



Urban Stormwater Management And Sustainable Design

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Abstract: Climate change is increasingly affecting urban environments, particularly through extreme rainfall events that challenge traditional water management systems. Rainwater from impervious surfaces and storm runoff can lead to heightened wastewater volumes that require treatment, often resulting in combined sewer overflows and the release of untreated effluent into the environment, which can damage urban infrastructure. To address these issues, many cities are adopting sustainable water management strategies aimed at enhancing resilience and environmental protection. This paper highlights Oslo's success in implementing such sustainable stormwater solutions, demonstrating how analyzing effective cases can reveal patterns and practices that urban planners and policymakers can adopt to improve stormwater management and urban sustainability.

I. INTRODUCTION

Stormwater runoff

Runoff, generated by rain or snowmelt, flows over surfaces and into drainage systems, waterways, and sewers, with the extent of runoff influenced by surface permeability; natural landscapes like meadows and forests absorb most of this water, gradually releasing it into groundwater and local water bodies, whereas impervious surfaces such as roads, rooftops, and parking lots cause increased runoff, which often carries pollutants like oil, trash, heavy metals, pesticides, and bacteria into water systems. Urban stormwater frequently bypasses treatment facilities, resulting in contaminated runoff that harms aquatic ecosystems, causes erosion, and contributes to water quality issues, including the spread of pathogens and toxins. Combined sewer systems can overflow during heavy storms, releasing untreated sewage and runoff into waterways, leading to environmental and public health hazards. This pollution also exacerbates flooding, damages infrastructure, and imposes economic costs, including increased flood damages and health-related expenses. To combat these issues, green infrastructure strategies focus on capturing and filtering stormwater through natural processes like soil absorption, plant uptake, and evapotranspiration, thereby reducing runoff volume and improving water quality, which are essential for protecting ecosystems, public health, and water resources amid climate change challenges.



Water washes into a storm sewer partially clogged with litter.

II. Stormwater management

Stormwater management primarily focuses on prevention to control pollution caused by runoff. Green infrastructure plays a vital role in maintaining healthy waterways through two main mechanisms: water retention and water quality enhancement. By capturing rainwater at its source, green infrastructure helps reduce runoff, allowing water to seep into the ground to replenish aquifers, return to the atmosphere via evaporation and transpiration, or be reused for purposes like irrigation or landscaping. Additionally, it enhances water quality by decreasing the volume of stormwater reaching natural water bodies and filtering out pollutants. Soil and plant systems work together to remove contaminants through processes such as adsorption, where pollutants adhere to surfaces; filtration, which traps particles; plant uptake, where vegetation absorbs nutrients and toxins; and organic matter decomposition. These natural processes effectively break down or remove a wide range of pollutants, including heavy metals, oils, and bacteria, thereby protecting water resources and ecosystems.

Green infrastructure

Green infrastructure includes various water management techniques like green roofs, roadside plantings, rain gardens, and other approaches designed to capture, filter, and minimize stormwater runoff. These practices help reduce flooding and limit the amount of polluted water that flows into sewer systems, streams, rivers, lakes, and oceans. By capturing rain where it falls, green infrastructure replicates natural hydrological cycles, utilizing elements like soil and vegetation to transform rainfall into a valuable resource rather than waste. Additionally, it enhances local water availability and quality, while offering numerous environmental, economic, and health advantages—particularly in urban areas lacking sufficient natural green spaces.

Reduced flooding

Over the past five decades, the frequency and intensity of heavy rainfall events have increased, with climate change exacerbating these trends and elevating the risks of flooding and sewer overflows. The EPA projects that the typical extent of a 100-year floodplain could expand by approximately 45 percent by the end of the century. Urban flooding, driven primarily by excessive rainfall on impermeable surfaces rather than storm surges or overflowing water bodies, poses a significant threat to neighborhoods, often damaging homes and infrastructure. Vulnerable communities, including low-income and communities of color, are disproportionately affected, experiencing health issues such as asthma and mold-related illnesses. Green infrastructure mitigates flood risks and enhances community resilience to climate impacts by capturing rain where it falls, preventing excess water from overwhelming sewer systems and waterways.

Increased water supply

Water & Land Use Partnership, over half of the rainfall that occurs in urban areas—primarily covered by impervious surfaces—becomes runoff. Green infrastructure strategies help mitigate this by capturing stormwater, which can then be used to replenish groundwater sources or be harvested for uses such as irrigation and toilet flushing. This approach reduces reliance on municipal water supplies, a particularly important benefit given the challenges posed by drought, decreased snowpack, and early snowmelt driven by climate change and rising temperatures. Techniques like bioswales and infiltration systems promote water conservation by absorbing and directing rainfall into underground aquifers. For example, up to 75 percent of rainwater falling on rooftops can be collected for reuse. Studies estimate that in Wisconsin, green infrastructure could capture or redirect as much as four billion gallons of stormwater, while in California, it has the potential to save up to 4.5 trillion gallons.

Downspout disconnection

Even a few inches of rain falling on a house can result in thousands of gallons of stormwater runoff; just a single one-inch rainfall on a 1,300-square-foot rooftop can generate 832 gallons or 12 gallons per minute. Often channeled into storm drains by gutters and downspouts, this runoff increases the risk of sewer system overflows. Downspout disconnection is the practice of redirecting rooftop runoff from storm drains to a permeable surface, such as a lawn, or to rain barrels or cisterns, which capture and hold the water for later use. The city of Portland, Oregon, disconnected the downspouts of more than 26,000 properties from the city's combined sewer system between 1993 and 2011. Now, an estimated 1.2 billion gallons of stormwater get diverted from the sewer system each year, alleviating combined sewer system backups in city neighborhoods.

Rainwater harvesting

Rainwater harvesting, which involves collecting and storing rainwater to reduce runoff, has the potential to meet between 21 and 90 percent of a city's annual needs for non-potable water, supplying enough water for hundreds of thousands of residents in some cases. This method typically uses cisterns or rain barrels to collect water from impervious surfaces like rooftops. It provides an effective way to supplement municipal water supplies, especially as climate change, rising populations, and increased demand from industries such as agriculture and energy continue to strain existing water resources in many regions.

Rain gardens

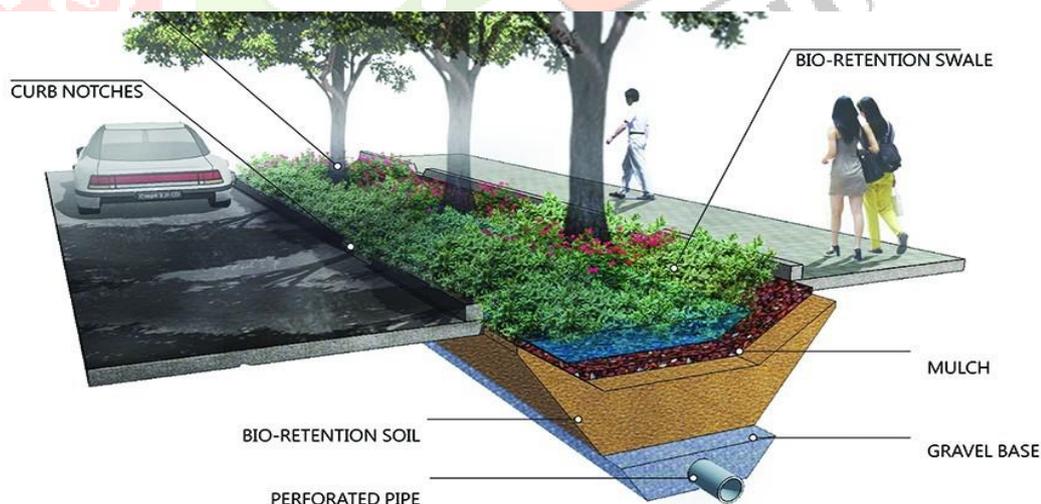
Rain gardens suitable for various locations from street medians to small residential yards, typically consist of native shrubs, perennials, and grasses planted within a shallow basin. Their primary function is to capture and absorb runoff from rooftops, sidewalks, and streets. Beyond enabling rainfall to evaporate or gradually seep into the soil, rain gardens also help to replenish underground aquifers, prevent stormwater from reaching water bodies, support local wildlife habitats, . They are highly effective, being approximately 30 percent more absorbent than traditional lawns. According to a study conducted by the 12,000 Rain Garden campaign in the Seattle area, a single rain garden can filter up to 30,000 gallons of stormwater annually, while a network of 12,000 rain gardens could collectively absorb around 160 million gallons. Planter boxes, a specific type of rain garden often placed between sidewalks and streets, feature raised edges that facilitate water absorption by plants and soil, with small drainage openings controlling runoff flow.



A rain garden built into a New York City sidewalk

Bioswales

Bioswales are long, relatively deep channels lined with native plants, grasses, flowers, and specially designed soils that run alongside parking lots or roads, capable of managing substantial runoff from large impervious surfaces. They not only absorb and hold back water from small storms but also help to filter and slow the flow of water during heavy rains, directing it toward sewers or surface water bodies while reducing flood risks and initial pollutant levels. According to the City of Lincoln Transportation and Utilities, effective bioswales can remove up to 90 percent of solids like sediment, 80 percent of trace metals, oil, and grease, and approximately 65 percent of phosphorus from the collected runoff.



Urban tree canopy

Trees contribute to natural stormwater management while also improving air quality and providing cooling effects. Their canopies intercept rainfall before it reaches the ground, offering a surface—comprising branches and leaves—that facilitates evaporation. Additionally, the roots of trees play a crucial role in managing runoff by absorbing water and releasing it through transpiration. They also create channels and spaces within the soil, increasing the ground's capacity to absorb water and reduce runoff.



Downtown San Antonio, Texas

Permeable pavement

Permeable pavement, also called porous pavement, is commonly used for sidewalks, parking lots, and driveways, enabling rainwater to pass through the surface and reach underlying layers of soil that filter pollutants before the water enters groundwater sources. When considering installation costs, permeable pavement can be up to 20 percent more affordable initially compared to traditional pavement options, and it often proves to be less expensive to maintain over time.

Types of Permeable Pavement

- I. **Permeable Interlocking Concrete Pavers (PICP):**
 - a. Small concrete blocks with gaps filled with gravel or sand.
 - b. Common in driveways and patios.
- II. **Porous Asphalt:**
 - a. Asphalt mix with reduced fines (small particles), allowing water through.
 - b. Looks like regular asphalt but is more open.
- III. **Pervious Concrete:**
 - a. Concrete with little or no sand, creating a network of voids.
 - b. Strong but less dense than traditional concrete.



Porous surfaces allow rainfall to seep through to underlying layers of rock and soil that filter out pollutants.

Green parking lots

Designed to curb rainfall runoff, green parking lots often feature permeable pavement, vegetated areas around or within their perimeter, and shade trees that can help reduce the urban heat island effect.



Green streets

Green streets represent an innovative approach to sustainable roadway design by integrating various green infrastructure techniques to better manage stormwater. Unlike traditional roads that route runoff directly into storm drains, green streets utilize permeable pavements, bioswales, planter boxes, and other methods to capture, absorb, and filter rainwater at its source, reducing the volume of runoff reaching water bodies and enhancing water quality. According to the EPA, green streets can eliminate up to 90 percent of stormwater pollutants. A notable example is a project in Los Angeles' Watts neighborhood initiated in 2016, which has successfully prevented nearly 30 million gallons of stormwater from reaching local rivers and beaches annually. Beyond stormwater management, green streets provide cost-effective alternatives to extensive sewer system upgrades, while also improving air quality, offering shade, increasing pedestrian and cyclist safety, and beautifying communities. When these streets incorporate features such as energy-efficient lighting, recycled or locally sourced materials, and enhanced spaces for walking, biking, or public transit, they are often called complete streets.



According to the National Research Council's comprehensive report on urban stormwater management, most drainage systems in American cities were developed after World War II, relying on basic technologies like catch basins and pipes to divert water and prevent flooding. However, many growing urban areas quickly realized that these systems often simply moved floodwaters rather than reducing them, leading to increased runoff and a decline in groundwater levels, which negatively impacted nearby water bodies. During the 1970s, the approach to stormwater management shifted as landscape architects promoted low-impact development strategies that focused on working with natural hydrology, including infiltration through vegetative channels and swales. Simultaneously, concerns about water pollution from stormwater—contaminants such as heavy metals, sediments, and pathogens—became more prominent, especially following studies like the Nationwide Urban Runoff Program in the 1980s. As the 21st century approached, infrastructure designed to facilitate near-source infiltration gained popularity as a means to combat pollution, and the term "green infrastructure" likely emerged during this period. One of the earliest and most notable examples of this approach is New York's Staten Island Bluebelt, initiated in the 1990s but rooted in a broader history starting with the 1964 completion of the Verrazano-Narrows Bridge, which spurred development and overwhelmed existing drainage systems. The Bluebelt project addressed these challenges by conserving natural streams, wetlands, and other corridors that use natural processes to capture, store, and filter stormwater effectively. Today, the Bluebelt covers over 14,000 acres, can temporarily hold and treat up to 350,000 gallons of rainwater, and has saved millions of dollars in infrastructure costs compared to conventional storm sewer systems.

III. CONCLUSION

Urban stormwater management has evolved from traditional gray infrastructure systems—such as underground pipes and concrete channels—to more sustainable and ecologically responsible strategies. Green infrastructure (GI) plays a crucial role in this transformation, offering a nature-based approach to manage stormwater where it falls.

By integrating elements like permeable pavements, green roofs, bioswales, rain gardens, and urban trees, green infrastructure helps cities:

- 1) Reduce surface runoff
- 2) Enhance water quality
- 3) Alleviate urban flooding
- 4) Improve urban biodiversity and aesthetics
- 5) Adapt to climate change impacts

In the context of sustainable design, green infrastructure promotes resilience, resource efficiency, and livability. It also aligns with broader sustainability goals by restoring the natural hydrological cycle, reducing energy use (e.g., by cooling cities), and supporting healthier urban environments. Ultimately, the successful integration of green infrastructure into urban stormwater management is essential for building sustainable, climate-resilient cities. It reflects a shift from engineering-focused solutions to holistic, environmentally integrated design thinking.

Reducing surface runoff from stormwater can be achieved by collecting it for later use in drinking water supplies and by implementing non-piped urban drainage solutions like Sustainable Urban Drainage Systems (SUDS), which help alleviate water stress in the area. The design philosophy for urban drainage emphasizes an approach that favors the integration of SUDS rather than viewing them as alternative options, often complemented by minor components. This strategy involves directing rainwater toward green spaces, grass strips, or vegetation-covered basins to slow runoff velocity, decrease volume, reduce peak flows, and promote infiltration into the soil. Additionally, in the context of stormwater management, efficient diversion methods are often seen as a sign of progress, especially when considering that in less developed or emerging countries, increased rainfall typically causes significant disruptions with limited resilience, whereas in developed nations, the impacts are generally lower and resilience is higher.

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