Watershed Scale Application and Evaluation of Green Infrastructure for CSO Control

L’application et l’évaluation des infrastructures vertes à l’échelle du bassin hydrographique pour le contrôle des rejets urbains de temps de pluie

Angela Licata*, Magdi Farag, PE**, Raymond Palmares***, Sandeep Mehrotra, PE****, William Leo, PE******, Matthew Jones, PE, PhD******

* New York City Department of Environmental Protection, 59-17 Junction Boulevard, 11th Floor, Flushing, NY, USA magdif@dep.nyc.gov
** New York City Department of Environmental Protection, 59-17 Junction Boulevard, 11th Floor, Flushing, NY, USA magdif@dep.nyc.gov
*** New York City Department of Environmental Protection, 59-17 Junction Boulevard, 11th Floor, Flushing, NY, USA rpalmares@dep.nyc.gov
**** Hazen and Sawyer, PC, 498 Seventh Avenue, 11th Floor, New York, NY, USA smehrotra@hazenandsawyer.com
***** HDR-HydroQual, 1200 MacArthur Boulevard, Mahwah, NJ, USA William.Leo@hdrinc.com
****** Hazen and Sawyer, PC, 4011 WestChase Boulevard, Suite 500, Raleigh, NC, USA mjones@hazenandsawyer.com

RÉSUMÉ


ABSTRACT

To reduce combined sewer overflows, New York City is underway with efforts to implement green infrastructure source controls throughout combined sewer areas. A comprehensive pilot program serves as a foundational component of these efforts, providing valuable information on implementation logistics and performance. Building upon efforts piloting individual source controls, the New York City Department of Environmental Protection is piloting implementation of green infrastructure within three localized watersheds, ranging in size from 4 to 10 hectares. In addition to on-site controls, more than 70 right-of-way bioswales were distributed across the three pilot areas. These watershed pilots are expected to provide key lessons on the opportunities and challenges of applying green infrastructure at a watershed scale, while also providing valuable information regarding the aggregate effect of these individual controls on sewer flows through consolidated flow monitoring.

KEYWORDS

Bioswales, Infiltration, Monitoring, Sewershed, Source Control, Stormwater, Sustainability, Weather Management, Wet
1 INTRODUCTION
Like many other long established urban areas, storm drainage from much of New York City is managed by a combined sewer system. With approximately 110 cm of annual rainfall and predominantly impervious surfaces, the City faces considerable challenges in managing stormwater runoff and minimizing combined sewer overflows (CSOs). Over the years, the New York City Department of Environmental Protection (DEP) has made substantial efforts to reduce CSOs by increasing capacity at wastewater treatment plants, improving regulators, and providing more detention storage throughout the sewer system; however, additional efforts are required. With the challenges of relying solely on a grey infrastructure approach to CSO reduction evident, the City made a commitment to utilize green infrastructure throughout combined sewer areas to improve stormwater control, while also providing an array of additional benefits. In 2010, New York City released the NYC Green Infrastructure Plan, outlining this alternative approach to stormwater management. Outlined within this plan is New York City's goal of utilizing green infrastructure to manage the runoff generated by a 2.5 cm storm event across 10% of impervious surfaces within combined sewer areas.

A central part of New York City's green infrastructure efforts is an adaptive management approach, where lessons learned from constructed stormwater controls can be utilized to refine future efforts. This approach has proven to be essential in understanding the unique challenges and benefits of green infrastructure in the ultra-urban environment of New York City. DEP has led efforts to pilot green infrastructure stormwater controls throughout the city, as a central component of this adaptive management approach. Through these efforts, more than 20 individual green infrastructure controls have been designed, constructed, and monitored throughout combined sewer areas of the City. In general, activities at these pilots have focused on gaining an in depth understanding of the implementation logistics and performance of these individual controls. However, with plans to widely distribute green infrastructure controls throughout the City, it was important to not only understand these issues at an individual site scale, but also on a watershed basis. To address this consideration, DEP has undertaken pilot implementation of green infrastructure throughout three localized watersheds in New York City. The overall objective of green infrastructure pilot implementation at a watershed scale was to better understand the logistics of identifying, designing, and constructing green infrastructure controls throughout a watershed, and better understand the effect of these distributed controls on sewer flows, supporting refined modelling and planning efforts.

2 METHODS
Three watersheds were selected for pilot implementation, one within the Bronx, and two within Brooklyn (Figure 1). These watersheds vary in size from approximately 4 to 10 hectares. The impervious coverage of these watersheds varied from approximately 80 to 90%. A key consideration in the selection of these pilot watersheds was the existence of a single sewer suitable for monitoring that conveyed drainage from the entire area.

![Figure 1: Overview of three pilot area watersheds](image-url)
The objective of green infrastructure efforts in these areas was to distribute source controls throughout the watershed, reducing the rate and volume of runoff entering the combined sewer system, and thereby reducing the amount of CSO discharges into local waterways. Identification and evaluation of green infrastructure opportunities focused on the right-of-way (ROW) and public properties within each watershed, as implementation on public property was expected to facilitate construction, monitoring, and maintenance of these controls. Like most of New York City, these watersheds were fully developed, meaning green infrastructure implementation would be addressed through retrofitting existing streets, sidewalks, and buildings. Public properties within these watersheds consisted primarily of schools and public housing facilities. With the ROW containing almost entirely impervious surfaces and representing roughly one third of the total land area in these watersheds, effectively managing ROW runoff was a key objective. Additionally, installation of green infrastructure within the ROW was expected to facilitate inter-agency coordination, as similarities exist throughout the City, as well as maintenance, since the controls would be readily visible and accessible with maintenance equipment.

Bioswale designs were utilized as the predominant mechanism for managing ROW runoff. These bioswales were installed on the sidewalk, immediately adjacent to the street. ROW bioswales derived their basic functional elements from bioretention, and operate by capturing runoff from the street and allowing that water to infiltrate into the soil. At a basic level, a ROW bioswale consisted of a shallow vegetated basin underlain by a sandy soil mixture and a stone drainage layer (Figure 2). These elements provide temporary surface storage for diverted runoff in conjunction with soil and stone that can effectively support storage and infiltration of that runoff. As these systems are generally constructed without an underdrains system, it was important that they be installed over soils that can support infiltration of any captured runoff, which played an important role in site selection.

![Figure 2: Three-dimensional schematic of a ROW bioswale](image)

In order to facilitate effective implementation of ROW bioswales within these watersheds, as well as other areas city-wide, a series of standard designs were developed. These standard designs built upon lessons learned through early pilot implementation, and were intended to maximize consistency across bioswales installed in similar situations, facilitating design, construction, and maintenance. An example of design elements incorporated into these standard designs is the inlet curb cut, which diverts runoff from the street into the bioswale. A depressed concrete apron was incorporated into the curb cut design in order to improve runoff capture efficiency beyond that attained by a simple curb cut used for some early pilot installations. Bioswale designs were developed to address a variety of dimensional constraints and vegetation requirements, among other elements. A standard bioswale
was 20 m long and 1.5 m wide, with approximately 60 cm of stone and 75 cm of soil. Designs for bioswales with lengths of 10 and 15 m were also developed to accommodate varying site constraints. ROW bioswales were distributed throughout the pilot watersheds in order to maximize their effective runoff management capacity. Generally, bioswales were proposed just upstream of existing catch basins, allowing them to capture the greatest amount of storm flow and allow bypassed flow to drain into the sewer system. In cases where the contributing drainage area was expected to exceed the capacity of an individual bioswale, additional bioswales were proposed along the curb upstream. Bioswales were initially distributed to target the management of 3,000 ft² of impervious surface per bioswale. Additionally, apparent surface constraints, such as driveways, narrow sidewalks, building entrances, and surface utilities, affected site selection. Inter-agency coordination also played a role in the placement of ROW bioswales, addressing concerns related to pedestrian and vehicular traffic, and impacts to existing tree pits, among other issues.

Following initial bioswale placement, detailed site evaluations, surveys, and soil investigations were conducted to refine site selection and bioswale design. These evaluations considered the location of subsurface utilities, curb and sidewalk elevations, and the permeability of underlying soils. The presence of rock at shallow depths and soils with limited permeability were expected to reduce opportunities for bioswale implementation in some areas. Drainage areas were delineated based upon survey and GIS data and used in conjunction with calculations of bioswale capacity in order to establish the total impervious area managed by bioswales within each watershed. These estimates accounted for the storage provided at the bioswale surface, within the soil and stone layers, and infiltration during a storm event.

In addition to ROW bioswales, on-site green infrastructure controls were identified and designed. These controls consisted of various configurations of bioretention, permeable pavement, and subsurface detention and infiltration (Figure 3). While opportunities for these on-site controls are generally less prevalent throughout the city, they are capable of consolidating stormwater control for large impervious areas in some cases.

Monitoring within these pilot watersheds is being conducted before and after green infrastructure implementation in order to evaluate the combined effect of these controls on storm flows. Flow monitors were installed within a manhole at the downstream end of each watershed while green infrastructure planning and design activities were underway, and left in place for a period of 10 months. As the monitored manhole is part of the combined sewer system, analyses are conducted to minimize the impact of diurnal dry weather sewer flows on wet weather comparisons. Additionally, a tipping bucket rain gauge within each watershed records rainfall depths and timing to support wet weather analyses. In addition to quantifying flows from the sewer system, monitoring evaluations are being conducted at individual bioswales. Individual bioswale monitoring setups consist of piezometers and soil moisture loggers to evaluate water storage within the systems and drawdown rates. These evaluations are expected to support improved understanding of the functionality of these controls, and
establish linkages between performance at individual controls and the overall watershed.

3 RESULTS AND DISCUSSION

Following initial bioswale site selection, fewer than 25% of proposed bioswales were eliminated or relocated due to site constraints. The presence of subsurface utilities and concerns regarding impacts to nearby existing trees were among the most frequent reasons for bioswale elimination or relocation. Soil investigations prompted the relocation of additional bioswales, particularly for the Bronx pilot watershed, where shallow bedrock was encountered at 10 proposed bioswale locations. Measured soil permeabilities were generally conducive to bioswale implementation, often exceeding 7.0E-04 cm/s. In total, more than 70 bioswales were distributed across the three watershed areas (Figure 4). When combined with on-site stormwater controls, the anticipated impervious coverage managed by green infrastructure exceeds 10% in each of the pilot watersheds.

Effective construction sequencing and staging has proved to be an important element of constructing these green infrastructure controls within a dense urban environment. Where feasible, efforts were made to minimize disruptions to pedestrian and vehicular traffic by minimizing the footprint of construction activity (Figure 5). Activities have been sequenced, such that multiple bioswales are under construction at any given point in time, maximizing the efficiency of crews focused on saw cutting and removal of pavement, excavation, landscaping, etc. This sequencing has also made it possible to add the stone and engineered soil components to multiple bioswales at a time, minimizing the need for multiple hauls from material suppliers or locally stockpiling materials, which is critical within a dense urban area where available space is limited.

Monitoring analyses of sewer flows before green infrastructure construction have indicated persistent diurnal fluctuations in dry weather flow, as expected. Monitoring analyses of wet weather flow have demonstrated a storm response consistent with evaluations of impervious coverage contributing runoff to the sewer system. In addition to overall sewershed monitoring, remote monitoring equipment at individual bioswales, consisting of piezometers and soil moisture sensors, are providing critical information regarding the stormwater management capacity of individual controls and their performance during storms of varying characteristics. These monitoring efforts have also provided insight into long term maintenance needs. Initial observations have indicated that storm depth and intensity can have an impact on the effectiveness of these systems in capturing and retaining runoff, as expected.
Figure 4: Bioswale distribution within a pilot watershed in Brooklyn
4 CONCLUSION

To address substantial challenges regarding the management of stormwater runoff, New York City has committed to utilizing green infrastructure for stormwater control throughout much of the City. Through the implementation and evaluation of green infrastructure pilots at a variety of scales, the City is gaining crucial knowledge regarding the logistics of planning, design, and construction, and the performance of these controls. Specifically, three watershed scale pilots within the Bronx and Brooklyn are yielding information on the nature of green infrastructure opportunities and common site constraints. Ultimately, monitoring storm flows from these watersheds before and after green infrastructure implementation will characterize the effects of these smaller distributed controls on storm flow rates, volumes, and timing within the larger watershed, supporting more effective implementation of green infrastructure throughout New York City.