastructure (for example, railway or transportation hub)	In principle, better aligns beneficiaries and cost	Practical application can be challenging (for example, identifying boundary and level of benefits)	Beneficiaries pay for increased property value provided by IUFM measures
Tax concessions	Income or business tax offsetting some or all of the cost of property-based flood mitigation measures (for example, installation of rainwater tanks)	Can encourage desired action or behavior as well as raise funds Can encourage more efficient investment and risk management Can encourage co-investment, increasing the return on government expenditure	Can lead to unanticipated outcomes if not well designed Involve costs to establish and administer	Small-scale, distributed structural solutions, such as rainwater tanks, absorption wells, rain gardens, and so on Commercial and community property investment in flood-resilient homes and businesses
Tariffs				
Service fees and charges	Drainage authority charge Water authority or utility bills Private-sector toll payments	Good if there is a clear link between the benefits and costs Can provide a secure ongoing revenue stream for maintenance and nonstructural programs Good for nonpublic / excludable services Can send an economic signal or provide a financial incentive for investments that reduce flood risk (that is, change behavior and raise funds) Can avoid price shocks by spreading construction cost over asset life Can also reflect intergenerational equity (funding not financing)	May not be set or maintained at full cost recovery level Process for setting prices critical in situations involving significant monopoly or public good elements Can be administratively expensive if complex Capacity to pay or inelastic demand may constrain ability to recover costs and to send meaningful price signal. Require oversight if there is monopoly or market failure	Charges on property owners reflect the life-cycle costs of flood management in that area. Options range from a flat amount when a uniform level of flood protection is provided (beneficiary pays) to charges reflecting impervious area (polluter pays) or property values (capacity to pay)

(Continued)

Table 5.1: **SOURCES OF FUNDING** ***(Continued)***

Type of funding	Examples	Pros	Cons	Potential applications for IUFM
Developer charges and offsets	Up-front charge imposed on developers reflecting the life-cycle cost of structural interventions Offsets and market mechanisms for developers, businesses, and property owners	Up-front payment good for big structural infrastructure solutions Can send a price signal about the economic cost of development in flood-prone locations	Funds collected up front may not be available when maintenance renewal needed (even if included in net present value) Future costs should be known with confidence to establish a fair price Capacity to pay may be an issue, and prices below cost can incentivize undesirable investment	Developments for which flood benefits are excludable and accrue to developers or property owners Developments for which inaction can impose flood damage or risk on downstream areas Cities where the cost of flood-sensitive development varies materially across the catchment Offset mechanisms that offer counterbalance (for example, downstream developments could contribute to upstream interventions when these are lower in cost and more effective)
Transfers				
Grants provided by one level of government to another	National government grants to state or provincial governments	Can reflect broad benefits of better flood management Can better manage risks of responding to extreme but uncommon events	Require links to clear, transparent, and robust analysis to ensure that funding is allocated based on genuine need/ opportunity	Investment in large flood protection delivers national benefits, or it provides local benefits in areas where flooding rivers cross provincial boundaries. Support to roll out a nationally consistent early warning system Emergency response to extreme flooding events

(Continued)

Table 5.1: **SOURCES OF FUNDING *(Continued)***

Type of funding	Examples	Pros	Cons	Potential applications for IUFM
Costs transferred to the private sector	Complying with government regulation relative to building construction standards	Targeted to ensure desired level of flood protection Can encourage innovation if risk and outcome based rather than narrowly defined Can encourage "polluters" to reduce their contribution to the underlying problem being addressed	May not lead to the most efficient, effective, or fair allocation of costs if not well designed and communicated May discourage private sector investment and economic activity Costs may be passed to community with low capacity to pay	Encourage innovation in the delivery of both large- and small-scale interventions Encourage more efficient allocation of risk and private sector investment in flood resilient assets
Costs transferred to community	Community contributing time and effort to constructing and maintaining a nature-based solution: parks or shared community assets	Can encourage active community engagement and action from those who may receive most of the benefits	May not lead to the most efficient, effective, or fair allocation of costs if not well designed. May lead to community resistance if not well designed and communicated or if not cognizant of community's capacity to pay	Encourage innovation and effectiveness in the delivery of nonstructural flood management interventions (such as preparedness or flood-resilient homes) and local scale nature-based assets (such as parks and wetlands) Encourage more efficient allocation of risk and investment in flood-resilient communities

Source: Original table for this publication.

Box 5.1: **BUSINESS IMPROVEMENT DISTRICTS AND TAX INCREMENT FINANCING**

Type: Public financing

Public financier(s): Localized tax

Private financier(s): n.a.

Originally developed in Canada, a business improvement district (BID) defines a geographical location where local stakeholders oversee and fund the maintenance, improvement, and promotion of a designated area. Stakeholders within a specific area enter an agreement with the local government to contribute an additional levy to finance improvements in this area. Such a model has now also been used in financing the development of nature-based solutions (NbS) for integrated flood management.

One of the first BIDs set up for such purpose is the Lower Don Valley Flood Defence Project in Sheffield, United Kingdom. The project aims to improve flood defenses at more than 50 locations along an 8-kilometer stretch of the River Don, helping to protect more than 500 businesses and thousands of jobs and ensuring that the valley remains an attractive place for new investments. The funds are used for construction of the flood defenses and for the maintenance of green infrastructure, such as constructed wetlands. The BID applies an annual levy based on businesses' expected benefits from those projects. A higher levy rate of 2.25 percent per year applies to businesses expected to receive the greatest flood protection from the scheme, and a lower annual rate of 0.75 percent applies to businesses that would also benefit significantly but to a lower extent.

Similarly, a tax increment financing (TIF) district is set up when tax revenues going to general city services are frozen at a certain rate in the base year. All additional tax revenues (normally because of property value appreciation) directly fund new development or service debts related to new development until the end of the TIF period, which usually lasts 20 to 30 years. For example, a TIF has been used as a special funding tool by the city of Chicago, United States, to promote public and private investments across the city.

Source: Sheffield Chamber of Commerce and Industry 2013. Sheffield Chamber of Commerce and Industry. 2013. Sheffield Lower Don Valley Flood Defence Project. Business Improvement District (BID) Business Plan. Sheffield, UK. **https:**//www.sheffield.gov.uk/content/dam/sheffield/docs/planning-and-development/beyond-city/ldv-flood/Sheffield%20LDV%20BID%20Business%20Plan.pdf

5.3 Sources of Financing for NbS

The sources of funding provide cash flows that can form the basis for attracting repayable financing, typically debt (loans and bonds) and equity. Equity secures resources in return for a share in the ownership of the asset and for access to the future benefits that ownership affords. Debt secures resources that must be repaid over time with appropriate compensation paid to the lender.

Revenue from the three sources of funding can provide the foundation for sustainable financing, but repayable financing provides an interim mechanism to bridge a financing gap. As such, repayable financing is usually mobilized to finance capital expenditure for the development, repair, renewal, or expansion of infrastructure, while ongoing operating costs and ordinary maintenance are routinely financed by a mix of tariffs, taxes, and transfers.

Government has traditionally played a key role in providing economic and social infrastructure both in a financial capacity and by establishing the enabling polices and regulations for private and community sector involvement. This participation reflects both the public good and the natural monopoly of these assets; stable governments can usually secure debt at a relatively low cost. However, government investment alone will often not be sufficient, given the size of investment required to meet future challenges related to integrated urban flood management (Figure 5.2).

Box 5.2: **SUBSIDIES FOR NATURE-BASED SOLUTIONS FOR INTEGRATED URBAN FLOOD MANAGEMENT**

Type: Public financing

Public financier(s): Government tax

Private financier (s): n.a.

Governments can use taxes to subsidize (part of) the costs of developing nature-based solutions (NbS) for integrated urban flood management, especially on private properties. This can leverage off the private benefits to landowners from green infrastructure, stimulate additional investments, and increase public benefits.

A good example is the purchase scheme for rainwater management installations in Bratislava, Slovak Republic. Since 2016, the Bratislava municipality has used a subsidy scheme to encourage its households to contribute to protecting the city from pluvial flooding risks. Private organizations and households are eligible to apply for a subsidy that covers 50 percent of total costs of the installation, with a cap at €500. As a result, rainwater tanks, rain gardens, permeable surfaces, and green roofs have been constructed in Bratislava.

The city of Rotterdam, Netherlands, also encourages the construction of green roofs through a subsidy system. Green roofs retain rainwater and, therefore, reduce stormwater runoff. They can also generate multiple cobenefits, including cooling and human well-being. Rotterdam city government grants €30 per square meter for green roofs that are no smaller than 10 square meters. As a result, there are about 220,000 square meters of green roofs in Rotterdam.

Sources: Rijpkema 2016.
Climate-ADAPT – Bratislava profile: http://bit.ly/2xudg8j.

Box 5.3: **OXLEY CREEK IN AUSTRALIA**

Type: Public-private partnership

Public financier(s): Localized tax

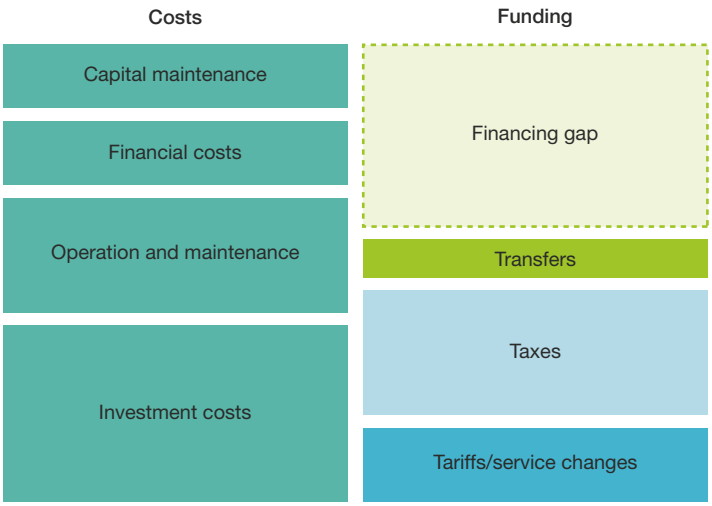
Private financier (s): n.a.

The flood-prone Oxley Creek, which was devastated during floods in 2011 in Brisbane, Australia, is being transformed into an 1,830-hectare “super park.” This project is designed to bring multiple benefits to the area, including increased flood resilience, recreational opportunities, and ecosystem habitats. The $A100 million project is financed by a series of public-private partnerships (PPPs) involving a number of different stakeholders. A new company owned by the Brisbane City Council was established—the Oxley Creek Transformation Pty Ltd—to oversee and manage this project.

The project plans to transform some old land uses and to create new economic development opportunities to repay the investors. For example, 5 percent of the green space area is designated as “economic hubs” for industries.

Source: Moore 2016.

Figure 5.2: **IDENTIFYING THE FINANCING GAP**



Source: Original figure for this publication.

New business models are needed to respond to these challenges and to leverage greater contributions from the private and community sectors. First, mainstream approaches typically do not deliver the benefits that communities are expecting, particularly in the face of increasing levels of socioeconomic development. Second, taxpayer funds are too constrained to deliver the entire investment required. Most people are familiar with government and private sector sources (both debt and equity), particularly direct investments in large infrastructure assets, public-private partnerships (PPPs) (Example: Box 5.3), private land developments, and green bonds (Example: Box 5.4). Community financing [particularly funding from nongovernmental organizations (NGOs) and crowdfunding] is also becoming more recognized as a finance source (see table 5.2).

Typical financing instruments for NbS in cities include the following:

- **public budgets**
- **grants and donations, including development funding, philanthropic contribution, crowdfunding, and so on**
- **revenue from land sales or leases, user fees, or voluntary contributions from beneficiaries**
- **green finance, including loans from public or private financing institutions, and green bonds, among others.**

Other innovative financing instruments that could potentially be applied include the following:

- **business development district or tax increment financing (TIF) district (Box 5.1)**
- **market-based mechanisms, such as credit-trading system and payment for ecosystem services (Box 5.6)**
- **revolving funds**
- **PPP or state-owned enterprise-public partnership**
- **community asset transfers (Baroni, Nicholls, and Whiteoak 2019).**

Box 5.4: **SAN FRANCISCO GREEN BOND**

Type: Mix financing

Public financier(s): San Francisco Public Utilities Commission

Private financier(s): na.

As one of the world's largest municipal issuers of green bonds, the San Francisco Public Utilities Commission (SFPUC) in California, United States, has issued green bonds worth a combined US$1.44 billion since 2015 to finance water, wastewater, and power projects that have clear environmental benefits.

Proceeds from the bonds benefit green infrastructure projects for stormwater management while beautifying neighborhoods and improving the ecological environment and urban habitat. The SFPUC has invested in 272 green infrastructure projects, which divert 63 million gallons of stormwater annually from the sewer system in addition to increasing flood resilience and improving water quality. Examples of these projects include rain gardens, permeable pavement, and harvesting systems for rainwater.

Source: San Francisco Public Utilities Commission 2019.

Table 5.2: **SOURCES OF FINANCING**

Equity/grants	Examples	Pros	Cons	Potential applications for integrated urban flood management
Government	Infrastructure grants or direct investment Funding/grants for technical assistance and capacity building Government-funded regulation and enforcement activities Publicly owned utility investment paid from retained earnings International development organization grants	Suitable for public good nonexcludable outcomes or natural monopoly services Costs can spread over a large tax base Developed through (ideally) transparent and accountable processes May act as seed funding to stimulate future private investment or community capacity building May be appropriate for disaster response Well suited to pilot projects or early-stage innovative approaches for which government may be better able to absorb project risk	May involve trade-offs with other government spending priorities Can take time to organize and involve material administration and transactions costs Can be affected by short-term or local political priorities	**Retreat:** Planning controls and regulation, people relocation, and asset recycling **Adapt:** Procurement of flood mapping and warning systems **Defend:** Capital grants for large public good assets and subsidies for insurance, disaster response, and recovery

(Continued)

Table 5.2: **SOURCES OF FINANCING *(Continued)***

Equity/grants	Examples	Pros	Cons	Potential applications for integrated urban flood management
	Selling of public assets Asset recycling	Puts underperforming assets in private sector hands Can create funding for reinvestment Can increase efficiency and innovation (for example, if transferred to private sector)	Requires appropriate competition and regulatory frameworks to ensure public benefit, particularly for monopoly assets Regulation and oversight may be costly Proceeds may not be reinvested to build long-term capacity	Capital-intensive structural solutions to expand system capacity Flood-affected land recycling and redevelopment
Private	Equity investments in public-private partnerships (PPPs) for large infrastructure Private land developments	Can offer improved risk allocation from public to private sector (albeit at a cost) Can complement debt financing. May be more suited to infrastructure operation phase than to riskier construction phase for which debt financing may be more appropriate Can drive commercialization and scaling of innovation when private benefits are significant	Can have higher cost finance than debt or government equity (risk premium may be too high) When applied to PPPs, information asymmetries, incomplete contracts, suboptimal risk allocation, and transactions costs may see suboptimal allocation of project risks, benefits, and costs between public and private interests or policy objectives not being achieved	**Retreat:** Redevelopment of flood-affected land **Adapt:** Household and business defenses, private goods assets, services, or research land development **Defend:** Large infrastructure project delivered via PPP, targeting flood mitigation alone or providing multiple benefits (for example, dam and elevated road, among others). Household and business insurance also fall into this category
Community	Community labor (sweat equity) or community support to manage own risk at own cost Capacity-building programs funded by nongovernmental organizations (NGOs) Crowdfunding	Can encourage awareness empowerment and capacity building for lasting benefit Suitable for public good activities Well suited for low-tech solutions Suitable for innovations with strong public good or local community benefits	Administration costs can be high Delivery efficiency may be low Needs to be supported with capacity building	**Retreat:** Government-supported community relocation **Adapt:** Community construction of nature-based solutions (for example, wetlands) or community assets (for example, parks). Homeowners fund flood-resilience improvements to their homes. **Defend:** NGO-funded investments (for example, planting and maintaining mangroves for storm surge protection

(Continued)

Table 5.2: **SOURCES OF FINANCING *(Continued)***

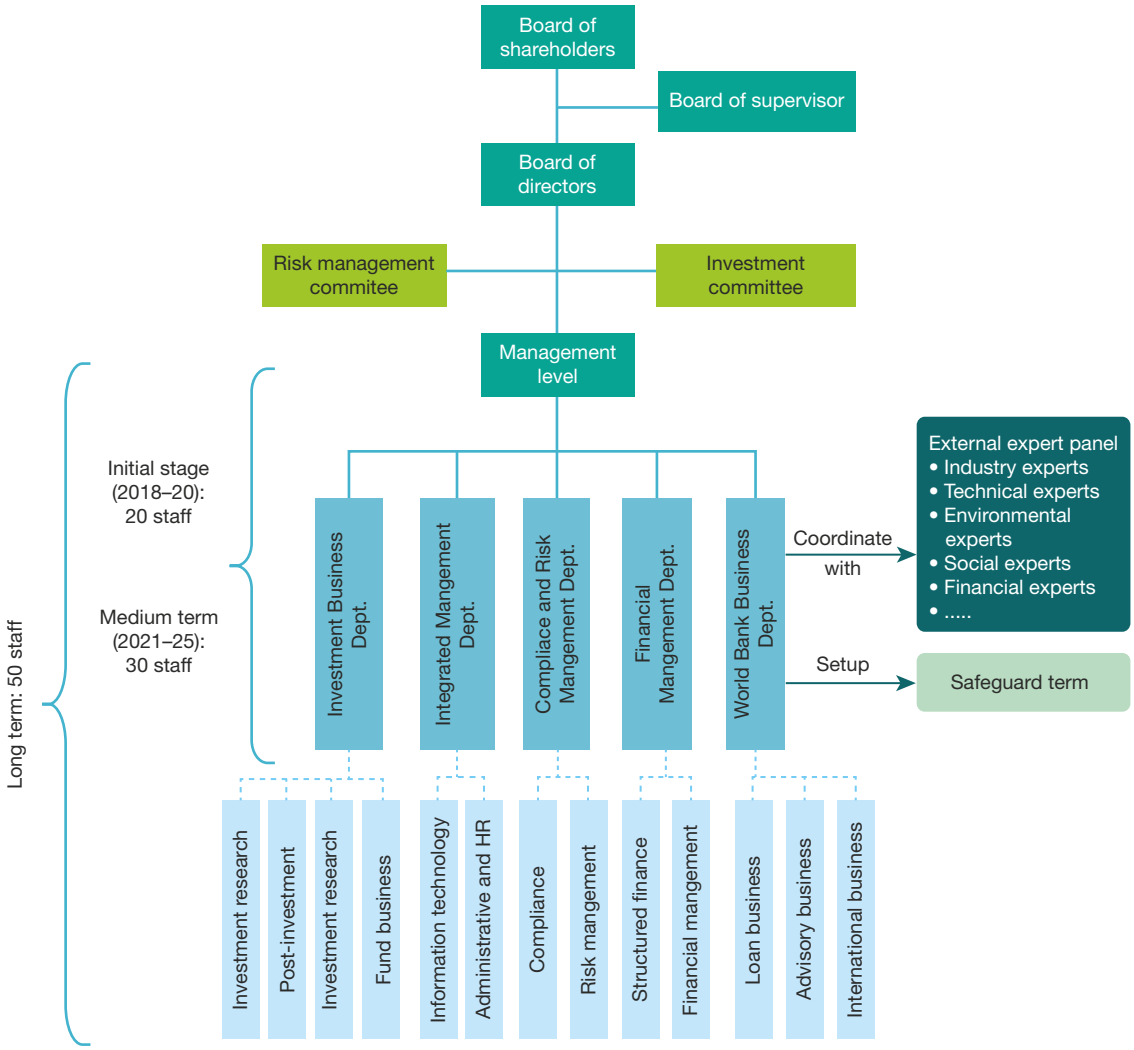
Debt	Examples	Pros	Cons	Potential applications for integrated urban flood management
Government	Loans by government Government-issued bonds International development organization loans "Off government balance sheet" borrowing by government trading enterprises	Better matches costs with benefits for long-lived assets Often lower cost than equity and private debt May better suit the construction phase of major projects (relative to equity)	Appropriateness may be constrained by political and economic conditions, existing debt levels, and underlining resilience of the economy. Higher debt may reduce capacity to respond to economic and climate shocks. If additional debt affects credit rating, it then can increase the cost of funds.	**Retreat:** Buyback of flood-affected land **Adapt:** Infrastructure construction low-interest loans for flood-resilient home improvements **Defend:** Infrastructure construction and disaster recovery
Private	Public-private partnerships Corporate green bonds	Can drive innovation and faster approval May improve risk allocation Can increase pool of funds if private sector has higher risk tolerance than public sector Can increase the pool of funds available when government funding is constrained relative to need or if government debt is already high	May target most profitable activities rather than those most needed by community Information asymmetries, incomplete contracts, suboptimal risk allocation, and transaction costs can reduce benefits. Risk allocation may not stick, and government may remain supplier of last resort	**Retreat:** Asset recycling for flood-affected land **Adapt:** Property (re) developments on flood-affected land **Defend:** Structural solutions (for example, dams and levees) delivered and maintained via PPPs
Community	Microloans or insurance	Good for inventory and disaster recovery	Not good for large investments Capacity to pay may be an issue.	**Retreat:** Microloans to support resettled communities **Adapt:** Microloans for home improvements **Defend:** Microloans/ insurance or NGO donations for disaster recovery

Source: Original table for this publication.
Note: Combinations of sources of funding are common.

In addition to direct financing instruments mentioned in table 5.2, other innovative financing mechanisms may include the following:

- **Equity fund: A blended financial arrangement dedicated to support NbS projects and interventions. One example is the Irish Sustainable Forest Fund backed by the Natural Capital Financing Facility of the European Investment Bank (EIB).**
- **Financial intermediary: Provider of onlending to end borrowers. Original funding may come from a pool of different sources, often with longer loan service periods. The World Bank has provided a US$200 million IBRD loan to support Shanghai, China, in setting up a financial intermediary (Shanghai Green Urban Financing and Services Co., Ltd) to raise medium- to long-term funds in the capital market that can be on-lent for specific subprojects (Figure 5.3).**

Figure 5.3: **ORGANIZATIONAL STRUCTURE OF THE PROPOSED FINANCIAL INTERMEDIARY IN SHANGHAI**



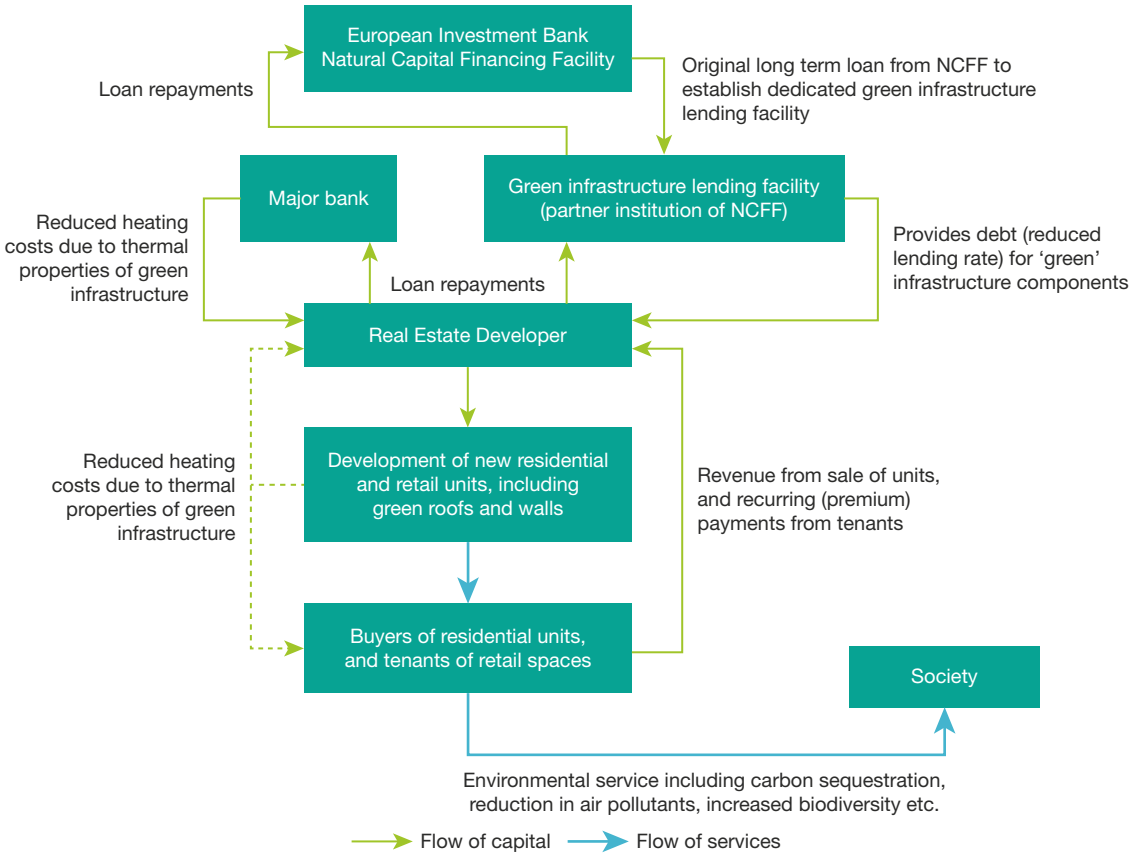
Source: World Bank 2019.

Similarly, in a theoretical case given by the European Investment Bank (EIB 2020), a green infrastructure lending facility is setting up partnership with the Natural Capital Financing Facility of EIB, which provides debts with reduced rates for real estate developers to invest in green infrastructure, such as green roofs, walls, rooftop parks, and so on. A theoretical structure and flow of funds are illustrated in figure 5.4.

- **Blended financing: Structured transactions in which development finance and philanthropic funds are used to mobilize private resources to achieve environmental and social goals (Figure 5.5), such as greater flood resilience, improved water quality, and reduced water consumption, which deliver adequate risk-adjusted financial returns for the private investor. Guarantees, debts, and equity are all commonly used financial instruments to structure a blended financial case. For example, the Global Environmental Facility (GEF 2019) has invested more than US$700 million in 91 blended finance projects and mobilized US$7 billioncofinancing.**

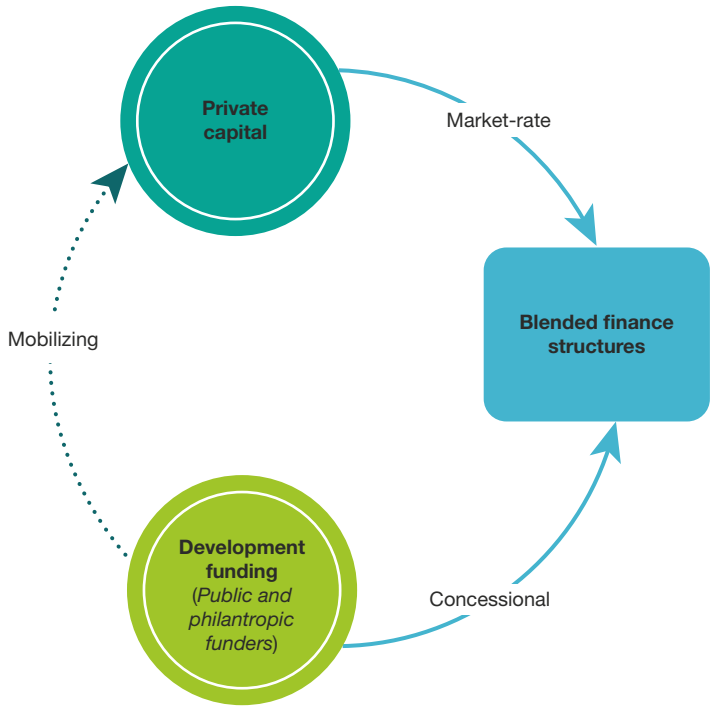
Private sector partners and community co-investment have the potential to unlock additional project value and revenue streams, increasing the pool of potentially available funds, reducing the net cost, and improving financeability (World Bank 2017, 17). Private and community lenders also have a different risk appetite compared with government. For example, private financing may be available for investments that offer higher risks and rewards (for example, property development), but community financing (for example, microloans) are sometimes available to people who would not be able to access financing. Furthermore, the innovation potential of the private

Figure 5.4: **GREEN INFRASTRUCTURE LENDING FACILITY SET UP BY THE EUROPEAN INVESTMENT BANK**



Source: European Investment Bank 2020.

Figure 5.5: **BLENDED FINANCING USING DEVELOPMENT FUNDING TO MOBILIZE PRIVATE CAPITAL**



Source: WWF 2020. Bankable Nature Solutions.

sector and community organizations will be essential for sustainable context-specific solutions. There are several prior conditions for a project to attract financing from the private sector:

- **Revenue stream generation**
- **Sufficient collateral**
- **High probability of success/low risks**
- **A clear exit strategy**
- **An acceptable risk-adjusted rate of return**
- **A clear concept and proven track record (WWF 2020).**

There are many different models of public, private, and community investment partnerships. Options range from PPPs to schemes that finance, design, construct, and operate large infrastructure services to impact bonds, grants and, and service contracts. The relatively low-tech nature of many NbS and the services they deliver have meaning for communities and create opportunities for community involvement (for example, involvement in planting for an ecological park or flood buffer zone), reducing costs and creating a sense of ownership that can lead to advocacy for ongoing maintenance and renewal.

Private investors can not only help provide financing, but they can also help ensure that projects are run efficiently. However, clarity of objectives, roles, and governance is essential in realizing the potential benefits of these models. For example, the potential efficiency improvements offered by the private sector must be balanced with the maturity of the regulatory framework and political processes, the higher cost of private finance, and the potential for information asymmetries, higher transaction costs, and incomplete contracts, all of which can erode these gains (Poole, Toohey, and Harris 2014, 99). If contracts are designed properly, private investors have an incentive to see that an infrastructure project is executed efficiently because it increases the likelihood that their investment is safe and as profitable as expected. The challenge for project owners, and hence the public sector, is to design contracts so that the risks and returns are distributed in an incentive-compatible way (Ehlers 2014, 1).

Risk allocation is a key consideration in determining the most appropriate financing strategy. In general, risks should be allocated to the party best able to manage them, considering:

- **The party best able to control the likelihood of the risk's occurring. For example, the private party might be better placed to minimize construction cost overruns or delays or unnecessarily costly project design because the private party is in control and has more expertise.**
- **The party best able to control the effect of the risk on project outcomes by assessing and anticipating a risk and by responding to it. For example, although no party can control the risk of an earthquake, a private firm might more effectively use design techniques to reduce damage if an earthquake occurs.**
- **The party best able to absorb the risk at lowest cost when the risk cannot be controlled by either party. The cost of absorbing a risk depends on several factors, including the extent to which the risk correlates with the value of the party's other assets and liabilities, the ability to pass the risk on (for example, to users or third-party insurers), and the nature and risk preferences of the ultimate risk bearers (Irwin 2007; OECD 2008).**

However, putting this broad principle into practice is not straightforward. Transferring risk is not "free". Private and community operators must be compensated for assuming risk. Furthermore, investors will only be prepared to commit large sums of financing for the long horizon if they can trust the legal and political procedures (Ehlers 2014, 1).

The involvement of the public, private, and community sectors may also change over time. Governments can play an important role in fostering innovations, public-private and community partnerships, and new approaches. They are better able to spread project risk associated with early-stage innovations (or applications of innovative approaches to new contexts) that are linked with policy objectives. Government grants and investments send a signal to the private sector, and together with enabling regulation, they can support the growth and mainstreaming of innovative approaches (Box 5.7). Nongovernmental organizations and multilateral development banks (MDBs) can also play a key role in providing seed funding, but the private sector's role often increases as projects move into their operational phases (Browder et al. 2019).

A less common but potentially significant source of finance is insurance, which can be seen as financing future actions in response to specific but uncertain events, such as floods. Insurance is a key pillar in any comprehensive strategy of adapting to natural hazards because it (1) increases resilience against residual risks that cannot be prevented or mitigated; (2) can incentivize engagement and investment in risk mitigation measures; and (3) reduces pressure on the fiscal budget from natural disasters (White 2011).

Increasing the level of insurance penetration reduces the effects that disasters have on economic output (OECD 2015). For example, increasing the proportion of projects and assets that are insured by 1 percent could decrease the taxpayer burden of economic losses by an estimated 22 percent (Lloyd's 2012). The Organisation for Economic Co-operation and Development (OECD) further notes that countries with lower levels of insurance penetration experience larger declines in economic output and larger increases in fiscal deficits following disasters and that the effects on economic activity last longer. In the event of a disaster, such as urban flooding, insurance payments tend to be larger and to be disbursed more quickly than government assistance, thus providing for a timely source of

funds in support of reconstruction efforts and recovery in local economic activity. The global nature of reinsurance markets also means that a portion of the financing of payment claims is likely to be absorbed by international markets, reducing the burden on national economies.

Despite the potential advantages, insurance coverage of floods around the world is low, a situation that leads to suboptimal financial management of flood risks. Microinsurance can provide opportunities to increase both the coverage of insurance and the application of NbS (Box 5.5). Indexed or parametric funding has advantages for low- and middle-income countries because it can speed up payouts, it's simpler, and it's less prone to moral hazard and disputation. However, people may underestimate their actual risk exposure and underinsure.

5.4 Choosing an Appropriate Mix of Financing and Funding

Identifying a sustainable funding stream is critical for a project's long-term success. This is particularly so for NbS requiring maintenance and protection of natural processes. Nature-based solutions for IUFM may have significant public good elements, so government funding may be most appropriate for at least part of the project. Going through the process of identifying, quantifying, and valuing the wide range of benefits provided by NbS can help justify the investment and potentially raise the governmental budget allocation for these projects. In addition, NbS can include private benefits and provide additional revenue streams that can be privatized and used to offset the project cost, so there are still important roles for the private sector and opportunities for collaboration to deliver both public and private benefits.

For example, a private property development may pay to reduce the direct cost of flood damage (private benefit), but avoiding an outbreak of disease as a result of flooding will benefit the whole community (public good). Using pluvial flows and wetlands to treat and recharge groundwater can increase water available for agriculture. Reclaimed and rehabilitated flood-affected land can be made available for private property development. Similarly, creating a park that is also a flood retardation asset will provide health and well-being benefits to the whole community unless the park is fenced off from the public.

Box 5.5: **MICROINSURANCE—OPPORTUNITIES AND ISSUES**

Microfinance has been used successfully around the world in creating effective markets for financial services for people with low incomes. These financial services can include microinsurance, which provided coverage for about 135 million low-income people in 2009.

Key factors driving demand for microinsurance include urbanization and climate change (including more extreme weather events), among others. It is important to note that microfinance has proven effective in markets having little experience with insurance if:

- products, procedures, and policies are simple;
- premiums are low;
- administration is effective; and
- distribution channels are innovative.

The main suppliers of microinsurance have traditionally been commercial insurers. However, community-based and informal insurance schemes are valuable sources of innovation with international organizations, development partners, nongovernmental organizations, and governments playing an important facilitatory role.

Source: Lloyd's 2012.

Box 5.6: **STORMWATER RETENTION CREDIT TRADING**

Type: Government regulations

Public financier(s): n.a.

Private financier(s): Stormwater retention credit purchasers

In 2013, the Washington, D.C., Department of Energy and Environment (DOEE) introduced standards requiring new developments larger than 5,000 square feet to install green infrastructure, such as green rooftops, to reduce stormwater runoff. Developers in the US capital are required to meet 50 percent of their water retention requirements onsite. For the remaining 50 percent, developers may purchase stormwater retention credits from others in the city who have either voluntarily installed green infrastructure on unregulated sites or have exceeded their retention requirements on regulated projects. The DOEE certifies the stormwater retention credits for up to three years, and sellers are responsible for maintaining the green infrastructure projects, which are subject to DOEE inspections.

To reduce the investment uncertainty for the credit generators, DOEE has also introduced a price lock mechanism for the stormwater retention credits. As a buyer of last resort, DOEE agrees to purchase credits from the sellers at a price that is lower than the market price. This encourages the sellers to sell their credits on the market but also provides them with some certainty that their investment will bring them reasonable returns.

More than 650 transactions occurred between 2014 and 2019 at an average market price of US$1.82 per credit, which is attractive compared with the equivalent installation fee of US$3.61 as of 2017, estimated by DOEE.

Source: Odefey et al. 2019.

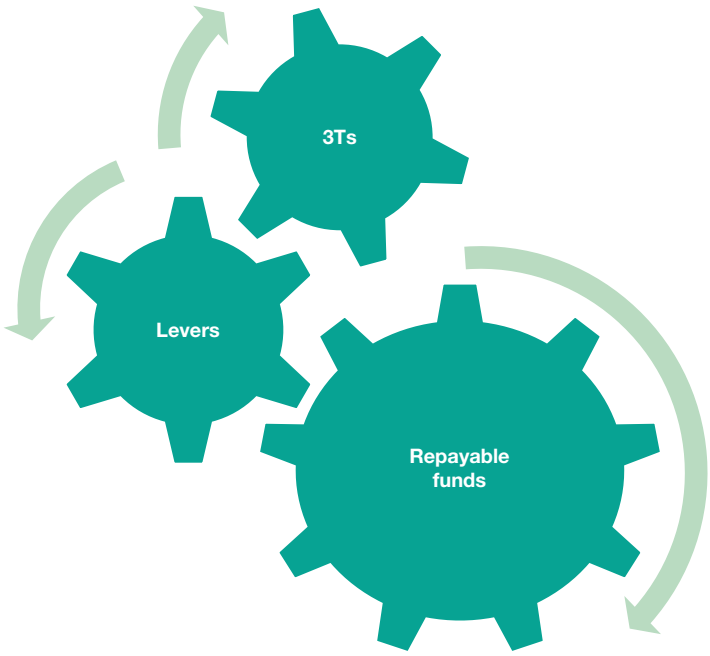
Box 5.7: **A PUBLIC-PRIVATE RESEARCH-TO-PRACTICE PARTNERSHIP THAT INCREASES LOCAL CAPACITY AND POSITIONS FOR MAINSTREAMING**

In 2014, a memorandum of understanding was signed between the province of Jiangsu, China, and the Victorian State Government and between the province's city of Kunshan and the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) headquartered in Melbourne, Australia. This research-to-practice collaboration is working to help solve some of the complex urban water problems in Kunshan: degraded waterways, catchment pollution, poor water circulation, poor drainage, and frequent flooding.

The CRCWSC's innovative social-technical approach introduces technical solutions and fosters collaboration and integrated governance among the many stakeholders involved in city planning, infrastructure delivery, and water environment protection. Working together, the CRCWSC and local stakeholders are using nature-based solutions (NbS) to embed four elements—water, forest, food, and culture—into open spaces and along road and rail transportation corridors, conserving strategic natural features and creating an urban mosaic of ecological landscapes for framing and guiding the city's development.

In four years, this collaboration resulted in more than 30 small-scale proof-of-concept NbS flood protection and water quality projects. It also has involved applications at scale via a 40-kilometer ring road and an ecological park project. Building on the initial demonstration projects, partnerships with local industry are exploring lot scale innovations, a "sponge city brain" IoT platform, and a 10-hectare sponge city innovation park. Public and private collaborators are applying this experience to other opportunities in Australia, China, and beyond.

Figure 5.6: **LEVERAGING THE 3TS TO ACCESS REPAYABLE FINANCING AND TO BRIDGE THE FINANCING GAP**



Source: Original figure for this publication.
Note: 3Ts = tariffs, taxes, and transfers.

Levers can be used to magnify the ability of funding and future cash flow to attract repayable sources of financing and to bridge the "financing gap" (figure 5.6). There are various ways of increasing the leverage exerted by taxes, tariffs, and transfers in attracting repayable funding sources. These work either by mitigating specific risks that would otherwise hamper financing or by packaging the financing in a form that is more attractive to potential suppliers. These levers include guarantees, insurance, cofinancing, B loans, blending, output-based aid, and so on. The funds themselves can be applied to provide public or private goods that in turn generate revenues.

Strategic financial planning is central to finding the right mix of the three sources of funding and to leveraging repayable sources of finance. A key distinction between revenue from the three sources of funding and repayable finance is that tariffs, taxes, and transfers can fill the financing gap, but repayable finance can only bridge the financing gap. Repayable finance requires compensation, that is, repayment at a future date plus remuneration for the use of capital in the form of interest or dividends. Thus, although grants are a true transfer, loans are not. Having recourse to repayable finance is not a substitute for inadequate cash flow from the three sources of financing. Loans, even those on concessional terms, have to be repaid, bond holders have to be serviced, and equity holders need dividend payments.

Selecting the right context specific approach can involve several complex trade-offs. Such trade-offs can include issues, such as efficiency and equity, sophistication and cost, risk and return. Tables 5.1 and 5.2 provide examples of different funding and financing options, together with their pros, cons, and suitability for different IUFM strategies.

The most appropriate mix of measures may change over time and over the project's planning, construction, and operation phases (Ehlers 2014). For example, debt and equity financing options can be used together, but there

Box 5.8: **DC WATER BOND**

Type: Mix financing
Public financier(s): DC Water
Private financier(s): Goldman Sachs and Calvert Foundation

The District of Columbia Water and Sewer Authority (DC Water) issued a 30-year US$25 million municipal pay-for-success bond in 2016. The bond is designed to share performance risks associated with green infrastructure among DC Water and two private investors, Goldman Sachs and Calvert Foundation. The bond provides all of the up-front capital cost for three green infrastructure projects to better manage stormwater in the US capital city to improve the incidence and volume of combined sewer overflows. The bond has an initial 3.43 percent interest coupon payable semiannually for the first five years. At the five-year mark, a one-time US$3.3 million contingency payment may be made to investors or DC Water, based on performance evaluations and the US Environmental Protection Agency's determination of the success of the installations. If the green infrastructure projects perform better than expected, for example by reducing more stormwater runoff than designed, the $3.3 million goes to investors as a reward payment; otherwise, it goes to DC Water as a risk-sharing payment. If the projects reduce stormwater runoff as expected, just the basic principal and interest are due from DC Water to investors.

This model encourages investors to do due diligence because they have a financial stake in the performance of the project; investors funding sustainable, innovative water management solutions such as this may also gain reputation benefits.

Source: Goldman Sachs, DC Water, and Calvert Foundation, n.d.

may be a greater focus on debt in the risky construction phase relative to the operation phase (Poole, Toohey, and Harris 2014). Furthermore, clearly defined performance indicators can help leverage innovative performance-based financing instruments (Box 5.8).

5.5 Challenges and Opportunities for Funding and Financing NbS for IUFM

Several aspects of NbS and nonstructural solutions can affect the relative appeal of some forms and sources of funding and financing. Often, projects that would deliver a net benefit to the community do not proceed because they cannot secure the necessary resources. This may happen for several reasons, such as the following:

- **Size of investment required. The level of funding required for many (particularly structural) solutions is often significant, and it may well be beyond the local or even national government's capacity to support the project. This is particularly the case in low- and middle-income countries (Browder et al. 2019).**
- **· Scope of investment required. Effective implementation often requires action by many stakeholders across time. The more coordination needed, the higher the transaction costs and the greater the risk of one partner's walking away, unravelling the financing and funding arrangements.**
- **Competing priorities. Flood management often involves up-front investment for long-term and uncertain benefits. In developing countries in particular, short-term urgent issues often crowd out long-term important actions, and acute events override chronic risks (Jha, Bloch, and Lamond 2012).**
- **Inability to sustain benefits and funding. Financial support is often easy to obtain after a flood event. But realizing the full benefits of IUFM projects over time needs sustained funding. Infrastructure must be maintained and renewed over time so that it delivers the promised functionality day to day (for example,**

maintaining the amenity provided by parks used as retention basins) and during peak events (for example, reducing litter and cleaning drains so that they convey large volumes of water during a flood). Governments and development agencies may provide up-front capital support for construction without ensuring that the beneficiaries have the financial or technical capacity to maintain an asset over its useful life.

- **Ensuring a fair distribution of costs and benefits. The costs and benefits of IUFM projects are distributed across stakeholders, geography, and time. They also often have a significant public good component; that is, the benefits of flood management are often nonexcludable. The challenge is to ensure that those who benefit also bear an equitable share of the costs. Benefit-cost analysis can provide insights into the most efficient means of achieving an outcome. It can also make the distribution of costs and benefits transparent, but it cannot judge if that distribution is fair. Ultimately, the distribution of costs and benefits is a decision for the community concerned (or their representatives). It is often more complex to identify who benefits, and hence, who should pay for NbS. Projects in which NbS are used are often multipurpose projects involving a wider range of sectors and stakeholders. This creates several additional challenges in bringing together funding from different sectors and requires a higher degree of facilitation than relatively simple single-sector, one-dimensional projects.**

NbS and nonstructural solutions have different cost, risk, and benefit profiles when compared with traditional structural flood-protection responses, such as levees and dams. These differences can also affect the cost and appropriateness of different financing options. For example, nature-based projects are often smaller in scale; they can involve lower initial capital investment, and they are more "scalable." Thus, they may have a lower financing requirement, and investments can be staged as NbS investments that are prioritized and rolled out over time. An example is a network of detention basins or wetlands distributed across a catchment.

However, although adding flexibility, a collection of distributed NbS may add complexity and cost when compared with the economies of scale associated with a large structural solution, such as a levee. Bundling groups of NbS investments may be one way of overcoming this problem. As well as addressing the risk, a bundled approach can promote innovation and learning across projects (Liang 2018).

NbS may involve less up-front investment, but these solutions require ongoing maintenance. It can be challenging to secure and maintain financing for a project with higher ongoing costs relative to a project dominated by a large up-front investment (such as a levee). Creating a trust or sinking fund as part of financing the up-front investment is one way of addressing this, but there is also a risk that these funds will be reprioritized to other areas over time.

NbS are site specific, and they involve natural processes. They are open systems, not closed like constructed systems of pipes and pumps. Consequently, these nature-based projects can have higher construction and operational risks and, therefore, attract a greater risk premium, which in turn may make it more challenging to raise financing through traditional means. However, pilot projects and the scalability of NbS approaches can mitigate this risk. The growth of green bond and loan markets is also improving financing options for NbS.

Nonstructural solutions (for example, behavior change programs or planning regulations) can also involve lower or no up-front capital. However, they often involve more uncertainty than structural solutions and require ongoing investment to remain effective. Regulations, such as planning controls and design standards, may not involve direct capital investment but do incur costs to develop and enforce; often these costs are financed and funded via taxes, fees, or charges. They can also constrain economic activity that may otherwise occur, which may have a net positive or negative effect on the community (depending on their design and application).

Recognizing these features of NbS and nonstructural solutions is important for decision making. This manual does not advocate one type of flood management over another. But it is important to recognize these features of NbS and nonstructural solutions so that access to financing does not become a barrier to implementing the best integrated combination of measures for a specific context. For example, a levee may be simpler to finance, but combining mangroves, a smaller levee, building controls, and improved access to insurance may be a more effective response to storm surge risks. Therefore, although the financing cost of the IUFM response may be higher, the overall benefit may justify the added cost and complexity.

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6 Application Example and Case Studies



This chapter provides hypothetical worked examples and real-life case studies to illustrate how the manual and supporting tools can be applied.

6.1 Case Study: A Worked Example in a Hypothetical Australian City (Appendix B)

A case study of a hypothetical Australian city facing pluvial and coastal flooding provides plausible illustrations of how this manual and supporting tools can be applied. This example outlines both a conventional approach applying gray infrastructure and an integrated approach combining green and gray infrastructure to address flooding issues. In addition, the case study compares the net present value (NPV) of benefits and costs of both the conventional approach and the integrated approach with the scenario of doing nothing.

6.1.1 Urban and Flood Contexts

Flood mapping and modelling show that rapid urban intensification and impervious area increases have resulted in increased stormwater overland flows from both within and outside the study site, leading to the inability of local drainage to meet the required 1:100-year design standard. Sea levels around the site are expected to rise 0.8 meters by 2100 due to climate change, and rainfall intensity is expected to increase by 35 percent. Consequently, the extent of the spatial inundation above 2 meters with a 100-year average recurrence interval (ARI) is expected to increase greatly in the future in comparison with current risk levels. Population density in the area is expected to increase as the population grows at about 1.7 percent per year during the next 30 years. Due to these effects, the number of properties affected at 5-, 20-, 50-, and 100-year ARIs is expected to increase by 5 to 10 times the current risk level. Figure 6.1 shows flood management interventions for coastal flooding (upper) and pluvial flooding, respectively.

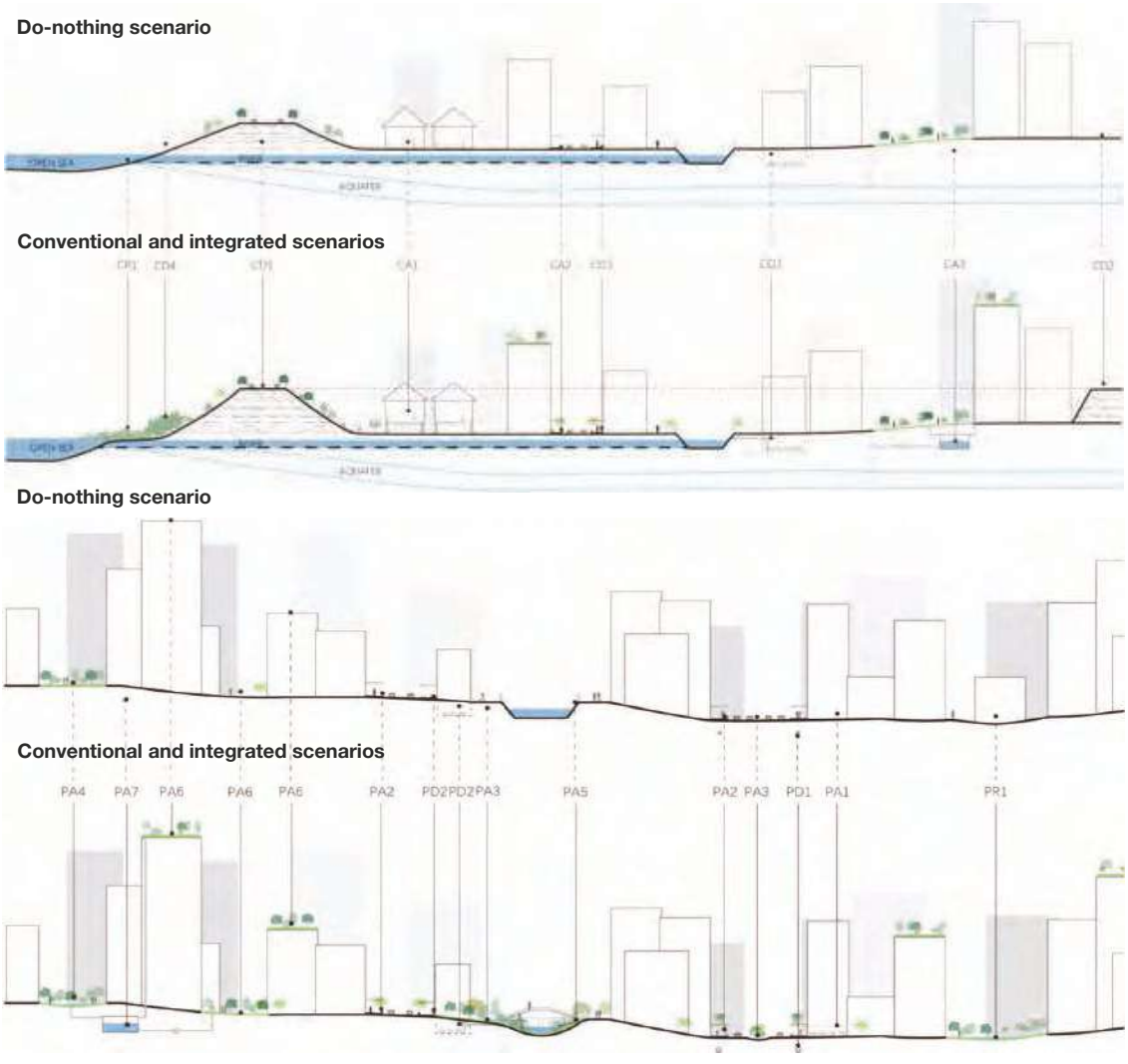
6.1.2 Do-Nothing Scenario

Direct costs. The cost metric used to measure flood damage is the expected annual average damage cost. For the do-nothing scenario, the annual average tangible costs are expected to rise from US$2.5 million in 2012 to US$14.5 million in 2100, in real dollars.

Intangible costs. Intangible costs are separated into four categories: health and well-being, employment, education, and community. Within each broad category are several specific subcategory items. In this hypothetical study, intangible costs in any given year are set at 110 percent of tangible costs according to a flood event from 2010 to 2011 in Queensland, Australia.

Net present value estimate parameters. The base case time horizon for the evaluation is 30 years, and the base case discount rate is 7 percent, real.

Figure 6.1: **CONVENTIONAL AND INTEGRATED SOLUTIONS TO REDUCE COASTAL FLOODING (UPPER) AND PLUVIAL FLOODING**



Source: Original figure for this publication.

6.1.3 Conventional Gray Infrastructure Solution

The conventional infrastructure solution involves constructing levee/sea walls, with provision for wave run-ups and storm surges and upgrading core drainage infrastructure, such as pumps and pipes. The conventional engineering solution delivers mitigation of 70 percent of the annual average damage cost.

6.1.4 Integrated Green and Gray Solution

The integrated solution consists of a set of interventions, listed below, that also achieve a combined reduction in flood risk of 70 percent.

PR1: Converting low-lying land in a flood-prone area to parks and public open space, an intervention that reduces sea wall construction cost and provides benefits, including the resale value of the land; developer profit; amenities for properties nearby; recreational opportunities for the broader community; health benefits via access to more public open space; and nutrient load reduction.

PA1: Applying adaptive building design toward rising water level

PD1: Upgrading core drainage infrastructure, such as pumps and pipes

PA5: Introducing naturalized waterway with dwellings enjoying direct frontage to the natural waterway

PA6: Increasing green area and soakage higher up in the catchment, providing benefits of nitrogen removal

CR1: Converting residential parkland into an ecological landscape

CA6: Building social resilience through community preparedness, flood response, and flood recovery

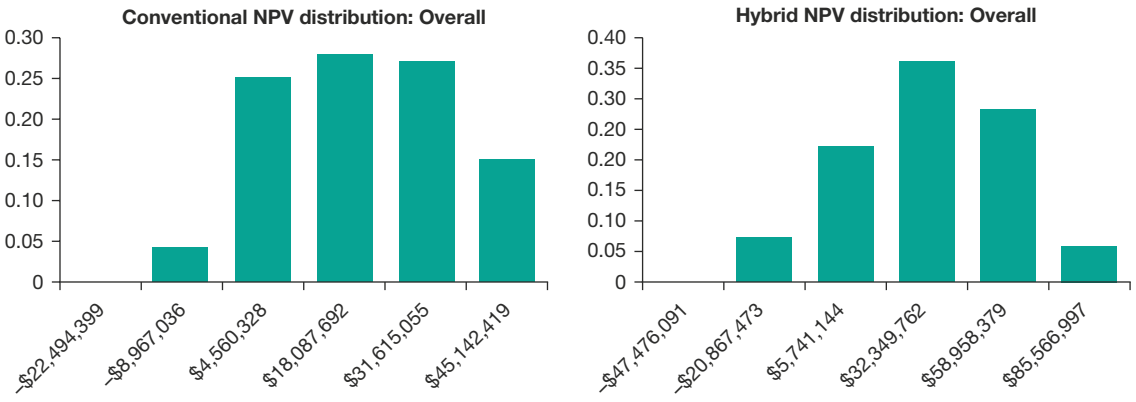
CD1: Constructing a small sea wall compared with the conventional approach

CD4: Introducing a mangrove forest belt in front of the coastal embankment to reduce maintenance cost and to provide biodiversity and carbon sequestration benefits

The NPV for the integrated solution has increased overall by US$8 million to US$26 million compared with the conventional solution (the figures are subject to cost uncertainties) (Figure 6.2). These figures were determined by applying the value tool and the benefit-cost analysis (BCA) tool of the Investment Framework for Economics of Water Sensitive Cities (INFFEWS).

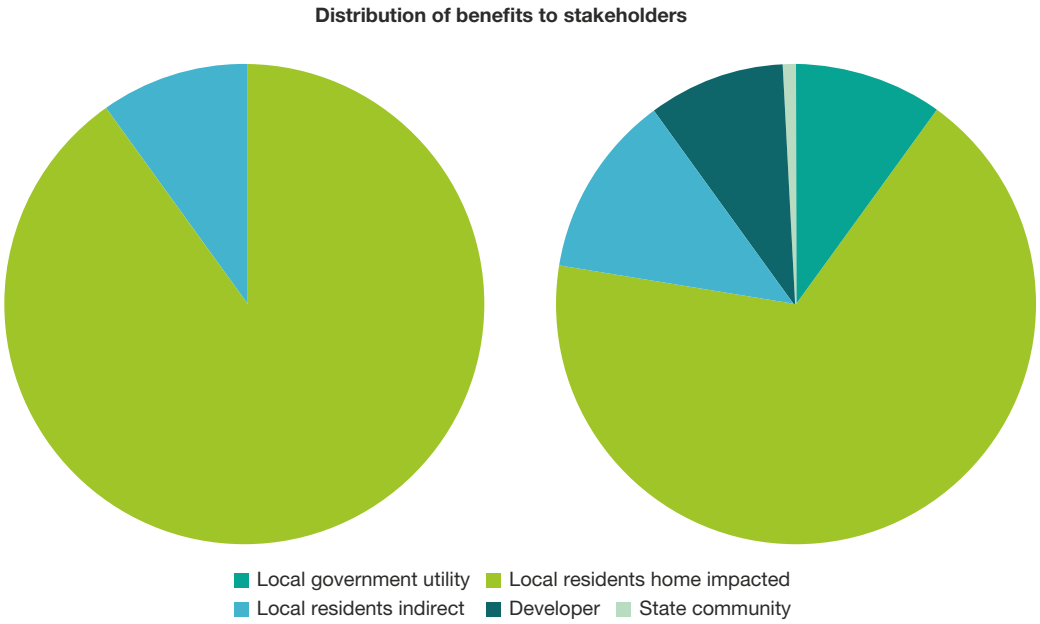
The distribution plots (figure 6.3) show that there is much greater potential upside with the integrated solution than with the conventional solution. However, the overall uncertainty about the outcome is more pronounced applying the integrated approach.

Figure 6.2: **COMPARISON OF NPV DISTRIBUTIONS FOR CONVENTIONAL (LEFT) AND INTEGRATED SOLUTIONS**



Source: Original figure for this publication.
Note: NPV = net present value; X axis indicates the NPV amount (US$) while y axis represents probability The BCA tool also identifies the following distribution of benefits under both solutions.

Figure 6.3: **DISTRIBUTION OF BENEFITS AND COSTS OF CONVENTIONAL (LEFT) AND INTEGRATED SOLUTIONS**



Source: Original figure for this publication.

6.1.5 Conclusions

This case study applies the INFFEWS valuation and BCA tools to conduct a standard benefit-cost analysis of a conventional gray infrastructure solution and an integrated green and gray infrastructure solution toward coastal and pluvial flooding risks in a hypothetical Australian city. This example considers the wide range of benefits that can be derived from green infrastructure investment. The results highlight four main conclusions:

- ***Integrated solution offers greater overall benefits.*** **Although both conventional and integrated green and gray solutions achieve the same flood reduction, the integrated solution offers higher overall benefits.**
- ***Integrated solution embodies higher uncertainties.*** **Although the integrated solution in this example has a higher net present value, there is also a greater level of uncertainty associated with the outcome because of the nature of assets involved and the higher complexity of the integrated portfolio of interventions.**
- ***Integrated solution can generate a wider pool of beneficiaries*** **(see table 6.1). Thus, the integrated solution can increase financing and funding options.**
- ***Integrated solution also increases opportunities for community involvement.*** **This participation could occur in such areas as construction and maintenance of nature-based solutions (NbS).**

Table 6.1: **SUMMARY OF BENEFICIARIES AND POTENTIAL FINANCING AND FUNDING MECHANISMS FOR DIFFERENT FLOOD MANAGEMENT INTERVENTIONS**

Strategy	Beneficiaries	Financing		Funding	
		Who	How	Who	How
Conventional approach—gray infrastructure					
• CD1: Levee • PD1: Drainage infrastructure upgrade • CR1: Ecological flood zone	• Current and future residents • Current and future commuters	• Water and drainage utility	• Water and drainage utility retained earnings • Water and drainage utility debt	• Water and drainage utility customers	• Water and drainage bills
Integrated approach—green and gray infrastructure					
• CD1: Levee • PD1: Drainage infrastructure upgrade	• Current and future residents • Current and future commuters	• Water and drainage utility	• Water and drainage utility retained earnings • Green bonds	• Water and drainage utility customers	• Water and drainage bills
• PR1: Land redevelopment	• Current property owners • Property developers • Nearby residents	• Private developers	• Debt and equity	• Property buyers	• Property price
• PA1: Smart building design	• Current and future property owners	• Developers (new properties) • Government retrofit program (existing properties)	• Higher construction costs • Debt and equity • Grant/rebate	• Property buyers • State taxpayers	• Property price • State land tax
• PA5: Naturalizing drainage canal	• Local residents	• Water and drainage utility	• Green bond	• Water and drainage utility customers	• Water and drainage bills • Foregone parking
• CR1: Coastal ecological park	• Coastal residents • Wider community	• Water and drainage utility	• Green bond	• Water and drainage utility customers	• Water and drainage bills
• CD4: Mangroves in front of coastal levee	• Local residents • Wider community	• Water and drainage utility	• Green bond	• Water and drainage utility customers	• Water and drainage bills
• CA6: Community preparedness	• Local residents • Wider community	• Government	• Grant	• Property owners and residents	• Water and drainage bills • Flood response Insurance

Source: Original table for this publication

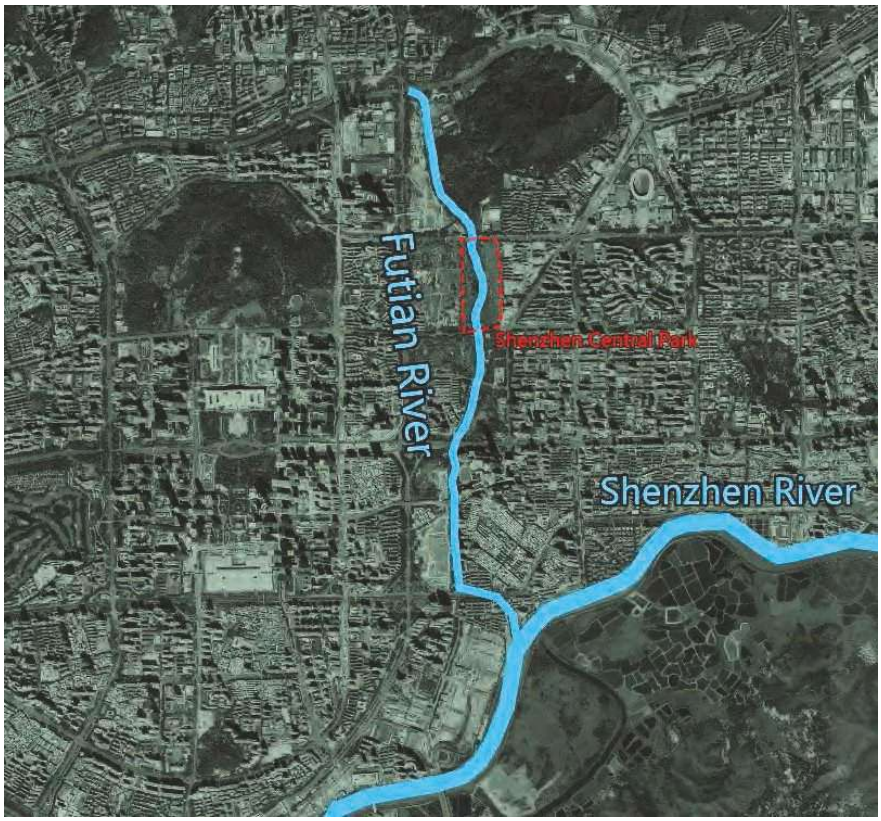
6.2 Case Study: Valuing the Comprehensive Benefits of Shenzhen Futian River Ecological Restoration (Appendix C)

6.2.1 Urban Context of Shenzhen, China

Shenzhen has experienced rapid development and urbanization since 1978. Located in the Pearl River Delta on the southeast coast of China, adjacent to Hong Kong, Shenzhen is the first special economic zone (SEZ) in China. In these zones, trade and market regulations are different from the rest of the country; the zones were designed to boost foreign investments and overall economic growth. From 1978, when China started its reform and opening-up policy, the population of Shenzhen has increased by almost 40 times to 13 million in 2018, which classifies it as a megacity, and its municipal gross domestic product (GDP) has grown by more than 10,000 times, reaching more than US$$340 billion (roughly RMB2.4 trillion), with per capita GDP reaching approximately US$28,653 (RMB 189,568) in 2018.

The Futian River is in the central area of the Shenzhen municipality (figure 6.4) and has significant ecological and environmental importance. With a catchment area of 15.9 square kilometers and mainstream length of 6.8 kilometers, the Futian River connects two of Shenzhen's major municipal parks: Bijiashan Park and Central Park. The area surrounding the Futian River is densely populated, and the river offers one of the main leisure and sightseeing sites for residents.

Photo 6.1: **AERIAL VIEW OF THE FUTIAN RIVER**



Source: Original for this publication based on Google imagery.

The Futian River has suffered from ecological degradation caused by rapid urbanization and economic development, which have exacted a heavy toll on the environment. As part of the central urban area, the Futian River catchment has also been developed on a large scale, which has brought a series of problems, including river pollution, deterioration of water quality, insufficient flood control, diminishing lack of aesthetics, embankment encroachment, extinction of aquatic biodiverity, poor ecology, and so on.

In 2009, the Shenzhen Water Bureau initiated the ecological renovation of the Futian River to address several urban water issues, including urban flood control, pollution reduction, water quality improvement, and so forth, in an integrated manner. Construction for the project was carried out from 2009–11 in preparation for the 2011 Summer Universiade, a multi-sport event for university athletes. The designed operational life span is 40 years, or until 2050. The project has provided multiple benefits, including economic, environmental, and social advantages, among others. However, there is a lack of quantitative analysis and understanding of the comprehensive benefits and costs associated with the project. The BCA tool from INFFEWS has been applied in this study to quantify the comprehensive benefits of the Futian River Ecological Restoration Project.

6.2.2 Project Interventions

Construction occurred in two phases, the first of which ran from the middle of 2009 to early 2010. Major construction works in phase 1 included the following:

- **Reconstruction of all 4,181 meters of embankment**
- **Installation of initial stormwater collecting system, including 5,032 kilometers of pipelines and three stormwater storage ponds with a total capacity of 60,000 cubic meters**
- **Creation of Futian's Central Park landscape**
- **Construction of artificial lakes and wetlands with a total area of 67,000 square meters**
- **Development of a pumping station with the capacity of 30,000 cubic meters per day**
- **Creation of a lake water circulation system with the capacity of 15,000 cubic meters per day and a vertical wetland system equipped with the capacity of 4,000 cubic meters per day.**

The major construction works in phase 2 (from the middle of 2010 to early 2011) included the following:

- **An advanced water treatment facility with the capacity of 30,000 cubic meters per day**
- **Reclaimed water pipeline work with a total length of 5,617 meters.**

Specifically, the project used planting ditches and detention ponds to transport, purify, and retain rainwater to reduce flood peaks. At the same time, an underground reservoir was constructed to collect and use all rainwater, reducing drainage pressure on the municipal rainwater pipeline downstream. The parking lot was transformed into a biological infiltration belt with a landscape effect that extends to the edge of the street to collect rainwater, slow down the water flow, clean the rainwater, and filter the rainwater. Although the Futian River suffers from a dry season during the winter, this project uses treated water as well as water transferred to the upper stream as river base flow to enhance the water environment and water quality.

6.2.3 Costs of the Futian River Ecological Renovation Project

The project's expenses were fully covered by the Shenzhen Water Bureau, and they mainly consisted of five components: design costs, construction costs, land use compensation, maintenance costs, and project working liquidity (Summarized in Table 6.2).

Table 6.2: **PROJECT COSTS FOR PHASES OF FUTIAN RIVER ECOLOGICAL RENOVATION PROJECT**

Cost category	Phase	Cost (million RMB)	Payment mode	Period
Design	Phase 1	56.5	One time	2009
	Phase 2	6.1	One time	2010
Construction	Phase 1	359.9	One time	2009
	Phase 2	36.8	One time	2010
Land use compensation		1.38	One time	2009
Maintenance	Embankment maintenance	0.9	Annual	2012–50
	Dredging costs for maintenance	1.6	Annual	2012–50
	Pipeline maintenance	1.6	Annual	2012–50
	Sewage pump station maintenance	1.2	Annual	2012–50
	Green land maintenance	2.4	Annual	2012–50
	Water treatment facility maintenance	1.9	Annual	2012–50
Project working liquidity		2.2	One time	2011

Source: Original table for this publication

6.2.4 Comprehensive Benefits of Futian River Ecological Renovation Project

- **Reduced flood risk. The flood control benefit calculation uses the frequency method. The difference between flooding losses before and after the project is completed is taken as the flood control benefit of the project. It is assumed that the flood control benefit increases by 8 percent annually along with development of the economy.**
- **Reduced water consumption. The benefits of reduced water consumption are calculated as the product of the amount of water supplied to the upstream Futian River from the wastewater treatment plant and the price difference between water supply and wastewater treatment cost in Shenzhen.**
- **Improved air quality. The benefits of improved air quality include increasing negative ions in the air and dust absorption, which are calculated respectively using the market price for a negative ion generator and expenses avoided for industrial dust treatment.**
- **Carbon fixation. The benefit relative to carbon fixation is calculated by carbon tax and afforestation cost. Literature estimates on carbon prices in China and afforestation costs are used in the calculation.**
- **Sediment transport. The benefit of river sediment transport is calculated using the alternative engineering method based on the dredging expenses that are avoided because of this project.**
- **Increased tourism. The benefits of increased tourism are calculated based on the designed annual visiting capacity and ticket price of similar parks in Shenzhen.**
- **Reduced investment in water storage infrastructure. Renovation of the Futian River provides the capacity to restore water both for the surface and groundwater, which avoids the expense of developing water storage infrastructure.**

- **Water quality improvement. According to water quality monitoring data, implementing the project caused the chemical oxygen demand (COD) to drop dramatically from 74.34 mg/L to 29.79 mg/L, and ammonia (NH3-N) to decrease from 11.87 mg/L to 7.2 mg/L. Such benefits are calculated based on avoided wastewater treatment costs.**
- **Increased property prices. To quantitatively measure the effect of the project on property prices, the value tool from INFFEWS was used. This tool provides changes in percentage in property prices from proximity to the Shenzhen Central Park based on relative studies.**
- **Residual value of fixed assets after designed service period. After the 40-year designed service period, residual values for the project's fixed assets are estimated by the initial investor.**

Because the project was completed in early 2011, it is assumed that all benefits will be fully realized from 2012. In 2011, it will be considered a trial operation stage, and the annual benefits are calculated at 50 percent of 2012. A discount rate of 7 percent is applied.

Table 6.3 presents the quantified benefits of the Futian River Ecological Renovation Project.

Table 6.3: **COMPREHENSIVE BENEFITS OF FUTIAN RIVER ECOLOGICAL RENOVATION PROJECT**

Type of benefit	Benefit (million RMB)	Period
Reduced flood risk	4.28	2011
Reduced water consumption	6.94	2011
Improved air quality	0.006	2011
Carbon fixation	4.75	2011
Sediment transport	0.19	2011
Increased tourism	10	2011
Reduced investment in water storage infrastructure	1,300	2011
Water quality improvement	1.4	2011
Increased property prices	234	2011
Reduced flood risk	8.56	2012–50
Reduced water consumption	13.87	2012–50
Improved air quality	0.013	2012–50
Carbon fixation	9.5	2012–50
Sediment transport	0.37	2012–50
Increased tourism	20	2012–50
Water quality improvement	2.8	2012–50
Residual value of fixed assets after retirement	167	2050

Source: Original calculation for this publication.
**Note:* for benefits that occur from 2012 to 2050, the figure amounts to the total discounted benefit per year throughout the period.

Of all the benefits, flood risk reduction contributes the most to the project, accounting for 41.1 percent of the total project benefit, followed by increased property values and avoided investment in water storage infrastructure, which contribute 25.4 percent and 14.1 percent respectively. Air quality improvement also makes a significant contribution to the overall benefit that carbon fixation ranks third, contributing 14.2 percent.

6.2.5 Project Net Present Value and Benefit-Cost Ratio

According to the INFFEWS BCA tools, the Futian River Comprehensive Project shows an expected NPV of negative 6.34 million RMB overall for the investment. The project has achieved a benefit-cost ratio (BCR) of 0.99, which indicates that it has generated considerable benefits from the investment.

According to the sensitivity analysis of different cost-benefit parameters, the expected NPV range runs from the worst-case scenario of negative 484 million RMB to positive 510 million RMB, corresponding to BCR ratios of 0.38 to 2.21. Specifically, applying different discount rates results in a low discount rate the NPV increases to 347 million RMB with BCR of 1.44 (table 6.4).

6.2.6 Cost and Benefit Distribution among Different Stakeholders

Although project costs were fully funded by the Shenzhen Water Bureau, the benefits that could potentially be derived are distributed to different beneficiaries. According to our initial assessment on cost reductions for different stakeholders, the benefits distribution among different beneficiaries is shown in figure 6.4. Shenzhen Water Bureau is the primary beneficiary, sharing 42.58 percent of the total benefits, followed by real estate developers (16 percent), Shenzhen Public Works Bureau (14.57 percent), surrounding residents (13 percent), Shenzhen Housing Bureau (12.00 percent), Shenzhen Tourism Bureau (2.47 percent), and Shenzhen Environmental Bureau (0.01 percent). Although the urban residents are the final beneficiaries of the Futian River Ecological Renovation Project, the line departments/bureaus being identified as beneficiaries indicates public resources being used from different channels, instead of from the project organizations (i.e. municipal water bureau). Identifying a broader range of cobenefits and beneficiaries not only helps leverage private and community resources, but also better justifies the use of public resources as appropriate.

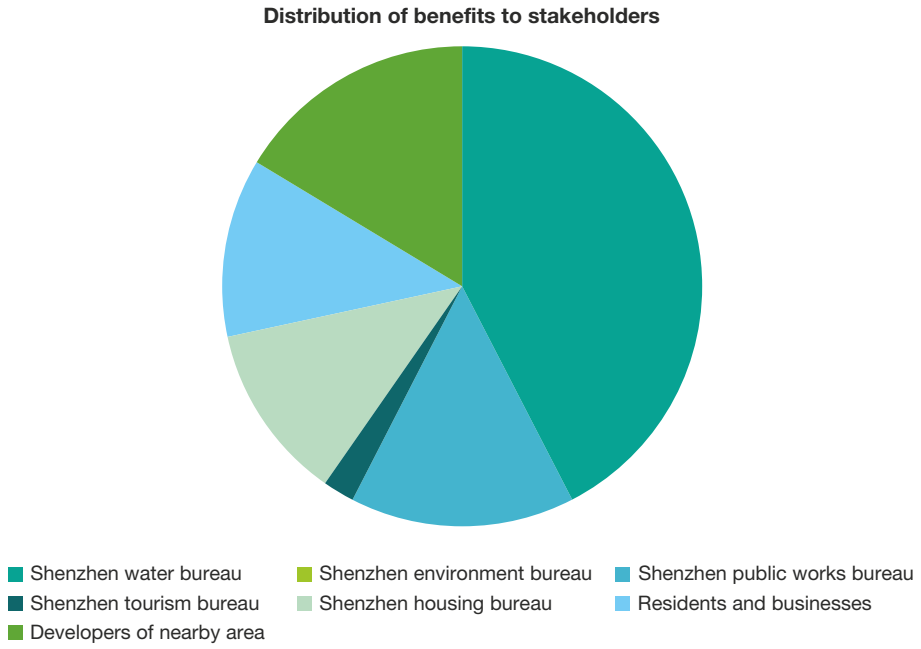
For the Shenzhen municipal government, the NPV of this project investment was negative 143.39 million RMB with a BCR of only 0.76, indicating that it was an unrecoverable investment. However, quantifying the comprehensive benefits demonstrates the rationale of such an investment. Furthermore, beneficiary analysis enables the identification of potential investors and contributes to leveraging other financial options, such as the private sector and community resources.

Table 6.4: **RESULTS OF DISCOUNT RATE SENSITIVITY ANALYSIS**

Overall	Low discount rate 0.04	Default discount rate 0.07	High discount rate 0.1
Benefits (present value, RMB)	955,956,221	595,365,132	427,924,669
Costs (present value, RMB)	664,804,500	601,709,555	566,596,571
Net Present Value (NPV, RMB)	291,151,721	–6,344,423	–138,671,902
Benefit: Cost Ratio (BCR)	1.44	0.99	0.76

Source: Original figure for this publication.

Figure 6.4: **DISTRIBUTION OF BENEFITS TO DIFFERENT BENEFICIARIES**



Source: Original figure for this publication.

6.3 Case Study: Valuing the Comprehensive Benefits of Kunshan Forest Park (Appendix D)

6.3.1 Urban Context of Kunshan in Jiangsu Province of China

Kunshan is in southeastern Jiangsu Province. As the eastern gate of the province, the city borders on the Jiading and Qingpu districts of Shanghai in the southeast. Kunshan is in the Taihu Lake Basin of the Yangtze River Delta; it has a dense river network and flat terrain, slight inclination from southwest to northeast, and small, natural slopes. The Loujiang River and the Wusong River run across the central part of the city, which is divided into three large areas, namely, the low-lying area north of the Loujiang River, the semi-high field area between the Loujiang and Wusong rivers, the semi-high field area and the high field area south of the Wusong River.

Kunshan lies in the monsoon climate zone. The average annual precipitation of Kunshan City is 1,133.3 millimeters, with a great annual difference. The maximum annual precipitation is 1,522.4 millimeters (1991), and the minimum precipitation is 826.1millimeters (1992). The distribution is uneven in the year, with heavy rains at the turn of spring and summer and many rainstorms in summer and autumn. The annual average evaporation is 822.2 millimeters, and the annual average temperature is 16.8°C.

Kunshan has made remarkable achievements in economic and social development. Kunshan has a permanent population of about 1,662,400, including a registered population of 862,700. In 2019, the city's GDP exceeded RMB 400 billion, amounting to RMB 240,616 per person (US$33,975), three times China's national GDP per capita at just over US$10,000.

The Kunshan Forest Park is in the western part of Kunshan. This area is positioned as "an important demonstration area for green development, innovative development, and coordinated development of Kunshan City"[1] which plays a significant role in Kunshan's overall development as the Kunshan New and High-Tech Industrial Development Zone. The Kunshan Forest Park is an ecological link connecting the old urban area with two lakes—that is, Yangcheng and Kuilei lakes (Photo 6.2). With a total area of about 2 square kilometers, Forest Park is composed of water surfaces, wetlands, and vegetation covers.

The Forest Park underwent an ecological renovation in 2016. Taking the opportunity for joint sponge city constructions in Jiangsu Province and the Victoria state of Australia, the Kunshan Forest Park began to carry out ecological upgrading and transformation aimed at improving drainage and storage capacity, enhancing the protection and restoration of urban wetlands and ecosystems, integrating the park landscape with urban water management, improving water quality, and so forth.

The Forest Park Ecological Renovation project has generated significant economic, social, and environmental benefits. However, because of the lack of quantitative analysis of those comprehensive benefits versus the construction and operation costs, the project values have not been effectively manifested. This study uses the INFFEWS BCA tools to quantitatively analyze the comprehensive benefits and costs of the project and further clarify the significance of the Forest Park's renovation.

Photo 6.2: **AERIAL VIEW OF THE KUNSHAN FOREST PARK**



Source: Original for this publication based on Google Imagery.

[1] Kunshan Municipal Government (20xx) Urban planning of Kunshan (Internal Document).

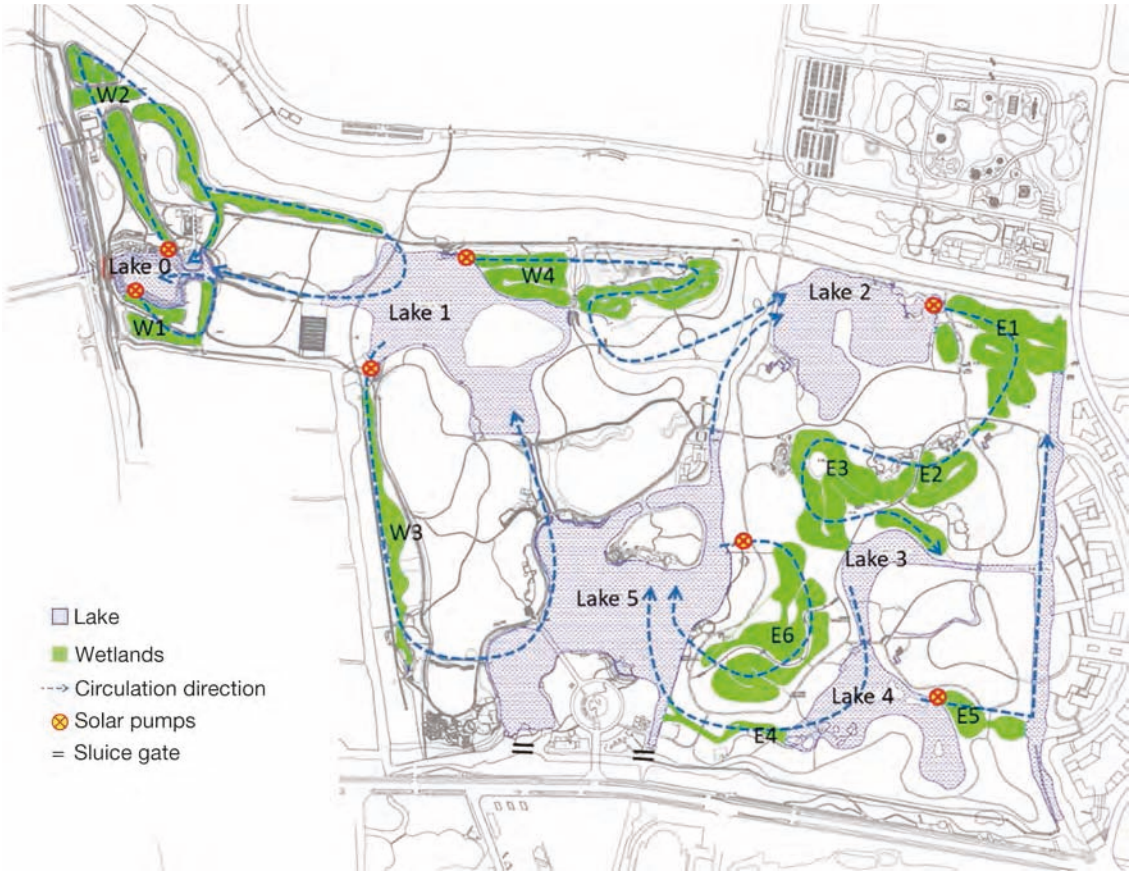
6.3.2 Project Design

This project aims to build a multifunctional forest park and simultaneously implement landscape and sponge city transformation engineering designs. The objectives of sponge city transformation of the Forest Park include the following:

- **Connecting the Forest Park with the surrounding water systems to improve circulation of the water system and water quality of the park**
- **Improving the drainage and storage capacity of the surrounding areas by enhancing the polder system of the Forest Park for rainwater regulation and storage**
- **Improving the urban ecosystem diversity of the park by land and water ecosystem restoration.**

Water circulation wetlands. Several water circulation wetlands are constructed in the park. Water is continuously pumped from the lake through the wetlands and then returned to the lake by small solar pumps to continuously remove water pollutants, such as nitrogen and phosphorus. At the same time, the lake system is used as rainwater storage space in the polder area to improve the effective water surface rate and the overall flood control capacity of the area (Map 6.1).

Map 6.1: **LAYOUT AND OPERATION DIAGRAM OF RECYCLING WETLAND IN FOREST PARK**



Source: Based on Kunshan Forest Park Design Documents.

According to the design standard of a maximum 30-day turnover time and five-day hydraulic retention time in the river, the area of wetland required for the ideal management of water quality of a deep-water lake in the Forest Park is about 29 hectares. Wetland distribution and operation processes are shown later in this chapter.

Ecological improvement. The original vegetation types and areas in the park were constructed for landscape purposes without considering ecosystem diversity. The bird island, with relatively little development and high ecological potential, and the surrounding areas are specially selected to implement both active and passive ecological restoration strategies. Passive restoration strategies include stopping bank gardening, and so forth. Active restoration strategies focus on large-scale dead tree branch planting at the bank of the bird island.

6.3.3 Project Cost-Benefit Analysis

Evaluation period and discount rate. The INFFEWS BCA tool can analyze the appraisal project for up to 50 years. Therefore, in combination with the construction data of the Kunshan Forest Park project, whose starting year was 2016, the analysis period is set as *50* years. The discount rate in China is generally set at 8 percent, and the fluctuation of high and low discount rate provided by the BCA user guide is ± 3 percent.

Cost analysis. The total cost of the sponge city transformation project of Forest Park consists of two parts: the project construction cost and the operation and maintenance cost after the completion of the project. The total construction cost is about RMB 21.1 million (about US$3 million). According to relevant project materials, the operation and maintenance (O&M) cost is about US$0.039 million per year. Because the construction phase occupies four years, the operation phase requires 46 years of the 50-year period, and the project's total O&M cost is about US$1.8 million (Table 6.5)

6.3.4 Project Benefits

Ecological and biodiversity improvement. The estimated benefit per hectare is US$405, and the estimated value is US$25,515 (US$405 × 210 hectares × 30 percent) one year after the reconstruction.

Air quality improvement. The Forest Park is improving the air quality in surrounding areas. The number of beneficiaries is estimated at 75,000, based on the residential population living within 500 to 800 meters. The benefit per person per year is estimated at US$28.

Water quality improvement. This benefit is calculated as the avoided treatment cost for water quality, odor, and other related issues.

Flood risk reduction. The Jiangpuwei polder area consists of about 485 hectares. The Forest Park renovation project increases the standard for flood control in this polder area from a 20- to 50-year return period. The flood losses before and after the project are obtained from statistical data and project materials.

Table 6.5: **BREAKDOWN OF EXPENSES IN EACH STAGE**

Period	Period (Year)	Cost (US$ Million/Year)	Total Cost (US$ Million)
Construction Period (1)	2016–19	0.75	3.00
Operation Period (2)	2020–65	0.039	1.80

Source: Original calculation for this publication

Commercial value increase. After the completion of this project, the income of retail stores, parking lots, and water entertainment facilities will increase compared with figures before the project. According to the municipal internal statistics, the annual business income will increase by about US$58,000 (RMB 410,000).

Real estate value increase. With Kunshan City Ecological Forest Park as the starting point, the distance of some communities was measured. According to the survey distance and the wetland area, the house price growth rate (based on the minimum value) can be obtained with the INFFEWS value tool, as shown in table 6.6. It is estimated that the total benefit of these six buildings in 45 years (2020–65) after the completion of the project is about US$10 million (RMB 70 million), which amounts to US$222,000 per year.

Reduced water consumption. The project enhances water circulation and reduces water consumption for planting and gardening purposes. According to the annual water consumption reduction amount and water prices in Kunshan, the total benefit amounts to about US$122,000 (RMB 858,000) per year.

Health benefits. The Forest Park project reduces the incidence of illness caused by extreme high temperatures. Literature shows that 20 percent of people suffered from extreme heats and assumes that 90 percent reduction can be achieved; therefore, 13,500 people will benefit, with US$193 saved per person per year.

Reduced greenhouse gas emissions. The number of trees in the park is estimated at 50,000, and each tree is able to capture 1.83 tons of carbon dioxide (CO_2) every year. The social cost of each ton of CO_2 is estimated at US$16. The summary of benefits provided by the Kunshan Forest Park is given below in Table 6.6:

Overall, it can be seen from Table 6.7 that, based on INFFEWS BCA tool, when the discount rate is set at 8 percent, the total NPV is US$57.91 million. Compared to the total cost of US$2.8 million, a total BCR of 49.63 can be realized. For the project organization, the Kunshan Forest Park Limited Company, the total NPV is US$3.07 million, compared with its total investment of US$1.13 million, generating an investment BCR of 2.71. In conclusion, this project is expected to generate significant financial profits and overall economic benefits.

Table 6.6: **COMPREHENSIVE BENEFITS OF THE KUNSHAN FOREST PARK RENOVATION PROJECT**

Type of Benefit	Benefits (US$ million)	Percentage (%)
Health benefits	23.244	38.90
Air quality improvement	18.734	18.21
Greenhouse gas reduction	7.137	6.94
Reduced flood losses	6.843	6.65
Increased real estate values	1.963	1.91
Reduced water consumption	1.084	1.05
Increased commercial values	0.517	0.5
Water quality improvement	0.182	0.18
Biodiversity improvement	0.049	0.05

Source: Original calculation for this publication.

Table 6.7: **RESULTS OF PROJECT BCA ANALYSES OF KUNSHAN CASE**

Overall BCA results		
	$57,915,880	(adjusted for adoption and project risk)
Benefits (present value) Costs (present value)		
– Project organization	$1,132,811	
– Other stakeholders	$1,699,217	
– Excess burden	$0	
Net Present Value (NPV)	$55,083,852	
Benefit: Cost Ratio (BCR)	49.63	= (Benefits – Other costs – Excess burden)/Project org. costs
Results Attributable to project organization		
Benefits (present value)	$3,066,018	(adjusted for adoption and project risk)
Costs (present value)	$1,132,811	
Net Present Value (NPV)	$1,932,207	
Benefit: Cost Ratio (BCR)	2.71	

Source: Original calculation for this publication.

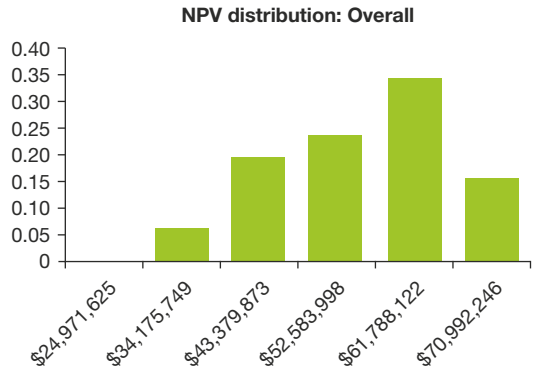
Sensitivity analysis shows the robustness of the analysis, with project's overall NPV and specific NPV being positive and 100 percent across a range of possibilities (Figure 6.5). The overall NPV ranges from US$24.97 million to US$70.99 million whereas the NPV for the project organization ranges from US$0.047 million to US$3.117 million.

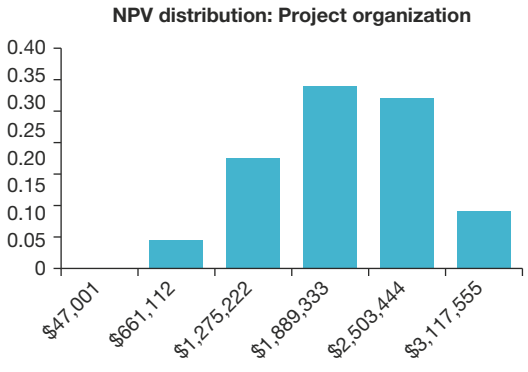
Sensitivity analysis of the discount rate shows that the lower discount rate corresponds to an even higher BCR. Under a discount rate of 5 percent, the overall BCR and the BCR for the project organization can reach 73 and 3.93 respectively. Even under the high discount rate of 11 percent, the overall BCR and the BCR for the project organization still amount to 35.95 and 1.99 respectively, indicating the forest project is a profitable project.

Analysis of the beneficiaries has shown that although Kunshan Financial Bureau and Kunshan Forest Park Limited Company are the primary funding sources for the project, the benefits are widely distributed among seven main stakeholders. Among them, Kunshan Health Commission benefited the most at 29.75 percent because of improved health benefits, followed by Kunshan Ecology and Environment Bureau at 25.86 percent, followed by improved air and water quality. See figure 6.6.

Figure 6.5: **SENSITIVITY ANALYSIS OF KUNSHAN CASE**

Distribution. Up to ...	Probability	Distribution. Up to ...	Probability
$24,971,625	0.00	**$47,001**	0.00
$34,175,749	0.06	**$661,112**	0.05
$43,379,873	0.20	**$1,275,222**	0.20
$52,583,998	0.24	**$1,889,333**	0.33
$61,788,122	0.35	**$2,503,444**	0.31
$70,992,246	0.15	**$3,117,555**	0.10
Total	1.00	**Total**	1.00





Height of each bar = relative frequency of results between that NPV and the next lower NPV.

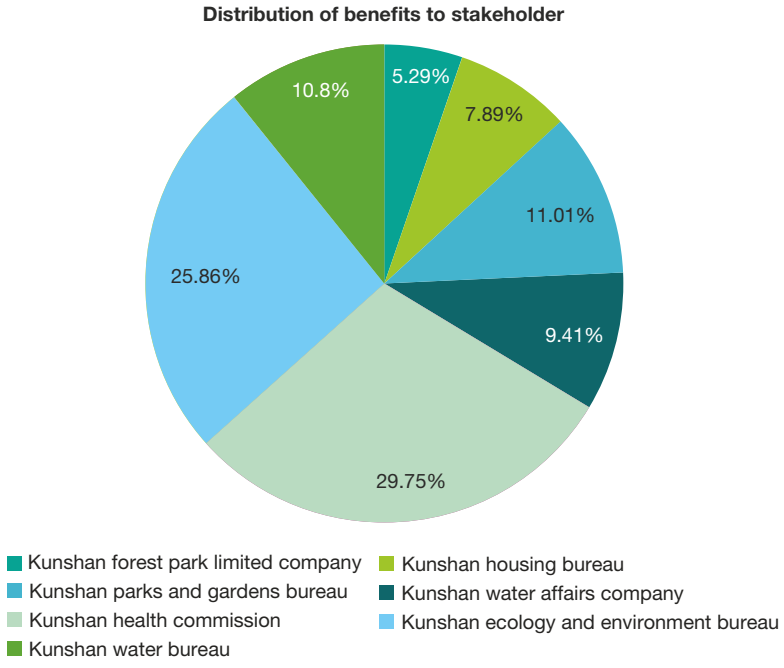
Source: Original figure for this publication.

Table 6.8: **SENSITIVITY ANALYSIS OF DISCOUNT RATES IN KUNSHAN CASE**

Sensitivity to discount rate			
Overall	**Low discount rate 0.05**	**Default discount rate 0.08**	**High discount rate 0.11**
Benefits (present value)	$ 94,405,769	$56,216,663	$36,788,529
Costs (present value)	$1,293,261	$1,132,811	$1,023,385
Net Present Value (NPV)	$93,112,508	$55,083,852	$35,765,143
Benefit: Cost Ratio (BCR)	73.00	49.63	35.95
Project organization	**Low discount rate 0.05**	**Default discount rate 0.08**	**High discount rate 0.11**
Benefits (present value)	$5,077,424	$3,065,018	$2,034,019
Costs (present value)	$1,293,261	$1,132,811	$1,023,385
Net Present Value (NPV)	$3,784,163	$1,932,207	$1,010,634
Benefit: Cost Ratio (BCR)	3.93	2.71	1.99

Source: Original figure for this publication.

Figure 6.6: **DISTRIBUTION OF BENEFITS FROM KUNSHAN PROJECT TO STAKEHOLDERS**



Source: Original figure for this publication.



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7

Recommendations for Funding and Financing NbS for IUFM in China



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This chapter summarizes financing and funding forms available in China and reflects on the preceding chapters to inform recommendations around financing options that could assist future interventions involving nature-based solutions.

7.1 Funding and Financing IUFM projects in China

Although nature-based solutions (NbS) for integrated urban flood management (IUFM) are relatively well established and widely recognized as key to climate adaptation, mitigation, and resilience, securing sustainable sources of funding and mobilizing appropriate sources of financing remain major challenges to realizing their potential at scale. Overcoming these challenges hinges on efforts to effectively monetize the range of cobenefits derived from NbS and to internalize future returns against upfront costs of implementing them. These challenges are compounded by difficulties in predicting the effectiveness of such solutions, leading to high uncertainty about their cost-effectiveness compared with alternatives, as well as limited approaches to economic appraisal, and poor financial models.

A series of standards, policies, and guidelines informs the development of sponge cities (appendix F), but limited guidance exists regarding financing options. The technical standards provide a comprehensive framework for the construction of sponge cities and build on the guidance issued by the State Council in October 2015: "The Promotion of Sponge City Construction".[1] This outlines arrangements for promoting sponge cities, providing details about general requirements, planning, coordination and construction, and efforts to improve supporting policies. General guidance relating to the financing of sponge cities has been issued by the China Development Bank and the Ministry of Housing and Urban-Rural Development: "Promoting the Development Finance to Support the Construction of Sponge Cities."[2] This provides details about aspects of the project pipeline, credit support, and coordination mechanisms. Similarly, the Agricultural Development Bank of China and the Ministry of Housing and Urban-Rural Development jointly issued the notice "Promoting Financial Support for Sponge City Construction"[3] about the project reserve system, credit support, innovations using public-private partnership financing models, and measures to strengthen policies for financial support for the sponge urban construction.

The financing and funding of the infrastructure and services to support China's urban growth has relied heavily on government contributions. Among the four levels of government in China, the central government has provided significant financing for retreat, adapt, and defend measures as part of China's Sponge City Program, allocating an estimated US$50 million to US$100 million for each of the initial 30 pilot cities (figure 7.1) (Liang 2018; Nguyen et al. 2019). By April 2017, pilot projects for the sponge city concept covered about 420 square kilometers with total investments estimated at US$7.7 billion (RMB 54.4 billion). However, most expenditures for urban infrastructure and services are devolved to lower levels of government (Huang and Chan 2018) while much of the tax income is collected centrally since the 1994 tax reform (table 7.1). This has resulted in a fiscal gap within local governments, particularly in urban environment-related sectors. This funding gap at the local government level fluctuates and encompasses 50 percent to 60 percent of total local spending.

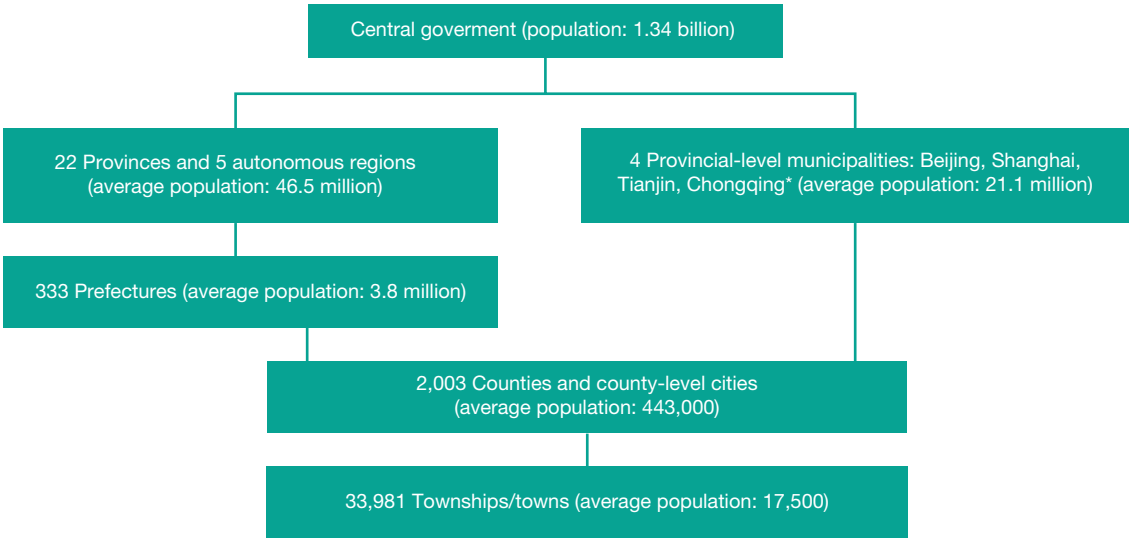
Traditionally, subnational governments in China (that is, provincial governments, municipal governments, counties, and townships) have addressed the fiscal gap through several means. These include imposition of "off-budget"

[1] General office of the State Council (No. 75 [2015] of The State Council).

[2] No. 208 (2015) of the Ministry of Housing and Urban-Rural Development.

[3] No. 240 (2015) of the Ministry of Housing and Urban-Rural Development.

Figure 7.1: **CHINA'S LEVELS OF GOVERNMENTS**



Source: Wong 2013.
Note:

Table 7.1: **BUDGETARY EXPENDITURE BY LEVEL OF GOVERNMENT**

Government level	All budgetary expenditures	Education	Health	Social security and employment	Capital spending (2006)
Central	23.0	5.5	1.7	6.3	27.9
Provinces	17.7	15.0	17.2	24.9	18.5
Municipalities	22.2	18.8	26.2	27.7	28.8
Counties and townships	37.1	60.7	54.9	41.2	24.8

Source: *Wong 2013.*[8]

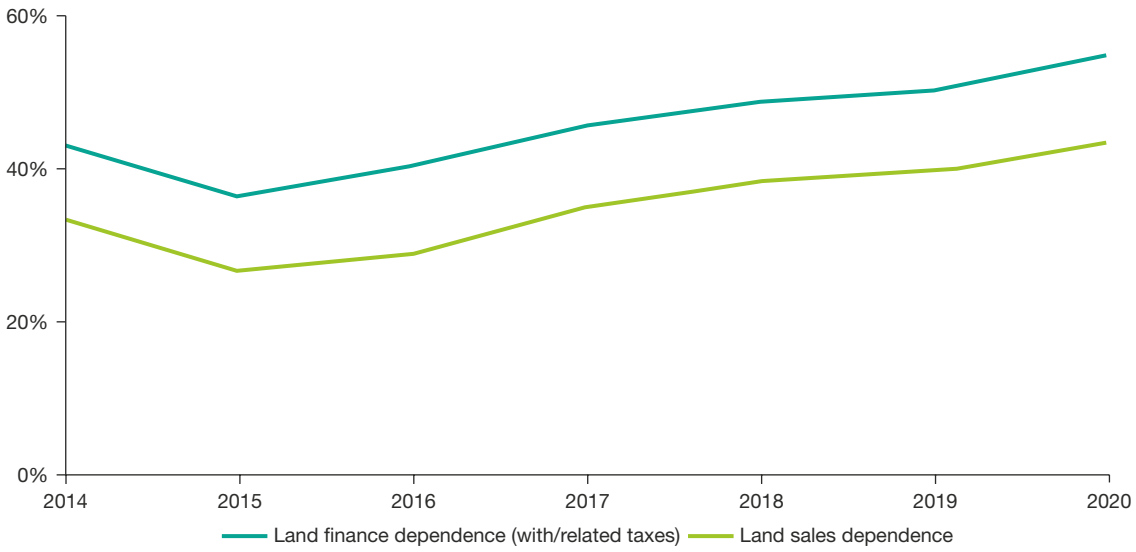
fees, charges, fines, and penalties on local business and households; monetization of state assets, particularly land; and establishment of local investment corporations.[4] Although initially created as vehicles for loans from international development organizations, these local investment corporations now play an important role in financing investment in local urban infrastructure, including flood protection.

Land value capture has proven to provide a major source of local revenue for addressing the fiscal gap (figure 7.2). This is because income from land conveyances is not part of budgetary revenue; thus, local governments do not need to share it with the central government (Ding 2003). To overcome restrictions on direct financing, many local governments established local government financing vehicles (LGFVs),[5] including Urban Development Investment Corporations (UDICs or Chengtou) as shown in figure 7.3 and state-owned enterprises. These are defined as

[4] The 1994 Budget Law prohibits subnational government borrowing without explicit permission from the State Council. Local investment corporations were a way for subnational governments to secure investments.

[5] The 1994 Budget Law prohibits subnational government borrowing without explicit permission from the State Council. Local investment corporations were a way for subnational governments to secure investments.

Figure 7.2: **LOCAL GOVERNMENT REVENUE DEPENDENCE RATIO ON LAND FINANCE, 2014–20***



Source: MoF, cited by China Policy September 4, 2020, policycn.com.
Note: *2020 estimation.

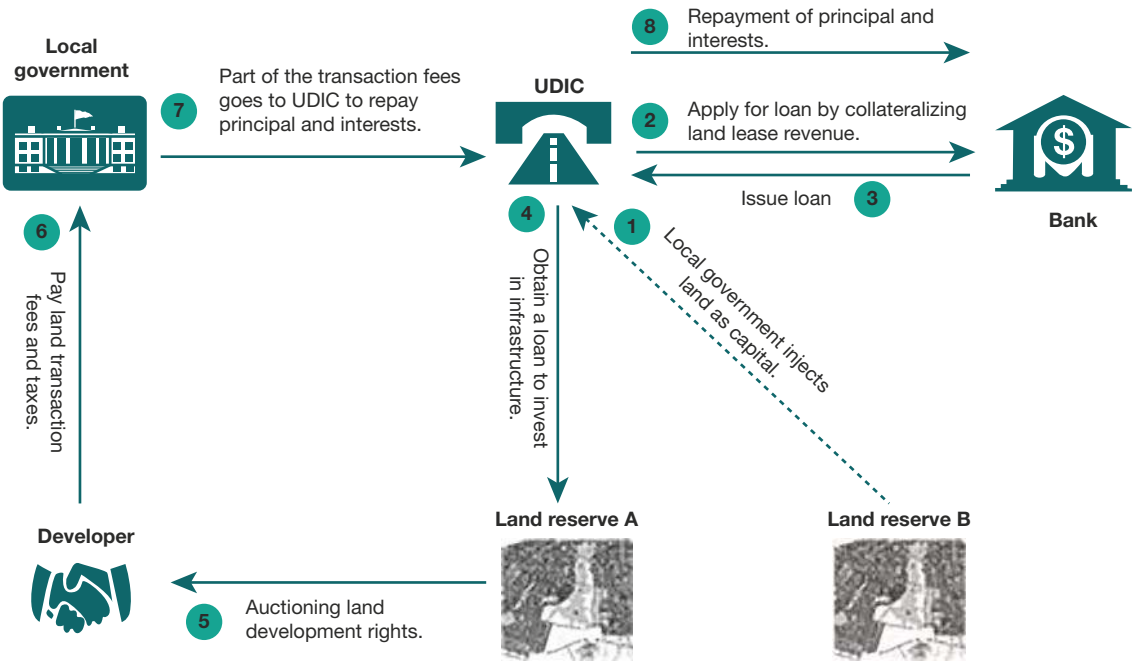
"economic entities with independent legal personality, which are established by local governments and their departments and agencies through fiscal appropriation or injection of assets such as land and equity, to perform the functions of financing government-invested projects" (Fan 2016). The LGFVs could apply for bank loans or issue corporate bonds to support development of urban infrastructure, including NbS, with implicit guarantee by local governments. However, the heavy reliance on land-based financing can be problematic, and it has led to overdevelopment of land in many municipalities. Furthermore, this reliance exposes local governments' fiscal health to volatility in land prices and inventory of land assets (Campanaro and Masic 2017).

Amendments to the State Budget Law (SBL) in 2015 introduced a new framework for local infrastructure finance. These changes place legal constraints on government income and spending, requiring off-balance sheet borrowing from the market. The new SBL forbids government guarantees for LGFV bonds to restrain local government debts and to separate government debts from corporate debts (Wu 2019). Under the new framework, municipalities can issue local government bonds for debt financing of urban infrastructure. Revenue-earning utilities and infrastructure service providers can issue corporate bonds or apply for commercial bank loans for urban infrastructure financing. Institutional investors such as social security funds and insurance companies are also encouraged to play a more active role.

Although the property tax system generates limited revenues, the central government has been exploring various reforms since 2003. Several pilot programs supported the introduction of a modern property taxation system for more than a decade. Six pilots were introduced in 2006, another 10 a year later, and pilot property tax schemes were introduced in Shanghai and Chongqing in 2011. However, scaling up of these pilots has faced resistance from various stakeholders and interest groups. A property tax would have implications for property-related industries that make up a significant share of the economy, but local governments also have resisted the idea because of the reliance on land leases for local revenues (Ng 2019).

Government investment alone, however, will not suffice to ensure the successful mainstreaming of NbS for integrated management of urban floods. The State Council guidance on "Promoting the Construction of Sponge Cities" estimated in October 2015 that it would require roughly US$300 billion (RMB 2 trillion) to achieve the national target of 20 percent sponge cities by the end of 2020. Initial funding for the 30 pilot cities was estimated at US$30 billion (RMB 200 billion). Calculations based on the three-year subsidy program and various incentive programs indicate that central government

Figure 7.3: **SCHEMATIC OF CHINA'S MUNICIPAL FINANCING WITH UDICS, BEFORE 2015**[14]



Source: World Bank 2017.
Note: UDICs = Urban Development Investment Corporations.

funding will only account for about 20 percent of the financing needs. Recognizing the challenges with financing, the guidance also established three principles requiring sponge city pilots to do the following:

- **Leverage NbS**
- **Adopt a systematic approach**
- **Promote public-private partnerships (PPPs) to attract private sector and social capital.**

Partnerships between private sector developers and the public sector can help mobilize additional sources of funding and financing for infrastructure under the right circumstances, enhance project selection, and foster gains in efficiency. Recognizing opportunities for mobilization of alternative capital for infrastructure financing, the SBL law also encourages PPPs and the establishment of revenue-earning entities that can provide services through concession contracts or service agreements. According to the PPP project database of the Ministry of Finance, 55 cities have implemented PPPs associated with sponge city construction with a total investment of US$16.43 billion (RMB 115.2 billion). The average project investment is about US$283 million (RMB 1.984 billion); the maximum investment, US$3.47 billion (RMB 24.3 billion); and the minimum investment, US$4.87 million (RMB 34.16 million). The shortest project term has been 10 years, and the longest has been 30 years. The average term: 17 years. The main payment methods are typically through government (53 percent) and feasibility gap (44 percent) subsidies, whereas payments from users reportedly account for only 3 percent (Li and He 2020).

7.2 Recommendations for Financing NbS for IUFM in China

The range of financing options to support NbS for integrated urban flood management are informed by the values associated with the direct and indirect benefits. These are typically context specific and informed by the level

of social and economic development, as well as exposure to floods. Given the diversity of urban conditions in China, the realization of these values and the appropriate financing instruments will be further informed by both the affordability and collectability of the associated revenue streams. Where these are limited, public instruments and concessional funding will continue to be essential for promoting NbS for IUFM and leveraging private flows. However, the diversity of determining characteristics across the urban landscape in China creates a range of opportunities for various policy instruments and financing options, particularly in higher income urban areas. Blended financing options can facilitate the transition of middle-income urban areas toward greener development models with increasing contributions from a diversity of financing sources.

Many investments in NbS present unique risks because of their cash profiles that limit access to private financing and social capital. Successful mobilization of private financing and social capital requires certain conditions, including a sizable market for such projects, a good return on investment (compared with alternative investments), and a limited amount of risk (or risk that can be managed without too many complications). Within this context, the major challenges associated with mobilization of private sector financing and social capital for sponge city construction in China are widely recognized as the following:

- **Large scale and long cycle of investment and construction costs**
- **Lack of clear and sustainable return mechanisms or revenue streams that rely heavily on government or user payments without long-term income guarantees**
- **Inadequate risk-sharing mechanisms in the absence of a comprehensive set of laws and regulations on PPPs (Zhang and Zheng 2019).**

In order to leverage a wider range of potential sources of private financing and social capital there is a need to provide a more systematic and comprehensive framework for policy makers, investors, and practitioners to identify and evaluate the wide range of tangible and intangible environmental, social, and economic benefits derived from NbS associated with integrated urban flood management. Investments in hybrid infrastructure that bridge the continuum from gray to green and incorporate blue considerations require country-specific policies and instruments led by the public sector and tailored to local conditions. The following recommendations outline a framework for facilitating sustainable funding mechanisms and appropriate financing options to realize those values in support of building an ecological civilization in China.

7.2.1 Recommendation 1: Improve the Recognition and Valuation of Benefits Provided by NbS for IUFM

Improving access to appropriate financing requires a robust approach to project preparation and appraisal over the entire life cycle. This should include appraising fiscal affordability, assessing social and environmental aspects, identifying risks, determining financial viability by comparing public and private options, and sounding out the market. This should include identifying the full range of benefits derived from NbS and the values associated with each of the benefits, in addition to adopting innovative technology and striving toward environmental and social sustainability, resilience against natural disasters, and governance to assure transparency in procurement and robust institutions. It is particularly important to identify all beneficiaries and to show the distribution of benefits among stakeholders and beneficiaries. Investments aligned with these principles will support the value-for-money proposition, help extend the life of the infrastructure asset, and increase returns on investment. To do so, a comprehensive database of values associated with the each of the benefits to be derived from NbS for integrated urban flood management should be developed.

7.2.2 Recommendation 2: Enhance the Policy, Institutional, and Regulatory Framework

The national government should implement fiscal policies to improve incentives for-nature based solutions for IUFM. These policies should improve targeting of public resources through performance-based subsidies and conditional transfers as well as through interest rate support and tax incentives to stimulate demand. China has issued a large number of departmental regulations and documents, but the legal basis is not sufficiently robust. Departments and governments at all levels have different interests, demands, and administrative processes, resulting in contradictions and operational difficulties in realizing policy intentions.

The national government should accelerate the formulation and issuance of specific financing laws and regulations related to sponge cities. For example, there is a need to clarify risk-sharing mechanisms for PPPs to increase confidence among private sector investors. Provincial and municipal governments should establish water management entities with dedicated offices for guiding the planning and implementation of sponge cities as core components of IUFM. This would help unite management and supervision of urban water-related administrative affairs, avoid fragmentation of departments and authorities, and promote coordination among departments and levels of government. Given variations in climate, geography, and hydrological conditions, each city in China should be encouraged to develop context-specific guidance that best fits its socioeconomic and natural environmental conditions (Sun 2019).

7.2.3 Recommendation 3: Improve Targeting of Public Funds for NbS for IUFM

Public financing will continue to play an important role in developing hybrid solutions and funding blue and green infrastructure. In addition to setting policies that enable investments in NbS for IUFM, government will continue to have an important financing role. There are a range of sources of public funding, including general revenue along with such dedicated revenues as levees on water-related services, that can be directed toward financing NbS. The performance of government funding can be improved through targeted performance-based subsidies and conditional transfers for national priority programs. Strengthening arrangements for managing performance expectations, providing support for improvements, and monitoring progress can go a long ways toward rewarding performance, creating positive incentives for facilitating fiscal transfers, and improving accountability for results. Such incentives can also shift expenditures from postdisaster responses to more cost-effective preventive measures, such as incorporating NbS into integrated urban planning and integrated spatial planning at the catchment scale. The advent of machine learning provides opportunities for mapping city-scale landscapes to a typology of urban characteristics that can provide the foundation for a performance-based investment framework applicable to NbS for IUFM.

7.2.4 Recommendation 4: Use Market Mechanisms to Promote NbS for IUFM

A range of regulatory measures can promote market-based approaches and create positive incentives for investing in NbS for IUFM. Systems for trading stormwater rights have emerged as one such area; the government allocates rights to users and allows free trade between owners of these stormwater rights. Such regulations typically include onsite retention or detention requirements for new development and redevelopment projects above a certain size. For example, Kunshan municipality issued a regulation in 2013 requiring all new development to apply NbS, thus laying the foundation for establishing stormwater rights that could be traded if a proper market is established. Urban planners in Shenzhen are also gradually introducing a system for stormwater management charges and trading of rainwater discharge rights. The “Planning Guidelines of Rainwater Utilization System in Shenzhen” requires the retention and use of all rainwater in residential areas. Residential areas that do not invest in facilities to use rainwater—or fail to meet targets for usage—will be charged a “rainwater discharge fee.” Residential areas that exceed the requirement may be granted rainwater credits which can be sold to residential areas that fail to fully meet the requirements (see Box 7.1). Where land developers are identified as major beneficiaries, specific requirements can be used to encourage commitments in investing in NbS, such as linking higher floor-area ratios to commitments by developers to invest in NbS. Such regulations provide opportunities for promoting NbS by enabling property owners or developers to meet a portion of their obligations by buying volume-based “credits” generated through blue and green investments in offsite NbS. To succeed, such initiatives require a strong regulatory foundation and sufficient local development to drive demand for credits informed by guidelines developed according to local conditions, clearly defined program boundaries, and an independent oversight body.

7.2.5 Recommendation 5: Establish a Revolving Fund for NbS Investments for IUFM

A dedicated revolving fund could guide investments and make affordable credit available to support blended financing solutions. The fund could be established as a window under the National Green Development Fund established in 2020 (see box 7.2) with a specific focus on NbS. This would allow the close coordination of NbS

Box 7.1: **THE FIRST STORMWATER PURCHASE AGREEMENT IN CHINA**

On September 25 2020, Changsha Gaoxin District Park Company and Hunan Yuchuang Environmental Protection Company have signed the first stormwater purchase agreement in China at the Hunan Province Green Development Exhibition Sponge City Forum.

According to the agreement, Changsha Gaoxin District Park Company will purchase stormwater from Hunan Yuchuang Environmental Protection Company at a 20 percent of the piped water price for landscaping and cleaning purposes. Hunan Yuchuang Environmental Protection Company has worked on rainwater retention and utilization from 2014 and has since utilized 0.5 million m3 of rainwater, which amounts to only 2 percent of the total rainwater amounts during the last 6 years, which means there is still large potential for rainwater utilization.

Source: Changsha Evening News (2020) https://www.icswb.com/h/168/20200925/677746.html

investments with other green projects and to leverage the full range of cobenefits and environmental outcomes. Advantages of a guiding fund include the following:

- **Risk-sharing between the government and partners and investors to help build confidence**
- **Leveraging comparative advantages of the private sector, government, and financial institutions and more effectively integrating technical, administrative, and financial resources (An 2016)**
- **Transparency in definition and distribution of benefits to meet expectations of different shareholders**
- **Flexible and diverse exit methods, including project liquidation exit, equity repurchase/transfer, securing of assets, and so on, which would eliminate investors' concerns about the long investment cycle.**

National regulations provide for such mechanisms. The approved trust scheme establishes the trust company as the trustee, which can issue infrastructure investment certificates to the public to raise trust funds. The trustee can then use the proceeds to invest in nature-based investments associated with the sponge city initiative in accordance with the approved trust scheme and national regulations (figure 7.4).

7.2.6 Recommendation 6: Issue Green Bonds Targeting NbS for IUFM

The emerging green bond market has the potential to help mobilize financing for NbS within the urban context, particularly in areas with strong revenue streams. The green bond market has grown more than tenfold since 2013, with US$389 billion in labeled green bonds issued in 2017, with China recognized as a global leader since introduction of its Green Credit Policy in 2007. This provides a comprehensive policy, including specific provisions for monitoring and evaluation (International Finance Corporation 2018), that can further contribute to mainstreaming NbS for IUFM. The Green Credit Guidelines issued by the Banking Regulatory Commission in 2012 and the Green Credit Statistics System introduced in 2014 attempt to define green credit (including a tool for monitoring environmental benefits). The People's Bank of China subsequently required bond issuers to refer to the China Green Bond Endorsed Project Catalogue, which lists six categories (31 subcategories) of projects eligible for financing via green bonds. Although the use of bonds has been limited in the financing of sponge cities, the green bond market has developed rapidly, reaching about US$7.1 billion (RMB 260 billion) in 2016. The number of issuances doubled in 2017, with a similar scale, providing promise for investments in NbS associated with sponge cities. In May and October of 2018, the Urban Development Company (Chengtou) of Anji county in Zhejiang province issued two Sponge City Green Bonds of RMB 0.5 billion each, both with a 7-year tenor period, specifically for investments in the construction of a sponge city demonstration zone in the eastern part of Anji county.

Box 7.2: **CHINA GREEN DEVELOPMENT FUND CO., LTD.**

The National Green Development Fund Co., Ltd was established on July 14, 2020 with a registered capital of RMB 88.5 billion. The scope of the Fund includes general equity investments, project investments, investment management, and consulting on green development, including environmental protection, pollution reduction, and energy resource conservation, among others. It aims to generate replicable and scalable experiences for green development, particularly in the Yangtze River Economic Belt (YREB).

The Ministry of Finance is the largest shareholder with a ratio of 11.30 percent. The second largest shareholders are the China Development Bank; Bank of China Co., Ltd.; China Construction Bank Co., Ltd., Industrial and Commercial Bank of China Co., Ltd.; Agricultural Bank of China Co., Ltd.; each holding 9.04 percent; the third largest is Bank of Communications Co., Ltd. with a shareholding ratio of 8.47 percent. The provinces, related departments and agencies in the YREB are among the fund promoters.

Source: Ministry of Finance of China 2020, http://www.mof.gov.cn/zhengwuxinxi/tupianxinwen1/202007/t20200715_3550334.htm.

Compared with traditional credit mechanisms upon which sponge cities rely, green bonds have several advantages, including low yields, which can effectively reduce the cost of financing. They also lend themselves to promoting green industries because of their long bond cycles that allow for more effective management of the asset maturity mismatch of upstream banks. However, most green bonds are issued by banks, and the average tenor of issuances is still between three to five years, which may be too short for investments required to support NbS for IUFM. Lengthening the tenor of such bonds will require the entry of institutional investors such as pension funds and insurance companies. These kinds of institutional investors are typically not familiar with NbS for IUFM, so efforts are required to sensitize the concept of blue investments and to develop standard guidelines. Furthermore, comprehensive assessments of the environmental and ecological benefits of sponge city investments before and after the issuance of green bonds are required to meet the identification needs of investors. The methodology established in this report can be used to facilitate such approaches.

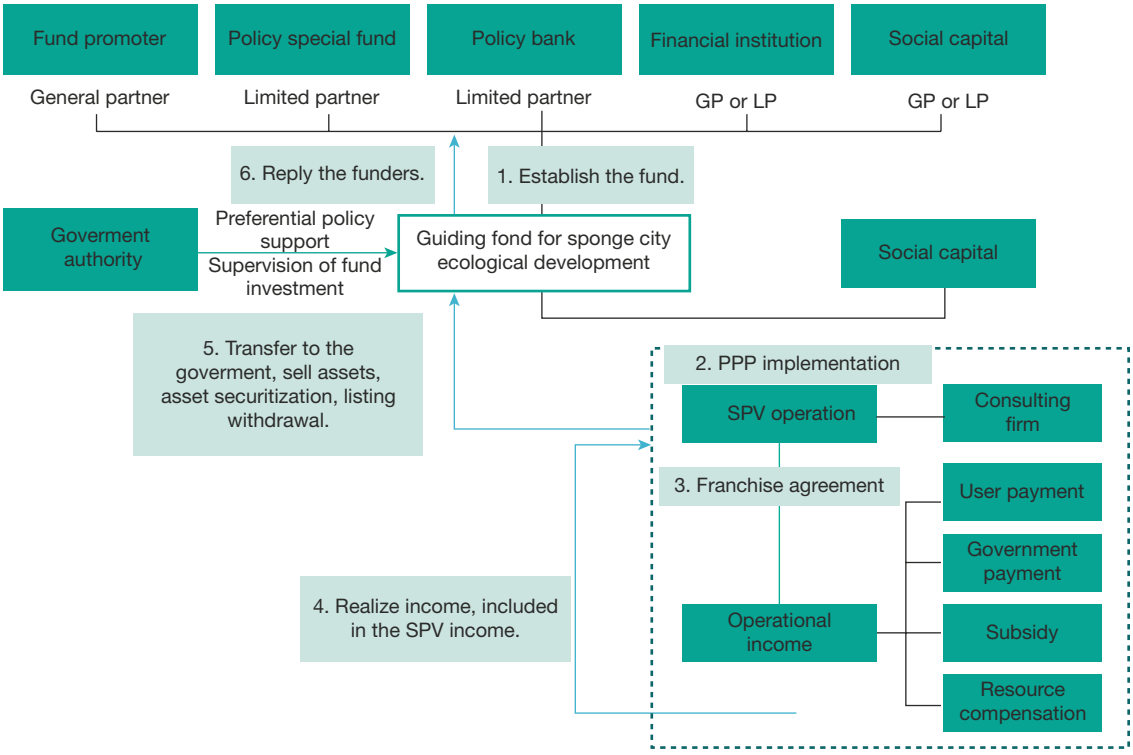
7.2.7 Recommendation 7: Develop Special Asset-Backed Programs to Leverage Future Revenues from NbS for IUFM

Asset-backed programs provide an opportunity to finance NbS for IUFM by taking future revenues from underlying investments and financial subsidies from PPPs as the basic assets to secure financing (Figure 7.5). Such approaches allow the pooling of smaller, often illiquid individual assets to make them marketable to potential investors. The advantages of asset-backed financing programs include the following:

- **Investors pay more attention to the future income of the project, and the issuer does not need to pay dividends or interest in the short term, which can effectively save cash flow and reduce the cost of financing.**
- **Effective adjustment of the debt structure reduces the scale of debt and improves the level of asset liability management and capital operation efficiency (He 2019).**

Such approaches in China have leveraged the rights to receive service fees in connection with wastewater treatment projects, and they could work for investments in NbS for IUFM. Typically stand-alone investments in NbS for IUFM cannot generate sufficient cash flow from individual benefit streams, but together, they can create an asset-backed security marketable to potential investors for the mobilization of resources (see figure 7.5).

Figure 7.4: **SCHEMATIC OF A GUIDING FUND FOR FACILITATING PPPS TO BUILD SPONGE CITIES**



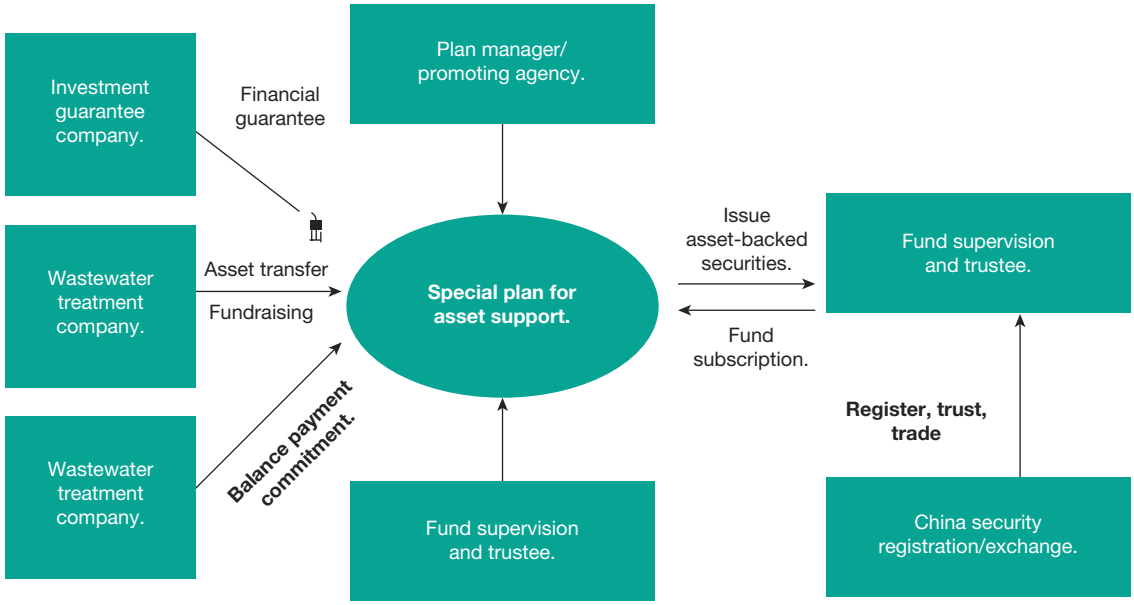
Source: Original figure for this publication.
Note: GP = general partner, LP = limited partner, PPPs = public-private partnerships, and SPV = Special Purpose Vehicle.

7.2.8 Recommendation 8: Improve Flood Insurance and Risk-Sharing Mechanisms

Flood insurance provides another potential source that could play a more significant role in improving the efficiency and effectiveness of responses to flood events in China (Jiang, Zevenbergen, and Ma 2018). Although there have been several flood insurance pilot projects since the 1980s (Walker, Lin, and Kobayashi 2009), flood insurance remains limited and disaster response continues to rely heavily on government funding. For example, only 2 percent of the damage caused by the July 2016 floods are thought to have been insured, compared with an average of 70 percent of homes covered in the United States (Liu 2016). Where flood insurance is available in China, it is often part of general property insurance, and although several commercial agricultural insurance schemes include flood insurance, these are usually limited to specific locations in high-yield areas where the risks are well understood. Experiences from these pilot programs reflect global experience, demonstrating that flood insurance is most effective when the following occur:

- **Insurers can assess the risk (including assessment through access to flood data), and they have confidence in the regulatory framework and the effectiveness of mitigation measures.**
- **Insurance purchasers can accurately assess their risk and undertake mitigation measures with appropriate insurance products available to cover the residual risk.**
- **The risk pool is deep enough (for example, through a national scheme or access to reinsurers).**

Figure 7.5: **SCHEMATIC OF A POTENTIAL ASSET-BACKED PLAN FOR NATURE-BASED SOLUTIONS FOR IUFM**



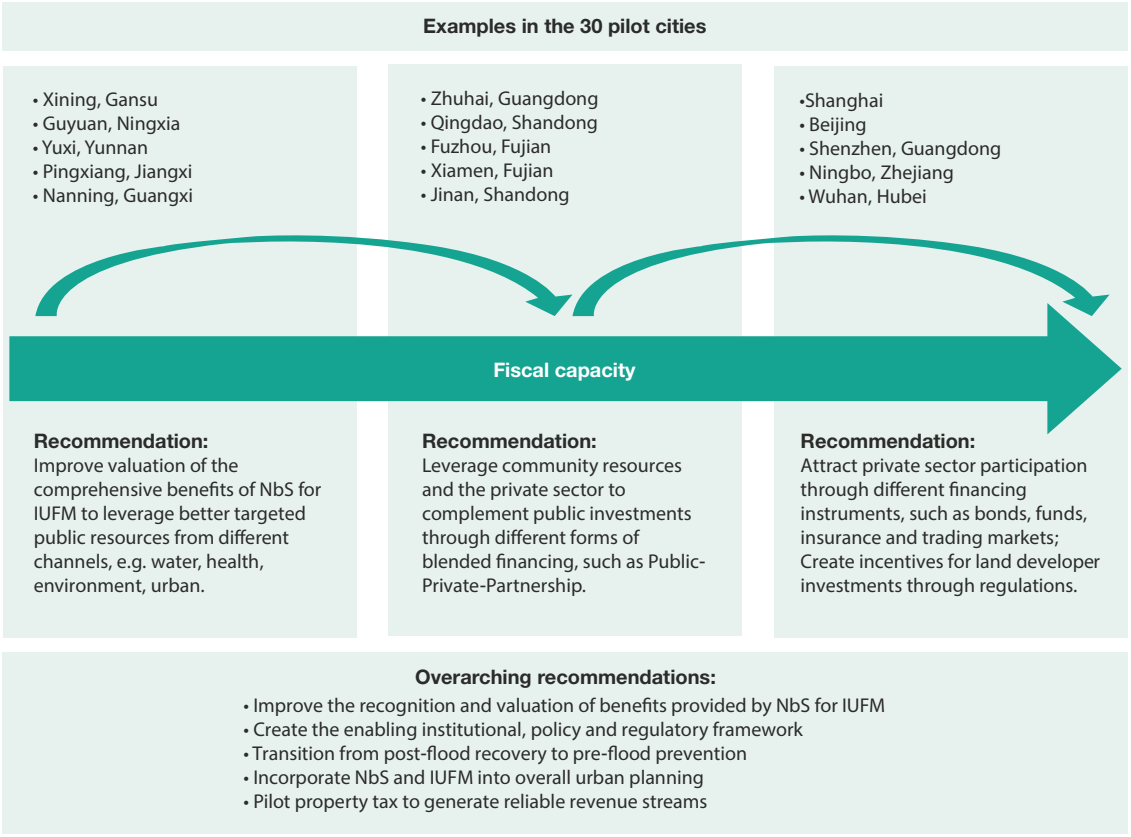
Source: Original for this publication.

The relatively underdeveloped nature of China's insurance market makes it unlikely that insurance companies will develop such products in the absence of strong demand. Such demand is limited by the high cost, particularly in high-risk areas. As such, China should consider establishing an insurance facility for flood-related risk. This facility could develop a nationwide flood disaster risk pool and serve as a platform for developing and implementing financing solutions for risks associated with disasters.

The future success and scale of China's sponge city program and the promotion of NbS for integrated urban flood management will require an appropriate mix of sustainable funding and appropriate financing sources. Recurrent market value-based property taxes typically provide effective revenue streams for local government investments because they are closely tied to public service delivery through property values, their base is immobile, and they are highly visible, which can improve accountability of local officials. However, the experience with property taxes in China remains limited to a few pilot cities, and there is a need to explore other measures for generating local revenues in support of NbS for IUFM. Given the diversity of urban conditions, a range of funding and financing options could be targeted and tailored to local conditions.

Determining the appropriate mix of funding and financing will rely on the affordability and collectability of associated revenue streams. Where these are limited, public funding will continue to be essential for the investment in public goods associated with many of the benefits derived from NbS for IUFM. However, the deployment of government funding can be improved through an appropriate mix of public funds, structured incentives, and specific policy instruments to promote the inclusion of NbS for IUFM and the participation of private financing and social capital along a continuum. These measures include leveraging government funds as cost-share, targeting performance-based subsidies and conditional transfers, adopting regulatory measures to promote market-based approaches, creating positive investment incentives, establishing special project vehicles that can issue dedicated bonds marketed to institutional investors, pooling investments across project beneficiaries and promoting new

Figure 7.6: **RECOMMENDATIONS TAILORED TO LOCAL CONDITIONS TO IMPROVE FINANCING FOR NBS FOR IUFM**



Source: Original for this publication.

asset-backed instruments, developing blue infrastructure guidelines for the green bond market, and engaging insurance companies in developing appropriate products along with the establishment of flood risk insurance facilities to develop a nationwide flood disaster risk pool.

There is increasing recognition of many of the direct and indirect cobenefits that can be derived from NbS for IUFM. However, the value of these derived benefits are not well captured by traditional approaches to project economic analyses. Improving the methods to fully identify and account for the changing values associated with the benefits derived from NbS for IUFM will help increase the sources of funding and options for financing, improve long-term sustainability and increase the liveability of urban environments, facilitating the transition toward greener development models.

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A Flood Mitigation Strategies



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Mitigation Strategies for Pluvial Flooding

Table A.1: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR PLUVIAL FLOODING**

Mitigation strategy, associated benefits, and beneficiaries mapping for pluvial flooding																	
			Retreat		Adapt											Defend	
		Benefits group	PR1	PR2 (N)	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8 (N)	PA9 (N)	PA10 (N)	PA11 (N)	PD1	PD2
B1	Reduced water consumption	Market									Harvested water as alternative to potable water through reuse						
B2	Reduced or delayed investment in infrastructure	Cost savings	Reduced local drainage upgrading requirement		Reduced local drainage upgrading requirement		Reduced local drainage upgrading requirement	Reduced local drainage upgrading requirement		Reduced drainage upgrading requirement as a result of less runoff	Reduced drainage upgrading requirement as a result of less runoff						
B3	Reduced recurring costs	Cost savings								Reduced drainage cleansing frequency as a result of less sediment loads	Reduced drainage cleansing frequency as a result of less sediment loads						
B4	Improved management of wastewater	Market, cost savings, nonmarket															
B5	Increased business profits	Market									Revenue generated through reuse or potable water savings						
B6	Increased work productivity	Market													Faster postevent recovery		
B7	Increased tourism	Market and nonmarket															
B8	Improved aesthetics	Nonmarket	Increased area of public open space						Improved water landscape	More distributed vegetated green space							

Continued

Table A.1: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR PLUVIAL FLOODING (*Continued*)**

Mitigation strategy, associated benefits, and beneficiaries mapping for pluvial flooding																	
			Retreat		Adapt											Defend	
		Benefits group	PR1	PR2 (N)	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8 (N)	PA9 (N)	PA10 (N)	PA11 (N)	PD1	PD2
B9	Improved opportunities for recreation	Market and nonmarket	More space available for recreational activities						Improved water landscape and water quality								
B10	Reduced crime, increased community cohesion	Market and nonmarket															
B11	Reduced mortality	Nonmarket and market (health system costs)	Relocation of affected community from flood-prone area; reduced heat stress for surrounding community as a result of increased green space		Improved flood-safety building design										Through community preparedness, response, and recovery	Improved flood-protection level	Improved flood-protection level
B12	Reduced morbidity, improved health	Nonmarket and market (health system costs)	Reduced heat stress for surrounding community as a result of increased green space; improved public health for creating more access to green space		Improved flood-safety building design										Through community preparedness, response, and recovery	Improved flood-protection level	Improved flood-protection level
B13	Reduced greenhouse gas emissions, increased CO_2 sequestration	Market and nonmarket	More trees in green space														

Continued

Table A.1: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR PLUVIAL FLOODING (*Continued*)**

Mitigation strategy, associated benefits, and beneficiaries mapping for pluvial flooding																	
			Retreat		Adapt											Defend	
		Benefits group	PR1	PR2 (N)	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8 (N)	PA9 (N)	PA10 (N)	PA11 (N)	PD1	PD2
B14	Groundwater recharge	Market and nonmarket								Shallow groundwater recharge through infiltration	Groundwater recharge if harvested water is pumped back to aquifer						
B15	Ecological improvement, biodiversity	Nonmarket	Creation of biodiversity in new green space						Increased aquatic biodiversity	More vegetated green space							
B16	Improved air quality	Nonmarket	More trees in green space														
B17	Reduced water pollution load to receiving water body	Market and nonmarket							Improved water quality as a result of natural cleansing	Reduced diffused stormwater pollution to receiving water body	Reduced diffused stormwater pollution to receiving water body						
B18	Reduced risks of flood damage (financially and economically)	Risk reduction	Reduced risks for affected community as a result of relocation		Reduced risk for building infrastructure damage for community and business as a result of flood-proof design	Reduced risks for basement and car damage for vulnerable community	Reduced risks for vulnerable community as a result of better managed overland flow	Reduced risks for downstream vulnerable community as a result of peak flow reduction		Reduced risks for vulnerable community as a result of less runoff	Reduced risks for vulnerable community as a result of less runoff					Reduced risks for vulnerable community through Improved flood-protection level	Reduced risks for vulnerable community through Improved flood-protection level
B19	Increased productivity of aquatic and terrestrial ecosystem (aquaculture, water resources, land produce)	Risk reduction							Increased aqua production								
B20	Improved security of water supply	Nonmarket									Potable water savings through alternative supply						

City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures																
		Retreat		Adapt											Defend	
	Benefits group	PR1	PR2 (N)	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8(N)	PA9(N)	PA10(N)	PA11(N)	PD1	PD2
S1	Water resource authority									Potable water savings						
S2	Water and infrastructure utilities	Reduced drainage upgrading investment		Reduced drainage upgrading investment		Reduced drainage upgrading investment	Reduced drainage upgrading investment		Reduced pipe upgrading investment as a result of less runoff	Delay in capacity augmentation in water supply		Implementation of adaptation pathway to save costs and deal with uncertainty				
S3	Urban-rural development authority										Implementation of development and building control regulation					
S4	Development and reform commission										Implementation of stormwater reuse policy					
S5	City garden and landscape authority	Impacts of flood inundation to be managed on parks				Impacts to be managed on green space	Impacts of inundation to be managed on parks and public open space	Improved quality of water landscape	More vegetated green space	Improved vegetation health if harvested water is reused for irrigation						
S6	Transport authority					Less road traffic impacts as a result of better managed overland flow									Reduced flood disruption to road traffic	
S7	Agriculture authority															
S8	Environmental protection authority							Improved water quality in water body	Less stormwater pollution load to receiving environment	Less stormwater pollution load to receiving environment						

Continued

City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures																
		Retreat		Adapt											Defend	
	Benefits group	PR1	PR2 (N)	PA1	PA2	PA3	PA4	PA5	PA6	PA7	PA8(N)	PA9(N)	PA10(N)	PA11(N)	PD1	PD2
S9	Planning authority		*Implementation of planning policy*										Implementation of catchmentwide strategy			
S10	Land authority		*Implementation of land-use policy*													
S11	Health authority			Reduced mortality and morbidity										Reduced mortality and morbidity	Reduced mortality and morbidity	Reduced mortality and morbidity
S12	Treasury authority			Reduced expenditure for reduced impact on public health										Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health
S13	Meteorology authority													Implementation of flood early warning		
S14	Emergency management authority													Implementation of flood preparedness, response, and recovery		
S15	Private insurance sector	Reduced claim as a result of reduced risks of flood damage on property and health		Reduced claim as a result of less health impact	Reduced claim as a result of less property damage		Reduced claim as a result of less property damage								Reduced claim as a result of less property damage and less health impact	Reduced claim as a result of less property damage and less health impact

Mitigation Strategies for Coastal Flooding

Table A.2: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR COASTAL FLOODING**

Mitigation strategy, associated benefits, and beneficiaries mapping for coastal flooding														
		Retreat			Adapt						Defend			
		Benefits group	CR1	CR2 (N)	CA1	CA2	CA3	CA4 (N)	CA5 (N)	CA6 (N)	CD1	CD2	CD3	CD4
B1	Reduced water consumption	Market					Potable water savings if used as alternative water supply							
B2	Reduced or delayed investment in infrastructure	Cost savings	Reduced levee protection upgrading		Reduced drainage upgrading requirement	Reduced drainage upgrading requirement	Reduced levee upgrading as a result of less land subsidence if water is put back to aquifer					Reduced extensive levee construction		Reduced height requirement of levees as a result of reduced runup and overtopping
B3	Reduced recurring costs	Cost savings												Reduced maintenance of levees as a result of reduced wave attract
B4	Improved management of wastewater	Market, cost savings, nonmarket												
B5	Increased business profits (for example, from sewer mining)	Market												
B6	Increased work productivity (for example, from less extreme heat)	Market								Faster postevent recovery				
B7	Increased tourism	Market and nonmarket												Mangrove forest as tourism attraction

Continued

Table A.2: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR COASTAL FLOODING (*Continued*)**

Mitigation strategy, associated benefits, and beneficiaries mapping for coastal flooding														
		Retreat			Adapt						Defend			
		Benefits group	CR1	CR2 (N)	CA1	CA2	CA3	CA4 (N)	CA5 (N)	CA6 (N)	CD1	CD2	CD3	CD4
B8	Improved aesthetics	Nonmarket	Increased green space											Ecological landscape belt aesthetically softening the hard embankment
B9	Improved opportunities for recreation	Market and nonmarket	More parks for activities											Passive and active recreation
B10	Reduced crime, increased community cohesion	Market and nonmarket												
B11	Reduced mortality (for example, from reduced extreme heat)	Nonmarket and market (health system costs)			Improved flood-safety building design					Through community preparedness, response, and recovery	Improved flood protection for people	Improved flood protection for people	Improved flood protection for people	
B12	Reduced morbidity, improved health	Nonmarket and market (health system costs)	Improved public mental health for accessing green space		Improved flood-safety building design					Through community preparedness, response, and recovery	Improved flood protection for people	Improved flood protection for people	Improved flood protection for people	
B13	Reduced greenhouse gas emissions, increased CO_2 sequestration	Market and nonmarket												Carbon sink by mangrove trees
B14	Groundwater recharge	Market and nonmarket					Recharge groundwater if water is put back to aquifer (geohydrological benefits)							

Continued

Table A.2: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR COASTAL FLOODING (*Continued*)**

Mitigation strategy, associated benefits, and beneficiaries mapping for coastal flooding														
		Retreat			Adapt						Defend			
		Benefits group	CR1	CR2 (N)	CA1	CA2	CA3	CA4 (N)	CA5 (N)	CA6 (N)	CD1	CD2	CD3	CD4
B15	Ecological improvement, biodiversity	Nonmarket	Coastal biodiversity increase											Improved habitat
B16	Improved air quality	Nonmarket												Air quality improvement by mangrove forest
B17	Reduced water pollution load to receiving water body	Market and nonmarket	Water cleansing if combined with stormwater treatment				Reduced stormwater pollution load into coastal area							Improve coastal water quality
B18	Reduced risks of flood damage (financially and economically)	Risk reduction	Reduced risks for affected community		Reduced risk for building infrastructure damage for community and business as a result of flood-proof design	Reduced risks for basement and car damage for vulnerable community					Improved flood protection for building and infra-structure	Improved flood pro-tection for building and infrastruc-ture	Improved flood protection for building and infra-structure	
B19	Increased productivity of aquatic and terrestrial ecosystem (aquaculture, water resources, land produce)	Risk reduction					Protection of coastal soil from saltwater intrusion and salinity increase to maintain soil quality							
B20	Improved security of water supply	Nonmarket					Protect coastal aquifer when used as drinking water source							

City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures													
	Benefits group	Retreat		Adapt						Defend			
		CR1	CR2 (N)	CA1	CA2	CA3	CA4 (N)	CA5 (N)	CA6 (N)	CD1	CD2	CD3	CD4
S1	Water resource authority					Protect coastal aquifer as drinking water source							
S2	Water and infrastructure utilities	Reduced drainage and levee investment		Reduced drainage upgrading investment		Reduced need for levee upgrade							Less maintenance cost for levees
S3	Urban-rural development authority	Impact on community relocation to be managed					Implementation of development and building control regulation						
S4	Development and reform commission												
S5	City garden and landscape authority	Increased park land				Reduced salinity impact on coastal park land							Improved landscape value
S6	Transport authority												
S7	Agriculture authority					Protect coastal soil from salinity increase							
S8	Environmen-tal protection authority	Improved coastal environment											Improved coastal environment

Continued

City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures													
		Retreat		Adapt						Defend			
	Benefits group	CR1	CR2 (N)	CA1	CA2	CA3	CA4 (N)	CA5 (N)	CA6 (N)	CD1	CD2	CD3	CD4
S9	Planning authority		Implementation of land-use policy										
S10	Land authority		Implementation of land-use policy										
S11	Health authority	Public mental health improvement		Reduced mortality and morbidity						Reduced mortality and morbidity	Reduced mortality and morbidity	Reduced mortality and morbidity	
S12	Treasury authority			Reduced expenditure for reduced impact on public health				Implementation of adaptation pathway to save costs and deal with uncertainty		Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health	
S13	Meteorology authority								Implementa-tion of flood early warning				
S14	Emergency management authority								Implementa-tion of flood preparedness, response, and recovery				
S15	Private insurance sector	Reduced claim as a result of less property damage		Reduced claim as a result of less health impact	Reduced claim as a result of less property and car damage					Reduced claim as a result of less property damage and health impact	Reduced claim as a result of less property damage and health impact	Reduced claim as a result of less property damage and less health impact	

Mitigation Strategies for Fluvial Flooding

Table A.3: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR FLUVIAL FLOODING**

			Mitigation strategy, associated benefits, and beneficiaries mapping for fluvial flooding												
			Retreat		Adapt						Defend				
		Benefits group	FR1	FR2 (N)	FA1	FA2	FA3	FA4(N)	FA5(N)	FA6(N)	PD1	FD2	FD3	FD4	FD5 (N)
B1	Reduced water consumption	Market													
B2	Reduced or delayed investment in infrastructure	Cost savings	Reduced levee protection		Reduced pipe upgrading requirement		Reduced levee protection level				Reduced levee protection level downstream		Reduced extensive levee construction		
B3	Reduced recurring costs	Cost savings													
B4	Improved management of wastewater	Market, cost savings, nonmarket													
B5	Increased business profits	Market									Profit if combined with hydropower generation				
B6	Increased work productivity	Market								Faster postevent recovery					
B7	Increased tourism	Market and nonmarket	Major riparian parks as tourism attraction												
B8	Improved aesthetics	Nonmarket	Increased public open space area												
B9	Improved opportunities for recreation	Market and nonmarket	More public open space for activities												

Continued

Table A.3: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR FLUVIAL FLOODING (*Continued*)**

			Mitigation strategy, associated benefits, and beneficiaries mapping for fluvial flooding												
			Retreat		Adapt						Defend				
		Benefits group	FR1	FR2 (N)	FA1	FA2	FA3	FA4(N)	FA5(N)	FA6(N)	PD1	FD2	FD3	FD4	FD5 (N)
B10	Reduced crime, increased community cohesion	Market and nonmarket													
B11	Reduced mortality (for example, from reduced extreme heat)	Nonmarket and market (health system costs)	Improved urban cooling as a result of increased green space		Improved flood-safety building design		Improved flood-conveyance safety			Through community preparedness, response, and recovery	Reduced health risk for downstream community	Improved flood protection for people	Improved flood protection for people	Improved flood protection for people	
B12	Reduced morbidity, improved health	Nonmarket and market (health system costs)	Improved public mental health for accessing green space		Improved flood-safety building design		Improved flood-conveyance safety			Through community preparedness, response, and recovery	Reduced health risk for downstream community	Improved flood protection for people	Improved flood protection for people	Improved flood protection for people	
B13	Reduced greenhouse gas emissions, increased CO_2 sequestration	Market and nonmarket													
B14	Groundwater recharge	Market and nonmarket													
B15	Ecological improvement, biodiversity	Nonmarket	Biodiversity creation in riparian parks								Impacts on ecosystem to be managed				
B16	Improved air quality	Nonmarket	If more trees to be planted in riparian parks												

Continued

Table A.3: **MITIGATION STRATEGY, ASSOCIATED BENEFITS, AND BENEFICIARIES MAPPING FOR FLUVIAL FLOODING (*Continued*)**

			Mitigation strategy, associated benefits, and beneficiaries mapping for fluvial flooding											
			Retreat		Adapt						Defend			
		Benefits group	FR1	FR2 (N)	FA1	FA2	FA3	FA4(N)	FA5(N)	FA6(N)	PD1	FD2	FD3	FD4	FD5 (N)
B17	Reduced water pollution load to receiving water body	Market and nonmarket													
B18	Reduced risks of flood damage (financially and economically)	Risk reduction	Reduced risks for affected community			Reduced risks for basement and car damage for vulnerable community	Reduced risks for vulnerable community				Reduced risks for downstream vulnerable community	Improved flood protection for building and infrastructure	Improved flood protection for building and infrastructure	Improved flood protection for building and infrastructure	
B19	Increased productivity of aquatic and terrestrial ecosystem (aquaculture, water resources, land produce)	Risk reduction													
B20	Improved security of water supply	Nonmarket									If the attenuated water is harvested as an alternative water source				

	Benefits group	City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures												
		Retreat		Adapt						Defend				
		FR1	FR2 (N)	FA1	FA2	FA3	FA4(N)	FA5(N)	FA6(N)	PD1	FD2	FD3	FD4	FD5 (N)
S1	Water resource authority									If the attenuated water is harvested as an alternative water source				Implementation of upstream and downstream strategy
S2	Water and infrastructure utilities	Reduced local drainage investment		Reduced pipe upgrading investment		Reduced levee investment				Reduced levee investment downstream				Implementation of upstream and downstream strategy
S3	Urban-rural development authority						Implementation of development and building control regulation							
S4	Development and reform commission													
S5	City garden and landscape authority	Increased parks area and public open space				City landscape will be improved if designed as blue and green corridor								
S6	Transport authority													
S7	Agriculture authority									If the attenuated water is harvested for agricultural irrigation				
S8	Environmental protection authority													

Continued

	Benefits group	City public and private stakeholders as beneficiaries for structural measures or executor of nonstructural measures												
		Retreat		Adapt						Defend				
		FR1	FR2 (N)	FA1	FA2	FA3	FA4(N)	FA5(N)	FA6(N)	PD1	FD2	FD3	FD4	FD5 (N)
S9	Planning authority		Implementation of land-use policy											Implementation of upstream and downstream strategy
S10	Land authority													
S11	Health authority	Public mental health improvement		Reduced mortality and morbidity		Reduced mortality and morbidity					Reduced mortality and morbidity	Reduced mortality and morbidity	Reduced mortality and morbidity	
S12	Treasury authority			Reduced expenditure for reduced impact on public health		Reduced expenditure for reduced impact on public health		Implementation of adaptation pathway to save costs and deal with uncertainty			Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health	Reduced expenditure for reduced impact on public health	
S13	Meteorology authority								Implementation of flood early warning					Implementation of upstream and downstream strategy
S14	Emergency management authority								Implementation of flood preparedness, response, and recovery					Implementation of upstream and downstream strategy
S15	Private insurance sector	Reduced claim as a result of less property damage		Reduced claim as a result of less health impact	Reduced claim as a result of less property damage	Reduced claim as a result of less property damage					Reduced claim as a result of less property damage and health impact	Reduced claim as a result of less property damage and health impact	Reduced claim as a result of less property damage and less health impact	

B

Worked Examples



The following hypothetical case studies provide plausible (but not real) illustrations of how the manual and supporting tools can be applied. Both consider conventional and hybrid approaches to flooding scenarios in Australian cities.

- **Example A relates to a city precinct experiencing pluvial and coastal flooding. It outlines a conventional approach and a hybrid approach to address the flooding and then demonstrates how to conduct a standard benefit-cost analysis (BCA) of each. This analysis compares the net present value (NPV) of the benefits and costs against the base case of doing nothing—that is, it presents absolute values of each approach.**
- **Example B relates to a city precinct experiencing fluvial and pluvial flooding. Like example A, it also outlines a conventional approach and a hybrid approach to address the flooding. However, unlike the first one, this example compares the benefits and costs of the hybrid approach relative to the conventional approach—that is, it presents the net benefits and costs of the hybrid approach compared with the conventional approach, rather than the absolute values of each approach.**

These examples highlight some important issues to examine when considering hybrid and conventional approaches to urban flooding.

Example A shows:

- **The different costs and benefits associated with conventional and hybrid green and gray solutions and their potential impact on the overall outcome of the project. In particular, though both scenarios achieve the same overall improvement in flood protection and have very similar benefit-cost ratios (BCRs), the hybrid solution offers higher overall community benefits.**
- **Although the hybrid solution in this example has a higher NPV, there is also a greater level of uncertainty associated with the outcome given the nature of assets involved and the higher complexity of the integrated package of measures.**
- **Hybrid approaches can generate a wider pool of beneficiaries and therefore increase financing and funding options. Funding options can involve trade-offs between costs to implement and administer and fairness.**
- **Hybrid options also increase opportunities for community involvement in elements such as constructing and maintaining nature-based solutions. In this example, community involvement was not identified as a cost savings because the aim was to improve community engagement and flood awareness.**

Example B shows:

- **The hybrid approach builds on the conventional solution, adding additional costs but also additional benefits.**
- **Taking a wider perspective, considering costs and benefits outside the flood-affected area, can identify material benefits and costs that should be accounted for. This example takes a catchment perspective and considers how the conventional and hybrid approaches affect both upstream and downstream communities. For example, the state community as a whole benefits from ecosystem services, such as nutrient removal (like nitrogen) from waterways, carbon abatement, and improved biodiversity. By including these other benefits, the hybrid approach goes from being marginally beneficial to obviously beneficial.**
- **An integrated portfolio of actions can deliver greater benefits than individual components by themselves. Some benefits—such as flood protection, biodiversity benefits, nutrient removal, and carbon abatement—depend on multiple strategies and may include smart combinations of technology and natural processes.**
- **Considering these broader costs and benefits can also create opportunities for innovative financing and funding options. For example, in this hypothetical case, development across the catchment is affecting downstream water quality, so the state government is piloting a "nitrogen tender" scheme to encourage innovative solutions to reducing discharges to protect downstream environmental values.**

Example A: Hypothetical Australian City (Pluvial/Coastal Flooding)

1. Define your urban system context



Manual reference: Section 1.4 (defining context and values)

Considerations:

- What are the objectives and functions of the urban area of focus from a hydrologic, social, environmental and economic perspective?
- How do these objectives and functions interact with wider catchment and regional factors?

The study area for this simplified hypothetical example is an established coastal suburb that is experiencing rapid urban densification and regular flooding. Local infrastructure is at capacity, and the small amount of shared public open space is under significant pressure from development. The largely residential suburb was built on a drained ephemeral swamp and is located at the mouth of a river whose lower reaches are now largely concrete drains.

Pluvial flooding is already having a significant effect on local residents and businesses each year, and the risk of storm surge and coastal flooding is an increasing concern for both municipal and city planners.

Consultation with the local community has identified the following priorities:

- **A safe, healthy community with improved access to green space**
- **Less economic disruption and loss from floods and turning waterways into a valued community and economic assets**
- **Attracting new developers and entrepreneurs to the area for a vibrant local economy**
- **An informed and empowered local community in which there is a clear understanding of the costs and benefits of flood mitigation**

The catchment area for this hypothetical example lies entirely within a medium-sized city. A material percentage of the city's workforce come from, or transit through, the suburb each day. Additionally, city planners advise that the cultural legacy of the area, and its unique coastal environment, are important to the city overall, and future city strategies identify the suburb as a valuable source of economic growth, higher density living, and amenity.

Flows from three upstream municipal areas feed both the river and overland flows into the study area, contributing to the risk of both fluvial and pluvial flooding.

Flood policy is currently set at a within catchment scale by the municipal government and at an intercatchment scale by the state, who is also responsible for emergency management and response. Drainage, water, and sanitation services are all provided by a government-owned water and drainage utility that services the entire city. Local parks and property development are managed by the municipal government.

2. Undertake a flood risk assessment



Manual reference: Section 1.5 (flood risk assessments)

Considerations:

- What type of flooding does your area experience?
- How does your catchment and urban area perform in dry, wet or extreme flooding scenarios?
- What economic, social and envrironmental objectives are at risk?

Annual rainfall is about 600 millimeters, distributed seasonally. Although upstream drainage infrastructure discharges into the river within the suburb, the river has mostly been converted to a large concrete drainage canal that can currently contain up to 1:100 return event. Fluvial flooding by itself is not a priority issue for the foreseeable future, though there are no gates on the river or canal mouth and the suburb is at sea level.

Flood mapping and modeling has shown that rapid urban intensification and impervious area increases have resulted in increased stormwater overland flows from both within and outside the suburb, leading to local drains no longer meeting their 1:100-year design standard (figure B.1). Pluvial flooding and damage to private property now result from a 1:20 return event. A timely response to pluvial flooding is a priority for municipal and city planners as damage to residential buildings, recreational spaces, commercial buildings, transport, and coastal assets are a regular event. The effect on transport infrastructure is also having a direct impact on the efficient function of the city, imposing a material cost in terms of lost productivity each year. The risk to human life is also increasing.

Current storm surge protection is minimal, consisting of a small seawall and coastal park providing a buffer zone, but damage to public and private properties is becoming increasingly common, and it is seen as a significant future risk for the area under all climate change scenarios. A particularly concerning extreme scenario is coastal flooding and pluvial flooding occurring concurrently.

Climate change and population intensification are expected to see further growth in the risks and costs associated with pluvial and coastal flooding over time. By 2100, sea levels around the site are expected to rise by 0.8 meters, and rainfall intensity is expected to increase by 35 percent. Consequently, the extent of the spatial inundation above 2 meters with a 100-year Average Recurrent Interval (ARI) event is greatly increased in the future relative to current risk levels. Population density in the area is expected to increase as the population grows at about 1.7 percent per year over the next 30 years. The forecasts imply a total population increase of about 52,000 people over the next 30 years in the case study site. The combined effect of the increase in population, sea level, and

Figure B.1: **COASTAL AND PLUVIAL FLOODING AT AN ESTABLISHED COASTAL SUBURB**



Source: Original figure for this publication
Note: 1:50-year flood event and potential damage.

rainfall intensity is that the number of properties affected at 5-year, 20-year, 50-year, and 100-year ARI are expected to increase by between five and 10 times relative to the current risk level.

Climate change is also leading to more frequent extreme heat days and droughts. When greater extreme heat days are combined with less green public open space and higher population density, local community aspirations for a healthy and livable local environment are put at risk. City planners and community members are keen to investigate the potential of an integrated response to the floods, drought, and extreme heat. This integrated or hybrid approach will be compared with a more conventional response to the identified flood risks.

"Do-Nothing" Scenario

Direct Costs

Independent consultants were engaged to assess the impact of these risks under a no investment in mitigation infrastructure scenario to provide a base for comparing other options.

The cost metric used to measure flood damage is the expected annual average damage cost. This metric represents the sum of the probability of the event type (minor flooding through severe flooding) in a given year,

multiplied by the associated damage cost for that type of event. For the no infrastructure investment case, the annual average tangible costs in the case study area are estimated to rise from US$2.5 million in 2012 to US$14.5 million in 2100, in real dollars.

The time path for costs between the two end point values is not detailed in the primary study, and in the base case, modeling costs are assumed to increase linearly through time. Alternate assumptions, such as assuming costs increase exponentially through time, would result in relatively modest changes to estimate of benefits when converted to NPV. However, as these differences are common to both the conventional and hybrid solutions, the assumption makes no difference to the relative ranking of the two projects.

Intangible Costs for the Do-Nothing Scenario

Intangible costs for the base case are derived from the ratio of tangible to intangible costs associated with the 2010–11 flood event in Queensland, Australia. In Deloitte (2016, p. 26), intangible costs are separated into four categories—health and well-being, employment, education, and community—and within each broad category, there are several specific subcategory items. For the purposes of the case study, the focus is on only the high-level relationship between total tangible and intangible costs for the flood, where intangible costs were found to be US$7.4 billion and tangible costs were found to be US$6.7 billion. Intangible costs in any given year are therefore set at 110 percent of tangible costs.

Net Present Value Estimate

The base case time horizon for the evaluation is 30 years, and the base case discount rate is 7 percent, real. With these settings, the NPV of the tangible damage cost under the no investment in infrastructure scenario is US$43.2 million, and the NPV of the intangible costs is US$47.8 million.

3. Identify context-appropriate interventions

Considerations:

- Identify a selection of context-appropriate flood management interventions, based on three-tiered strategy: retreat, adapt and defend.



Manual reference: Chapter 2 (integrated water management approaches)

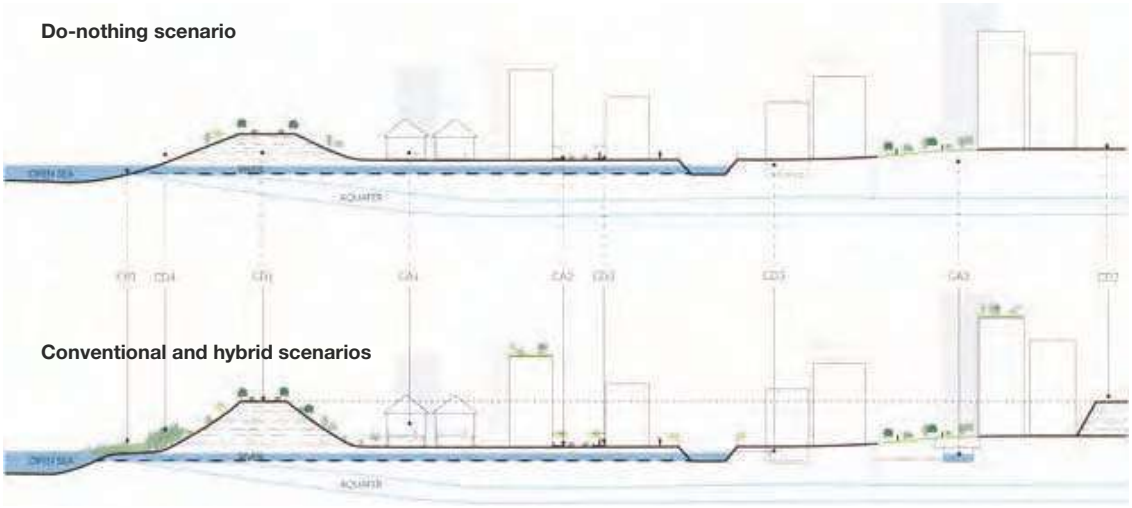
A range of strategies are available to address the coastal and pluvial flooding affecting the site. Figure B.2 shows the coastal flooding strategies available, and figure B.3 shows the pluvial flooding strategies.

Solutions were determined for both a conventional and a hybrid approach, accounting for the context-specific flood-risk analysis, potential damage assessment, and community visioning and objectives at the suburb and city scale.

The conventional structural approach includes addresses pluvial (P) and coastal (C) flooding through a combination of defend (D) and retreat (R) measures:

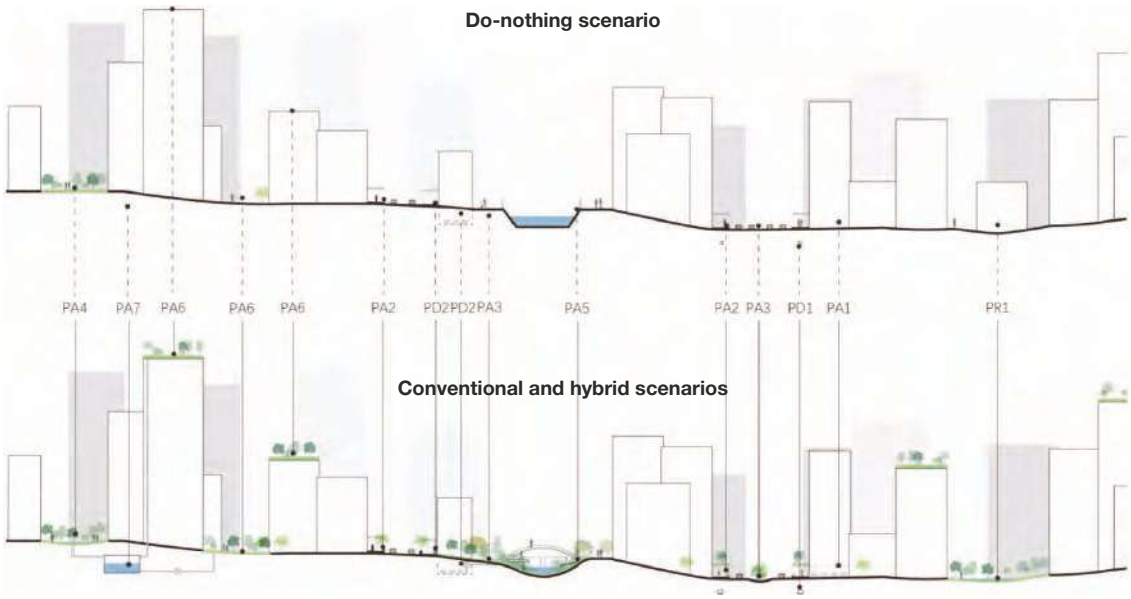
- **Increasing the capacity of the existing drainage system, including both increased diameter pipes and the addition of flood pumps (PD1)**
- **Construction of a 3-kilometer foreshore levee (CD1)**
- **Conversion of the existing parkland into an ecological landscape and relocation of approximately 100 families (CR1)**

Figure B.2: **CONVENTIONAL AND HYBRID APPROACHES TO REDUCE COASTAL FLOODING**



Source: Original figure for this publication

Figure B.3: **CONVENTIONAL AND HYBRID APPROACHES TO REDUCE PLUVIAL FLOODING**

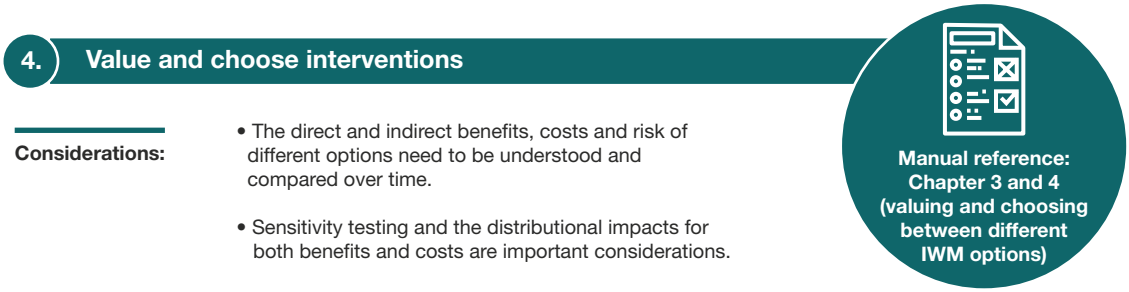


Source: Original figure for this publication

The hybrid approach includes elements of the conventional response (but at a lower scale) and a range of adapt (A) responses:

- **A more substantial program of conversion of low-lying areas into parkland and public open space (PR1, CR1)**
- **Adaptive building design (PA1)**
- **Naturalization of part of the drainage canal (PA5)**
- **Upstream investment to increase detention and absorption (PA6)**
- **A mangrove belt in front of the coastal levee (CD4)**
- **Increasing community areas and preparedness for flooding (CA6)**

Figure B.4 provides a summary and the location of the measures included in each approach, and table B.1 provides more detail on the proposed conventional structural and hybrid approaches.



Reference Service Standard

Neither the conventional solution nor the hybrid solution reduce flood risk to zero. Rather, both solutions mitigate expected flood damage by 70 percent, relative to the no new investment in infrastructure scenario. Furthermore, the extent of coastal erosion resulting from climate change is such that for both the conventional infrastructure solution and the hybrid infrastructure solution, not all coastal properties can be protected. Government decisions with respect to the subdivision of land that took place in the past can be dealt with in many ways. In the Australian context, for example, the legal system is such that governments generally provide a right to use and develop land, not a guarantee of a right to the existence of land. Governments may choose to acquire affected private land parcels and compensate the owners, but they are not required to do so. Over time, the relevant private land parcels will become valueless, but because the loss of these properties is common to both scenarios, these costs are not considered as part of the example.

Conventional Infrastructure Solution

Key Inputs and Assumptions

The conventional infrastructure solution involves: (a) the construction of a 3-kilometer levee/seawall, with provision for wave run-up and storm surge, and (b) upgrades to core drainage infrastructure, such as pumps and pipes, throughout the case study site. The seawall is located away from areas subject to severe coastal erosion, and the construction standard is set to meet a fixed level of flood protection, which has been defined as a 70 percent reduction in flood risk, relative to no new infrastructure investment. The conventional engineering solution therefore delivers mitigation of 70 percent of the annual average damage cost, and this is included as a benefit of seawall construction.

Figure B.4: **IMPACT OF FLOODING USING CONVENTIONAL AND HYBRID APPROACHES**



Table B.1: **PLUVIAL FLOODING COMBINED WITH COASTAL FLOODING FOR ESTABLISHED URBAN ENVIRONMENT**

Scenario									
Protection level	**Coastal flooding: 100-year ARI storm surge tide level + 500-mm wave Pluvial flooding: 20-year ARI local rainfall**								
Strategy number	**PR1**	**PA1**	**PD1**	**PA5**	**PA6**	**CR1**	**CA6**	**CD1**	**CD4**
Strategy short description	Convert low-lying land and flood-prone area to parks and public open space	Adaptive building design to rising water level	Upgrading of existing drainage infrastructure (including pumps)	Naturalizing drainage canal	Increasing green area and soakage at upper catchment	Convert coastal low-lying land into an ecological landscape	Build social resilience through community preparedness, flood response, and recovery	Construct levees and embankments	Mangrove forest belt in front of coastal embankment
Conventional structural solution description	Nil	Nil	Increase pipe sizes servicing a 47-ha area and install upgrades of flood pumps as per traditional understanding of flood mitigation	Nil	Nil	The conversion involves the relocation of approximately 100 dwellings across a 20-ha area to a location behind the flood wall proposed in CD1. Existing dwellings are uninsurable as a result of frequent flood inundation and increasing severity of coastal erosion.	Nil	Construct a 3-km levee with provision for wave runup and storm surge. The wall needs to be located away from areas subject to severe coastal erosion.	Nil

(Continued)

Table B.1: **PLUVIAL FLOODING COMBINED WITH COASTAL FLOODING FOR ESTABLISHED URBAN ENVIRONMENT *(Continued)***

Scenario									
Protection level	Coastal flooding: 100-year ARI storm surge tide level + 500-mm wave Pluvial flooding: 20-year ARI local rainfall								
Strategy number	PR1	PA1	PD1	PA5	PA6	CR1	CA6	CD1	CD4
Hybrid design solution description	Redevelop 10-ha land adjoining a main waterway to create 7 ha of open space and landscaped wetlands created for flood inundation to relieve upstream flooding. The existing area is currently occupied by 150 dwellings of old building stock subjected to extensive and frequent flooding. The dwellings are purchased at assessed market value. The local government approves the development of several medium rise residential apartments over a 3-ha footprint around the wetlands, creating significant property value uplift. Other key benefits: • Wetland parks are designed to cope with frequent inundation as a flood storage mechanism. • The wetland parks function as natural habitats, and water nutrient cleansing will providing space for flood storage and reduce peak flood levels.	New building design requirements to introduce local flood inundation protection are imposed over an area, including 450 dwellings. New design standards include: • Raised driveway into underground or basement parking; • Water proofing building entries; • Buildings on podiums or stumps with ground level (subject to inundation) with designated permissible uses, such as private garden/ open space, car parks, storages, and so on; and • Habitable floor level 300 mm above 100-year creek flood event.	Introduce hybrid green infrastructure combining gray and green solutions distributed through precinct such that the extent of pipe and pump upgrades is reduced by 20% for pipes and 25% for pumps, relative to the conventional solution.	Existing stormwater pipe along a major tributary line has insufficient capacity, causing local surcharging of stormwater and extensive local area flooding. In combination with PA6, undertake daylighting and naturalization of the major tributary drainage line to increase discharge capacity from that currently provided by the existing stormwater pipe. Road corridor of 14 m to be converted to 10 m of road pavement and 4 m of naturalized waterway. 700-m section of naturalized waterway with 140 dwellings with direct frontage to the natural waterway that experience property value uplift.	7 ha of upstream catchment draining into the naturalized waterway described in PA5. Dwellings within that are subject to special design guidelines for incorporating raingardens in private open space and road verges. Voluntary uptake of design guidelines is assumed to be 30%, with a 6,000 m^3 reduction in runoff volume and, therefore, corresponding nutrient reduction.	The conversion involves the relocation of approximately 100 dwellings across a 20-ha area to a location behind the flood wall proposed in CD1. Existing dwellings are uninsurable as a result of frequent flood inundation and increasing severity of coastal erosion.	Building flood resilience among the 15,000 people living in the precinct. Social resilience includes preparedness for flood inundation through understanding flood warnings and the relationship between the reference flood levels broadcast in flood warning and the local vicinity of individual resident, evacuation and emergency procedures and services, and flood recovery process.	Construction of a floodwall along a 3-km section of the foreshore. Relative to the conventional solution, the height of the floodwall is reduced, owing to the effect of CD4 in dampening wave run-up and storm surges, as well as the structural integrity strengthened by the wave protection afforded by the establishment of the mangrove swamp (CD4). Relative to a conventional solution, capital costs are reduced by 25%.	Reconfigure low-lying areas into a mangrove swamp to dampen the effect of storm surges and thus reduce coastal erosion and the height of the flood wall described in CD1. Total area planted out to mangrove forest is 3 km × 20 m = 6 ha.

Note: A = adapt response; ARI = Average Recurrent Interval; C = coastal flooding; D = defend measure; ha = hectare; km = kilometer; m = meter; mm = millimeter; P = pluvial flooding; R = retreat measure.

The cost of construction for the seawall is based on costings for a 1-kilometer seawall and foreshore development project in the southwest of Western Australia, with downward adjustments to per kilometer of construction costs of 15 to reflect: (a) the larger scale of the project and (b) a more competitive tender market on the East Coast of Australia. The seawall has a project life of 100 years, so the residual value of the wall is recorded as a project benefit at year 30. Annual maintenance costs for the seawall are set at 1 percent of construction costs.

The cost of pipe and pump upgrades were estimated for this specific site to be US$5.0 million for pipe upgrades and US$1.2 million for pumping infrastructure. In both cases, the useful life of the infrastructure is set at 30 years. For pipes, this is achieved with annual maintenance expenditure of 3 percent of installation cost, but for the pumping infrastructure, annual maintenance costs are set at 10 percent of capital costs. A higher maintenance cost for pumps explains the longer useful life for the pumps. For pumping infrastructure, it would also be possible to allow for a lower rate of maintenance, a shorter productive life, and a second round of capital investment.

As the assumption for this scenario that the public water utility builds the infrastructure, there is no adoption risk associated with implementing the conventional infrastructure solution. For capital costs, the Investment Framework For Economics of Water Sensitive Cities (INFFEWS) assumes that all contingency expenditure is incurred.

It is assumed that the utility accesses the debt markets to finance the project. The coupon rate on the debt is 3.0 percent, and the duration is 20 years.

Results Summary

With the conventional infrastructure solution, all costs associated with achieving a 70 percent reduction in flood risk are incurred by the local water utility, and all benefits accrue to local residents. How expenditure should be recovered is not considered part of this stage of the evaluation, so the base case assessment shows an expected NPV of positive US$18.6 million for the investment overall and an NPV for the public water utility of negative US$73.9 million. These values match the specific values entered into the INFFEWS spreadsheet.



	Overall		Project organization	
NPV	$18,563,472	NPV	–$73,932,288
BCR	1.25	BCR	0.00

Note: BCR = benefit-cost ratio; NPV = net present value.

Rather than relying on only a single best-guess value, the INFFEWS BCA tool also calculates a range of values that reflect the underlying uncertainty of cost-benefit parameters. In addition to the default case, table B.2 provides information on some key points of the NPV distribution for this infrastructure investment. For the organization leading the project, which is the water utility, there is a relatively high degree of certainty regarding incurred costs. The maximum loss, in NPV terms, across all simulation scenarios, is US$63 million; the minimum loss, in NPV terms, is US$51 million. This relatively tight range reflects the high degree of expertise and experience that exists within the water sector when implementing conventional infrastructure solutions. Recall, for the conventional solution, it is only project costs that accrue to the water utility, so variation in the NPV is entirely because of cost uncertainty.

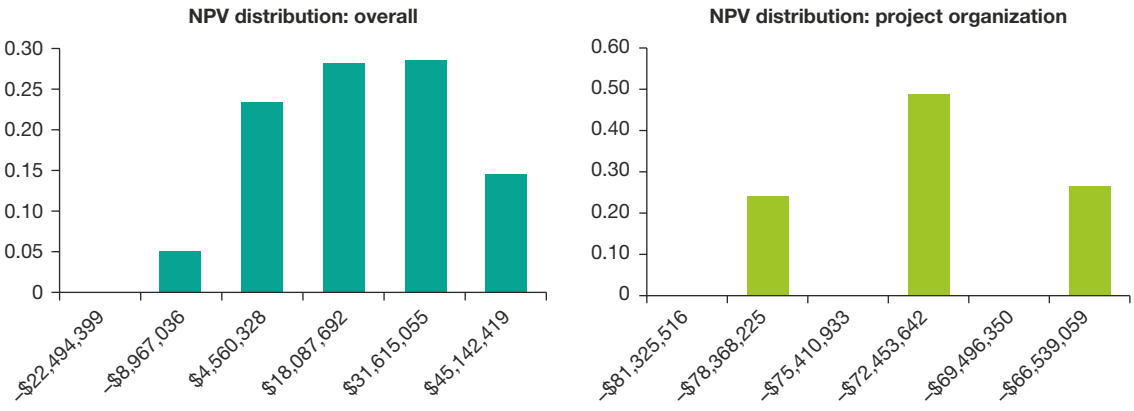
For the overall project evaluation, across all simulation results, the expected NPV range runs from a worst case scenario of negative US$22 million through to positive US$45 million. Whether the NPV is positive is checked for each simulation, and the last row of the results shown in table B.2 provides information on the probability that the NPV is positive. As can be seen for this example, the NPV is positive for 83 percent of the simulations. In the INFFEWS BCA tool, the distribution of NPV values is also shown below the summary results Figure B.5, for both the project overall and the project organization. The summary histogram plots provide an easy way to understand the extent to which the results might be skewed in either direction.

Table B.2: **CONVENTIONAL INFRASTRUCTURE SOLUTION NPV**

	Overall		Project organization
Net Present Value (NPV)		**Net Present Value (NPV)**	
Minimum	-$22,494,399	Minimum	$81,325,516
Maximum	$45,142,419	Maximum	-$66,539,059
Default case	$18,563,472	Default case	-$73,932,288
Mean	$14,196,469	Mean	$73,777,030
Median	$14,863,641	Median	-$73,932,288
Probability that NPV > 0	0.83	Probability that NPV > 0	0.00

Note: NPV = net present value.

Figure B.5: **CONVENTIONAL INFRASTRUCTURE SOLUTION NPV DISTRIBUTION**



Note: NPV = net present value. Y-axis represents probability and X-axis represents NPV values

Reporting against NPV is one way to summarize results. The main alternate summary metric is the BCR, and summary BCR information is also reported below the NPV results. In this case, for the conventional infrastructure solution, the default BCR is 1.25, and the range is 0.72 to 1.68. Furthermore, in 83 percent of the simulations, the BCR is greater than 1. Because no project benefits accrue directly to the water utility, a BCR is not calculated.

To mitigate against optimism bias, some organizations choose to set the critical value for the BCR to a value greater than 1. The INFFEWS BCA tool allows the user to specify a target BCR and shows the probability that the BCR is greater than that value. The default setting for the target is a BCR of 2.0 (Table B.3), though this can be set at any level the organization deems appropriate.

It is generally recommended that sensitivity of the results to changes in the discount rate be explored as part of any benefit-cost analysis process, and by default the INFFEWS BCA tool reports summary information for real discount rates of 4 percent and 10 percent (Table B.4), alongside the default discount rate of 7 percent. All calculations in this example exclude tax. For the conventional infrastructure solution, it can be seen that with a lower discount rate the NPV increases to US$56 million (BCR 1.69), and with a high discount rate the NPV falls to negative US$2 million (BCR 0.97). Given the nature of the project, a real discount rate of 10 percent is quite high, and the results suggests that there is a degree of confidence that the conventional solution delivers benefits greater than costs across all reasonable discount rate assumptions.

Table B.3: **CONVENTIONAL INFRASTRUCTURE SOLUTION BCR INFORMATION**

	Overall		Project organ isation
Benefit: Cost Ratio (BCR)		**Benefit: Cost Ratio (BCR)**	
Minimum	0.72	Minimum	0.00
Maximum	1.68	Maximum	0.00
Default case	1.25	Default case	0.00
Mean	1.20	Mean	0.00
Median	1.20	Median	0.00
Probability that BCR > 1	0.83	Probability that BCR > 1	0.00
Target BCR	2	Tanget BCR	2
Probabilrly BCR > Target	0.00	Probability BCR > Target	0.00

Note: BCR = benefit-cost ratio.

Table B.4: **CONVENTIONAL INFRASTRUCTURE SOLUTION DISCOUNT RATE SENSITIVITY**

Sensitivity to discount rate			**Video help**
Overall	**Low discount rate 0.04**	**Default discount rate 0.07**	**High discount rate 0.1**
Benefits (present value)	$138,895,926	$92,495,759	$66,162,819
Costs (present value)	$82,313,810	$73,932,238	$68,045,501
Net Present Value (NPV)	$56,582,116	$18,563,472	–$1,882,682
Benefit: Cost Ratio (BCR)	1.69	1.25	0.97

Note: BCR = benefit-cost ratio; NPV = net present value

When funds for investment are raised via taxation, distortions to the economy are introduced—this is referred to as the tax excess burden effect. By default, the INFFEWS BCA tool incorporates this effect, so to understand its impact, information is also reported on the NPV that excludes this effect from the results (Figure B.5). Not all jurisdictions account for the tax excess burden effect when conducting project evaluations. For the current assessment, the assumption is that the project is debt-financed, and as such, there is no taxation effect to consider. The include and exclude tax excess burden calculations are therefore the same for this scenario.

Hybrid Solution

Key Inputs and Assumptions

The hybrid solution consists of a set of interventions that also achieve a reduction in flood risk of 70 percent. Although some of the solutions are more novel than conventional infrastructure solutions, the budgeted cost used for implementing each intervention has been set such that the final project achieves the desired flood mitigation performance with certainty. For example, the budget for the wetlands construction project includes an allowance for spending to complete follow-up works to adjust pond heights that might not be exactly correct when initially created. Rather than explicitly allow for a high level of capital expenditure to ensure a specific standard is met, an alternate approach that can be implemented in the INFFEWS BCA tool would be to allow for a probability that the intervention succeeds. In this instance, it was felt that allowing for a high implementation cost to achieve the same level of flood mitigation as the conventional solution with certainty made for a more consistent comparison of the two approaches.

Similar to the conventional solution, it is assumed that the capital cost of the project is funded via the capital market via a 20-year bond. However, the package of solutions is able to be marketed as a green bond, and because of the added interest in such bonds, the market clearing coupon rate is set at 15 basis points below a standard state government-backed bond.

Strategy number PR1. Convert low-lying land in a flood-prone area to parks and public open space, and allow more intense development on the remaining fraction of land that will no longer be flood-prone because of Earth works and the other investment strategies.

The strategy involves the compulsory acquisition at fair market prices of 10 hectares of land adjoining the main waterway that is then redeveloped into 7 hectares of public open space and wetlands that will relieve flooding.

Table B.5: **CONVENTIONAL INFRASTRUCTURE SOLUTION EXCESS BURDEN OF TAXATION**

Sensitivity to excluding the excess burden of taxation		
Overall BCA results	**Cost includestax excess burden**	**Cost excludes tax excess burden**
Benefits (present value)	$92,495,759	$92,495,759
Costs (present value)	$73,932,288	$73,932,288
Net Present Value (NPV)	$18,563,472	$18,563,472
Benefit: Cost Ratio (BCR)	1.25	1.25

Note: BCA = benefit-cost analysis; BCR = benefit-cost ratio; NPV = net present value.

The remaining 3 hectares of the site will be developed into medium-rise residential apartments. The existing 10-hectare site is occupied by 150 dwellings of old building stock subject to extensive and frequent flooding. Properties are compulsorily acquired at fair market value, which is low because of frequent inundations in the area. At the completion of the wetlands development, the area is then rezoned for higher-density housing and sold to a developer. The developer subsequently incurs the development cost for new apartments, takes on the development project risk, and is rewarded with an appropriate expected return on capital and entrepreneurship.

The wetlands will provide a beautiful new habitat in which residents can appreciate open water all year and connect directly with nature. The local community and visitors will be able to walk and run along paths; relax and enjoy community facilities, such as barbecue and picnic areas; observe birds; and explore the wetlands. The wetlands will have an educational viewing platform so that local schools can visit the site. Students studying environmental science at the regional university will also use the wetlands for water-quality monitoring and ecology practical classes on plant identification.

The wetlands design will retain as many mature trees as possible and will be planted with tens of thousands of plants, including nitrogen-stripping plants. As the wetlands will be extensively vegetated, regular inspections to monitor weed ingress and identify any damage to hydraulic structures will be required. A dewatering system will be incorporated into the design to allow for water-level manipulation and emptying the system if fish require removal, or for other maintenance activities.

The key costs to implement the strategy are the cost of compulsory acquisition of land (US$30 million), the construction of the wetlands (US$7 million), and additional annual ongoing maintaining costs to ensure the wetlands performs to the expected level of performance ($90,000 per year). The land acquisition cost reflects the relatively low value of land subject to frequent inundation. The construction and maintenance costs are based on those incurred for a similar project in South Australia.

The key benefits of the strategy include the resale value of the land, developer profit, amenity benefit to those properties in the near neighborhood of the development, recreation opportunity benefits to the broader community, health benefits through providing access to increased public open space, allowing the construction of a smaller seawall, and nutrient load reduction.

It is assumed that the 3 hectares of land adjacent to the wetlands is resold to a developer for US$15 million. Apartment construction costs are based on standardized reference per meter construction costs for medium-quality, medium-density housing; and the modeling assumes an expected return to the developer of 20 percent on total funds invested. It also assumes that the developer builds 180 apartments to replace the previous 150 houses, which reflects a realistic density intensification that balances the community desire for predominately low-rise developments and the profit incentive of the developer to maximize the number of apartments in the development. These houses, and 140 additional nearby properties, benefit from a property value uplift because of the creation of the wetlands. The extent of the property value uplift is derived using the INFFEWS Value tool wetlands transfer function and an assumed average property price of US$490,000. The property price is, in turn, a function of developed land acquisition cost, construction cost, and developer profit margin. The base case uses the medium-impact scenario property impact value. It is also assumed that the property value uplift is not realized until the wetlands has become fully established.

The general community recreation benefit estimate is derived from the Brent et al. (2017) study reported in the INFFEWS Value tool. The biodiversity benefit value is derived from the Morrison and Hatton Macdonald (2010) study reported in the Value tool. The carbon abatement value is based on Carnell et al. (2018), in which the value of a ton of abated carbon is based on the December 2018 auction price for the Australian government Emissions Reduction Fund. The value used for the removal of nitrogen is the reference value used by a major Australian water utility and is also the value used in the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) research evaluating the cost effectiveness of rain garden installations for nutrient removal. The assumed nutrient removal rate is based the CRCWSC experience with similar systems.

The health benefit attribution is derived from a separate tool that has been developed for the Water Services Association of Australia. Benefits can be derived using either a cost of illness (CoI) approach or a willingness to pay (WTP) approach. Estimates derived using the latter are typically much higher than estimates derived using the former. Here, estimates based on the CoI approach are used and hence can be considered conservative. The report associated with the tool is Frontier Economics (2019).

The strategy also makes a material contribution to the overall ability of the hybrid strategy to lower the amount of capital funding that needs to be invested in seawall construction.

Strategy number PA1. Adaptive building design to rising water level for 430 buildings. This strategy imposes new building design requirements to introduce local flood inundation protection, including raised driveway into underground or basement parking to mitigate flooding; water-proofing entry doors; buildings on podium or stumps with ground level (subject to inundation) with designated permissible use, such as private garden and open space, car parks, storages, and so on. Based on an average home size of about 140 square meters, these additional building requirements are expected to cost, on average, approximately US$9,100 per household. This is equivalent to an increase in construction costs of 5 percent, and without residents investing in these additional measures, it would be necessary to invest in a higher seawall. The primary benefit of this strategy is therefore the reduction in seawall construction cost.

Strategy number PD1. With both the conventional infrastructure approach and the hybrid approach, upgrades of drains and pumps are required. The size of the upgrade for the hybrid approach is less because of the incorporation of other nature-based and nonstructural solutions. Upgrading of existing drainage infrastructure (including pumps), is reduced. Based on the CRCWSC analysis of the drainage function requirement, it has been estimated that the cost of pipes would be reduced by 20 percent and the cost of pumps reduced by 25 percent.

Strategy number PA5. Introduce a 700-meter section of naturalized waterway with 140 dwellings enjoying direct frontage to the natural waterway. The existing stormwater pipe along a major tributary line has insufficient capacity, causing local surcharging of stormwater and extensive local area flooding. The hybrid solution increases discharge capacity. Implicit in the solution in that a road corridor of 14 meters is converted to 10 meters of road pavement and 4 meters of naturalized waterway. This involves the loss of some street parking but no loss of the road function. Both the benefit, in terms of property value uplift, and the cost of converting the section of drain, are based on Polyakov et al. (2017). This study is detailed in the INFFEWS Value tool.

Strategy number PA6. Increasing green area and soakage higher up in the catchment. For this strategy, dwellings within the upper catchment are subject to special design guidelines for incorporating raingardens in private open space and road verges. The model assumes that there is voluntary uptake of design guidelines of 30 percent and that this delivers 30 kilograms of nitrogen removal per year. This action also contributes to the overall strategy that allows for less investment in the seawall and other hard infrastructure as it slows the flow of water through the landscape. Because the uptake is voluntary, it must be the case that the private benefits are at least as great as the private costs. The model therefore includes the benefit of nitrogen removal and the cost of the policy communication strategy, but it does not include the cost associated with installing a raingarden or the amenity benefit residents may obtain from it.

Strategy number CR1. Conversion to parkland for a strip of residential dwellings into an ecological landscape to accommodate increasing frequency of inundation as a result of rising sea level. The existing dwellings become uninsurable because of frequent flood inundation and increasing severity of coastal erosion. The conversion involves the relocation of approximately 100 dwellings to an area behind the flood wall. As this is a common element to both the conventional and hybrid solutions, the costs and benefits net out for the purposes of comparing the two approaches and are not considered in the analysis.

Strategy number CA6. Building social resilience through community preparedness, flood response, and flood recovery. Social resilience includes preparedness for flood inundation through understanding flood warnings and

the relationship between reference flood-level information broadcast during times of potential flooding for the local vicinity of individual residents, evacuation, and emergency procedures and services, and flood recovery processes. The strategy works to decrease the intangible cost of flood events, and the cost associated with this activity is assumed to be about one full-time person, ongoing. Without investing in social resilience, it would not be possible to achieve the overall strategy.

Strategy number CD1. With a hybrid infrastructure solution, it is still necessary to construct a seawall, but because of the green infrastructure investment, the size and construction cost are reduced by 25 percent. This is a direct cost savings on conventional engineering construction cost items.

Strategy number CD4. The introduction of a mangrove forest belt in front of the coastal embankment reduces the seawall maintenance cost. Both the cost and return as a result of lower maintenance costs from planting out the mangrove to a depth of 20 meters along the 3-kilometer seawall is calibrated to Narayan et al. (2016). In addition to maintenance cost reduction, the mangrove also provides biodiversity and carbon sequestration benefits. The biodiversity benefit value is derived from the Morrison and Hatton Macdonald (2010) study reported in the INFFEWS Value tool, though for a different vegetation type than that used for the constructed wetlands. The carbon abatement value is based on Carnell et al. (2018).

Results Summary

The hybrid infrastructure solution delivers the same 70 percent reduction in flood risk as the conventional infrastructure solution, but the NPV for the project overall has increased by US$8 million to US$26 million. Although the BCRs for the two approaches are almost identical, because the hybrid approach delivers greater net benefits, it is the preferred approach.



	Overall		Project organization	
NPV	$26,141,094	NPV	–$88,086,493
BCR	1.26	BCR	0.13

Note: BCR = benefit-cost ratio; NPV = net present value.

As can be seen by looking at the overall project results, although the base case NPV is greater for the hybrid solution, the overall uncertainty about the outcome is more pronounced than with the conventional solution. The range of values observed in the simulation results vary between negative US$52 million and positive US$87 million (Table B.6). The chance of realizing a negative NPV is still low, but it is slightly higher than for the conventional infrastructure solution.

To understand the difference in the expected payoff between the two approaches, it can be valuable to compare the NPV distribution plots. In figure B.6, the plot in panel a is the NPV distribution for the conventional infrastructure solution and the plot in panel b is the NPV for the hybrid infrastructure solution. When visualized this way, it can be seen that not only is the expected value US$8 million higher for the hybrid solution, but there is also a significant chance the actual benefits will be even greater. The distribution plots show that there is a much greater potential upside with the hybrid solution than with the conventional solution. That said, the hybrid solution has a chance of a bigger downside.

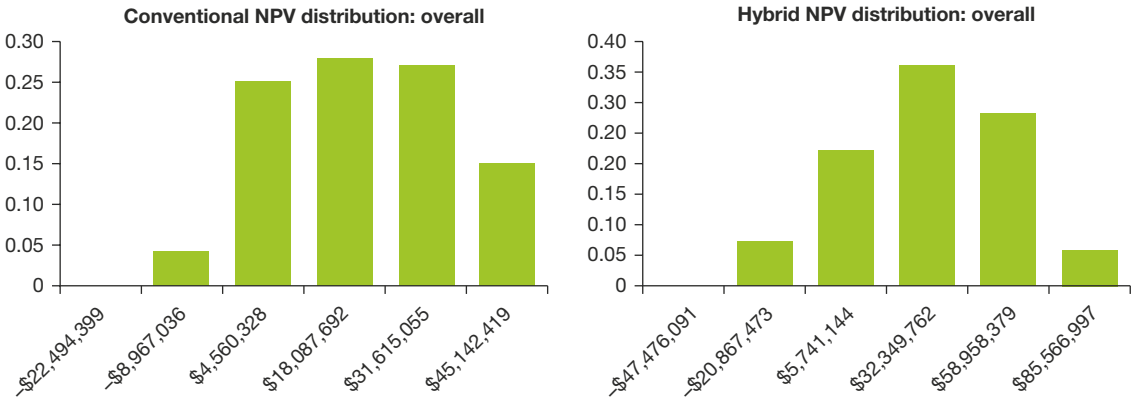
Similar to the conventional infrastructure investment approach, the expected NPV varies substantially with the discount rate assumption, increasing to US$68 million with a discount rate of 4 percent and falling to US$3 million with a discount rate of 10 percent (Table B.7).

Table B.6: **NPV RANGE HYBRID SOLUTION**

	Overall		Project organization
Net Present Value (NPV)		Net Present Value (NPV)	
Minimum	$51,857,659	Minimum	-$114,784,628
Maximum	$86,647,894	Maximum	-$63,961,639
Default case	$26,141,094	Default case	$88,086,493
Mean	$19,758,851	Mean	$88,612,267
Median	$20,906,561	Median	$88,204,407
Probability that NPV > 0	0.78	Probability that NPV > 0	0.00

Note: NPV = net present value.

Figure B.6: **COMPARISON ON NPV DISTRIBUTIONS FOR CONVENTIONAL AND HYBRID SOLUTION**



Note: NPV = net present value; Y-axis represents probability while X-axis represents NPV values

5. Identify appropriate financing and funding mechanism/s

Considerations:

- Once you have selected the optimal mix of interventions, principles for fair and efficient financing options need to be identified and options assessed.

Manual reference: Chapter 5 (financing IWM approaches)

Table B.7: **HYBRID SOLUTION SENSITIVITY TO DISCOUNT RATE ASSUMPTION**

Sensitivity to discount rate			
Overall	**Low discount rate 0.04**	**Default discount rate 0.07**	**High discount rate 0.1**
Benefits (present value)	$178,386,385	$127,037,033	$96,701,051
Costs (present value)	$110,776,245	$100,895,939	$93,663,605
Net Present Value (NPV)	$67,610,140	$26,141,094	$3,037,447
Benefit: Cost Ratio (BCR)	1.61	1.26	1.03

Note: BCR = benefit-cost ratio; NPV = net present value

In a no-investment scenario, the direct and indirect costs of inaction accrue to local residents. The local community is affected through damage to private property and increased municipal charges to repair public infrastructure. Consultation with the local community about an appropriate approach to sharing costs has identified support for the beneficiary pays principle.

Conventional Infrastructure Solution

Distributional Analysis

In the conventional structural approach, property owners benefit from high property values; residents and businesses benefit from reduced flood disruption and cost; whereas higher property values and economic activity increase municipal and state government income. The costs associated with realizing these benefits are financed by the publicly owned water and drainage utility city and paid for through a flat charge to all utility customers.

The INFFEWS BCA tool identifies the following distribution of benefits and costs for the conventional approach (Figure B.7 and Table B.8).

Financing and Funding

From the above Figure B.7 and Table B.8, it can be seen that the benefits accrue either directly or indirectly to the local residents. The costs are incurred by the water and drainage utility, who finances the significant upfront cost through a combination of debt and retained earnings. A capital grant was discussed with the state government, but it was determined that the increase in debt did not adversely affect the financial health of the utility.

In this scenario, the utility also decided to recover (fund) these costs of the investment over the life of the assets via a fixed charge included in customer bills. A property value-based charge was considered on capacity to pay any equity grounds, but it was decided that the establishment and administration cost of this approach was prohibitive and that existing concessional arrangements for low-income customers ensured that the overall size of the bill remained within the local community's capacity to pay.

This is a low-cost and administratively simple approach to financing and funding the investment and ensures the associated costs are spread over the asset life and therefore current and future generations. The funding approach sees all residential, commercial, and industrial customers contribute to the works on an equal basis—if all benefited equally, this would align with the fairness principle adopted, but this is unlikely to be the case. This highlights a common trade-off between pragmatic, administratively simple low-cost approaches and the in-principle ideal funding outcome.

Figure B.7: **CONVENTIONAL SOLUTION DISTRIBUTION OF COSTS AND BENEFITS**

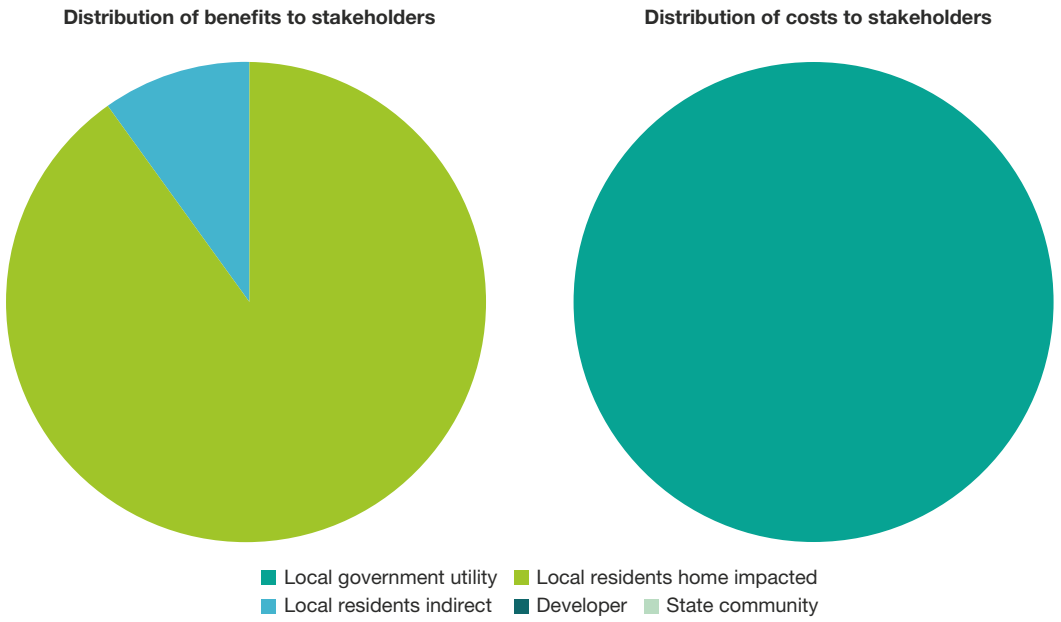


Table B.8: **CONVENTIONAL SOLUTION DISTRIBUTION OF BENEFIT TYPES ACROSS BENEFICIARIES**

	Local government utility	Local residents home impacted	Local residents indirect	Developer	State community
Ben 1, per penson	$0	$0	$0	$0	$0
Ben 2, usen specified	$0	$0	$0	$0	$0
Ben 3, abatement	$0	$0	$0	$0	$0
Ben 4, annual aggnegate	$0	$0	$0	$0	$0
Ben 5, delay cost	$0	$0	$0	$0	$0
Ben 6, pnotect asset	$0	$0	$0	$0	$0
Ben 7, neduce nisk	$0	$0	$0	$0	$0
Ben 8, custom benefits	$0	$83,246,183	$9,249,576	$0	$0
Total benefits (PV)	$0	$83,246,183	$9,249,576	$0	$0
Costs (PV)	$73,932,288	$0	$0	$0	$0
Net Pnesent Value	-$73,932,288	$83,246,183	$9,249,576	$0	$0

Note: NPV = net present value

Hybrid Solution

Distributional Analysis

In the hybrid approach, the benefits of the conventional approach are captured together with additional benefits to property developers and additional property value, health, and well-being benefits to local residents. However, unlocking these benefits also involves additional complexity and coordination.

The INFFEWS BCA tool identifies the following distribution of benefits and costs for the hybrid approach (Figure B.8 and Table B.9).

The above Figure B.8 and Table B.9 highlight that relative to the conventional approach, the hybrid approach generates a wider pool of beneficiaries, although the additional benefits are still largely concentrated in the local area.

Financing and Funding

In this scenario, the nature-based solutions have been grouped and financed through a green bond. Institutional and investor support for impact investment has seen strong demand for green bonds and led to favorable terms being secured. The use of the bond also aligns with the utility's and its government owner's public commitment to the Sustainable Development Goals. Although the community will be involved in some elements of the construction (for example, tree planting days) and maintenance (litter cleanup initiatives) of the green assets, ownership will

Figure B.8: **HYBRID SOLUTION DISTRIBUTION OF COSTS AND BENEFITS**

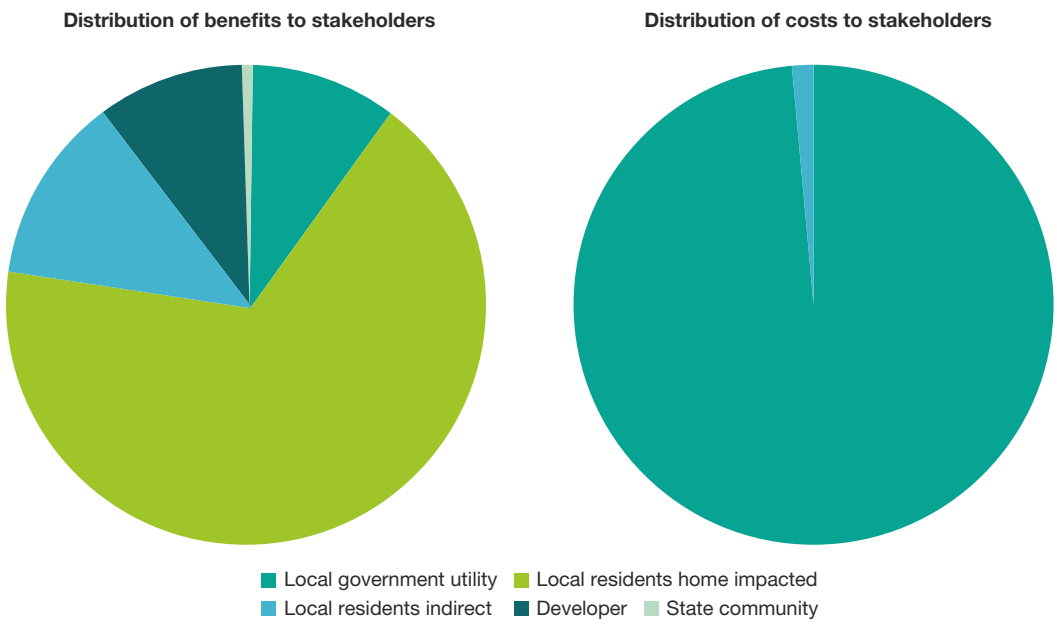


Table B.9: **HYBRID SOLUTION DISTRIBUTION OF BENEFIT TYPES ACROSS BENEFICIARIES**

	Government utility	Local residents home impacted	Local residents indirect	Developer	State community
Ben 1, per person	$0	$4,138,667	$459,852	$0	$0
Ben 2, user specified	$0	$0	$6,393,067	$0	$530,319
Ben 3, abatement	$0	$0	$0	$0	$218,302
Ben 4, annual aggregate	$12,708,533	$0	$0	$12,153,447	$0
Ben 5, delay cost	$0	$0	$0	$0	$0
Ben 6, protect asset	$0	$0	$0	$0	$0
Ben 7, reduce risk	$0	$0	$0	$0	$0
Ben 8, custom benefits	$0	$82,319,693	$9,146,633	$0	$0
Total benefits (PV)	$12,708,533	$86,458,360	$15,999,552	$12,153,447	$748,620
Costs (PV)	$100,795,026	$0	$1,031,481	$0	$0
Net Present Value	–$88,086,493	$86,458,360	$14,968,071	$12,153,447	$748,620

Note: NPV = net present value.

remain with the utility ensuring appropriate levels of maintenance and renewal over their useful life. The extent of public engagement does not lower construction costs, as the point of such activities is community engagement, not cost saving.

The development sector plays a more active role in improving flooding outcomes in this scenario. This creates some additional costs in complying with improved building standards but also sends a clearer signal to buyers about the real costs of property development and of living safely in the area. Developers also have the opportunity to recycle flood-affected land in PR1.

The community is also an active participant in this scenario, supported by a state government grant-financed and tax payer-funded program. These programs will be piloted in the study suburb before being rolled to flood-affected communities across the state. The insurance sector has also been an active collaborator in the design of this program.

Tables B.10 and B.11 summarize the beneficiaries, sources of flooding, financiers, and funders of each scenario.

Table B.10: **CONVENTIONAL INFRASTRUCTURE SUMMARY**

Strategy	Beneficiaries	Source of flooding (polluter)	Financing		Funding	
			Who	How	Who	How
Conventional infrastructure solution						
(CD1) Levee (PD1) Drainage infrastructure upgrade (CR1) Ecological flood zone	Current and future residents Current and future commuters	Coastal flooding Within catchment pluvial flows Upstream pluvial flows	Water and drainage utility	Water and drainage utility retained earnings Water and drainage utility debt	Water and drainage utility customers	Water and drainage bills

Table B.11: **HYBRID INFRASTRUCTURE SUMMARY**

Strategy	Beneficiaries	Source of flooding (polluter)	Financing		Funding	
			Who	How	Who	How
Hybrid solution						
(CD1) Levee (PD1) Drainage infrastructure upgrade	Current and future residents Current and future commuters	Within catchment pluvial flows Upstream pluvial flows Coastal flooding and storm surge	Water and drainage utility	Water and drainage utility retained earnings Green bonds	Water and drainage utility customers	Water and drainage bills
(PR1) Land redevelopment	Current property owners Property developers Nearby residents	Upstream pluvial flows Within catchment flows	Private developer	Debt and equity	Property purchasers	Property price

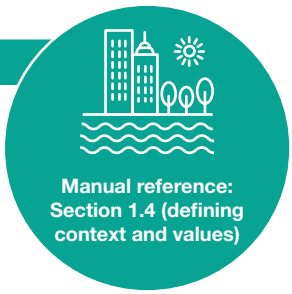
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Table B.11: **HYBRID INFRASTRUCTURE SUMMARY *(Continued)***

Strategy	Beneficiaries	Source of flooding (polluter)	Financing		Funding	
			Who	How	Who	How
(PA1) Smart building design	Current and future property owners	Within catchment pluvial flows	Developers (new properties) Government retrofit program (existing properties)	Higher construction costs, debt, and equity Grant/rebate	Property purchaser State taxpayer	Property price State land tax
(PA5) Naturalizing drainage canal	Local residents	Within catchment pluvial flows	Water and drainage utility	Green bond	Water and drainage utility customers	Water and drainage bills Forgone parking
(CR1) Coastal ecological park	Coastal residents Wider community	Coastal flooding	Water and drainage utility	Green bond	Water and drainage utility customers	Water and drainage bills
CD4 Mangroves in front of coastal levee	Local residents Wider community	Coastal flooding and storm surge	Water and drainage utility	Green bond	Water and drainage utility customers	Water and drainage bills
(CA6) Community preparedness	Local residents Wider community	Within catchment pluvial flows Upstream pluvial flows Coastal flooding and storm surge	Government	Grant	Property owners and residents	Water and drainage bills Flood response actions insurance

Example B: Hypothetical Australian City (Fluvial/Pluvial Flooding)

1. Define your urban system context



Manual reference: Section 1.4 (defining context and values)

Considerations:

- What are the objectives and functions of the urban area of focus from a hydrologic, social, environmental and economic perspective?
- How do these objectives and functions interact with wider catchment and regional factors?

The study area for this example is a large redevelopment planned to accommodate the needs of an established but growing city. The city's population is forecast to increase by 30 percent over the next 20 years, and the state government has determined higher-density living will accommodate the majority of this growth.

The 480-hectare site will transition from industrial uses to residential and commercial uses. High-density residential and commercial towers and apartment buildings will replace the existing warehouses and factories. Eventually, it will be home for more than 80,000 people, with another 80,000 people visiting daily for work—that is, about 80,000 people will experience the amenity and healthy environment benefits all the time.

The site is located at the bottom of a large mixed-use catchment. Agriculture and forested land in the upper reaches transition to lower-density suburbs and industrial areas and then to a high-density central business district (CBD). A large river runs through the CBD and past the site on its way to the ocean.

The state government is leading the redevelopment, and the decision on the location has already been made. The state government has also announced the development will be a leading example of *environmental sustainability, livability, connectivity, diversity, and innovation*. There is a state government election in 12 months, and the costs and benefits of the proposed development is a topical issue.

The site's location and industrial history create several challenges:

- **The site's industrial legacy means the land and groundwater are contaminated.**
- **The site will require significant drainage infrastructure capacity upgrades under a business-as-usual approach.**
- **The site is subject to fluvial and pluvial flooding, which are expected to be exacerbated by climate change and upstream development.**

The project is made even more complex by a large number of stakeholders:

- **The project involves several state government departments, and the river forms a municipal government boundary.**
- **Water, sewer, and drainage services are delivered by a state-owned water utility.**
- **A range of large and small private developers will lead construction activities, with varying levels of experience and different commercial approaches.**
- **Several large national and international corporations are considering moving to the site and expect a high level of amenity, functionality, and value for money.**
- **Passionate and active environmental groups are championing improved health for the bay into which the river drains and is home to internationally significant habitats.**

2. Undertake a flood risk assessment

Considerations:

- What type of flooding does your area experience?
- How does your catchment and urban area perform in dry, wet or extreme flooding scenarios?
- What economic, social and envrironmental objectives are at risk?

Manual reference: Section 1.5 (flood risk assessments)

Currently, the redevelopment site is highly flood-prone and experiences regular fluvial and pluvial flooding for several reasons (figure B.9).

First, it is at a choke point of the river, and impervious surfaces upstream have increased the volume, velocity, and pollution levels of wet weather flows. This situation is expected to continue as population density and urban infill occurs upstream to accommodate the city's growing population.

Most of the area is at, or in some places below, sea level, and the highest point is less than 4 meters above sea level. The groundwater table is quite high, so sea level rise is expected to have a material impact. The site's industrial legacy means surfaces are almost completely impervious, increasing stormwater quantity and pollution. Stormwater is often pumped off site. River levels are also affected by the tides, and the flat, low-lying site is increasingly at risk from storm surges.

Figure B.9: **FLUVIAL AND PLUVIAL FLOODING AT THE REDEVELOPMENT SITE**



The site has recorded several events that included both pluvial and fluvial flooding. Changing the land use from industrial to commercial and residential uses will increase the cost of these events. At the same time, climate change is expected to increase the frequency and intensity of flooding events. Reflecting this, the plans for the redevelopment require a flooding and drainage service level that protects private property from an annual exceedance probability (AEP) of 1 percent and the public realm from an AEP of 5 percent.

Do-Nothing Scenario

The plans for the site require a higher level of flood protection than is currently available, yet without action, the site's flood resilience is expected to keep falling. At the same time, the state government has determined it would be significantly more expensive to accommodate the city's expected population and economic growth via other development or redevelopment sites. In addition, the government has already invested significant time and resources into promoting the site locally, nationally, and internationally.

Given these factors, the do-nothing scenario is not considered a viable option. The rest of this case study considers a conventional structural approach to improving flood resilience *relative to* a hybrid approach that includes nature-based solutions.

3. Identify context-appropriate interventions

Considerations:

- Identify a selection of context-appropriate flood management interventions, based on three-tiered strategy: retreat, adapt and defend.



Manual reference: Chapter 2 (integrated water management approaches)

A range of strategies are available to address the pluvial and fluvial flooding affecting the site. Figure B.10 shows the pluvial flooding strategies available, and figure B.11 shows the fluvial flooding strategies.

The proposed solutions for this site include both a conventional (that is, business as usual) and a hybrid approach, reflecting the site's flood risk analysis and stakeholder aspirations for the site and the city.

The conventional approach addresses fluvial (F) and pluvial (P) flooding through a combination of defend (D), retreat (R), and adapt (A) measures:

- **Constructing a 6-kilometer levee (FD2)**
- **Increasing the capacity of the existing drainage system by using wider-diameter pipes and adding flood pumps (PD1)**
- **Returning about 50 hectares adjoining the river to the floodplain (FR1)**
- **Installing rainwater tanks on all buildings, which will supply water for toilets and laundry areas but not drinking or bathing (PA7)**

Like the conventional approach, the hybrid approach combines retreat, adapt, and defend responses. It includes elements of the conventional approach but reduces the size of the pipes and pumps needed for PD1. To achieve this, it includes more local detention and adds a local relief structure to the levee planned in FD2. It also augments the rainwater tanks, making them centrally controlled smart tanks, to increase distributed storage capacity during peak rain events (PA7).

Figure B.10: **CONVENTIONAL AND HYBRID APPROACHES TO REDUCE PLUVIAL FLOODING**

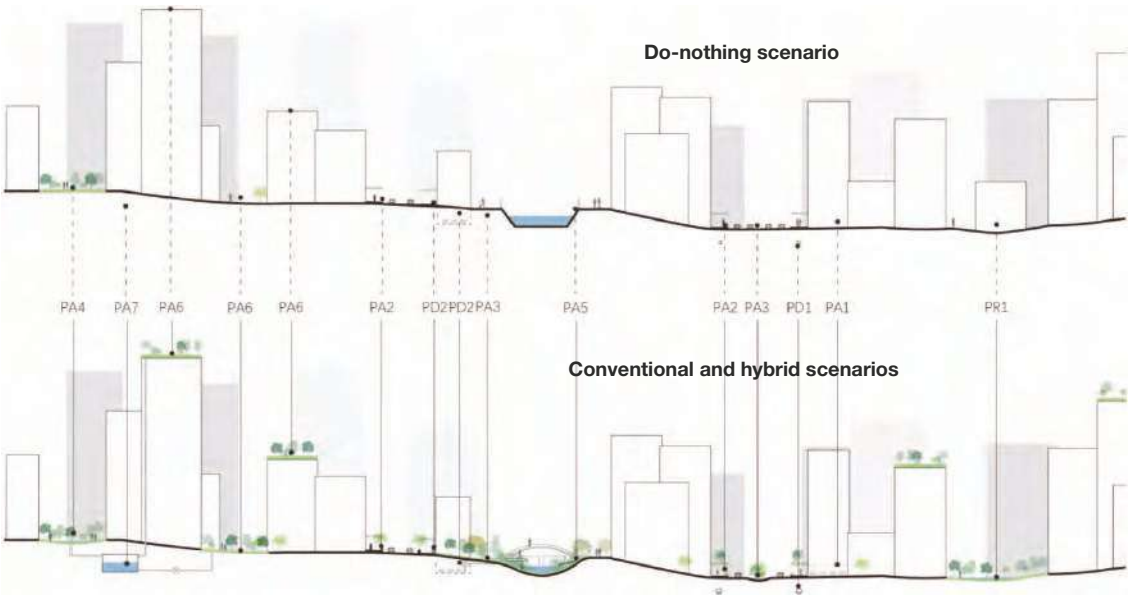
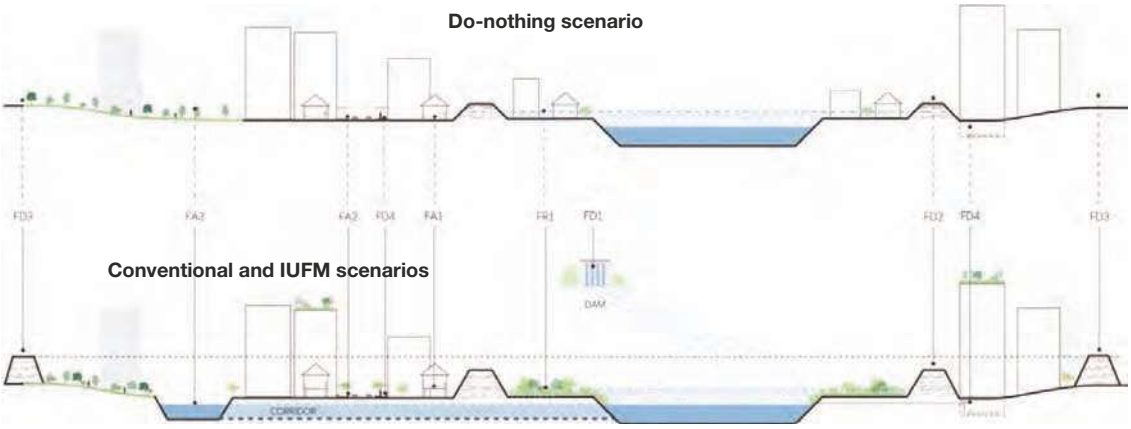


Figure B.11: **CONVENTIONAL AND HYBRID APPROACHES TO REDUCE FLUVIAL FLOODING**

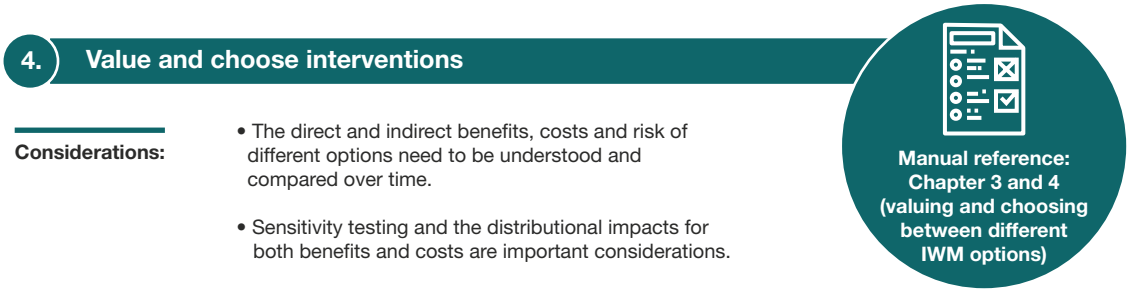


Note: IUFM = integrated urban flood management.

The hybrid approach also includes the following strategies:

- **Converting a four-lane street into two lanes, with a central median that acts as a sunken green verge to convey above-design flow (PA3)**
- **Converting an existing 11-hectare park for flood inundation as peak storage (PA4)**
- **Redeveloping about 50 hectares adjoining the river as an ecological riparian park that contain wetlands and provides flood conveyance (FA3)**
- **Regulating for mixed-use (commercial and residential) buildings with permissible uses at different floor levels, with residential and high occupancy levels to be 300 millimeters above 100-year river ARI (FA1)**
- **Designating 22 hectares of parkland with lakes and wetlands as a flood corridor during extreme floods (FA3)**

Figure B.12 shows the location of the measures included in each approach, and table B.12 provides more detail on the proposed conventional and hybrid approaches.



Reference Service Standard

This case study compares the relative benefits of the conventional and hybrid approaches. The analysis of costs and benefits is based on the following assumptions:

- **The state government will acquire the land at the beginning of the project. This cost is the same for both approaches, so it is not included in the analysis.**
- **Both solutions achieve the desired flood protection standard, although neither reduces the flood risk to zero. The flood mitigation benefits are the same for both solutions (for example, less flood-prone land). For this reason, they are not considered in the analysis.**
- **The BCA for both solutions assumed a discount rate of 7 percent.**

Conventional Solution

Key Inputs and Assumptions

The conventional solution relies on the following:

- **A 6-kilometer levee integrated with the local urban form. The cost of constructing the levee is the same for both approaches, so it is not included in the analysis.**
- **A 50-hectare parcel of land returned to the floodplain. Currently, the area contains industrial buildings that are subject to extensive and frequent flooding. The cost of the land is included in the initial cost to the state government of acquiring the land at the beginning of the project, so it is not included in the analysis.**

Figure B.12: **IMPACT OF FLOODING USING CONVENTIONAL AND HYBRID APPROACHES**

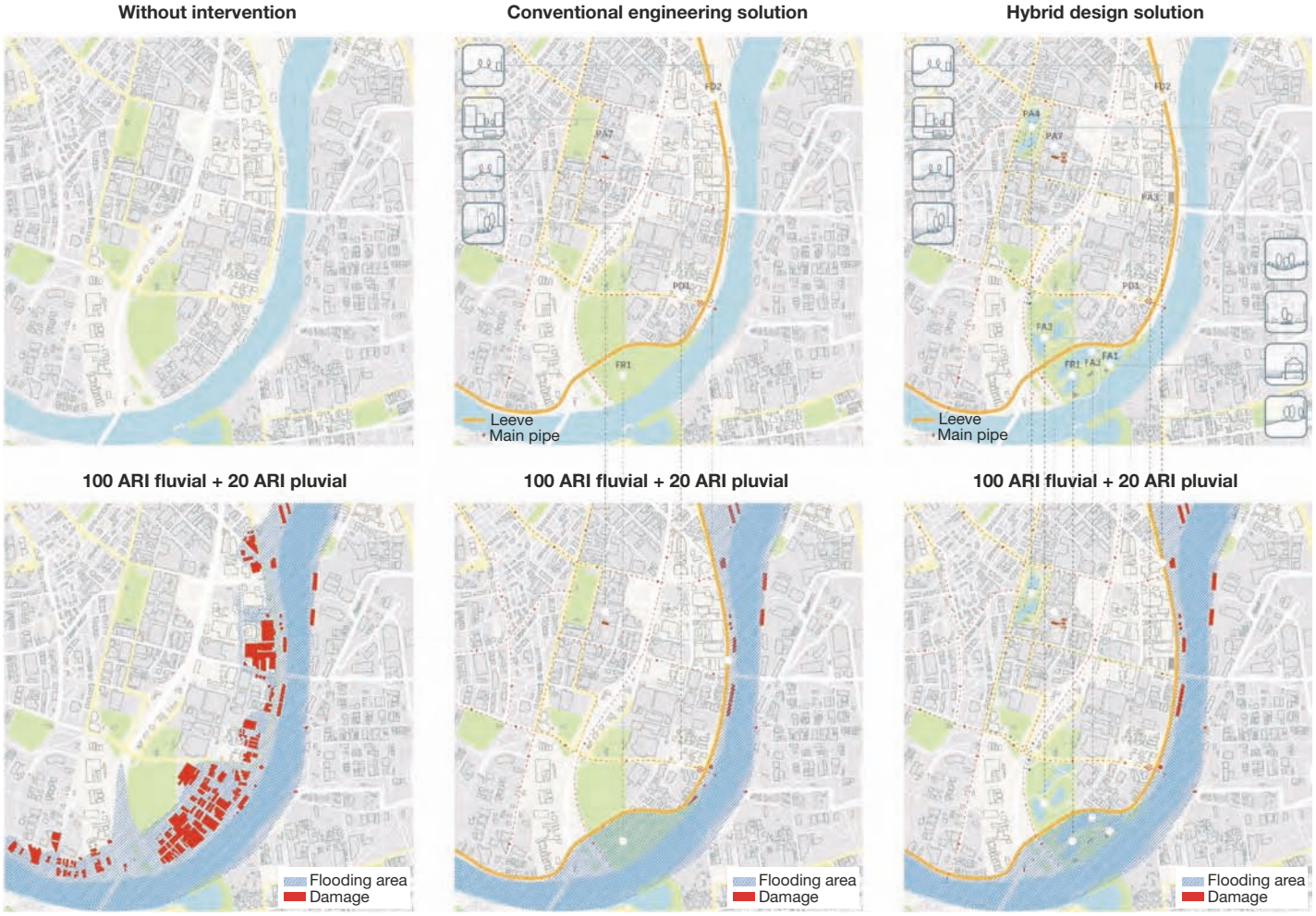


Table B.12: **PLUVIAL FLOODING COMBINED WITH FLUVIAL FLOODING FOR RENEWAL URBAN ENVIRONMENT**

Scenario								
Protection level	**Fluvial flooding: 100-year ARI river basin flooding + 300-mm freeboard Pluvial flooding: 20-year ARI local rainfall drainage**							
Strategy number	**PA3**	**PA4**	**PA7**	**PD1**	**FR1**	**FA1**	**FA3**	**FD2**
Strategy short description	Designated flood conveyance for above-design events (such as overland flow pathway management)	Flood detention in parks and public open space	Rainwater and stormwater harvesting and reuse catchment wide	Upgrade of existing drainage infrastructure (such as capacity increase, pumping stations, emergency storage)	Return of occupied floodplain to wetlands and parks as ecological landscape and public open space	Adaptive building design to rising water level (such as floating house, bedrooms above water level, waterproof housing, building on podium, minimum floor levels and associated planning control for permissible use of ground level, critical services located above water level)	Designated flood conveyance (such as major flood corridors)	Flood levee and embankments
Conventional solution			Local rain tanks installed at each building	• Pipe sizes increased to 20-year ARI for servicing almost 80,000 residents within an approximately 480-ha area • Flood pumps installed	• 50 ha of land adjoining the river returned to the floodplain • Area is currently occupied by industrial buildings subjected to extensive and frequent flooding			• 6-km levee • The wall is integrated with local urban form

(Continued)

Table B.12: **PLUVIAL FLOODING COMBINED WITH FLUVIAL FLOODING FOR RENEWAL URBAN ENVIRONMENT *(Continued)***

Scenario								
Protection level	**Fluvial flooding: 100-year ARI river basin flooding + 300-mm freeboard Pluvial flooding: 20-year ARI local rainfall drainage**							
Strategy number	**PA3**	**PA4**	**PA7**	**PD1**	**FR1**	**FA1**	**FA3**	**FD2**
Hybrid design solution	• Four-lane street converted into two lanes with the central median as a sunken green verge to convey above-design flow. • Street is 700-m long. • Street pipe sized for five-year ARI, and 20-year ARI is contained in central median as overland flow. • Bike lane is integrated into the central median.	• Existing 11-ha park converted for flood inundation as peak storage. • Existing area is currently both active and passive space. • The new park will include a lake and wetlands and ovals, all of which can be inundated to store floodwaters.	• Local smart rain tanks installed at each building. • Tanks supply water for nonpotable uses, such as irrigation, toilet flushing, and general cleansing. • Tanks are smartly controlled and operated as flood storage, responding to various storm events to reduce peak floods. • Smart controls mean the full tank volume is available storage, offering better flood attenuation than conventional tanks.	• Pipe size reduced as a result of use of hybrid infrastructure combining gray and green solutions. • Pumps installed to discharge local floodwater. • Pump capacity reduced to reflect detention storages.	• Same as conventional solution. • Under hybrid solution, the 50 ha of land will be adapted (refer to description in FA3).	• Five multiple-story commercial buildings on stumps with floating terraces (to cope with variations in water levels when the river floods) to connect to roads. • Mixed-use (commercial and residential) buildings constructed, with planning control of permissible uses at different floor levels, with residential and high occupancy levels 300 mm above 100-year river ARI.	• 22 ha of park land with lakes and wetlands used as designated flood corridor during extreme floods. • A relief structure on the levee will activate this corridor during extreme floods. • The park will need an overflow outlet to convey water downstream without flooding the protected city area. • 50 ha of land adjoining river redeveloped as ecological riparian parks that can be flooded.	• 6-km levee • The wall must be integrated with local urban form. • The wall must also include a local relief structure to enable FA3. • The height of the floodwall is the same as for the conventional approach. • Includes additional relief structure.

(Continued)

Table B.12: **PLUVIAL FLOODING COMBINED WITH FLUVIAL FLOODING FOR RENEWAL URBAN ENVIRONMENT *(Continued)***

Scenario								
Protection level	**Fluvial flooding: 100-year ARI river basin flooding + 300-mm freeboard Pluvial flooding: 20-year ARI local rainfall drainage**							
Strategy number	**PA3**	**PA4**	**PA7**	**PD1**	**FR1**	**FA1**	**FA3**	**FD2**
Anticipated additional benefits that must be compared with additional costs	• Increased value of adjoining properties • Reduced or deferred drainage infrastructure cost (already included in PD1 benefit estimate)	• Increased value of adjoining properties, from eliminating flood inundation to buildings and improved landscape amenity • Reduced drainage infrastructure cost (already included in PD1 benefit estimate) • Additional habitat, biodiversity, nutrient removal, and carbon abatement benefits • Additional stormwater cleansing and harvesting benefits	• Reduced rainwater runoff and corresponding reduction in size of stormwater drainage infrastructure and/or augmentation of existing downstream drainage infrastructure (already included in PD1 benefit estimate)	Reduced drainage infrastructure cost from BaU by 20% (This reduction is attributed to PA3, PA4, PA7, and FR1)	Increased value of adjoining properties The hybrid approach also provides additional biodiversity, nutrient removal, and carbon abatement benefits	Increased property value (by 20%) through good design and connection to street level and additional usable space with the permissible use planning control	Increased value of adjoining properties The hybrid approach also provides additional biodiversity, nutrient removal, and carbon abatement benefits	
Reference example	Elster Creek (Victoria, Australia)	Bishan Park (Singapore)	AquaRevo (Victoria, Australia)		Bishan Park (Singapore)	Brabham (Western Australia)	Fishermans Bend (Victoria, Australia)	Elwood (Victoria, Australia)

Note: A = adapt measure; ARI = Average Recurrent Interval; BaU = Business as Usual; D = defend measure; F = fluvial flooding; ha = hectare; P = pluvial flooding; R = retreat measure.

- **Significant infrastructure upgrades, given the location and forecast growth both inside and outside the redevelopment site and the forecast impact of climate change. The upstream water supply network and downstream sewer system are at capacity. Desalinated water will be used to supply additional water to accommodate growth, which is expensive. Rainwater tanks are planned to reduce water demand, and a sewer mine and local recycling are also planned to reduce impacts on the sewer system. These measures are adopted in both the conventional and hybrid scenarios and therefore are excluded from the analysis.**
- **A cost of upgrading drainage pipes that is different for the two scenarios and estimated to be US$37.5 million in the conventional solution, whereas the extra pumping facilities will cost an estimated US$12.5 million.**
- **Rainwater tanks that provide some distributed storage. However, these tanks are very passive assets because the level of storage depends on how empty the tanks are at the start of the storm event. The cost of the tanks is the same for both approaches, so it is not included in the analysis. Similarly the rainwater tanks provide the same water supply system demand reduction under both conventional and hybrid approaches, so the associated costs and benefits were not included.**

Cost estimates are based on similar cases in Australia.

Hybrid Solution

Key Inputs and Assumptions

The hybrid solution includes the four responses included in the conventional approach, though with some modifications. It also incorporates several nature-based floodwater detention and conveyance strategies and adaptive building design that reduce the likelihood and cost of flood damage to buildings.

The hybrid solution delivers additional direct benefits (for example, smaller diameter drainage pipes and less pumping) and indirect benefits (higher amenity and property values, biodiversity benefits, reduced nutrient levels, and carbon abatement).

Strategy number FD2. Construct a 6-kilometer levee. The height and alignment of the levee will be the same as for the conventional approach. The levee will be integrated with local urban form and, for the hybrid approach, will also include a local relief structure to enable strategy FA3 (designated flood conveyance). That is, the relief structure will direct water to the designated flood conveyance.

The cost of constructing the levee is the same as for the conventional approach. However, the hybrid approach will incur the extra costs of constructing the relief structure—US$514,000 (present value) to build the relief structure and US$49,000 (present value) to maintain it.

The flood protection benefits of this strategy are the same as for the conventional approach, so they are not included in this analysis.

Strategy number FR1. Return occupied floodplain to wetlands and parks as ecological landscape and public open space. Under this strategy, 50 hectares of land next to the river will be developed into riparian parks that can be flooded.

This strategy will incur additional costs—US$36 million (present value) to construct the wetlands and US$3.8 million (present value) to maintain the wetlands.

As well as flood protection benefits, it will also deliver a range of other benefits:

- **It will improve the value of properties near the wetlands. For this example, we assumed the wetlands will improve property values by 6.2 percent, based on the wetlands value function in the INFFEWS Value tool (Polyakov et al. 2017). This translates to a benefit of US$8.4 million (present value).**

- **The wetlands will provide ecosystem services, such as biodiversity benefits (US$1.1 million, present value), nutrient stripping (US$46.9 million, present value), and carbon abatement (US$2,700, present value). The biodiversity benefit value is derived from Morrison and Hatton-MacDonald (2010). The carbon abatement value is based on Carnell et al. (2018): The value of a ton of abated carbon is based on the December 2018 auction price for the Australian government Emissions Reduction Fund. The value of nitrogen removal is the reference value used by a major Australian water utility and is also the value used in the CRCWSC research evaluating the cost-effectiveness of raingarden installations for nutrient removal. The assumed nutrient removal rate is based on the CRCWSC experience with similar systems.**
- **The wetlands will allow residents to connect directly with nature. For example, the residents and those working in the precinct can observe birds and explore the wetlands. Strategies PA4 and FA3 (discussed later) will provide similar recreational benefits; together these benefits are valued at US$6.7 million (present value). This general community recreation benefit estimate is derived from the Brent et al. (2017) study reported in the INFFEWS Value tool.**
- **Together with strategies PA4 and FA3, this strategy will also provide additional cost of illness benefits via access to increased public open space, valued at US$1 million (present value). The health benefit attribution is derived from a separate tool that has been developed for the Water Services Association of Australia (Frontier Economics 2019). Benefits can be derived using either a CoI approach or a WTP approach. Estimates derived using the latter are typically much higher than estimates derived using the former. This example used estimates based on the CoI approach, so they can be considered conservative.**

Strategy number PD1. Upgrade existing drainage infrastructure by increasing pipe size and installing pumps. The hybrid approach uses smaller pipes and fewer pumps than in the conventional approach. This is possible because of the other detention storages distributed throughout the precinct (discussed later) that detain floodwater and therefore reduce the amount of water flowing into drainage infrastructure.

Based on the CRCWSC analysis, the cost of upgrading existing drainage infrastructure is expected to fall by 20 percent under the hybrid solution, compared with the conventional approach. That is, the cost of replacing pipes will fall to US$30 million (from US$37.5 million), and the cost of pumps will fall to US$10 million (from US$12.5 million).

Because this example compares the hybrid solution with the conventional approach, this reduced cost is included as a benefit. The present value of the capital expenditure savings is US$8.8 million, and the present value of the operating expenditure savings is US$1.4 million.

Strategy number PA7. Install smart rainwater tanks on all buildings, which will supply water for nonpotable uses, such as irrigation, toilets, and washing machines. These centrally controlled tanks receive weather forecasts and then release water before a heavy downfall to maximize storage capacity and minimize overflows or flooding in local waterways.

This strategy is more costly than under the conventional approach: US$1.8 million for the smart control devices. At the same time, it provides a higher level of flood protection than the conventional approach because it allows for more distributed storage. However, this additional benefit is reflected in savings associated with PD1 (the smaller investment in upgrading drainage infrastructure).

Strategy number PA4. Convert an 11-hectare park for flood detention. Currently, this park is used for both active and passive recreation. The new converted park will include a lake and wetlands landscape and ovals, all of which can be inundated to detain floodwater.

This strategy involves capital costs of converting the existing park and installing pipes (US$6.6 million, present value) and operational costs to maintain the park (US$274,000, present value) and the pipes (US$137,000, present value).

This strategy will deliver benefits similar to those for strategy FR1:

- **Significant value uplift, reflecting improved amenity, and reduced flooding, estimated at $43.3 million (present value)**
- **Biodiversity benefits of US$461,000 (present value)**
- **Nutrient stripping benefits of US$9.5 million (present value)**
- **Carbon abatement benefits of US$560 (present value)**
- **A portion of the recreational and cost of illness benefits identified under strategy FR1**

Strategy number FA3. Designate flood conveyance, such as major flood corridors. Specifically, 22 hectares of parkland with lakes and wetlands will be a designated flood corridor during extreme floods. The relief structure on top of the levee will activate this corridor by directing floodwaters to the parkland. The park will also include an overflow outlet to convey the water downstream without flooding the protected city area.

The capital costs of this strategy are estimated to be US$16.4 million (present value), and the operating costs are estimated to be US$1.8 million (present value).

This strategy will deliver benefits similar to those for strategy FR1:

- **Property value uplift, reflecting improved amenity, and reduced flooding, estimated at $40 million (present value)**
- **Biodiversity benefits of US$501,000 (present value)**
- **Nutrient stripping benefits of US$16.2 million (present value)**
- **Carbon abatement benefits of US$1,200 (present value)**
- **A portion of the recreational and cost of illness benefits identified under strategy FR1**

Strategy number PA3. Designate flood conveyance for above-design events. In this example, the strategy involves converting a four-lane street into two lanes, with a central median as a sunken verge to convey above-design flow. This central median will contain a pipe sized to accommodate a 20-year ARI, whereas the street pipes will accommodate a five-year ARI. The central median will also integrate a bike lane for active transportation.

This strategy will incur capital costs of US$2.7 million (present value) and operating costs of US$333,000 (present value). At the same time, it will boost property values by US$6.5 million (present value).

Strategy number FA1. Apply adaptive building design to rising water level for five buildings. This strategy imposes new building design requirements to introduce local flood inundation protection, including:

- **Mixed-use (commercial and residential) buildings with planning control of permissible uses at different floor levels:**
  - **Residential and high occupancy levels to be 300 millimeters above 100-year river ARI**
  - **Private gardens/open space, car parks, and storages at lower heights**
- **Five multiple-story commercial buildings on stumps with**
  - **Floating terraces (to cope with variations in the river water level during floods) to connect to roads;**
  - **Raised driveways into underground or basement parking to mitigate flooding; and**
  - **Water-proofing entry doors.**

This strategy imposes costs on the developer (purchase, planning, design, and construction costs). The present value of these costs is US$15.5 million, but it also generates benefits, including the sale of land for development (US$15 million, present value) and the developer value added (US$11.5 million, present value).

Results Summary

The hybrid infrastructure solution delivers the same reduction in flood risk as the conventional infrastructure solution and will deliver an additional US$125.4 million in benefits when compared with the conventional approach. However, the results show the organization leading the project (in this case the state government) will incur significant additional costs yet receive a relatively small proportion of the additional direct benefits.



	Overall		Project organization
NPV	$125,391,743	NPV	–$39,449,805
BCR	2.94	BCR	0.39

Note: BCR = benefit-cost ratio; NPV = net present value.

Overall, uncertainty about the outcome is low—the probability of realizing a positive NPV is 1.00. The NPV values in the simulation range from positive US$13.0 million to positive US$198.1 million (Table B.13).

The distribution plot illustrates the expected payoff for the hybrid solution compared with the conventional solution. Figure B.13 shows there is a significant chance that the hybrid solution will realize benefits greater than the default case.

The expected NPV varies substantially with the discount rate assumption, increasing to US$166.8 million with a discount rate of 4 percent and falling to US$99 million with a discount rate of 10 percent (Table B.14).

5. Identify appropriate financing and funding mechanism/s

Considerations:

- Once you have selected the optimal mix of interventions, principles for fair and efficient financing options need to be identified and options assessed.

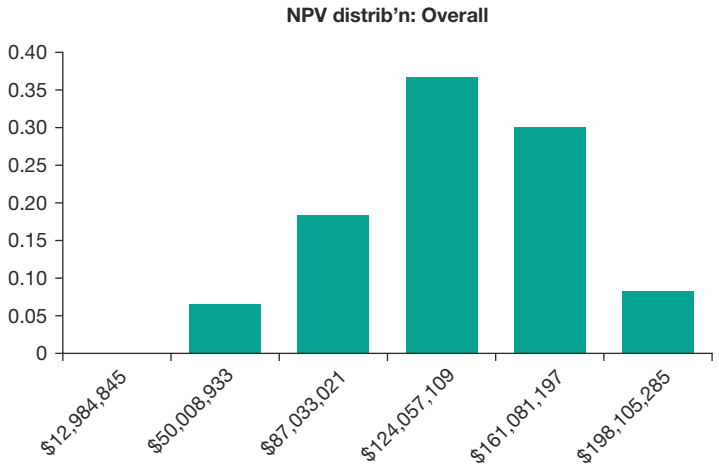
Manual reference: Chapter 5 (financing IWM approaches)

Table B.13: **NPV RANGE FOR THE HYBRID SOLUTION**

	Overall		Project organization
Net Present Value (NPV)		Net Present Value (NPV)	
Minimum	$12,984,845	Minimum	-$71,073,321
Maximum	$198,105,285	Maximum	-$12,637,761
Default case	$125,391,734	Default case	-$39,449,805
Mean	$110,431,487	Mean	-$41,238,422
Median	$112,944,122	Median	-$41,113,976
Probability that NPV > 0	1.00	Probability that NPV > 0	0.00

Note: NPV = net present value.

Figure B.13: **NPV DISTRIBUTIONS FOR HYBRID SOLUTION COMPARED WITH THE CONVENTIONAL SOLUTION**



Note: Y-axis represents probability and X-axis represents NPV values

Table B.14: **HYBRID SOLUTION SENSITIVITY TO DISCOUNT RATE ASSUMPTION**

Sensitivity to Discount Rate			
Overall	**Low discount rate 0.04**	**Default discount rate 0.07**	**High discount rate 0.1**
Benefits (present value)	$237,216,446	$190,047,655	$159,474,375
Costs (present value)	$70,430,534	$64,655,921	$60,402,116
NPV	$166,785,911	$125,391,734	$99,072,260
BCR	3.37	2.94	2.64

Note: BCR = benefit-cost ratio; NPV = net present value.

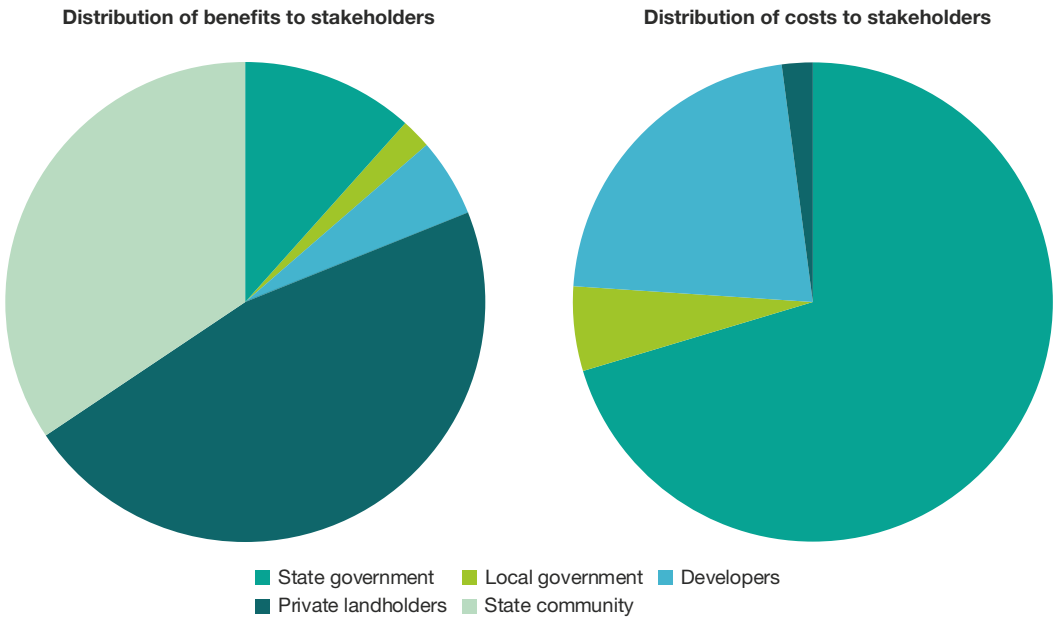
Distributional Analysis

Figure B.14 illustrates the distribution of additional benefits and costs associated with the hybrid approach.

Like the conventional solution, the hybrid approach provides the required level of flood protection. But it also delivers additional benefits to all stakeholders. Private landholders incur very few extra costs but capture almost 50 percent of the benefits, largely reflecting the improved property values and the recreational and health benefits of having access to more public open space.

By contrast, the state government captures only 12 percent of the additional benefits but incurs 70 percent of the additional costs. Like private landowners, local governments benefit from improved property values, whereas the state community benefits from ecosystem services, such as biodiversity improvements, nutrient removal, and carbon abatement. Developers receive developer value added.

Figure B.14: **HYBRID SOLUTION DISTRIBUTION OF COSTS AND BENEFITS**



Financing and Funding

The state government (via its water, sewer, and drainage utility) finances the drainage infrastructure upgrades through a combination of retained earning and debt financing. Utility customers across the city fund a proportion of the upgrade over the assets' useful life via higher customer charges given the redevelopment's wider benefits. This results in a relatively small increase per customer given the long life of the assets and the size of the city. The utility also imposes a special one-time flood abatement levy on redeveloped land to contribute to the capital works. This levy is paid by developers and passed on to private landholder through high property prices.

Developers finance aspects of several responses (for example, smart rainwater tanks and using adaptive building design) through increased construction costs. Private landholders largely fund these responses through higher property prices.

Local government also incurs some of the costs of converting parkland to flood detention, which it finances through retained earnings. It funds ongoing maintenance through municipal rates. It uses the same funding mechanism to pay for ongoing maintenance of the in-street flood conveyance.

The state government is also piloting a nitrogen tender program for the catchment as part of a program to reduce nitrogen discharges, which are currently putting at risk internationally significant environmental values in the bay at the bottom of the catchment. The program provides an opportunity for municipal governments and private developers to apply for government grants through by a blind auction process. If successful, the nitrogen tender program may, over time, evolve into an ongoing nitrogen market. If the pilot program is unsuccessful, the state government is considering several less efficient but lower-cost polluter pay taxes or transfers to protect the bay. Table B.15 gives a summary of different financing mechanisms that are appropriate for different beneficiaries.

Table B.15: **HYBRID INFRASTRUCTURE SUMMARY**

Strategy	Beneficiaries	Source of flooding (polluter)	Financing		Funding	
			Who	How	Who	How
Hybrid solution						
(FD2) Flood levee	Current and future property owners Local governments State community	Fluvial flooding as a result of climate change and upstream development	State government	Water sewer and drainage utility retained earnings and debt	Utility customers Private landholders	Higher utility tariffs Developer charge, which is passed on to private landholders through higher developed property prices
(FR1) Conversion of occupied floodplain to wetlands and parks	Current property owners Local governments State community and environment	Fluvial flooding as a result of climate change and upstream development	State government	Water sewer and drainage utility retained earnings and debt Developer charge	Utility customers Private landholders	Higher utility tariffs Developer charge, which is passed on to private landholders through higher developed property prices
(PD1) Drainage infrastructure upgrade	Current and future property owners Current and future commuters State government	Within site pluvial flows arising from higher impervious area and climate change	State government	Water and drainage utility retained earnings Developer charge	Utility customers Private landholders	Higher utility tariffs Developer charge, which is passed on to private landholders through higher developed property prices

(Continued)

Table B.15: **HYBRID INFRASTRUCTURE SUMMARY *(Continued)***

Strategy	Beneficiaries	Source of flooding (polluter)	Financing		Funding	
			Who	How	Who	How
(PA7) Smart-controlled rainwater tanks	Current and future residents	Within site pluvial flows arising from higher impervious area and climate change	Private developer	Higher construction costs, debt, and equity	Private landholders	Property price
(PA3) Designated flood conveyance for above-design events	Current property owners Local governments	Within site pluvial flows arising from higher impervious area and climate change	State government	Water and drainage utility retained earnings Developer charge	Utility customers Private landholders	Higher utility tariffs Developer charge, which is passed on to private landholders through higher developed property prices
(PA4) Flood detention in parks and public open space	Current property owners Local governments State community	Within site pluvial flows arising from higher impervious area and climate change	Local government	Retained earnings Higher construction costs, debt, and equity State government nitrogen tender program	Private landholders Local government State taxpayers	Property price Municipal rates State government taxes
(FA1) Adaptive building design	Current and future property owners Developers State government	Fluvial flooding as a result of climate change and upstream development	Private developer	Private debt	Private landholders	Property price
(FA3) Designated flood conveyance	Current property owners Local governments State community	Fluvial flooding as a result of climate change and upstream development	State government	Water and drainage utility retained earnings Developer charge	Utility customers Private landholders	Higher utility tariffs Developer charge, which is passed on to private landholders through higher developed property prices

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C

Case Study—Shenzhen Futian River Ecological Restoration



Background Introduction

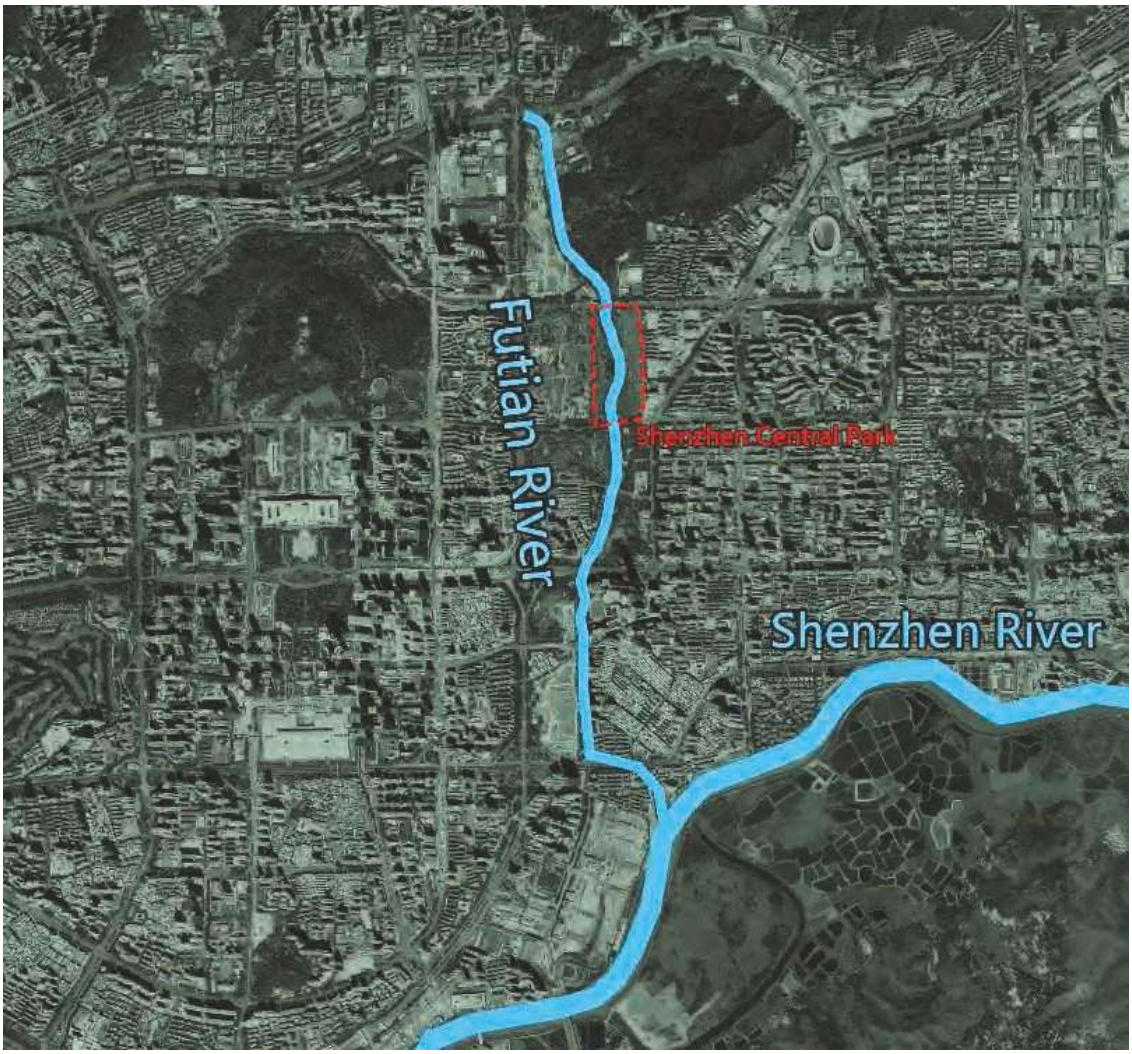
Futian River is located in the central area of Futian District, Shenzhen, China (Map C.1). The area of the catchment is 15.9 square kilometers, and the length of the mainstream is 6.8 kilometers. The upper reaches of the catchment are low-lying hilly areas, with an average ground elevation of 10 to 23 meters, and the vegetation coverage is in good condition. The surrounding area of Futian River is densely populated, and the river crosses Bijiashan Park and Central Park, the two major municipal parks and main leisure and sightseeing places for Shenzhen residents.

Futian River is playing as a green ecological link that connects the southern mangrove natural ecological reserve and the northern Meilin Mountain natural ecological reserve. It is an important node for the city's environmental quality improvement and livable ecological city implement.

Shenzhen has experienced a rapid development of society and economy during past decades yet has also suffered a lack of consideration of environmental protection, especially with its population size of more than 20 million. As part of a central urban area, Futian River catchment has also been developed on a large scale, which brings a series of problems, including river pollution, deterioration of water quality, insufficient flood control conditions, lack of aesthetics, embankment encroachment, extinction of aquatic animals, poor ecology, and so on.

Since August 2009, Shenzhen Water Bureau took the opportunity of organizing the 2011 Universiade and made full use of the 800-meter-wide green belt reserve space. The project integrated major tasks of flood control, pollution control, water quality improvement, landscape aesthetics improvement, and greenway construction. Apparently, the planning and construction of the Futian River Comprehensive Improvement Project could solve local flood issues and improve the investment environment, which could accelerate the development and construction of riverside areas, enriching and improving the regional landscape and ecology. The project started in 2009, and construction was finished in about two years. In 2011, the project started trial operation, and it turned fully functional a year later. The design operating period is 40 years since completed, which leads to 2050. Apparently, the project plays a positive role in promoting economic development and has significant economic, social, and environmental benefits. However, there is a lack of quantitative analysis regarding the real benefit and cost of the project. The benefit-cost analysis (BCA) tool from the Investment Framework For Economics of Water Sensitive Cities (INFFEWS) has been applied in this study, which quantitatively measures the potential benefits and costs behind the project itself.

Map C.1: **FUTIAN RIVER MAP**



Project Interventions

The Futian River Comprehensive Improvement Project is about 3.9 kilometers long from the sluice gate in Bijiashan Park, which is north of Sungang Road, to the estuary of Futian River, which is next to the Hong Kong SAR, China-mainland border, and 31,29 meters of them are open channels. The project also included 1,052-meter-long branches of the Futian River. The road-crossing and covered box culverts are not included in the scope of this project. The flood control standards for the open channel section of the river are once in 100 years. The river channel of Bijia Mountain was renovated in 2002, and the landscape has been greatly improved without reconstruction. The content of this project is carried out on the basis of the river reconstruction work.

The project construction has two phases. Phase I included: (a) total length of 4,181 meters of embankment reconstruction; (b) initial stormwater collecting system, including the total length of 5.032 kilometers of pipelines

and three total capacity of 60,000 cubic meters stormwater storage ponds; (c) Futian Central Park landscape construction and planting works; (d) total area of 67,000 square meters of artificial lakes and constructed wetlands; (e) a pumping station with the capacity of 30,000 cubic meters per day; and (f) lake water circulation system with the capacity of 15,000 cubic meters per day and a vertical wetlands system equipment with the capacity of 4,000 cubic meters per day.

The phase II included: (a) an advanced water treatment facility with the capacity of 30,000 cubic meters per day and (b) reclaimed water pipeline work with total length of 5,617 meters.

Key Inputs and Assumptions

Because a long period of 40 years will be studied in this analysis, inflation needs to be considered. A discount rate of 7 percent is used to convert future benefits and costs into present values.

Costs

The project expenses are fully covered by Shenzhen Water Bureau, and the costs mainly consist of five parts: design costs, construction costs, construction land use compensation, maintenance costs, and project working liquidity.

The project construction stage has been split into two phases, and there is time overlap between them in practice. But to simplify the simulation and calculation, it is assumed the two phases were working sequentially, which means phase I was from mid-2009 to early 2010 and phase II was from mid-2010 to early 2011.

Design Costs

Design costs are the expenses paid to design companies and consultancies by Shenzhen Water Bureau for the project design and planning works. They are usually related to the investment of construction, which is detailed in the next section. The design costs of the two phases are listed in table C.1.

Table C.1: **DESIGN COSTS**

	Cost (RMB million)	Payment method	Period
Design costs, phase I	56.5	One time	2009
Design costs, phase II	6.1	One time	2010

Construction Costs

Construction costs are the expenses paid to contractors by Shenzhen Water Bureau for the construction works, including surveying, construction equipment, building materials, workers' salary and insurance, and so on. The construction costs of the two phases are listed in table C.2.

Table C.2: **CONSTRUCTION COSTS**

	Cost (RMB million)	Payment method	Period
Construction costs, phase I	359.9	One time	2009
Construction costs, phase II	36.8	One time	2010

Construction Land Use Compensation

The construction of the project had requested an area of extra land for construction preparation, equipment storage, and workers' temporary housing, which leads to the cost of construction land use compensation paid to landowners by Shenzhen Water Bureau. It was a one-time payment of RMB 1.38 million in 2009 (Table C.3).

Table C.3: **CONSTRUCTION LAND USE COMPENSATION**

	Cost (RMB million)	Payment method	Period
Construction land use compensation	1.38	One time	2009

Maintenance Costs

The maintenance of project have been classified into six categories, and each of them are estimated by the expenses annually. The detailed annually maintenance costs are listed in table C.4.

Table C.4: **MAINTENANCE COSTS**

	Cost (RMB million)	Payment method	Period
Embankment maintenance	0.9	Annual	2012–50
Dredging costs	1.6	Annual	2012–50
Pipeline maintenance	1.6	Annual	2012–50
Sewage pump station maintenance	1.2	Annual	2012–50
Green land maintenance	2.4	Annual	2012–50
Water treatment facility maintenance	1.9	Annual	2012–50

Project Working Liquidity

The project has set RMB 2.2 million cash in 2011 as liquid assets to enrich the capability of purchasing or constructing necessary infrastructure and enhancing human resources. It provides security in the project financial operation (Table C.5).

Table C.5: **PROJECT WORKING LIQUIDITY**

	Cost (RMB million)	Payment method	Period
Project working liquidity	2.2	One time	2011

Benefits

Considering that the project was completed in early 2011, it will not achieve full benefits in 2011. In this study, it is assumed that all benefits will be formally benefited from in 2012. In 2011, it will be considered as a trial operation stage and calculated at 50 percent of 2012. Multiple benefits were analyzed in this study, and they are described in detail in the following section.

Reduced Flood Risk

Through measures, such as rebuilding the Futian River bank and raising the embankment in some open channel sections, the project will enable the river channels in the area of the reconstruction to reach the prescribed 100-year return period flood control standard, which will greatly enhance the river's flood carrying capacity and protect the property and physical safety of the people on both sides of the river channel. The flood control benefit calculation uses the frequency method, and the difference between the flooding loss before and after the project is completed is taken as the flood control benefit of the project.

The comprehensive improvement project uses planting ditches and detention ponds to transport, purify, and retain rainwater to reduce flood peaks. At the same time, an underground reservoir is constructed to collect and use all rainwater, which reduces the drainage pressure of the municipal rainwater pipeline downstream. The parking lot is transformed into a biological infiltration belt with a landscape effect that extends to the edge of the street to collect rainwater, slow down the water flow, clean the rainwater, and filter the rainwater.

According to the conditions within the protection scope of the Futian River and the local economic development situation, it is estimated that the annual flood control benefit of the project is RMB 8.56 million at 2012. We have assumed the flood control benefit increases 8 percent annually along with the development of economy (Table C.6).

Table C.6: **REDUCED FLOOD RISK**

	Benefit (RMB million)	Growth rate (%)	Period
Reduced flood risk	8.56	8	2012–50
Reduced flood risk (trial operation)	4.28	–	2011

Reduced Water Consumption

Because Shenzhen is a city with a clear rainy and dry season, and Futian River catchment is relatively small and mainly within constructed areas, there will be almost no water on the riverbed during the winter. The project has used treated water and transferred to the upper stream as river base flow to enhance the water environment and water quality.

According to the survey in 2011, the price of the administrative greening water of Shenzhen Water Supply Company is RMB 2.70 per cubic meter. The project will use the recycled water, which can replace the tap water for water replenishment in the Futian River (Map C.2). Taking into account the sewage treatment costs of the Binhe Wastewater Treatment Plant, with reference to the calculation results of the sewage treatment costs of other wastewater treatment plants, it is calculated at RMB 1.6 per cubic meter. The reduced water consumption benefits are RMB 1.1 per cubic meter. The recycled water supply of the river in this project is 38,000 cubic meters per day, and the economic benefits are RMB 13.87 million per year (Table C.7).

Map C.2: **FUTIAN RIVER RECLAIMED WATER RECHARGE ROUTE**

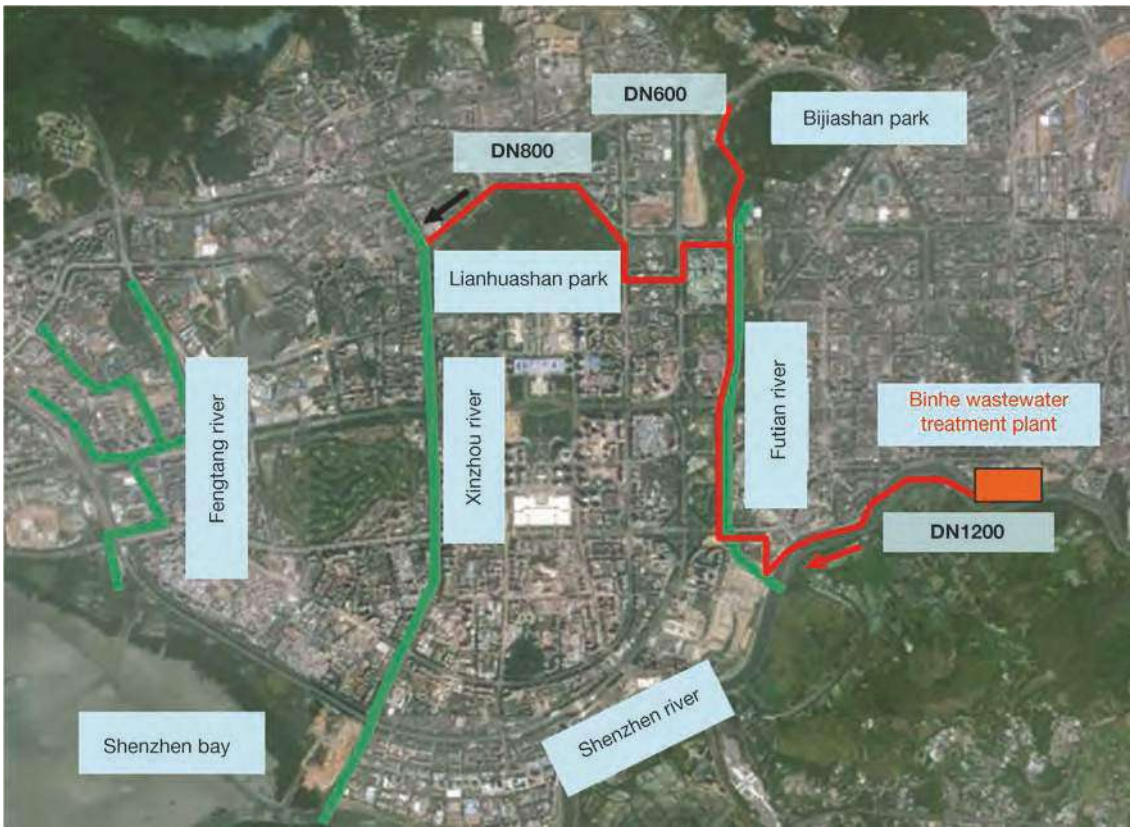


Table C.7: **REDUCED WATER CONSUMPTION**

	Benefit (RMB million)	Period
Reduced water consumption	13.87	2012–50
Reduced water consumption (trial operation)	6.94	2011

Improved Air Quality

The benefits of improved air quality is calculated using alternative engineering methods, which includes two parts, increasing the function of negative ions and absorbing dust.

Because of the recycled water recharge and the existence of rivers, the increased air anion concentration was 2,800 NAIs/cm^3. It is assumed the total number of negative ions contained only 10 centimeters above the river channel water surface, whose area is 147,300 cubic meters. According to the unit price of ions generated by the

negative ion generator on the Chinese market of RMB 2.08 per 10^{10}, Futian River increased the functional value of negative ions to 8,579 RMB per year.

Dust absorption benefit is calculated according to the amount of dust absorbed by the waters. The annual dust fall in Shenzhen was 3.9 tons per square kilometer and the cost of industrial dust treatment is RMB 0.15 per kilogram, so the benefit of dust absorption in Futian River is RMB 3,971 per year (Table C.8).

Table C.8: **IMPROVED AIR QUALITY**

	Benefit (RMB)	Period
Improved air quality	12,550	2012–50
Improved air quality (trial operation)	6,275	2011

Carbon Fixation

Carbon fixation benefit is calculated by carbon tax and afforestation cost. The total weight of new wetlands plants in the project is estimated to be 2,834.2 kilograms. The primary phytoplankton production of Futian River is estimated by their average weight and density in the water, and it is calculated as 7.55 million kilograms of phytoplankton in the river. A relevant carbon fixation effectiveness study in China used the carbon fixation ratio of 1.63. The average price of carbon tax and afforestation cost was RMB 770 per ton, which leads to the total carbon fixation benefit of the project as RMB 9.5 million annually (Table C.9).

Table C.9: **CARBON FIXATION**

	Benefit (RMB million)	Period
Improved air quality	9.5	2012–50
Improved air quality (trial operation)	4.75	2011

Sediment Transport

The benefit of river sediment transport function is calculated using the alternative engineering method. In southern China, the cost of manual river dredging is RMB 4.7 per ton. According to the statistical data of Futian River sediment transport, the average annual sediment transport is 78,840 tons. Thus, the sediment transport benefit is RMB 0.37 million per year (Table C.10).

Table C.10: **SEDIMENT TRANSPORT**

	Benefit (RMB million)	Period
Sediment transport	0.37	2012–50
Sediment transport (trial operation)	0.19	2011

Increased Tourism

The construction of Shenzhen Central Park was the major part in the comprehensive improvement project. It is designed for an annual visiting capacity of 4 million. Considering the local economy, it is assumed the average consumption of each visitor is RMB 5. The increased tourism benefit is RMB 20 million per year, including transportation costs and catering consumption. The benefit contributes to the income of local transportation system and businesses in the surrounding area, and their distribution ratios are assumed as 70 percent and 30 percent, respectively (Table C.11).

Table C.11: **INCREASED TOURISM**

	Benefit (RMB million)	Period
Increased tourism	20	2012–50
Increased tourism (trial operation)	10	2011

Reduced Investment in Water Storage Infrastructure by Maintaining Surface Water Level and Groundwater Level

The rebuild of the Futian River provides the capability of restoring the water both for the surface and groundwater. According to the local water resource report, the total surface water in the Futian River catchment is estimated as 174 billion cubic meters, and the total groundwater in the Futian River catchment is estimated as 38 billion cubic meters. As the investment of reservoir construction is approximately RMB 6.11 per cubic meter, the total benefit of reduced investment in water storage was RMB 1,300 million. This benefit is a one-time return (Table C.12).

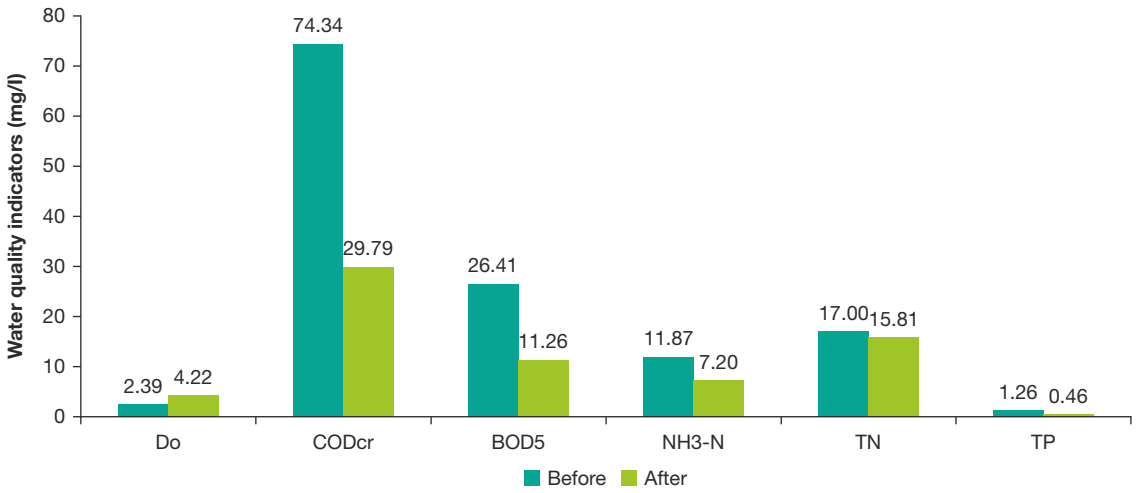
Table C.12: **REDUCED INVESTMENT IN WATER STORAGE INFRASTRUCTURE BY MAINTAINING SURFACE WATER LEVEL AND GROUNDWATER LEVEL**

	Benefit (RMB million)	Period
Reduced investment in water storage infrastructure by maintaining surface water level and groundwater level	1,300	2011

Reduced Cost in Wastewater Treatment by Water Quality Improvement

The project used reclaimed water for river base flow recharge, which not only increases the water quantity but also significantly improves the water quality. According to the water quality monitoring data, by implementing the project, Chemical Oxygen Demand (COD) drops dramatically from 74.34 to 29.79 milligrams per liter, and Nitrogen Ammonia (NH_3-N) decreases from 11.87 to 7.2 milligrams per liter. Although the wastewater treatment unit price of COD and NH_3-N are RMB 3.5 per kilogram and RMB 1.5 per kilogram, respectively, the total benefit from reduced cost in wastewater treatment was RMB 2.8 million per year (Figure C.1 and Table C.13).

Figure C.1: **FUTIAN RIVER WATER QUALITY INDICATORS COMPARISON BEFORE AND AFTER THE PROJECT**



Note: DO - Dissolved oxygen; CODcr – Chemical Oxygen Demand; BOD5 – Five-day Biochemical Oxygen Demand; NH3-N – Nitrogen Ammonia; TN – Total Nitrogen; TP – Total Phosphorous

Table C.13: **REDUCED COST IN WASTEWATER TREATMENT BY WATER QUALITY IMPROVEMENT**

	Benefit (RMB million)	Period
Reduced cost in wastewater treatment by water quality improvement	2.8	2012–50
Reduced cost in wastewater treatment by water quality improvement (trial operation)	1.4	2011

Increased Property Prices from Proximity to the Project

The improvement of living environment contributes to the surrounding property prices. It benefits the property owners, including local residents, developers, and the Shenzhen Housing Bureau. The benefit allocation among stakeholders is determined by affected land use—about 50 percent are public areas, which is government-owned; 30 percent are residential areas, which is resident-owned; and 20 percent are business areas, which is owned by the developers.

To quantitatively measure the impact of the project to the property prices, the INFFEWS Value tool was used. The worksheet provides percentage changes in property prices from proximity to the Shenzhen Central Park based on relative studies (Map C.3 and Table C.14).

The INFFEWS Value tool provides three different levels of impact. The low-impact rate was applied in this study because the property price in Shenzhen, a special economic zone with rapid economic growth, is flying with the economic boost.

Map C.3: **THE ASSUMED IMPACTED BUILDING AREAS NEAR THE PROJECT**



Note: The red line refers to Shenzhen Central Park, the yellow area refers to the building area within a 100-meter range, the green area refers to the building area within a 200-meter range, and the blue area refers to the building area within a 300-meter range..

Table C.14: **THE BUILDING AREA FROM DIFFERENT DISTANCES TO THE PROJECT AND THEIR INCREASE RATES BY INFFEWS VALUE TOOL**

Distance from the park (m)	Building area (m^2)	Floor area ratio	Increase rate (%)
100	83,000	1.6	1.2
200	127,000	1.6	1.8
300	155,000	1.6	3.0

Note: INFFEWS = Investment Framework for Economics of Water Sensitive Cities; m = meter.

The area of Shenzhen Central Park is 23,1614 square meters, and the property price in 2011 was about RMB 22,000 per square meter in Huafu Village, which is next to the park. Thus, the total one-time benefit of increased property prices from proximity to the project was RMB 234 million (Table C.15).

Table C.15: **INCREASED PROPERTY PRICES FROM PROXIMITY TO THE PROJECT**

	Benefit (RMB million)	Period
Increased property prices from proximity to the project	234	2011

Residual Value of Fixed Assets after Designed Service Period

After the 40-year designed service period, through certain renovations and redesigns, the project can still play its original role. Its residual value in 2050 is estimated by the initial investor as RMB 167 million (Table C.16).

Table C.16: **RESIDUAL VALUE OF FIXED ASSETS AFTER DESIGNED SERVICE PERIOD**

	Benefit (RMB million)	Period
Residual value of fixed assets after designed service period	167	2050

Results

The INFFEWS BCA tool integrated in a very precise way to evaluate the net present value (NPV) and benefit-cost ratio (BCR) for the project. The Futian River Comprehensive Improvement Project shows an expected NPV of negative RMB 6.34 million for the investment overall and the NPV for the local Shenzhen municipal government of negative RMB 143.39 million. The overall project achieved a BCR of 0.99, meaning the project has generated considerable benefits out of the investment. As for the Shenzhen municipal government, the BCR of the project is 0.76. So theoretically, it is an unrecoverable investment for them as an investor, but this is already higher than the BCRs of most water conservancy projects in the world (Figure C.2).

Rather than relying on only a single best-guess value, the INFFEWS BCA tool also calculates a range of values that reflects the underlying uncertainty of cost-benefit parameters. In addition to the default case, figure C.3 provides information on some key points of the NPV distribution for this infrastructure investment.

Figure C.2: **TOTAL NPV AND BCR FOR OVERALL PROJECT AND THE ORGANIZATION**



Overall		Project organization	
NPV	RMB –6,344,423	NPV	RMB –143,387,675
BCR	0.99	BCR	0.76

Overall BCA results	
Benefits (present value)	RMB 643,501,896
Costs (present value) - Project organization - Other stakeholders - Excess burden	 RMB 601,709,555 0 RMB 48,136,764
Net present value (NPV)	RMB –6,344,423
Benefits: Cost ratio (BCR)	0.99

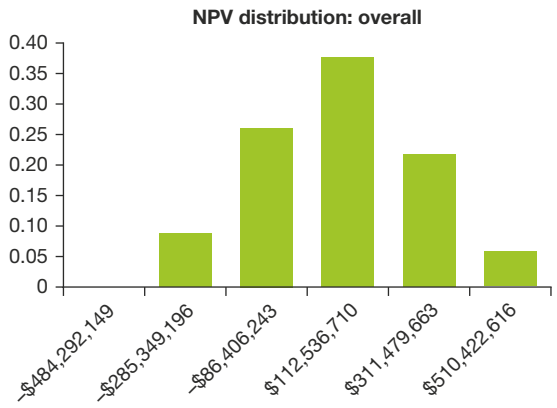
Results attributes to project organization	
Benefits (present value)	RMB 458,321,881
Costs (present value)	RMB 601,709,555
Net present value (NPV)	RMB –143,387,675
Benefits: Cost ratio (BCR)	0.76

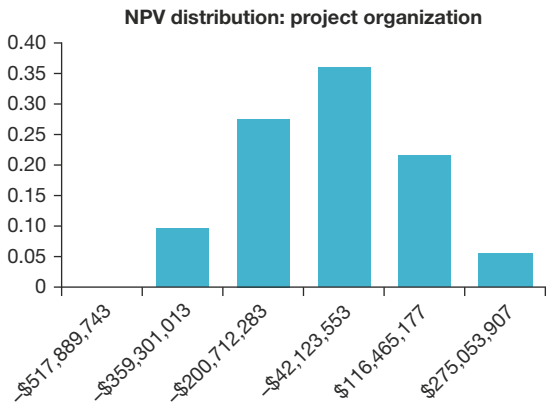
Note: BCA = benefit-cost analysis; BCR = benefit-cost ratio; NPV = net present value.

Figure C.3: **THE NPV SENSITIVITY ANALYSIS RESULTS**

Net present value (NPV, RMB)	Overall
Minimum	–484,292,149
Maximum	510,422,616
Default case	–6,344,423
Mean	–11,840,343
Median	–7,482,737
Probability that NPV > 0	0.47

Net present value (NPV, RMB)	Project organization
Minimum	–517,889,743
Maximum	275,053,907
Default case	–143,387,675
Mean	–147,036,384
Median	–143,502,009
Probability that NPV > 0	0.21





Note: NPV = net present value; Y-axis represents probability and X-axis represents NPV values.

For the overall project evaluation, across all simulation results, the expected NPV range runs from the worst-case scenario of negative RMB 484 million to positive RMB 510 million. The last row of the results shown in the table in figure C.3 provides information on the probability that the NPV is positive. In this case, the chance of realizing a negative NPV is almost half—53 percent.

For the project organization, which is the Shenzhen municipal government, there is an extremely high degree of uncertainty, with only 21 percent chance the NPV could be positive. The range of NPV values for Shenzhen municipal government vary between negative RMB 517 million and positive RMB 275 million.

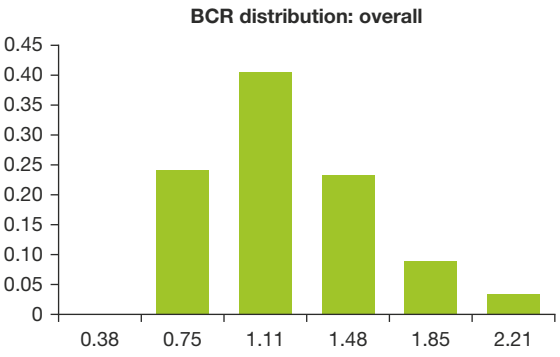
In the INFFEWS BCA tool, the distribution of NPV values is also shown below the summary results table, for both the project overall and the project organization. The summary histogram plots provide an easy way to understand the extent to which the results might be skewed in either direction.

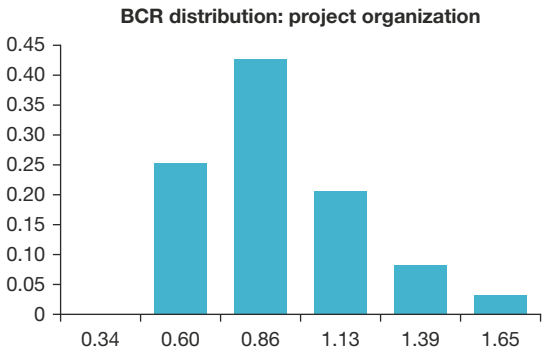
Reporting against NPV is one way to summarize results. The main alternate summary metric is the BCR, and summary BCR information is also reported below the NPV results. In this case, the default BCR is 0.99, ranging from 0.38 to 2.21. In 47 percent of the simulations, the BCR is greater than 1. Note that, because there are no project benefits that accrue to the water utility, a BCR is not calculated.

Figure C.4: **THE BCR SENSITIVITY ANALYSIS RESULTS**

Benefit: Cost ratio (BCR)	
Minimum	0.38
Maximum	2.21
Default case	0.99
Mean	1.03
Median	0.99
Probability that BCR > 1	0.47
Target BCR	**2.00**
Probability that BCR > Target	0.02

Benefit: Cost ratio (BCR)	
Minimum	0.34
Maximum	1.65
Default case	0.76
Mean	0.79
Median	0.76
Probability that BCR > 1	0.21
Target BCR	**2.00**
	0.00





Note: BCR = benefit-cost ratio; Y-axis represents probability and X-axis represents BCR values.

To mitigate against optimism bias, some organizations choose to set the critical value for the BCR to a value greater than 1. The INFFEWS BCA tool allows the user to specify a target BCR and shows the probability that the BCR is greater than the target value. In this case, we assumed the target BCR is 2.0, the probability of the overall project BCR to be higher than the target will be only 21 percent, and it is unlikely for the Shenzhen municipal government achieve the target (Figure C.4).

The sensitivity analysis was explored as part of this BCA process. The recommended low and high discount rate of 4 percent and 10 percent were applied in addition to the default discount rate of 7 percent. All calculations in this example exclude tax.

For the overall project, with a low discount rate, the NPV increases to RMB 291 million (BCR 1.44). With a high discount rate, the NPV falls to negative RMB 139 million (BCR 0.76), and it shows the chance for the project achieve a negative NPV if the discount rate continues to be high.

For the project organization, Shenzhen municipal government, with a low discount rate, the NPV increases to RMB 60 million (BCR 1.09). This shows the project still could not achieve a positive NPV for the organization, even if the discount rate remains at a lower level. With a high discount rate, however, the NPV falls to negative RMB 232 million (BCR 0.59) (Table C.17).

Among all the benefits, the benefit of flood risk reduction contributed most to the project, which accounted for 41.1 percent of the total project benefit. Increased property prices and reduced investment in water storage infrastructure follow by 25.4 percent and 14.1 percent, respectively. The air quality improvement also shows a significant contribution to the overall benefit that carbon fixation ranked third, with 14.2 percent (Table C.18).

Table C.17: **THE DISCOUNT RATE SENSITIVITY ANALYSIS RESULTS**

Overall	**Low discount rate 0. 04**	**Default discount rate 0. 07**	**High discount rate 0. 1**
Benefits (present value, RMB)	1,054,073,239	658,318,571	471,850,089
Costs (present value, RMB)	666,727,168	602,308,706	566,789,399
Net Present Value (NPV, RMB)	387,346,071	56,009,865	–94,939,311
Benefit: Cost Ratio (BCR)	1.58	0.99	0.83
Project organization	**Low discount rate 0. 04**	**Default discount rate 0. 07**	**High discount rate 0. 1**
Benefits (present value, RMB)	810,980,807	513,313,002	372,989,977
Costs (present value, RMB)	666,727,168	602,308,706	566,789,399
Net Present Value (NPV, RMB)	144,253,639	–88,995,704	–193,799,422
Benefit: Cost Ratio (BCR)	1.22	0.85	0.66

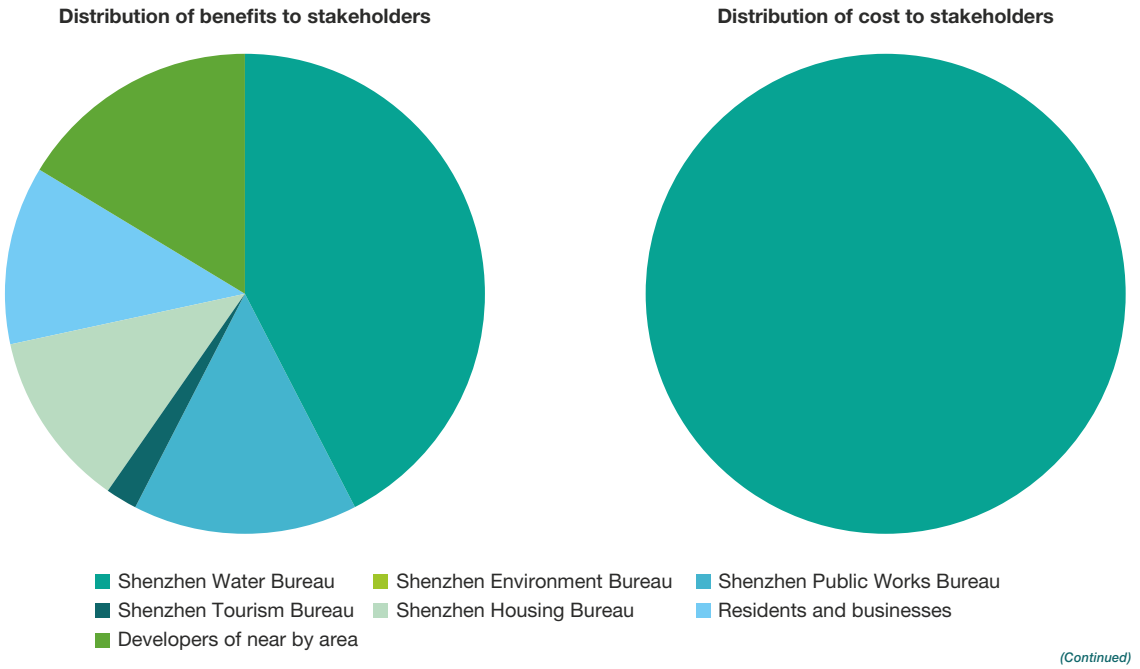
Note: BCR = benefit-cost ratio; NPV = net present value.

Table C.18: **THE CONTRIBUTION OF TOP-RANKED BENEFITS**

Rank	Benefits	Total benefits (RMB million)	Proportion
1	Reduced flood risk	264.58	41.1%
2	Increased property prices from proximity to the project	163.53	25.4%
3	Carbon fixation	91.23	14.2%
4	Reduced investment in water storage infrastructure by maintaining surface water level and groundwater level	90.88	14.1%
5	Other benefits	33.47	5.2%

The distributional analysis of both costs and benefits to all stakeholders are detailed in figure C.5. Because all investment of the project was funded by Shenzhen Water Bureau, there is only one stakeholder contributing to the project cost. For the benefit distribution, Shenzhen Water Bureau allocated about 42.58 percent of the total project benefit, Shenzhen Environment Bureau allocated 0.01 percent, Shenzhen Public Works Bureau allocated 14.57 percent, Shenzhen Tourism Bureau allocated 2.47 percent, Shenzhen Housing Bureau allocated 12.00 percent, residents and businesses allocated 13.00 percent, and developers of nearby areas allocated the remaining 16.00 percent.

Figure C.5: **THE BENEFITS DISTRIBUTION ACROSS STAKEHOLDERS**



(Continued)

Figure C.5: **THE BENEFITS DISTRIBUTION ACROSS STAKEHOLDERS (*Continued*)**

Benefit	Shenzhen Water Bureau	Shenzhen Environment Bureau	Shenzhen Public Works Bureau	Shenzhen Tourism Bureau	Shenzhen Housing Bureau	Residents and businesses	Developers of nearby area
Increased tourism	$0	$0	$0	$16,220,543	$0	$5,561,329	$0
Increased tourism (Trial 2011)	$0	$0	$0	$611,407	$0	$209,625	$0
Reduced water consumption	$14,142	$0	$0	$0	$0	$0	$0
Reduced greenhouse gas emissions, increased CO2 sequestration (Carbon Fixation)	$0	$0	$70,333,521	$0	$0	$0	$0
Reduced greenhouse gas emissions, increased CO2 sequestration (Oxygen Release)	$0	$0	$25,315,806	$0	$0	$0	$17,583,380
Sediment Transportation	$3,434,566	$0	$0	$0	$0	$0	$0
Reduced water consumption (Trial 2011)	$533	$0	$0	$0	$0	$0	$0
Reduced greenhouse gas emissions, increased CO2 sequestration (Carbon Fixation)(Trial 2011)	$0	$0	$2,651,108	$0	$0	$0	$662,777
Reduced greenhouse gas emissions, increased CO2 sequestration (Oxygen Release)(Trial 2011)	$0	$0	$954,238	$0	$0	$0	$0
Sediment Transportation (Trial 2011)	$129,460	$0	$0	$0	$0	$0	$0
Reduced flood risk	$183,110,056	$0	$0	$0	$0	$26,158,579	$52,317,159
Improved air quality	$0	$93,060	$0	$0	$0	$0	$23,265
Reduced flood risk (Trial 2011)	$2,093,458	$0	$0	$0	$0	$299,065	$598,131
Improved air quality (Trial 2011)	$0	$3,508	$0	$0	$0	$0	$877
Reduced investment in water storage infrastructures by maintaning surface and ground water level	$90,884,429	$0	$0	$0	$0	$0	$0
Reduced investment in wastewater treatment infrastructures by water quality improvement	$1,986,277	$0	$0	$0	$0	$0	$0
Residual value of fixed assets 2050	$8,356,375	$0	$0	$0	$0	$0	$0
Increased property prices from proximity to the project	$0	$0	$0	$0	$81,765,828	$49,059,497	$32,706,331
Total benefits (PV)	$290,009,297	$96,567	$99,254,673	$16,831,950	$81,765,828	$81,288,096	$103,891,920
Costs (PV)	$602,308,706	$0	$0	$0	$0	$0	$0
Net Present Value	-$312,299,410	$96,567	$99,254,673	$16,831,950	$81,765,828	$81,288,096	$103,891,920

Note: NPV = net present value.



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D

Case Study—Kunshan Forest Park Renovation



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Urban Context of Kunshan City in Jiangsu Province of China

Kunshan City is located in the southeast of Jiangsu Province. As the east gate of the province, it borders on Jiading and Qingpu districts of Shanghai. Kunshan is located in the Taihu Lake Basin at the Yangtze River Delta, with a dense river network and flat terrain, slightly inclined from southwest to northeast, small natural slopes, and Loujiang and Wusong Rivers running across the central part of the city. The city is divided into three large areas, namely the low-lying area in the north of Loujiang River, the semi-high field area between loujiang and Wusong rivers, and the semi-high field area and the high field area in the south of Wusong River.

Kunshan belongs to the monsoon climate zone. The average annual precipitation of Kunshan City is 1,133.3 millimeters, with great annual difference. The maximum annual precipitation is 1,522.4 millimeters (1991), and the minimum is 826.1 millimeters (1992). The distribution is uneven, with heavy rains at the turn of spring and summer and many storm rains in summer and autumn. The annual average evaporation is 822.2 millimeters, and the annual average temperature is 16.8°C.

Kunshan City has made remarkable achievements in economic and social development. Kunshan has a permanent population of about 1,662,400, including 862,700 registered population. In 2019, the city's gross domestic product (GDP) exceeded RMB 400 billion, amounting to RMB 240,616 per person (US$33,975)—three times China's national GDP per capita of a little more than US$10,000.

Project Context

The Kunshan National Forest Park is located in the western part of Kunshan City. This area is positioned as "an important demonstration area for green development, innovative development and coordinated development of Kunshan City," **(Kunshan Municipal Urban Planning Document)** which plays a significant role in Kunshan's overall development as the Kunshan High-Tech Development Zone. The Forest Park is an ecological link connecting the old urban area with two lakes—that is, Yangcheng and Kuilei. With a total area of about 2 square kilometers, the Forest Park was composed of water surface, wetlands, and vegetation covers.

The Forest Park underwent an ecological renovation in 2016. Taking the opportunity of joint Sponge Cities constructions between Jiangsu Province and Victoria state of Australia, the Kunshan Forest Park began to carry out ecological upgrading and transformation aimed at improving drainage and storage capacity, enhancing the protection and restoration of urban wetlands and ecosystems, integrating the park landscape with urban water management, improving water quality, and so on.

The Forest Park ecological renovation project has generated significant economic, social, and environmental benefits. However, because of the lack of quantitative analysis on those comprehensive benefits versus the construction and operation costs, the project values have not been effectively reflected. This study uses the Investment Framework For Economics of Water Sensitive Cities (INFFEWS) benefit-cost analysis (BCA) tools provided by the Cooperative Research Centre for Water Sensitive Cities (CRCWSC) to quantitatively analyze the comprehensive benefits and costs of the project and further clarify the significance of forest park renovation.

Status before the Renovation Project

Flood Protection

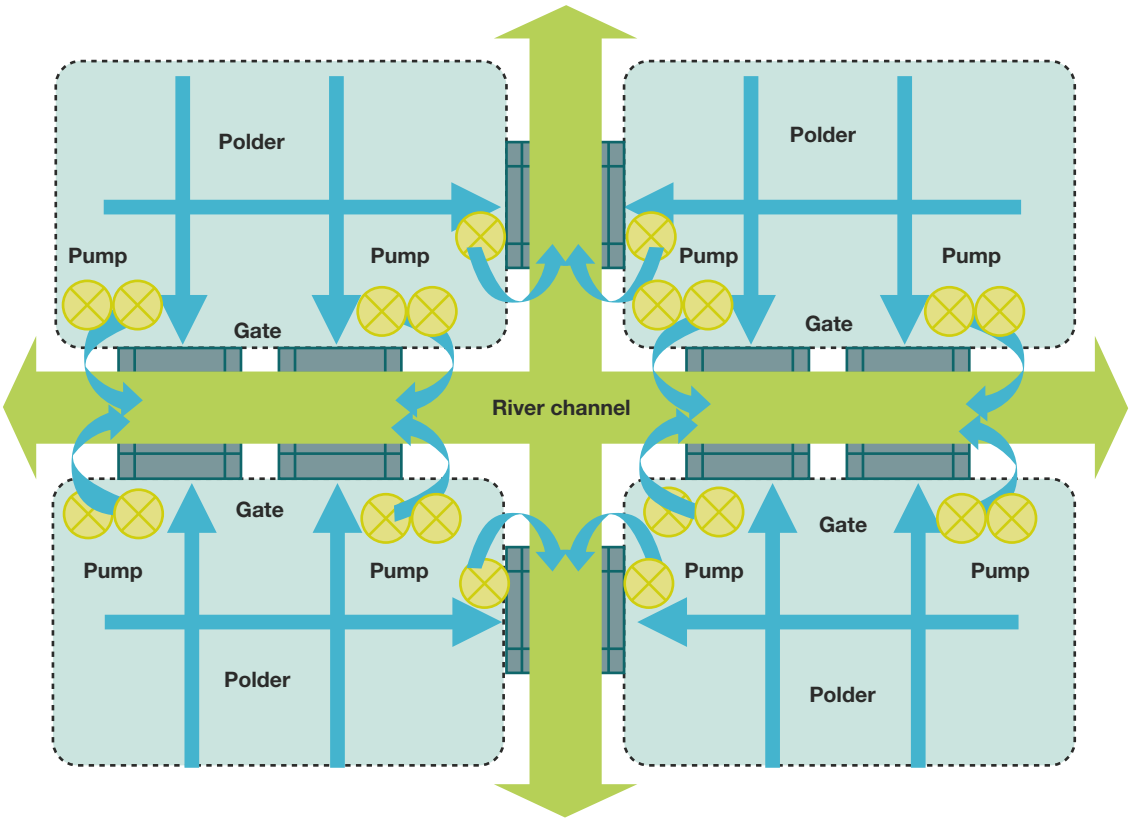
Kunshan mainly adopts the form of polder area for flood control and drainage (Figure D.1). During the rainy season, a closed flood control circle is formed by relying on the peripheral flood control dike to resist the external flood; the internal drainage pump station in the river channel is used to pump the excessive rainwater in the polder area to the external river. The polder area where the Forest Park is located is Jiangpu polder, which belongs to the semi Gaotian area, and mainly drains water to the rivers outside the polder, including Loujiang River, Sichang port, and Yehe River (Map D.1).

Before the renovation project, the water surface in Forest Park was not connected with the river channel in the polder, and the polder area mainly used the river channel for rainwater regulation, storage, and drainage. The total water surface rate in Jiangpu polder was 9.5 percent, but it was mainly composed of the Forest Park lake water

Map D.1: **LOCATION OF THE FOREST PARK**



Figure D.1: **POLDER SYSTEM IN KUNSHAN**



system (about 7.5 percent). However, the water system in Forest Park had not participated in flood detention in the past flood season, and the actual participation in water surface is limited only to the river channel outside the polder (2 percent). With the acceleration of urbanization construction, the types of underlying surface in polder have changed greatly, and the number of impermeable grounds has increased, which leads to waterlogging and ponding during extreme rainstorms, and the waterlogging control standard was less than 30 years.

Therefore, from the perspective of water safety, one of the reasons for the Sponge Cities transformation of the Forest Park is to provide Jiangpu polder with the largest adjustable storage space for rainwater. In doing so, it reduces the discharge pressure to the river in the rainy season and avoids waterlogging that results from poor drainage of the pipe network caused by the river jacking.

Water Environment

Kunshan is close to the upstream of Shanghai. The special political and economic status of Shanghai puts high requirements for wastewater discharge and water environment treatment in the upstream area. Even though in recent years Kunshan water environment management has been strengthened significantly, and the water quality of rivers and lakes has been improved significantly, the overall water quality of Kunshan City is still not optimistic because of the small flow velocity in the area. In 2019, 37 monitoring sections of 31 water functional areas in Kunshan City were measured and the compliance rate of class II, III, and IV was only 59.5 percent, which is lower than the average level of the city of Suzhou.

The main pollution sources of Kunshan River are point source pollution and rainwater nonpoint source pollution. With the increasing treatment of point source pollution in Kunshan City, the water quality pollution comes mainly from nonpoint source pollution and basically from the overflow of combined system pipe network and the surface runoff pollution of initial rainwater. Therefore, it is necessary to improve the self-purification capacity of river channel and strengthen combined system overflow pollution—that is, initial rainwater pollution control is pressing.

According to relevant data, because of the poor water flow before the renovation project, the internal construction is still in the stage of promotion, and the water quality in Jiangpu polder was in class IV and V as a whole. Among them, the Central River of Xiejing across Miaojing polder and Jiangpu polder was a black and smelly body of water. Miaojing River was the channel for transporting water source in Jiangpuwei. The water quality met the class III standard. The raw water of Kuilei Lake flew from west to east through Miaojing River to the water intake of the water source plant, with a total length of about 4.7 kilometers. Along the way, it needs to pass through three traffic arteries, namely Ring Expressway, Gucheng Road, and Zuchongzhi Road. Once the toxic and harmful materials are leaked, the water quality of the raw water and production safety will be affected.

As for Forest Park itself, before the Sponge Cities transformation, the water quality of the lakes was seriously affected by algae in summer, showing a state of eutrophication.

Tourism

As an important ecological park in the west of Kunshan Mountain, the Forest Park project has played an important role in ecology, leisure, tourism, and so on. The park has become a large-scale public theme park, integrating regional environmental improvement, animal and plant diversity protection, leisure tourism, health sports, science popularization, and education. According to statistics, since 2007, the number of tourists received each year has exceeded 1 million, becoming an important tourist and leisure resort in Kunshan.

The Establishment of the Kunshan Forest Park Company

A joint venture construction company was established with Kunshan University Park, on the one hand providing supporting services for the construction of the park and university town, on the other hand providing related services to the society, including building a comprehensive building together with a real estate developer in Kunshan and jointly developing commercial and residential land projects west of Hongqi Road and south of Ma'anshan Road. The company has jointly funded the establishment of a property management company to provide relevant services to the community, which gives full play to the company's own advantages to provide the community with landscaping, seedling sales, and other businesses. These market-oriented operations drive the daily operation and maintenance of the park and produce good economic benefits and commercial value.

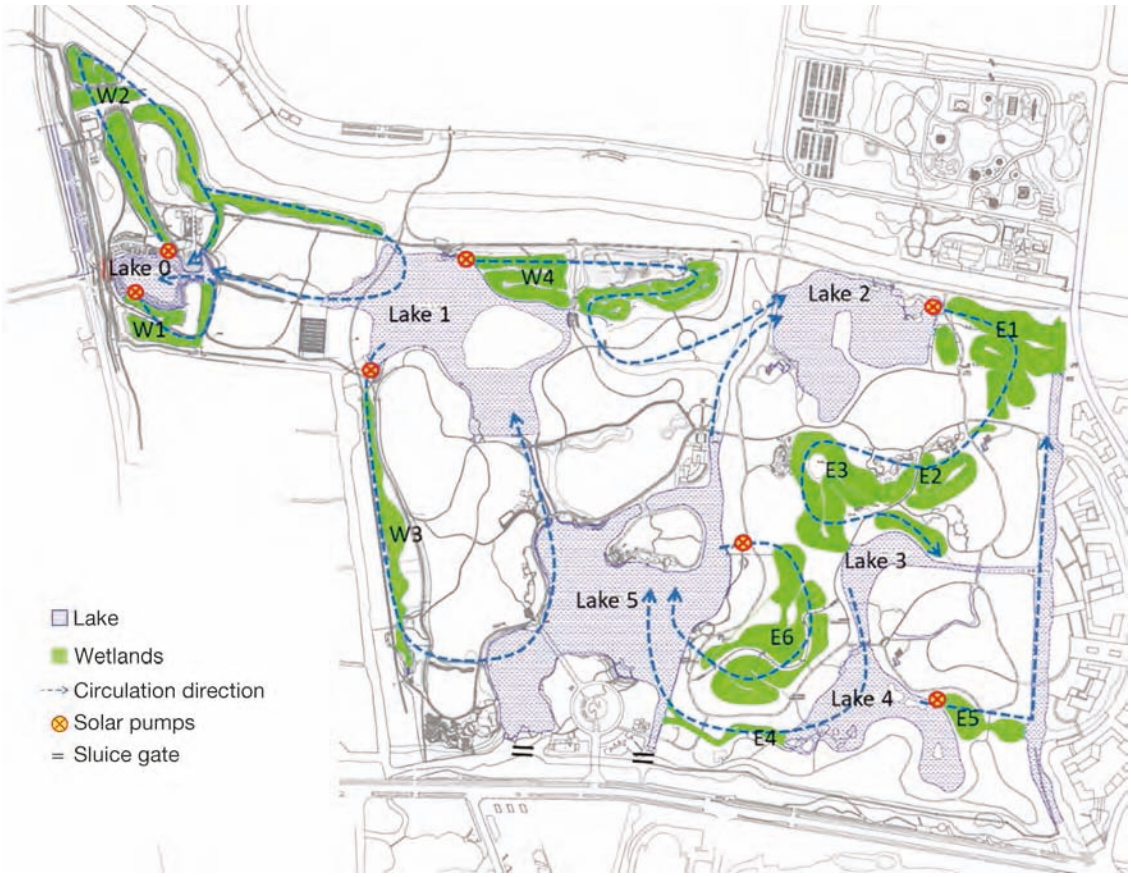
Project Design

This project aims to build the Forest Park to be multifunctional and simultaneously implements the landscape and Sponge Cities transformation engineering designs, with the following objectives:

- **Connect the Forest Park with the surrounding water systems to improve the circulation of water system and the water quality of the park**
- **Improve the drainage and storage capacity of the surrounding areas by enhancing the polder system of the Forest Park for rainwater regulation and storage**
- **Improve the urban ecosystem diversity at the park by land and water ecosystem restoration**

Water circulation wetlands: Several water circulation wetlands are constructed in the park. Water is continuously pumped from the lake through the wetlands and then returned back to the lake by small solar pumps to continuously remove water pollutants, such as nitrogen and phosphorus. At the same time, the lake system is

Map D.2: **LAYOUT AND OPERATION DIAGRAM OF RECYCLING WETLANDS IN FOREST PARK**



used as rainwater storage space in the polder area to improve the effective water surface rate and the overall flood control capacity of the area.

According to the design standard of maximum 30-day turnover time and five-day hydraulic retention time in the river, the area of wetlands required for the ideal management of water quality of deep-water lake in Forest Park is about 29 hectares. Wetlands distribution and operation process are shown in map D.2.

Ecological improvement: The original vegetation types and areas in the park were constructed for landscape purposes without considering ecosystem diversity. The bird island with relatively little development but higher ecological potential and the surrounding areas are specially selected to implement both active and passive ecological restoration strategies. Passive restoration strategies include stopping bank gardening, increasing the difficulty of walking, and so forth. Active restoration strategies focus on large-scale dead tree branch planting at the bank of the bird island.

Project Cost-Benefit Analysis

Evaluation period and discount rate: The INFFEWS BCA tool can analyze the appraisal project for as long as 50 years. Therefore, in combination with the construction data of Kunshan Forest Park project, the starting year

of the project is 2016 and the analysis period is set as 50 years. The discount rate in China is generally set at 8 percent, and the fluctuation of high and low discount rate provided by BCA user guide is ±3 percent.

Cost analysis: The total cost of the Sponge Cities transformation project of the Forest Park consists of two parts: the project construction cost and the operation and maintenance cost after the completion of the project. The total construction cost is about RMB 21.1 million (about US$3 million). According to relevant project materials, the operation and maintenance cost is about US$0.039 million per year. Because the construction phase occupies four years, the operational phase makes up the remaining 46 years, and the total project operation and maintenance cost is about US$1.8 million (Table D.1).

Table D.1: **BREAKDOWN OF EXPENSES IN EACH STAGE**

Period	Period (year)	Cost (US$ million/year)	Total cost (US$ million)
Construction period (I)	2016–19	0.75	3.00
Operational period (II)	2020–65	0.039	1.80

BENEFIT ANALYSIS:

Ecological and biodiversity improvement: The estimated benefit per hectare is US$405, and the estimated value is US$25,515 (US$405 × 210 hectares × 30 percent) one year after the reconstruction.

Air quality improvement: The Forest Park can improve the air quality in its surrounding areas. The number of beneficiaries is estimated at 75,000 based on the residential population in the 500- to 800-meter surrounding areas. The benefit per person is estimated at US$28.

Water quality improvement: This benefit is calculated as the avoided treatment cost for water quality, odor, and other related issues. It is calculated that the total removal amount of Nitrogen Ammonia (NH_3-H) and Total Phosphorous (TP) are 7,540 and 2,610 kilograms per year, respectively. The costs for their removal are RMB 15 and RMB 12 per kilogram, respectively.

Flood risk reduction: The Jiangpuwei polder area is about 485 hectares. The Forest Park renovation project increases the standard for flood control in this polder area from a 20-year to 50-year return period. The flood losses before and after the project are obtained from statistical data and project materials.

Commercial value increase: After the completion of this project, the income of retail stores, parking lots, and water entertainment facilities in the park will increase compared with that before the project. According to statistics, the annual business income will increase by RMB 410,000 (about US$58,000).

Real estate value increase: Taking Kunshan Ecological Forest Park as the starting point, the distance of some communities was measured. According to the survey distance and the wetlands area, the house price growth rate (based on the minimum value) can be obtained according to the INFFEWS Value tool, as shown in table D.2.

Kunshan Ecological Forest Park covers an area of 2,100,000 square meters. The floor price of Wanfang Jiangnan forest villa community next to the park were about RMB 41,000 per square meters in April 2018 and RMB 54,000 per square meter in April 2020; the floor price of Hefeng Yasong community in April 2018 and April 2020 were about RMB 22,000 per square meter and RMB 29,000 per square meter, respectively; the floor price of Zhongda future city community in April 2018 and April 2020 were about RMB 22,000 per square meter and RMB 28,000 per square meter, respectively. The real estate prices of Qingfeng Huayuan community in April 2018 and April 2020 were about RMB 22,500 per square meter and RMB 27,000 per square meter, respectively; the real estate prices of Kangju Jiangnan community in April 2018 and April 2020 were about RMB 17,500 per square meter and RMB

Table D.2: **DISTANCE WITH REAL ESTATE VALUE INCREASE**

Compound name	Distance to the park (m)	Size (m^2)	Plot ratio	Minimal growth rate (%)
Wanfang Jiangnan	800	30,000	0.35	1.37
Hefeng Yasong	950	360,000	1.49	1.13
Zhongda	1,200	450,000	2.48	0.85
Qingfeng Huayuan	1,400	350,000	1.59	0.69
Kangju	1,500	72,000	1.6	0.62
Nanhuayuan	1,800	-	2.3	0.47

Note: m = meter.

27500 per square meter, respectively; the real estate prices of Nanhuayuancommunity in April 2018 and April 2020 were about 18,000 per square meter and RMB 22,000 per square meter, respectively. It is estimated that the total benefit of the aforementioned six buildings in 45 years (2020–65) after the completion of the park project reconstruction is RMB 70 million (about US$10 million converted), which is divided into US$222,000 each year.

Reduced water consumption: The project enhances water circulation and reduces water consumption for planting and gardening purposes. According to the annual water consumption reduction amount and water price in Kunshan, the total benefit amounts to RMB 0.858 million (US$0.122 million) per year.

Health benefits: The Forest Park reduces sickness caused by extreme high temperature. Literature shows that 20 percent of people suffer from extreme heats, so assuming that 90 percent reduction can be achieved, 13,500 people will benefit. It is assumed that each person spends US$193 on extreme heat.

Reduced greenhouse gas emissions: The number of trees is estimated to be 50,000 in the park, and each tree is able to capture 1.83 tons of carbon dioxide every year. The social cost of each ton of carbon dioxide is estimated at US$16.

The comprehensive benefits of the Kunshan Forest Park renovation project is estimated in table D.3.

Table D.3: **COMPREHENSIVE BENEFITS OF KUNSHAN FOREST PARK RENOVATION PROJECT**

Type of benefits	Benefits (US$ million)	Percentage (%)
Health benefits	23.244	38.90
Air quality improvement	18.734	18.21
Greenhouse gas reduction	7.137	6.94
Reduced flood losses	6.843	6.65
Increased real estate values	1.963	1.91
Reduced water consumption	1.084	1.05
Increased commercial values	0.517	0.5
Water quality improvement	0.182	0.18
Biodiversity improvement	0.049	0.05

Overall, it can be seen from table D.4 that, based on the INFFEWS BCA tool, when discount rate is set at 8 percent, the total net present value (NPV) is US$57.91 million. Compared to the total cost of US$2.8 million, a total benefit-cost ratio (BCR) of 49.63 can be realized. For the project organization, the Kunshan Forest Park Company, the total NPV is US$3.07 million, compared with its total investment of US$1.13 million, generating an investment BCR of 2.71. In conclusion, this project is expected to generate significant financial profits and overall economic benefits (Table D.4).

Through 1,000 times robustness analysis on different parameters, it is shown that the possibilities of project overall NPV and NPV for the project organization being positive are both 100 percent. The overall NPV ranges from US$24.97 million to US$70.99 million, and the NPV for the project organization ranges from US$0.047 million to US$3.117 million (Figure D.2).

Assuming the target BCR is 2 percent, there is 100 percent possibility for the overall BCR to reach that goal and 77 percent possibility for the project organization to reach the target. The overall BCR is most likely to be 46.82 (38 percent possibility), although for the project organization, its BCR will most likely be 2.59 (39 percent possibility) (Table D.5).

Sensitivity analysis on discount rate shows that lower discount rate corresponds to even higher BCR. Under a discount rate of 5 percent, overall BCR and BCR for the project organization can reach 73 and 3.93, respectively. Even under a high discount rate of 11 percent, overall BCR and BCR for the project organization still amount to 35.95 and 1.99, respectively, indicating the forest park project is a profitable project (Table D.6).

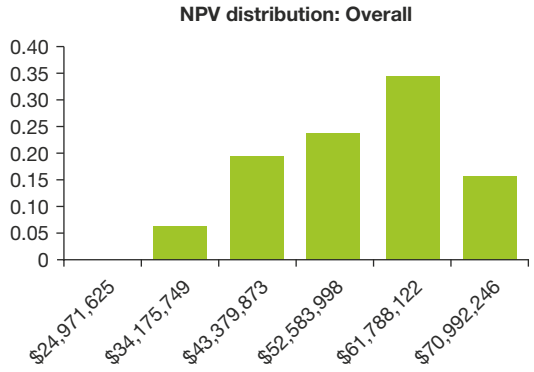
Table D.4: **RESULTS OF BCA ANALYSES FOR OVERALL PROJECT AND FOR PROJECT ORGANIZATION**

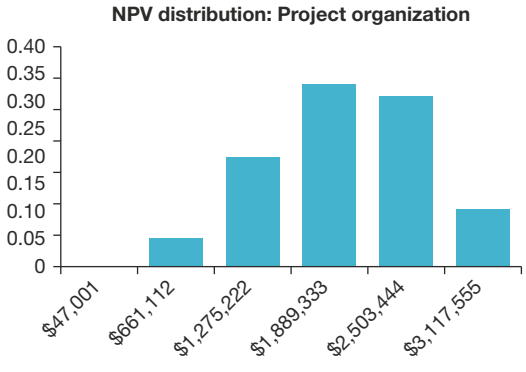
Overall BCA results		
	$57,915,880	(adjusted for adoption and project risk)
Benefits (present value) Costs (present value)		
– Project organization	$1,132,811	
– Other stakeholders	$1,699,217	
– Excess burden	$0	
Net Present Value (NPV)	$55,083,852	
Benefit: Cost Ratio (BCR)	49.63	= (Benefits – Other costs – Excess burden)/Project org. costs
Results attributable to project organization		
Benefits (present value)	$3,066,018	(adjusted for adoption and project risk)
Costs (present value)	$1,132,811	
Net Present Value (NPV)	$1,932,207	
Benefit: Cost Ratio (BCR)	2.71	

Note: BCA = benefit-cost analysis; BCR = benefit-cost ratio; NPV = net present value.

Figure D.2: **SENSITIVITY ANALYSIS ON ALL PARAMETERS**

Distribution, Up to...	Probability	Distribution, Up to ...	Probability
$24,971,625	0.00	**$47,001**	0.00
$34,175,749	0.06	**$661,112**	0.05
$43,379,873	0.20	**$1,275,222**	0.20
$52,583,998	0.24	**$1,889,333**	0.33
$61,788,122	0.35	**$2,503,444**	0.31
$70,992,246	0.15	**$3,117,555**	0.10
Total	1.00	**Total**	1.00





Note: NPV = net present value.
Height of each bar = relative frequency of results between that NPV and the next lower NPV.

Table D.5: **POSSIBILITY OF BCR REACHING 2**

Default case	49.63	Default case	2.71
Mean	48.09	Mean	2.63
Median	46.37	Median	2.5I
Probability that BCR > 1	1.00	Probability that BCR > 1	1.00
Target BCR	2	Target BCR	2
Probability BCR > Target	1.00	Probability BCR > Target	0.77
Distribution. Up to ...	**Probability**	**Distribution. Up to ...**	**Probability**
17.96	0.00	1.03	0.00
32.39	0.14	1.81	0.15
46.82	0.38	2.59	0.39
61.25	0. 30	3.37	0.28
75.68	0.12	4.15	0.11
90.11	0.07	4.93	0.07
Total	1.00	Total	1.00

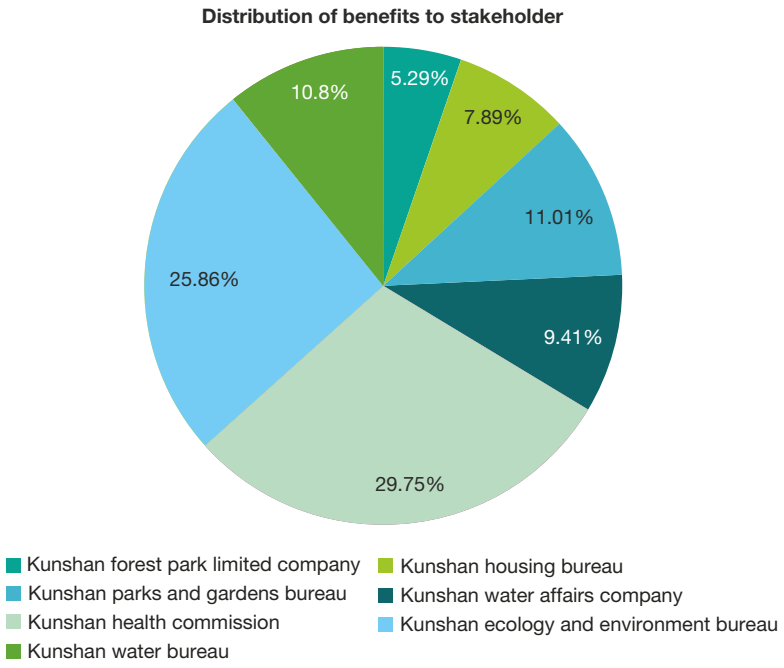
Note: BCR = benefit-cost ratio.

Table D.6: **SENSITIVITY ANALYSIS ON DISCOUNT RATES**

Sensitivity to discount rate			
Overall	**Low discount rate 0.05**	**Default discount rate 0.08**	**High discount rate 0.11**
Benefits (present value)	$94,405,769	$56,216,663	$36,788,529
Costs (present value)	$1,293,261	$1,132,811	$1,023,385
Net Present Value (NPV)	$93,112,508	$55,083,852	$35,765,143
Benefit: Cost Ratio (BCR)	73.00	49.63	35.95
Project organization	**Low discount rate 0.05**	**Default discount rate 0.08**	**High discount rate 0.11**
Benefits (present value)	$5,077,424	$3,065,018	$2,034,019
Costs (present value)	$1,293,261	$1,132,811	$1,023,385
Net Present Value (NPV)	$3,784,163	$1,932,207	$1,010,634
Benefit: Cost Ratio (BCR)	3.93	2.71	1.99

Analysis on the beneficiaries has shown that though Kunshan Financial Bureau and Kunshan Forest Park Company are the two main funders for the project, the benefits are widely distributed among seven main stakeholders. Among them, Kunshan Health Commission benefits the most with 29.75 percent as a result of the improved health benefits, followed by Kunshan Ecology and Environment Bureau with 25.86 percent, followed by the improved air and water quality (Figure D.3).

Figure D.3: **DISTRIBUTION OF BENEFITS TO DIFFERENT STAKEHOLDERS**





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E

Nonmarket Valuation Methods and Flood Risk—An Overview



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Integrated water infrastructure projects should be evaluated against economic criteria and shown to be economically viable once all the social and environmental considerations have been considered. Although the appropriate framework for project evaluation is understood, there are practical difficulties regarding the estimation of the social, economic, and environmental impacts of projects required for a complete economic evaluation.

In most applications, the market price for a good or service would be a basic building block in the economic evaluation process. The market price provides clear information on the extent of private benefits to purchasers of a good. The social and environmental costs and benefits are then used to augment this initial market-derived value, and these values are captured via the use of nonmarket valuation methods.

These methods normally used by economists to capture the monetary value of environmental goods and services have limitations and are not universally applicable. Although there are several conceptual approaches, the two main groups of nonmarket valuation methods are revealed preference methods, which include the travel cost method and the hedonic price method, and stated preference methods, which include the contingent valuation method and choice experiments. The main difference is that the former estimates the value of environmental goods and services based on observed real-world consumer behavior, whereas the latter relies on information from community surveys in which respondents are asked about hypothetical scenarios.

The main limitation of the revealed preference method is that, because it is based on observed consumer behavior, the approach can capture information only on the "use values" associated with assets. Use values are the benefits from direct or indirect utilization of natural resources. Nonuse values are benefits that accrue from environmental resources without a person directly using them—these include option value, existence value, and bequest value. None are captured in revealed preference analysis. Both use and nonuse values can be estimated using stated preference methods, although these methods in turn have a range of limitations, including problems with survey respondents not having enough information to understand the nature of the tradeoffs they are being asked to make and general issues regarding the validity of values inferred from hypothetical scenarios in which real-money transactions do not take place.

In addition to the main stated preference and revealed preference valuation methods, there are several other methods that can be used to obtain information on nonmarket values. These additional approaches include the averting behavior method, which is based on cost analysis, and the dose response method, which is based on examining the physical process of environmental impacts and estimating the losses (or avoided losses) from environmental degradation (or environmental quality improvement). The focus on costs, or avoided costs, distinguishes these methods from the revealed preference and stated preference methods that focus on benefits.

A brief overview of each method is presented here.

Averting Behavior Approach

The averting behavior or averting cost approach estimates values through examining the costs that consumers incur if a service is not available. For example, if drainage and associated groundwater flood protection is not of a sufficient standard, averting behavior could include the costs associated with installing and maintaining household-level pumping infrastructure. Consumers may, however, have been willing to pay an amount substantially greater than this for the convenience of having an effective central drainage service. The averting behavior approach can therefore be seen as finding the lower-bound estimate to consumers' willingness to pay (WTP) for the improvement of environmental goods and services.

In terms of using insurance costs as a measure of flood costs, Chivers (2001) argues that insurance expenses may fail to accurately predict potential flood damage risks as people underestimate damages before a significant flood event and overestimate risks after it. For example, Bin and Polasky (2004) compared house price differences pre- and post-Hurricane Floyd for homes on the floodplain in North Carolina, USA. They found that the house price discount doubled within flood zones after Hurricane Floyd. This discounted price was also significantly higher than the net present value (NPV) of the additional insurance premiums, which means residents would be willing to pay a much higher value to avoid flood risks than the actual required insurance fees.

Stated Preference Techniques

The contingent valuation method relies on creating hypothetical market scenarios and is a specific type of stated preference technique. It seeks to uncover individual preferences for changes in the quantity or quality of a nonmarket good or service in the format of individuals' WTP. Using this method, respondents' WTP for an environmental good is asked directly, and historically the contingent valuation method has been the most commonly used stated preference method in environmental economics research (Carson et al. 2001). An example of a representative question format is as follows: *Would you pay $X every year, through a tax surcharge, to support a program to improve water supply services?* An advantage of the contingent valuation method is that it can capture the public's reaction to each pricing level and establish an upper-bound estimate of the value of changes in environmental conditions, which can then be used by policy makers when considering investment decisions (Wang et al. 2010).

A common criticism of the contingent valuation method is that it may not be able to capture the true value of an environmental good or service because people may not answer truthfully. Respondents may intentionally understate their true value or seek to "free ride" on the responses of others, which leads to invalid results (Lindsey and Knaap 1999). It is argued that the choice experiments approach can overcome this problem because respondents are asked to choose among alternatives, and that represents a more realistic decision framework (Alberini and Kahn 2006). For this reason, choice experiments are increasingly seen as preferable to contingent valuation for most environmental asset valuation applications. The other common criticism of the contingent valuation method is that the value derived from it is sensitive to the level and extent of information provided by the respondents (Wang et al. 2010).

Choice experiments, as applied to nonmarket valuation scenarios, is a technique that comes from the conjoint analysis literature of marketing. In marketing applications, conjoint analysis is used to determine the attributes of goods that consumers see as important. In environmental economics applications, choice experiments may be thought of as a generalization of the contingent valuation method (Snowball et al. 2008). With choice experiments, consumers are not asked directly how much they would be willing to pay to achieve some specific environmental improvement. Rather, they are asked to choose their preference from a series of alternatives that differ in terms of the attributes and the levels of attributes (Bateman et al. 2002). One representative question is as follows: *Which one of the following schemes do you favor, and which one would you be least likely to choose? Please keep your financial conditions in mind while answering.* Note that one of the options presented to respondents is the example of a choice sets as shown in table E.1. A status quo option that allows the respondents to select the option of no change in environmental conditions at no cost is a feature of all choice sets.

Table E.1: **ILLUSTRATIVE EXAMPLE OF A CHOICE SET USED IN THE CRC WASTEWATER BUFFER ZONE SURVEY**

There are 4 different land use categories below to consider in each option	Option 1 (Current situation)	Option 2	Option 3
Nature conservation areas 	No change: 30%	10%	50%
Commercial /industrial areas 	No change: 30%	20%	10%
Agricultural areas 	No change: 30%	50%	30%
Sporting and recreation areas 	No change: 10%	20%	10%
There is an increase in your service provider's bill (e.g. water bill) for each option (in $ per **quarter**)	$0	$21	$39
Most preferred option			
Least preferred option			

Source: Zhang et al. 2015a.
Note: CRC = Cooperative Research Center

Both the choice experiments method and the contingent valuation method rely on survey techniques and have specific strengths and weakness. An advantage common to both is that they involve public opinion in the decision-making process, and both allow use and nonuse values to be estimated (Bennett and Blamey 2001). The main difference is that the choice experiments method allows the valuation of the characteristics or attributes of the environmental good or service, whereas the contingent valuation method arrives at an estimate of the environmental good or service as a whole (Bateman et al. 2002).

One criticism of the choice experiments method is that it assumes respondents view the sum of the attributes as equal to the whole value of an environmental good or service, which may be incorrect (Louviere et al. 2000). Using this method, respondents are also required to understand the differences in each option, in which multiple attribute levels are varied. The relative complexity of the question format means that there are concerns about respondents using decision heuristics to simplify their decision-making process, in which case the results from the study would be biased. A detailed discussion of this issue is presented in Bennett and Blamey (2001).

Contingent Valuation Studies

Thunberg and Shabman (1991) used the contingent valuation approach to analyze the determinants of WTP for flood control projects of the residents of the city of Roanoke in Virginia, USA. The analysis was

based on a relatively small sample size (74 usable responses) and focused on owners of flood-prone land. The results show that property protection aspects will influence residents' WTP for flood control investment and nonproperty considerations, such as reduced psychological stress and reduced community disruptions.

The contingent valuation method is used in Bateman et al. (1995) to estimate the WTP in Broadland, U.K., for a multifunction project that included a flood control function. Based on 344 responses, the mean WTP was estimated to be £21.75 per year per household to build flood defense works.

Zhai and Ikeda (2006) investigated the WTP of residents in the cities of Toki and Nagoya, Japan, to avoid the inconveniences caused by flooding, such as evacuations. Based on 1,259 responses, the study found that the mean WTP was ¥1,030 per person per night. The authors stated that household income, individual preparedness, and flood experiences played a significant role in determining the WTP value.

Brouwer and Bateman (2005) examined residents' WTP in East Anglia, U.K., to conserve wetlands that had a flood control function. The study relied on 1,747 completed surveys and found a mean WTP of about £216 per year per resident. In the study, the percentage contribution to total value attributed to the flood control function was not separated from the other functions of the wetlands.

Revealed Preference Techniques

The basic premise of the hedonic price method is that the price of a market good is related to its characteristics, or the services it provides. This method is most commonly applied to estimate the value of local environmental attributes through modeling the variation in house prices. The central idea is that the value of a house can be decomposed into a set of main characteristics, such as lot size, building area, number of bedrooms, or distance to the city center, as well as social and environmental characteristics, such as crime rate, whether there are schools and universities nearby, proximity to environmental assets, such as wetlands, and so on. The hedonic regression approach treats the hedonic good as weakly separable in the consumer utility function such that consistent estimates of an implicit price for each attribute can be obtained.

There are generally accepted standards available for property valuations, such as Uniform Standards of Professional Appraisal Practice (USPAP) in the United States, Generally Accepted Valuation Principles (GAVP) in Germany, and Australian Property Institute (API) Valuation Standards in Australia. These standards help establish acceptable general equations considering different characteristics. Another advantage of the method is that the required house price data are generally available in a relatively open and transparent market. Thus, although the statistical issues involved in the estimation of a hedonic price model can be significant, the method is often the least difficult to implement.

The travel cost method is especially popular for estimating recreational values (Ward and Beal 2000). It aims to convert the physical and social benefits produced by outdoor recreation, such as river, dam, and beach visits into monetary terms (Ward and Beal 2000). The basic theory behind the travel cost method in valuing nonmarket goods, especially recreational sites and recreational activities, is that the travel cost is the implicit price visitors pay for their trip to access sites or to be able to take part in particular activities (Becker et al. 2005; Phaneuf and Smith 2005). Through analyzing the relationship between the travel costs (price) in accessing a recreational site and the number of visits per year to this site (demand), a demand curve relating the two can be found. An advantage of the travel cost method is the consistency with consumer demand theory—that is, the higher the cost, the fewer the visits. One major limitation of this method is that nonusers are normally not sampled; therefore, only use value can be captured (Ward and Beal 2000).

Hedonic Price Studies

Streiner and Loomis (1995) calculated the property value changes in the United States following urban stream restoration measures, including flood protection measures. The authors found that flood damage reductions and stream stabilizations together can add about 3 to 5 percent to the value of properties. Note, however, that from the information contained in the paper, it is not clear exactly how specific values were obtained.

The hedonic price method is used in Harrison et al. (2001) to estimate the housing discount for homes in the 100-year floodplain. The data for the study relate to the period 1980–97 and are for Alachua County in Florida, USA. The discount for being in the 100-year floodplain was found to be about US$3,000. The authors also note that the NPV of the additional insurance premiums associated with a home on the 100-year floodplain are more than the discount in the capital price of a home on the floodplain.

Daniel et al. (2009) provided a meta-analysis of economic impact from reduced flooding risk. They used 19 studies from the United States in their analysis and found that an increase in the probability of flood risk by 1 percent in a year could result in 0.6 percent reduction in prices for an otherwise similar house. It was observed that, with time, the marginal WTP for reduced risk exposure has increased and higher-income areas have slightly lower WTP. However, these estimates could be sensitive to the interactions of amenity benefits and risk exposure from living closer to water.

Stage-Damage Method

Another method that can be used to estimate costs relies on the use of stage-damage curves. Following Smith (1994), this approach can be implemented as follows:

- **Select the individual land use categories for analysis.**
- **Identify the main characteristics of a flood (such as depth, duration, velocity, and load).**
- **Within each land use category, identify significant subgroups of building types (such as one- or two-story houses, houses with a basement, and so on).**
- **Use the main characteristics (or variables) of the flood to establish relationships between the variables and damages (such as deriving a depth damage curve) for each land use subgroup.**
- **Use the other flood characteristics, such as velocity, to modify the base curve. For example, the stage-damage curve could have low-, medium-, or high-velocity variants.**

With the assistance of Geographical Information System (GIS) methods and hydrological modeling techniques, it is then possible to build flood damage assessment models to evaluate the damages caused by flood events. Existing models of this type include the HAZUS model from the United States (FEMA 2012b) and the NHRC model (Leigh and Kuhnel 2001) developed by Macquarie University in Australia. Both are capable of generating stage-damage curves, which can be used to estimate the damage costs caused by floods under various conditions.

The state of Queensland (2002) provided stage-damage relationships for residential (table E.2) and commercial properties (table E.3), and it can be seen that damage cost increases with higher flood depth. It should, however, be noted that the state-damage curve captures only the direct costs. Often a rule of thumb is used to calculate indirect costs. For example, for residential properties, it might be assumed that indirect damage is 15 percent of the direct damage, whereas for commercial properties, the indirect cost might be estimated as 55 percent of the direct cost. Note indirect damages do not consider intangible costs and risk mitigation costs. Furthermore, these cost functions show only potential damage. Actual damage could be lower or higher, depending on the preparedness of the community.

Table E.2: **STAGE-DAMAGE RELATIONSHIPS FOR RESIDENTIAL PROPERTIES**

Depth over floor level (m)	Small house: <80 m² and/or 1–2 bedrooms	Medium house: 80–140 m² and/or 3 bedrooms	Large house: >140 m² and/or 3+ bedrooms
0	905	2,557	5,873
0.1	1,881	5,115	11,743
0.6	7,370	13,979	25,351
1.5	17,379	18,585	32,276
1.8	17,643	18,868	32,768

Source: The state of Queensland 2002.
Note: m = meter.
The numbers are AUD in 1992.

Table E.3: **STAGE-DAMAGE RELATIONSHIPS FOR COMMERCIAL PROPERTIES IN QUEENSLAND**

Depth over floor level	Value class				
	1	2	3	4	5
Small commercial properties (<186 m²)					
0	0	0	0	0	0
0.25	2,202	4,405	8,809	17,618	35,237
0.75	5,506	11,011	22,023	44,046	88,092
1.25	8,258	16,518	33,034	66,069	132,137
1.75	9,176	18,352	36,705	73,410	146,819
2	9,726	19,454	38,907	77,814	155,628
Medium commercial properties (186–650 m²)					
0	0	0	0	0	0
0.25	6,975	13,948	27,896	55,791	111,583
0.75	16,884	33,768	67,537	135,074	270,147
1.25	25,693	51,387	102,773	205,574	411,094
1.75	28,445	56,893	113,785	227,570	455,140
2	30,281	60,564	121,126	242,252	484,504
Large commercial properties (>650 m²)					
0	0	0	0	0	0
0.25	7	15	32	61	122
0.75	39	78	154	308	619
1.25	81	162	326	649	1,297
1.75	132	267	533	1,065	2,129
2	159	318	636	1,272	2,545

Source: The state of Queensland 2002.
Note: m = meter.
Examples under individual value classes: 1: florist, garden centers, sports pavilions, consulting rooms, vehicle sales areas, schools, churches; 2: cafés/takeaway, service stations, pubs, second hand goods, clubs; 3: chemists, musical instruments, printing, electronic goods, clothing; 4: bottle shops, cameras; and 5: pharmaceuticals, electronics. The numbers are AUD in 1992.

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