



GREEN INFRASTRUCTURE PERFORMANCE METRICS REPORT

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**The City of New York
Department of Environmental Protection**

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ACRONYMS AND ABBREVIATIONS

Ac	Acre
BGY	Billion gallons per year
BRWI	Bronx River Watershed Initiative
BWSO	Bureau of Water and Sewer Operations
cfs	cubic feet per second
CHI	Computational Hydraulics International
CS	Combined Sewer
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
DDC	New York City Department of Design and Construction
DEC	New York State Department of Environmental Conservation
DEP	New York City Department of Environmental Protection
DOE	New York City Department of Education
DOB	New York City Department of Buildings
DOT	New York City Department of Transportation
DPR	New York City Department of Parks and Recreation
ER/OW	East River or Open Waters
EWRI-WRC	World Environment & Water Resources Congress
GI	Green Infrastructure
GI-RD	Green Infrastructure Research and Development Project
GIS	Geographic Information Systems
<i>GreenHUB</i>	GI Project Tracking System used by DEP
JFK, 2008	Typical hydrologic year of 2008 John F. Kennedy International Airport rainfall and corresponding tidal conditions
LID	Low Impact Development
LISFF	Long Island Sound Futures Fund
LTCP	Long Term Control Plan
MG	million gallons
NFWF	National Fish and Wildlife Foundation
NYC	New York City
NYCHA	New York City Housing Authority
OGI	DEP Office of Green Infrastructure
Order	2012 Amended Consent Order
PCM Report	DEP's Post-Construction Monitoring Report for Green Infrastructure Neighborhood Demonstration Areas
ROW	Right-of-way
ROWB	Right-of-way Bioswale
SGS	Stormwater Greenstreets
SWCD	Soil and Water Conservation District
SWMM	Storm Water Management Model
WEFTEC	Water Environment Federation Technical Exhibition and Conference
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

The Order on Consent (the Order)¹ that was developed between the New York City (NYC) Department of Environmental Protection (DEP) and the New York State Department of Environmental Conservation (DEC) outlines, among other things, a roadmap for the implementation of green infrastructure (GI) Citywide. The goal is to manage stormwater and reduce Combined Sewer Overflows (CSO), thereby improving water quality and promoting sustainability policies. The Order requires DEP to implement GI to manage the equivalent of stormwater generated by one inch of precipitation on impervious surfaces in combined sewer (CS) areas in the following five-year increments: 1.5% (December 31, 2015), 4% (December 31, 2020), 7% (December 31, 2025), and 10% (December 31, 2030).

The Order also requires the City to develop and submit to DEC by June 30, 2016 CSO performance metrics, including the cumulative Citywide CSO volume reduction associated with implementing the 1.5% implementation rate and the modeled CSO volume reduction associated with the 10% GI implementation rate, which will be the “Citywide baseline CSO reduction credit.” Additionally, the Order requires DEP to establish an equivalency rate based on the 1.5% GI implementation to Citywide CSO volume reduction.

This report presents performance metrics for the 1.5% GI implementation rate and a modeled CSO volume reduction based on the 10% implementation rate. The 1.5% equivalency rate incorporates data on the existing and planned GI implemented through the GI Program to date, which has primarily focused on retention based right-of-way (ROW) bioswales (ROWB), using site-specific information to model individual, distributed assets. By contrast, the 10% equivalency rate incorporates a lumped approach to estimate future projects where GI asset specifics such as location, technology type and design details are unknown. The 10% equivalency rate also assumes a much greater share of detention based GI projects, assuming that the Program will need to diversify to include different GI technologies in the future. Finally, for the 1.5% GI implementation rate, DEP has included two equivalency rates that are defined as: a) “Stormwater capture to CSO reduction ratio” and b) “Million Gallons (MG) of CSO eliminated on an annual basis per acre (Ac) of impervious area managed by GI.”

Since 2010, DEP has been constructing GI assets throughout the City's combined sewer tributary areas, both on publicly and privately owned land, including the ROW. The types of GI assets include but are not limited to bioinfiltration, permeable paving, subsurface retention systems, stormwater harvesting and reuse systems, and green roofs. See Figures below for examples.

Of these types of assets, DEP has primarily focused on the construction of ROW GI retention assets, specifically ROWBs that were implemented in what DEP has determined to be priority tributary areas. DEP maintains detailed information about each GI asset in a centralized asset tracking database called *GreenHUB*. As of February 2016, the *GreenHUB* database contained

¹Order on Consent (DEC Case No. CO2-20110512-25, modification to DEC Case No. CO2-20000107-8)
http://www.nyc.gov/html/dep/html/cso_long_term_control_plan/index.shtml

information on about 4,470 DEP assets that have been constructed, are in construction, or are in design, of which approximately 90% are ROWBs.

DEP has utilized existing NYC InfoWorks CS² (InfoWorks) models that are currently being used in the development of DEP's CSO Long Term Control Plans (LTCPs) to evaluate GI performance. These models already incorporate the grey infrastructure components of the combined sewer system (CSS), its drainage area, and collection system characteristics.

In order to model ROWB performance in a typical year,³ DEP used existing monitoring data that allowed for the development and validation of a detailed ROWB representation. This detailed representation accounted for the actual design specifications and site specific information for the constructed and planned GI assets tracked in *GreenHUB*, and then applied them to the CS area as individual, distributed assets. Attached to this report are detailed appendices which provide technical descriptions for the development and validation of the "distributed" GI modeling approach. Using the distributed approach, the 1.5% implementation rate resulted in estimated annual CSO volume reductions of 507 MG of CSO, or 2.4% of Citywide CSO baseline flow.

For the 10% GI implementation rate, DEP retained the GI modeling approach currently used for LTCP evaluations for the remaining 8.5% GI. This approach is referred to as a lumped approach and is commonly used for planning purposes where GI project specifics such as locations, technology type and design details are unknown. The estimated annual CSO reduction is estimated to be 1.677 billion gallons per year (BGY) or 8.1%. The modeling approaches are further described in Section 4.

Equivalency rates can be developed to assist with estimating CSO reduction benefits associated with planned GI or until additional performance monitoring and/or modeling is implemented to better quantify the future benefits. The equivalency rates reported here are averaged from tributary area implementation rates and reflect known GI assets with actual design specifications and site specific information (i.e. soil permeability). On a tributary area basis, equivalency rates can vary widely depending on the local hydrologic and sewer hydraulic conditions, as well as the type and penetration rate of GI. An average Citywide equivalency rate is overly simplistic and not likely to be representative on a watershed specific basis.

As mentioned above, ROWBs are by far DEP's most numerous type of asset and were primarily implemented in DEP's priority tributary areas. Therefore, the equivalency rates established for 1.5% implementation are representative of the CSO reduction benefits from implementing a retention-based ROW GI Program. However, the future Program milestones will require additional GI technologies to be considered which will result in different equivalency rates. Because the site constraints for GI implementation in many areas of the City and the mix of GI technologies that will be implemented in the future are not yet known, it would be inaccurate to use the equivalency rates from the 1.5% implementation to extrapolate future CSO reductions for the future GI

² InfoWorks CS is a software used to simulate hydrological modeling of the complete urban water cycle

³ 2008 John F. Kennedy International Airport rainfall data (JFK, 2008) that represents the average hydrologic year adapted by DEP for LTCP and other water quality studies

implementation. For example, both ratios will differ based on the extent to which DEP must rely on GI technologies such as retention, extended detention, and/or standard detention for stormwater management. These equivalency rates are also dependent upon local hydrologic and sewer hydraulic conditions in CSO tributary areas.

DEP intends to expand the GI toolbox and future implementation scenarios to include various detention and retention technologies that will result in different equivalency rates. Therefore, DEP will be reevaluating the stormwater runoff and CSO reductions and associated equivalency rates in connection with the interim 4% and 7% implementation rate milestones.

For the 1.5% implementation rate, the “stormwater capture to CSO reduction ratio” equivalency rate is 2.1 MG/MG Citywide, and the equivalency rate of “MG of CSO eliminated on an annual basis per acre of impervious area managed from GI” is 0.4 MG/Ac Citywide.

DEP has initiated a Green Infrastructure Research and Development (GI-RD) project to assist the agency in closing identified gaps in GI performance data and developing additional GI designs as part of the overall toolbox for both public and private property. Future GI performance monitoring activities under the GI-RD project will provide additional information for better understanding of GI performance and further refinement of GI modeling representation for subsequent performance metrics evaluations.



Figure ES-1. Right-of-Way Rain Garden (Bioswale)



**Figure ES-2. PS 261, Brooklyn, School Yard Retrofit
(Turf Field/Subsurface Retention, Rain Garden, Porous Pavement)**



Figure ES-3. Shoelace Park, Bronx, Rain Garden



Figure ES-4. Bishop Laughlin High School, Brooklyn, Green Roof

1 INTRODUCTION

1.1 Green Infrastructure Program Background

In 2010, DEP released the *NYC Green Infrastructure Plan* (GI Plan) that sets forth a cost-effective integrated green/grey approach for reducing CSO. In early 2011, DEP's Office of Green Infrastructure (OGI) was established to lead the design and implementation of the GI Program. The Order sets forth targets for implementation of GI in four five-year increments, ultimately targeting the management of stormwater equivalent to one inch of precipitation on 10% of impervious area in CS areas by 2030.

The GI Program's implementation strategy is an "area-wide" approach, the goal of which is to saturate tributary areas categorized by DEP as priority areas with distributed assets to manage runoff where it falls, thereby reducing the peak flow and volume of runoff that can enter the CSS. These priority areas have been selected based on several criteria, including CSO volume and frequency, historical water quality conditions in the water bodies, and projected water quality benefits of GI project implementation (e.g., confined tributaries vs. open waters). Outfalls that are in close proximity to existing and planned public access locations were also taken into consideration when determining priority areas.

GI assets can be divided into two primary performance categories: retention and detention. Retention assets allow stormwater to infiltrate into existing soils below and around the asset and are not connected to the sewer system through orifices or underdrains. Detention assets allow controlled release of stormwater from a storage system (usually a tank or roof) to the sewer system at a defined rate. Detention assets reduce peak flow but do not eliminate or reduce the quantity of runoff that ultimately enters the sewer system, as retention assets do.

DEP is also pursuing widespread implementation of GI retrofits on other City owned properties, such as schools, parks, and housing, and is providing funding for the implementation of GI assets on private properties through the GI Grant Program. Typical GI assets installed as part of the Program include bioswales, stormwater greenstreets (SGS), rain gardens, green roofs, subsurface retention systems, and permeable pavements, among others. Most of the GI assets have been constructed in the ROW with standard designs developed by DEP⁴ (see Figure 1-1 below). DEP is continually working to optimize the typical GI typologies for both ROW and on-site public and private properties and will continue to expand the GI Program toolbox in the future. For more information on the implementation status of the GI Program, see the Annual Reports on DEP's website.⁵

⁴ http://www.nyc.gov/html/dep/html/stormwater/green_infrastructure_standards.shtml

⁵ http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml



Figure 1-1. Standard Right-of-Way Green Infrastructure

1.2 Performance Metrics Requirement and Modeling Approach Summary

As described above, the GI Program is being measured by impervious acres managed within New York City’s CS areas, with targets to meet every five years. DEP provides updates on the progress of the Program in Annual Reports, which include both the cumulative built and planned impervious acres to be managed each year. This Performance Metrics report presents the relationship between impervious acres managed and reductions in stormwater runoff and CSO volume based on asset-specific information and progress as part of the 1.5% implementation rate, and an estimated projection for the 10% implementation rate. However, note that the 1.5% implementation performance metrics results are based primarily on retention practices and therefore reflect better stormwater runoff reductions than we expect to see in the remainder of the Program. This is reflected in the 10% performance metrics results.

- **1.5% Green Infrastructure Implementation**

This scenario utilized the “distributed GI modeling” approach for the 1.5% implementation rate, as further described in Section 4. Available GI design and spatial distribution data for assets constructed and in construction was utilized from *GreenHUB*, a centralized asset tracking database, as well as average assumptions for any GI assets that will be constructed as part of the 1.5% target for which specific design and location information have not yet been determined. Those pending assets were assumed to be of average ROWB size and local site conditions (such as soil permeability) and were distributed evenly throughout the priority areas. These assets were

entered into the InfoWorks models in addition to the built and planned assets to estimate stormwater runoff reductions and CSO reductions for the 1.5% implementation rate.

The modeling approach for the 1.5% distributed model was developed using data collected as part of the Neighborhood Demonstration Area⁶ (Demo Area) study to validate the GI ROWB representation and utilized the NYC InfoWorks models currently used for LTCP efforts. A simplified schematic representation of the InfoWorks model is shown in Figure 1-2.⁷ Due to the prevalence of ROWBs, the majority of the modeling effort for this report focused on developing an accurate representation of this type of GI in the InfoWorks model to estimate performance.

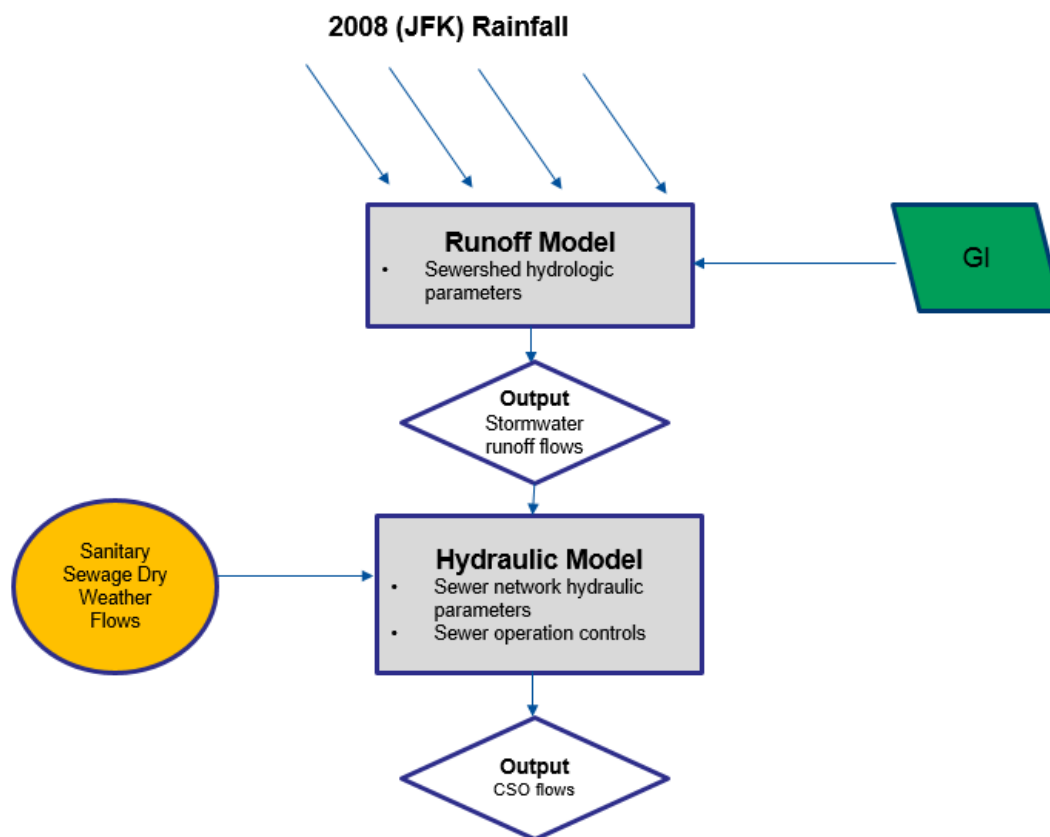


Figure 1-2. Schematic Representation of the InfoWorks Model

In order to best represent the ROW GI asset in the distributed model, DEP had to create an accurate representation of a ROWB, including its capacity and its connected impervious tributary

⁶ http://www.nyc.gov/html/dep/html/stormwater/neighborhood_demonstration_area_projects.shtml

⁷Additional information can be found in the development of the LTCP reports on DEP's website here: http://www.nyc.gov/html/dep/html/cso_long_term_control_plan/index.shtml

area. Currently, DEP calculates impervious area managed based on the estimated volume of stormwater that can be managed by each asset. As part of this calculation, DEP assumes that the asset is designed to have a static volumetric capacity equivalent to the managed stormwater runoff from a one-inch, eight-hour rain event. A schematic of how DEP calculates impervious area managed is shown in Figure 1-3.

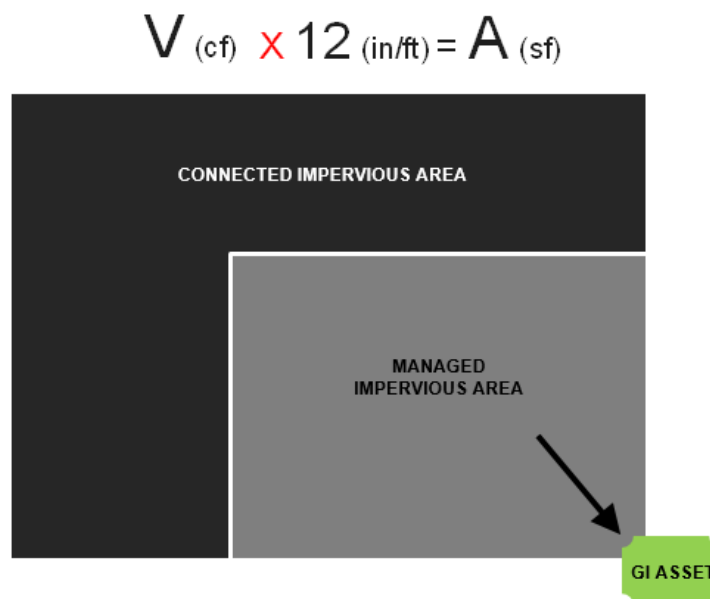


Figure 1-3. Schematic of the Managed Impervious Area for GI Assets as Currently Report by DEP

However, in most cases, ROWBs are sited in locations where the physically connected impervious area is larger than the assumed managed area, and therefore a greater area can be managed during rain events less than one inch and/or for longer duration than eight hours, as shown in Figure 1-4. This analysis allowed DEP to estimate stormwater runoff reduction resulting from GI over a typical year (2008),⁸ rather than for only the one inch, eight-hour event.

⁸ 2008 John F. Kennedy International Airport rainfall data (JFK, 2008) that represents the average hydrologic year adapted by DEP for LTCP and other water quality studies

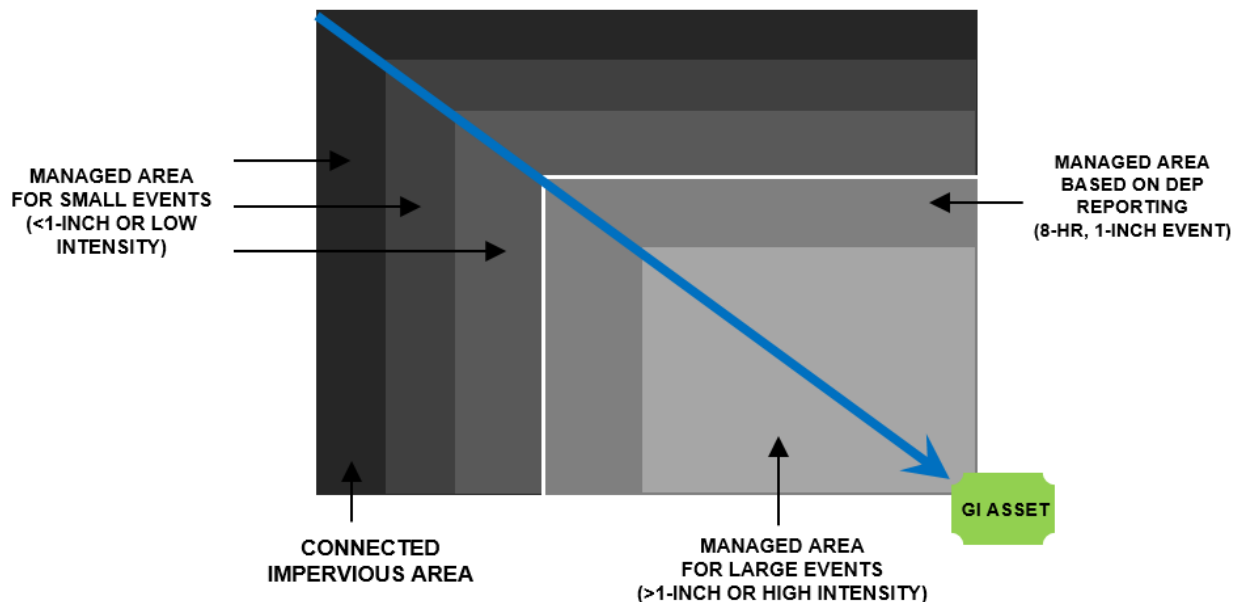


Figure 1-4. Schematic of Connected vs. Managed Impervious Area for GI Assets

The annual stormwater runoff reduction as shown in Figure 1-5 below is an important modeling output for estimating CSO reduction. It is used for calculating the stormwater capture to CSO reduction ratio equivalency rates defined in Section 5 and provides a robust methodology for estimating the percentage of the impervious area managed by GI on an annual basis. Annual stormwater volumes from individual subcatchments (drainage areas) in the InfoWorks models are extracted for pre- and post-GI scenarios to calculate this output, the results of which are presented later in this report.

The annual CSO reduction resulting from the 1.5% GI implementation rate is illustrated in Figure 1-6 and directly related to the stormwater runoff reduction as well as the amount of impervious area that is managed by GI implementation. Annual CSO volumes from individual CSO outfalls in the InfoWorks models are extracted for pre- and post-GI scenarios to calculate this output.

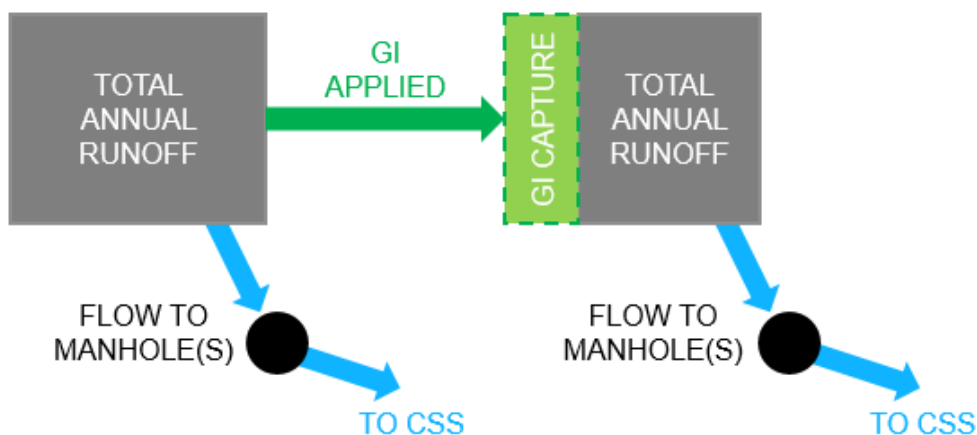


Figure 1-5. Schematic of the Stormwater Runoff Reduction from GI Capture

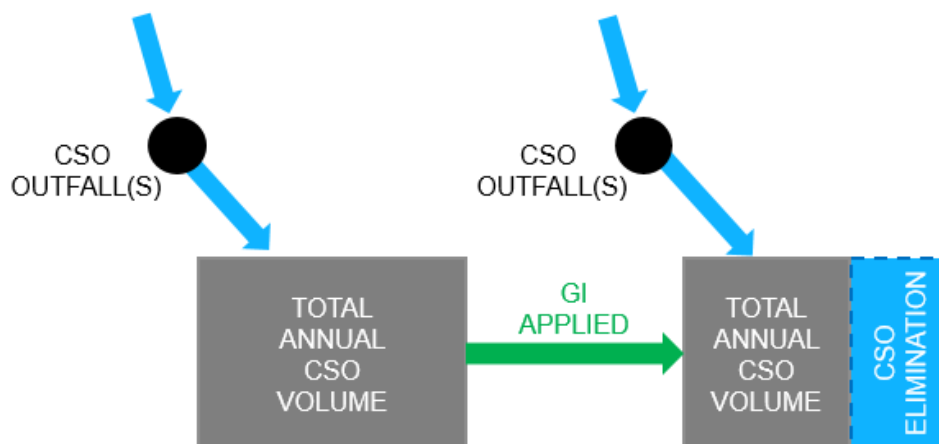


Figure 1-6. Schematic of the CSO Reduction from Stormwater Runoff Reduction

As required under the Order, this report also establishes an equivalency rate associated with the 1.5% GI implementation scenario. The two types of equivalency rates defined in this report are “Stormwater capture to CSO reduction ratio” and “MG of CSO eliminated on an annual basis per acre of impervious area managed by GI”.

- **10% Green Infrastructure Implementation**

This scenario utilized the “distributed GI model” up to 1.5% implementation as described above, and overlaid the additional 8.5% GI implementation utilizing the “lumped modeling” approach currently employed by the LTCP effort. The “lumped” approach is necessary for the future projections due to the fact that specific GI assets, types and locations for this future milestone have not yet been identified.

2 GREEN INFRASTRUCTURE ASSET TRACKING

2.1 Tracking Implementation in *GreenHUB*

In order to track constructed GI assets, DEP has developed a Geographical Information Systems (GIS)-based project tracking system called *GreenHUB* for DEP's thousands of assets. *GreenHUB* tracks all construction details for the GI assets represented in the database, including type of GI, construction status, dimensions, local permeability data, and calculated managed stormwater volume capacity of the asset. As of February 2016, the *GreenHUB* database contained information for 4,469 assets that have already been constructed, in construction, or designed and awaiting construction bid. Of these assets, approximately 90% are ROWBs, with other types of ROW GI and public and private on-site GI assets making up the remaining 10%.

Each project in the *GreenHUB* database is updated on a monthly basis so that it accurately reflects the most current information about GI assets. The most recent *GreenHUB* data available as of February 2016 was used in this analysis, as the model construction, analysis, interpretation and documentation were performed over a period of five months from February 2016. Generally speaking, DEP divides assets into two categories: ROW and on-site. The ROW projects are only those constructed in the public ROW (i.e., streets and sidewalks). On-site projects are defined as land within a public or privately-owned parcel (or tax lot) within the City.

2.2 Right-of-Way Green Infrastructure

DEP has primarily focused on implementing ROW GI in this first phase of the GI Program. ROW projects proceed with interagency coordination including the Department of Design and Construction (DDC), Department of Transportation (DOT) and Department of Parks and Recreation (DPR). The majority of ROW assets in *GreenHUB* fall into the following categories.

- **DEP-Initiated Area-wide Right-of-Way Green Infrastructure**

The largest proportion of GI assets in *GreenHUB* are funded by DEP. Out of the 4,469 assets in *GreenHUB* previously discussed, over 4,000 of them are ROW GI initiated by DEP through Area-wide ROW GI contracts. More information on the construction of ROW GI can be found in the Green Infrastructure Annual Reports.

- **Partner Agency-Initiated Projects with DEP-Funded Right-of-Way Green Infrastructure**

GreenHUB contains 62 ROW GI assets that were constructed by other agencies and funded by DEP. This typically occurs when a ROW GI asset is installed as part of a pre-existing City capital project in the ROW. Roughly 70% of these assets are ROWBs, with SGS, rain gardens, permeable pavement and subsurface retention systems making up the remainder. The partner agencies for this category of GI asset are DOT, DDC, and DPR.

- **Non-DEP-Funded Right-of-Way Green Infrastructure**

There are 15 assets included in *GreenHUB* that were constructed by other agencies and were not funded by DEP. The majority of these assets are SGSs constructed by DPR.

2.2 On-site Green Infrastructure

In addition to the ROW GI installations, DEP and other agencies have installed numerous on-site GI assets as retrofits to public and private property. DEP considers this an important tool that must be utilized in order to meet the milestones outlined in the Order and also to maximize the co-benefits of the GI program. Typical on-site GI types include bioretention practices (such as rain gardens or swales), subsurface detention/retention systems or synthetic turf fields with infiltration capacity, green roofs, permeable pavement, as well as others. As with ROW GI, the goal for these projects is to manage one inch of runoff generated from the site's impervious surfaces, such as driveways, pathways, paved areas or recreation courts, rooftops, and others. The majority of on-site assets in *GreenHUB* fall into the following categories.

- **DEP -Funded Public Property Retrofits/On-site**

DEP has collaborated with partner agencies such as the New York City Housing Authority (NYCHA), DDC, and Department of Education (DOE) to identify the best opportunities to implement GI on public properties. There are 87 assets in *GreenHUB* that are public on-site GI projects funded by DEP, with the majority being permeable pavement, subsurface retention, and rain gardens, with various other types of GI making up the remainder.

- **Partner Agency-Initiated Projects with DEP Funds**

DEP also works with partnering agencies to identify opportunities within their respective capital programs to add incremental GI funding to planned capital projects on public property. These projects are fewer in number and often limited by pre-existing scopes and goals, but can allow for multiple benefits to be met with one project, and often providing more than stormwater management such as improved public spaces. There are 61 assets in *GreenHUB* falling into this category.

- **DEP-Funded Projects on Private Property**

Since its introduction in 2011, the GI Grant Program has sought to strengthen public-private partnerships and public engagement in regards to the design, construction and maintenance of GI on private property in combined sewer tributary areas. There are 66 GI Grant Program assets included in *GreenHUB*.

- **Private Property Projects not Funded by DEP**

GI assets funded by private or non-DEP parties and listed in the *GreenHUB* database include 25 green roofs. These private green roofs collectively manage at least one inch of rainfall over a total impervious area of 20 acres, with the Javits Center Green Roof being responsible for roughly half of the area managed. Ten of these assets are managed by DPR and 15 of them are listed as private green roofs. Of these private green roofs, five went through the Green Roof Tax Abatement program.

2.3 Excluded Data

DEP is aware of many additional GI assets that have been funded and constructed by various entities since 2010. However, DEP does not maintain them nor have a way to account for all of them, so these known assets are not included in this analysis. Therefore, the performance metrics results presented in this report can be considered conservative. For example, the NYC Soil and Water Conservation District (SWCD) has built multiple downspout disconnection projects throughout the City, most of which were designed to manage one inch of rainfall from the rooftop. Another entity is the National Fish and Wildlife Foundation (NFWF), which has funded multiple GI projects throughout the Bronx, Queens, and Manhattan through the Bronx River Watershed Initiative (BRWI) and the Long Island Sound Futures Fund (LISFF). These projects include permeable pavements, bioretention systems (rain gardens), constructed wetlands, and green roofs. The Water Resources Group, a coalition of environmental organizations, including GrowNYC and Green Thumb, have built more than 100 rainwater harvesting systems in community gardens distributed around the city. These systems typically feature a 500 or 1,000 gallon cistern connected to the downspout of an adjacent building. In addition, there are many other private green roofs within NYC that are not being accounted for by DOB, and therefore the exact number, size, and other details of these green roofs are currently unknown. Although GI projects like the above are managing stormwater runoff from impervious areas throughout the CSS, DEP is not taking credit for these projects in this Performance Metrics Report.

2.4 On-site Detention and the Stormwater Performance Standard

DEP's Bureau of Water and Sewer Operations (BWSO) works closely with the NYC Department of Buildings (DOB) to review the site-connection proposals required by the 2012 Stormwater Performance Standard⁹. The performance standard established two criteria, one of which is based on the allowable flow calculated from DEP's old drainage criterion. Allowable flow is the stormwater flow from a development that can be released into the existing storm or combined sewer based on the drainage plan and built sewers within the borough where the new or redevelopment project is located. For new developments, the peak flow is restricted to the greater of 0.25 cubic feet per second (cfs) or 10% of the allowable flow. If the allowable flow is less than 0.25 cfs, the allowable flow becomes the peak flow criterion. For alterations, the peak flow criterion is set directionally proportional to the ratio of the altered area to the total site area.

BWSO maintains a list of approved permits and inspected detention elements that were constructed pursuant to the Stormwater Performance Standard. However, the list does not currently include all the details of individual sites (e.g., impervious area managed) necessary to perform the calculation of associated benefits in terms of peak flow reductions.¹⁰ As a result, DEP has not included these systems as a conservative assumption in this Performance Metrics Report. DEP will compile the necessary information and include the impervious area managed by these systems in the next 5-year milestone report. Modeling of these GI assets for future GI implementation milestones will be consistent with how the detention was modeled in the LTCP process and can be refined as the Program progresses.

⁹ http://www.nyc.gov/html/dep/html/stormwater/stormwater_management_construction.shtml

¹⁰ DEP's Stormwater Rule tracking does not include Site Connection Proposals/House Connection Proposals certified by the DOB hence the Stormwater Rule may include additional sites.

3 GREEN INFRASTRUCTURE IMPLEMENTATION

3.1 Built and Planned Green Infrastructure

As seen in the table below, the GI Program will manage 1.0% of the impervious area within combined areas in waterbodies other than East River/Open Waters and 0.6% of the impervious areas Citywide.

Table 3-1. Built and Planned GI as Reported in the 2015 Annual Report

Waterbodies	Impervious Area within Combined Sewer Tributary, IACS (ac)	10% of IACS Tributary (ac)	1.5% of IACS Tributary (ac)	2010-2015		
				Number of Assets	Total IACS Managed (ac)	Total Percent of IACS Managed
TOTAL WATERBODIES (Other than ER/OW)	37,622	3,762	564	3,734	392	1.0%
East River & Open Waters (ER/OW)	41,127	4,113	617	96	46	0.1%
TOTAL CITYWIDE	78,749	7,875	1,181	3,830	437	0.6%

3.2 Planned Green Infrastructure for 1.5% Implementation

In order to achieve a Citywide implementation rate of 1.5%, DEP will be constructing more projects through 2020 as discussed in DEP’s June 27, 2016 Contingency Plan. These GI assets will be constructed through area-wide contracts in priority areas and are in design at this time within the Bronx River, Flushing Creek, Jamaica Bay, Westchester Creek, Newtown Creek, and East River/Open Waters watersheds.

3.3 Projected Green Infrastructure for 10% Implementation Rate

In addition to the above, DEP continues to expand its tool box and strategies to work around the multiple physical and operational challenges to implement the GI Program and works toward the 10% GI target. Physical limitations such as poor soils, high groundwater and bedrock, space constraints in the right of way, conflicting capital projects, environmental conditions, procurement timelines, and other constraints common throughout the City may delay, limit, and/or preclude green infrastructure implementation in some watersheds.

Also as described earlier, since 2012, all new development and redevelopment projects are required to comply with the Stormwater Performance Standard (Stormwater Rule) set forth by DEP by implementing detention practices or retention practices into the sites. Based on this Rule, DEP is making a conservative assumption in this analysis that all private projects will be 100% detention-based.

One of the major goals of the GI Program is to achieve measurable water quality benefits in the priority waterbodies while also providing co-benefits such as improved resiliency in order to adapt to the changing climate. To that end, DEP has, and will continue to, prioritize efforts and

investment of resources for installation of GI in priority combined sewer tributary areas. While DEP continues to advance the development of green infrastructure in the City with significant success as part of a long-term endeavor, DEP will also reevaluate the level of program activity and benefits in East River and Open Waters in light of the major capital investments already made, resulting in the vast majority of the Open Waters currently in attainment with existing water quality standards.

4 MODELING APPROACH FOR GREEN INFRASTRUCTURE PERFORMANCE

Provided below are summaries and key conclusions for each of the steps taken to develop and refine the approach used to model GI performance under the implementation scenarios defined in this report. Each are detailed technical descriptions that provide the background for the GI modeling approach and are also attached as appendices. DEP:

1. documented current GI modeling procedures used by NYC for the CSO LTCP development (refer to Appendix A);
2. conducted a literature review to identify the best available practices for model representation of GI technologies (refer to Appendix B);
3. conducted a survey of peer utilities to identify their GI modeling practices and benchmark them to the NYC approach (refer to Appendix C); and
4. conducted microscale modeling evaluations and calibrations using GI monitoring data collected in the Neighborhood Demonstration Area¹¹ study to validate the “distributed” GI modeling approach (refer to Appendix D);

In addition, DEP utilized existing InfoWorks models developed as part of the LTCPs together with the distributed GI modeling approach and available *GreenHUB* data to evaluate performance metrics and equivalency rates for the 1.5% GI implementation scenario. DEP also used existing InfoWorks models and the current LTCP GI modeling approach to estimate a modeled CSO volume reduction for the remaining 8.5% necessary to achieve the 10% GI implementation rate.

4.1 Overview of Current Modeling Practices

LTCP team currently employs a lumped modeling approach for GI that is one of the common approaches found in the literature. The lumped approach explicitly accounts for retention versus detention-based GI practices, which is illustrated below in Figure 4-1 showing the GI model representation currently used in LTCP evaluations.

For the representation of retention GI practices in the lumped approach, the managed impervious acreage is connected to a “storage node” with a capacity equivalent to managed impervious area multiplied by one inch of runoff. The storage node in the model is then drained via an infiltrating bottom, so captured stormwater is not reintroduced into the system. The runoff in excess of this volume is bypassed to the drain manhole.

¹¹ In 2011, DEP scaled up its monitoring efforts by implementing Neighborhood Demonstration Area projects in three neighborhoods in priority combined sewer tributary areas: Hutchinson River in the Bronx and Newtown Creek and Jamaica Bay in Brooklyn, to test the effectiveness of (GI) systems on a multi-block scale. The study's Post Construction Monitoring Report can be found on DEP's website. http://www.nyc.gov/html/dep/html/stormwater/neighborhood_demonstration_area_projects.shtml

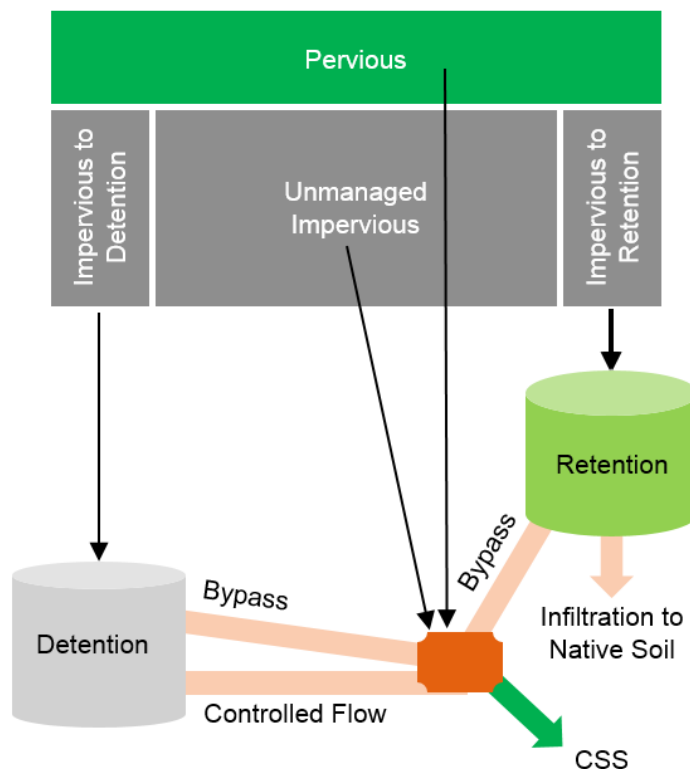


Figure 4-1. Lumped Representation in Existing LTCP InfoWorks Model per Subcatchment

In contrast, detention GI practices are assumed to be “storage nodes” that allow no infiltration and have outlet orifices to control discharge flows for site connections to the City’s sewers in accordance with the 2012 performance standard – greater of 0.25 cfs or 10% of allowable peak flow estimated using the DEP’s drainage criterion.

It must be emphasized that the managed impervious acreage for retention and detention practices in each subcatchment for the GI modeling used in the LTCPs is not based on the type or number of GI practices but rather on an assigned GI target “managed impervious acre” for a given subcatchment. Based on the literature review and utility survey results presented further in this section, the lumped modeling approach is widely used for planning-level evaluations of GI performance where exact GI technologies and/or design parameters have not yet been defined.

4.2 Summary of Literature Review and Utility Survey

DEP conducted a literature review in order to determine common methodologies used for modeling GI practices, how modeling results compare to monitored performance, and what protocols are used for modeling GI technologies in municipalities with similar urban and climate conditions to New York City. This review examined conference proceedings, peer-reviewed literature, as well as government documents. Conference papers were pulled from the proceedings of four regularly occurring conferences dating back to 2005 (Low Impact Development (LID) Conference), Computational Hydraulics Institute (CHI) Conference, Water Environment Federation’s Annual Technical Exhibition and Conference (WEFTEC), and World Environment & Water Resources Congress (EWRI-WRC). Peer-reviewed papers were obtained

from the Web of Science and government documents consisted primarily of municipal modeling reports prepared by different stormwater utilities and their consultants.

The review of government reports established that InfoWorks is currently the preferred hydrologic and hydraulic model used by municipal utilities to simulate wet-weather flow through complex urban environments. Many municipalities, including San Francisco, Omaha, Atlanta, Chicago, Baltimore, Seattle, and Indianapolis, among others, use calibrated InfoWorks models for strategic sewershed planning. However, only utilities in San Francisco, Seattle, and New York have documented how they use this software in GI planning activities.

In lumped InfoWorks simulations, GI is typically represented with “storage nodes” inserted into the sewer network. Impermeable bottom “storage nodes” are used for simulating detention GI systems, and permeable bottom storage nodes are used for representing retention GI. This is consistent with the modeling method currently utilized in the LTCP effort.

The other GI modeling methodology commonly mentioned in the literature is the “distributed” approach. In distributed models, simulation of GI performance is currently best enabled by the Storm Water Management Model (SWMM) through the use of LID controls first introduced in 2010. In contrast to the lumped approach which typically utilizes weighted averages to assign values to the hydrologic and GI design parameters in all of the subcatchments, the distributed approach utilizes many parameters derived from actual physical conditions. In distributed models not using SWMM’s LID controls, a common approach is to model GI systems as 100% pervious subcatchments with depression storage used to represent ponding depth and effective depth of the GI porous media.

Overall, the literature review provided a great deal of information on methodologies used for representing GI in both distributed and lumped models. Although distributed models represent a more accurate physical representation of GI, it was found that both distributed and lumped models produced similar results in terms of predicting stormwater runoff peak flow and volume reductions. For a more detailed discussion of the results of the literature review, refer to Appendix B.

In addition to the literature review, DEP sought to understand other peer utilities’ approach to modeling and evaluating GI performance. In order to do so, a questionnaire on GI modeling programs/procedures was developed. Fifteen utilities of various sizes across the country agreed to respond to the questionnaire. The participating utilities are listed in Table 4-1. DEP will consider using the findings in future coordination with LTCP modeling methods and to develop updated GI modeling guidelines for future performance evaluations at different spatial scales.

Table 4-1. Peer Utility Name and Location

Utility Name	Municipality
Allegheny County Sewer Authority (ALCOSAN)	Pittsburgh, PA
Boston Water and Sewer Commission (BWSC)	Boston, MA
Citizens Energy Group (CEG)	Indianapolis, IN
Columbus Division of Sewerage and Drainage (DOSD)	Columbus, OH
District of Columbia Water and Sewer Authority (DC Water)	Washington, D.C.
Louisville Metropolitan Sewer District (MSD)	Louisville, KY
Metropolitan Sewer District of Greater Cincinnati (MSD GC)	Cincinnati, OH
Metropolitan Water Reclamation District of Greater Chicago (MWRD)	Chicago, IL
Northeast Ohio Regional Sewer District (NEORS)	Cleveland, OH
Onondaga County	Syracuse, NY
Pittsburgh Water and Sewer Authority (PWSA)	Pittsburgh, PA
Philadelphia Water Department (PWD)	Philadelphia, PA
Bureau of Environmental Services (BES)	Portland, OR
San Francisco Public Utilities Commission (SFPUC)	San Francisco, CA
Seattle Public Utilities (SPU)	Seattle, WA

The responses gathered from the 15 peer utilities represented the current state of the industry in terms of modeling approaches for GI and revealed consistency across nearly all sizes of utilities and geographic locations. Naturally, there were differences in the approach utilized to represent specific GI facilities within a model based on the preferences and level of effort investment of the individual utilities.

The methods used to model GI vary from utility to utility; no single approach was identified as the leading approach to modeling GI. Most utilities simply increase abstractions/depression storage and/or reduce impervious area percentage contributing to sewers in order to simulate stormwater capture by GI, and some utilities have begun creating more detailed GI representations. Most of the utilities that are actively evaluating GI within their models do have documented procedures for GI modeling, and many were willing to share information on their procedures.

The results of the questionnaire confirm that the lumped approach currently used by DEP is comparable to those being used by most utilities surveyed. The findings also indicated that as utilities progress in utilizing the models through GI planning, design and post construction monitoring, distributed modeling approaches will likely become more common.

As the GI analysis and implementation continues to develop, data collected in the GI-RD project can lead to further assessment and refinement of the approaches in the future. Further details

on the findings from the peer utility survey, as well as the completed survey from each utility can be found in Appendix C.

4.3 Microscale Modeling Evaluations and Distributed Green Infrastructure Modeling Approach

As mentioned above, DEP implemented, monitored, and reported on GI performance in three Demo Areas. Neighborhood and site scale data collected by DEP as part of the Demo Area monitoring provided invaluable information on the performance of GI projects. The findings of this study are presented in the PCM Report (DEP, 2014). The information gained as a part of this study, especially pre- and post-GI Demo Area monitoring data was used extensively in validating the ROWB performance and the distributed GI modeling approach.

DEP determined it was important to conduct the microscale modeling analysis because the only available GI performance monitoring data at that time was on a neighborhood scale while the existing LTCP InfoWorks models represent the CS on a Citywide scale with much larger subcatchments. Using this monitoring data required modeling evaluations on a similar scale referred to as microscale.

Microscale modeling evaluations performed using the Demo Area monitoring data were focused on the establishment and validation of the most appropriate modeling approach for the representation of ROWB performance in the macroscale (LTCP) InfoWorks models. Given that the ROWBs represent the vast majority of planned and/or implemented GI in the 1.5% GI scenarios, establishing an accurate modeling representation of ROWB performance was instrumental in quantifying expected performance from GI installations. The ROWB representation was then used in a distributed model and applied Citywide using the LTCP InfoWorks models.

In order to complete the distributed model for the 1.5% GI scenario, a detailed representation of each ROWB was developed, as presented in Figure 4-2. Using this procedure, each individual GI asset was assigned to its respective model subcatchment using the X and Y coordinates available in *GreenHUB*. Within each subcatchment, individual connected areas to each ROWB are apportioned, using the GIS analysis described below. Under simulated rainfall conditions, stormwater runoff from the connected impervious area is stored in each ROWB, and prevented from entering the CSS through unit processes such as vertical and horizontal infiltration as well as evapotranspiration. Stormwater runoff in excess of ROWB capacity flows over a bypass weir to the collection system.

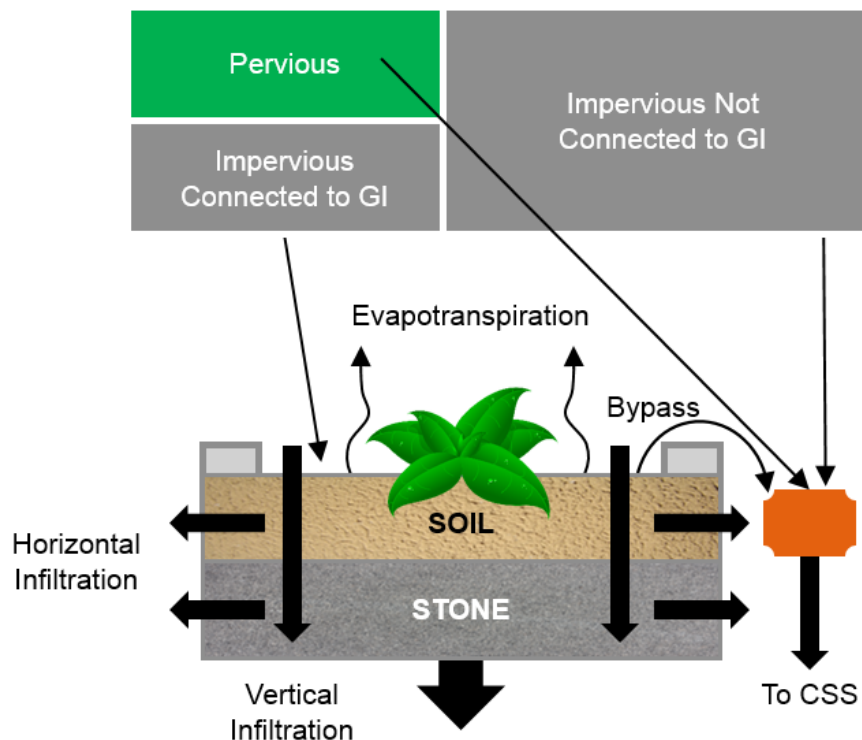


Figure 4-2. A Schematic of the Detailed ROWB Representation for Distributed GI Model in InfoWorks

Using monitoring data from Demo Areas 2 and 3,¹² the detailed ROWB representation in the distributed microscale model provided a very good correlation between the modeling results and monitored data. Model-predicted ROWB performance in terms of stormwater runoff volume reduction is conservative for both Demo Areas, which was likely attributed to lower than actual horizontal infiltration rates used in the model.

Examples of the pre- and post-GI correlation plots for volume reduction in Demo Area 2 are presented in Figure 4-3. Modeled vs. monitored volume linear regression line (dotted black) located above the 45-degree exact fit line (solid blue) illustrates that the model slightly under-predicts stormwater volume reduction in ROWBs during the modeled events (see Appendix D for a more detailed explanation of this analysis).

¹² Demo Area 1 results were inconclusive due to several potential issues documented in the PCM Report (DEP, 2014).

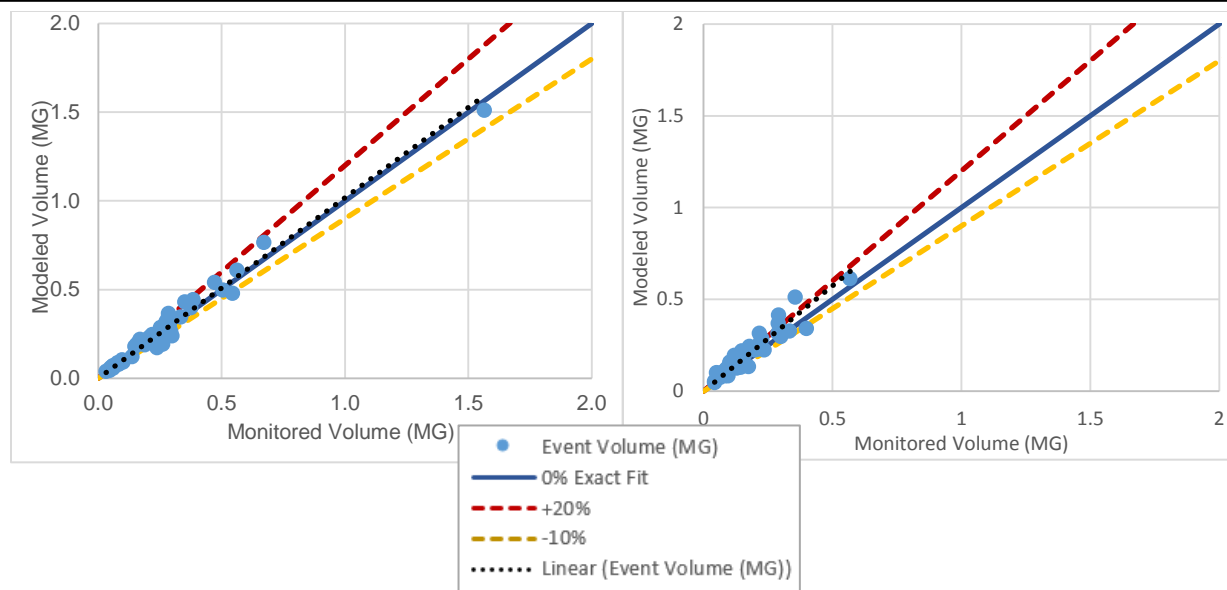


Figure 4-3. Volume Result Comparisons of Demo Area 2 Pre-GI conditions (left) and Post-GI conditions (right)

The validation process documented in Appendix D has allowed DEP to carry forward the final ROWB model representation depicted in Figure 4-2 in confidence for the continuous simulations to assess CSO and stormwater volume reductions for the 1.5% scenario. Given the conservative nature of the distributed microscale modeling results for GI performance in terms of stormwater runoff volume reduction, it is reasonable to assume that the distributed modeling evaluation of the 1.5% GI performance will also yield conservative results.

For the 1.5% GI scenario, the detailed GI representation allowed for each individual GI asset to be assigned to its corresponding model subcatchment using the X and Y coordinates available in *GreenHUB*. Under simulated rainfall conditions, stormwater runoff from the connected impervious area is stored in each asset and then “eliminated” via vertical and horizontal infiltration and evapotranspiration during and after the rain event. Excess stormwater runoff that cannot be stored or “eliminated” is bypassed to a combined sewer along with stormwater runoff from unmanaged impervious and pervious areas. This allows the model to account for actual GI performance where site-specific design and soil permeability data are available.

A key advantage of using the distributed modeling approach is the ability to use the individual GI unit design data and site characteristics without having to average or aggregate multiple modeling parameters such as connected area, GI unit size and storage volume, individual design characteristics (e.g., chimney, stone columns), soil permeability and others. This approach allows DEP to directly utilize GI asset information stored in *GreenHUB* to model constructed or soon to be constructed assets. This approach is further described below.

In addition, many assets will be monitored in the field and based on results from these studies the model can be improved by adding additional GI types with validated representations. As the Program progress, it will become more and more important to accurately reflect the GI assets within the individual subcatchments to evaluate CSO benefits from GI.

4.4 Distributed Modeling Approach for 1.5% Implementation Rate

The evaluation of the 1.5% implementation rate utilized the distributed approach for all constructed or planned GI assets and modeled each of the individual GI assets as derived from *GreenHUB*, using the actual design and site information per asset. This design information includes GI type and dimensions, while site specific data includes each practice X and Y coordinates and vertical infiltration data from permeability tests.

A GIS analysis was performed to delineate the actual connected area to each GI practice using Light Detection and Ranging (LIDAR) topographic survey data, which was then used in the modeling. This analysis was necessary since in most cases the actual connected impervious area is greater than that reported by DEP as the managed impervious area. Currently, DEP calculates impervious area managed based on the estimated volume of stormwater that can be managed by each GI asset during a one-inch, eight-hour rain event utilizing the processes of storage, horizontal and vertical infiltration, and evapotranspiration. The assumption is that the asset is designed to have a static capacity equivalent to the one-inch rain event, which is then used to calculate the one inch of water over the tributary square feet, or the managed area. However, in reality for most GI installations, the assumed managed area is smaller than the physically connected impervious area. As a result, GI assets can manage runoff from larger areas than reported as managed when accounting for rain events less than one inch and/or for longer duration than eight hours.

Additionally, the DEP calculation assumes that 100% of precipitation falling on the managed impervious area is converted to stormwater runoff reaching the GI asset. Typically, a portion of stormwater runoff is lost prior to reaching the GI asset due to depression storage, infiltration through pavement cracks and evaporation that occur in the impervious tributary area. Because of these assumptions the managed area reported by DEP can be considered conservative and depending on the storm event, runoff from the larger impervious area (up to the physically connected area) may be successfully managed by the GI asset, as shown in Figure 4-4.

Only using the reported managed area in the model would underestimate the volume of runoff managed during longer duration lower intensity storms. For consistency, the managed impervious area presented in the performance tables is the same as reported by DEP in all Annual and Quarterly Reports as progress toward Order milestones, as shown in Table 3-1 above.

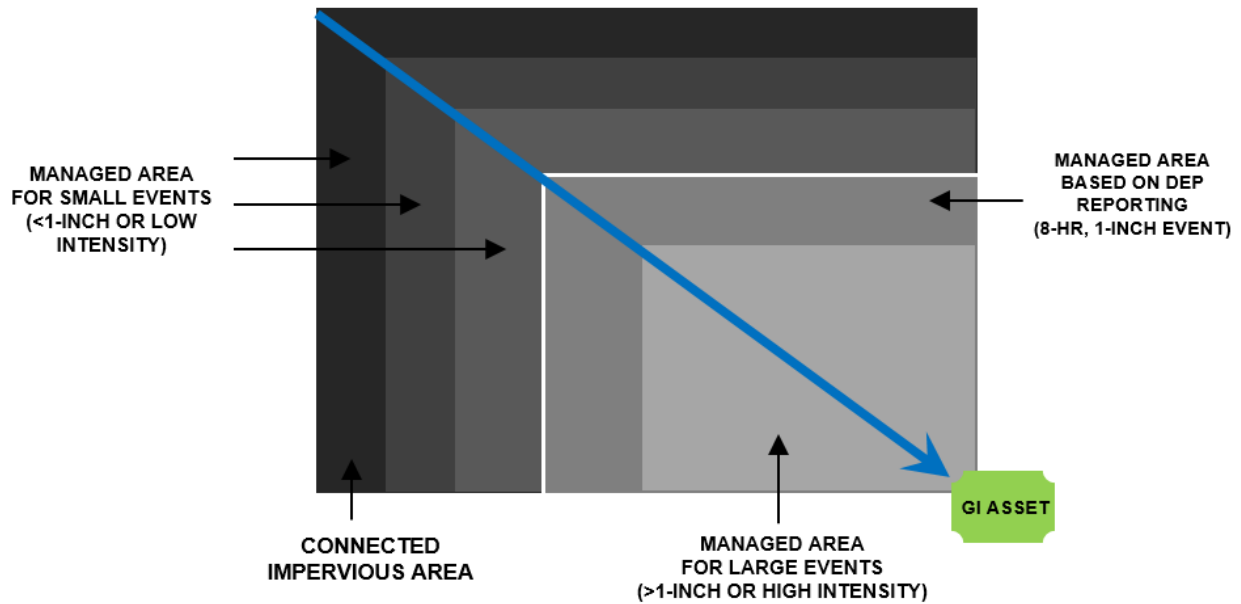


Figure 4-4. Schematic of Connected vs. Managed Impervious Area for GI Assets

As shown in Figure 4-5, each individual constructed or planned ROWB is represented in the model using the ROWB model representation developed and validated under the microscale modeling evaluations (refer to Section 4.3).

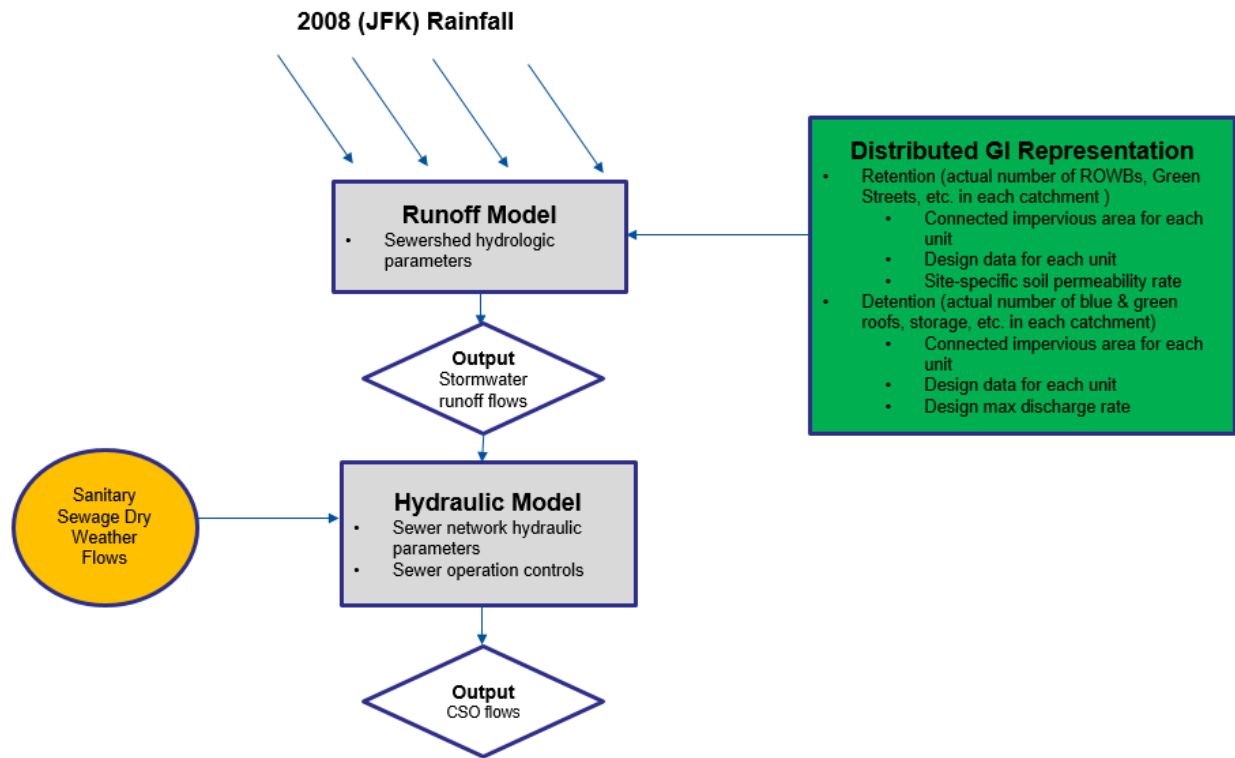


Figure 4-5. Flow Chart of the Distributed Modeling Approach in InfoWorks

The model representations for various GI technologies were consolidated as follows:

- ROWBs, SGSs, and rain gardens were modeled as retention systems with both evaporation and infiltration as illustrated in Figure 4.2.
- Permeable pavements were modeled as retention systems with infiltration only.
- Blue roofs, green roofs, and detention storage were modeled as detention systems with the assumption that they would manage one inch of rainfall.¹³

These modeling representations were similar to those observed in literature reviews and peer utility surveys.

For the additional GI to be constructed in the 1.5% implementation scenario for which existing data is not available in *GreenHUB*, the assets were modeled as standard ROWBs with the average dimensions of 5'x15', which represent the average ROWB surface area size in *GreenHUB*. These ROWBs were distributed among combined sewer subcatchments and were assigned connected area based on the average connected estimated from the GIS analysis of the built and designed GI assets. Infiltration rates were assigned based on the average values for nearby constructed ROWBs.

4.5 Lumped Modeling Approach for the 10% Implementation Rate

To estimate CSO reduction for the future 10% GI implementation Citywide within CS areas, DEP maintained the distributed model for the 1.5% implementation and used the LTCP “lumped” approach for the remaining 8.5%. This is because the exact types and locations of these future assets are not available. Assumptions for retention GI are based on units sized to capture one inch of stormwater volume from the tributary impervious areas, which is determined based on the amount of impervious area that drains to a given waterbody. Assumptions for detention units are based on maintaining discharge flows from the tributary impervious areas in accordance with the 2012 performance standard. The retention and detention GI units were then apportioned across the model subcatchments that discharge to CSO outfalls and are represented using the lumped modeling approach. A schematic of the flow chart used for the lumped approach used in the InfoWorks modeling approach is presented in Figure 4-6.

¹³ DEP will monitor green roofs as part of the GI-RD project that will eventually inform the selection of performance-based green roof designs for stormwater management for NYC and evaluate the retention characteristics under various conditions.

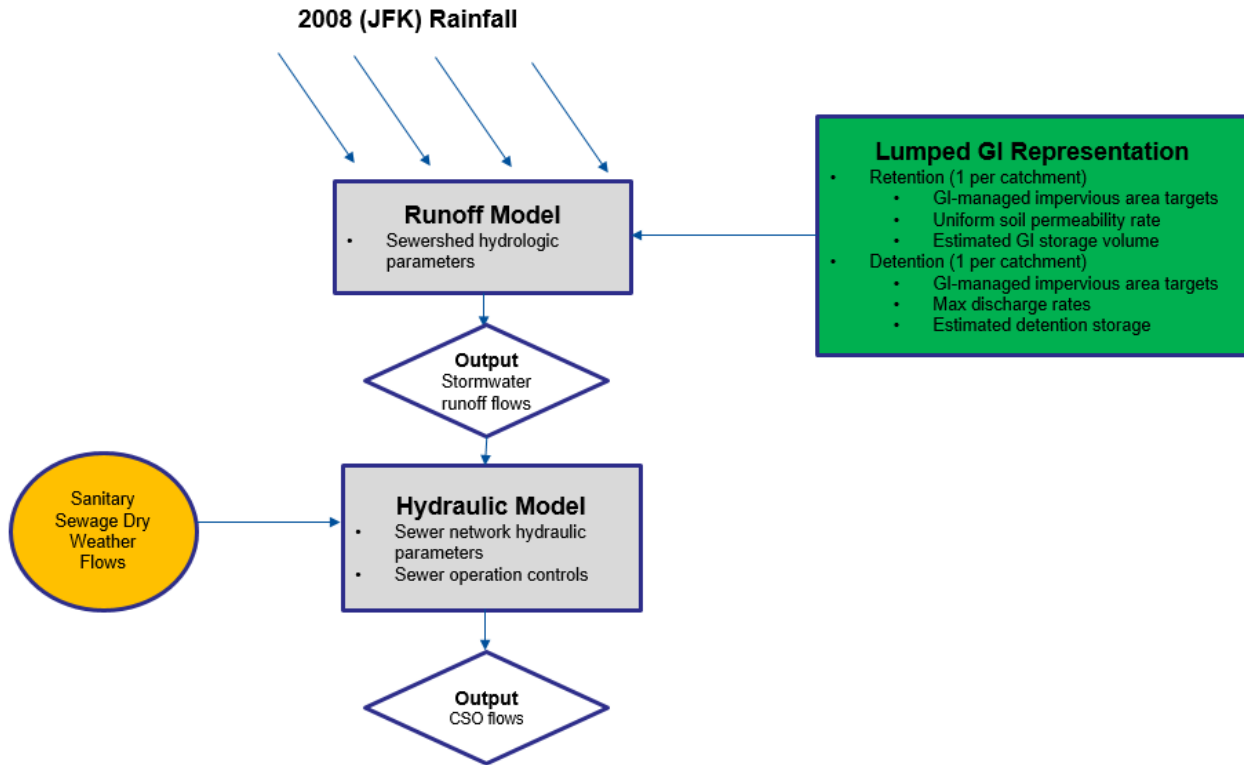


Figure 4-6. Flow Chart of the Lumped Modeling Approach in InfoWorks

5 GREEN INFRASTRUCTURE PERFORMANCE MODELING AND EVALUATION OF RESULTS

5.1 Establishing Baseline Conditions

Eleven InfoWorks Collection System models for twelve wastewater treatment plants (WWTPs) service areas with combined sewers are currently used by DEP for LTCP development and were used for establishing the stormwater runoff volume and CSO volume baseline conditions without GI implementation. To establish this baseline, LTCP models as of December 2015 were utilized with the following key parameters kept unchanged for the consistency purposes with the LTCP evaluations:

- Combined sewer system hydraulic representation for all combined sewer piping, pump stations, regulators, outfalls, etc.
- 2040 Dry weather (sanitary) flows
- 2008 John F. Kennedy International Airport rainfall data (JFK, 2008) that represents the average hydrologic year adapted by DEP for LTCP and other water quality studies
- Corresponding tides at all outfall locations
- Corresponding monthly evapotranspiration values
- All committed consent order grey projects that were included in the LTCP baseline. These have been previously referred to as Cost Effective Grey projects, as detailed in Appendix A of the Order.

To create the “Baseline without GI”, the hydrologic representation in the baseline LTCP models was modified by eliminating all GI practices. The baseline models without GI form the starting points for performance metrics reporting efforts described here

The baseline without GI values for total impervious acreage within the combined sewer tributary area, and the annual stormwater runoff volumes that enter the combined sewer system during the typical year, and the annual CSO discharge volumes during the typical year precipitation are presented in Tables 5-1 and 5-2 together with the 1.5% GI and 10% GI performance results, respectively. The stormwater runoff volume is an output from the hydrologic module of the model and represents the amount of stormwater that enters the CS system via nodes (manholes). CSO discharge is an output from the hydraulic module of the model and represents the volume of CSO discharge via the outfall pipes.

5.2 1.5% GI Implementation Performance

Once the stormwater runoff and CSO discharge volume baselines were established, the modeling simulation for adding the 1.5% GI implementation rates was completed, giving DEP the volume of stormwater runoff captured by GI and the resulting CSO discharge reductions from the implementation rates for the 1.5% implementation rate. The 1.5% GI modeling results estimate annual CSO reduction of 507 MG or 2.4% Citywide as shown in Table 5-1.

Table 5-1. 1.5% GI Implementation Modeling Results

Waterbody	Impervious Area (Ac)			Stormwater Runoff Volume (MG/yr)			CSO Volume (MG/yr)		
	Total Impervious Area	Managed Area	% Imp. Area Managed	Baseline	Volume Reduction	% Reduction	Baseline	Volume Reduction	% Reduction
TOTAL CITYWIDE	78,749	1,182	1.5%	59,035	1,084	1.8%	20,806	507	2.4%

The equivalency rates presented here are based on known GI assets and it is anticipated that future implementation will utilize more diverse tools for various circumstances; as a result, DEP plans to update these rates as the GI Program unfolds. As stated above, the first 1.5% implementation rate relied almost entirely on the ROWB installations. Therefore these equivalency rates are reflective of a ROW GI implementation program. They are not representative of the future implementation that will include more detention projects as feasible retention opportunities become scarcer.

Table 5-2. 1.5% GI Implementation Stormwater Capture to CSO Reduction Equivalency Rate

Waterbody	Stormwater Runoff Reduction (MG/yr)	CSO Volume Reduction (MG/yr)	Stormwater Capture to CSO Reduction Ratio (MG/MG)
TOTAL CITYWIDE	1,084	507	2.1

Given the above, the “stormwater capture to CSO reduction” ratio equivalency rate for the 1.5% implementation rate is equal to 2.1 MG/MG Citywide as shown in Table 5-2. GI spatial variation greatly impacts this metric due to the individual hydrologic and sewer hydraulic conditions in each tributary area where GI has or will be installed. Additionally, the annual stormwater runoff reduction is not applicable for detention-based GI because detention assets only delays stormwater from entering the CSS and does not prevent it from entering the CSS. Therefore, this equivalency rate will not be representative of future GI performance that that accounts for detention assets.

Table 5-3. 1.5% GI Implementation MG of CSO Eliminated on an Annual Basis per Acre of Impervious Area Managed by GI

Waterbody	Impervious Area Managed (Ac)	CSO Volume Reduction (MG/yr)	CSO Reduction per Managed Impervious Acre Equivalency Rate (MG/Ac)
TOTAL CITYWIDE	1,182	507	0.4

The equivalency rate of “MG of CSO eliminated on an annual basis per acre of impervious area managed by GI” presented in Table 5-3 is equal to 0.4 MG/Ac Citywide. This equivalency rate is also dependent upon individual hydrologic and sewer hydraulic conditions, GI type and soil

permeability in each tributary area. This metric is based on acres managed using ROWB assets, which are retention assets. Therefore this metric will be affected by diversifying future GI tools, specifically using detention assets, and the application rates at which future GI will be installed.

5.3 10% Green Infrastructure Implementation Performance

The 10% implementation rate was modeled using the distributed model representations for all GI assets included in the 1.5% implementation rate, and used LTCP lumped representations only for the remaining 8.5% representing future GI assets.

Table 5-4. 10% GI Implementation Modeling Results

Waterbody	Impervious Area (Acres)			CSO Volume (MG/yr)		
	Total Impervious Area	Managed Area	% Imp. Area Managed	Baseline	Volume Reduction	% Reduction
TOTAL CITYWIDE	78,749	7,875	10.0%	20,806	1,677	8.1%

As noted earlier, the GI program is evolving by utilizing new tools and incorporating lessons learned that will result in programmatic course corrections as part of the adaptive management principles. While anticipating these changes, Table 5-4 provides an estimated annual CSO volume reduction associated with the 10% GI implementation rate. The assumptions included for the 10% rate maintained the GI implementation rates included in submitted LTCPs. For the East River and Open Waters, where the vast majority of waterbodies meet water quality standards, DEP assumed that detention assets would manage the majority of impervious acres with limited retention opportunities. The 10% GI modeling results estimate annual CSO reduction of 1,677 MG or 8.1% Citywide. Future LTCPs will continue to assume GI implementation as part of the baseline scenario for each waterbody respectively.

6 ADDITIONAL GREEN INFRASTRUCTURE MONITORING

Additional performance monitoring work is planned over the next five years as a part of the GI-RD project and will provide field-collected data for further documenting GI performance and improving modeling representation. This significant undertaking will create inputs for evaluating GI life cycle costs, volumetric stormwater runoff and CSO reduction performance and co-benefits. The work will be used to compare GI to traditional grey infrastructure options, incorporate the real cost of maintenance into financial consideration.

The monitoring program will advance the role of co-benefits in decision making by improving upon the processes and business rules of consideration of co-benefits in new projects, which may or may not include the entire list below. Co-benefits extend beyond the volumetric metrics commonly used to assess effective stormwater management to recognize broader environmental, social, and economic benefits. Co-benefits include but are not limited to the following:

- **Carbon Sequestration:** Refers to the process of plants growing and storing carbon-containing biomass in their plant structure or in the soil. GI introduces new vegetation and absorbs CO₂ from the atmosphere.
- **Urban Heat Island Mitigation:** The urban heat island effect is a phenomenon where urban surfaces capture significant amounts of heat, raising urban air temperatures, which during the summer increases energy costs for cooling and increases the rate of heat-related stress, illness and even death. This effect can be mitigated by using vegetation and other surfaces that reflect more solar radiation.
- **Reduced Building Energy Demand:** In addition to reducing the urban heat island effect, urban trees can reduce cooling needs during the summer through direct shading and green roofs can reduce heating and cooling by increasing roof insulation. This decrease in cooling and heating demands results in reduced building energy use.
- **Urban Habitat:** GI has the potential to support biodiversity by providing foraging and potential nesting habitat for pollinators and other beneficial wildlife within the urban environment.
- **Air Quality:** Through natural respiration processes, vegetation in GI physically and chemically removes pollutants from the air.
- **Quality of Life:** GI, when implemented with easy public access and in areas with scarce existing vegetation, provides significant community benefits which can be reflected in increased property values, crime mitigation, and enhancement of the public's health and psychological state.
- **Reduced Stormwater Treatment Needs:** By retaining runoff during a typical storm event and preventing it from reaching the wastewater treatment facility, costs associated with electricity and chemicals for treatment are avoided.
- **Green Jobs:** Implementation of GI has the potential to create new job opportunities or sustain existing jobs, especially in the operation and maintenance fields for workers who may otherwise be unemployed or underemployed. This can be particularly important for socially and economically disadvantaged neighborhoods within the City.

6.1 Future Refinements

As noted above, future GI performance monitoring activities conducted under the GI-RD project will provide additional information for better understanding of GI performance and further refinement of GI modeling representation. These additional refinements may include:

- Distributed representation of additional GI technologies (e.g., green roofs, permeable pavement, etc.)
- Better quantification of horizontal infiltration
- GI practice inlet control representation
- Distributed representation of private detention and retention projects
- Co-benefits quantification as described above
- Reductions in pollutant loads based on water quality data collected at individual assets

For performance related updates, DEP will eventually incorporate results from the GI-RD monitoring into the GI design standards and other working assumptions about performance. The monitoring work will begin this summer and extend over a five-year period. The current version of the Monitoring Protocol is included as Appendix E as a reference. Note that the Protocol is a working document and will be updated regularly throughout the five-year period.

7 SUMMARY OF CONCLUSIONS

In order to document GI performance metrics and establish equivalency rates required by the Order, DEP undertook a number of steps to identify the best, most appropriate GI modeling practices and validate the selected modeling approaches using available monitoring data and the GI assets tracked in *GreenHUB*. The key conclusions are discussed below.

- Due to the prevalence of ROWBs constructed by DEP, the majority of the modeling effort for this report was focused on developing an accurate representation of this type of GI in the model to estimate its performance.
- Literature review and utility survey activities confirmed that the lumped modeling approach currently used by DEP for LTCP evaluations is comparable to those used by other peer municipalities. DEP retained this approach for modeling a representation of all future GI assets for the 10% GI implementation. The 10% GI models continued using distributed model representations for all GI units already included into the first 1.5% milestone and used lumped representations only for the remaining 8.5% representing future GI assets.
- The literature review and survey of peer utilities indicated that as utilities progress from high-level planning to detailed design and performance evaluation, distributed GI modeling representation becomes more prevalent.
- Microscale modeling evaluations performed under this study using the 2014 Demo Area monitoring data collected by DEP allowed for the development and validation of a ROWB representation for distributed GI Modeling approach in the LTCP InfoWorks models. The wealth of design and site specific information for the constructed, and planned GI assets available from the *GreenHUB* database allowed for a detailed representation of ROWBs in a distributed GI model for the 1.5% GI implementation rate.
- Using the distributed approach, the 1.5% GI modeling results estimate annual CSO reduction of 507 MG or 2.4% Citywide.
- While the Order intended the equivalency rates to be used as a tool to project CSO reductions at the 4% and 7% implementation rates, the Program has unfolded in a way that it is now inaccurate for the equivalency rates based on the 1.5% to be used in that manner. These rates are representative of performance of a specific GI asset (the ROWB) applied in specific locations that will not likely be utilized to achieve the full 10%. DEP will continue to work toward developing more tools for a variety of locations and conditions. All of the assets' specific information will continue to be stored in *GreenHUB* allowing DEP to revise and update the metrics and equivalency rates for future milestones.
- For the 10% GI scenario, the modeling results estimated an annual CSO reduction of 1,677 MG (8.1%) Citywide. These represent high-level estimates for CSO reductions consistent with the ongoing LTCP efforts. Future assets that will make up the 10% target may include both ROW GI and public/private on-site projects to the extent that they are feasible, cost effective, and expected to positively benefit water quality.