Bioretention Systems for Managing Urban Stormwater

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The world's population has surpassed 8 billion, with urbanization being a dominant trend. In 1950, urban population was only 33% of the total, but it has steadily grown, reaching 55% today. Projections indicate it could be 66% by 2050. In 1950, urban population was 746 million, constituting 33% of the total. Over time, the urban population has steadily increased, surpassing rural in the late 2000s. Projections suggest it will reach 66% by 2050. But urbanization has dominant impact on hydrologic scale for the urbanized areas.

Impacts of Urbanization on Hydrology

1. Increase in Water Demand

The growing urban population intensifies the demand for freshwater, which leads to increased withdrawals from surface as well as groundwater sources located in the urban areas.

2. Wastewater Load

Urban expansion results in higher wastewater loading, which invariably challenges the existing treatment and disposal systems and at the same time there is a chance of contamination for the existing freshwater bodies.

3. Solid Waste Generation

Urban development generates more solid waste, contributing to the growing issue of waste management and disposal.

4. Altered Water Flow

As there is increase in impervious surfaces over the time period, it alters natural water flow, causing increased runoff rates, reduced groundwater recharge, and congestion during storms leading to the problem of stormwater disposal.

5. Environmental Impacts

Changes in hydrology contribute to downstream flooding, streambank erosion, and declining water quality among some of the major impacts.

Low Impact Development (LID) as a Solution

To counteract these impacts of urbanization, Low Impact Development (LID) emerged in the early 1990s. LID, or otherwise known as sustainable urban drainage, integrates land planning and engineering to implement small-scale hydrologic controls with integrated pollutant treatment. Among various forms of LID, Bioretention is one widely adopted, aiming to manage runoff, enhance surface water quality, improve groundwater recharge, and enhance community aesthetics.

Bioretention Systems

Bioretention systems which is an integral components of sustainable urban stormwater management, function as purposefully designed landscaped depressions. Which primarily serves as sponges for runoff from impermeable surfaces, such as roads and rooftops and these systems play a crucial role in emulating natural hydrologic processes.

Components of Bioretention Systems

1. Vegetation Layer

- The main purpose is the evapotranspiration of the congested stormwater retained in the system.

- It functions as gradual absorptive area of stormwater.

2. Mulch Layer

- It reduces incoming stormwater velocity which helps in increasing infiltration opportunity time.

- It has also the function to retains debris and soil particles from going into soil media.

3. Soil Layer

- It provides structural support to plants.

- Along with this facilitates stormwater infiltration with filtration.

4. Media Layer

- This is one of the key layers for runoff reduction and pollutant removal sometimes known as the heart of the system.

- It also functions as filter for debris, particles, and pollutants from runoff.

5. Underdrain

- This layer is not present for all the systems. But it is included only when soil permeability is low.

6. Hydraulic Control Structures

- Facilitates water conveyance to and from the system.

Function of Bioretention Systems

1. Hydrologic Performances

Some of the parameters on which hydrologic performances depends are given below

a. Media Porosity and Storage

- Pore space and storage depend on media texture.

- This links between soil texture, porosity, wilting point, and field capacity.

b. Infiltration and Conductivity

- Media selection is a crucial aspect for adequate infiltration.

- For majority of systems it is expected to have at least 75% sand with minimal fines.

c. Evapotranspiration

- Contribution of evapotranspiration to water balance varies for different systems as species of plant may vary.

- Depends on climate, vegetation, media, and system parameters.

2. Water Quality Performance

Some of the parameters on which water quality performances depends are given below

a. Media Reactivity

- Media as it is heart of the system, selection of media is crucial for removing urban runoff contaminants.

- Reactive minerals are very effective in removing harmful elements.

b. Evapotranspiration and Soil Wetting/Drying

- Wetting/drying cycles and inter-event durations also impacts water quality of the system.

- Interevent dry periods are very much crucial for nutrient capture.

c. Plant Uptake

- Plant uptake directly contributes to solute removal.

- Species-specific contribution to pollutant removal, especially nutrients can be done with proper planning.

d. Microorganisms

- Microorganisms also impact nutrient retention.

- Interactions with vegetation is very critical for nutrient cycles and water quality.

Selected Comprehensive Analysis of Bioretention Systems

Hydrologic Performance of Bioretention Systems Based on Different Media Depths

Li *et al.* (2009) conducted an experiment to investigate the hydrologic performance of six distinct bioretention cells located in various regions, aiming to address the challenges posed by urban impervious surfaces. The cells vary in size, media depth, and monitoring duration, providing a comprehensive analysis of their effectiveness. The research utilizes consistent monitoring methods across all cells, including direct measurement of rainfall intensity, inflow monitoring in Maryland, and application of the SCS curve number method in Greensboro. The study introduces key metrics, such as peak flow rate ratio (R_{peak}), peak discharge time span ratio (R_{delay}), and effluent/influent volume ratio (f_V24), to assess the restoration of hydrologic conditions. Results show that bioretention cells effectively mitigate post-development hydrology, demonstrating peak flow reduction and enhanced infiltration. However, their performance diminishes under more extreme precipitation events, and deeper media depths (>0.9 m) tend to promote more infiltration and evapotranspiration.

Bioretention System Comparison for Different Media Layers

As media layers are heart of the bioretention system, Yang *et al.* (2020) explores the impact of filler layer structure on hydrologic performance and pollutant removal efficiency in bioretention systems with different media layer. The experiment was setup with three different layers, filler layer, transition layer and drainage layer. Three configurations

1. All Three Layers,
2. Without Transition Layer,
3. Without Drainage Layer were tested using synthetic stormwater.

Lab-scale bioretention units were constructed, and runoff control effects were evaluated under different rainfall intensities. Results indicate that the presence of a 200 mm drainage layer plays a crucial role in runoff control. As rainfall intensity increases, differences in runoff reduction rates between configurations decrease, emphasizing the importance of the filter layer in stormwater runoff reduction.

Water Quality Performances of Bioretention Systems with Different Media Depths

As water is drained through the system so, to examining conventionally drained bioretention cells in Nashville, Brown *et al.* (2013) conducted this study, which focuses on the influence of previous events on outflow concentrations. Flow-weighted composite samples from consecutive events during different seasons reveal insights into cumulative pollutant loads, seasonal impacts, and the role of consecutive events. Results show that the 0.9-m media depth cells release approximately twice the load of dissolved pollutants compared to the 0.6-m media depth cells. The study concludes that while bioretention cells sufficiently reduce pollutant loads, deeper media depths exhibit varying water quality performances influenced by antecedent conditions.

Water Quality Performance Measurement Using Bioretention Cells

As the cells are meant to protect the water from harmful elements. To assess this an experiment was conducted at the University of Maryland by Davis (2007), which assesses water quality improvements in parking lot stormwater runoff through standard bioretention and anoxic sump-incorporated systems. Twelve stormwater events were monitored for TSS, TP, NO3-N, lead, copper, and zinc concentrations. Results demonstrate overall composite median percent removals for pollutants, with mass removals consistently greater than concentration-based removals due to flow attenuation. Water quality leaving both cells was consistently good, with future research recommendations focusing on computational models, system maintenance, cost considerations, and life cycle assessments.

So, in conclusion it is found that the bioretention systems are effective way to counter the bad effect of urbanisation on the hydrologic regime on the urbanized area.

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