NYLCVEF: Background paper on NYC's Green Infrastructure Program
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EXECUTIVE SUMMARY

New York City (NYC or City) receives 43-50 inches of precipitation annually, at a relatively constant rate from month to month. Since the founding of the City in 1624, 72 percent of the natural surfaces of Manhattan, Queens, Brooklyn, the Bronx, and Staten Island have gradually been covered with artificial, impervious surfaces such as asphalt, concrete, brick, stone, and compacted urban soils. Unlike natural surfaces such as vegetation and soil, these impervious surfaces do not permit water to percolate through them, or absorb moisture for later evaporation. In areas of NYC served by combined sewer systems (60% of the metropolitan area), the single pipe collecting both sanitary waste and stormwater runoff can be overwhelmed if rain falls at the rate 0.1 inches per hour or 0.4 inches over a day[1].

During these events (Combined Sewer Overflows or CSOs), the runoff produced by impervious surfaces can exceed the capacity of a combined sewer system to collect and transport stormwater and sanitary water to the wastewater treatment facility. The combined wastewater either backs-up in the City's sewer system or moves directly into adjacent water bodies, lowering water quality and violating federal Clean Water Act requirements. In these combined sewer areas, the amount of impervious surface area thus contributes directly to local flooding, the magnitude of CSOs, and the illegal transport of raw sewage to local waters. It is estimated an excess of 27 billion gallons of raw sewage and untreated stormwater are discharged each year into New York harbor from 460 CSO outfall pipes[1].

To address this problem, in 2005 NYC received a consent order from New York State to control the amount of stormwater generated by 1 inch of rainfall on 10% of the existing impervious area within the combined sewer watershed by December 31, 2030. Currently, the New York City Department of Environmental Protection (DEP) is constructing green infrastructure with the goal of achieving the first consent order milestone of managing 1 inch of rainfall from 1.5% of impervious area served by the combined sewer system by December 31, 2015. However, this interim goal is unlikely to be met, and the City has planned to commit $192 million in public funds to green infrastructure improvements, mainly in the form of right of way (ROW) bioswales. Green infrastructure may be more cost-effective than grey infrastructure upgrades alone, and have co-benefits such as improving air quality and urban aesthetics while reducing the urban heat island effect on local climate. However, more aggressive and comprehensive green infrastructure approaches may be required to adequately bring NYC towards compliance. Since the release of the Green infrastructure plan in 2010, 30+ source control projects constructed by NYC have indicated that although local site conditions (the ratio of green infrastructure area to drainage area and topography) can reduce their effectiveness, ROW projects will capture most of the local runoff from 1-inch rainfall events (the majority of NYC storms).

[1] NYC Department of Environmental Protection (DEP) Jamaica Bay Watershed Protection Plan.

These early research efforts support the City's long-term plan to invest $1.5 billion in public infrastructure supported by $900 million in private sector upgrades and targeted green infrastructure installations over the next 20 years. Nearly twice that amount, $2.9 billion, is expected to fund cost-effective grey infrastructure upgrades. Although the first milestone (1.5% conversion by 2015) appears out of reach, progress in refining and adapting green infrastructure technologies to NYC's unique landscape is apparent and will likely lead to future milestones being met.

This paper addresses the following questions:

Is the NYC Green Infrastructure Plan[2] achieving its aims?	**Mixed answer (Yes and No).** **By completing construction of three pilot demonstration areas, NYC has met green infrastructure milestones of the 2012 consent order. However, NYC is unlikely to manage runoff produced by 1.5% of the impervious area in CSO tributaries to pervious surfaces by 2015.**
Is NYC green infrastructure having an impact on CSO volume?	**Too soon to tell.** **Modeling results provided by NYC indicate a 4% increase in wet-weather capture between 2010 and 2012. However, grey infrastructure upgrades in 2011 may account for this. Between 1985 and 2000, NYC reduced CSOs annual volume 88% from 109 billion to 23 billion gallons per year with grey infrastructure upgrades. Between 2010 and 2013, NYC only built 50 acres of green infrastructure, a long way from the 2015 goal of 1,181 acres. Much more green infrastructure is needed before significant results may be seen.**
Should the NYC green infrastructure program be expanded citywide as a way of managing CSOs?	**Definitely.** **Relative to other cities, NYC has pursued a larger range of initiatives (private incentives, public guidance, dedicated funding, etc.), but has yet to frame green infrastructure as an effective tool reducing the myriad adverse effects of CSOs (flooding, decreased water quality, erosion). To expand green infrastructure more broadly, NYC should develop more robust private incentives, expand public guidance programs, and dedicate more funding**.

[2] NYCDEP Green Infrastructure Plan and Annual reports available at: http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml

Should green infrastructure be expanded as a flood management and climate resiliency tool?	**Yes.** **Solutions for climate resiliency should incorporate current green infrastructure technologies that can reduce the impact of CSOs and more effectively drain floodwaters. Green infrastructure can be used as a demonstration of the benefits of building a more resilient city. Incorporation of proven technologies and development of new, green technologies is the best way to adapt NYC to a warmer, wetter climate.**

To ensure the goals will be achieved, the researcher recommends the following actions:

- Expand the green infrastructure (GI) program to the whole city, not just CSO areas.
  - The regulatory framework for GI in NYC is governed by quality of NYC waters. Only addressing the problem of CSOs within certain areas of the city will meet the technical guidelines required by the consent order, but water quality will be most improved by the NYC adopting a comprehensive approach.
  - The City should use the opportunity presented by the expanded construction of ROW bioswales, updating of the InfoWorks Model, and broadening of the Harbor Survey Program to obtain better baseline data on the impact of GI city-wide.
  - These results should then be used to support citywide expansion of the GI program, allowing maximization of ancillary benefits, public support, and reduction of CSO volume and the impact of future storm surges predicted by global climate change models.
  - NYC should use the opportunity presented by the recently revised Municipal Separate Storm Sewer Systems (MS4) permit from the NYS Department of Environmental Conservation (DEC) and the required Stormwater Management Program Plan (SWMP) to integrate a focus on water quality with implementation of green infrastructure.
  - Combine contaminated site cleanup and GI approaches. Contaminated site remediation, such as Superfund sites or Brownfields, may be able to utilize GI to manage their stormwater footprint and possibly go beyond traditional GI to treat a CSO.
- Incentives for green infrastructure (GI) development on private property.
  - Overall, the City needs greater incentives. In other cities where this approach has been used, the potential savings are greater and the scope is larger. Incentives that shift public behavior on such a scale also need to be more publicized and simpler to understand.
  - Explore scalable, private-property retrofit incentive programs like Seattle or Philadelphia. These programs have been very successful at increasing participation.
  - Set value targets for new development or re-development projects that will drive developers to greater adoption of GI. Set similar interagency stormwater standards (e.g.: Department of Transportation road projects, NYC Department of Parks and Recreation capital projects, schools, etc.)

    - Perform cost-benefit analysis of a stormwater-fee based incentive program to encourage property owners to convert a certain percentage of their property to GI.

- Research & Development.
    - Encourage development and testing of advanced GI technologies for storage, retention, and treatment of CSOs. (e.g. constructed treatment wetlands at end-of-pipe)
    - Explore the role of GI to create a more resilient NYC: minimize storm impacts; improve water quality to create healthier coastal ecosystems that have natural resiliency; and implement innovative projects that combine CSO treatment with stormwater retention.
    - Develop metrics for linking impact of GI on CSO volume (by outfall) and key parameters of water quality (biological oxygen demand, fecal coliform, etc.) This will enable the city to better adapt the scale and type of local GI to support federally required water standards in local waterways.
- Public education & awareness.
    - Institutionalize and streamline access to monitoring and hydraulic performance data generated from pilot monitoring studies and demonstration projects (this will enable non-profit and academic stakeholders to gather the necessary data for the below steps).
    - Launch a public campaign highlighting the potential savings to the community in taxes supporting infrastructure damaged by CSO events.
    - Expand the number of demonstration areas – Philadelphia, for example, built 12. NYC has three demonstration areas. The city should consider demonstration areas that also highlight the integration of these technologies with improved water quality, such as projects that return native flora and fauna to impacted areas such as the Gowanus Canal, with improved water quality due to GI.
    - The limited impact of the Green infrastructure Grant program is likely due to barriers to entry for less well-funded parties (private, public, and NGO). DEP could lower this barrier by reducing upfront costs and developing a second, more streamlined track for applicants with smaller projects.
    - Create more GI research partnerships with local educational institutions.

BACKGROUND

Underlying geology and soils:
New York City's surficial environment mostly reflects the impact of glaciation during the last ice age. The deposits left after glaciers retreated can be broadly classified as till and outwash. Till is unconsolidated sediment comprised of large and small-sized grains while outwash is smaller, more stratified sediment. Till is found throughout Manhattan and is underlain by bedrock. In the north of Manhattan and the Bronx, till gives way to exposed and shallow bedrock. According to the New York City Soil Survey[3] 20% of

[3] Natural Resources Conservation Service (NRCS) New York City Soil and Water Conservation District

Manhattan soils are till, while 80% is pavement and asphalt. Rapid urbanization and long history of industrialization have converted much of the NYC watershed into impervious surfaces. Although till has low stormwater infiltration rates which can limit the types of infiltration-based stormwater projects, other types of green infrastructure projects are feasible[4].

Anthropogenic modification

Prior to Dutch settlement of NYC only exposed outcrops of granite and schist were impervious to rainfall and surface flows. In the 400+ years of increasing urbanization in NYC, impervious surfaces such as asphalt, brick, pavement and stone have come to dominate the landscape. This is significant because these surfaces do not allow rainfall to percolate into local soils. Significant rain events create runoff, which combines with contaminants and toxic by-products from industrial and human activity. The resulting mix of water, chemicals, human and animal waste products, and excess nutrients flows downslope toward New York waterways.

NYC sewer infrastructure

Historically, a portion of NYC's sewers ("grey" infrastructure) was designed as a combined sewer system (CSS) that would convey sanitary wastewater and stormwater runoff to wastewater treatment plants (WWTP), where the water would be treated before being discharged into the surrounding waters. This was thought to be beneficial because for the cost of installing one sewer pipe, both sanitary waste and contaminated stormwater would be treated. However, WWTPs are currently unable to handle flows that are more than twice design capacity. When this occurs, a mix of excess stormwater and untreated wastewater discharges directly into the city's waterways at certain outfalls. This is called a combined sewer overflow (CSO). Since 60% of NYC is served by combined sewers, CSOs are possible throughout most of the City. CSOs are most likely when rain falls in excess of 0.4 inches during a single day in sections of the City where homes and businesses are served by a single, combined sewer. On average, CSOs occur once a week throughout the year. Grey infrastructure typically refers to "end-of-pipe" controls on excess surface runoff. Examples of grey infrastructure are floatables control, retention tanks, bending weirs, or sewer modifications that manage flow. This flow generally directs sanitary waste toward wastewater treatment plants. Grey infrastructure offers the benefit of treating influent water, storm or waste, before discharging the effluent to the surrounding waterways.

Objectives of this paper

NYC and the New York League of Conservation Voters are concerned about CSOs because of their effect on water quality. The New York City Bureau of Water Treatment (BWT) within the Department of Environmental Protection (DEP) have made impressive gains in the management of CSO since the 1980s – reducing the annual discharge volume from 33 billion gallons per year (bgy) in 1994 to 25 bgy in 2000 and approximately the same today. Reported CSO annual volume was as high as 43 bgy in 1985,

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[4] United States Environmental Protection Agency (EPA) Office of Water website. http://water.epa.gov/infrastructure/greeninfrastructure/gi_barrier.cfm

suggesting that while recent grey infrastructure upgrades and new construction have maintained earlier gains, further improvement will require substantial investment in grey infrastructure or a new strategy, such as a combination of grey and green infrastructure.

What is Green Infrastructure?

Green Infrastructure (GI) refers to a set of technologies designed to increase the infiltration rate, detention, and treatment of stormwater. GI uses gravel, soils, vegetation, and natural processes to reduce urban runoff and improve the health of urban environments. At different scales, GI can refer to different processes. At the larger scale of the city or county, integrated natural areas with urban development can provide habitat for wildlife, protection from floods, as well as improved air and water quality. At more local scales – such as neighborhoods, green infrastructure usually refers to improved management of stormwater by absorbing and storing excess stormwater.

Green Infrastructure in Other Cities

The impetus for GI projects across the country was the revision of the Clean Water Act in 1987 by Congress. In this revision, Municipal Separate Stormwater Systems (MS4) were redefined as "point sources" of water pollution, which made cities subject to requirements for a discharge permit. Although the concept of "green" Infrastructure has been used since 1994 in various state, federal, and private publications, its application to stormwater management has been specifically promoted by the U.S. Environmental Protection Agency (EPA) as part of a "Low Impact Design" (LID) approach to management of stormwater since 2007[5]. However, prior to that, the use of GI has been prevalent in many cities since the early 1990s. It is important to note that "green infrastructure" can refer to a wide range of technologies. The term can refer to anything from rain gardens, to artificially constructed wetlands (such as the Harbor Brook treatment wetland in Onondaga County, Syracuse, NY[6]), to incorporating existing wetlands and riparian systems into stormwater management plans for urban watersheds. Another motivation for GI is the potential for cost savings relative to grey infrastructure. Although upfront construction costs can be higher for GI, maintenance costs are generally lower over the long term, and co-benefits (if properly quantified) can further improve marginal savings.

One city that has been an early adopter and promoter of GI is Philadelphia. Philadelphia has been recognized by the Natural Resources Defense Council (NRDC) as having the most extensive and successful GI program in the country. One of the ways Philadelphia achieved this status was through early adoption of strict standards for new development. In 2006, Philadelphia required the first inch of rainfall onsite to be managed in all new development and redevelopment projects (of at least 15,000 sq ft). To complement this centralized, regulatory approach, in 2010 Philadelphia added an innovative, phased, "carrot and stick" incentive program that (over four years) combined stiff stormwater fees (the

[5] A Short History of the Term Green Infrastructure and Selected Literature, by Karen Firehock (January 2010).

[6] Save the Rain Project Fact Sheet: Onondaga County Executive, 12/27/12.

stick) with generous credits for the implementation of GI projects, including technical guidance and financial assistance (the carrot)[7].

A key aspect of the program was the potential for complete mitigation of the stormwater fee (100% rebate), and the shift from a fee based on the water meter reading to the size of impervious area on-site. The direct proportionality of the fee, free technical assistance from city agencies, and a low-interest loan program to support conversion combined to make the program popular and successful. Other cities, such as Seattle and NYC, have also developed fee-based systems for incentivizing green retrofits to private property. Unlike Philadelphia, the Seattle stormwater fee is for non-residential properties only and NYC's new stormwater release standard (outlined in greater detail below) applies mainly to larger (>5,000 sq ft) properties and does not explicitly incorporate GI.

In Washington, DC, one of the main lessons learned is that intensive GI programs are more likely to achieve significant results than a "moderate greening scenario[8]." The EPA funded a modeling study to examine the impact of trees and green roofs on stormwater runoff in the Washington, DC area. They discovered that during an average year, an intensive green infrastructure program could prevent over 1.2 billion gallons of stormwater from entering the sewer systems, resulting in a reduction of over 1 billion gallons in discharges to local rivers. This scenario required installing 55 million square feet of green roofs in the Combined Sewer System (CSS) area, but such an investment would potentially reduce CSO discharges by 435 million gallons, or 19%, each year. The models further indicated savings of $1.4 and $5.1 million per year in maintenance costs for grey infrastructure could be realized by moderate and intensive GI strategies (respectively). This result suggests an intensive GI program may prove less costly over the long run.

Other municipalities, such as Syracuse, NY, also provide a useful example of the impact community activism and involvement can have on the pace and scope of GI. In 1998, the county in which Syracuse is located, Onondaga, received an order to reduce CSOs and originally adopted a "grey infrastructure" approach. The county spent $300 million on four regional treatment facilities (RTFs) but local opposition to siting of the RTFs led the county to develop a GI approach as well. This led to a "Green Improvement Fund" (which distributes up to $200K per applicant), a pledge to produce 50 GI projects in one year, and construction of a 60,000 ft^2 green roof on the Onondaga County Convention Center, one of the largest green roofs in the Northeast. These examples highlight how community involvement and publically-pledged support for GI by civil authorities can lead to larger-scale GI projects and improvements in CSO reduction.

Stimulus for NYC to Pursue "Green Strategy" to Reduce CSOs

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[7] Rooftops to Rivers II: Green Strategies for Controlling Runoff and Combined Sewer Overflows. NRDC
[8] The Green Build-out Model: Quantifying the Stormwater Management Benefits of Trees and Green Roofs in Washington, DC. Casey Trees: Barbara Deutsch, ASLA, ISA, Senior Director, Principal Investigator, Heather Whitlow, Director, Planning and Design and LimnoTech Michael Sullivan, Vice President Anouk Savineau, PE.

According to the New York City Soil Survey[9] 20% of Manhattan soils are till, while 80% is pavement and asphalt. A long history of urbanization and industrialization have converted much of NYC's land cover to impervious surfaces. These surfaces (such as asphalt, brick, pavement and stone) do not allow rainfall to percolate into local soils. This creates runoff, which combines with organic and inorganic contaminants as it flows to downslope towards New York waterways. When rain falls in excess of 0.4 inches during a single day, sections of the city where homes and businesses are served by a single, combined sewer (merging both sanitary and stormwater pipes), may experience a CSO.

In the 60% of NYC served by combined sewers, sufficient rainfall may cause CSOs (on average) once a week throughout the year. The root causes of CSOs in the five boroughs are the broad extent of impervious surfaces in NYC and the increasing burden on city sanitary infrastructure due to population growth. These factors, along with increased precipitation due to climate change, result in more than 27 billion gallons of raw sewage and polluted stormwater discharging from 460 CSO outfall pipes into New York Harbor annually. These discharges render the City in violation of the Clean Water Act, since CSOs are treated as point sources of pollution and are thus subject to National Pollutant Discharge Elimination System (NPDES) permit requirements.

Consent Order

In 2005, the EPA found NYC in violation of the Clean Water Act and ordered NYC to improve water quality by reducing CSO discharge. The resulting consent order (enforced by DEC and superseding previous orders in 1992 and 1996) was intended to force the city to reduce CSO discharge – with the expected effect of improving water quality of local waters. Under the 2005 order, the DEP was tasked to develop a strategy to manage CSOs in the form of Long-Term Control Plans (LTCP) and Waterbody/Watershed Facility Plans. In addition, over 20 years, $1.5 billion was to be allotted for public projects and $900 million planned for private projects. In 2011/2012, the DEC and the DEP identified modifications to the consent order, incorporating GI and more cost-effective grey infrastructure, and fixing dates for LTCPs. Critically, the updated NYC Green Infrastructure Plan is thus a hybrid of "green" and "grey" technologies. The NYC Green Infrastructure Plan[10] was expected to reach the following milestones in application:

- Management of 1 inch of rainfall on 1.5% of combined sewer watershed by 2015
- Management of 1 inch of rainfall on 4.0% of combined sewer watershed by 2020
- Management of 1 inch of rainfall on 7.0% of combined sewer watershed by 2025

These metrics are cumulative and support the ultimate goal of managing 1 inch of runoff from 10% of impervious surfaces within combined sewer-served areas in NYC by the year 2030. The specific timeline of the milestones imply an increase in the efficiency of green infrastructure development over time. The

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[9] New York City Soil Survey.
[10]NYC Green Infrastructure Plan. 2010. http://www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_LowRes.pdf

increment of percent managed per year increases from 2.5% for 5 years between 2015-2020 to 3% between 2020-2025 and 2025 and 2030.

Analysis of NYC Green Infrastructure Plan - Critical Review of Goals and Objectives

In 2007 NYC launched PlaNYC, an unprecedented plan with 127 initiatives to create a greener, more resilient New York able to adapt to global climate change. The goal of the plan was to reclaim NYC's waterways by "greening our streets, planting trees and expanding our Bluebelt network" and "upgrading our wastewater treatment infrastructure." A year later, In the Sustainable Stormwater Management Plan of 2008, GI was specifically recommended on the basis of cost, especially when compared to CSO storage tunnels.

Cost-effective, targeted grey infrastructure upgrades were projected to reduce CSO volume at the cost of $0.36 per gallon, new grey infrastructure construction (specifically retention tanks and tunnels), were expected to cost more than $2.00 per gallon, while GI costs were projected to range from $1.00-2.00 per gallon. Thus, on a cost-benefit basis, the 2010 NYC Green Infrastructure Plan was developed with a combination of GI and "targeted" grey infrastructure projects. When co-benefits to property values were included, this approach was preferable to costlier, larger new grey infrastructure programs.

The first listed objective of the 2010 Green Infrastructure Plan was to reduce CSO volume by 3.8 billion gallons per year (bgy). This figure was also specifically compared to possible reduction via a strictly grey infrastructure strategy, which would only reduce CSO volume by 1.8 bgy. The second objective listed was to capture or detain the first inch of rainfall on 10% of the area of impervious surface watersheds in the five boroughs served by combined sewers. If achieved, this objective was expected to reduce CSO volume loading by 1.5 bgy.

To achieve these objectives, the DEP examined the surfaces of existing NYC CSO areas and found opportunities for GI development in 52% of the watershed. In the remaining CSO area, stormwater retrofits were deemed too expensive or difficult to build. This land was characterized as "other development" which, although not specifically characterized, comprised the greatest (at 48%) of the possible area available for green infrastructure upgrades. The specific upgrades mentioned were:

1) Green roofs (through tax credits and direct construction)
2) Stormwater sewer charges
3) Physical surface/subsurface detention (rain barrels/cisterns)
4) Bioretention (rain gardens, swales, enhanced tree pits, Greenstreets)
5) Permeable pavement.

Sidewalks and streets comprised the next largest percentage of surface area available (26.6%) for GI development – with swales, tree pits, Greenstreets, and permeable pavement listed again as appropriate technologies for reducing CSO runoff. Parks comprised 11.6% of the available area in NYC, and in addition to swales and permeable pavement, could also potentially use engineered treatment wetlands to help manage CSO runoff. Of note, the initial focus seemed to be green roofs despite the greater logistical, engineering, and permitting factors involved relative to existing programs such as Greenstreets and Bluebelts.

Cost-effective grey infrastructure investments were also planned and executed by the DEP. $2.9 billion was allocated for targeted grey infrastructure upgrades and construction to reduce CSOs at a cost of $0.36 per gallon. Further optimization of existing grey infrastructure was to be accomplished through surveys of tide gates, interceptor sewers, lateral collection sewers, and inflow and infiltration rates for local soils. The DEP anticipated these measures would reduce CSOs by approximately 586 million gallons per year (mgy). The 2010 Green Infrastructure Plan also mentioned the reduction of sanitary wastewater from individual household use as an optimization strategy for the existing wastewater treatment system that was potentially as effective as GI upgrades and could potentially reduce CSO volumes by 1.7 bgy by 2030, or 8% of the City's overall CSO volume.

Nevertheless, the plan explicitly identified GI as a core element of the overall strategy for reducing CSO volumes, and described the specific milestones for management of the first inch of rainfall on impervious watershed areas as outlined above.

To determine the operating parameters for GI projects in New York, and establish local best-practices for the design, construction, and maintenance of GI, the DEP allocated $5.7 million for source-control demonstration projects. The funds for these projects included $2.6 million in grants for nonprofit and academic organizations to build GI in the Gowanus and Flushing Bay watersheds. The DEP also committed $15 million for a GI planning study, building several GI installations on public property to provide valuable information about source-control performance over time and under NYC-specific conditions.

NYC Green Infrastructure Plan 2010: Is it having an Impact?

The NYC GI planning process began during the Bloomberg administration in 2007. Since then, 50 acres of impervious area within combined sewer tributary (IACS) have been managed via construction of GI. To achieve the consent order milestone of 1.5% of the citywide IACS managed by 2015, NYC must manage an additional 1,131 acres of IACS by Dec 31, 2014. Given how little progress appears to have been made, it is unlikely any significant impact has been directly made on CSO volume by existing GI projects. Further, no data has been made public indicating whether there is a link between CSO volume at outfalls and nearby, larger pilot monitoring sites or demonstration areas. This would allow a more integrated evaluation of the potential of GI in reducing CSO volume directly rather than relying on local measurements and calculations.

This highlights a larger issue with the GI program – the accuracy and suitability of metrics based on management of estimated impervious area runoff as opposed to actual measurements of reduced CSO volume at the outfall or changes in water quality. Most of the pilot monitoring data has been site-specific, measurements of the inflow and outflow of stormwater during a rain event, rather than measurements at the local outfall or changes in measurements of water quality. This is surprising given that, since 2007, PlaNYC incentivized construction of more green roofs and called for construction of Bluebelts, Greenstreets and "green parking lots" to address the continuing issues with the quality of the natural waters surrounding NYC.

However, in 2011 the DEP supported this potential goal by improving the scope and access of the Harbor Survey Program. In that year, the number of sampling stations in the Harbor Survey Program increased by 20% from 60 to 72. The parameters measured at these sites, such as fecal coliform and enterococci bacteria density and biological oxygen demand, are crucial to understanding the spatial differences in CSO outfalls and ultimately the relationship between GI and water quality. The DEP took the critical step in 2011 of making recent and historical data from the harbor survey program available online, and the next step will be to link this data by CSO outfall to GI area and technology.

NYC pilot monitoring technologies have generally followed the guidelines from the EPA Low Impact Development manual. However, some of these technologies (such as bioretention) were not suitable for areas where either the water table was too high or bedrock layers too close to the surface. This left certain areas of the Bronx (too much bedrock close to the surface) out of consideration. However, since analysis of the average amount of available surface area for GI projects – roughly half the watershed – was carried out, the locations of projects have largely allowed adequate evaluation of the impact of different GI technologies on CSO volume.

A critical component of managing and implementing GI is locating projects where the capacity of the GI is appropriate for the volume, and flow of CSO's. After releasing the 2010 Green Infrastructure Plan, the DEP began recalibrating the InfoWorks hydrologic models used to predict CSO volume for six of the 13 watersheds using the latest data (2009) on the spatial extent of impervious surfaces. If the city is successful in implementing the 1,000 ROW GI projects it plans for during 2014, a new survey of the spatial extent of impervious surfaces will probably be helpful in modeling CSO volume. These results could be combined with data from the Harbor Survey Program, integrating performance metrics for GI, CSOs, and water quality.

Co-benefits of Green Infrastructure

The city has recognized that an effective approach to enlisting and engaging stakeholders is to highlight the co-benefits of green infrastructure. These corollary objectives -- improving air quality, reducing the urban heat island effect, increasing property values, etc. -- are natural consequences of pursuing a primarily "green" infrastructure approach as opposed to an all "grey" approach. However, since the rate of GI construction has been so low, and no data released by the city quantifying whether local temperatures around GI projects have decreased or local property values increased, it is difficult to estimate which co-benefits have been achieved. If the city were able to quantify these co-benefits, it could potentially publicize them even more.

Green Infrastructure Challenges and Costs

Stormwater presents unique challenges for urban water management relative to domestic sewage. Unlike domestic sewage, stormwater contains greater heavy metals concentrations (due to increased mobilization from contact with urbanized surfaces). Over time, high heavy metal concentrations may select for undesirable or nuisance plant species with shallower root systems that slow rain infiltration[11].

Since 60-95% of mean annual rainfall in forested catchments can be lost to evapotranspiration, selecting the ideal vegetation cover for swales and bioretention areas can have long-term implications for the management of CSOs[12]. Several studies[13] have indicated over the long-term (4+ years) reduction in total runoff volume by swales was between 30-47%, although others suggest the range may be lower (10-20%). This reduction in runoff volume decreases sharply as rainfall exceeds 1.14 inches however, but half the rainfall events were fully contained. Since 90% of the storms in NYC are less than 1.2 inches, the performance of swales implemented in the city (as a function of rainfall levels) will likely be consistent with observations.

A persistent problem reported over the long-term with biofilter systems (such as swales) is clogging caused by the accumulation of sediment at the surface and within the pore spaces of the biofilter soil column. In interannual studies, biofilter systems with high initial hydraulic conductivity (such as gravel swales) decreased by ~50% after 3-5 years, suggesting long-term management will require long-term interagency coordination for surveillance, maintenance, and upkeep of green infrastructure projects.

Another area of potential growth in GI is the Green Infrastructure Grant program. Although the program has disbursed $6 million in funds for GI, there has been limited participation. Part of the reason for limited participation by private homeowners, businesses and smaller non-profit organizations is the high capital cost required up front for successful funding by the Green Infrastructure Grant program. In the three years the Green Infrastructure Grant program has been operating, 29 projects have been allocated $11 million dollars. The smallest grant project funded cost $40,000 dollars and resulted in a 2,500-square-foot roof. The minimum grant size allowed is $35,000 dollars, and upfront costs for design and legal fees borne by the applicant have tended to be ~$10,000. Since this cost is only reimbursed after final approval of the plan, it's likely this deters applications for smaller-scale green infrastructure projects by private homeowners and smaller organizations.

Review of NYC Green Infrastructure Pilot Monitoring Studies and Demonstration Projects

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[11] Paul Z. Gulezian, Jennifer L. Ison, and Kelly J. Granberg. Establishment of an Invasive Plant Species (*Conium maculatum*) in Contaminated Roadside Soil in Cook County, Illinois. *The American Midland Naturalist*, Vol 172, 2014. 375-395.

[12] T.D. Fletcher et al., Understanding, management and modeling of urban hydrology and its consequences for receiving waters: A state of the art. Advances in Water Resources 51. 2013. 261–279

[13] Allen P. Davis, et al. 2012. Hydraulic performance of grass swales for managing highway runoff. Water Research 46. 6775-6786. Deletic, A., 2001. Modelling of water and sediment transport over grassed areas. J. Hydrol. 248 (1-4), 168-182.

Green infrastructure in NYC has only been implemented with adequate performance monitoring in a few key neighborhoods. This section will thus only address the findings and results from these areas to develop general considerations for the future of GI in NYC. In 2010, the DEP selected tributary zones for demonstration projects designed to highlight the aesthetic and sanitary benefits of GI. The three initial zones were 1) Hutchinson Creek 2) Jamaica Bay and 3) Newtown Creek.

Hutchinson Creek appears to have been chosen as it included a site within and adjacent to the NYC Housing Authority's (NYCHA) largest public housing development in the Bronx. A similar rationale was used in Newtown Creek, where projects were sited within the Hope Gardens NYCHA development. In Jamaica Bay, the East New York Demonstration Area is in a mixed-use area of residential, business, and industrial buildings, and the decision to build GI does not appear driven by NYCHA development, but rather, a strong business-community relationship. In other areas, by partnering with NYCHA, required maintenance for bioretention and swales was easier to implement. These areas were also supplemented with a Pilot Monitoring Program (PMP), which tracked over 30 individual GI projects at 15 different sites throughout the city. The goals and objectives of all pilot monitoring studies were the same: to evaluate the extent to which the technologies employed managed the runoff produced by 1-inch storms. The total result is thus a combination of the area managed and percentage of 1-inch or less storms fully-retained.

Type	**Technology/ function**	**Impervious area managed (total) (acres, all sites)**	**≤1 inch storms fully managed (per site)**	**Potential for CSO reduction and ancillary benefits**
Right Of Way (ROW)	**Swales (infiltration)**	**0.05 – 0.15**	**23-92%**	**Diffuse, requires widespread use.**
	Tree pits (Infiltration)	**0.04 – 0.45**	**0-96%**	**Same as above**
	Bioretention (infiltration and retention)	**0.41 – 1.90**	**50-100%**	**Must be targeted to proper location, but high potential.**
Porous pavement	**FilterPave™ Porous asphalt**	**0.1 – 0.15**	**100% 50-100%**	**Diffuse, little ancillary benefit.**
Blue roof	**Flow control and detention**	**0.61**	**0-5%**	**Same as above.**
Green roof	**Flow control, bioretention**	**0.08**	**30-100%**	**Diffuse, requires widespread use.**
Wet meadow Stormwater wetland	**Constructed wetland**	**0.32**	**100%**	**Must be targeted to proper location, but high potential.**

The results of the pilot monitoring studies indicate that the best combination of total impervious area managed and percentage of 1-inch or less storms fully managed is larger bioretention areas. These natural, vegetated "rain gardens" also hold potentially the highest level of ancillary benefits. However, since they tend to be larger, they are more challenging to build and locate within the existing infrastructure of NYC. Perhaps for this reason, the city has chosen to focus on ROW swales. These have greater variability in their impact on CSOs and potential ancillary benefits, but are easier to implement.

Green roofs and blue roofs, which have substantial logistical and engineering costs and difficulties, are similar to swales in their effectiveness at fully retaining or managing ≤1 inch storms, but have less ancillary benefits than either swales or bioretention areas (access by the public to green and blue roofs is limited, since these technologies are more likely to be on private property and away from public thoroughfares). Nevertheless, blue roofs have been much more widespread relative to other technologies. Porous pavement, although less likely to have aesthetic ancillary benefits, appears much more effective at managing ≤1 inch storms, but has not been widely applied. Wet meadows also have good potential to manage fully ≤1 inch storms, and have high ancillary benefits, but need to be located properly to fully realize this potential.

Grey Infrastructure Successes

In general, on a per-gallon basis, grey infrastructure upgrades, new construction, and retrofits have had the largest impact on CSO volume. Recent DEP grey infrastructure construction projects have included upgrades in key wastewater treatment facilities, storm sewer expansions and the construction of several large CSO retention tanks to further mitigate this chronic source of pollution. Existing infrastructure developments have increased the DEP's standardized CSO capture rate from about 30% in 1980 to over 80% today. Some of the most recent increases can be attributed to the implementation of additional CSO control measures such as the Spring Creek and Flushing Bay CSO Retention Facilities that came online in 2007, and the Paerdegat Basin and Alley Creek CSO Retention Facilities, which came online in 2010.

The DEP further estimated the costs of implementing GI (on a per-gallon CSO volume reduction basis), and found that the costs for implementing GI in the Jamaica Bay watershed were much higher than grey infrastructure ($5.80 versus $2.34)[14]. The most expensive areas to implement GI were Coney Island, Jamaica Bay, and Paerdegat Basin. These three areas combined, on a cost per-gallon CSO reduction basis, nearly equaled the combined costs per gallon reduction for the other 11 areas examined ($16.14 vs $17.17 per gallon CSO reduced)[13]. This discrepancy reflects the marginal benefit of CSO reduction by GI relative to planned or built cost-effective grey infrastructure such as the Avenue V force main and pumping station (Coney Island Creek watershed), the detention facility at Paerdegat Basin and the Spring Creek CSO detention facility (Jamaica Bay & CSO Tributaries watershed).

[14,] NYC Green Infrastructure Plan. 2010.
http://www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_LowRes.pdf

However, when considering all tributaries and potential areas for upgrades, a strategy incorporating GI and cost-effective grey infrastructure was cheaper ($0.45 per gallon CSO reduction) than an all-grey infrastructure strategy ($0.62 per gallon CSO reduction)[13]. It should be noted although, that these cost estimates were made on the basis of modeling data projecting to 2045, and may need to be revised if water usage or extreme weather events (such as Hurricane Sandy) change baselines from which assumptions are made.

The DEP also identified that one of the most cost-effective ways to reduce CSO volume was to optimize the effectiveness of the existing wastewater treatment system. To this end, NYC included in the 2010 Green Infrastructure Plan a goal to survey and repair as necessary interceptors and tide gates within the sewer system. For context, these programs alone are estimated to reduce CSOs by at least 586 mgy, which is roughly a third of the projected CSO reduction due to all proposed green infrastructure upgrades (1,514 mgy). The pace and effectiveness of these upgrades will ultimately depend on coordination with and support from NY State Department of Environmental Conservation (DEC) however.

Grey Infrastructure Challenges

In addition to population growth, impervious area, and poorly drained areas, NYC has 149 miles of large intercepting sewers that connect former outfalls of the 7,400-mile lateral collection sewer system to the WWTPs. Between 2010-2013, the DEP committed funds for construction of high-level storm sewers. High-level storm sewers collect up to 50% of the rainfall, before it enters combined sewer systems, but must discharge untreated runoff directly into adjacent, permitted waterways via a separate outfall. They are thus restricted to coastal areas. While much higher concentrations of contaminants would be encountered in combined sewers, the outfalls of high-level storm sewers should be monitored closely to assess their impact on water quality during severe storm events. Adding a GI treatment component to high-level sewer outfalls is something that the city should evaluate.

Another factor affecting the capacity of the sewer system to handle large rain events is the existing load due to sanitary, household water use. When such use is low, the sewer system can accommodate greater amounts of runoff, which ultimately lowers the magnitude of CSO events. Between 2002 and 2009, NYC water consumption declined on average 0.9% per year. 1.42 billion gallons per day (bgd) of water were used in 1990, 1.24 bgd in 2000, 1.11 bgd in 2005, and 1.01 bgd in 2009. A portion of that additional capacity can now convey and store more stormwater. Although these are impressive gains, the DEP predicts annual water consumption is likely to stay ~ 1.1 bgd over the next 10-20 years.

The challenges to grey infrastructure are thus likely to remain constant, but provide a platform for the advancement of GI solutions. For example, in one of the most impacted waterways in NYC (Newtown Creek), the city is currently in the process of designing a full-scale aeration project to increase dissolved oxygen concentrations and promote the return of native flora and fauna that will absorb excess nutrients in a more sustainable manner. Newtown Creek receives approximately more than 1.4 billion gallons of CSO annually[15]. While this project shows the commitment of the city to improve water quality, it also focuses on a symptom of the CSO problem, and not on a solution. Solutions need to incorporate both diversion strategies (i.e., green infrastructure) as well as storage/treatment approaches to fully address the CSO problem, improve water quality and protect our waterways. Opportunities for GI projects that address the in-creek water quality and provide treatment for ongoing CSO events were explored in the Newtown Creek Brownfield Opportunity Area (BOA) Nomination Report[16]. One innovative concept incorporates treatment wetlands to treat the CSOs and improve water quality in the creek. Treatment wetlands for the management of stormwater[17] and sanitary wastewater, separately, are a well-accepted practice demonstrated worldwide[18]. Technology advances with treatment wetlands should be investigated and evaluated in the overall CSO solution.

NYC Climate Resiliency Challenges

Sea level rise in the NYC area for the past 100 years has been between 1 to 2.5 mm/year[19]. Presently, the rate of sea level rise in the NYC is estimated at 2.73 mm/year, or roughly one inch per decade[20]. However, this rate could be accelerated by human–induced global warming[21]. If carbon emissions continue at their current rate, sea levels could rise between 10 and 43 inches by 2080. This is alarming, since according to a recent study, the odds of a storm surge surpassing Manhattan's harbor defense are 20 times greater than they were prior to the current warming trend[22]. Since much of the NYC's sewage infrastructure is 50-150 years old, it was not designed during a period of such frequent storm surges. During Hurricane Sandy, 1.6 billion gallons of sewage were discharged into New York waterways, both from CSO events and from wide-scale failure of the sewage treatment system due to storm surge[23].

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[15] Newtown Creek Waterbody/Watershed Facility Plan Report. City-Wide Long-Term CSO Control Planning Project. NYC Department of Environmental Protection. June 2011. http://www.hydroqual.com/projects/ltcp/wbws/newtown_creek.htm

[16] Newtown Creek Brownfield Opportunity Area Step 2 Nomination Report. May 2012. http://www.gmdconline.org/images/pdfs/Newtown-Creek-Final-Report-and-Appendix-2012-b.pdf

[17] Greening CSO Plans: Planning and Modeling Green Infrastructure for Combined Sewer Overflow (CSO) Control. U.S. Environmental Protection Agency. March 2014. http://water.epa.gov/infrastructure/greeninfrastructure/upload/Greening_CSO_Plans.PDF

[18] Kadlecm R.H. and S. Wallace. 2008. Treatment Wetlands, Second Edition. CRC Press. Print.

[19] Sallenger Jr*, A.H., Doran, K.S. and P.A. Howd. 2012. Hotspot of accelerated sea-level rise on the Atlantic coast of North America. *Nature Climate Change*. 1597: 1-5

[20] Gornitz, V.A., Couch, S.B., and E.K. Hartig. 2002. Impacts of Sea Level Rise in the New York City Metropolitan Area. *Global and Planetary Changes.* 32. 61-88

[21] Rosenzweig, C., and W.D. Solecki (ed.). 2001. Climate change and a global city: The potential consequences of climate variability and change-Metro East Coast. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York.

[22] Increasing storm tides in New York Harbor, 1844–2013, *Geophysical Research Letters*, S. A. Talke, P. Orton and D. A. Jay.

[23] Kenward A., Yawitz D, Raja U. 2013. Sewage Overflows from Hurricane Sandy. Climate Central, One Palmer Square, Suite 330, Princeton, NJ08542. http://www.climatecentral.org/pdfs/Sewage.pdf

Flooding resulted in $5 billion in damage to the subway system alone, while $14 billion in damage were done to other parts of the city.

Higher sea level and more frequent storm surges will potentially challenge attempts to manage flooding during large storms for coastal communities in NYC. Widespread GI will undoubtedly help by potentially increasing the infiltration rate of floodwaters in coastal areas. However, since most of the vegetation chosen for existing bioretention projects and bioswales are chosen for drought[24] and not saltwater tolerance, storm surges that reach farther inland will probably require extensive cleanup and replanting, unless more saltwater tolerant species are added.

Because GI utilizes natural processes to manage stormwater, it has the potential to be more resilient than traditional grey infrastructure. Solutions for climate resiliency should incorporate advanced GI technologies that can not only reduce the impact of storm events but provide storage, retention and treatment of CSOs and storm surge. In this way, GI can be used to also build a more resilient city. New GI technologies should look for ways to integrate the resiliency and recovery of the city's coastal ecosystems as a buffer against storm surge and CSO management.

Future of Green infrastructure in NYC

Working with the NYC Department of Transportation (DOT), the DEP has planned to build 1,000 ROW GI projects during the summer of 2014. This plan represents the culmination of efforts beginning in 2011, when the DEP began working with the Department of Design and Construction (DDC), the DOT and the Department of Parks and Recreation (DPR) to standardize designs for ROW projects and coordinate selection of possible sites across the city. The speed with which the process has unfolded reflects the integration of ROW swales into existing capital projects, lowering the time and cost required.

Further city interagency coordination is expected by the DEP with the Department of Education (DOE) and the Trust for Public Lands as well. Over the next several years, the DEP plans to shift its focus to implementing more GI projects on public school property, converting impervious playgrounds to permeable pavement and constructing more swales.

The DEC has also recently released a draft of the 2014 Municipal Separate Storm Sewer System (MS4s) permit and fact sheet for public comment. The City's MS4 permit clarifies responsibilities for NYC's management of stormwater discharged from the City's separate sewer system. This permit requires NYC to draft a Stormwater Management Program Plan (SWMP) that, among other requirements, will specifically address the following:

1. Public education and participation
2. Illicit discharges
3. Discharges from construction sites and NYC municipal facilities and operations

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[24] New York City 2011 Green Infrastructure Plan Update, NYC Department of Environmental Protection.

The intent of these modifications appears to be standardization of the controls required for small MS4 facilities under the City's MS4 Phase 1 (Large City) Permit and development of an industrial source control program. Until the MS4 is finalized, the predictions for the impact of these requirements would be premature.

A post-construction monitoring report for the GI demonstration areas is due in August 2014, based on data gathered continuously since 2010, in 5-15 minute intervals. The latest (2012) report indicates substantial variability in the performance of key ROW projects: enhanced tree pits, street side infiltration swales and larger, bioretention areas. Enhanced tree pits can be the first step in a GI developmental sequence leading to swales, which are larger (40ft versus 20ft long). Both are constructed within sidewalk areas adjacent to the roadway. Pilot bioretention areas are much larger, (1,000s ft) and, although constructed in ROW zones, tend to occupy formerly impervious medians.

Variation within and between different pilot source control projects was significant. Enhanced tree pits (a precursor to later street-side swale development) were the most variable, fully retaining between 0-96% (mean 61%) of volume from storms producing one-inch or less of rainfall. The key factors affecting the variability in performance were mainly site-specific, with zones in which the local drainage area was large relative to the green infrastructure area (99:1) becoming saturated more quickly than sites with smaller ratios of green Infrastructure area to drainage area. For swales, other similar site-specific criteria increased performance variability. Swales fully retained between 23-92% (mean 64%) of one-inch storms, but in steeper areas, where runoff velocity would be higher, only storms producing less than 0.2 inches of rain were likely to be fully retained. Data suggests that for 0.4 inch storms, swales located at higher slopes tended to retain roughly half the runoff produced during larger storms.

Despite this variability, the DEP has indicated they do not intend to release a 2013 Pilot Study Report, which might confirm whether site-specific hurdles to increased efficiency had been overcome. Substantial modifications to ROW GI projects have been reportedly made on the basis of 2010-2012 monitoring data however, most notably in the form of curb cuts. These modifications increase access of surface runoff to ROW GI projects and may alleviate the problem of high slopes limiting runoff infiltration for some swales.

Other Considerations for Green Infrastructure

In 2011, the DEP and the interagency Green Infrastructure Task Force addressed the problem of ensuring maintenance of GI in ROW areas. This is a critical component, since 2011 and 2012 Pilot projects demonstrated that clogging of swales and bioretention areas, as well as invasion by non-native vegetation (such as Japanese clover) diminished the capacity of these systems to handle runoff. With this in mind, in November 2011, the DEP, DOT and DPR committed "Greenstreets" crews to maintain vegetated green infrastructure in the right of way through June, 2015.

The DEP met with interagency, industry and environmental stakeholders to develop a stormwater management standard for new construction and redevelopment. The performance standard was issued on January 4, 2012 and specified a "stormwater release rate" of at least 0.25 cubic feet per second or 10% of the new development's "allowable flow," (whichever is greater, but within design parameters). This new standard requires larger lots (greater than 5,000 square feet) to increase their capacity to retain stormwater on-site, while smaller lots will most likely only need to comply with existing sewer availability.

To further incentivize the adoption of GI, in 2011 the DEP began charging standalone parking lots with no water service $0.05 per square foot for wastewater services, a yearly average of $669 per lot. Along with this new fee, the DEP implemented a credit program to simultaneously waive charges for standalone parking lots that can prove their ability to retain stormwater and prevent it from entering the sewer system.

CONCLUSIONS

There are 136,500 acres of impervious surfaces in NYC. The city is required to manage the runoff produced by 1,181 acres (1.5%) by 2015. Since 2010, the DEP has constructed GI sufficient to manage 50 acres of impervious watershed within their priority focus of 564 acres in tributaries. Limited undeveloped, open space in NYC presents a challenging environment to develop and grow GI. The legacy costs of older but vital sanitary systems along with increasing pressure from climate change and population growth slow modernization and conversion to sustainable systems.

However, many of the recommended steps for GI development have already been taken by New York and are outlined above. Both New York and Philadelphia have long-term green infrastructure plans, both cities require the use of green infrastructure to manage runoff from some portion of the watershed, and both provide incentives for residential and commercial parties to use green infrastructure. Both also use technical manuals, workshops, and demonstration projects to provide guidance and support for the use of green infrastructure. In most respects, NYC has a fairly robust, expanding GI program, albeit in its early stages.

Maintaining this progress will require sustained coordination of city agencies and "buy-in" by local stakeholders. In addition, metrics should be refined for both the percent of existing impervious area (as mentioned above, the last survey was 2009) and relationship between extent of green infrastructure installed, volume of CSO reduced and change in water quality. A 2016 Performance Metrics report has been alluded to by DEP[25], and may very well answer this question. The systems appear to be in place for these linkages to be analyzed and highlighted for local, state and federal audiences. Simply meeting the pro forma requirements of the CSO order (1.5% conversion by 2015, etc) will undoubtedly generate co-benefits identified in the 2010 Green Infrastructure Plan, but whether improvements in water quality occur and CSO discharges no longer result in violations of the Clean Water Act will be a different matter.

[25] Personal communication.

RECOMMENDATIONS

- Expand the green infrastructure (GI) program to the whole city, not just CSO areas.
  - The regulatory framework for GI in NYC is governed by quality of NYC waters. Only addressing the problem of CSOs within certain areas of the city will meet the technical guidelines required by the consent order, but water quality will be most improved by the NYC adopting a comprehensive approach.
  - The city should use the opportunity presented by the expanded construction of ROW bioswales, updating of the InfoWorks Model and broadening of the Harbor Survey Program to obtain better baseline data on the impact of GI citywide.
  - These results should then be used to support citywide expansion of the GI program, allowing maximization of ancillary benefits, public support, and reduction of CSO volume and the impact of future storm surges predicted by global climate change models.
  - NYC should use the opportunity presented by the pending Municipal Separate Storm Sewer System (MS4) permit from the NYS Department of Environmental Conservation (DEC) and the required Stormwater Management Program Plan (SWMP) to integrate a focus on water quality with implementation of green infrastructure.
  - Combine contaminated site cleanup and GI approaches. Contaminated site remediation, such as Superfund sites or Brownfields, may be able to utilize GI to manage their stormwater footprint, after remediation goals are met.
- Incentives for green infrastructure (GI) development on private property.
  - Overall, the city needs greater incentives. In other cities where this approach has been used, the potential savings are greater and the scope is larger. Incentives that shift public behavior on such a scale also need to be more publicized and simpler to understand.
  - Explore scalable private property retrofit incentive program like Seattle or Philadelphia. These programs have been very successful at increasing participation.
  - Set value targets for new development or re-development projects that will drive developer to greater adoption of GI. Set similar interagency stormwater standards (e.g.: Department of Transportation road projects, NYC Department of Parks and Recreation capital projects, schools, etc.).
  - Perform a cost-benefit analysis of a stormwater-fee based incentive program to encourage property owners to convert a certain percentage of their property to GI.
- Research & development.
  - Encourage development and testing of advanced GI technologies for storage, retention, and treatment of CSOs. (e.g. constructed treatment wetlands at end-of-pipe).
  - Explore the role of GI to create a more resilient NYC; minimize storm impacts; improve water quality to create healthier coastal ecosystems that have natural resiliency; and implement innovative projects that combine CSO treatment with stormwater retention.

    - Develop metrics for linking impact of GI on CSO volume (by outfall) and key parameters of water quality (biological oxygen demand, fecal coliform, etc.) This will enable the City to better adapt the scale and type of local GI to support federally required water standards in local waterways.
- Public education & awareness.
    - Institutionalize and streamline access to monitoring and hydraulic performance data generated from pilot monitoring studies and demonstration projects (this will enable nonprofit and academic stakeholders to gather the necessary data for the below steps).
    - Launch a public campaign highlighting the potential savings to the community in taxes spent on repairing the damage to infrastructure from frequent CSO events.
    - Expand the number of demonstration areas – Philadelphia, for example, built 12. NYC has three demonstration areas. The city should consider demonstration areas that also highlight the integration of these technologies with improved water quality, such as projects that return native flora and fauna to impacted areas such as the Gowanus with improved water quality due to GI.
    - The limited impact of the Green infrastructure Grant program is likely due to barriers to entry for less well-funded parties (both private, public and NGO). The DEP could lower this barrier by reducing upfront costs and developing a second, more streamlined track for applicants with smaller projects.
    - Create more GI research partnerships with local educational institutions.