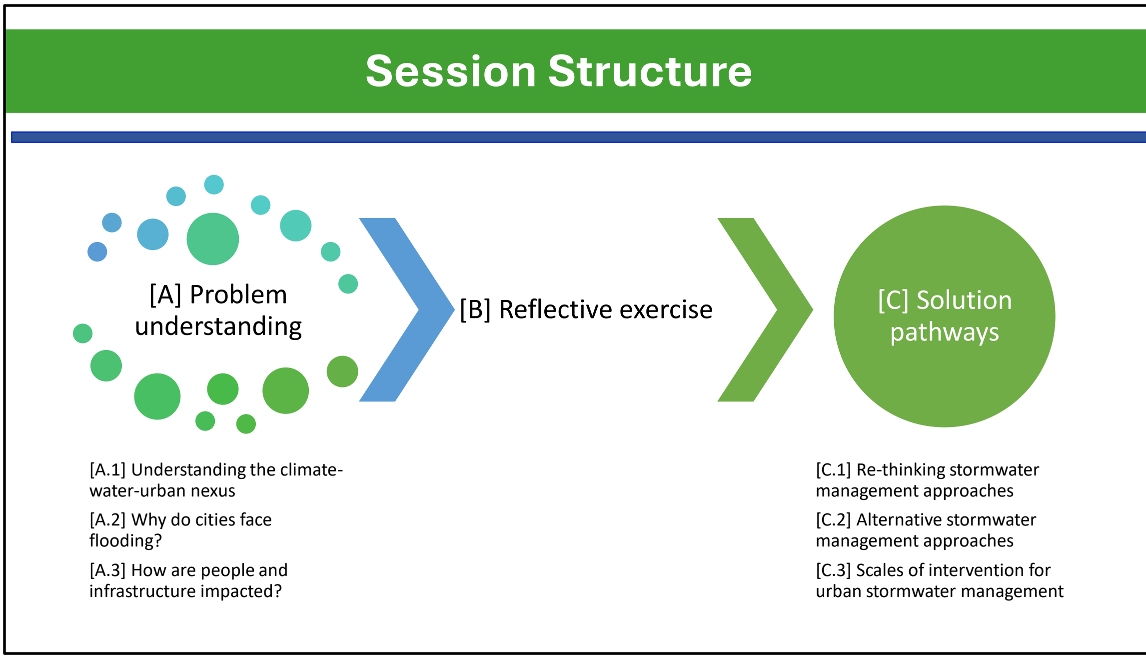
This module, titled "**Nature-Based Solutions to Mitigate Flooding and Stormwater Risks in Cities**," is the last part of a three-part capacity building training series co-organized by WRI India, UrbanShift, and Cities4Forests.

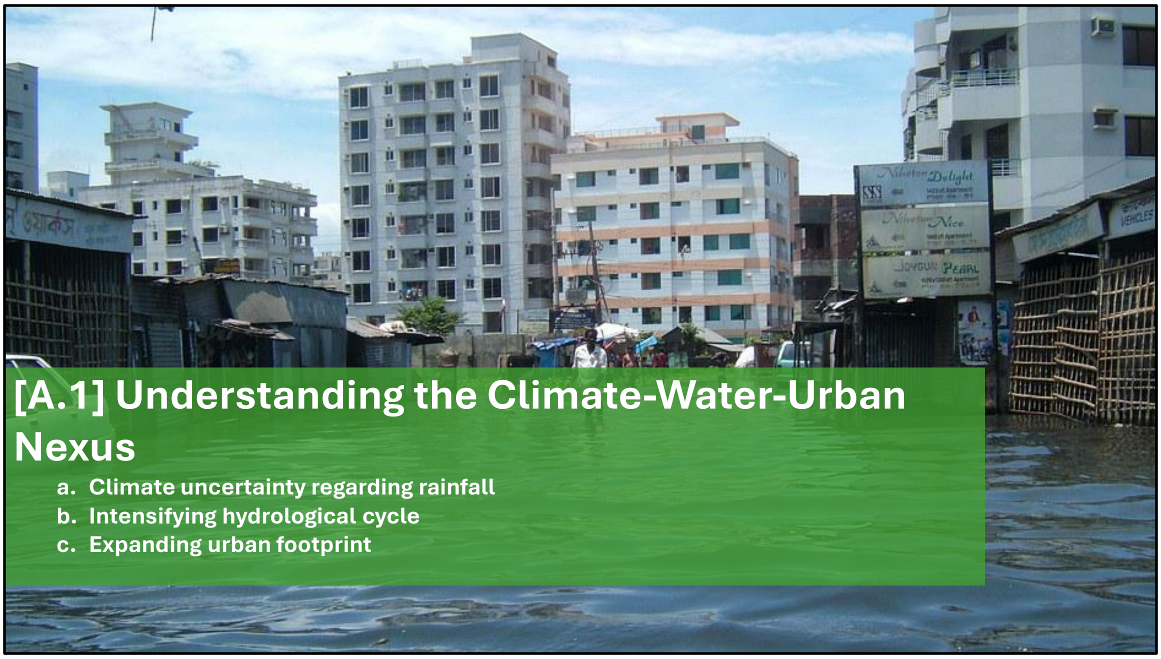
This module will explore issues of urban flooding in growing cities and the possible pathways that various regions are exploring towards urban stormwater management and flood resilience.



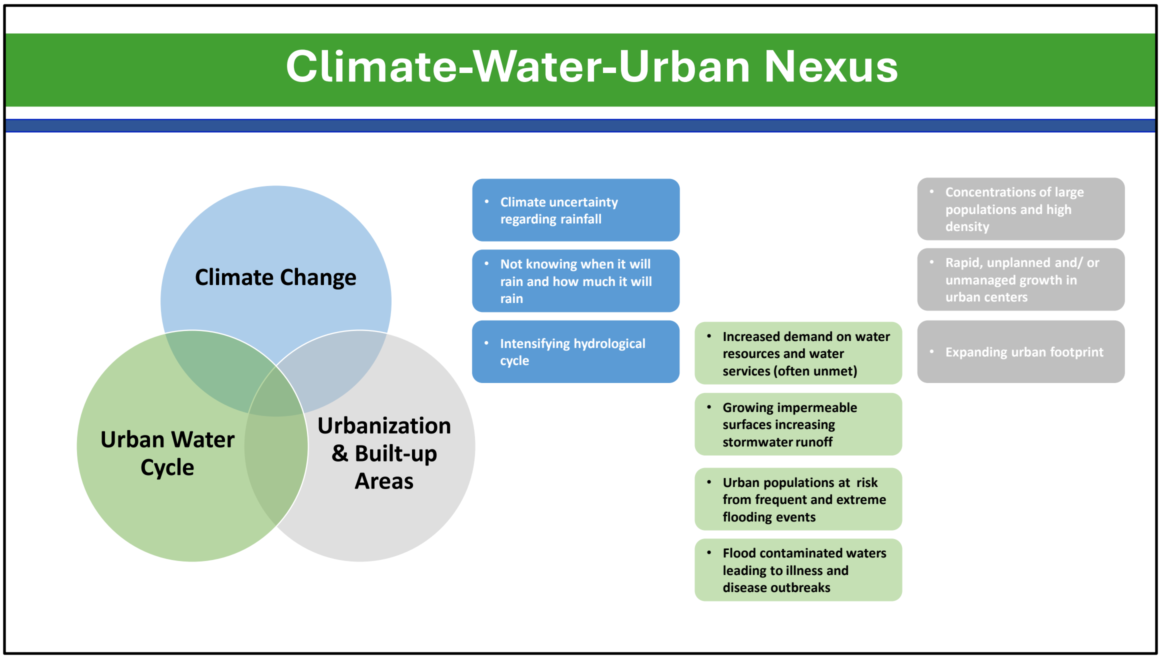
This module has been divided into two major sections:

1. The first exploring the interconnected causes and issues that lead to urban floods.
2. The second on innovative approaches and solutions towards improved resilience.

These two sections are separated by reflective exercises where we can apply our understanding of the urban-stormwater nexus to identify complex interlinked causes.



To understand flooding in cities we need to gain a deeper knowledge of how climate change, the water cycle and urban areas intersect and consequently impact stormwater flows in surface and underground areas, in both human constructed and naturally occurring networks.



- At the nexus of these 3 factors lie: growing and highly dense population centres exposed to extreme rainfall events; increased flooding from the way we build our cities as impermeable surfaces; and the subsequent exposure to water and vector borne diseases following flooding, due to contamination of drinking water and sanitation services.

Climate-Water-Urban Nexus
A. Climate Uncertainty Regarding Rainfall

In the context of urban flooding, climate uncertainty limits our ability to forecast accurately when and how much rainfall will occur at a specific location

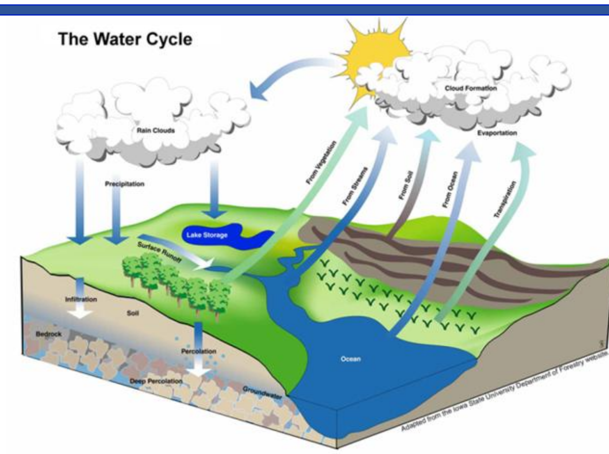
The climate change and the urban water cycle intersection is leading to an increase in uncertainty and variability. This means that we cannot consistently and accurately predict when and how much rainfall will occur. Long standing seasonal weather patterns are seeing significant disruptions – for example south and east Asian monsoon starts are delayed causing an extended hot, dry summer; rainfall is not evenly distributed across the monsoon months, but we see intense rainfall over a week or even 24 hours.

Climate uncertainty refers to the difficulty of predicting the consequences of climate change. This is due to climate systems being complex and interdependent, with many socioecological factors

The climate system is the highly complex global system consisting of 5 major components: the atmosphere, the oceans, the cryosphere (snow and ice), the land surface, the biosphere, and the interactions between them. Various factors such as volcanic activity, human activity generated GHG emissions and more can disrupt this system in complex and dynamic ways.

In the end – with regards to rainfall – we are limited in our ability to accurately predict all the time when and how much rainfall a region will receive, impeding people and urban system operators in these areas to be adequately prepared.

Climate-Water-Urban Nexus
B. Intensifying Hydrological Cycle



Source: https://scied.ucar.edu/learning-zone/climate-change-impacts/water-cycle-climate-change | https://www.pettitpastures.com/water-cycle-affects-weather/

Climate change affects evaporation and precipitation

A warmer climate draws more moisture from land and water bodies and holds more water vapour in the atmosphere.

- More rain and flooding
- More extreme drought
- Stronger hurricanes
- Heat waves

In detail – climate change causes and **intensification of the hydrological or water cycle** in a variety of ways -

- Warmer and wetter conditions as: Climate change (or more precisely, increasing global temperatures) increases evaporation rates and precipitation volumes.
- More rain and flooding: With more evaporation, there is more water in the air so storms can produce more intense rainfall events in some areas. This can cause flooding – a risk to the environment and human health.
- More extreme drought: Warmer temperatures cause more evaporation, turning water into vapor in the air, and causing drought in some areas of the world. Places prone to drought are expected to become even drier over the next century. This is bad news for farmers who can expect fewer crops in these conditions.
- Stronger hurricanes: Warmer ocean surface waters can intensify hurricanes and tropical storms, leading to more hazardous conditions as these storms make landfall. Scientists continue to research how climate change affects the number of these storms, but we know that the storms will be powerful and destructive in the future.
- Heat waves: It is likely that heat waves have become more common in more areas of the world.

Climate-Water-Urban Nexus
C. Expanding Urban Footprint

Source: Johnny Miller/Unequal Scenes

- High-density urban populations are more vulnerable to extreme events.
- More buildings mean less permeable ground, causing excessive runoff that causes floods.

Cities concentrate large populations in relatively small areas, creating higher densities. This concentration increases the number of people vulnerable to extreme events like floods. A single extreme rainfall event or multiple days of heavy rain can impact a much larger number of people in a densely populated urban center compared to a rural area.

As cities grow, increased building construction replaces natural, permeable surfaces like soil and vegetation with impervious materials like concrete and asphalt. This reduction in permeable surfaces leads to faster and greater volumes of stormwater runoff. Consequently, these larger runoff volumes often exceed the capacity of both natural drainage channels and engineered stormwater systems, increasing the risk of flooding.

Over the next few slides, we will explore how the urban footprint contributes to flood conditions in specific ways.

Why Do Cities Face Flooding?
A. Urban Impermeability and Runoff

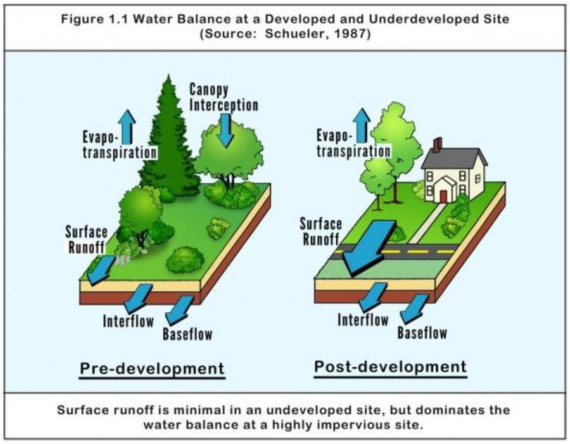


Image: City of Norman, OK | https://www.normanok.gov/your-government/departments/public-works/stormwater-maintenance-division

- Methods to estimate stormwater runoff in relation to urbanized footprint have been available for around 4 decades.
- The greater the extent of urbanized, impermeable area, the higher the volume of runoff that will be present at the location.

"Impervious areas" are land areas covered by buildings, pavement, gravel or other material that significantly inhibits stormwater from penetrating the soil. Because of its composition or compacted nature, impervious areas impede or prevent natural infiltration of water, thus these areas cause significant increased volumes of runoff from precipitation and quicker peak flows of discharge, which contributes to urban flooding and downstream drainage problems.

Water balance:
Water balance is the relationship between water that enters and leaves a system over a period of time. It can refer to the balance of water in the body, in a river basin, or for the Earth as a whole.

Surface runoff is water that flows over the ground's surface instead of being absorbed by the soil. It can be caused by heavy rainfall, snow melt, or stormwater.

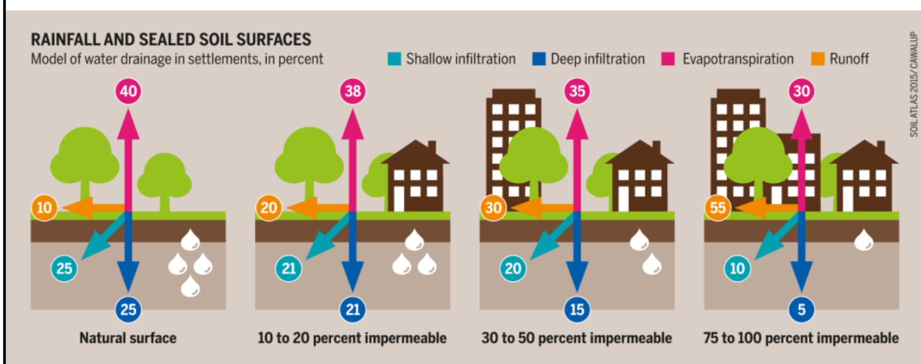
How does it happen?
When precipitation falls on the land, it flows over the surface.
If the soil is saturated, it can't absorb any more water, so it flows downhill.
Water can also settle on impervious surfaces like concrete or asphalt, and flow into

storm sewers.

Where does it go?
Surface runoff flows into creeks, streams, and rivers.
These rivers eventually empty into ponds, lakes, or oceans.

Effects of surface runoff:
Erosion: Surface runoff can cause severe erosion, especially in tropical and subtropical areas with steep slopes.
Leachate: Runoff from landfills can contribute to leachate generation.
Bioaccumulation: Runoff can carry heavy metals into the oceans, which can accumulate in aquatic animals.

Why Do Cities Face Flooding?
A. Urban Impermeability and Runoff



- Not just highly concertized or tarred surfaces, but compacted, bare earth (after clear-cutting of woodlands or in preparation for construction) have high runoff coefficients.

Source: Bartz/Stockmar, Flickr (CC.3.0) | *International Journal of Urban Sciences · June 2018* | https://beckleysanitaryboard.org/impervious-surface/

A range of studies identify the percentage of runoff generated based on the type of surface. Not just highly concertized or tarred surfaces, but compacted, bare earth (after clear-cutting of woodlands or in preparation for construction have high runoff coefficients.

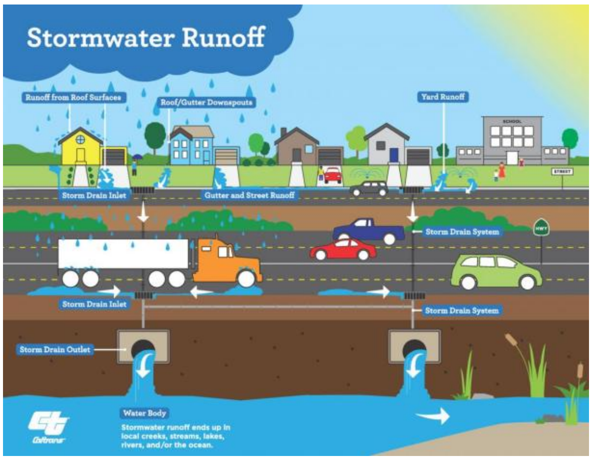
The **runoff coefficient (C)** is a number that compares the amount of runoff to the amount of rainfall. It's a tool used in hydrology to understand how precipitation is transformed into runoff.

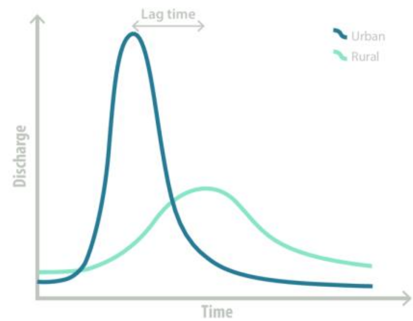
How it's calculated?
Based on the soil type, gradient, permeability, and land use
Depends on the intensity and duration of precipitation
Depends on the antecedent (pre-storm) conditions

What it indicates?
A higher runoff coefficient indicates that more water is flowing from a given amount of precipitation
A higher runoff coefficient may indicate flash flooding areas during storms

Runoff coefficient values:
Values range from 0.0 to 1.0
A value of 0.0 means that all rainfall is lost to infiltration, interception, and evaporation
A value of 1.0 means that all rainfall is converted to runoff

Why do Cities Face Flooding?
B. Rainfall Volumes and Runoff





- Peak flows in highly concretised watersheds

Source: Designing Effective Stormwater Management Policies, Lefranciose 2015; Image by Caltrans, California

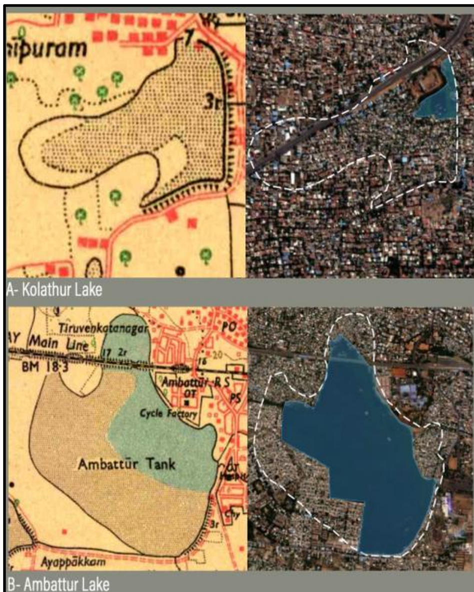
Traditional stormwater management in densely urbanized areas relies on extensive underground drainage networks and infrastructure. However, the challenge lies in having to continuously expand these systems to keep pace with sprawling development across jurisdictional boundaries. This rapid urbanization causing more impermeable surfaces leads to faster peak runoff and increased volumes, placing immense strain on existing drainage capacity.

Runoff peak is the highest rate of runoff that occurs after rainfall. It's a key factor in designing drainage systems and soil conservation structures.

Factors affecting peak runoff

- Rainfall intensity: The amount of rain that falls in a given period of time
- Drainage area: The size of the area that drains into a body of water
- Soil moisture: The amount of water in the soil before and during a rainfall event
- Snowmelt: The amount of water that melts from snow

Stormwater drainage *is a system that collects and carries excess rain and groundwater away from paved surfaces and into natural bodies of water.*



Source: Goswami, S., S. Basak, A. Malik, R.B. Palanichamy. 2023. "Urban Blue-Green Conundrum: A 10-City Study on the Impacts of Urbanization on Natural Infrastructure in India." Working Paper. WRI India.

Why do Cities Face Flooding?
C. Building on Flood Pathways

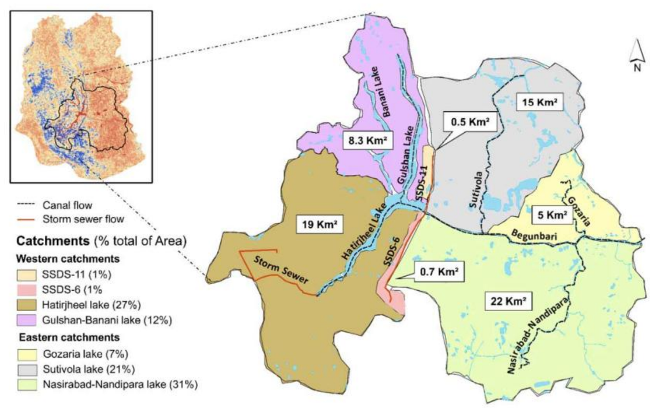
- Urban development degrades natural flood defenses like upstream woodlands and wetlands.
- Water flows into former water bodies and low-lying areas even if they are built over.
- Infrastructure like roads disrupts natural water flows and drainage, exacerbating floods.

Here we see images from the city of Chennai, India – where we overlay the extents of 2 historical manmade tanks. These extents are derived from detailed Survey of India maps from the 1970s. Overlaying on more recent google earth images we can see that buildings, roads and other urban assets have developed within the historical demarcations of these water bodies. During rainfall events these areas face frequent flooding.

It is very likely that we can think of examples of areas and neighborhoods in cities we know of and live in where such encroachment of lake areas has taken place. Maybe the neighborhood has lake view, lakebed, riverfront in its name – but neither lake nor river visible any longer - having been covered up and built over.

Alongside erratic and extreme rains, and impermeable surfaces increasing runoff, a very fundamental reason for urban areas to flood is that we have built in areas where water flows or collects.

Case Example
Urbanization and Stormwater Runoff: Dhaka,Bangladesh



This image shows different areas in Dhaka that drain rainwater into canals and storm sewers. The largest areas, like Hatirjheel Lake (27%) and Nasirabad-Nandipara (31%), are important for managing rainwater. Water flows from these areas into the Begunbari canal and other drainage systems.

Impact of Urbanization

- Urban Growth: Dhaka's built-up area increased by **96% from 1989 to 2009**.
- Wetlands and water bodies decreased by **60%** in the same period.
- Future estimates predict **90.4%** built-up area by 2040.

Stormwater Runoff

- Increased impervious surfaces raise the **runoff coefficient by 11%** in 2040 relative to 2013.
- Climate-induced change in rainfall intensity along with land-use change show **three times higher** runoff in 2040 than in 2013.

Key Challenges

- In 2013, **42% of Begunbari Canal's cross-sections** overflowed during moderate storms, showing current capacity issues.
- By **2040**, all sections of the canal are predicted to overflow due to a **3x increase in runoff**, driven by climate change and urbanization.
- Downstream areas, especially after tributaries like **Sutivola** and **Nasirabad-Nandipara**, are highly prone to flooding without drainage improvements.

The first case example is from Dhaka, Bangladesh, which can stand in as an example for any number of global south cities across the world.

Urbanization in Dhaka has drastically reduced wetlands and water bodies, leading to a significant increase in built-up area. This expansion, coupled with climate change, is projected to triple stormwater runoff by 2040, overwhelming existing drainage systems like the Begunbari Canal. Consequently, downstream areas face severe flooding risks without substantial infrastructure improvements.

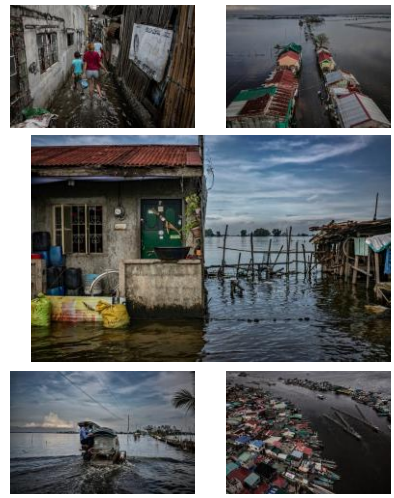
Source: https://iwaponline.com/jwcc/article/12/5/1944/79182/Adequacy-assessment-of-an-urban-drainage-system

Case Example
Flood Risk in Coastal Communities - Manila Bay, Philippines

Manila experiences 20 typhoons annually, making the region highly susceptible to flooding. Many communities lack protection from the seawalls built to shield parts of Metro Manila, resulting in persistent flooding for areas outside this protection.

Rapid urbanization has led to the conversion and loss of mangrove forests (reduced from 133,400 acres to less than 1,236 acres), which once acted as a natural barrier against flooding.

These images depict severe flooding in Manila Bay's coastal communities. Densely packed urban areas, with homes built on stilts and residents relying on boats, highlight the vulnerability of these regions to flooding and storm surges.



The second case example is from Manila Bay, Phillippines, an area already in a high-risk zone of a slightly different form of urban flooding. Here, urbanization is linked to coastal flooding risks. And here too development has converted vast swathes of natural mangrove forests, that are critical natural protectors from storm surges, high winds and typoons, to have development and built areas as seafront properties.

Source: https://insideclimatenews.org/news/18112022/sinking-land-and-rising-seas-threaten-manila-bays-coastal-communities/?gad_source=1&gclid=Cj0KCQjwmt24BhDPARIsAJFYKk0UmJFvQHGGuFh1UQ2VT_XuNRp4pJPrXu3rn4wRUdbzcP4Oxq1NS6kaAtPpEALw_wcB

As we looked through the earlier sections on the various factors that are relevant to causing and exacerbating urban floods, there is also much to learn on the various ways people, communities and infrastructure are impacted. Flood waters entering homes, businesses and utilities is but one of the ways in which urban floods can cause disruptions to urban lives.

How are People and Infrastructure Impacted?
A. Property Loss and Damage

Source: Pushkar V/ Flickr

- Flooding disrupts urban life in complex and interconnected ways affecting livelihoods, education, (physical and mental) health and more

The most immediate and visible impact from floods in urban regions is loss of life and damage to property.
These damages are bundled with impacts on various socio-economic factors such as affecting education and livelihoods, as schools and colleges and workplaces may be flooded or roads leading to these may be water logged, or floods may have swept away school books.

How are People and Infrastructure Impacted?
B. Pollution

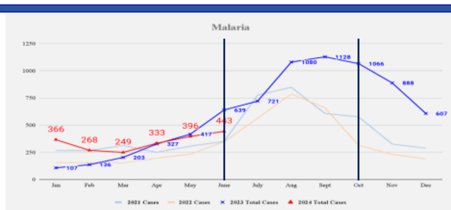
Source: Images left: Bangalore, Borgen Magazine, 2020 ; middle: Mumbai, Times of India, 2022; right: Hyderabad, Sahana Goswami, WRI India

- Larger storm drains often become dumping grounds for solid waste
- Stormwater systems when not separated and protected from sewer inflows carry large volumes of sewage and biological wastes and deliver them to downstream water bodies like lakes and rivers
- Large variety of contaminants (chemicals, vehicle fuels) are carried as street runoff into storm drains and water bodies

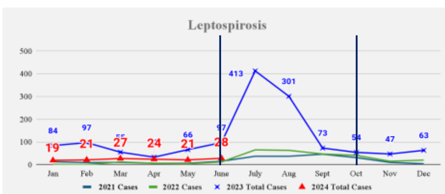
In addition, combined sewer and stormwater systems and inadequate solid waste management, decreases the carrying capacity of drains and increase pollution loads in water that is carried in these channels.

Frequent and labor intensive maintenance is undertaken to desilt the drains before monsoons as seen in these images from Chennai, Mumbai and Hyderabad in India. But removing the comingled sewage component is a much more intractable problem.

How are People and Infrastructure Impacted?
C. Health Impacts



Compared to 2022, during monsoon months- July to October
2023 saw an **approx. 1.5 times increase** in number of cases of Malaria (Mumbai)



Compared to 2022, during monsoon months- July to October
2023 saw an **approx. 4 times increase** in number of cases of Leptospirosis (Mumbai)

- Increase in humidity and heat is conducive to mosquito incubation period resulting in increased breeding. Thereby, accelerating the transmission cycle.
- Irregular rainfall with pressing need for water storage also result in increasing breeding grounds.
- Similarly, higher annual mean temperature along with humidity enhance the growth and activity of bacteria called Leptospira spp. causing Leptospirosis.
- Heavy rainfall, storms, and associated waterlogging and flooding events increase human exposure to contaminated water.

Source: *Capacity Building on Climate Change in Mumbai*, co-developed with BMC's EHO dept

Urban flooding presents a complex web of health hazards. Immediate risks include drowning and physical trauma from debris. However, the aftermath brings a surge in waterborne diseases like cholera, typhoid, and leptospirosis *, due to contaminated water mixing with sewage. Mosquito-borne illnesses, such as dengue and malaria, also proliferate in stagnant water.

Beyond physical health, flooding inflicts significant psychological trauma. Displacement, loss of property, and the constant threat of future events contribute to anxiety, depression, and post-traumatic stress disorder (PTSD) . Vulnerable populations, including the elderly, children, and those with pre-existing conditions, are disproportionately affected.

Furthermore, floodwaters can carry chemical pollutants, posing long-term health risks.

Mold growth in damp buildings triggers respiratory problems. Access to essential healthcare services is often disrupted, exacerbating existing health issues. Therefore, urban flooding has severe and multifaceted health impacts.

Reflecting on disease data from Mumbai, India from 2022 and 2023 sees a sharp spike in prevalence of malaria and leptospirosis of the same period; this is following a record breaking rainfall period of 1,770 mm in July 2023.

*Leptospirosis, a bacterial disease spread by the Leptospira bacteria present in animal urine, becomes more common after heavy rainfall and flooding. This is because heavy rain and flooding can contaminate water and soil with animal urine, increasing the risk of exposure for humans.

Case Example
Health Impacts of Urban Flooding in Kampala, Uganda

Flood Frequency: Floods increased from 5 events in 1993 to 9 in 1997, fluctuating to 8 by 2007.

Vulnerable Populations: 60% of Kampala's population lives in informal settlements highly prone to flash floods (e.g., Bwaise, Kinawataka, Natete, Ndeeba, and Katwe). These areas lack basic infrastructure, making residents particularly vulnerable to the impacts of flooding.

Health Risks:

Cholera: Annual outbreaks due to water contamination during floods.

Malaria: Flood water fosters mosquito breeding, increasing malaria cases.

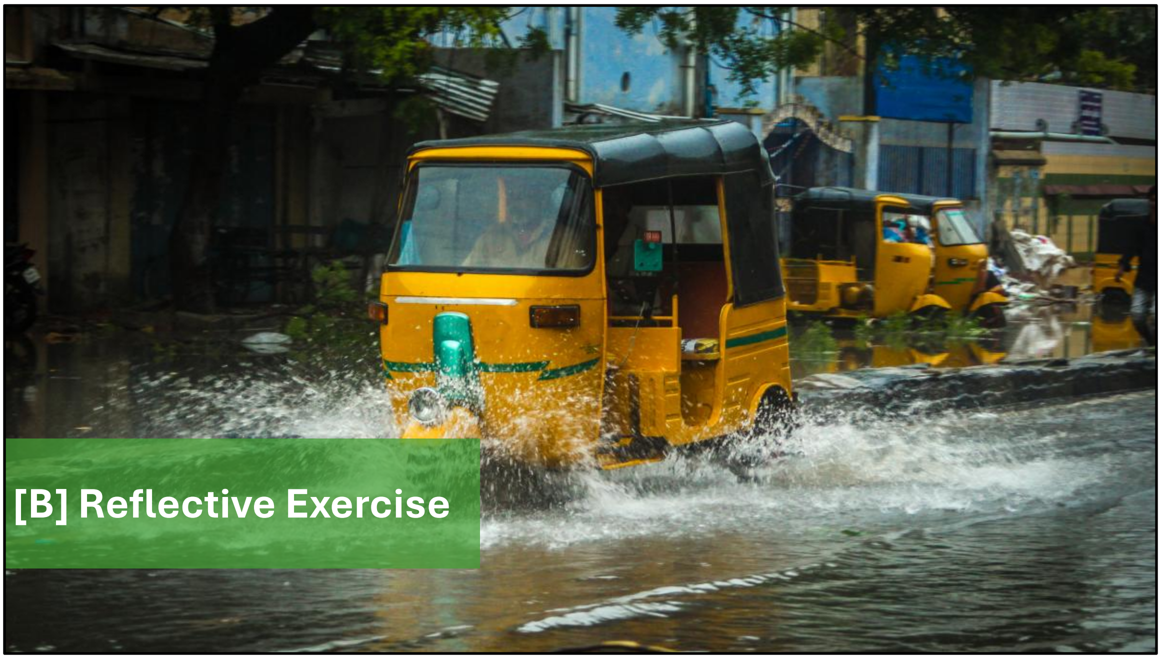
Dysentery: Poor sanitation leads to rising cases of gastrointestinal diseases.

Sanitation & Infrastructure Issues:

Only 67% of the population has piped water access; 40% of waste is collected.

Weak drainage systems cause frequent flash floods, especially in low-lying areas.

Source: https://www.sciencedirect.com/science/article/abs/pii/S1877343510000540



Here over the next 5 slides – we will look at a major flood event in August 2022 in the city of Bengaluru, India and reflect on the conditions and interactions that led to this situation.

Flooding event in 2022 | Bengaluru, India

Parts of East, Southeast Bengaluru bear the brunt of overnight heavy downpour

Published – August 30, 2022 08:30 pm IST – Bengaluru

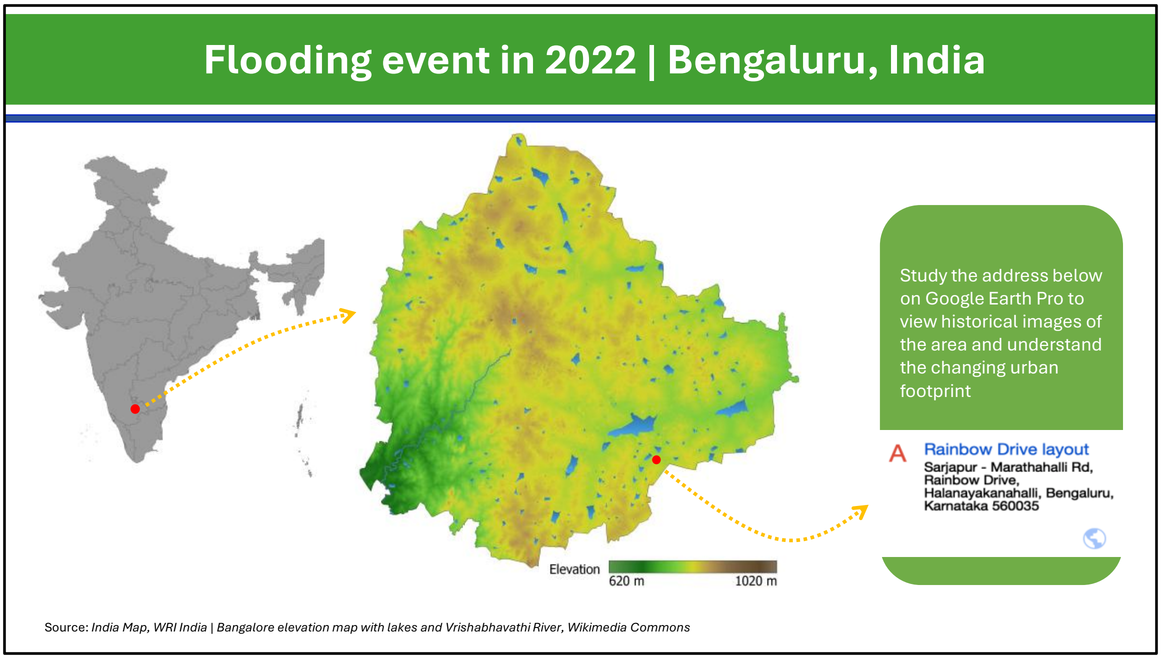
DARSHAN DEVAIAH B.P.

Firefighters and Civil Defence personnel evacuating a patient from the waterlogged Rainbow Drive Layout. | Photo Credit: PTI

As you can see in this image from August 30th the situation was dire with people having to be rescued by boat from flooded homes.

To give context, Bengaluru sits in a semi-arid zone. But this particular year was an extreme case. The city did receive excessive rainfall through the monsoon season. August 2022 alone got 400% more rainfall in the month than the long-term average based on records. And none of the daily rainfall in August was as high as the 131.6 mm the city was to receive on 5th to 6th Sept – causing flood waters to stagnate for weeks.

Over the next few slides we will move the rainfall information to the back of our minds and see what other factors might have contributed to create these flood conditions.



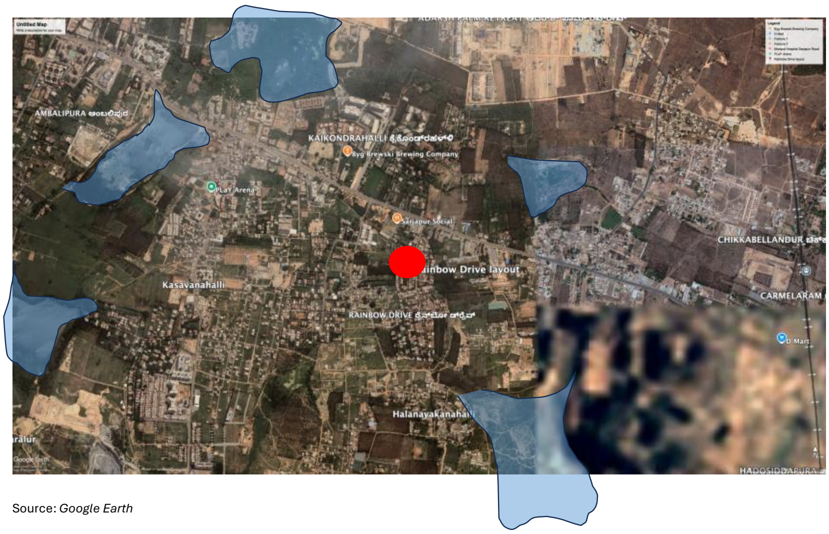
Bengaluru is a peninsula in India fairly equidistant from the surrounding ocean bodies. The city has undulating terrain and is dotted with a lot of water bodies (which were originally constructed as irrigation tanks for local villages). The growing city has been changing the relationship with these water bodies rapidly and extensively.

Satellite View of the Region in 2025

Source: *Google Earth*

This is a current google earth image of the affected region. The red dot indicates approximately where the photograph in the earlier slide was taken. The image is quite clearly showing 5 lakes (in blue) and still undeveloped spaces, which are marked in green in this area, with a fairly dense urban footprint with roads and buildings.

Satellite View of the Region in 2011



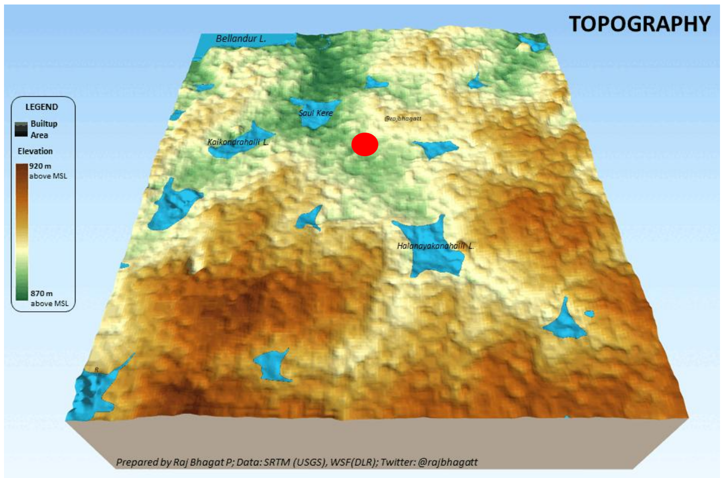
Flood affected area

Water bodies

Source: *Google Earth*

This image of the same region for 2011, shows a much sparser building footprint and more natural spaces between lake areas. Clearly there was a change to the natural landscape. The next slide shows an animation of how dramatic this change has been from 1995 to 2015. And with topographic detail clearly shows how built areas in low-lying zones are also a major contributor to the flood conditions that occurred.

Changes to Landscape from Natural to Urban and Disruptions to Natural water flows



LEGEND
GREEN LOW
BROWN HIGH

Across the city of Bengaluru is very undulating terrain with numerous valleys which act as conduits carrying water towards two major rivers, the Kaveri and the Ponnaiyar (Dakshina Pinakini) rivers. Historically, settlements were concentrated on the higher elevation zones, like ridges while the valleys were used for agriculture. Man-made bunds created cascading tanks used for irrigation.

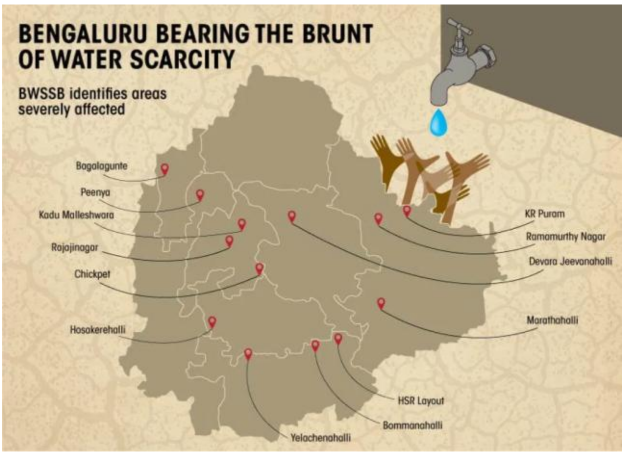
The rapid and extreme growth in the city over the past 3 decades has triggered a massive demand for land and the city has sprawled. Ignoring the topography of the land, construction began in the valleys and ridges, which in turn altered the original topography, with minor drains disappearing. Today the lakes remain as isolated water bodies, with their upstream and downstream connections often compromised or completely severed.

The new structures not only impacted water infiltration into the soil but also began obstructing the movement of water in the valleys. Most of the drains on private properties disappeared, while public ownership drains proved insufficient to carry water during heavy rainfall days. These existing canals, which were not created for inundation requirements, proved inadequate to the task of carrying excess rainwater. Extreme amounts of construction, sewage flow and clogging further hampered flow in the canals.

The bulk of the flooding and stagnation in Bengaluru happened because of the obstructions in the valleys. There were very few instances of flooding outside the valley.

Read more at: https://www.indiatoday.in/news-analysis/story/decoding-the-causes-behind-bengaluru-flooding-woes-1997488-2022-09-07

When not Underwater, Bengaluru is Struggling with Water Scarcity



Groundwater levels in Bengaluru set to plummet, especially in outer zones

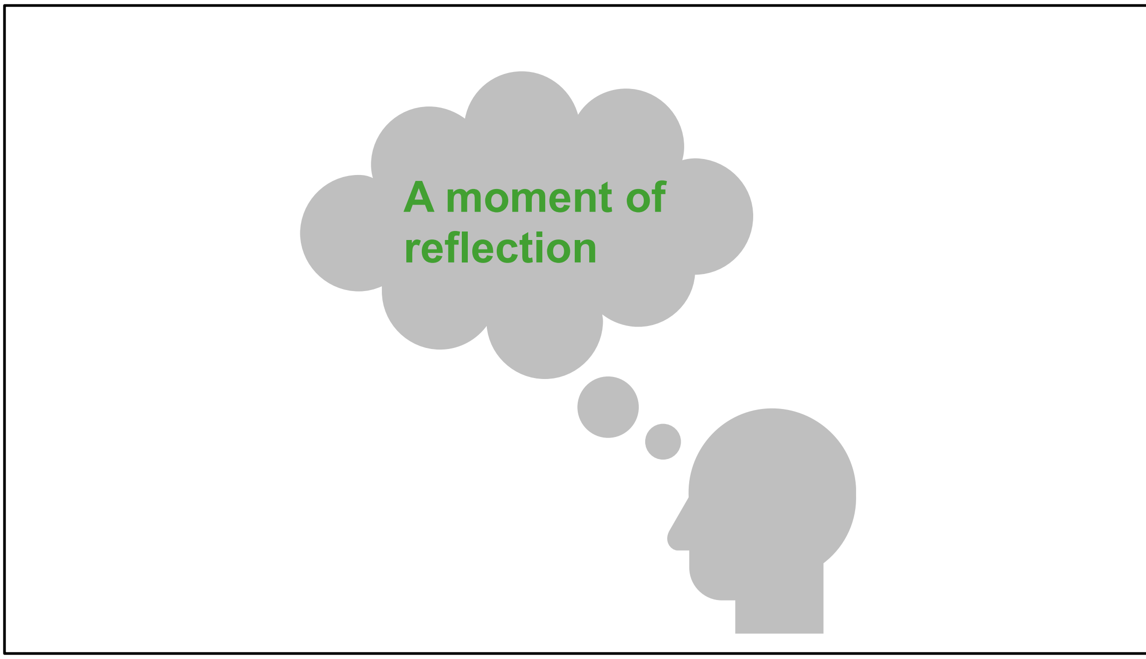
BWSSB appeals to residents to take Cauvery water supply connection

Updated - January 25, 2025 11:11 pm IST - Bengaluru

THE HINDU BUREAU

Source: Down To Earth | *https://www.downtoearth.org.in/water/bengaluru-water-crisis-bwssb-announces-20-water-cut-to-bulk-consumers-identifies-areas-bearing-the-brunt-94973*

But Bengaluru, like many other cities, faces a water crisis when not underwater, as the availability of local sources drops during the hot summer months.



After having completed your review of the previous slides – you are invited to try this reflective exercise using a location of your choice that you are familiar with, where recent or frequent inundation is occurring.

The review of historic maps showing changes to buildings, roads and development, modification of natural spaces can inform your understanding of the various reasons why flooding is occurring in the location you have selected.

Does the same area also face droughts or water shortages in hot summer months? Are there parallels you can draw between the example of Bengaluru and the location you have chosen?

Many global south cities (possibly the city you live in too) are increasingly grappling with the paradoxical challenges of both flooding and water scarcity, often simultaneously. These extreme events are becoming more frequent and severe. Recent water crises in major metropolitan areas in India, like Bengaluru and Delhi underscore the urgency of addressing this issue. Rapid urbanization and the resulting impermeable surfaces and changed topography affecting hydrological flows are hindering groundwater recharge, while over-exploitation of aquifers exacerbates the impacts of both floods and droughts.

Intensifying climate change is trapping cities in a vicious cycle of floods and droughts. To safeguard against these extremes and ensure long-term water security, urban areas must urgently adopt more resilient practices.

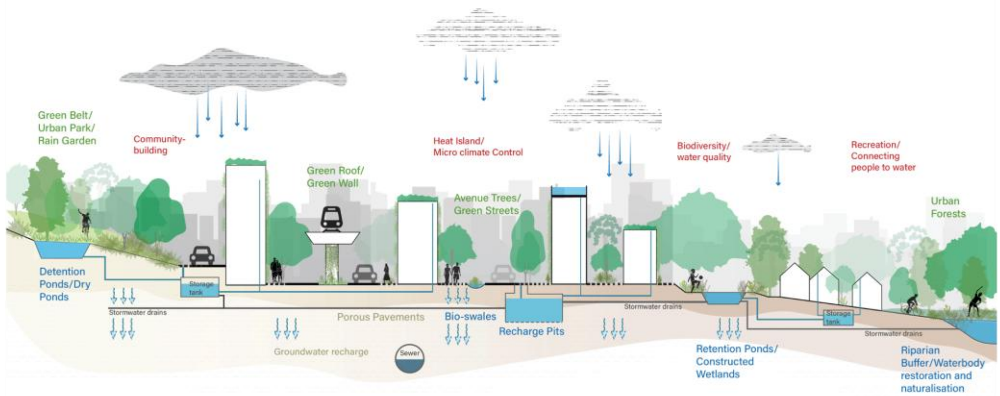
This is a moment to reflect on our usual practices to mange stormwater and urban flooding.

How do we think of stormwater in our cities, 25 years into this new millennium?
Is it enough to keep devising faster and faster ways to drain water and remove it at the earliest possible?
Is there a possible alternative in this era of climate change extremes?

The reimagined approach to stormwater management should seek to leverage resources and stakeholders on critical water risks, such as flooding and scarcity, to provide holistic interventions which address interlinked water threats simultaneously.

In the next section we will explore various solution pathways to solve for such complexities in urban settings. We will look at types of solutions and the scales they can be deployed at in urban regions.

[C.1] Re-Thinking Stormwater Management Approaches



What if we could think of a variety of measures to manage stormwater

so that its harmful impacts are reduced and it can also be conserved for the dry days to follow?

A reimagination of stormwater management practices is of utmost importance. When stormwater is imagined as a resource to be conserved and used and drained away only as a last resort of the excess waters that cannot be absorbed, detained or recharged.

Select benefits of transitioning to this approach are –

- Flood mitigation
- Reduction of loss and damage during flood events (economic / non-economic)
- Increased capacity to absorb flood waters protecting built infrastructure
- Recharged aquifers and improved water availability
- Reduced runoff, erosion, sedimentation and pollution in drainage networks and receiving water bodies

[C.1] Re-Thinking Stormwater Management Approaches

This revised approach to stormwater management, concurrently looks at flood mitigation and water security, and applies measures that will aid both goals. The six processes in the diagram enable improved stormwater management and increased water security for urban areas –

- **SLOW:** This approach aims to reduce the peak runoff volume and speed across the entire catchment. By slowing down the flow, we can prevent flooding and erosion. Techniques include permeable pavements, green roofs, and vegetated swales.
- **DETAIN:** In this method, water is held for short durations in grey or blue-green assets (such as detention basins, rain gardens, or retention ponds). By doing so, we reduce the pressure on the drainage network and prevent overwhelming downstream systems.
- **RETAIN:** Water is held back for longer periods in grey or blue-green assets to increase the local availability and channel towards recharge of surface and sub-surface water bodies.
- **TREAT:** Treating stormwater involves providing nominal treatment to reduce contaminant loads before they enter receiving bodies (such as rivers or lakes). Treatment options include settling basins, filtration systems, and constructed wetlands.
- **RECHARGE:** This strategy focuses on using treated stormwater to replenish surface

and sub-surface reservoirs (aquifers). Recharging aquifers helps maintain groundwater levels and supports sustainable water supply.

- **RELEASE:** Excess water is allowed to travel through drainage networks and enter receiving bodies downstream of the region. Proper management ensures that only surplus water is released, minimizing environmental impact.

There are various alternative paths to stormwater management that do not depend solely on drainage. There are many commonalities across these approaches. Let us understand a few of these.

[C2] Alternative Stormwater Management Approaches: Sponge Cities

- Sponge cities are urban areas that absorb, store, and slowly release rainwater to reduce flooding.
- They are designed to be more permeable and have more open spaces to store rainwater.

The Sponge City philosophy, widely adopted in China, aims to manage water by retaining it at its source, slowing its flow, cleaning it through natural processes, and adapting to water accumulation at the sink. This stands in stark contrast to conventional grey infrastructure, which centralizes and accumulates water in large reservoirs, speeds up its flow through pipes and channelized drains, and attempts to control it at the end point with higher and stronger flood walls and dams.

Case Example: Sponge Cities China

Sponge Cities are designed to absorb rainwater using natural infrastructure, reducing flood risks and providing sustainable urban drainage systems

Qnuli Stormwater Park, China

Haikou Meishe River - before and after shots of the 'sponge city' hotspot

Tianjin Wetland Park, China

Objectives:
- Combat urban flooding caused by rapid urbanization and climate change
- Collect, store, and purify rainwater for reuse

Main Features:
- Use of permeable surfaces, green roofs, rain gardens, and wetlands to absorb excess rainwater
- Creation of natural ecosystems within cities to control water runoff

Achievements:
- By 2030, China aims for 80% of urban areas to absorb and reuse at least 70% of rainwater
- Over 30 cities, including Beijing, Shanghai, and Wuhan, have adopted sponge city strategies

Impact:
- Improved urban resilience to extreme weather events
- Enhanced biodiversity and green spaces within cities

Source: *https://www.euronews.com/green/2022/10/22/china-s-sponge-cities-are-a-revolutionary-rethink-to-prevent-flooding*

Qnuli Stormwater Park, China

Beginning in 2006, a 2,733 hectare (6,753 acres) new urban district, Qunli New Town, was planned for the eastern outskirts of Haerbin in northern China. Thirty-two million square meters (344,445,133 sq. ft.) of building floor area will be constructed in the next 13 to 15 years. More than one third of a million people are expected to live there. While about 16 percent of the developable land was zoned as permeable green space, the majority of the former flat plain will be covered with impermeable concrete. The annual rainfall there is 567 millimeters (22 inches), with the months of June, July, and August accounting for 60 to 70 percent of annual precipitation. Floods and waterlogging have occurred frequently in the past, while at the same time the ground water table continues to drop due to its overuse.

In mid-2009, a landscape architect was commissioned to design a park of 34 hectares (84 acres) right in the middle of this new town, which is listed as a protected regional wetland. The site is surrounded on four sides by roads and dense development. This wetland had thereby been severed from its water sources and was under threat. The original task was to preserve this wetland. Going beyond the original task of preserving the wetland, the landscape architect proposed to transform the area into an urban stormwater park that will provide multiple ecosystems services, and will collect, cleanse, and store stormwater and infiltrate it into the aquifer, protect and recover the native habitats, proved a public space for recreational use and aesthetics experience, as well as foster urban development.

Haikou Meishe River – hotspot sponges

Haikou is a tourist city in South China’s tropical area with a monsoon climate. In the past four decades, the city has experienced a frenzied ten-times growth in population from a quarter million to 2.3 million. Compared to the sprouting skyscrapers, little attention was paid to the natural water system and the urban water infrastructure which are critical for a city in a monsoon climate. The Meishe River, 23 kilometers long, literally meaning the “beautiful mother river” in local language, which runs through the built up area, had become a nightmare for the city, for decades, a sewage dump. The single-minded counter flooding control walls had turned the river into a lifeless concrete channel that people turned their backs on.

In 2016, the Haikou government decided to make a change, this time in a holistic and systematic way. A landscape architect was commissioned to lead the mission of recovering the mother river. The project includes a major park, the Fengxiang Park, 80 hectares (about 200 acres) in size and a linear river corridor 13 kilometers long that runs through the densely built area, which makes up the major part of the planned green infrastructure.

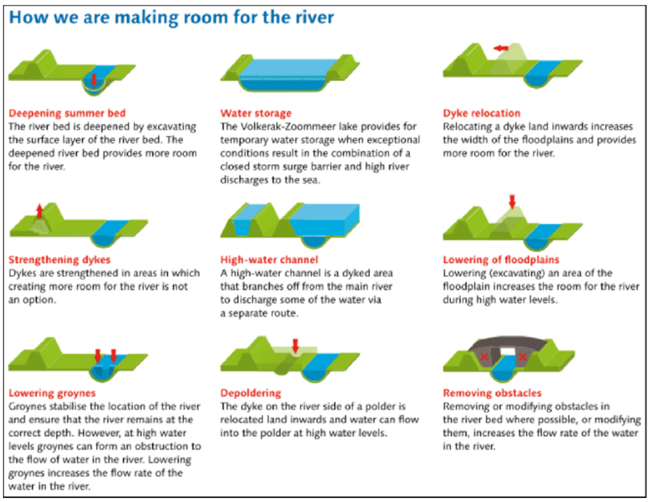
By integrating the works of civil engineering that deal with a gray drainage system of sewage pipes and treatment plants that will collect the sewage of the point sources, and cut off some major pollution sources, the landscape architect designed the river corridor as a comprehensive ecological infrastructure to solve holistically the problems of flood and pollution, recover habitats for biodiversity, create pleasant recreation opportunities, and make it beautiful.

Tianjin Wetland Park, China

The Ecological Wetland Park is a 630,000 m2 artificial wetland located in a high-tech industrial pioneer zone, adjacent to the Tianjin Harbor. The project was initiated by an agency of the local government and constructed with financial support from the Asian Development Bank . The area of the park used to be "a natural coastal salt marsh, which become reclaimed land in the early 2000s. The resulting saline-alkaline area had minimal ecosystem value and use value (as it was not considered to be suitable for agricultural activities either). The wetland park's objective is threefold: 1) to provide a natural wastewater treatment plant for the industrial area to decrease pollutant discharge into the Bohai Bay and improve water quality; 2) to rehabilitate and restore the once thriving biodiversity in the Harbor Area and the Hai river's estuary 3) to create a place for recreation and leisure for residents.

Source:
https://www.euronews.com/green/2022/10/22/china-s-sponge-cities-are-a-revolutionary-rethink-to-prevent-flooding
https://www.chinese-architects.com/en/turenscape-haidian-district-beijing/project/the-transformed-stormwater-park-qunli-national-urban-wetland
https://landezine.com/qunli-national-urban-wetland-by-turenscape/
https://www.turenscape.com/en/project/detail/4676.html
https://blog.meratch.com/2024/01/20/sponge-cities-urban-plannings-answer-to-flash-floods/
https://landezine.com/tianjin-qiaoyuan-park-by-turenscape-landscape-architecture/

[C2] Alternative Stormwater Management Approaches: Room for Rivers



Source: https://www.forestandbird.org.nz/campaigns/room-rivers

- Making room for rivers allows the land adjacent to rivers to flood safely, while providing for a whole range of other benefits such as riparian planting, wetland restoration and carbon sequestration, increased groundwater recharge, river habitat restoration for native fish and birds, and more recreation opportunities for people.

The "Room for the River" program in the Netherlands stands as a testament to innovative flood management, demonstrating a proactive shift from traditional dike reinforcement to a more integrated and sustainable approach. Faced with the increasing threat of climate change and rising river levels, the Dutch government recognized the limitations of solely relying on ever-higher dikes. The program, initiated in response to the near-catastrophic floods of the 1990s, aimed to expand the capacity of rivers to handle peak water flows, thereby reducing the risk of inundation in densely populated areas. Instead of solely building upwards, the strategy involved giving rivers more physical space. This was achieved through a variety of measures, including the relocation of dikes further inland, the deepening of floodplains to increase water storage capacity, and the creation of side channels to divert excess water. Obstacles within the riverbeds were removed, and "green rivers" were designed to provide temporary storage during high water events. These interventions not only enhanced flood safety but also created new natural habitats and recreational spaces, improving the overall environmental quality of the river landscapes. The program’s success hinged on close collaboration between various stakeholders, including government agencies, local municipalities, and residents, ensuring that the projects were tailored to the specific needs and characteristics of each river area. Furthermore, the "Room for the River" program represented a paradigm shift in thinking, moving away from a purely defensive approach to flood control towards a more adaptive and resilient strategy that acknowledges the dynamic nature of river systems and the importance of integrating natural processes. By prioritizing space for rivers, the Netherlands has effectively demonstrated a forward-thinking model for managing flood risks in a changing climate.

Read more at -
https://www.forestandbird.org.nz/campaigns/room-rivers
https://dredging.org/media/ceda/org/documents/events/ceda/room%20for%20the%20river.pdf

Case example: Making Room for the Mithi River, Mumbai, India

Space for the river to swell

A maidaan for holding stormwater

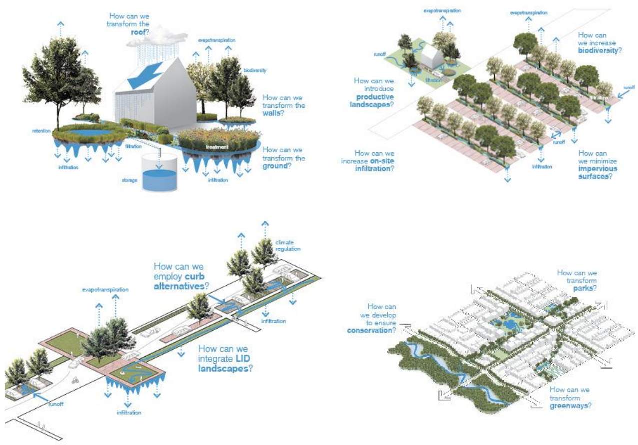
- The Mithi is an urban river in Mumbai which is heavily altered.
- A reimagined vision for the river finds spaces where openings could allow the river to “swell” during periods of heavy rainfall and recreational lands, such as a *maidaan* (playground), can detain excess stormwater when a river water surge submerges stormwater drain outlets to the river.

The Mithi is an urban river whose course has been trained and altered over the years, for almost its entire 17 km stretch. Channelizing the Mithi river for effective flood-risk mitigation has altered its capacity in several places, the impact of which is borne by those who live and work on the riverfront.

A reimagined vision for the river finds spaces where openings could allow the river to “swell” during periods of heavy rainfall and recreational lands, such as a *maidaan* (playground), can detain excess stormwater when a river water surge submerges stormwater drain outlets.

Source:
https://wri-india.org/blog/walking-along-mithi-river-five-opportunities-improve-flood-resilience

[C2] Alternative Stormwater Management Approaches: Low-Impact Developments(LID)



- Low impact development (LID) is a land planning and design approach that uses natural processes to protect water quality and aquatic habitats.
- LID aims to mimic a site's pre-development hydrology by using techniques that filter, store, and evaporate stormwater.

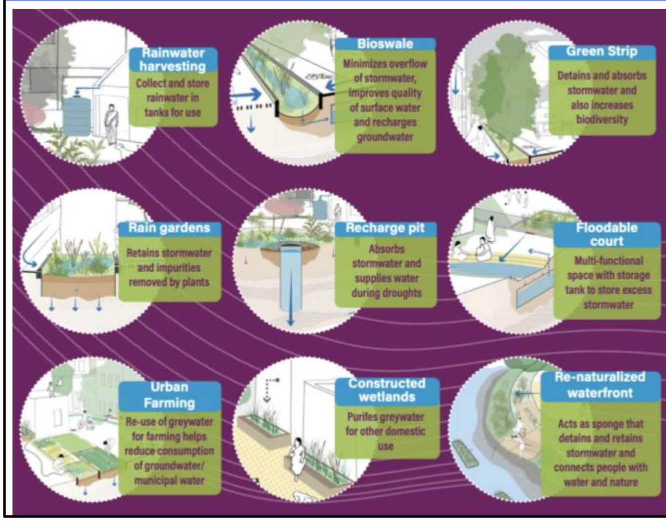
Source: *http://uacdc.uark.edu/work/low-impact-development-a-design-manual-for-urban-areas*

Low impact development (LID) is a set of practices that use natural processes to manage stormwater and reduce its impact on the environment. LID is a site-level planning process that can be used for new construction or redevelopment.
A few LID techniques are as follows:

- **Green roofs:** Roofs covered with plants and shrubs that absorb rainfall and slow it down
- **Rain gardens:** Depressions in the ground that collect runoff and manage it through evaporation and infiltration
- **Bioretention areas:** Landscaped depressions that collect runoff and manage it through infiltration, evaporation, and biological uptake of nutrients and other pollutants
- **Permeable pavers:** Pavements that allow water to pass through
- **Rain barrels:** Collect rainwater for later use

The goals of Low Impact Development (LID) are to reduce runoff and pollutant loads, protect water quality and aquatic habitats, and restore or maintain the ecological and hydrologic functions of a watershed. LID also seeks to conserve natural resources and mimic the area's natural hydrology, promoting more sustainable and resilient urban water management.

[C2] Alternative Stormwater Management Approaches: Water Sensitive Urban Design (WSUD)



- Water sensitive urban design (WSUD) is a planning and design approach that integrates water systems into urban environments.
- WSUD aims to reduce the impact of development on water resources and improve water quality.

Water Sensitive Urban Design (WSUD) is a set of principles that can be applied to sustainably manage water, providing opportunities for the development industry, local government and their communities to achieve more liveable cities with vibrant and healthy waterways.

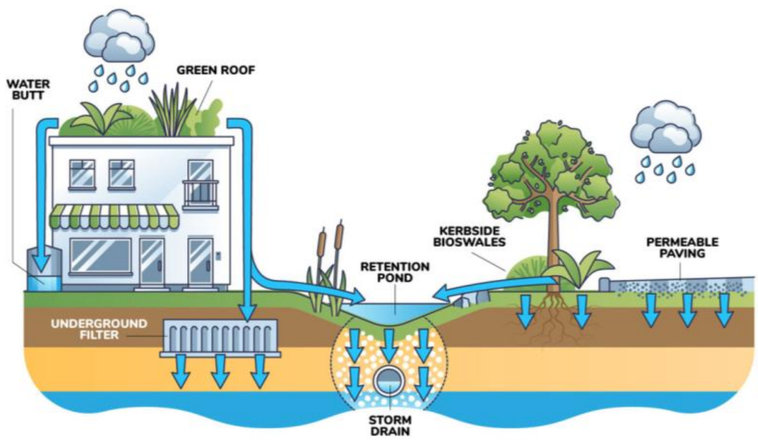
Goal:

- To manage water as a valuable resource by minimizing the negative effects of urban development on the natural water cycle.

Examples of WSUD techniques:

- **Permeable pavements:** Allows rainwater to infiltrate the ground instead of running off
- **Green roofs:** Vegetation on rooftops to capture and filter rainwater
- **Rain gardens:** Depressed areas planted with vegetation to temporarily store and filter stormwater
- **Bioswales:** Shallow vegetated channels designed to filter runoff
- **Rainwater harvesting systems:** Collecting rainwater from rooftops for irrigation or other uses
- **Swales and detention ponds:** Areas designed to slow down and temporarily store stormwater

[C2] Alternative Stormwater Management Approaches: Sustainable Urban Drainage Systems (SUDS)



- Sustainable Urban Drainage Systems (SUDS) are a network of green spaces and engineered areas that manage surface water. They are designed to mimic natural water processes to reduce runoff and improve water quality.

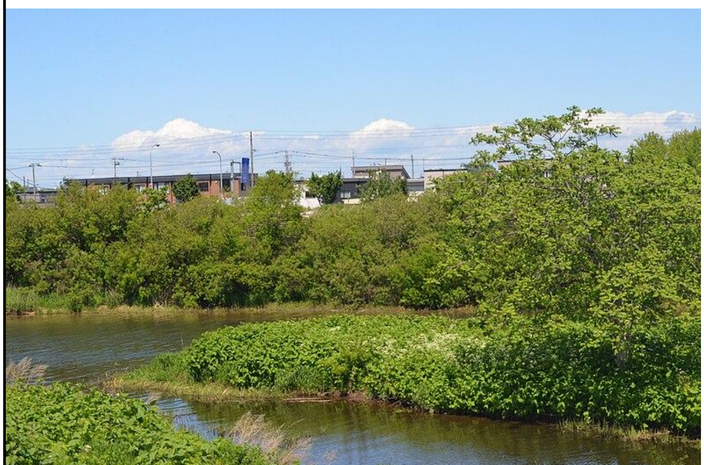
Sustainable urban drainage systems (SUDS) offer a more natural approach to managing drainage systems in and around properties and developments than traditional drainage systems. They are designed to temporarily store water during storm events, reduce peak flows and reduce surface water runoff, by mimicking the natural cycle of water management by retaining water where it lands.

How do SUDS work?
SUDS work by gradually holding back water and then allowing natural processes to remove pollutants. They can also allow water to soak into the ground or evaporate from the surface.

SUDS components: green roofs, rain gardens, porous pavements, ponds, wetlands, basins, swales, bioretention basins, and filter drains.

This section would explain various scales of interventions for Urban Stormwater Management.

[C3] Scales of Intervention for Urban Stormwater Management: Watershed and regional interventions



- Flood management for urban areas often requires large watershed scale interventions such as river restoration with renaturalizing floodplains, wetland conservation and daylighting covered streams.

This is a case example from Indonesia.
A 7-hectare pilot public project, the Tebet Eco park is located in South Jakarta in a neighbourhood that is densely populated. Before the intervention the park was in an acute state of deterioration and prone to floods as well as ecological degradation, as the park is streamed by a river which made it only more susceptible to heavy rains. As such, the municipal authorities of Jakarta planned to revitalize the area by "increasing the hydraulic capacity of the existing canal, improving site-wide pedestrian connectivity, and adding a new recreation program". This meant that the park was transformed by planting and conserving new and older trees, as well as using vegetation and natural embankments. Furthermore, the implementer planted riparian vegetation to improve water quality by filtering and cleansing surrounding runoff, which also enhanced the site's biodiversity. Besides these elements, a thematic garden, a forest buffer, and a community garden were implemented complementing the entire eco-design that the park aimed for. The park's rehabilitation focused greatly on the human element, providing maximum benefits for park users, the surrounding natural habitats and species, as well as increasing the land value of the area.

The intervention started in 2021 when the local municipality of Jakarta started renovating a former green area of the Tebet district. Residents were consulted in terms of their needs and how the new intervention could respond to this. It was noticed that the municipality should prioritize ecological functions, especially flood control, social space functions, and of the creation of educational and recreational spaces. The once highly polluted 714-metre-long straight concrete canal was revitalised into an active waterway with the use of vegetation and natural embankments and hydraulic capacity was increased at least two times. Eight zones were developed and 1500+ new trees and 400,000+ new shrubs were planted.

Source:
https://blogs.worldbank.org/en/eastasiapacific/indonesia-enhancing-urban-flood-resilience-investments-healthy-and-green-multi

Blue-Green Infrastructure in Indonesia

Indonesia is investing in blue-green infrastructure as part of its urban flood resilience strategy. The aim is to create healthier and more sustainable urban environments while addressing the increasing risk of floods

- **Flood Management**: The integration of natural green spaces, wetlands, and water management systems helps reduce flood risks in cities like Jakarta by absorbing and redirecting stormwater.
- **Healthier Urban Environment**: Green spaces such as parks and urban forests not only help manage water but also provide areas for recreation and improve air quality, contributing to better public health.
- **Community Resilience**: The approach combines infrastructure investment with community engagement, enhancing local capacity to manage water and create more livable urban spaces.

Taman Tebet, located in South Jakarta, a multifunctional green space that also serves flood management purposes

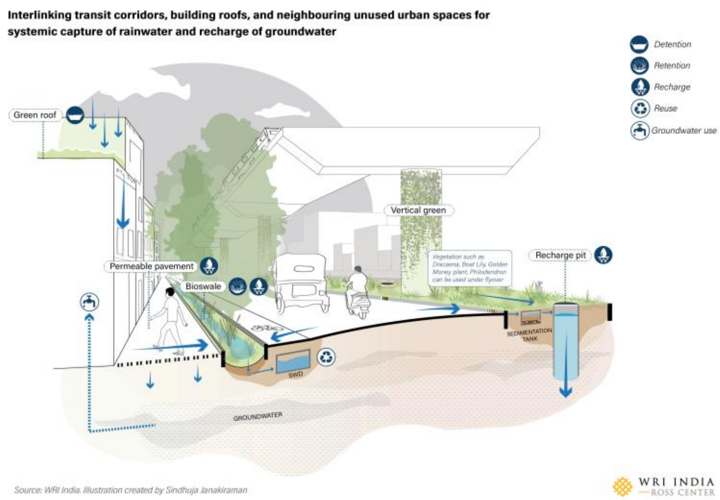
Source: https://blogs.worldbank.org/en/eastasiapacific/indonesia-enhancing-urban-flood-resilience-investments-healthy-and-green-multi

This is a case example from Indonesia.
A 7-hectare pilot public project, the Tebet Eco park is located in South Jakarta in a neighbourhood that is densely populated. Before the intervention the park was in an acute state of deterioration and prone to floods as well as ecological degradation, as the park is streamed by a river which made it only more susceptible to heavy rains. As such, the municipal authorities of Jakarta planned to revitalize the area by "increasing the hydraulic capacity of the existing canal, improving site-wide pedestrian connectivity, and adding a new recreation program". This meant that the park was transformed by planting and conserving new and older trees, as well as using vegetation and natural embankments. Furthermore, the implementer planted riparian vegetation to improve water quality by filtering and cleansing surrounding runoff, which also enhanced the site's biodiversity. Besides these elements, a thematic garden, a forest buffer, and a community garden were implemented complementing the entire eco-design that the park aimed for. The park's rehabilitation focused greatly on the human element, providing maximum benefits for park users, the surrounding natural habitats and species, as well as increasing the land value of the area.

The intervention started in 2021 when the local municipality of Jakarta started renovating a former green area of the Tebet district. Residents were consulted in terms of their needs and how the new intervention could respond to this. It was noticed that the municipality should prioritize ecological functions, especially flood control, social space functions, and of the creation of educational and recreational spaces. The once highly polluted 714-metre-long straight concrete canal was revitalised into an active waterway with the use of vegetation and natural embankments and hydraulic capacity was increased at least two times. Eight zones were developed and 1500+ new trees and 400,000+ new shrubs were planted.

Source:
https://blogs.worldbank.org/en/eastasiapacific/indonesia-enhancing-urban-flood-resilience-investments-healthy-and-green-multi

[C3] Scales of Intervention for Urban Stormwater Management: Citywide Network Solutions



- City-scale flood management solutions typically involve a combination of structural measures like improved drainage systems, underground tunnels, alongside nature-based approaches like wetlands, flood pools, bioswale, street side rain gardens, and permeable pavements.

To Integrate green infrastructure throughout the city, the **network** mimics natural hydrological processes, reducing runoff and improving water quality. Rain gardens, green roofs, and permeable pavements act as distributed sponges, absorbing and filtering rainwater at the source. Urban wetlands and bioswales provide additional storage and filtration, slowing down peak flows and reducing the strain on traditional drainage systems. Urban forests and parks also reduce the volume of stormwater runoff. Implementing these solutions requires a coordinated approach, integrating NBS into urban planning and development. A citywide network not only mitigates flood risks but also enhances biodiversity, improves air quality, and creates aesthetically pleasing urban spaces.

Local residents wait for waters to subside in Dar es Salaam, Tanzania

Source: https://blogs.worldbank.org/en/sustainablecities/turning-flood-risk-economic-opportunity-dar-es-salaam-Tanzania

A. Flood Management and Economic Transformation in Dar es Salaam, Tanzania

Flood Impact: The Msimbazi Basin, home to many vulnerable communities, frequently experiences severe floods, causing significant economic losses and damaging infrastructure.

Economic Loss: Annual flood damages are estimated to cost approximately $100 million.

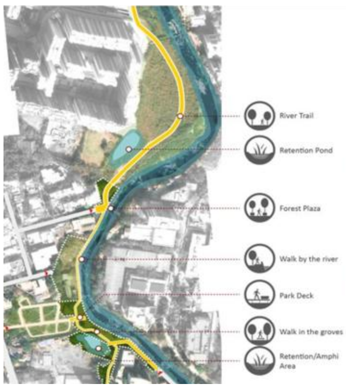
Msimbazi Opportunity Plan:Aims to restore the floodplain, reduce flood risk, and create potential for sustainable urban development worth $300 million, including green spaces and flood protection infrastructure.

The Presidential Office – Regional Administration and Local Government of Tanzania has conducted a study and developed phased plans to combat flooding by the Msimbazi river in the city centre of Dar es Salaam caused by intense rainfall and rapid urbanisation. The Msimbazi River Basin City Park project tackles a multitude of urban challenges in Dar es Salaam, such as poor connectivity, lack of green spaces, heat stress, and more. The project started off with charettes, involving 59 institutions, and it is this collaborative effort that laid the foundation for the transformative approach. The interdisciplinary approach made it possible to align different wishes and requirements, yielding a feasible design that addresses erosion control, flood-safe terraces, habitat restoration, and the creation of mixed neighbourhoods connected to recreational facilities in the public park.

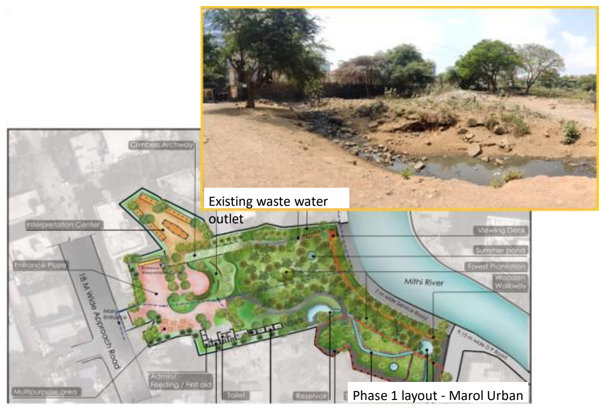
The Msimbazi Opportunity Plan represents a new paradigm in urban open space design, which recognizes that rivers are dynamic systems and emphasises the importance of adopting a holistic approach that involves collaboration between different stakeholders and sectors. The approach embraces natural processes to combat flood risk, recognises multisectoral needs, such as infrastructure development, and has been tailored to the local context. Additionally, the project is bankable, driven by enabling revenues from urban development, ensuring that the proposed solutions are economically feasible and sustainable.

Sources:
https://blogs.worldbank.org/en/sustainablecities/turning-flood-risk-economic-opportunity-dar-es-salaam-Tanzania
https://www.ajlajournal.org/articles/msimbazi-river-basin-city-park-project

B. Increasing absorptive landscapes along the Mithi River, Mumbai, India



Vision for Marol Urban Forest – 1 km stretch



Phase 1 layout - Marol Urban Forest

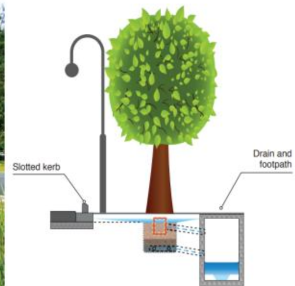
Landscape interventions particularly around greening and vegetation have added co-benefits of heat mitigation, micro-climate control and potentially air quality improvements

Urban wetlands and bioswales provide additional storage and filtration, slowing down peak flows and reducing the strain on traditional drainage systems.

This is being tried along the Mithi river in Mumbai – where eventually a network scale intervention is envisioned instead of piecemeal projects. The whole hydrological network leading into the Mithi River is addressed in the plan that has been conceptualized for this urban river.

A citywide network not only mitigates flood risks but also enhances biodiversity, improves air quality, and creates aesthetically pleasing urban spaces as seen in these photos for initiatives along the Mithi River in Mumbai.

C. Roadside Blue-Green Infrastructure



Design of raingardens along roads, which increases green cover along roadside and slows the surface-runoff, increasing permeability.

Source: pub.gov.sg/-/media/PUB/Reservoirs/ABC/PDF/Condensed_Booklet_of_Engin_Procedures.pdf

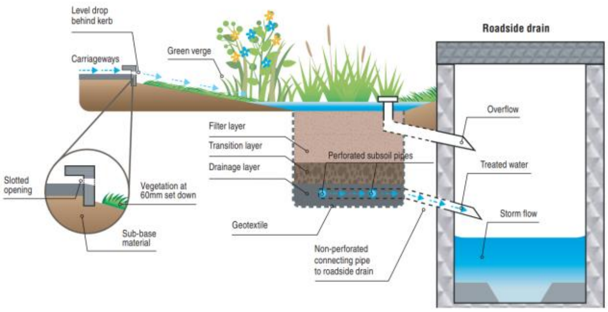
There is a growing global movement where cities are undertaking action to transform their hard streets into porous, green landscapes. Portland, Seattle, New York in the United States, to name a few, have mitigated the risk of urban floods with integrated blue-green-grey solutions undertaken as part of green streets program. Sheffield , United Kingom incorporated similar infrastructure, i.e., street trees, permeable pavements, bioswales and retentions planters and rain gardens at local street scale to help build resilience. Successful cases of such interventions use a multi-disciplinary approach to transport infrastructure planning and design—one that integrates engineering, landscape design and hydrology.

- Roadside blue-green infrastructure integrates natural elements into streetscapes to manage stormwater effectively.
- Bioswales, rain gardens, and permeable pavements along roadsides capture and filter runoff, reducing peak flows and improving water quality.
- Ditches can be designed as vegetated swales, slowing down water and promoting infiltration.
- Trees and other vegetation planted along roadsides intercept rainfall.
- Blue infrastructure, like small retention ponds or constructed wetlands adjacent to roads, can store excess water during heavy rainfall.

This approach reduces the burden on traditional drainage systems, minimizes flooding risks, and enhances urban biodiversity. By integrating blue-green infrastructure into roadside design, cities can create more resilient and sustainable stormwater management systems while also improving the aesthetic and environmental quality of urban streets.

Read more at:
https://www.mdpi.com/2073-4441/11/10/2024#:~:text=These%20elements%20manage%20stormwater%20through,transport%2C%20while%20providing%20such%20multiple
https://www.epa.gov/soakuptherain/soak-rain-permeable-pavement#:~:text=In%20addition%20to%20reducing%20the,that%20contribute%20to%20water%20pollution.
https://thefloodhub.co.uk/blog/how-blue-green-infrastructure-can-reduce-flood-risk-and-provide-lots-of-other-benefits/
https://www.chijournal.org/C475

C. Roadside Blue-Green Infrastructure



Multi-functional roadside landscape. Increasing green cover and permeable surface along with road safety and greening.

Street side rainwater harvesting structures in Chennai, India

Application

- Roadside landscape on footpath
- Median landscape
- Traffic island landscape
- Retention areas

Source: pub.gov.sg/-/media/PUB/Reservoirs/ABC/PDF/Condensed_Booklet_of_Engin_Procedures.pdf

Of more than 75 rainwater recharge wells in Chennai's Kalakshetra Colony, the resident welfare association (RWA) has financed the construction of 28, to combat the torrential downpours and floods.

In 2003, the Tamil Nadu government mandated all buildings in the state to include rainwater harvesting structures. However, the policy took into account excess rainwater collected only on the terraces, not in open spaces within a residential area or on the roads beside them. Kalakshetra Colony undertook the initiative to construct rainwater recharge wells in these areas, building 75 rainwater recharge wells within its premises spread across six major roads.

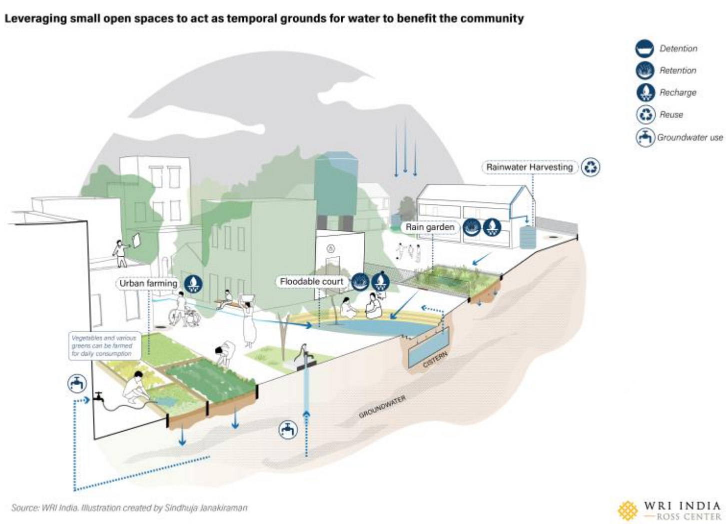
While the Kalakshetra Colony Welfare Association (KCWA) is credited with financing the construction of 28 of these, the rest were built with the help of the Greater Chennai Corporation (GCC). Excess rainwater percolated in the wells has prevented flooding in streets alongside 800 residential units, of both independent houses and apartment complexes.

Rainwater recharge wells ensure minimal wastage of “precious rain” and make for a much more viable alternative than stormwater drains (SWD s) in a city like Chennai, where the earth is predominantly sandy and readily absorbs rainwater.

Sources:
https://thebetterindia.com/267764/chennai-floods-rainwater-recharge-wells-rainwater-harvesting-how-to-contact/

Chennai Mega Streets Project: Corporation to revamp 25 km stretch of road in the city under ‘quick wins’ | Cities News, The Indian Express

D. Neighborhood Projects



Neighbourhood scale flood solutions focus on managing stormwater runoff through nature-based approaches like rain gardens, bioswales, permeable pavements, green roofs, and improved drainage systems.

Many cities like Singapore, Rotterdam, have transformed existing open/vacant spaces such as city parks, playgrounds and post-industrial zones into water-prudent landscapes using green interventions. These spaces integrate nature into the urban fabric increasing biodiversity and reconnecting urban dwellers to nature both visually and physically.

The Bishan-Ang Mo Kio Park, in Singapore, uses blue-green infrastructure for flood control, biodiversity management, microclimate control and adds a high-quality public space asset to the city for recreation and educational use.

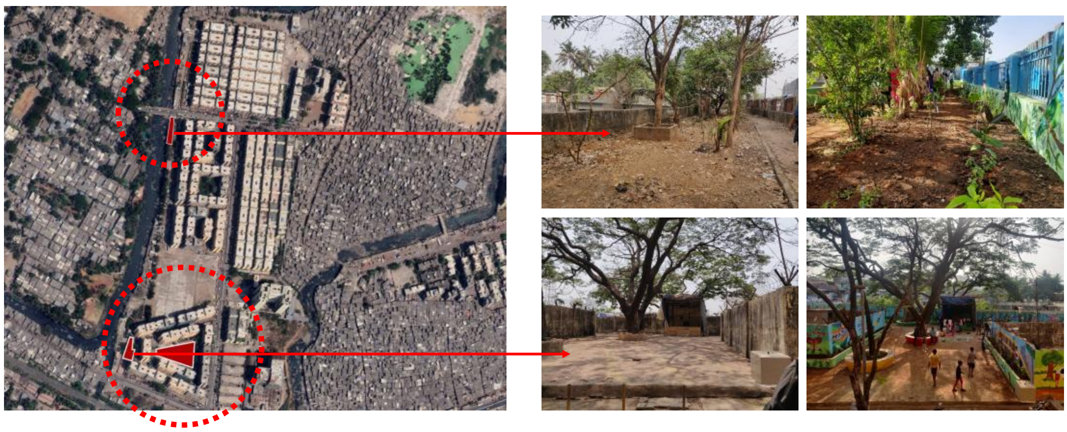
Benthenheim Water Square in Rotterdam, an example of integrated multi-use blue-green-grey solution, is a conventional play and sports areas with permeable surface that doubles as an unconventional stormwater catch basin

An 11-acre rooftop park in Bangkok's commercial district directs runoff into a retention system reducing pressure on underground drainage and sewer systems.

Most neighborhood scale examples of integrated blue-green solutions use medium to large open spaces (parks/rooftops) to absorb and/or store excess stormwater. Integrating these spaces with networks of smaller blue-green interventions (green roofs and streets) across neighborhoods can help create decentralized off-grid systems for effective urban flood management.

Learn more at –
https://web.mit.edu/nature/projects_14/pdfs/2014-Bishan-Ang-Mo-Kia-Park-Schaefer.pdf
https://www.publicspace.org/works/-/project/h034-water-square-in-benthemplein
https://wbae.com/living-with-water-2/
https://www.youtube.com/watch?v=uWjGGvY65jk

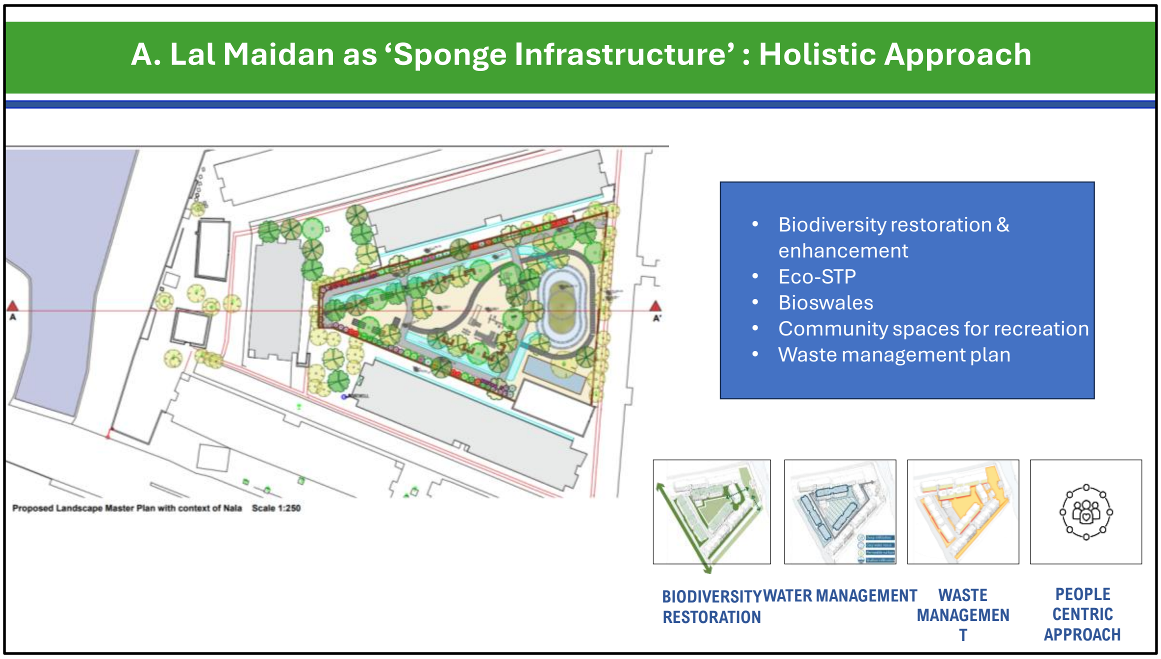
A. Case example: Lal Maidan as 'Sponge infrastructure', Mumbai, India: Holistic Approach



- **Lallubhai Compound** is a Rehabilitation and Resettlement colony located in Mankhurd, Mumbai.
- **Holistic solutions for greening** were proposed and carried out in two plots to address flooding and heat issues together

This neighborhood intervention approach is being tried in the Lallubhai compound in Mumbai. This rehabilitation and resettlement colony faces a range of issues.

This example highlights the adaptability of nature-based systems such as greening, and its ability to provide multiple benefits.



Further, the use of natural systems also revives biodiversity and creates a recreational space for the community, if well designed and well maintained, becoming a key natural hub and asset for the low-income community.

E. Property Scale Projects

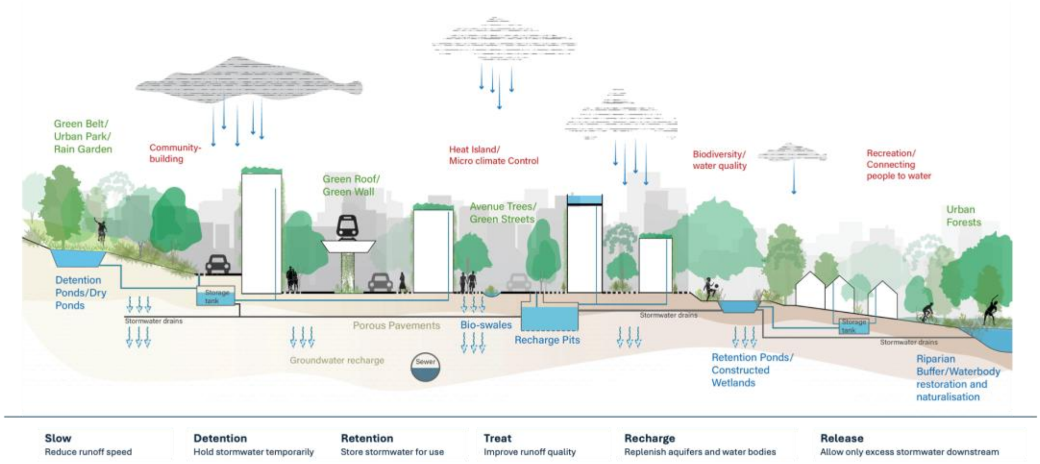
Simple measures like rain barrels and cisterns capture rooftop runoff, reducing strain on municipal drainage systems. Permeable paving in driveways and patios allows rainwater to infiltrate the soil, minimizing surface runoff. Rain gardens, strategically placed in low-lying areas, absorb and filter excess water, preventing localized flooding. Vegetated swales along property lines direct runoff and promote infiltration. Green roofs on sheds or garages reduce runoff volume and slow down peak flows. Proper landscaping, including terracing and contouring, can manage water flow and prevent soil erosion. Rainwater harvesting systems, coupled with filtration, can provide non-potable water for irrigation and toilet flushing, reducing reliance on municipal water supplies.

This is a particularly useful approach to be implemented, especially in large properties like institutional campuses or IT or business parks – as large volumes of rainwater can be diverted away from municipal systems and managed on site.

Read more on raingardens from University of Wisconsin-Milwaukee
https://uwm.edu/sustainability/what-we-do/water/rain-gardens/
Read more about rainwater harvesting practices in the WIPRO campus, Bengaluru India - https://www.rainwaterclub.org/industrial_wipro.htm

Read more about various techniques at –
https://www.kingspan.com/ie/en/knowledge-articles/rainwater-harvesting-for-water-conservation/
https://www.epa.gov/soakuptherain/soak-rain-rain-barrels
https://stormwater.pca.state.mn.us/index.php/Overview_for_permeable_pavement
https://jacksonvillenc.gov/872/Rain-Gardens
https://stormwater.pca.state.mn.us/index.php?title=Green_Infrastructure_benefits_of_vegetated_swales#:~:text=Check%20dams%20incorporated%20into%20the,thus%20increasing%20the%20volume%20of
https://www.researchgate.net/publication/258773837_Terraced_landscape_from_an_old_best_practice_to_a_rising_land_abandoned-related_soil_erosion_risk#

Call to Action



Reimagine Stormwater as a resource. Drain it as the last resort

Thank you for viewing this self-study module on urban flooding and stormwater management. We would like to close this learning module with a call to action.

You are invited to continuously revisit and rethink how stormwater is addressed in YOUR city and YOUR neighborhood. In whatever role you play in your city, be it as a citizen or a practitioner or a student, you can inform and transform your city's approaches from stormwater drainage to stormwater management, and think of stormwater as the critical resource that can underpin urban water security.

Call to Action

Urban Practitioner

- Test and measure effectiveness of drainage alternatives for stormwater management methods
- Explore NBS augmentation to improve conventional drainage solutions

City Planners

- Enable integration of NBS in stormwater management practices
- Apply a range of (integrated) solutions for stormwater management instead of only drainage solutions
- Develop policy for encouraging property level runoff reduction practices

Community

- Be good stewards and be involved in monitoring and upkeep of stormwater infrastructures (both grey and NBS)
- If stewarding, managing or owning large properties implement on-site stormwater management practices to reduce load on municipal stormwater systems
- Be champions of alternative measures to simultaneously improve stormwater management and reduce water scarcity

To **urban practitioners** – whether on field or academics –you are at the very forefront of bringing together innovations and new practices (maybe retention systems, maybe nature-based solutions) – and to test these solutions and evaluate their effectiveness over various scenarios.
Another aspect to explore is how these solutions can be integrated with conventional drainage systems to augment their capacity. In large, dense cities, existing drainage infrastructure cannot be fully replaced—but it is also not sufficient on its own. The key question is what complementary measures can be added and to what extent they can enhance overall system performance.

To **city planners and stormwater department officials** – can you explore pathways and processes that will enable the integration of alternative/ unconventional stormwater practices. Whether it is an update of tenders and procurement practices or setting up stormwater labs to test new solutions – you can join practitioners and academics to investigate these possibilities.
This point may seem repetitive, but it is important to look beyond drainage. Conventional drainage shifts a valuable resource—rainwater—from one jurisdiction to another. Cities also contain large areas of private property, and municipal codes and policies must address how stormwater is managed in these spaces. This could

include incentives for on-site rainwater detention, or higher fees for properties that discharge stormwater onto public infrastructure, such as storm drains or roads.

And the final call to action is to **community stakeholders** – who at the end are the ones facing issues with stormwater and have the most to lose or to gain.
Can community become engaged stewards of stormwater infrastructure – whether it is tending the local rain garden or keeping the storm drain free of solid wastes?
Large property owners (like campuses) can improve their stormwater practices on-site, and become demonstration sites for safely keeping the maximum stormwater on site.
And also champion the cause of integrated and holistic stormwater practices.

Contact Us

For more information:

Please email Sahana Goswami, Senior Program Manager, WRI India

Sahana.Goswami@wri.org