Ancient cities in Asia have witnessed floods over many centuries, but not as often and not as intense as the floods that have occurred in the past decade. Floods have become the result of greater interaction between human society and the natural environment, exacerbated by urbanization and climate change. This publication illustrates the more recent and unprecedented flood devastations in Bangkok, Beijing, and Manila and some of the international best practices in urban floodwater management. Following the pillars of “Green Cities Development,” it proposes an holistic approach, combining structural and nonstructural measures and seeking multifunctional solutions, in managing today’s urban floods.
Unflooding Asia
The Green Cities Way

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Contents

Flooding in Asia
   Metro Manila
   Bangkok
   Beijing
   2
   15
   21
   27

The Green Cities Way of Managing Floods in Urban Areas
   34

Learning from International Best Practices
   62

Implementing Green Cities: The Case of Beijing's Stormwater Management Initiatives
   68
Flooding in Asia

Asia has been the victim of the most destructive floods in recent history.
Countless lives have been lost.

The environment has been heavily damaged.
The fragile economies of the region’s developing countries have suffered considerable losses.
They face greater risks, as they absorb more and more people from rural communities.

Asia’s cities are the more prominent targets, especially those on coasts or along rivers.

Too many people, too many businesses, and the unstoppable expansion of slums have made cities and other urban areas more vulnerable to floods and flood related disasters.

Like mushrooms after the rain, urban slums have grown rapidly on riverbanks, clogging cities’ waterways.
Randomly disposed garbage block urban drainage channels and waterways, especially in slums.
Sewage and stormwater runoff, when left untreated, contaminate rivers and groundwater and the settled deposits from the sewage also block urban drainage systems.

Lack of stormwater and drainage systems contributes to flooding, and when mixed with solid waste and wastewater, the problem worsens.
Cities have been fighting floods for centuries. But despite advancements in engineering and technology, urban flooding continues, if not, increased in regularity and intensity.

Today’s floods are no longer caused by nature-related processes alone. Floods are the result of greater interaction between human society and the natural environment.
Increasingly, communities are learning to “live with flood risk” to be better prepared to respond to such disasters.

Traditional “flood defense,” “flood control,” and other engineering measures now seem inadequate.
Types of Floods in Urban Areas

Flooding in urban areas can be one or a combination of different types according to causes.

**Fluvial floods** are generally due to overflowing of rivers and failure of flood defenses.

**Flash floods** are a sudden, often destructive rush of water from a high or over sloping area, caused by heavy rainfall.
FLOODING IN ASIA

Pluvial floods are caused by heavy rains directly over urban areas whose volume exceeds the capacity of drainage systems.

Groundwater floods are caused by saturation of soil and the rise of the groundwater.

Coastal floods are caused by tidal or storm surges in cities close to coasts or in deltas.
Besides rapid urbanization, floods today are also caused by unusually heavy rains, shrinking of flood plains, weak flood management practices, and inefficient drainage systems.

Many cities have been the victim of these extreme climate events, and many more of such events are expected in the near future.
In Asia, Manila, Bangkok, and Beijing have experienced these flood disasters in the past decade.

Extreme rainfall events due to climate change have made floods more frequent and destructive.
Metro Manila
In October 2009, typhoon Ondoy (International name: Ketsana), brought a month’s worth of rain in just 12 hours.
Many families living in slums were displaced. They had to seek shelter in schools, churches, and evacuation centers.
Ondoy was the most devastating typhoon to hit Manila in the last 5 years.
It affected close to 5 million people; half a million of them were forced to leave their homes.
In 2011, Bangkok experienced one of the worst floods in recent history.
From March to August, heavy and successive rainfall up north joined forces with five tropical storms. The floodwaters ravaged provinces until it reached the city.
Bangkok's drainage system, enlarged and improved in the past 20 years, has been able to absorb water during monsoon seasons with average rainfall. But not this year.
The flood affected more than one-third of the country, killed hundreds of people, destroyed millions of hectares of crops, and forced thousands of factories to close.

Bangkok has not seen this great volume of floodwaters since the great flood in 1940.

Slums close to natural drainage canals suffered the highest toll. People had to be relocated outside the city.
Beijing was hit with some of the worst floods two years in a row in 2011 and 2012.
In June 2011, Beijing received the heaviest torrential rains that year. Citizens were stranded as floodwaters claimed many roads and forced the closure of subway stations.
In July 2012, a flash flood hit the city again. Within one day of the flooding, more than 50,000 people were evacuated and more than 70 perished.
Furthermore, these twin flood events resulted in waterlogging. Waterlogging happens when there is too much water in the soil.
The 2011 flood, in particular, caused water logging in more than 70 locations.
The Green Cities Way of Managing Floods in Urban Areas

A new, holistic way of thinking is needed to unflood Asia.
Cities are now home to about half of the world’s population, generate close to 80% of gross domestic product, and serve as global economic hubs. In Asia, developing countries’ economies rely highly on the growth of cities.
Rapid urban growth, however, comes with overpopulation that often leads to the overuse of natural resources and long-term environmental damage that primarily affects the urban poor.
For cities to continue to grow, environmental decline needs to be addressed in a sustainable way.
Environmental sustainability, therefore, holds the key to the survival and economic development of Asian cities.
Green cities development is concerned with how to design the whole city in a way that is more sustainable, efficient, adaptive, and resilient.

It offers a holistic perspective that recognizes the connections among different sectors and supports development strategies that can fulfill multiple functions and create multiple benefits for the society and urban ecosystems.

Green cities development calls for holistic planning and management of water, flood, solid waste, stormwater, and wastewater.
“Green Cities Development” is about creating vibrant, environment-friendly, livable cities.
Example of Holistic Planning for Green Cities Development

In this example of holistic planning of urban environments, there is a variety of flood protection measures which can range from engineering and structural to natural and non-structural. The stormwater is treated and used for nondrinking water purpose (e.g. flushing of toilets, washing, and irrigation of green spaces). Storing of rainwater at multifunctional sites can be implemented in such a way to enable greater efficiency of land use. As an efficient way of dealing with scarcity of available spaces (which is a common problem in urban areas), the actual water surface has been used in a multifunctional way through

Example of Holistic Planning for Green Cities Development (Source: Zoran Vojinovic)
the construction of floating buildings. Furthermore, internal sources of water, energy and nutrients within an urban area are utilized first. Urban wastewater is used as fertilizer for urban agriculture purposes. It is also used as a source of heat and for biogas production. At the same time, the wastewater treatment process is connected to productive landscapes as the efficient way of providing nutrients. The productive landscapes are designed for multifunctional purposes (i.e. they serve not only amenity and recreational purposes but also for keeping urban sites fresh and cool during heat waves as well as for urban farming and aquaculture).
Cities need to address urban flood within the framework of overall urban planning, development, and management.
The Green Cities approach to urban flood management takes a holistic view, favoring cross-sectoral, multifunctional solutions that are not only technologically and economically efficient, but are also ecologically sustainable and socially just. The approach goes beyond traditional, single-functional combination of structural and non-structural interventions, seeking for multifunctionality in each measure or a combination of measures, wherever possible, to maximize benefits.

The Green Cities approach therefore demands the full use and proper consideration of both structural and non-structural types of measures, or their resulting combination, within a holistic view. Not one solution can solve all the problems by itself.
Measures must be combined into solutions (preferably multifunctional) in a way that they can collectively bring greater benefits to urban ecosystems.

An example of multifunctional solutions can be seen in the Netherlands. The Dutch are offering incentives for green roofs; designing public squares and garages that double as catch basins for rain and floodwater; and constructing floating houses and reservoirs that double as recreational areas. One of the innovative ways the Dutch have approached flood management is through Rotterdam’s water plazas.

The plazas operate like any other public square during dry season, with steps that people can sit on, allowing space for special events. When it rains, water from surrounding streets is directed into the square through drains with filters, pooling clean water and relieving pressure on surrounding drainage. The square then drains at a much slower rate through a central point. The design of the plazas even allows rainfall to add to the square’s appeal as levels and channels open up little ponds, rivers, and water features. If a really big storm fills up the plazas entirely with water, the plaza would function solely as water basins.
Another example of multifunctional solution is found in the City of Cologne, Germany where flood abatement systems have been adopted for public flood protection instead of the conventional dikes. About 9.3 km along the river Rhine are protected by this system up to the level of 11.30 meter at the gauging station of the City of Cologne. On one side, the logistic requirements are to be considered for such a flood resilience strategy, which are as a rule considerably higher than in a case of a dike or permanent wall. On the other hand, this measure does not spoil the landscape qualities. This is a trade off which is to be decided upon among the key stakeholders through a participatory process. In order to keep the system functioning and to minimise the failure due to human error, regular flood trainings are taking place, in which the emergency forces mount and dismount the system and organise the required evacuation of the inhabitants.

Integration of the flood abatement system in the urban landscape in the City of Cologne

Mounting of the flood abatement system during a flood training in the City of Cologne, September 2010

This example shows that technology alone is not enough. It has to be combined with other measures (in this case, capacity building of stakeholders and emergency services) in order to achieve the required level of efficiency and effectiveness. Also, the amenities aspect plays an important role and has to be considered when developing flood resilience strategies.
Flood mitigation measures consist of **structural** or **nonstructural** measures.

**Structural Measures** involve physical construction:
- Floodproofing
- River and coastal flood protection
- Urban Drainage

**Nonstructural Measures** involve social or behavioral, policy or legal, and financial interventions:
- ‘Soft Structures’ (SUDS, WSUD, LID, BMP)*
- Land use Control and Regulation
- Capacity Building of Stakeholders
- Emergency Plans
- Flood Preparedness Action Plans

**Structural and nonstructural measures complement each other.**

In Green Cities development, neither structural nor nonstructural measures can solve all the problems. Dealing with flood-related problems while protecting and enhancing the floodplain environment requires the full use and proper consideration of both types of measures within the holistic framework of Green Cities.
Thinking holistically calls for adopting multifunctional solutions.

Combining measures, where applicable, offers possibilities for multifunctional solutions.

Dealing with processes and complexities of different types of floods requires combining different measures. For instance, pluvial floods should be dealt with through the combination of urban drainage and SUDs, LIDs, WSUD, BMPs, with land use control, zoning, early warning systems, and active stakeholder participation.
Multifunctionality should be sought in all types of measures (irrespective if they are classified as structural or non-structural) when and where possible, depending on the type of floods being addressed.

Structural Measures

Urban drainage (major and minor)

The major and minor drainage system, widely used in Australia, the USA and other developed countries, aims to ensure that hazardous situations do not arise on streets and footpaths and that all buildings are protected against floodwaters. It makes efficient use of limited urban space, reduces capital investment, and maximizes flow capacity during floods.

Sometimes referred as “dual drainage,” the system integrates flood management of roads and open spaces at the urban planning stage. “Minor” refers to the underground pipe network that carries runoff from low intensity or average storms (usually 1 in 2 to 10 years). “Major” refers to above ground drainage routes which convey runoff of high intensity storms (usually 1 in 50 to 100 years) to large drains or rivers.

The system is suitable for urban retrofitting, particularly in many old Asian cities whose narrow roads are usually congested with utilities and underground drainage pipe networks could no longer cope with higher volumes of rain. Such existing systems would require adopting a major and minor system design to maximize the use of already limited urban space.

Kuala Lumpur’s Storm Water Management and Road Tunnel (SMART) represents an example of multifunctional measure where stormwater conveyance and road system are both addressed in one solution.
**River and Coastal Protection Measures**

Structural river flood protection measures alter the river system and prevent floodwater from flowing into the floodplain, such as a dike.

Coastal flood protection measures include sea walls, sea dikes, tidal barrages, barrier islands, dunes and breakwaters, land reclamation fields, beach nourishment, near-shore disposal berms, geosystems or artificial reefs.

Multifunctional designs of these structures incorporate recreational areas such as bicycle lanes and green space on the riverbanks. The river Rhine in the City of Bonn, Germany provides a good example of such multifunctional design.
Floodproofing

Flood proofing is a set of techniques for making existing buildings and new developments more resilient to floods. They may be included in the planning stage, referred to as “fitting,” or applied to already standing structures, called “retrofitting.”
Soft Structures

In recent years, a swell of environment-friendly so-called soft structures have emerged developed by experts in Australia, Canada, the US, and the UK, each offering a different perspective. Some involve constructions that make smart use of the natural environment. Others involve creative repurposing or enhancements of existing infrastructures.

**Soft Structures**

**Water Sensitive Urban Design (WSUD)**, developed in Australia, pushes for integrating the urban water cycle into urban planning and design to minimize environmental degradation and improve aesthetic and recreational appeal.

**Sustainable Urban Drainage Systems (SUDS)**, familiar in the UK, drain surface water in a more natural way and to mitigate the adverse effects of urban stormwater runoff as close to the source as possible.

### Green Roofs

Gross or vegetation grown on roofs of buildings and houses helps reduce the volume of rainwater and floods, aside from offering other benefits to the environment. These modern Hanging Gardens can also filter pollutants in rainwater, retain much water for temporary storage, and help maintain natural air and temperature conditions.

### Permeable Pavements

Pavements made of porous materials can capture runoff and help in replenishing dried up groundwater tables. Permeable pavements also help maintain natural air and temperature conditions. They are used for car parks and roads or blind alleys in residential areas.

### Swales

Swales are natural open channels that can direct and redirect flood flows, reduce volume and speed of flowing floodwaters, and serve as temporary water storage. Larger swales that can reduce rainfall runoff are mostly situated besides roads or parking places. Smaller or "mini-swales" can be designed to receive rainwater runoff (from green roofs as example), store it for infiltration and drain the runoff into the drainage once it is full.
Best Management Practices (BMP), used mainly in Canada and the US, is a type of water pollution control that combines structural devices and systems (e.g. retention ponds) and operational practices (e.g. minimizing use of chemical fertilizers and pesticides).

Low-Impact Development (LID), an approach to land development (or re-development) originating from the US, seeks to manage water in a way that reduces the impact of built areas and promotes the natural movement of water within an ecosystem or watershed.

Typical examples of soft structures:

- **Constructed Wetlands**: Artificial wetlands help control floods in cities by capturing runoff. Different vegetation that can improve water quality by removing pollutants can be planted on their surface. Wetlands are typically designed to store water only for a short while to prevent mosquitoes from breeding.

- **Detention and Retention Ponds**: Both normally found upstream, these ponds capture excess runoff. Detention ponds are drained completely after the rains, usually within 3 days, while retention ponds hold water permanently or until it seeps through to the groundwater table, which may lead to subsequent increases in flood risk elsewhere. Retention ponds may also be already full at the start of heavy rains and hence have no spare capacity to take extra flows. To reduce these risks, these ponds should be designed using continuous rainfall model simulations and should include large magnitude events in the simulation period.

- **Rainwater Reuse**: Rainwater tanks in individual households or larger facilities capture and store rainwater and help ease stormwater runoffs. Captured rainwater can be reused for flushing toilets, watering greenery, washing cars, among other activities, to preserve the freshwater reserves.
Nonstructural Measures

Land Use Control and Regulation

Laws, policies, and regulations for land use planning and development of flood-prone areas, such as zone ordinances and building codes, should be formulated and enforced to restrict further urbanization that may increase flood risk and damage potential. Planning the efficient use of urban space should go hand-in-hand with flood management, especially in expanding cities where housing is also a problem. Adaptive land use plans can harmonize the different interests and activities of various interest groups, such as urban planners, ecologists, and flood managers. The flood zoning method minimizes flood impacts while supporting the urban development.
Disaster Preparedness, Emergency Management, and Early Warning Systems

Disaster management is about managing the risks and reducing the impacts and consequences brought by disasters. In holistic planning, the measures for flood related disasters should be placed in the context of other disasters, among them, chemical emergencies, dam failures, earthquakes, fires (including wildfires), hazardous materials, heat, hurricanes/typhoons, landslides, nuclear power plant emergencies, terrorism, thunderstorms, tornados, tsunamis, volcanic eruptions and winter storms. Integrated solutions must be sought.

Community awareness and readiness to respond in emergency situations are important aspects of disaster management. The use of early warning systems is invaluable for such purpose. Early warning systems can enable better preparation for floods, such as lowering the water level in a reservoir or a pond, activation of pumps, evacuation of residents, traffic regulation, and road closure. It also enhances preparatory lead time.

Typically, a combination of real-time measurement/communication technologies and modelling tools are used to forecast rainfall and other hydrometeorological factors. A well-proven modelling system is required to make reliable forecasts of flows and flood levels along the floodplain. The system would consist of three distinctive units:

- Data acquisition and processing, which makes use of meteorological data and simulation of a hydraulic model to predict an upcoming flood given the required lead time;
- Model simulations and results mapping, which generates important information (e.g., risk maps, safe areas notification, evacuation routes, traffic control etc.) from model results produced in real-time or gathered from a pre-prepared library of model results, and
- Information dissemination, which makes flood-related information available not only to flood managers but also to emergency management staff and the general public.

To make the warnings effective for wide dissemination, the forecasts have to be translated to readily understandable forms and related to the population and infrastructure by linking model outputs to various dissemination means. Timely issue of early warnings can provide substantial enhancements and make possible informed decision making in adopting proper measures towards disaster preparedness, mitigation, control, planning and management.
Financial Preparedness

The ability to recover financially after an event is an important aspect when dealing with floods and flood-related disasters. Financial shocks due to flood events may significantly differ from one community group to another, but some financial options include insurance and financial incentives for flood resilience measures.

In many developed countries, insurance is an important measure that has been applied for managing natural hazards, including floods. Insurance for floods, in many instances, is bundled with other hazards such as storms or earthquakes. In others, existing insurance policies are extended to include flood with payment of an additional premium. Australian, Germany, Japan, and the United Kingdom are pioneers in including floods in insurance package policies.

Insurance should take a more proactive role in raising risk awareness among the insured. Some recommend that the insurance industry should develop and implement industry guidance for flood events, covering reasonable expectations of the performance of insurers and reasonable actions of customers. Insurers should influence the attitudes of the clients by adopting incentives for risk reducing behavior, so that efforts to minimize damage are encouraged and not undermined. In other words, the insurance companies are not perceived as mere contractors in the area and should take a more active role in flood risk management, which also includes more intensive communication with those insured.

Another measure is the provision of financial incentives for implementing flood resilience measures. Government institutions, municipalities, and insurance companies use this strategy to grant a certain sum of money to residents if they implement flood resilience measures on their properties. Although the idea of financial incentives sounds attractive as they imply less expenses that are to be borne by dwellers, their effectiveness should not be taken for granted. Capacity of the community plays an important role, as well as the timing and the context this strategy is applied in.
Example of Holistic Flood Management in Green Cities

This example shows how combination of several resilience measures could provide adaptive capacity and protection at different stages in flooded areas. The presence of a dike/levee aims to provide first stage protection from coastal floods, whereas the floating buildings would resist from such impacts due to their flexible floating structure. If the flood wave would overtop the dike/levee, then the first row of buildings could meet their desired level of resilience through the use of stilts and/or amphibious building structure. If the flood wave would pass through even further, then a set of various SUDS measures combined with dry and wet proofing of buildings as well as temporary flood walls could possible provide resilience in other areas. The same SUDS measures combined with local drainage network are designed to also deal with pluvial floods. The overall idea is that each individual measure is designed to work in conjunction with other measures so as to provide an interactive (or interconnected) set of measures which can enable better resilience and adaptive capacity than any other measure when designed alone.

Example of Holistic Flood Management in Green Cities (Source: Zoran Vojinovic)
Adaptation to flooding
- surveillance and early warning

Adaptation to flooding
- water harvesting
- small wetland
- urban farming
- urban aquaculture
- rain gardens
- flood gardens

Adaptation to flooding
- dry- and wet-proofing
- swale
- permeable carpark
- drainage system

Adaptation to flooding
- dry- and wet-proofing
- temporary flood wall
- infiltration trench

Pluvial flooding

Settlement restrictions zone
Swale
Permeable carpark
Infiltration trench
Temporary flood wall

THE GREEN CITIES WAY OF MANAGING FLOODS IN URBAN AREAS
Learning from International Best Practices

There is no shortage of best practices around the world to draw inspiration from and to show evidence that these solutions are being adopted and actually working.
Reopening Rivers in a Highly Urbanized Area

The Cheonggyecheon River in downtown Seoul, Republic of Korea was covered by a busy, multi-lane roadway and elevated highway. An engineering survey in 2000 revealed structural weaknesses in these roads and recommended costly renovations. The city government opted to demolish the roads and restore the river to improve the environmental and aesthetic state of the downtown area, costing almost $1 billion. Traffic was finally rerouted, bridges were built, public parks and recreational space were created, and sites of historic and cultural importance were renovated. By widening the river banks, its capacity to accommodate and route up to 200-year flood event has been increased.

The reopening of Cheonggyecheon River was well received by the citizens, who got green public spaces where they can relax, interact, and appreciate the natural environment in a highly urbanised area. The success of the Cheonggyecheon river restoration project has inspired similar projects around the world.
Holistic Planning for Flood Resilience

In holistic planning, flood resilience measures should be designed within the context of the broader ecosystem, considering the spatial planning and architecture style of the area to be implemented. Local flood resilient materials should be used, permanent elements of flood barriers should not spoil the urban landscape and waterscape, and wherever possible, the existing built environment should be integrated into the design.

The city of Dordrecht in the Netherlands provides examples of ecosystem design solutions which take into account the risk from floods.
Holistic Rainwater Management

Krönsberg is an example of a settlement where rainwater management has been regarded in a holistic spirit, addressing a range of issues such as housing, energy, transportation, and water management. They had two overarching and pressing aims: to solve the serious housing shortage of the 1990s and to present a comprehensive example of visionary urban planning and construction at the World Fair in 2000, which was held from June to October in Hanover.

The new city district was designed and created following a holistic approach that aimed at efficient use of the ecology in construction and habitation, along with urban planning and social aspects according to the principles of Agenda 21, the UN’s action plan for sustainable development. Residential, commercial, and recreational needs were incorporated. Rainwater management was addressed along with other vital ecological concerns, such as energy efficiency optimization, waste concept, soil management, and environmental communications. The main objective was to minimize the use of natural resources and energy and to reduce environmental pollution.

(Photo notes: A seminatural drainage concept to minimize the effects of development on the natural water balance. The volume of water released into the drainage stream was limited to 3 l/s/ha to prevent the increase of runoff. The concept was developed combining infiltration, decentral and semi-decentral retention, and controlled and delayed release into the stream, with both surface and underground components. The variety of ecological requirements on Kronsberg is also apparent in the selection of construction materials (e.g. no PVC for drainage pipes). Top left: a public area in Krönsberg utilising pervious pavements and multipurpose detention ponds; top right: roadside drainage; bottom left: pervious pavements in a public space; bottom right: pervious pavement in a yard on a private property. (Source: Natasa Manojlovic)
Multipurpose Areas for Excess Flow

SUDS measures are typically designed for definite amounts of rain, but their capacity can easily be exceeded in cases of extreme rainfall. When this happens, excess flow should be collected and diverted to temporary storage areas. However, in urban areas with very limited space, the use of existing structures such as streets, parks, and parking spaces can be considered. Streets and roads can serve as conveyance of excess flow. Structures such as walls and curbs can serve as dams and flood barriers that can capture and divert surface runoff along streets, foot paths, or between building lots. Open public spaces, such as green areas and parks can be transformed into temporary storage areas.

An example of a multipurpose area is found in the underground storage the sport field in Rotterdam, the Netherlands.
Implementing Green Cities

The Case of Beijing’s Stormwater Management Initiatives.
Beijing’s Urban Stormwater Management

Phase I:
Direct stormwater discharge
Adopted before 2000, this approach involved the installation of an urban stormwater drainage system consisting of community stormwater pipes, municipal stormwater pipe networks, and water course.

Phase II:
Direct stormwater discharge and utilization
A serious water shortage on the early 1990s prompted Beijing in 2000 to combine the direct discharge approach with urban stormwater utilization to address the shortage.
Beijing’s Urban Stormwater management evolved through three stages.

**Phase III: Integrated stormwater management**

The introduction and application of international new concepts and technologies, including these under the LID and WSUD approaches, have led to a more integrated urban stormwater management approach. This approach includes a series of engineering, technical, regulatory, and legal measures to address urban floods, frequent waterlogging, and nonpoint source pollution caused by large-scale urbanization.
Structural Measures

Stormwater discharge system
Drainage pipelines in Beijing total 10,172 kilometers including municipal drainage networks in suburbs and affiliated counties. Combined systems play a major role in old urban areas while separate systems contribute more in newer urban areas. Currently, the Beijing Drainage Group operates 4,719 kilometers of stormwater pipelines and sewers under major roads and 89 pump stations in central Beijing, including 2,076 kilometers of sewers, 2,065 kilometers of stormwater pipelines, 578 kilometers of combined pipelines, 12 wastewater pump stations, and 77 stormwater pump stations.

Urban flood control system
City safety first requires flood control facilities that can prevent external flood. Beijing has built complete urban flood control facilities including reservoir, river course, dam and flood storage and retention zones. Beijing has 84 reservoirs with total capacity 9.35 billion cubic meters. There are 210 controlled gates on the rivers with total water storage capacity of 80 to 100 million cubic meters. 256 dams are built with total storage capacity of 8.3 million cubic meters and 65 rubber dams with total storage capacity of 70 million cubic meters.

Urban waterlogging control facility
Currently, Beijing does not have particular facilities to accommodate urban waterlogging caused by stormwater in excess of discharge capacity of stormwater pipes and channels, but the lakes in the urban area can be used for stormwater detention and storage and play an important role in waterlogging control. Many low-lying areas, rivers, and lakes that existed before 1949 and could be used for stormwater detention and storage were mostly filled in the process of urban development.

Urban stormwater utilization facility
Beijing is the pioneer in urban stormwater utilization, with tested three technical approaches, including land infiltration, collection and reuse, and controlled discharge. The city has also established multiple-level stormwater utilization technical system covering resident community, river course and stormwater diversion between urban and rural areas, including various physical facilities such as community, public green area, river course and sand pit. It has built also various stormwater utilization facilities supported by full government equity for major projects and supplemented by entity fund and government subsidy for other facilities.
Non-structural measures

Institutional arrangements
The Beijing Water Authority is responsible for all water affairs, including water supply, water conservation, drainage, wastewater management, flood control, urban waterlogging control, and groundwater and surface water resources utilization and protection. With guidance from Beijing Water Authority, water authorities of districts and counties are responsible for water affairs within their jurisdictions. Drainage department and water conservation office are set within Beijing Water Authority getting involved in stormwater discharge and utilization.

The Beijing Municipal Government Flood Control and Drought Relief Headquarters is the highest authority for flood control and drought relief of the city, led by city mayor and with the Flood Control and Drought Relief Office affiliated with the Beijing Water Authority. Additionally, Beijing Drainage Group, a state-owned utility, is responsible for construction, operation and maintenance of stormwater and wastewater collection system, and pump stations in the central urban area.

Emergency response
To strengthen capacity of emergency response to stormwater disasters, the Beijing Flood Control and Drought Relief Emergency Response Headquarters was setup in the Beijing Flood Control and Drought Relief Headquarters in 2005. Led by the Beijing Public Emergency Response Committee, this emergency response headquarters is responsible for organizing and coordinating assignments and actions associated with water supply and drainage following the principles of integrated leadership, responsibility allocation by levels, and inputs of professional teams.

Two flood emergency response teams, the Yongding River flood emergency response team and the Beijing hydraulic facility emergency response team, have been established. At the district/county level, similar teams have been established by the Changping District Water Authority and the Yanqing District Water Authority. About eight drainage emergency response teams have also been organized: drainage group, water supply group, municipal facility maintenance group, urban development group, urban public road company, urban road development group, urban road development company, and urban environment sanitation group. The military also provide efforts for flood emergency response.

To establish a reasonable timing framework for flood emergency response, Beijing has developed a weather pre-warning system by using four colours including red, orange, yellow, and blue. The forecast is based on data from satellite cloud photograph and meteorological radar. Now the weather forecast department uses web tools to provide weather information.

Stormwater management laws, policies, and regulations
While no stormwater management laws or policies have been particularly developed at national or local level, Beijing has taken initiatives to put in place guidelines, standards, and procedures which have facilitated urban stormwater management. These regulations include among others:

- Beijing Municipal Government Order No.66 issued on 1 December 2000 which presents urban stormwater and flood management, requirements for stormwater utilization or stormwater and flood control and utilization
- Interim Regulation on Stormwater Resource Utilization within Physical Facilities implemented since March 2003 (Document No.[2003]258),
- Notice of Strengthening Water Saving Facility Management jointly issued by Beijing Planning Commission, Construction Commission and Water Authority in December 2005,
- Stormwater Utilization Proposal jointly issued by seven agencies including Beijing Water Authority in April 2006,
- Notice of Strengthening Stormwater Utilization Facility of Construction Projects jointly issued by Beijing Water Authority, Development and
Reform Commission, Planning Commission, Construction Commission, Transportation Commission, Forestation Administration, Land Resource Bureau and Environmental Protection Bureau in November 2006


Low Impact Development in Beijing

In recent years, Beijing has started moving towards adopting multifunctional solutions using the LID approach. More specifically, the city currently features the largest application of pervious pavements, a popular LID measure in Beijing. Pervious pavements, on average, capture about 45mm of rainfall without runoff. LID measures are favored not only for their visual effect on the landscape, but also for their capacity to significantly reduce runoffs and pollution. They can control rainfall of up to 50mm without runoff discharge.

The Beijing Evaluation Standard for Green Buildings (DB11/T825-2011) published in 2011 requires that projects should reduce the destruction of the original hydrological and ecological environments. The policy also requires that pervious pavement should be at least 40% of pavement surface outside public buildings. By end of 2011, the total area of pervious pavements in the city runs up to 3.28 million square meters.

Other LID measures applied in Beijing include depressed green spaces, grass swales, rain gardens, bioretention troughs, and rainwater ponds.
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Photos Credits

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Lay-out and Graphics
Gino Pascua, ADB

Editing
Cezar Tigno, ADB

Overall Production (content and presentation)
Ellen Pascua, ADB
Ancient cities in Asia have witnessed floods over many centuries, but not as often and not as intense as the floods that have occurred in the past decade. Floods have become the result of greater interaction between human society and the natural environment, exacerbated by urbanization and climate change. This publication illustrates the more recent and unprecedented flood devastations in Bangkok, Beijing, and Manila and some of the international best practices in urban floodwater management. Following the pillars of “Green Cities Development,” it proposes an holistic approach, combining structural and nonstructural measures and seeking multifunctional solutions, in managing today’s urban floods.

About the Asian Development Bank

ADB’s vision is an Asia and Pacific region free of poverty. Its mission is to help its developing member countries reduce poverty and improve the quality of life of their people. Despite the region’s many successes, it remains home to approximately two-thirds of the world’s poor: 1.6 billion people who live on less than $2 a day. With 733 million struggling on less than $1.25 a day. ADB is committed to reducing poverty through inclusive economic growth, environmentally sustainable growth, and regional integration.

Based in Manila, ADB is owned by 67 members, including 48 from the region. Its main instruments for helping its developing member countries are policy dialogue, loans, equity investments, guarantees, grants, and technical assistance.