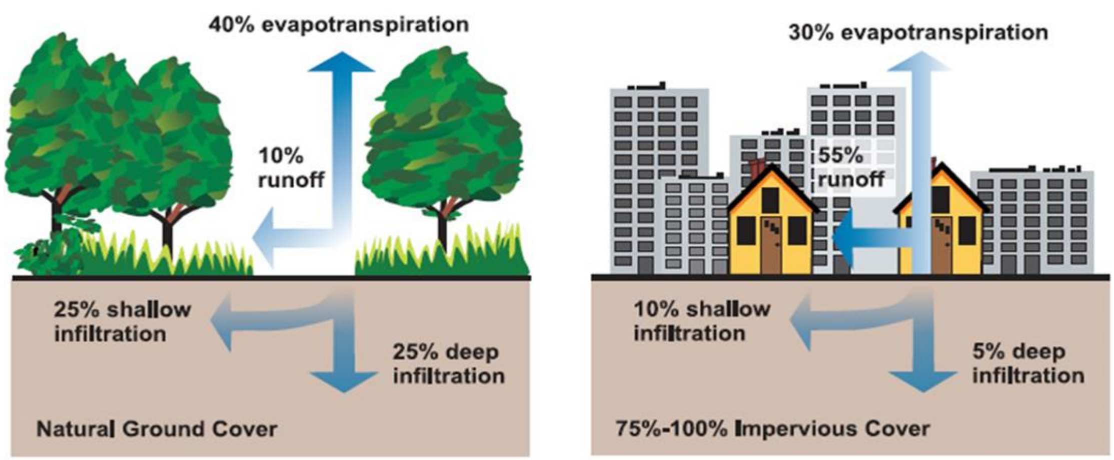
Understanding Stormwater Runoff in Highly Urbanized Areas

This fact sheet explains stormwater runoff, stormwater drainage systems, and ways communities manage runoff and reduce the impacts of urban flooding. The stormwater runoff from increasingly intense storms can overwhelm urban drainage systems, causing extensive flooding and widespread damage, injuries, and loss of life.

What is the Connection Between Surface Runoff and Stormwater Drainage Systems?

Stormwater or surface runoff is a component of the Earth's water cycle. Precipitation falls and either seeps into the ground or flows along the surface of the ground. If it seeps into the ground below the top layers of soil, groundwater aquifers may be replenished. In urbanized areas, surface runoff first collects in stormwater drainage systems, brooks, streams, and rivers, then flows to ponds, lakes, and the ocean. Water evaporates from the ground and those bodies of water. Trees, grass, and other vegetation also take water from the soil and transpire it to the atmosphere. In the atmosphere, the water condenses and forms clouds. Precipitation falls from clouds to the Earth's surface, continuing the water cycle.

Most of the rain that falls on areas with buildings, streets, parking lots, sidewalks, and other paved surfaces runs off more quickly than the rain that falls on parks, gardens, green spaces, forests, and farmland. In cities and highly urbanized areas, the runoff collects in urban stormwater drainage systems.



Source: Federal Interagency Stream Restoration Working Group

Relationship between impervious cover and surface runoff

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How is a Storm Defined?

Storms are typically identified based on wind velocity, rain intensity, duration, and the area impacted. Agencies such as the National Oceanic and Atmospheric Administration (NOAA) use other factors, including barometric pressure, to indicate the potential severity of storms. Federal, state, and local agencies use storm characteristics to indicate potential property damage and to encourage people in affected areas to be prepared, to take precautions for safety, to anticipate flooding and high winds. The NOAA National Hurricane Center uses the Saffir-Simpson Hurricane Wind Scale to classify the severity of winds and storm surge flooding produced by tropical storms and hurricanes.

Storms are also classified in terms of recurrence intervals. A recurrence interval is the expected time between occurrences of a storm of a particular severity. The probability or chance of a storm of a certain magnitude occurring in any given year is the inverse of the recurrence interval. The lower the probability or chance of occurrence, the more severe the storm. Statistical probability statements may create misunderstandings. In reality, a storm event of any magnitude may occur every year, or even multiple times in one year. Depending on state and local requirements, engineers use the following probabilities (and associated recurrence intervals) for various purposes, including designing urban stormwater systems and evaluating whether existing systems have adequate capacity to carry anticipated rainfall runoff amounts:

- 100-percent chance of occurring in a year (1-year storm)
- 20-percent chance of occurring in a year (5-year storm)
- 10-percent chance of occurring in a year (10-year storm)
- 1-percent chance of occurring in a year (100-year storm)
- 0.2-percent chance of occurring in a year (500-year storm)

What is the Recent History of Significant Rainfall Amounts for New York City?

The NOAA National Centers for Environmental Information reports that the average annual precipitation for the New York City urban area is 47 inches of rainfall, plus 25 inches of snow. Over the past decade, the time of year and amount of rainfall for the maximum 1-day totals have varied significantly (see table). On September 1, 2021, Hurricane Ida produced the most significant daily total amount of rain (7.13 inches) and the most intense hourly rate of rainfall (3.15 inches per hour).

Maximum Daily Total Rainfall Amounts in New York City from 2010 to 2021
(Source: Current Results – Weather and Science Facts)

Date of Storm	Inches	Date of Storm	Inches
March 13, 2010	3.86	January 23, 2016	2.31
August 14, 2011	5.81	October 29, 2017	3.03
April 22, 2012	2.45	August 11, 2018	2.90
June 7. 2013	4.16	October 16, 2019	1.83
April 30, 2014	4.97	July 10, 2020	2.54
January 18, 2015	2.10	September 1, 2021	7.13

What is a Stormwater Drainage System?

Communities build stormwater drainage systems, sometimes called stormwater sewer systems, to collect and convey surface runoff. Doing this minimizes local flooding which can disrupt traffic, damage buildings, and damage personal and public property. Drainage system components include curbs and gutters, drainage swales and ditches, inlets where water flows into catch basins, and below-ground stormwater pipes. The whole system is intended to carry rainfall runoff and snow melt to a stream, river, tidal body of water, or treatment plant. Some cities and urban areas use rain gardens, stormwater ponds, special paving materials, and other features to help runoff soak into the ground instead of flowing to their stormwater drainage systems.

When stormwater drainage systems are sized to carry anticipated runoff from frequent storms, the adverse impacts on traffic, buildings, and people are minimized. To function properly, drainage systems must be maintained. Communities need to inspect their systems, remove debris and leaves, clean out catch basins and stormwater pipes, and make repairs to keep the system working properly.

When older stormwater drainage systems were designed to carry smaller amounts of runoff, or if they are poorly maintained, they may not be able to handle the runoff from increasingly intense rainfall events. As a result, streets flood, soil and plantings wash away, and water may get into buildings, especially buildings with basements, cellars, and below-grade areas. The resulting accumulation of floodwater can damage walls, flooring, furnaces, appliances, furnishings, and personal property. Buildings with basements may be at a high risk of flooding if they are not protected from storm drain backup through floor drains, or if surface runoff can flow into the below-grade areas. Stormwater seeks the easiest path to enter buildings, which may be through foundation cracks, windows and vents that are close to the ground, exterior stairways, and driveways. Depending on how long water is able to enter, some basements may completely fill.

As urban stormwater drainage systems get older, they may not work as well as originally designed, especially if not maintained. Plus, as storms get more intense and rainfall amounts increase due to climate change, there will be more runoff water than some systems can convey. Having more buildings and impervious paving increases the amount of surface water runoff, and as rainfall runoff volumes increase, the drainage systems may not be able to handle the flows.

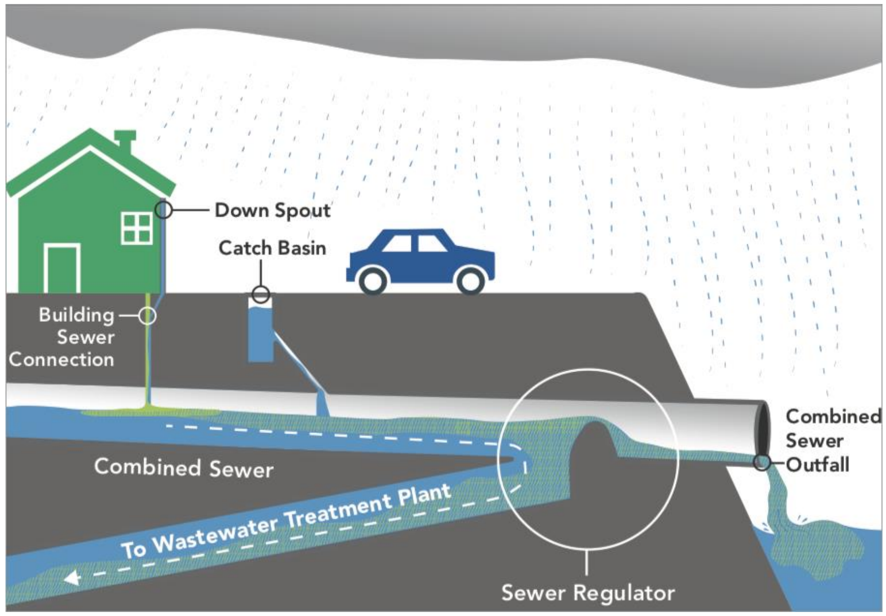
How do Combined Sewer Systems Work?

Combined sewer systems are designed to carry flows from sanitary sewers and stormwater runoff. They convey the flows to wastewater treatment plants, where cleanup occurs. During normal rainfall events, well-maintained combined sewer systems function effectively. However, during extreme rainfall events, the conveyance system is built with bypass locations that allow the flows to be discharged into receiving streams, rivers, or tidal waters without treatment. These discharge points are identified as combined sewer outfalls. They are governed by

Source: NYC Department of Environmental Protection regulations on water quality treatment. Some parts of many highly urbanized areas, including New York City, have combined sewer systems.

Heavy stormwater runoff can trigger combined sewer systems to surcharge. Surcharges occur when the amount of wastewater is too much for the system to carry. When surcharges occur, wastewater backs up in the system. Surcharges can lead to performance failures during extreme rainfall events, resulting in:

- Surcharged sanitary sewers, which may create backup flows that enter the plumbing systems of buildings.
- Lift station and pump station capacity may be reduced or pump systems may fail and lose power.



Source: NYC Department of Environmental Protection

Schematic of combined sewer system

What Happens When Rainfall Runoff Exceeds the Capacity of a Stormwater System?

Intense rainfall can trigger various conditions depending on the capacity of the stormwater drainage system to carry runoff. That capacity is defined in terms of the drainage system design standards in use at the time the system components were constructed. It is not unusual to find older systems that have less capacity to carry increased rainfall runoff as more intense storms occur. While most urban stormwater drainage systems handle flows under normal rainfall, they may not have adequate capacity to function under intense rainfall. The result is urban flooding.

> **Urban Flooding**
>
> The inundation of property in a built environment, particularly in more densely populated areas. Urban flooding may be caused by rainfall that runs off large amounts of impervious surfaces and overwhelms the capacity of stormwater drainage systems.

There are many ways that urban flooding increases hazards and damage:

- Surcharged stormwater systems
  - Pressure on the pipe network can damage components
  - Shifted manhole covers are risks to people on sidewalks and streets
- Sanitary backflow from combined sewer systems
  - Backs up into buildings, especially basements and below-grade spaces, through plumbing fixtures and floor drains
  - Environmental damage when sewage flows into streams, rivers, and tidal waters

- Building damage:
  - Basement wall and floor cracking and failures
  - Damaged machinery, equipment, contents, and finishes
  - Utility failures
- Building occupant hazards:
  - Basement and lowest floor flooding can trap people
  - Health problems caused by mold, bacteria, and pollutants carried by floodwater
- Street and road hazards:
  - Risks to drivers if cars hydroplane on wet streets or when moving water pushes cars off roads
  - Washed out roadbeds where the erosion of culverts or underlying soils is enough to affect roadbed integrity (undermining), creating failures such as potholes, sinkholes, and shoulder collapse
  - Bridge failures caused by erosion and scouring of the soil adjacent to a pier or abutment, resulting in instability and potential collapse

How do Communities Regulate Storm Drainage Performance Standards?

Communities throughout the United States establish requirements for their stormwater drainage systems. The requirements account for the impact of property use in the community, whether areas are densely developed with large amounts of impervious areas or less intensely developed. More heavily developed areas have larger volumes of stormwater runoff flows to their stormwater systems.

Typically, stormwater design requirements set limits on the conditions allowed for projects, both redevelopment projects and new developments. The minimum standards usually are based on flow rates, velocity controls, and local benchmarks, such as how much increased runoff is allowed under certain conditions. Impermeable surfaces prevent the infiltration of rainfall, increase pollutant levels in the runoff, increase rainfall runoff which can cause erosion, increase urban flooding, and create flood hazards downstream. Flooding and erosion are primary impacts if runoff is not managed as development changes the characteristics of the land.

Many cities use the 5-year storm (20 percent chance of occurring in any given year) to determine the volume of rainfall runoff, and others use the 10-year storm (10 percent chance of occurring in any given year). Over time, many cities have changed their design standards to accommodate the increasing frequency and intensity of storms. In New York City, the standard design criterion for new and replacement stormwater drainage systems is the intensity-duration values for the 5-year storm (equivalent to 1.75 inches of rain in 1 hour). Engineers evaluate the amount of rainfall runoff generated when that amount of rain occurs. That volume of water is then used to plan the number of catch basin inlets and to calculate the size of the sewer pipes needed to manage stormwater.

What Strategies and Actions Can Reduce the Impacts of Urban Flooding?

Strategies evaluated by cities to manage stormwater infrastructure balance what is a practical performance or design standard and what would be needed to manage flows from extreme rain events. Each community that decides to reduce the impacts of urban flooding will seek a balance between costs and benefits as they set performance standards for their stormwater infrastructure.

Cities consider a range of methods to control peak runoff rates, reduce pollutant flows, and effectively manage runoff volume. Failure to address these objectives can lead to negative impacts on the overall stormwater drainage system. Managing the peak runoff rate is critical to reduce the erosive impacts that can lead to failure of other drainage system components and natural systems. Limiting pollutants in the flow contributes to the overall environmental quality of the receiving streams, rivers, and ocean. Managing runoff volume reduces the occurrence of surcharging of the system (exceeding the system capacity).

Managing existing stormwater drainage systems to optimize both capacity and the ability to protect people and property is important in the long term. The foundation is an asset management system that identifies all components and allows local officials to monitor maintenance needs. With a management system in place, secondary steps can be effectively addressed to sustain the performance and extend the life of the system components. Communities can take a number of actions to maintain and improve their stormwater drainage systems, including:

- Cleaning and maintaining components on a regular schedule and checking known problem areas after significant storms
- Replacing damaged components and upgrading undersized portions, based on a risk assessment that considers age, material, and projected useful life of the components
- Expanding or adding catch basin inlets to eliminate spot flooding where the underground conveyance system can handle additional flows
- Increasing the size of pipes to improve capacity, starting downstream in a conveyance line to avoid creating new constraints in flow
- Increasing infiltration using tools such as green infrastructure
- Increasing upstream detention capacity to reduce velocity and flow rates

Many cities develop strategies to increase infiltration and retain or reuse stormwater runoff to reduce the negative impacts of urban flooding. Over the past several decades, many communities have preserved or increased the amount of green space which soaks up runoff from buildings and impervious surfaces. Tree canopy, greenways, rain gardens, and other natural systems (often referred to as “green infrastructure”) are key practices used to reduce urban flooding.

Cities use many of the green infrastructure best practices described in the table below. An introduction to types of green infrastructure used in New York City is online at https://www.nyc.gov/site/dep/water/types-of-green-infrastructure.page.

Green Infrastructure Practices Can Reduce Rainfall Runoff by Improving Infiltration

Practice	Description of Practice	Example
Bio-retention Areas (also called Rain Gardens and Porous Landscape Detention)	A low-lying vegetated area is underlain by a sand bed with an underdrain pipe. A shallow surcharge volume exists above the bio-retention area, for temporary storage of runoff. During storms, the accumulated runoff ponds in the vegetated area and gradually infiltrates the sand bed. The underdrain gradually dewaters the sand bed, discharging the runoff to a nearby channel or stormwater drain.	 Streetside rain gardens (NYC)
Tree Box Filters	A concrete box with a soil medium filtration system for trees. Runoff is collected and retained, then filtered through the vegetation and soil. The water is then either consumed by the tree or flows to the stormwater drainage system.	 Along sidewalks, streets, or parking lots (U.S. Environmental Protection Agency)
Infiltration Basins	A basin below a grassed or concrete surface that collects stormwater. Openings in the basin walls allow water to flow to an underlying stone layer. The water then infiltrates into the ground.	 Infiltration basin below concrete sidewalk (NYC)

Practice	Description of Practice	Example
Bioswales	A vegetated channel to collect and convey runoff. Its underground components store, filter, and infiltrate stormwater. Bioswales typically are planted with dense grasses over a layer of sand, a layer of gravel, and an underdrain pipe.	 Alternative to gutters, pipes, and ditches (Fairfax County, VA)
Permeable Pavements	Open graded asphalt or concrete, with reduced fine material and special binder, allows for the rapid through-flow of water. Stormwater runoff flows through voids between the aggregate and into the ground. Paver blocks also are used to make permeable paving surfaces. An aggregate sub-base is installed below that surface to filter and store runoff. “Grass-blocks” let grass grow in spaces formed in concrete pavers.	 Permeable paving allows infiltration (NYC)
Green Roofs	Green roofs can be installed on new or existing buildings, even some gently sloping roofs. They can use either a layered soil system or a modular system in which plants are pre-grown. Green roof plants should be hardy, self-sustaining, and drought resistant. A lightweight soil mix is used to reduce the structural load on the roof. Roofs that are designed to handle snow loads are usually suitable for a green roof.	 Green roofs absorb and retain rainwater (Fairfax County, VA)

Practice	Description of Practice	Example
Blue Roofs	Blue roofs are designed to detain stormwater without vegetation. Roof drain inlets are modified to allow rain to pond on the roof and be gradually released.	 Blue roofs detain rainwater (NYC)
Rain Barrels	Rain barrels catch and store stormwater from building roofs. The water can be used to water gardens, trees, and lawns.	 Rain barrels store roof runoff (U.S. Environmental Protection Agaency)
Bluebelts	A New York City initiative, the Bluebelt program reduces runoff to lower peak flow demand on the stormwater drainage system. Projects may involve catch basins and underground drains. Runoff is directed to wetland areas where it is naturally filtered.	 Sweet Brook Bluebelt (NYC)
Cloudburst Management	A New York City initiative, cloudburst management uses a combination of methods to absorb, store, and transfer stormwater to minimize flooding. It combines “grey” infrastructure, like pipes and underground tanks, and green infrastructure techniques. Some projects include amenities and open spaces for public use.	 Planned sunken basketball court (NYC)

How Can Communities Inform the Public About Urban Flooding?

One of the biggest challenges communities have when managing stormwater drainage systems is to gain community support to invest in the inventory, modeling, repair, replacement, rehabilitation, and maintenance of the conveyance and treatment components. Stormwater systems are “silent” infrastructure, usually out of sight and unnoticed until it rains. In extreme rain events that damage property, citizens and business owners ask a lot of questions about why and how the flooding occurred. Educating the public about stormwater is an ongoing challenge because the post-storm urgency and focus on stormwater must compete with many other important services delivered by communities.

Communities that develop outreach tools and techniques using common terms and language can effectively share basic need-to-know facts, engaging their target audience through clear, correct, concise, and complete information. It is best to avoid jargon and acronyms, and use simple concepts and words that translate easily into other languages. Reaching people where they live and work encourages a partnership in learning. This improves the usefulness of the information for the end user. Many communities build on neighborhood resources to reach the broadest audience.

Urban flooding can cause safety risks and damage buildings, personal property, and vehicles. When cities determine those risks are present, they may include the following messages in their public outreach initiatives:

- Preventive measures protect life and property from damage by urban flooding, with an important target audience of those who live in basements. People have drowned when trapped in flooded basements.
- Encourage everyone to recognize the risks when urban flooding occurs, including homeowners, renters, businesses, community centers, public transport users, daycare operators, and schools.
- Evacuation procedures and early warning signs, with an emphasis on preplanning safe routes from homes, schools, businesses, transportation systems, and churches. Families can identify a reporting location so each member will know where and how to obtain shelter.
- Key messages for all:
    - Have an emergency plan and kit. State emergency management agencies sponsor campaigns to encourage families and businesses to prepare for emergencies. New York City’s comprehensive initiative is online at https://www.nyc.gov/site/em/ready/ready-new-york.page.
    - Connect to emergency notification systems.
    - Follow the evacuation advice of emergency officials.
    - Be aware of local weather conditions before leaving home, and when driving or walking.
    - Do not walk or drive through floodwater. “Turn around, don’t drown!” is the National Weather Service safety campaign, online at https://www.weather.gov/safety/flood-turn-around-dont-drown.

Hurricane Ida NYC MAT Fact Sheet 1 describes what building owners and tenants should know about urban flooding and what they can do to minimize problems, especially if they know that stormwater runoff has flooded their buildings in the past.

- Begin to clean up as soon as floodwater recedes and it is safe to enter buildings. Follow the guidance from local and public safety officials, especially to learn how to pump water out of basements without causing more damage to basement walls.

For More Information

See the FEMA Building Science Frequently Asked Questions at https://www.fema.gov/emergency-managers/risk-management/building-science/faq.

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