Green Infrastructure in New York City:

A Case Study of the Systematic Integration of Engineered Natural Climate Solutions Into City Infrastructure

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Abstract. *To reduce discharges of raw sewage during rainstorms, New York City built green infrastructure at the "headwaters" of its combined sewer system to absorb and slow down stormwater runoff, thereby lowering the cost and increasing the effectiveness of its traditional, centralized treatment system. This innovative use of distributed, nature-based solutions for the wastewater program applied principles of watershed management from academic research pioneered in research forests and operationalized to protect source water quality in the hundreds of thousands of natural forests and agricultural lands that comprise New York City's drinking water system. Would such measures work in the densely developed urban landscape of New York City, where rain fell on sidewalks, public streets, and inlets to the sewer system? And was there enough interest in stormwater management, an unheralded and often ignored part of city government? The policy context shifted with the PlaNYC agenda for a sustainable city that also included broad, systematic investments in the City's parks and street trees, and when flooded subways made the front pages. Through careful planning of pilot measures, cultural change inside and outside of DEP and regulatory agencies, public pressure and support, and the enabling framework of PlaNYC, DEP was eventually able to institutionalize green infrastructure by working with regulatory agencies to develop a creative consent decree that included funded demonstration projects and implementation milestones. Just 15 years later, New York City had built and operated the largest green infrastructure program in the country, with over 16,000 green infrastructure assets constructed and over $1 billion invested. (NYCDEP, 2024). The program is now well-accepted and green infrastructure is seen as a functional tool for reducing combined sewer overflows and pollution from storm sewers and to make the city more resilient to extreme rainfall. More broadly, the green infrastructure program validated the idea that natural elements like engineered tree pits, park spaces, and wetlands should be taken seriously as city infrastructure and be funded, planned, built, and operated accordingly. By studying this policy success, we can better implement other distributed environmental initiatives.*

PlaNYC's Water Quality Goals and The Problem of Combined Sewer Overflows

Recognizing the ongoing and future redevelopment of formerly industrial waterfront areas, PlaNYC's original water quality goal was to "open 90% of our waterways to recreation by preserving natural areas and reducing pollution" (2007).[1] This acknowledged and addressed the

[1] PlaNYC 2007. This goal changed in each subsequent sustainability plan for the City. The goal was later modified to "Improve the quality of our waterways to increase opportunities for recreation and restore coastal ecosystems" (2011), and then "New York City will mitigate neighborhood flooding and offer high-quality water services" with a relevant indicator of "increase the CSO capture rate from 78 percent" (2015) and "improve the health and ecological function of NYC's waterways [by reducing] combined sewer overflows by more than 4 billion gallons per year by 2045 to improve water quality, [developing] a strategy

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remaining challenge to recreational use after decades of improvement: combined sewer overflows (CSOs) of raw sewage during storms, a structural feature of older cities that was not remediated by the Clean Water Act's permitting regime and related grants.

By the 2000s, New York City was the cleanest it had been since the Industrial Revolution. Coal-burning power plants, municipal solid waste incinerators, and many of the industrial processes for manufacturing had been stopped or relocated outside of the City's borders. After the completion of the North River Wastewater Treatment Plant in 1987, the discharge of raw sewage into the Hudson River, East River, Jamaica Bay, and smaller waterbodies was no longer a daily occurrence. More people were spending time recreating near, or even on or in the water, attracted by increasingly attractive waterfront parks and residential development projects that were beginning to replace the industrial activities that previously occupied much of the coast. NYC Parks had begun its work restoring the wetlands that had been such an important component of the City's earlier environmental history, and some environmental groups and educators were even thinking about bringing back the City's vast historical oyster beds.

These new stakeholders, however, soon realized that restoration of the New York Estuary and the value of access to water were stymied by the persistent discharge of raw sewage at nearly 500 different points, known as combined sewer outfalls (CSOs). CSOs had been deliberately built into the City's combined sewer system to protect treatment plants from being overrun with stormwater during rainfall events. The tradeoff to this design was that during wet weather, the diverted wastewater and stormwater had to be discharged directly to local waterbodies - untreated. Some CSOs discharged over 50 times a year, created ecological dead zones, triggered fishing, and swimming bans, and generated strong odors and health risks, with the effects lasting two days or more.

Earlier phases of environmental regulations had focused on managing so-called "point-source discharges," which occurred at the pipes leaving a wastewater treatment plant or a factory- but did not include CSOs. In 1972, The Clean Water Act (CWA) required that any facility that discharged pollutants from a single identifiable source obtain a permit. Water utilities like the NYC Department of Environmental Protection (NYCDEP) were mandated to obtain a permit for its treatment plant discharges. The permitting process was typically managed by the state, e.g., the NYS Department of Environmental Conservation (NYSDEC), and administered and coordinated nationally by the US Environmental Protection Agency (USEPA). The program was successful in part because of generous federal grants that were made available to permit holders, giving them the ability to plan, design, and build the required sewers and treatment plants.

In the late 1980s, Congress stopped granting direct federal money to water utilities. Thereafter, the capital and operational expenses that water utilities needed to comply with clean water regulations were financed through unpopular user fees, and a hodgepodge of loans, earmarks, and other mechanisms. But the financial challenges faced by water utilities got more acute at the turn of the century, when in December of 2000, the EPA amended the Clean Water Act, mandating that permit holders operating combined sewer systems also comply with its newly issued Combined Sewer Overflow Control Policy. This policy required permit holders to develop Long Term Control Plans (LTCPs) that would reduce discharge of untreated sewage through CSOs. CSO control policy was viewed as an unfunded mandate, and around the country a debate ensued about how to cost-effectively comply with the policy's multiple requirements. In NYC, this

to end the discharge of untreated sewage into the New York Harbor by 2060, [and improving] the health and ecological function of wetlands."

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dialogue involved NYCDEP and NYSDEC staff, their consulting engineers, as well as ordinary citizens and other stakeholders who were required by EPA to play a role in formulation of the LTCPs.

The National Debate: Grey vs. Green approaches to CSO management

The debate initially juxtaposed "grey" and "green" approaches. The "grey approaches" focused on building bigger and more efficient sewer systems, while the "green" approach focused on reducing stormwater inputs to the existing one.

Traditional "grey" the city's engineering consultants well understood approaches because they included pipes, tanks, tunnels, and other infrastructure components that their engineers had been designing for decades. But the grey approach was also known to be expensive, and its construction potentially disruptive in fully built out cities like New York. It was also not clear that grey systems – designed to manage a fixed amount of flow - could fully eliminate the dynamic CSO problem, which varied in scale based on rainfall amount.

One such solution, sewer separation, would replace the single pipe combined sewer with a two-pipe system. One pipe would convey sanitary flows from toilets, sinks, and showers, in residential, commercial, and industrial areas to wastewater treatment plants, while another would direct untreated stormwater directly to local receiving water bodies. Sewer separation, as a concept, was not unprecedented in NYC. Approximately 40% of the City - the more recently developed parts- had already been designed this way, with two pipes in the street ready to receive separate flows from two-pipe buildings. But retrofitting the remaining 60% of the City with a single pipe system would have involved tearing up thousands of miles of active roadways, including many major highways, installing thousands of miles of new pipe, connecting tens of thousands of street catch basins and an even greater number of residential pipes to the new storm sewer, and constructing hundreds of new outfalls. Estimates of that effort ran to $60 billion in 2000s dollars for the public portion alone, without even considering the cost of forcing homeowners to install separate storm piping. Even if funding for citywide sewer separation had been available, it was well understood that the resulting system would still discharge untreated stormwater – and the oil, road salt, tire crumbs, bird and pet waste, litter, and other pollutants found on streets, sidewalks, and roofs – into local waterways.

Another "grey" approach that was extensively vetted in NYC entailed construction of inline and above ground storage tanks and tunnels. Built within the existing combined sewer system, this infrastructure would temporarily store – e.g., detain – the combined sewage until the storm ended and it could be pumped to the wastewater plants. Tanks and tunnels also came with high costs, to buy the land on which the tanks and tunnels would be constructed, and to operate the pumps. Because each tank might store tens to hundreds of millions of gallons of combined sewage it could cost tens to hundreds of millions of dollars to construct in NYC. Pumping would require a great amount of energy, with significant financial and environmental implications.

By the early 2000s, some tanks and tunnels had been built in other cities using federal grants, creating an important precedent. Early systems were built in Chicago and Boston prior to EPA's CSO control policy. The Milwaukee Metropolitan Sewer District spent $1 billion dollars on a deep tunnel project that became operational in the 90s and reduced, but did not eliminate, CSOs into its local water bodies. For most of older cities, these kinds of grey systems would have required unaffordable rate hikes in this post-grant period.

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Around the same time, a third family of "green" approaches started to gain attention nationally. Originally referred to as Low Impact Development (LID), the strategy involved modifying the landscape to capture, infiltrate and/or reuse rainwater close to where it fell. The logic underlying this approach was that urban runoff did not need to be treated collected and disposed of as a waste product if it could be infiltrated into the ground in green spaces specifically allocated to this purpose. From a cost perspective, distributed stormwater infiltration could theoretically reduce or eliminate the need for expensive sewer upgrades or expansions. But it would also require thoroughly re-engineering where and how water moves through the urban environment. It was thus initially treated with skepticism by engineers and regulators who were much more familiar with the "grey" approach.

Nationally, LID was first incorporated in stormwater policy in Maryland in the late 1990s, when Prince George's County adopted stormwater management standards for new development that required diversion of stormwater to specially designed green spaces built into the site plan. The small incremental cost to overall construction was passed on to future tenants. Around the same time, variations of the approach emerged in other cities. Also in the 90s, Portland's pioneering Downspout Disconnect Program incentivized homeowners to redirect downspouts away from the combined sewer system to lawns and gardens where it could infiltrate, significantly reducing the amount of roof runoff directed to the City's sewer system. Between 1999 and 2001, Seattle Public Utilities deployed its Street Edge Alternatives Program, which attempted to mimic natural hydrology by integrating terraced green spaces and other natural drainage systems into the public right-of-way. In 1999, recognizing the high costs of tanks and tunnels, the Philadelphia Water Department created an "Office of Watersheds" to prevent pollution by treating stormwater as an asset, piloting its first green stormwater management projects soon thereafter.

NYC's background receptivity to green in NYC

The green approach began to attract national attention, especially among environmental activists who saw it as an opportunity for leveraging CWA compliance to advance a suite of interconnected sustainability goals. NYC was no exception. Increasingly referred to as "green infrastructure," it was increasingly touted by environmental groups, activist academics, practitioners, and a growing cohort of waterway stakeholders in a variety of public settings (Catalano de sousa 2016).

The background receptivity of New Yorkers to a green, nature-based approach to stormwater/CSO management is, on one hand, not surprising. The City had a long tradition of investments in natural areas, for social reform, civic engagement, recreation, and aesthetics in such features as Greenwood Cemetery, Central Park, Bryant Park, Highbridge Park, Ocean Parkway, community gardens, and playgrounds (Cook et al 2027). The city's water managers had also recognized the value of protected natural areas in ensuring a high-quality water supply as they planned the Croton system in the 1840s, the Catskill system in the 1890s, and the Delaware system in the 1940s.

In the 1980s and 90s, this historical appreciation for natural areas was converted into infrastructure plans, first in the NYC watershed and later in Staten Island. With passage of the Surface Water Treatment Rule in 1989, the EPA began requiring that public water systems be filtered. But the costs for NYC to filter and treat the one billion gallons a day of drinking water for eight million city residents and one million upstate customers were estimated at $10 billion or more. To avoid these costs and the rate hikes that would have accompanied them, DEP and the EPA entered a Filtration Avoidance Determination (FAD) in the 1990s. Under the FAD, DEP committed to buy land in the watershed and to prevent it from being developed, and to upgrade

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septic tanks and control agricultural runoff to preserve water quality. The FAD successfully used natural systems to limit pollution at its source and avoided the need for expensive grey infrastructure. By doing so, it operationalized nature-based watershed management principles in the city's upstate watershed.

If the FAD demonstrated that protection of natural areas could avoid the need for costly grey infrastructure upstate, the Blue Belt demonstrated how natural systems could be used to reduce it in the city itself. After the construction of the Verrazano-Narrows Bridge in 1964, development on Staten Island grew rapidly. Without a centralized sewer system, flooding and pollution rapidly became a problem. DEP developed a plan that would direct stormwater to low-lying wetlands and other natural drainage systems as an alternative to designing gravity-flow sewers. Built in the 1990s, the Bluebelt system saved $80 million in grey infrastructure costs, while creating an extensive network of accessible public open space and wildlife habitat (Catalano de sousa 2016).

Throughout the 1990s, green spaces also began to appear in other parts of the city as part of the NYC Greenstreets program, an initiative of NYC Parks. Initially an urban beautification program, the Greenstreets program sought to convert small, underutilized paved spaces in the right-of-way into aesthetically pleasing vegetated spaces. In 2006, one of these green spaces – a greenstreet located at the corner of 110th street and Amsterdam avenue, was specially designed to receive stormwater from the surrounding streets. In 2007, the opportunity for improving Jamaica Bay water quality through "stormwater source controls" was laid out in the Jamaica Bay Watershed Protection Plan, though the first stormwater capture Greenstreets in the Jamaica Bay watershed were not built until 2010. And in PlaNYC (2007) itself, the City committed to planting a million more trees (the Million Trees NYC campaign), protecting existing natural wetlands, and integrating nature into the city landscape.

Skepticism of the green approach in NYC

Despite these early precedents, in the early 2000s, the mainstream engineering consulting community, some decision-makers working inside DEP, and many of the regulators were skeptical that a nature-based approach to the management of stormwater could be scaled up adequately to meaningfully reduce CSOs. A common perception was that opportunities that may have been available to water managers in the Pacific Northwest, with its low intensity precipitation, and in suburban watersheds of Maryland were very different from those faced in most of the higher density boroughs of New York City. Despite the precedents nationally and locally for how green spaces could be woven into urban design, in the mid-2000s, there was little direct support among regulators or the engineering consulting firms advising the NYCDEP that a distributed network of pervious surfaces and small-scale retention basins to replace the large treatment plants and storage tunnels and other "grey" approaches.

At the NYSDEC, staff-level engineers suspected that the City was simply delaying action on multi-billion-dollar storage tanks that, in their view, it could easily afford. Other older cities in New York State – Buffalo, Rochester, Albany, Yonkers, Mt. Vernon, and Nassau County – were given more time to comply and more opportunities to seek cost-effective opportunities; DEC did not take action against Westchester towns that were discharging sewage in the upper Hutchinson and Bronx Rivers, even as it sought penalties from New York City for CSOs in the lower reaches. This hostility further hardened the attitudes of many decision-makers at DEP that the State would never accept non-traditional "green" solutions. Nevertheless, the integration of green infrastructure did allow the City to defer costly grey infrastructure solutions.

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The successful track record of federal grants for large grey infrastructure solutions for four decades after the 1972 Clean Water Act itself also became an obstacle. By concentrating capital and operational investments in a few, very large facilities, the "grey" approach was perceived as the way to take advantage of economies of scale. This skepticism of alternative approaches was perhaps the inevitable result of path dependency and grey-infrastructure lock-in from four decades of federal construction grants, and the lucrative contracts and accumulated knowledge from that period. Nevertheless, NYSDEC and EPA were slow to acknowledge that those paths were no longer so attractive when Congress stopped funding water infrastructure construction grants in the late 1980s. As with any technological shift that starts imperceptibly, the limits and diminishing returns of a previously proven approach were imperceptible to many of those who had partaken in prior waves of water infrastructure development. The feasibility and advantages of a potential change had to be firmly established. The skeptics inside and outside of government wanted proof that the early GI pilot programs could function cost-effectively at scale in a city as large, complex, and rainy as NYC.

The Case for GI in NYC Gains Momentum

Many of the individuals who would eventually build a successful case for GI in NYC first met earlier, during informal social and professional networks that formed in the early 2000s. In 2002, Green Drinks - an international attempt to bring people who care about the environment together – formed a NYC chapter. At its monthly meetings, environmental advocates, governmental practitioners, entrepreneurs, students, and others began to share ideas about environmental solutions to the city's various problems, including building green roofs, green corridors, constructed wetlands, living machines, and restoration of new kinds of habitat. At Columbia University, Dr. Cynthia Rosenzweig convened the New York Ecological Infrastructure Study, which assembled designers, academics, and others to investigate the potential for green roofs to address many of the city's environmental and human health challenges. An additional focusing event was the drought of 2002, during which community gardeners were prohibited from irrigating. In response, group of community gardeners, parks advocates, representatives from environmental organizations like the NYC Restoration Project and the Green Guerillas, formed the NYC Water Resources Group. This group mobilized to install rainwater harvesting tanks in hundreds of gardens across the city. In 2004, the Gaia Institute, a Bronx-based non-profit organization, had been advocating stormwater in the NYC watershed to be managed in a terraced, multi-barrier approach received NOAA funding to conceptually design a "green corridor" that would demonstrate how GI could be integrated into an ultra-urban streetscape in the Bronx.

The case for green infrastructure in NYC began to build significantly in 2006-2008 due to an additional convergence of factors. In 2006, the Natural Resources Defense Council (NRDC) published its highly influential Rooftop to Rivers report which made the case nationally that stormwater should be treated as a resource. The same year, several of the same authors collaborated on publication of Sustainable Raindrops, which made the case that "source control is the economical and sustainable alternative" to end-of-pipe tanks and in-line storage for CSO reduction in NYC.

Planning for PlaNYC, New York City's first ever blueprint for sustainability, also began in 2006. It was emblematic of the evolving view that nature had to be included in a future vision of a livable and growing city.[2] The Plan was conceived through organized task forces that convened

[2] PlaNYC was motivated by the projected increase at the time of a million more residents that would move to the city between 2005 and 2030. (PlaNYC 2007). The plan must be understood as a framework

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governmental leaders, agency officials, environmental and community advocates, academics, and others. The task force meetings were multisectoral convenings where attendees, many of whom had met previously, shared their respective and contrasting visions, explored the implications of those visions, and gradually built excitement among each other about the City that could be. The grey vs green debate regarding CSOs was a topic of intense deliberations in the Infrastructure and Natural Systems Task Force.

Parallel conversations were occurring at other fora, including the Citizen's Advisory Committee meetings (CACs) created by NYCDEP to satisfy the EPA's requirement that the public be engaged in development of the LTCPs. The Open Waters CAC specifically was a setting where DEP decision makers, their consulting engineers, academics, and environmental advocates debated the merits of the green approach. While the CAC meetings focused on specific water bodies, NYC Councilman James Genaro organized a series of council hearings beginning in 2007 that focused on the CSO issue city wide. Environmental organizations like the Hudson Riverkeeper and the NRDC, and lawyers at Columbia University's Environmental Law Clinic mobilized teams of activist researchers, law students, ecologists, and engineers to testify at these hearings. Many of these individuals were also tapped to draft supporting reports and policy briefs, and to attend other public meetings where opportunities to green the city presented themselves. For example, this group which eventually became the core founders of the Stormwater Infrastructure Matters (SWIM) coalition commented on the Draft Environmental Impact Statements of major redevelopment projects proposed for the World Trade Center site and for Hudson Yards in Manhattan, as well as for Atlantic Yards in Brooklyn, during their respective public comment periods. Indeed, the green roof at the Barclay's arena emerged in part in response to this heavily organized critique of the project's original conceptualization.

Finally, a highly influential paper, published in 2007 for the first time demonstrated that GI could be a cost-effective way to limit CSOs in Brooklyn's notorious Gowanus Canal, if it included a variety of public-private cost-sharing strategies that managed runoff from both public and private land (Montalto et al 2007). The Mayor's Office of Long-term Planning posted the paper on its website. For many, it seemed that the sustainability community had for the first time closed the circle, demonstrating how by synchronizing land use, green space, and water management programs, cities could bring about the sustainable city of the future.

Green Infrastructure becomes City Policy

Published in 2007, PlaNYC ultimately contained specific commitments on natural solutions -- planting a million more trees in the city, developing existing underutilized parkland and creating

for accommodating population and economic growth. The PlaNYC vision included the development of housing and commercial properties, many built on land that was no longer used for industry, as well as the transportation infrastructure to move people between home, work, and other destinations, and the water, waste, and wastewater infrastructure to support those new uses. PlaNYC also recognized that the City would have to make improvements to stay livable with such a population increase, and therefore call for a network of new recreational spaces, some created by simply lighting existing parks for night uses, some by opening up schoolyards for after-hour use by the broader public, and some by repurposing vacant industrial waterfront lands to brand-new parks like Brooklyn Bridge Park. These efforts were completed by various improvements to publicly-owned streets and sidewalks, now reconceptualized as the "public realm," with pedestrian plazas, bike lanes, and a commitment to plant a million more trees. Much of this work required novel approaches and sensibilities (e.g., DOT had to pay attention to pedestrians and cyclists) or was at the intersection of hitherto separate domains (e.g., economic development and parks).

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new open space (schoolyards, DOT spaces), and protecting wetlands – in addition to piloting best management practices for stormwater controls like expanded tree pits and swales along roads.[3] PlaNYC also committed to forming an interagency task force on reducing CSOs, though it did not commit the city to a CSO reduction plan based on GI. Perhaps more importantly, implementation of PlaNYC was the responsibility of the Mayor's Office, during an Administration that demanded interagency cooperation and showed little tolerance for silos within or between agencies.[4]

The Mayor's office used its convening mandate under PlaNYC to create inter-agency working groups on stormwater comprised of representatives from DEP, DOT, DDC, Parks, Planning, and other agencies, as well as citizen groups, to identify the root problems of impervious surfaces across the city, to codify ongoing efforts to establish the feasibility of the green infrastructure, as well as opportunities for early adoption. The grey vs green debate continued through these interagency working group meetings. Gradually, representatives from DEP, Parks, DOT, DDC, DOHMH, and other agencies worked together to develop feasible green infrastructure solutions that could also address traffic calming, urban heat island mitigation, climate resilience, and other city issues.[5]

Supported by a limited budget for stormwater modeling from DEP, the Mayor's Office next published the Sustainable Stormwater Management Plan in 2008. Among other things, this document committed the City to invest $2 million in approximately 20 pilot source controls designed to answer unresolved questions about the feasibility, costs, maintenance, and performance of various source control techniques. At a ribbon-cutting for one of the first tree pits designed to absorb street runoff, still working at Fourth Avenue and Dean Street in Brooklyn, it took commissioners from four agencies (NYCDEP, NYCDDC, NYCDOT, and NYC Parks) to commit to cooperating on funding, siting, and building such stormwater infrastructure projects.

The tide was shifting in Albany as well. State regulators were increasingly responsive to environmental and community stakeholders with a formal role in the LTCP CACs. These advocates began to pressure the NYSDEC to require the NYCDEP to incorporate GI into the LTCPs. As pressure from the environmental groups grew, DEP knew it needed to find solutions that would help it to comply with the CSO regs, that could be built with minimal community opposition, and that would avoid huge rate increases. In 2008, it submitted its Environmental Benefit Project Plan to NYSDEC. It proposed $4 million for the design and implementation of GI

[3] PlaNYC 2007.

[4] PlaNYC was led by a strong Mayor's Office that was focused on results and had little tolerance for the old rigid separations of agency missions, not to say territoriality. PlaNYC's shift in the philosophy of governing created opportunities for interesting and creative progress that were viewed with relief and enthusiasm by many City employees who had signed up for mission-oriented careers. Accordingly, most of the time agency silos were broken down voluntarily through the power of convening inter-agency staff working groups, with strong-arming of reluctant leaders a rare occurrence. PlaNYC also encouraged municipal officials to look outside of New York to benchmark the most innovative policies, from congestion pricing in Stockholm and London to the bus rapid transit program in Bogota. PlaNYC represented a break from the insular approach of prior Administrations, where the legitimate differences between New York City the rest of the low-density U.S. became an excuse to disregard policies from other cities and indeed to perpetuate idiosyncratic and even failed approaches such as piling bags of trash on sidewalks instead of in containers. With roots in an international competition to host the 2012 Olympics – which New York narrowly lost to London – PlaNYC broadened the perspective to the world stage where many cities matched or exceeded New York's population, density, and complexity.

[5]

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in the Flushing, Gowanus, and Bronx River watersheds. Academic research and modeling made the theoretical case that these practices could be scaled up and used to comply with EPA's CSO policy.

But to stand behind the green approach, the DEP needed to get DEC and the EPA to accept this approach, and it was required several more years to get the GI Plan adopted in the 2012 Consent Decree between DEC and DEP. On a parallel track, this effort required getting tacit approval by the federal government, and the EPA had taken a hard line on LTCP policies that were costing cities hundreds of millions of dollars in unfunded mandates. On the other hand, the new Obama Administration was favorable to city initiatives and policies, and PlaNYC had momentum and widespread recognition as a proactive, innovative approach to sustainability.[6] Appeals to DEC Commissioner Joe Martens and his senior leadership overrode staff concerns, especially after DEP proposed demonstration projects on larger scale than ever implemented: the installation of green infrastructure throughout the largest public housing campus in the Bronx, the 53-acre Edenwald houses, which was conveniently situated at the "headwaters" of a sewershed that would accommodate pre- and post-construction monitoring of stormwater volumes. This project eventually showed that a combination of porous pavement sidewalks and parking lots, bioswales, and raingardens could minimize CSO discharges by absorbing an inch of rain from 30% of the site[7]. If replicated across the city at that scale, green infrastructure would significantly reduce CSOs that are caused by a surge in peak runoff volumes over sewer capacity during storms. In the 2012 consent order, the City also committed to milestones for implementing green infrastructure to control stormwater from a certain percentage of combined sewer areas.

GI reformers within DEP also had to convince agency and city staff that the green infrastructure approach would be cost-effective. DEP staff were in the midst of implementing the Jamaica Bay Watershed Management Plan and the 2008 Sustainable Stormwater Management Plan, and many of its experimental green infrastructure projects. Monitoring these early pilot projects validated the runoff reduction claims made by academics and by practitioners working in other cities.

A working group representing different operating divisions within DEP produced the NYC Green Infrastructure Plan of 2010 (GI Plan). This plan estimated the co-benefits of a $1.5 billion commitment to green infrastructure at $700 million while costing less than deep storage tunnels that would otherwise have to be constructed to store an equivalent amount of stormwater, which made a mixed green and grey infrastructure approach a better benefit-cost proposition for the city than an all-grey approach.[8]

A key moment in the City's adoption of the GI Plan was after a briefing on the plan, when Mayor Bloomberg turned to Budget Director Mark Page for his opinion, which was that if the City was

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[6] More details in future drafts, including articles Cas and Carter wrote in law and environmental journals.

[7] [Author's note: This reads like a design-storm figure, but I think it was observed pre/post sewershed monitoring at Edenwald. That has to be clearer and matched with other field data on performance in real storms, in winter (frozen soils do not infiltrate), and after several years of sediment loading.

[8] [Author's note: The co-benefit figure is doing all the analytical work, so we might consider a full treatment: valuation method, discount rate, benefit incidence (who captures shade / property-value gains), additionality (would the trees have come anyway under MillionTreesNYC?), and a sensitivity range. At a minimum we need more details of the plan, e.g., grants to Brooklyn Grange.]

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going to spend over a billion dollars on CSO controls, it might as well also provide visible, beautiful benefits, unlike concrete in a hole in the ground. With that commitment, DEP hired staff to find suitable locations, developed mapping tools and measurement protocols, built a capital construction program, and invested substantial funds for design and construction. [9]

DEP's involvement in visible infrastructure that was part of the City's streetscape, and proactive planning with other stakeholders, required cultural change in that engineering-dominated agency that had successfully built thousands of miles of water and sewer pipes buried far below the surface and therefore out of public sight and mind. Control over stormwater performance standards of the sewer system – even then undersized for storms that exceeded the 1.5-1.75 inch per hour – was tightly controlled by individuals who had established control over that critical standard, at least internally. To consider green infrastructure at a meaningful scale, DEP's own internal critics had to be satisfied, and DEP's internal reformers needed to be supported. Nevertheless, the seeds of internal support had been planted in the also successful natural approaches to the upstate drinking water supply system that avoided billions in filtration costs and in constructed wetland areas known as "Bluebelts" that were only practical to limit street flooding in unsewered, low-elevation areas of Staten Island. There was a growing realization that useful, crowdsourced information like 311 complaints of sewer backups[10] depended on public engagement and that the automation of meter reading created the opportunity to use data to explain water bills, an inherently two-way communication. This gradual opening was greatly facilitated by the termination in early 2010 of a decade-long oversight by a federal monitor, and with that, the fear that every novel approach might lead to criminal penalties.[11]

GI Plan Post-Script

[9] [Author's note: it is a telling vulnerability if the pivotal adoption argument here is amenity and visibility, not CSO cost-effectiveness. If GI clearly won on $/gallon we would not need the aesthetics case to close the deal.]

[10] NYC311 was announced by Mayor Bloomberg in his 2002 State of the City address and launched on March 9, 2003, consolidating more than 40 separate agency call centers and hotlines into one non-emergency number. DEP's non-emergency hotlines were among the 40-plus lines folded into 311 at or shortly after the 2003 launch, so sewer and drainage complaints — including backups — were reachable through 311 from the system's early years rather than being added as a distinct later feature. DEP still maintains a parallel direct number, and 311 materials from the mid-2000s already route sewer/catch-basin complaints to DEP. The NYC Open Data "311 Service Requests from 2010 to Present" dataset — begins in 2010, and sewer complaints appear in it from the start. In that dataset, the relevant DEP entries sit under a "Sewer" complaint type with descriptors such as "Sewer Backup," alongside related sewer-adjacent options that are useful for the same kind of analysis: Catch Basin Complaint, Catch Basin or Sewer Odor, Dumping in Catch Basin, and Dry Weather Sewage Discharge Complaint.

[11] The monitor had been appointed in 200 under the OSHA program in the wake of fatalities from unapproved equipment modifications. Oversight created potential criminal penalties for not strictly following protocols and, understandably, this led to an internal culture that was reluctant to deviate from rules or even conventional engineering practices. The spillover effect was profound even in the non-criminal regulatory context, where it was easiest to plan, design, and build grey infrastructure CSO controls regardless of cost or lack of public support.

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Within 15 years of the 2012 consent decree, the DEP, working with other agencies, has created the largest green infrastructure program in the country, with over 16,000 green infrastructure assets constructed and over $1 billion encumbered.[12]

To achieve this goal, DEP had to resolve numerous obstacles around finding enough places that were not limited by surface configurations and conflicts (e.g., fire hydrants, existing street furniture, bus stops), underground infrastructure (e.g., utilities, pipes, subways, and sidewalk vaults), and site geology (e.g., high bedrock that would not infiltrate stormwater). Accordingly, DEP kept experimenting with green infrastructure designs beyond the original tree pits and bioswales. New typologies included infiltration basins with a concrete or grass strip top that allows water to pass through a structured inlet and accommodates residents with aesthetics that fit into existing curbs and sidewalks, porous pavement that could be used in areas with high bedrock like the Bronx, as a substitute for asphalt walk and roads (especially in parks), or where grass-topped green infrastructure on sidewalks would displace trees. Underground stormwater tanks under parking lots that would store and slowly release runoff. DEP located medians in Queens, Brooklyn, and the Bronx that could be retrofitted to serve as green infrastructure that absorbs street runoff.[13] And DEP is working with the Parks Department to pursue a large "daylighting" project to disconnect Tibbetts Brook in the Bronx from the sewers and restore it to its historic and natural course, which will free up 30 million gallons a day in sewer volume.

Expansion of Green Infrastructure to Private Property and for Climate Resiliency

To ramp up the program quickly, almost all the green infrastructure projects to date have been located in the public right-of-way along or in roads and sidewalks that the City controls, or in a few NYCHA complexes. These areas represent about 30% of the City's surface area, so continued progress requires DEP's green infrastructure program to expand to new development and redevelopment (7%), parks (12%), and existing buildings and developed areas (48%).[14]

In 2022, DEP adopted the Unified Stormwater Rule (USWR), which requires new public and private construction and redevelopment to capture significantly more stormwater.[15] For other properties over 50,000 square feet, the City has created the NYC Resilient Partners program to pay $350,000 per greened acre for voluntary stormwater retrofits, with Greenwood Cemetery an

[12] NYCDEP, 2024.

[13] Beach 67th Street, Hillside and Winchester Boulevards in southern Queens, Union Turnpike, Springfield Boulevard, Francis Lewis Boulevard, and North and South Conduit. Four more are in design in the Bronx (2) and Brooklyn (2). These medians are being used by DCP as examples of good urban designs in their NYC Urban Design Guidebook.

[14] A key challenge in reaching these areas is one of engagement and incentives, addressed below.

[15] The USWR requires any public or private development that disturbs 20,000 square feet (approximately 0.46 acres) or more of soil or creates 5,000 square feet (approximately 0.11 acres) or more of new impervious surfaces, such as rooftops, sidewalks, and pavements. These projects must adhere to stringent stormwater management requirements to mitigate the impact of runoff. Key mandates include the preparation of a comprehensive Stormwater Pollution Prevention Plan (SWPPP), which details stormwater management measures such as site maps, construction drawings, soil testing results, and erosion control practices. The USWR emphasizes the use of retention-based Stormwater Management Practices (SMPs) like bioretention, rain gardens, and permeable pavements to effectively manage stormwater on-site. SMPs are designed to protect, restore, or mimic the natural water cycle within built environments by retaining, detaining, and/or treating stormwater runoff.

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early adopter.[16] Separately, DEP has longstanding partnerships with DOE to retrofit hundreds of schoolyards at public schools.[17] and with NYCHA to retrofit pathways, parking lots, and basketball courts.[18] DEP recently announced a partnership with Parks to build Brooklyn's first Bluebelt in Prospect Park.[19] The legacy of the changes needed to implement a distributed green infrastructure helped DEP deliver complementary programs that use real-time monitors in streams, streets, and sewers to identify stormwater flooding areas and dispatch crews to uncover street basins and unclog sewers.[20]

New York City's green infrastructure program has utility beyond its additional purpose . First started as a CSO control program for areas in the city with combined sewers, it was extended to control stormwater pollution in separate sewered areas of the city, and more recently is being considered as part of the City's resilience plan to adapt to climate change. DEP had direct experience responding to heavy rainfall events known as cloudbursts that greatly exceed sewer design capacity, knew that climate change would mean more of those kinds of storms, and launched community-based resiliency planning.

Completed in 2017, the Cloudburst Resiliency Planning Study assessed and recommended incorporating blue-green approaches to retaining and conveying water during extreme conditions.[21] A critical factor was the opportunity to maximize community and environmental benefits, like shade from trees in normal conditions. This prescient effort received wide interest when record high rainfall from the remnants of Hurricane Ida – measured at 3.15 inches per hour – caused widespread street flooding in 2021. The City is now developing programs for cloudburst hubs that incorporate clusters of green infrastructure.[22] To be effective, these installations will have to capture much larger volumes of water to shave the peak from intense storms compared to green infrastructure that solely addresses CSOs.

Engaging the Public in Stormwater Planning and Maintenance

Rainfall is a natural phenomenon and the invisibility of stormwater infrastructure means that it has been taken for granted: rain falls, disappears into a catch basin, and residents rarely consider where it goes or what its management costs. Green infrastructure changes that equation because, unlike a buried tunnel or even above-ground CSO storage tank behind a wall, it lives at the surface

[16] [Author's note: Is $350k/greened acre an efficient price? Can we compare it to the City's own cost per greened acre in the public right-of-way, and compare the mandate approach (USWR) with the subsidy approach (Resilient Partners) on cost and coverage. This calls out that NYC has no stormwater / impervious-area fee, so private on-site retention is not self-financing and the City must pay for it.]

[17] There are over 280 green schoolyards, but we need to identify the number with stormwater controls.

[18] https://urbanland.uli.org/resilience-and-sustainability/learning-from-the-new-york-housing-authoritys-cloudburst-infrastructure-program

[19] DEP is spending $50 million, matching $20 million in Mayoral and City Council funding. https://www.nycgovparks.org/parks/prospect-park/pressrelease/22281

[20] [Author's note: operations and maintenance in action and the potential "Building and Sustaining the Assets" section develops the O&M and asset-performance - the truest test of durability at twenty years.]

[21] https://www.nyc.gov/assets/dep/downloads/pdf/climate-resiliency/nyc-cloudburst-study.pdf

[22] DEP has a pilot project built at S. Jamaica Houses and will be building at Clinton Houses, with four projects in advanced design and more in planning.

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in the public right-of-way, where it is seen, works (or fails), and inevitably affects the people who live alongside it. That visibility is both the program's greatest asset for public engagement and a source of new obligations.

Public engagement here is not outreach at a preliminary stage of an engineering project; it is part of the infrastructure itself. A bioswale performs only if neighbors refrain from dumping in it or letting litter block its inlet, and the fastest signal that an asset has failed often comes from a resident's 311 report rather than a scheduled inspection. In this sense community stewardship can function as distributed maintenance, extending asset life and lowering the cost of keeping thousands of dispersed assets in service. The City's early investments in two-way communication — 311 reporting of sewer backups, automated metering that made water bills explicable — built the channels on which that stewardship depends. But sustaining participation requires visible feedback loops: residents who report a problem and see it addressed keep reporting; those who do not, stop.

The program's next phase makes engagement decisive. Historically, New York has mobilized its public around water before — the nineteenth-century sanitary reformers, the civic ambitions of Olmsted's parks, and, more recently, the community gardeners, Green Drinks conveners, and neighborhood advocates whose grassroots energy helped launch this very program. That history carries a lesson and a caution. Engagement anchored to a visible, everyday benefit — a shadier street, a calmer intersection, a daylit brook — endures, while engagement conducted in the name of abstract compliance fades once its champions move on. The more frequent, severe climate-driven flooding of the 2020s is not abstract at all and may be the best opportunity to get a broader swath of city residents engaged in water management issues.

Regarding planning for the construction of green infrastructure, roughly *[48]* % of the city's surface lies on private and developed land beyond the public right-of-way, meeting long-term stormwater goals depends on the choices of private owners, institutions, and residents. Regulation (the Unified Stormwater Rule) and subsidy (the Resilient Partners program) each reach part of that landscape, but the most powerful engagement instrument remains unused: the City recovers stormwater costs through general water and sewer rates rather than a charge tied to impervious area, so an owner who retains runoff sees little direct reward.[23] A price signal linked to

[23] [Author's note: This may be too prescriptive for this paper. Nevertheless, here is some history.

Stormwater fees have been discussed for years in NYC since at least the 2008 Sustainable Stormwater Management Plan. The 2010 Green Infrastructure Plan continued that discussion and DEP began experimenting with stormwater charges in 2012, creating a Stormwater Pilot Program for stand-alone parking lots that requires lot owners to pay a charge for the stormwater runoff they produce, or demonstrate that they are managing it on-site with green infrastructure. IIn 2014 that fee generated $501,882 in bills across 557 parking lots. The rate has crept up over time — as of January 2018 the stormwater charge was about $0.065 per square foot. Notably, from 2011 through 2019 no parking lot owner opted to install green infrastructure to avoid the payment. This remains the only stormwater-specific charge NYC has ever imposed, and it applies to a narrow slice of properties. DEP's May 2023 proposal of a 4.42% water-rate increase "to pay for stormwater resilience" was a general water-rate increase funding stormwater and resilience work, not a stormwater fee based on impervious area.

However, in 2020. DEP initiated its Sustainable Rate Structure Analysis (SRSA) in 2020 — a holistic rate study of structure options intended to better reflect the water and sewer systems' needs, including a third-party review of water and stormwater rates in 10 cities that was published in August 2021. A recurring obstacle is ambiguity over localities' legal authority to impose such a fee; Ithaca is the only municipality in New York State with a general stormwater fee, adopted in 2014, and no other locality has followed. State legislation to resolve that has been introduced repeatedly — the 2023–2024 Albany session included A4019/S4169 to explicitly authorize local stormwater fees, with companion bills

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imperviousness would enlist private decision-makers more effectively than any outreach campaign, and pairing it with rebates, default-on retrofit standards, and salient information on the bill would turn an abstract public good into an individual incentive.

Another key engagement need is for the maintenance of distributed stormwater assets and asset performance over time.[24] A distributed green infrastructure program requires a new approach. Whereas a stormwater storage tunnel is a single large asset with a resident crew, much like the 14 wastewater treatment plants, NYCDEP also has dedicated crews and protocols for maintaining distributed "grey" assets such as nearly 7,000 miles of sewers, 150,000 catch basins, and 109,000 fire hydrants. Nevertheless, DEP uses PSAs and social media to encourage the public to co-manage these assets through such activities as clearing leaves from catch basins or working with a local firehouse to install sprinkler caps.

These longstanding programs are a template for the green infrastructure network of approximately 16,000 small assets dispersed across sidewalks, medians, and housing campuses, each exposed to traffic, weather, litter, road salt, and the daily life of the street. Inlets clog with sediment, leaves, and trash; soils compact and lose infiltration capacity; plantings are stressed by drought, winter salt, and, in some places, by vehicles and foot traffic; and an asset that no longer draws down within 24 to 48 hours has ceased to reduce runoff regardless of its original design. To manage this, DEP has developed inspection protocols, a maintenance-tracking system, and dedicated crews, and adapted asset designs — structured inlets, porous surfaces, subsurface storage — partly to reduce clogging and maintenance burden. Because different assets fall within the jurisdictions of different agencies — DEP, DOT, Parks, and NYCHA — clear assignment of maintenance responsibility has been an institutional as much as a technical challenge. In addition, DEP will have to engage the public in maintaining green infrastructure assets.

POTENTIAL NEW SECTION: Measuring Successes

[Note: the authors acknowledge that the preceding sections describe what the City built, i.e., program outputs, rather than water quality outcomes. This section new section could describe outcomes, but NYCDEP models would have to answer how much of any improvement is attributable to green infrastructure as distinct from the grey upgrades, disinfection, and floatables controls undertaken over the same period. However, this gets technical very fast and may not fit with the rest of the article; the citizen science on ambient water quality testing WOULD fit with the thesis.]

Goals. The city's goals for improving harbor water quality have been stated differently over the past twenty years. PlaNYC's original water quality goal was to "open 90% of our waterways to recreation by preserving natural areas and reducing pollution" (2007), which was later modified to "Improve the quality of our waterways to increase opportunities for recreation and restore coastal ecosystems" (2011), and then "New York City will mitigate neighborhood flooding and

introduced as of June 2023 that remained in committee, and a further version (A4831) carried into the 2025 session. In November 2023 the city's Independent Budget Office published two analyses — an explainer and a modeling study ("Raindrops Keep Falling on New York") — that applied the rate structures of Baltimore, Philadelphia, Seattle, and Washington, D.C. to NYC parcels to illustrate the revenue and distributional effects of a possible fee.]

[24] [Author's note: If time allows and we can get the data from DEP, we could report the share of constructed assets inspected as functioning to specification after five and ten years, the observed failure and rehabilitation rates by asset type, and the resulting cost per asset-year and per gallon managed. Where monitoring data are limited we could say so and note a gap between design capacity and verified field performance.]

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offer high-quality water services" with a relevant indicator of "increase the CSO capture rate from 78 percent" (2015) and "improve the health and ecological function of NYC's waterways [by reducing] combined sewer overflows by more than 4 billion gallons per year by 2045 to improve water quality, [developing] a strategy to end the discharge of untreated sewage into the New York Harbor by 2060, [and improving] the health and ecological function of wetlands."

Water-quality outcomes. Metrics that test the original 2007 recreational-access goal (shoreline enterococcus in wet weather, and 303(d) use-attainment for the enclosed creeks and canals) show the goal substantially unmet in places people most want to use. However, the later goals and metrics (capture rate, dollars committed, harbor-wide dry-weather averages) largely show targets met or on track. So, it is a mixed verdict: the city has improved open-water dry-weather conditions but still struggles to meet wet-weather shoreline recreation and tributaries under water quality goals.

- Regarding recreation and ecosystem outcome data, the Harbor Survey shows good results in open water and in dry weather. Sampling is now 40 sites, weekly in summer (May–October) and monthly in winter (November–April), with raw data on NYC Open Data. On bacteria: since the 1990s, average harbor-wide surface water fecal coliform levels have been well below the state maximum standard for fishing and boating (2,000 cells per 100mL) and bathing and other recreation (200 cells per 100 mL), and since NYCDEP began monitoring enterococci in the early 2000s, levels have remained below the state maximum standards. On oxygen: since the 1990s, the annual summer average for surface and bottom water dissolved oxygen levels of open water sites have been above New York State standards (the 5.0 mg/L minimum). Note that these improvements preceded the green infrastructure discussed in this article. Moreover, a critical qualifier attached to both: short-term spikes in bacteria may occur after heavy rain. So harbor-wide averages meet standards; wet-weather and shoreline conditions are where attainment breaks down.
- Regarding recreational uses in 303(d) impaired waters, the official pass/fail by waterbody, the 2007 PlaNYC recreational goal is clearly *not* met for the enclosed tributaries. The most recent finalized list is the 2020/2022 list, issued September 11, 2024; the 2024/2026 Integrated Report is still in progress (its data-solicitation window closed October 28, 2025). On September 11, 2024, New York State issued the Final 2020/2022 NYS Section 303(d) List and the 2020/2022 Section 305(b) Report. The listed impairments in the NYC tributaries are driven by exactly the wet-weather problem above — for the Bronx River and its region, for example, use of these public resources has been lost due to low dissolved oxygen, fish passage barriers, floatables, pathogens, and nitrogen, with CSOs, sewage, stormwater runoff, and unpermitted discharges named as the major factors. Newtown Creek, Gowanus Canal, Flushing Bay/Creek, and similar enclosed waters remain impaired on the same basis.
- CSO capture rate (the 2015 metric). DEP's standardized citywide capture rate has risen from about 30% in 1980 to over 80% today, up from the 78% baseline cited in the 2015 plan. Infrastructure developments have increased DEP's standardized CSO capture rate from about 30% in 1980 to over 80% today. Again, most of those improvements preceded green infrastructure. DEP does not publish a sharper single number than "over 80%" in its public-facing materials, so treat 78% → ~80%+ as the tracked movement. On this metric specifically, the city is at or just past its stated target — but note this is an engineering input, not an in-water outcome.
- CSO volume and the reduction commitments (the 2015/2045 goals). About 60% of the city is on a combined system. Approximately 60% of New York City has a combined sewer

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system, with approximately 400 CSO outfalls that annually discharge approximately 18 billion gallons of combined sewage, making it one of the largest combined sewer systems in the U.S. The enforceable green-infrastructure target was reset in the June 2023 Consent Order modification: NYCDEP must reduce CSOs by 1.67 billion gallons a year by 2040 and expend $3.5 billion to implement the program by 2045. Progress against this is tracked in DEP's quarterly CSO Consent Order reports. The ~18 billion gallons/year figure is the current discharge baseline against which the "4 billion gallons per year by 2045" and end-of-untreated-discharge-by-2060 aspirations are measured — so on volume, the city is early in a multi-decade path, not near completion.

- HEP State of the Estuary (the broad ecological scorecard). The current edition was released November 4, 2025. The Hudson River Foundation and the New York State DEC released the 2025 State of the Estuary Report, presenting key indicators and environmental trends across the Hudson-Raritan Estuary. It is organized around five long-term goals (Water Quality, Habitat and Ecological Health, Public Access and Stewardship, Port and Maritime, and Community Engagement), drawing on trends for 27 indicators compiled from 25 years of monitoring, with an interactive indicator map. Generally, the State of the Estuary shows strong long-term improvement and attainment of harbor-wide pathogen and historical DO conditions, but also that some DO gains are plateauing or reversing at some sites for climate-related reasons (warmer waters and algal blooms), and with the enclosed tributaries with some exceedance.

The counterfactual. The relevant comparison is not “green infrastructure versus nothing” but “the adopted green-and-grey portfolio versus the all-grey alternative the 2010 GI Plan displaced.” Under the all-grey alternative the City would have built the deep storage tunnels described in the GI Plan. There are two challenges to showing this:, much of the reported output is design-basis rather than monitored and observed field performance, especially for the large storms that generate most overflow volume and after several years of sediment loading; and because green and grey investments proceeded concurrently, attribution between them rests on the City’s hydraulic-and-hydrologic model rather than a controlled comparison.

Summary

New York City’s adoption of green infrastructure in the post-PlaNYC era provided foundational proof of concept and the efficacy of the distributed approach, as well as institutional support that allowed capacity-building at DEP and other agencies. DEP’s early pilot projects, controlled monitoring studies, and its decade-long and ongoing research and development efforts gave the agency the confidence and experience to increase the volume of water directed to green and other distributed infrastructure. The green infrastructure program was initially developed to improve water quality by reducing combined sewer overflows. Over time, the City expanded the use of green infrastructure to address other city issues, such as the quality of stormwater discharged from separately sewered areas, and to make the city more resilient to flooding. After program success, the City and its regulators are having a very different set of discussions about green infrastructure, sustainability, and natural climate solutions that before PlaNYC; it is now about how to scale, perfect, and adapt such approaches for old and new challenges, not whether to do them in the first place.

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