Evaluating the Performance of Green Infrastructure: Quantifying the Benefits in Washington, DC

Introduction

DC Water is the water and sewer authority for the District of Columbia; which also manages wastewater from surrounding counties. The District of Columbia has an antiquated combined sewer system installed over 150 years ago. During wet weather, combined stormwater and wastewater frequently overflows to the Potomac River, Anacostia River, and tributaries such as Rock Creek. The DC Clean Rivers project is a 25-year project to reduce Combined Sewer Overflows (CSOs) using a combination of deep river tunnels and green infrastructure.

In 2013, DC Water launched the Green|Challenge international design competition to drive innovative, replicable, cost-effective, and high-performing urban green infrastructure solutions for CSO reduction. As the selected streetscape project from the competition, the Nitsch Engineering team designed and implemented 33 interconnected green infrastructure techniques within one city block on Kennedy Street. Meanwhile, DC Water's metering and monitoring program measured the effectiveness of the green infrastructure solutions.

This report will share information about the flow metering and monitoring program that evaluated the performance of green infrastructure constructed as part of the Kennedy Street Green Infrastructure Streetscape project.

Key Collaborators

Owner: DC Water Authority
Metering & Monitoring Program Lead Engineer: Greeley and Hansen
Kennedy Street Green Infrastructure Streetscape Project Lead Engineer: Nitsch Engineering

Kennedy Street Key Partners:

Landscape Architect: Urban Rain|Design and Warner Larson, Inc.
Land Surveyor and Geotechnical Engineer: EBA Engineering, Inc.
Permitting: McKissack and McKissack
Community Engagement: Tina Boyd and Associates
Environmental Art: Stacy Levy/Sere Ltd.

Flow Metering Methodology

The DC Water Clean Rivers Project implemented a flow metering, monitoring, and data analysis program to measure how well their pilot green infrastructure projects performed. This included the ***Kennedy Street Green Infrastructure Streetscape*** project, three additional porous alleys, and one additional bioretention planter.

DC Water's flow metering program included the installation of one flow meter and one rain gauge. The flow meter (RC-B) was installed on the 21-inch combined sewer within a manhole on Kennedy Street, near the intersection of Second Street, N.W. An estimated drainage area of 16 acres contributes to flow meter RC-B, although it should be noted that this estimate is approximate due to the complexity of the system. The Kennedy Street green infrastructure project included a combination of strategies to retain approximately 8,000 cubic feet (approximately 60,000 gallons) for an estimated 9.95-acre drainage area.

A rain gauge (RC-A RC) was placed on the roof of the Latin School at the intersection of Ingraham St. NW and 2nd St. NW, approximately two blocks from the flow meter.

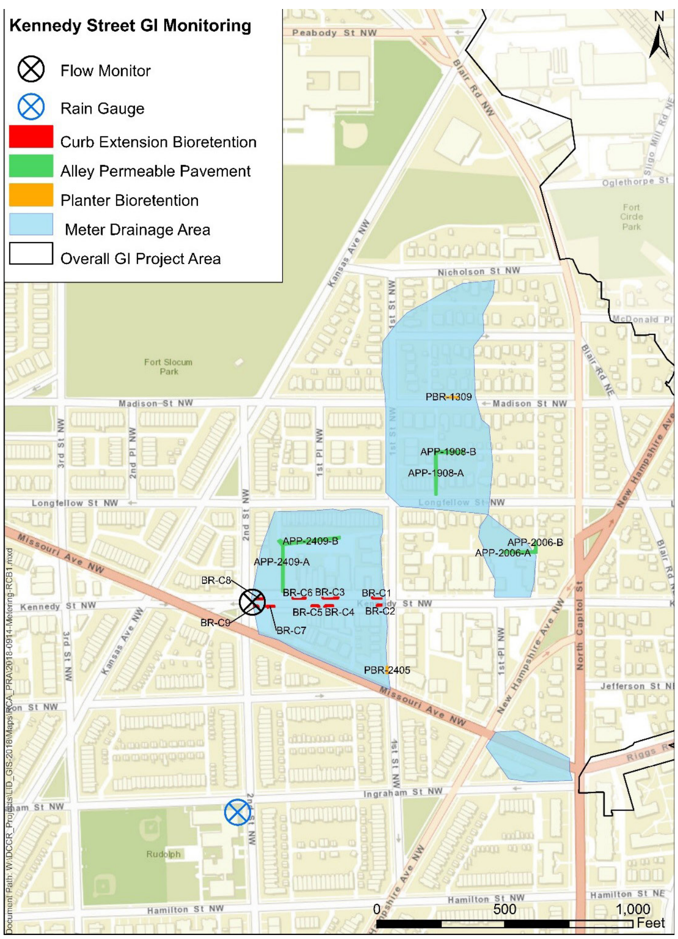


Figure 1: Map of Flow Meter and Rain Gauge Locations (prepared by Greeley and Hansen)

Figure 2: Photo of Flow Meter, RC-B (provided by Greeley and Hansen)

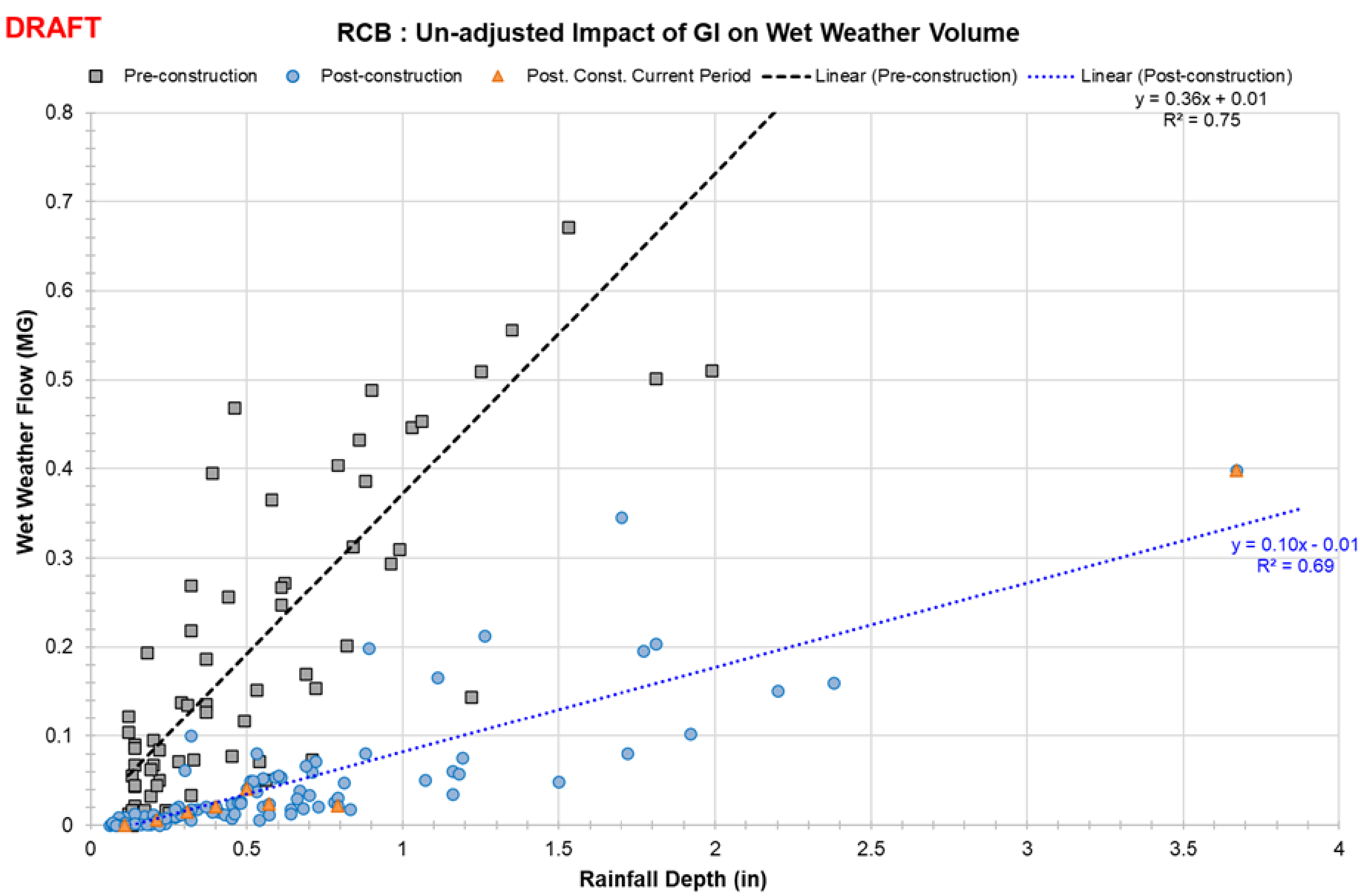
Figure 3: Photo of Rain Gauge, RC-A RG (provided by Greeley and Hansen)

The flow meter recorded the depth of flow (inches), velocity of flow (feet per second), and the rate of flow (million gallons per day [MGD]) in the combined sewer during dry and wet weather, with recordings tabulated at five-minute time increments over the course of a 24-hour period (day). The rain gauge was operated during the same pre- and post-construction timeframe, with rainfall depths recorded at five-minute time increments.

The flow meter was operated continuously through wet and dry weather flows for two separate time periods: pre-construction and post-construction. The pre-construction period was between August 25, 2015 and October 1, 2016. During the pre-construction period, 82 rainfall events occurred with the largest recorded event measuring 2.14 inches of rainfall over a 24-hour period. The post-construction recording period was between March 14, 2019 and October 8, 2020. During the post-construction period, 132 rainfall events occurred, with the largest recorded event measuring 3.88 inches over a 24-hour period. The rain gauge experienced an outage for a brief one-week period in July 2016.

Flow Metering Results

Greeley and Hansen synthesized the pre- and post-construction flow data for the dry and wet-weather conditions. For the wet weather conditions, a graph was prepared that plots the total measured flow in the combined sewer (volume, measured in million gallons [MG]) for each rainfall event (depth, measured in inches).



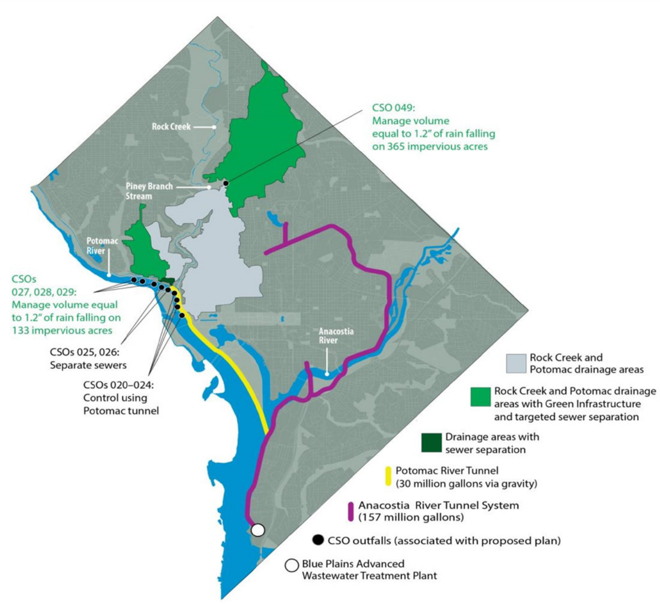
The total rainfall depth and wet weather flow volumes represent 24-hour totals for each corresponding event. Each wet weather event measured during pre-construction is plotted as a gray square. Each wet weather event measured post-construction is plotted as a blue circle (for events March through November 2019) or an orange triangle (for December 2019 through October 2020). The first series of post-construction data (March through November 2019) was initially plotted to provide DC Water with interim results; therefore, the final series of post-construction data (December 2019 through October 2020) was plotted as a separate color/icon to present the final data. A trendline was developed for the pre-construction data (gray squares) and the post-construction data (blue circles and orange triangles).

The comparison between the pre- and post-construction events is apparent even upon first glance, as the wet weather volumes associated with the pre-construction data are substantially larger than the post-construction data for the same or similar wet weather events. For example, during a 1.5-inch rainfall event, the combined sewer flow measured approximately 0.68 MG pre-construction and approximately 0.05 MG post construction. Favorable results were observed in rainfall events up to two inches. Unfortunately, no rainfall events that exceeded two inches were recorded during the pre-construction period.

On average, the wet weather flow volume was reduced by 72% after the construction of the green infrastructure projects in the watershed!

About the Kennedy Street Green Infrastructure Streetscape Project

As previously referenced, DC Water launched the Green|Challenge international design competition in 2013 to drive innovative, replicable, cost-effective, and high-performing urban green infrastructure solutions for CSO reduction. The Nitsch Engineering team was selected to design and build improvements for the streetscape pilot project; the Kennedy Street Green Infrastructure streetscape project was completed and constructed in 2018.



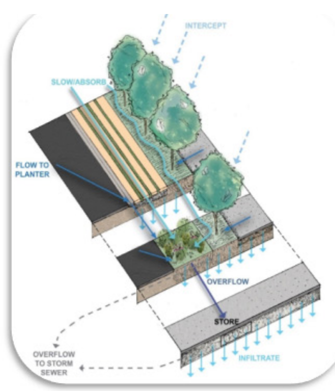
At almost 90% impervious cover, Kennedy Street generated a substantial amount of stormwater runoff to the combined sewer system, which ultimately contributed to combined sewer overflows in Rock Creek. In addition, DC Water selected Kennedy Street due to wide sidewalks, thin vegetation, and a streetscape that prioritizes vehicles to pedestrian movement; making it an ideal candidate for implementing green infrastructure to address stormwater runoff as well as a variety of other environmental and social co-benefits.

The following pre-existing conditions photo from 2013 provides a summary of the pre-existing conditions and key drivers for green infrastructure.

To create a better streetscape condition, the Team proposed and followed a series of design principles to guide the vision. First, we aimed to mimic natural hydrologic condition by maximizing permeable landscape surfaces and to absorb rainfall at its source. Next, we looked at decentralizing and spreading new landscape areas throughout the project area to micro-manage stormwater in smaller zones. Finally, we introduced a stormwater gradient that uses a "top down approach" to managing stormwater from enhanced tree canopy, to at-grade landscape-integrated elements, to enhanced soils.

Mimic the Natural Condition

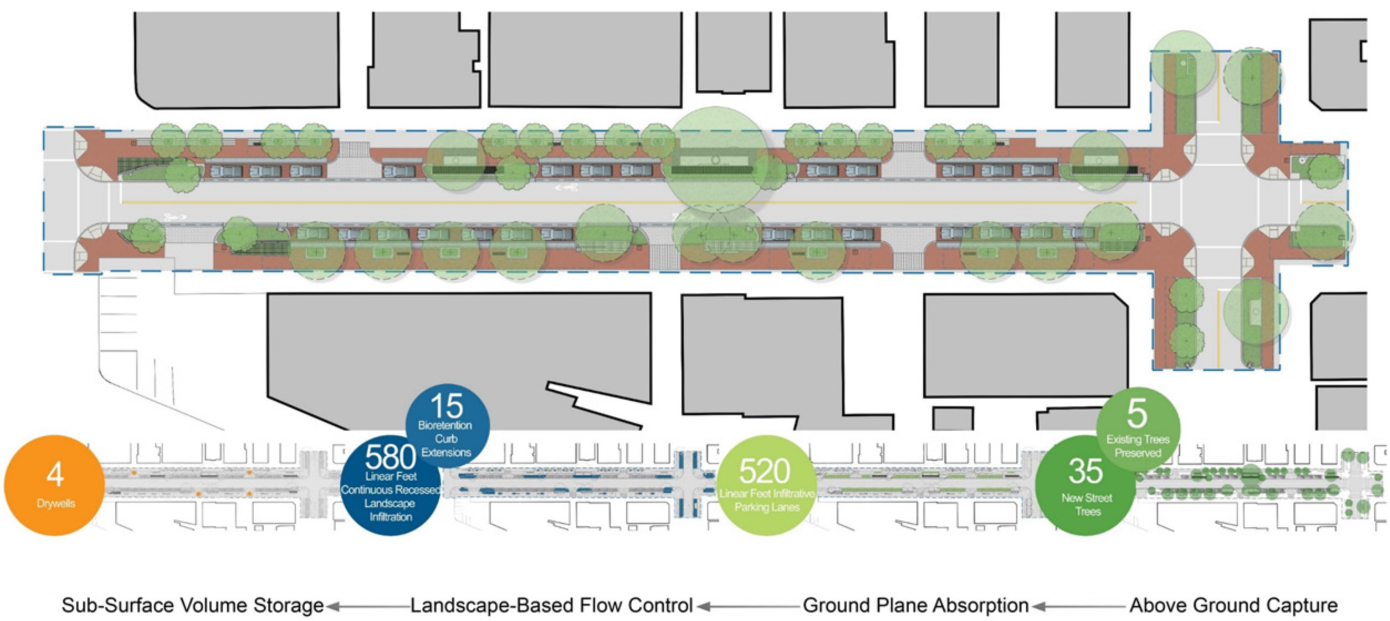
Decentralize the Landscape



Create a Gradient of Absorption

Instead of locating the stormwater facilities at the low point/end point of the site, the Kennedy Street design concept included strategies to spread the landscape-based approach across the length of the entire streetscape and include strategies that capture rainfall at the vertical and horizontal planes.

As the first line of defense, the project included the addition of 35 new trees and preservation of five established trees that vertically capture rainfall. When precipitation does hit the ground, the project includes 520 linear feet of permeable paving in the parking lanes, 15 bioretention curb extensions, and 580 feet of interconnected recessed landscape areas. The project also incorporates four leaching drywells to capture and infiltrate stormwater runoff from adjacent alleys.



Because Kennedy Street had many unique conditions, the Team explored and implemented several experimental design techniques. The three primary experimental designed techniques included:

- changing the street profile to a W-profile,
- using raised boardwalks and metal grates to layer stormwater techniques under pedestrian spaces and preserve existing trees, and
- introducing a concept called landscape infiltration gaps (LIGs) to capture sheet flow in small landscape strips.

Modifying the street profile from a traditional “crown” to a “W-profile” allowed the team to micro-manage stormwater from various zones across the streetscape to support the overall performance. The valley gutter between the drive and parking lane was used to separate and convey runoff from the roadway to each downstream bioretention curb extension, supporting the performance of the permeable parking lane by not adding additional un-treated “run-on.”

Before: All stormwater drains to gutter system, causing flooding and rapid runoff

After: Crown Street Profile collects stormwater in different channels to slow and distribute flow

The continuous recessed landscapes and LIGs in the sidewalk zone allowed for the management of sidewalk runoff, before reaching the bioretention curb extensions in the parking zone.

Before: Limited Infiltration on a Wide Sidewalk Resulting in Significant Runoff

After: Landscape Infiltration Gaps (LIGs) capture stormwater to Subsurface system

The elevated metal grates were used to span existing tree roots and provide accessible paths over stormwater management features.

Before: Old street trees destroy sidewalks and infringe upon ROW access

After: Elevated catwalks preserve trees and create accessible pathways

The Green Infrastructure Streetscape project was coordinated as part of a construction project for a larger segment of Kennedy Street in coordination with DDOT. Although many features were considered experimental and innovative, typical construction techniques were used.

Landscape Infiltration Gaps

Grated Boardwalk Overlooks

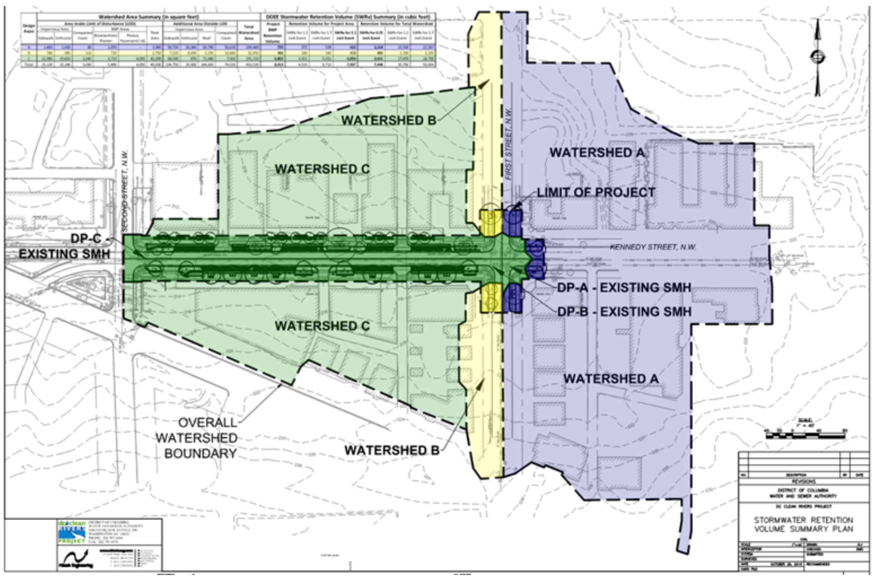
Valley Trench

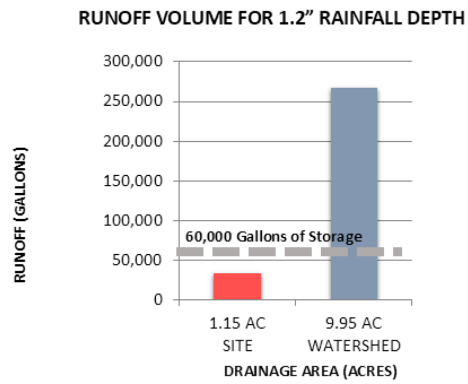
Permeable Pavers

Connected Sidewalk Planters

The project was required to retain 1.2-inch rainfall depth in accordance with Department of Energy and Environment (DOEE) requirements. The Kennedy Street project was designed to exceed this requirement, providing the equivalent volume to retain the 1.6-inch rainfall depth over the project site through the addition of 60,000 gallons of storage capacity in the combined green infrastructure elements.

During the design process, the Team developed hydraulic and hydrologic methods to help evaluate the effectiveness of the interconnected green infrastructure elements, which were anticipated to enhance the performance of the system overall. These predictions were further supported by the pre- and post-construction monitoring performed by DC Water and presented previously in this report.





KENNEDY GREENED PROVIDES 60,000 GALLONS OF STORAGE CAPACITY WHICH CAN STORE THE EQUIVALENT OF 2.1 INCHES OF RAINFALL OVER THE PROJECT LIMIT OF WORK

The following photograph from 2018 shows the completed Kennedy Street Green Infrastructure project.

Key Takeaways

The flow metering and monitoring program demonstrates the effectiveness of green infrastructure in reducing wet weather discharges to the district's combined sewers. One of the most important aspects of the Kennedy Street flow metering program was the collection of data both before and after construction. In total, the flow metering program captured data for 82 rainfall events pre-construction and 132 rainfall events post-construction, which allowed for the creation of trendlines and the calculated reduction in post-construction wet weather flow volume by 72%. The results of the flow metering helped validate the predicted effectiveness of the interconnected green infrastructure elements that were designed to optimize retention capacity. ***The actual results exceeded the predicted results developed using conservative stormwater models and calculations for permitting and design.***

The Kennedy Street Green Infrastructure Streetscape project helped pilot innovative approaches and strategies to optimize and measure the performance of green infrastructure techniques such as permeable pavement, bioretention, and infiltration practices. In addition to demonstrating an enhanced level of stormwater management, the project preserved and planted new trees to reduce urban heat island, improved access and accessibility, increased safety for pedestrians and cyclists, and enhanced the streetscape with social gathering spaces.

Mission Statement

At Nitsch Engineering, we embrace our tagline, "Building better communities with you." This mantra goes beyond words on paper – it represents our commitment to building stronger and more resilient communities through client collaboration and advocacy.

We define ourselves by *why* we do what we do – to positively impact our clients, employees, and communities by conducting ourselves with integrity and focusing on our core values; paying close personal attention to the needs and goals of our clients and employees; modeling professional behaviors and standards; focusing on equity, diversity, inclusion, and belonging; embodying a high level of corporate citizenship; and demonstrating, at all times, a caring attitude.

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