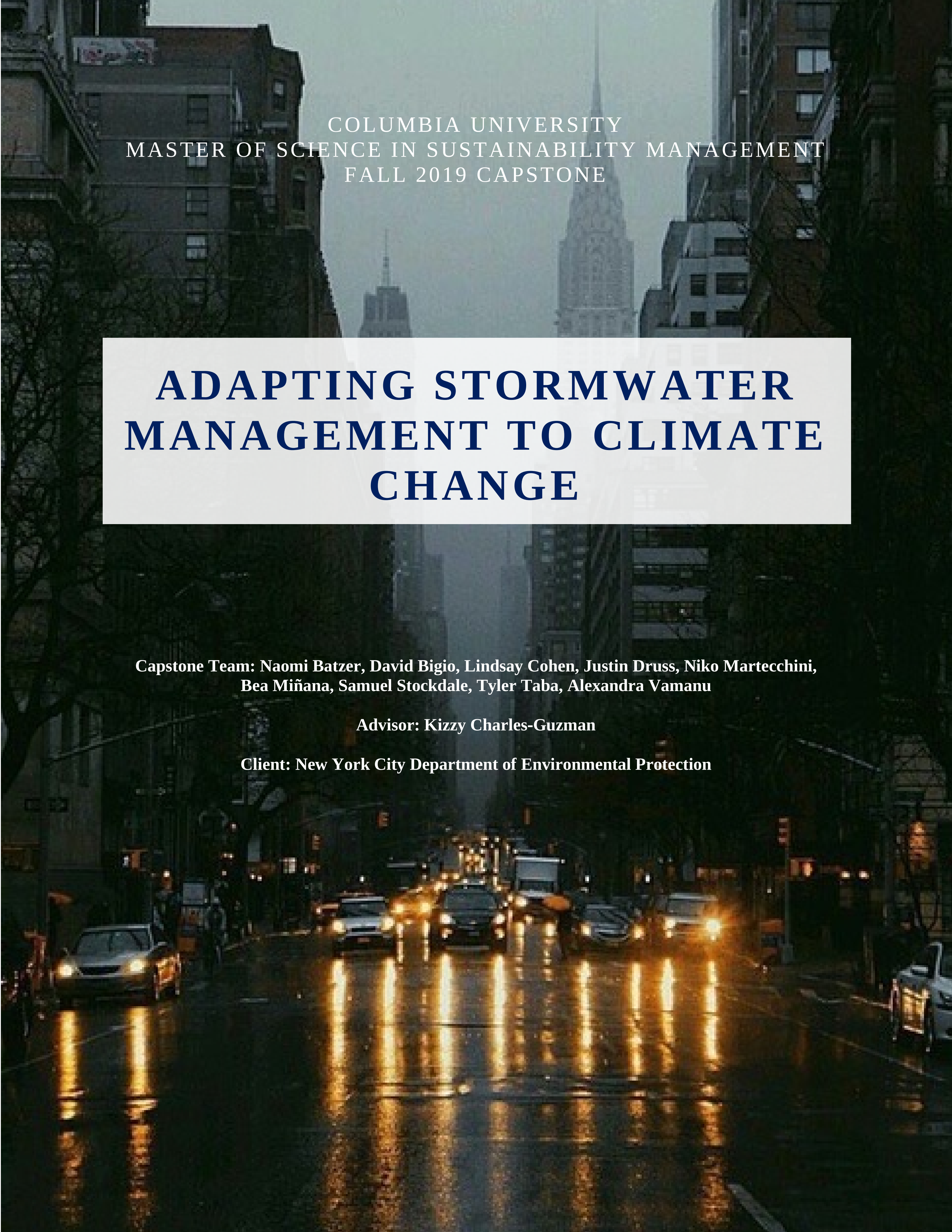

COLUMBIA UNIVERSITY
MASTER OF SCIENCE IN SUSTAINABILITY MANAGEMENT
FALL 2019 CAPSTONE

ADAPTING STORMWATER MANAGEMENT TO CLIMATE CHANGE

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Table of Contents

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Executive Summary

New York City has reached a critical point in the face of a changing climate. From 1958 to 2011, the city has experienced a 70% increase in intense precipitation events, and these trends are only expected to continue. Annual precipitation is projected to increase by 4 to 13% by the 2050s, and by up to 25% by the 2100s.[1] As a result of escalating rainfall levels, the city faces a threat of severe urban flooding, especially in regions near the coast and in areas without combined sewers: Staten Island, Jamaica Bay, and eastern Queens. Based on the research team's assessment, the combined effects of climate change and rapid urbanization have increased the frequency and intensity of flash floods, compounding the city's risk of damage from increased precipitation to the rough order of $15-35 billion, and the city's overall economic, social, and environmental risk to the rough order of $45 billion, over the next 100 years (see Appendix 3).

In light of these forecasts, the New York City Department of Environmental Protection (DEP) has tasked the Sustainability Management Capstone Workshop team to recommend ways in which the department can better incorporate climate change adaptation strategies in its stormwater management approach. DEP has already undertaken numerous projects to comply with federal mandates on water quality; however, without any mandates on climate change resiliency, the onus is on DEP to integrate climate change forecasts, and manage the influx of stormwater that is set to inundate the city's combined and separate sewer systems. Given DEP's priorities, they have asked the research team to focus on national and international stormwater management practices, integrated planning approaches for regulatory compliance, and key performance indicators (KPIs)—focusing primarily on flooding caused by extreme rain and cloudburst events.

The study explores current practices implemented by 10 national and international cities: Seattle; Portland; Copenhagen; Washington, DC; Miami; Cincinnati; St. Louis, Houston; Charleston; and Rotterdam. The research also focused on 11 key initiatives that were identified as priorities areas by DEP, related primarily to policy and governance. Findings from the research uncovered best practices with regard to stormwater data collection, modeling, funding mechanisms, market mechanisms, cooperative governance, and green infrastructure, which were then analyzed to inform the recommendations for DEP. Based on information collected through extensive desk research and interviews with subject matter experts in each city, the research team developed three-fold recommendations that are transferable and adaptable to New York City.

The first recommendation is to reposition the existing New York City Climate Change Adaptation Task Force to facilitate interagency relationships and initiatives focused on stormwater management in the city. The second is to issue a New York City Environmental Impact Bond, with measures to integrate climate projections into stormwater planning as the first capitalization priority. Finally, the third recommendation is to fund relevant best practice initiatives identified in the findings—in addition to DEP's current projects—including green infrastructure, stormwater data collection, and modeling, through the capital collected from the Environmental Impact Bond.

Glossary of Terms

Bioswales: a long, channeled depression or trench that receives rainwater runoff, and has vegetation and organic matter to slow water infiltration and filter out pollutants[2]

Bluebelts: ecologically rich and cost-effective drainage systems that naturally handle the runoff precipitation that falls on streets and sidewalks[3]

Climate Change: a long-term shift in global or regional climate patterns; often refers specifically to the rise in global temperatures from the mid-20th century to present[4]

Cloudburst: a sudden copious rainfall[5]

Combined Sewer Overflow (CSO): when the combined sewer system is overburdened during a storm event, a mix of stormwater and untreated wastewater is discharged directly into surrounding waterbodies at certain outfalls as a "combined sewer overflow"[6]

Combined Sewer System: sewers that are designed to collect rainwater runoff, domestic sewage, and industrial wastewater in the same pipe[7]

Compound Flooding: floods that arise through the joint occurrence of different source mechanisms, including oceanographic drivers such as tides, storm surges, or waves, as well as hydrologic drivers such as rainfall runoff or river discharge[8]

Convective Storms: a strong thunderstorm[9]

Debt Service: the cash that is required to cover the repayment of interest and principal on a debt for a particular period[10]

Environmental Impact Bond: an innovative financing tool that uses a Pay for Success approach to provide up-front capital from private investors for environmental projects, either to pilot a new approach whose performance is viewed as uncertain or to scale up a solution that has been tested in a pilot program[11]

Extreme Precipitation Event: days with precipitation in the top 1% of all days with precipitation[12]

Geographic Information System (GIS): a computer system for capturing, storing, checking, and displaying data related to positions on Earth's surface[13]

Governance: establishment of policies, and continuous monitoring of their proper implementation, by the members of the governing body of an organization; includes the mechanisms required to balance the powers of the members (with the associated accountability), and their primary duty of enhancing the prosperity and viability of the organization[14]

Green Infrastructure: a cost-effective, resilient approach to managing wet weather impacts that provides many community benefits; reduces and treats stormwater at its source while delivering environmental, social, and economic benefits[15]

Green Bond: a bond specifically earmarked to be used for climate and environmental projects; typically, asset-linked and backed by the issuer's balance sheet; also referred to as climate bonds[16]

Green Roof: vegetated landscape built up from a series of layers that are installed on a roof surface as 'loose-laid' or modular[17]

Grey Infrastructure: includes the pipes, pumps, ditches, and detention ponds engineered by people to manage stormwater[18]

Impervious Surface: land surfaces that repel rainwater and do not permit it to infiltrate the ground[19]

Integrated Stormwater Plan: offers a voluntary opportunity for a municipality to propose to meet multiple Clean Water Act requirements by identifying efficiencies from separate wastewater and stormwater programs and sequencing investments so that the highest priority projects come first[20]

Inter-fund Agreement: amounts transferred from the city's capital projects fund to the general fund for capital-related work performed by city employees or contractors; typically for planning and design work and project supervision[21]

Municipal Separate Storm Sewer System (MS4): a publicly-owned conveyance or system of conveyances (including but not limited to streets, ditches, catch basins, curbs, gutters, and storm drains) that is designed or used for collecting or conveying stormwater and that discharges to surface waters of New York State[22]

Nuisance Flooding: low levels of inundation that do not pose significant threats to public safety or cause major property damage, but can disrupt routine day-to- day activities, put added strain on infrastructure systems such as roadways and sewers, and cause minor property damage[23]

Pervious Surface: a surface that allows the percolation of water into the underlying soil[24]

Surface Runoff: water, from rain, snowmelt, or other sources, that flows over the land surface, and is a major component of the water cycle[25]

Urban Flooding: flooding caused by excessive runoff in developed areas where the water doesn't have anywhere to go[26]

Watershed: a land area that channels rainfall and snowmelt to creeks, streams, and rivers, and eventually to outflow points such as reservoirs, bays, and the ocean[27]

1 Project Scope

1.1 Problem Statement and Background on Issues

The Sustainability Management Capstone Workshop team is working with the New York City Department of Environmental Protection (DEP) to "recommend ways in which the [department] could better incorporate climate change projections in its stormwater management." Despite persistent forecasts of increased precipitation and cloudburst events, the city's built infrastructure, including buildings and the sewer network, is not currently positioned to withstand the water levels brought about by the projected heavy rainfall. New York City's 60% combined and 40% separate sewer system[28] is inundated with rising amounts of wastewater brought about by a growing urban population, encroaching sea levels, and increasingly frequent storms. With combined sewage overflows exacerbating pollutant discharge into the New York Harbor, regulatory compliance becomes an increasing challenge and capital investments becomes a growing need. However, while the city continues to allocate budgetary spending towards these critical issues, it needs to ensure that water rates remain affordable to customers. Beyond customer affordability, the city also faces the challenge of competing interests. Despite the necessity of climate change-adapted stormwater management, these investments often compete with regulatory mandates. Furthermore, other city resiliency investments tend to fund non-DEP projects, such as those related to sea level rise and greenhouse gas emissions.

Today, many U.S. cities face similar challenges, and many have created solutions that "allow utilities to raise revenues, enhance affordability, and negotiate regulatory flexibility." The U.S. Environmental Protection Agency (EPA) has created an integrated planning mechanism to help cities meet mandated requirements; however, only few have successfully implemented this in their cities because of the lack of data and organizational infrastructure to support the initiative. Given the current landscape of the issue, DEP has tasked the research team to conduct an exploratory study of solutions and best practices currently executed by domestic and international cities, conduct feasibility assessments in the context of New York City, and develop recommendations for how the city can better adapt its stormwater management approach to climate change projections.

1.2 Scale and Scope

As outlined in the project brief, research for this project includes national and international stormwater management practices, integrated planning approaches developed for Clean Water Act compliance, and KPIs currently used to measure stormwater management success beyond water quality. Based on initial discussions with the client, the scope of this study is focused primarily on flooding caused by extreme rain and cloudburst events across the five boroughs of New York City. In terms of climate-related events, sea level rise and the effects of coastal storms on city infrastructure are considered out-of-scope for this study.

While the city has implemented multiple initiatives to comply with DEC regulations, the research team has been tasked to explore policy and governance-related solutions that can mitigate both water quality and flooding issues. Technology, infrastructure, and fee-related recommendations are second in priority for this study, since DEP has already conducted extensive research and implementation on green infrastructure, and will be conducting a rate structure study beginning in 2020, where various rate structure and fee options will be explored. To supplement the recommendation, DEP has also asked the research team to identify new ways for the city to measure and pay for climate-adapted stormwater management solutions. This entails exploring new metrics and untapped funding mechanisms that have not yet been applied in New York City.

To maintain constant communication and oversight from the client, the research team prepared regular memorandums outlining research updates and identifying data points that required further feedback and guidance from DEP.

1.3 Critical Focus Areas

To direct the research on New York City's stormwater management and climate projections, the 10 target cities, and the 11 key initiatives, the researchers rooted findings around the following topic areas established by DEP:

1. Assessment of current challenges and solutions with regard to New York City's stormwater system, specifically focused on identifying gaps and opportunities for future improvement.

2. Research on existing practices for governance of stormwater in an urban context. This research includes both domestic and international cities, aiming to capture the various ways in which cities currently respond to, and plan to adapt their stormwater systems to, climate change.

3. Identification of innovative practices in target cities in consultation with DEP, and further investigation of those practices through interviews with subject matter experts in the cities.

4. Recommendation of research-backed strategies for incorporating best practices into New York City's stormwater management approach, considering DEP's governance structure, rate structure, and relationship to the New York City Water Board. This includes an implementation plan geared towards engagement with the Water Board and other local stakeholders.


100
MICHAEL SHAINBLUM

2 Climate Change in New York City

2.1 Current Local Observations

New York City experiences significant precipitation throughout the year, typically with relatively little variation from month to month. In Central Park, for example, precipitation has increased at a rate of approximately 0.8 inches per decade, from 1900 to 2013. There has been a small but statistically insignificant trend toward more extreme precipitation events in New York City since 1900.[i] Over the larger Northeast region, intense precipitation events have increased by approximately 70% over the period from 1958 to 2011.[ii] [29]

2.2 Projections

In 2015, the New York City Panel on Climate Change (NPCC) published a report (herein referred to as NPCC2) providing New York City-specific climate projections for the 21st century. NPCC2 generated a range of climate model-based outcomes for temperature and precipitation from global climate model (GCM) simulations based on two emissions trajectories. [iii] [30]

The NPCC's 2019 report (NPCC3) confirmed these projections and showed that increasing observed annual temperature and precipitation trends between 2010 and 2017 fell within the NPCC2 low- to middle-range estimates of temperature and precipitation changes for the 2020s time period. Nevertheless, there remain substantial uncertainties with climate projections that are amplified at smaller geographical scales.[31]

2.2.1 Mean Annual Precipitation

Most GCM simulations forecast small increases in precipitation, although some do not. Natural precipitation variability is large; thus, precipitation projections are uncertain. Table 2-1 shows middle range and high-end forecasts for mean annual precipitation changes through to 2100. Precipitation increases are expected to be largest during the winter months. Projections of precipitation changes in the summer are inconclusive, with approximately half of the models projecting precipitation increases and half projecting decreases.[32]

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[i] NPCC defines extreme precipitation events as the number of occurrences per year of precipitation at or above 1, 2, and 4 inches per day.

[ii] NPCC defines intense precipitation events as the heaviest 1% of all daily events.

[iii] The emissions trajectories are representative concentration pathways (RPCs) as defined by the Intergovernmental Panel on Climate Change (IPCC).

Table 2-1: Mean annual precipitation changes[33]

	Baseline (1971-2000)	2020s		2050s		2080s		2100	
		Middle range	*High end*	*Middle range*	*High end*	*Middle range*	*High end*	*Middle range*	*High end*
Precipitation	50.1 in	+1 to 8%	+11%	+4 to 11%	+13%	+5 to 13%	+19%	-1 to +19%	+25%

2.2.2 Heavy Downpours

The frequency, intensity, and duration of extreme precipitation events is projected to increase, with approximately one and a half times more events per year by the 2080s, compared to that of the current climate.[34] The primary large weather systems that affect New York City are cyclones, which can include extratropical cyclones (e.g., caused by Nor'Easters) and tropical cyclones (e.g., hurricanes). Extratropical cyclones cause the largest number of extreme 24-hour precipitation events in each month of the year. These storms are likely to drop all precipitation in a short time period and be associated with shorter-term heavy rainfall.[35]

Rainfall that drives urban and flash flooding in the Northeast is most often caused by thunderstorms. Downpours are very likely to increase by the 2080s.[iv] An increase in precipitation, both in terms of the mean and extremes, are expected for the region. These precipitation changes are expected to occur in both winter and summer. It is projected that there will be more convective storms over the Northeast United States during the later 21st century, which will additionally increase heavy downpours and flooding.[36]

2.2.3 Urban Flooding

Increases in extreme rainfall are expected to exacerbate urban flooding, given that an increase in water volume should lead to an increase in flood peaks. [v] The number of compound flooding events in New York City are increasing as weather patterns shift and sea levels rise, causing larger precipitation levels and greater storm surge. [vi] [37]

Baseline data on 311 calls for urban flooding indicate substantial spatial variation across New York City, from 2004 to 2015. Flooding appears to occur most often in areas near the coast, as well as areas without combined sewers: Staten Island, Jamaica Bay, and eastern Queens as shown below in Figure 2-1. Analysis has indicated that high groundwater tables influence flooding along the coast, while intense 1-hour to 1-day rainfalls cause flooding farther inland. Flooding in Staten Island is primarily caused by wintertime extratropical cyclones. Differences in flooding across the

[iv] NPCC defines heavy downpours as rarely occurring rainfall at less than daily timescales that can produce urban flooding.

[v] NPCC defines extreme rainfall as a rainfall amount that is a rare event that approaches the end of the probability distribution of all events.

[vi] NPCC defines compound flooding as flooding caused by the combination of heavy downpours and storm surge.

city are likely related to rainfall patterns, proximity to the coast, impervious coverage, and differing sewer coverage. The New York City 2019 Hazard Mitigation Plan additionally includes irregular topography, soil infiltration rate, and soil storage capacity as factors that influence flooding location.[38]

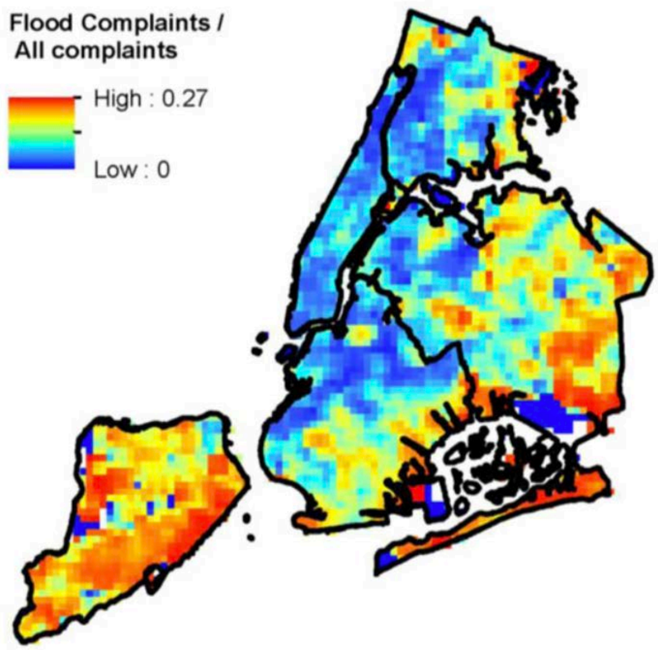


Figure 2-1: Flood observations based on 311 calls for the period 2004-2015[39]

Urbanization effects, including increased impervious surfaces, are likely to have larger impacts on the frequency and intensity of flash floods, as compared to climate change. According to the NPCC, the combination of urbanization and climate change requires flooding and stormwater management to be assessed in a nonstationary framework (i.e., a framework in which historic flood and runoff occurrence is not strictly relied upon to predict the probability of future flooding events).[40]

2.3 Impacts on Stormwater Management Infrastructure

Heavy downpours have significant impacts on New York City infrastructure, including the energy, transportation, telecommunications, and water supply sectors (see Appendix 2 for examples of potential impacts from heavy downpours by sector). Stormwater management is among the infrastructure sectors that is expected to be the most heavily impacted.[41] Examples of potential impacts include:

- Hydraulic capacity of sewers and wastewater treatment plants exceeded, owing to increased flows;
- Combined sewer overflow (CSO) facility capacity exceeded and pollutants discharged into waterways;
- Sewer backups;

- Treatment capacity of treatment plants exceeded, as result of increased flows; and
- Decline in water quality reflected in Clean Water Act standard variances.

2.4 Citywide Risk Level

Estimating the level of risk that New York City faces from climate-driven, precipitation-related flooding is difficult given various levels of uncertainty. However, past events and precedents from other cities may serve as an indication of the city's general risk level, given climate change trends.

2.4.1 Hurricane Sandy

Hurricane Sandy, the quintessential example of an extreme weather event in the Northeast, caused the deaths of 44 New York City residents, damaged over 69,000 residential units, left hundreds of thousands of New Yorkers without power, and resulted in an estimated $19 billion in damages and lost economic activity across the city in 2012.[42] It caused subway shutdowns for two days, resulting in further economic losses. During the 2005 transit strike, for example, city officials calculated that every day of Metropolitan Transit Agency (MTA) closures resulted in losses of over $300 million citywide.[43] The closures also had many far-reaching repercussions related to subway repairs. For example, the MTA recently awarded a $477 million contract for repairs to the L Train's Canarsie Tunnel, which was severely damaged due to Hurricane Sandy floodwaters.[44]

2.4.2 Precedents

Several cities have quantified the risk posed by increased precipitation and published their findings. These estimates, though not entirely indicative of New York City's risk level, can provide a starting point for developing an order of magnitude estimate.

2.4.2.1 Copenhagen

Copenhagen is planning for increasing precipitation (a 30% increase in the extrapolation of recent events), as well as rising sea and groundwater levels. The city estimated the net present value of the cost of damage caused by torrential rain over the next 100 years to be about $2.2 billion.[45] The net present value of the costs was calculated using a 7% discount rate.

2.4.2.2 New York City

DEP's Cloudburst Resiliency Planning Study (CRPS), published in 2017, focused on a pilot area in Southeast Queens. It simulated a cloudburst flood (defined as a 100-year storm) in the years 2015 and 2115 and estimated rough damage costs and risks. The overall risk over the entire 100-year period was estimated to be about $600 million: $310 million from physical damages and output loss; $290 million from social costs (injuries, mental stress, and anxiety); and $20,000 from environmental costs (water quality).

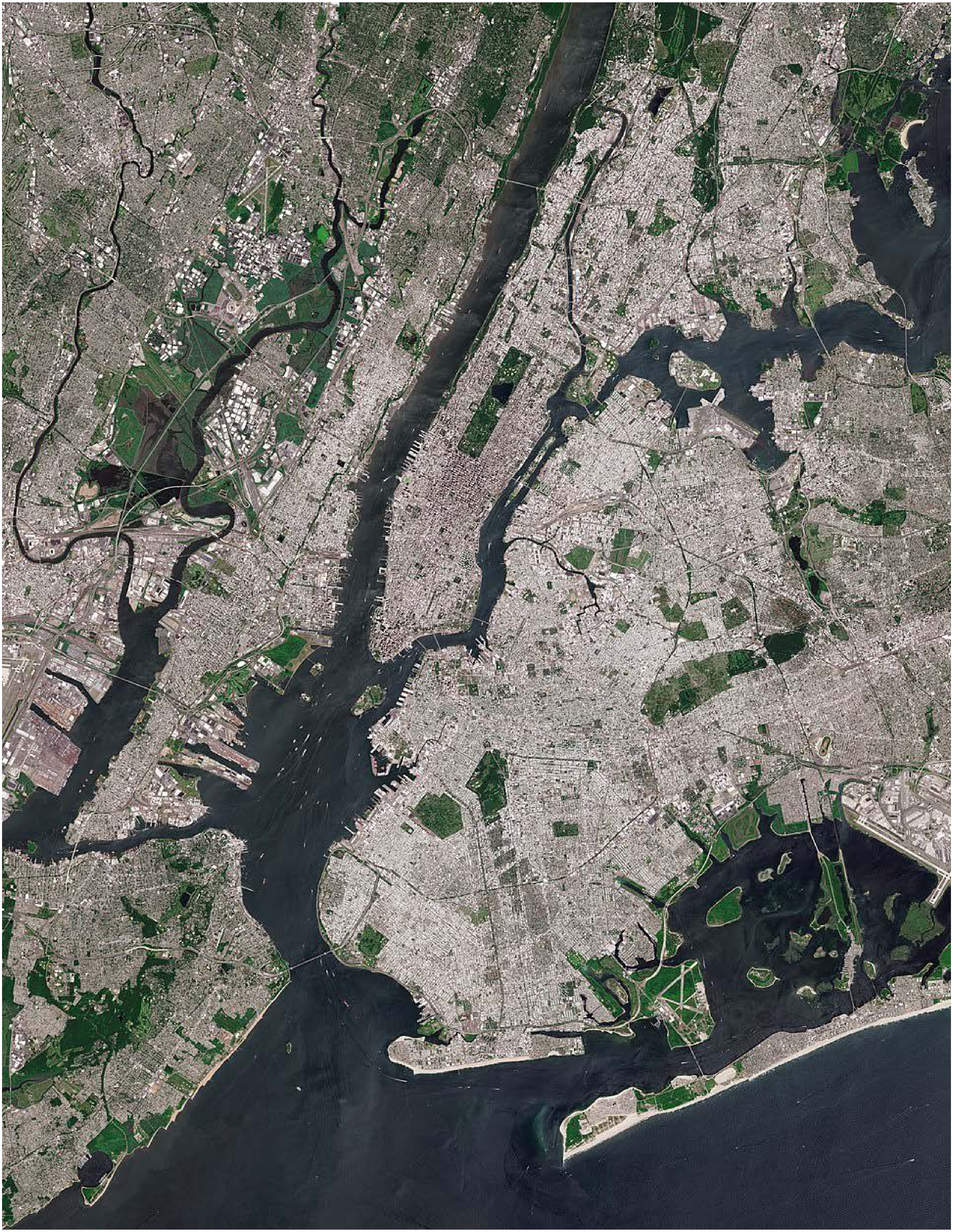
2.4.3 Order of Magnitude Risk

An order of magnitude estimate of New York City's risk level was created using the Copenhagen and the CRPS precedents as model inputs (see Appendix 3). The analysis is by no means comprehensive and serves only to provide a general idea of the city's exposure to precipitation-related impacts. Various factors—including but not limited to infrastructure locations, population vulnerability, elevation and topography, and chronic flooding locations—were not included in the scope of the analysis.

Using available data, it was determined that Copenhagen makes up about 11% of New York City's land area, is 38% less dense, and has 32% less storm intensity for a 100-year event.[46] As such, Copenhagen's estimate of $2.2 billion in risk of damage caused by torrential rain over the next 100 years was proportionally scaled to New York City. This produced an order of magnitude risk estimate of about $35 billion in damages.

It was determined that the Southeast Queens neighborhood that was the focus of the CRPS makes up less than 2% of New York City's land area, encompasses about 1% of the city's population, and is 23% less dense than the rest of the city. The $310 million from physical damages and output loss and the $20,000 from environmental costs were scaled to the city's overall land area and population density. The $290 million from social costs was scaled to the citywide population. This produced a discounted order of magnitude risk estimate of roughly $15 billion for damages alone and a total of $45 billion in overall economic, social, and environmental costs over the 100-year period.

It is therefore estimated that New York City's risk of damage because of increased precipitation over the next 100 years is on the order of $15-35 billion. It is also estimated that New York City's overall economic, social, and environmental risk over the next 100 years is on the order of $45 billion.



3 State of New York City's Stormwater Management

3.1 Current Stormwater System

New York City has a total of 7,400 miles[47] of sewer infrastructure that is crucial to draining and redirecting wastewater and stormwater. In addition to piping, DEP is responsible for operating and maintaining 135,000 catch basins, 96 pumping stations, and 14 wastewater treatment plants to manage runoff and outflow.[48] The city has two types of sewer systems: approximately 60% is a combined sewer system, while the other 40% is a separate sewer system.[49]

3.1.1 Combined Sewers

Combined sewers receive both wastewater and storm flow. Catch basins along New York City's streets collect and feed stormwater underground to be treated at the various 14 wastewater facilities.[50] When wastewater treatment plants exceed twice their design capacity, relief valves in the sewer system redirect both sewage and stormwater to the nearest outfall.[51] Events that activate outfalls are called Combined Sewer Overflows, or CSOs. The sudden rush of stormwater that creates these CSO events is primarily due to the city's impervious surfaces. 72% of New York City's land area is impervious, which does little to absorb stormwater and reduce the burden on sewers.[52] This overflow discharged to New York City waterways can create water quality issues.

3.1.2 Separate Sewers

Areas with separate sewers have grey infrastructure piping specifically for wastewater and stormwater. Wastewater is routed to treatment plants, while stormwater is discharged to the nearest New York City waterway via outfalls.[53] These areas are often referred to as MS4, or Municipal Separate Storm Sewer System, which will be discussed in section 3.4.

3.1.3 Data Collections & Modeling

DEP regularly performs hydraulic capacity studies of New York City's sewer system, and did so in 2010 and 2012 to fulfill a Best Management Practice (BMP) consent order required by the New York State Department of Environmental Conservation. Data collection used for the 2012 capacity analysis was pulled from InfoWorks, a collaborative data platform, which is built from a 2007 modeling study of the city's various sewer sheds.[54] Other data collection efforts for DEP and the City of New York are provided, open-sourced, on the New York City OpenData website.[55] Opportunities for modeling and scenario planning are an area of interest that DEP is actively pursuing.

3.1.4 Stormwater Fees

Currently, revenue required to manage stormwater in the city is collected from customers as part of wastewater rates. These rates are set to 159% of the customer's water consumption charges on their water bill.[56] DEP will be conducting a rate structure study beginning in 2020, where various rate structure and fee options will be explored.[57] Throughout the desk research and interviews, the researchers identified various fees and funding mechanisms that are worth noting. Examples of those funding mechanisms can be found in section 5.4.

3.2 DEP Organization

DEP is charged with protecting the environment and public health of all New Yorkers by providing high quality drinking water, managing wastewater and stormwater, and reducing air, noise, and hazardous pollution.[58] It falls under the control of the Deputy Mayor for Operations and the Mayor of New York City.[59]

The department was created in 1977, as a result of consolidating the water supply delivery and wastewater treatment organizations of the city. DEP receives funding through the New York City Municipal Water Finance Authority Act, established in 1985, which created two authorities: the New York City Water Board and the New York City Municipal Water Finance Authority.[60] The two authorities work with the City of New York to provide streams of funding for the water and sewer systems. The New York City Water Board sets water and sewer rates to support the system's financial responsibilities,[61] while the New York City Municipal Water Finance Authority issues investment bonds to finance the system's capital improvement projects.[62]

On a daily basis, DEP distributes approximately 1 billion gallons of clean drinking water, treats approximately 1.3 billion gallons of wastewater (combined sewer and stormwater) through 14 wastewater treatment plants, manages the separate sewer system under the Separate Storm Sewer System (MS4) permits, and regulates air quality, hazardous waste, and noise pollution through eight program areas (see Figure 3-1).[63] The department's primary focus is providing its services; however, investment decisions are driven by federal and state regulation compliance and maintaining current infrastructure levels. Since DEP has such a wide and important array of responsibilities, it can be challenging to initiate projects outside of its regulatory mandate, due to competing interests with other capital projects, competing interests with areas that are directly regulated by the federal or state governments, and its mission to keep rates low.

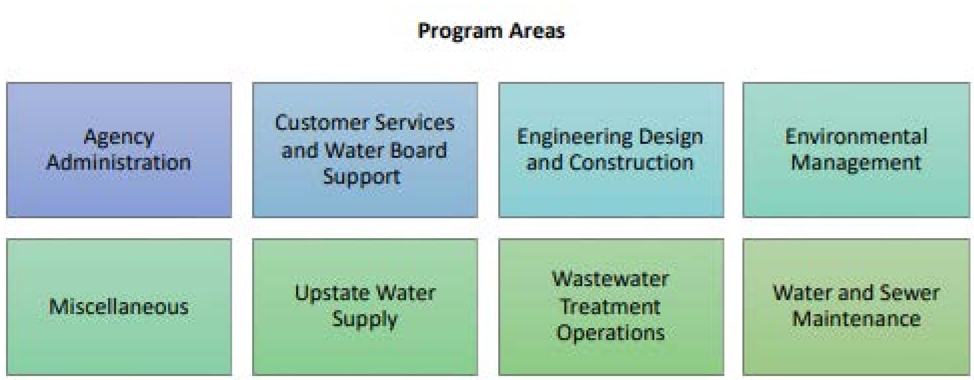


Figure 3-1: DEP Program Areas[64]

3.3 Funding and Revenue

DEP has set a 2020 preliminary budget of $1.32 billion—a 5.1% reduction from fiscal year 2019's budget of $1.38 billion. DEP's $1.32 billion budget is split into eight functions: (1) Agency Administration & Support, (2) Customer Services & Water Board Support, (3) Engineering Design and Construction, (4) Environmental Management, (5) Upstate Water Supply, (6) Wastewater Treatment Operations, (7) Water & Sewer Maintenance, and (8) Miscellaneous. Of those eight functions, Wastewater Treatment Operations, Upstate Water Supply, and Water & Sewer Maintenance comprise 82.9% of DEP's budget.

The department's $1.32 billion budget consists almost entirely of city funds through city tax-levies. 94.1%, or $1.24 billion is allocated for DEP from the city. Another 5%, or $70 million, comes from capital interfund agreements (IFA), and the remaining less of a percent comes from other methods such as grants or federal funding.[65]

Rates that are collected to fund the 94.1% of DEP's budget are collected through city water and sewer rates. These rates are set by the New York City Water Board.[66] The Water Board reviews the financial, regulatory, and capital landscape of the sewer system in order to set water rates that are fair for both the city and its customers.[67] Board members consist of seven members, serving two-year terms, who are appointed by the current New York City Mayor's administration.[68]

New York City creates long term debt through financing of bonds to fund capital expenditures, city maintenance, projects, and other initiatives. Each annual expense budget incorporates this debt through debt servicing, which is the payment of debt outstanding over fiscal years 2019 and 2020. New York City's total savings are expected to reach $916.3 million, to aid in balancing the budget and reduce debt servicing. Office of Management and Budget (OMB) has issued agencies Program to Eliminate the Gap (PEG) targets that aggregate to a total of $750 million in additional savings over fiscal years 2019 and 2020. OMB encourages new department initiatives that also improve efficiencies among resource sharing across departments. This is important to note as creating synergies across departments is encouraged and will aid in additional savings to meet PEG targets for the city.

3.4 DEP MS4 Structure

To maintain water quality despite its density and 40% separate sewer system, New York City is required to have a Municipal Separate Storm Sewer System (MS4) permit through a national mandate, under the 1972 Clean Water Act and National Pollution Discharge Elimination System (NPDES).[69] The permit was issued to the City of New York in 2015 by the New York State Department of Environmental Conservation (DEC).[70] Under the permit, DEP is required to develop a stormwater management plan that addresses (1) public education and outreach, (2) public participation, (3) illicit discharge detection and elimination, (4) management of construction site runoff, (5) management of post-construction site runoff, and (6) good housekeeping in municipal operations.[71]

DEP is working within the MS4 framework to create an integrated stormwater management plan that promotes a holistic view of water management; one that takes climate change and higher levels of precipitation into account. For example, to meet the needs of the MS4 construction and post-construction management of site runoff, DEP developed a program that includes green infrastructure. The department is also required to perform a study that recommends an appropriate reduction in the soil disturbance thresholds that trigger construction and post-construction stormwater management requirements. Through this study, DEP examined methods in grey infrastructure and green infrastructure. They found that green infrastructure, such as rain gardens and bioretention, had highest cost-benefit and water quality benefits.[72] These types of structures also add resiliency to the system, as they can absorb more precipitation and mitigate direct runoff into the water systems or water sent to wastewater treatment plants. By working within the MS4 framework, DEP can promote other stormwater agenda items that are not directly addressed within the EPA's guidelines.

3.4.1 Current Nuisance Flooding vs. MS4 Area

Working within the MS4 framework provides DEP some flexibility in its stormwater management practices. The EPA and Clean Water Act's regulatory framework gives DEP oversight and legitimacy in managing stormwater and water quality in order to meet federal regulations. This is a positive indicator, as DEP has the highest level of oversight and flexibility in areas with the highest amount of current nuisance flooding (see Figure 3-2). It is evident that the highest amount of MS4 drainage and outfalls are along the coast and in areas prone to flooding like Staten Island, the Rockaways, parts of Brooklyn and Queens. This allows DEP to manage the highest-risk areas in line with future climate change and rainfall projections.

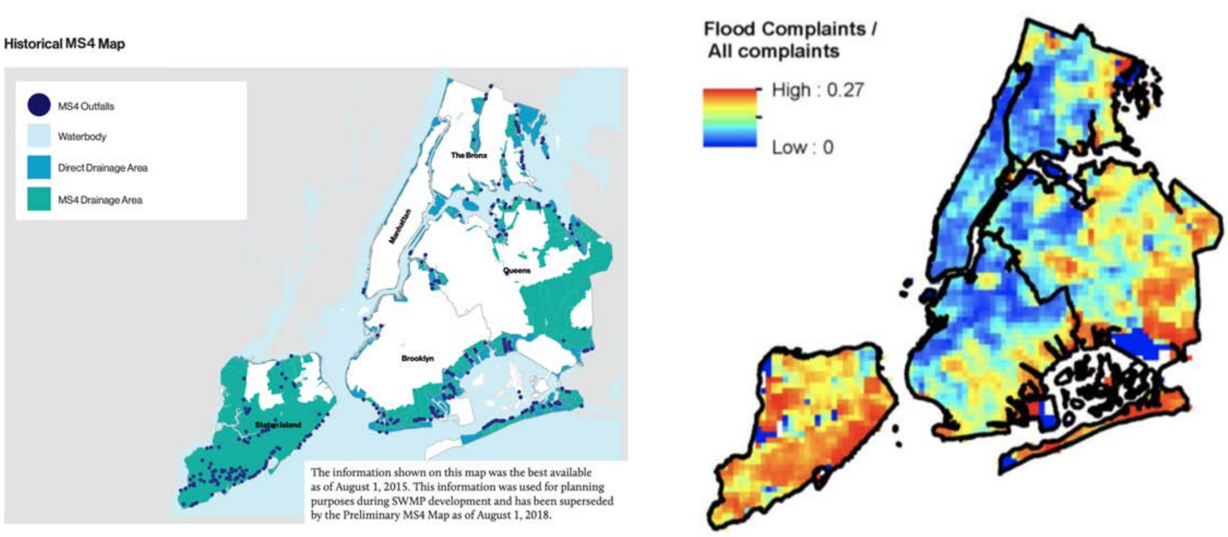


Figure 3-2: Comparison of New York City Sewer System Type[73] and Historical 311 Complaints[74]

3.5 Current New York City Practices

It is important to understand a few of the highlights to New York City's work within stormwater management, thus far. These programs provide a baseline towards DEP and New York City's scope of stormwater operations. Some of the recommendations in this report will build upon these efforts.

3.5.1 Green Infrastructure Retrofit Incentive Program

As a way of reducing stormwater runoff into New York City's combined sewer systems, the city has investigated funding and expanding above-ground green infrastructure. Based on extensive research, it has been established that green infrastructure provides numerous co-benefits to city residents, such as cooler environments, cleaner air, and better standards of living. DEP has increased funding towards a Green Infrastructure Retrofit Incentive program, scaling budgeted funds from $3.75 million in 2020, to upwards of $15.9 million in 2023. The program was devised to install green infrastructure onto privately held property in the city. It targets large parcels of land within combined sewer areas of the city that have impervious or paved areas. Increased funding and scaling of this program, along with incentives, will help reduce the strain on the city's combined sewer systems.

3.5.2 Bluebelt Program

DEP's Bluebelt Program on Staten Island provides a natural system of drainage corridors, while preserving stream and wildlife habitats in the surrounding Staten Island Greenbelt. These installed stream corridors filter and reduce stormwater runoff while providing green space for the surrounding communities. The natural system drains 16 watersheds that cover an area of approximately 10,000 acres. Drainage is connected to grey infrastructure storm sewers, which ultimately reduces the amount of precipitation runoff into sewers that would have resulted in urban flooding.

3.5.3 New York City Watershed Programs

DEP has established coordinated management of the city's water supply and quality standards. The Long-Term Watershed Protection Program and the Stormwater Retrofit Program fall under the Filtration Avoidance Determination (FAD), which has been implemented only by New York City and four other U.S. cities. These programs, in order to comply with FAD, are established to help protect and improve existing water quality without filtration. Stormwater retrofit proposals are continually assessed and reviewed by DEP, so that nearly half the population of New York State continues to receive high-quality water without the filtration costs and energy demands.

3.5.4 New York City Climate Change Adaptation Task Force

In 2008, New York City established the New York City Climate Change Adaptation Task Force (CCATF) to assist in Hurricane Sandy recovery efforts.[75] DEP was among the 60 stakeholders across city, state, and federal agencies, and the private sector, that were assigned working groups to better prepare for climate-related threats.[76] Local Law 42 (2012) established the New York City Panel on Climate Change with a mission to: identify critical infrastructure in New York City that could be at risk from the effects of climate change; facilitate knowledge sharing and to develop coordinated adaptation strategies to secure these assets; and develop a report with recommendations.[77][78] In the July 2015 meeting, CCATF developed an inventory of at-risk infrastructure that included water, sewer, and wastewater.[79]

CCATF is responsible for developing key directives that underscore some of DEP's initiatives with stormwater including:

- Review climate change projections;
- Create inventory of at-risk infrastructure;
- Develop adaptation strategies to protect at-risk infrastructure;
- Coordinate adaptation strategies across stakeholders; and
- Evaluate design guidelines to protect critical infrastructure.

4 Methodology

With New York City's climate change projections and DEP's current state as a foundation, the Sustainability Management Capstone Workshop team researched local, national, and international practices of stormwater management, and developed a set of recommendations to help DEP use climate change projections to improve New York City's stormwater management. The team selected individual cities to use as case studies on stormwater management practices, and based recommendations on information obtained during review of published literature, interviews with subject matter experts in other cities, and consultation with DEP.

4.1 Initial Research Strategy

The project commenced with a kick-off meeting between the capstone team and representatives from DEP. During the course of this meeting, the group discussed the expected content and direction of the project, and mapped out the general project progression: the team would select a number of cities to use as case studies to determine how municipalities are integrating climate change projections into their stormwater management.

The first step in this process was selecting the target cities for the case studies. The team began with a list of cities developed by DEP as part of a 2017 report on innovative national stormwater management practices.[80] 10 cities were identified as focus areas on the basis of whether DEP already had existing and extensive information on the location. Based on literature reviews and DEP's experience, the team then developed a list of 11 initiatives with which to screen the larger list of cities; the initiatives included practices like integrated planning and use of future rainfall projections based on climate change.

4.2 Ranking of Target Cities and Initiatives

To identify which initiatives to focus the analysis on, the research team ranked 11 types determined together with DEP, according to order of importance to the client, based on extensive discussions with Alan Cohn, Managing Director of Integrated Water Management at DEP, and Erin Morey, Director of Demand Management & Resilience Policy at DEP. The ranking of initiatives were determined as follows: (1) Governance, (2) Integrated Planning, (3) Green Infrastructure, (4) Key Performance Indicators, (5) Rainfall Magnitude, (6) Building Water Retention, (7) Public/Private Innovation, (8) Pumping Infrastructure, (9) Stormwater Fee, (10) Nuisance Flood Protection, and (11) Raising Road Levels.

In addition to this, based on the initial client meeting and information matrix, the researchers ranked nine out of the 10 cities considered, identifying which locations to conduct in-depth studies on. To determine the ranking of the cities, the team assigned numerical values to each of the 11 initiatives, based on how high or low they ranked in order of importance (i.e., the highest ranked initiative was assigned a score of 11, and the lowest ranked initiatives was assigned as score of one). Informed by the research compiled in the matrix, the team determined which of the 11 initiatives were implemented by each city. Given the initiatives implemented in each city, the numerical values were then summed, and the city with the highest number was ranked most important on the scale. There were few instances when a city with a lower number came before a city with a higher number; this only occurred if a city had fewer overall initiatives but a greater number of higher-priority initiatives implemented in their region. Informed by this force ranking method, the ranking of cities is as follows: (1) Seattle, (2) Portland, (3) Copenhagen, (4) Washington, DC, (5) Miami, (6) Cincinnati, (7) St. Louis, (8) Houston, (9) Charleston. In addition to these nine, Rotterdam was chosen as the innovation spotlight.

Deep-dive research was conducted on the top four cities that most effectively implemented the initiatives of interest, namely Seattle; Portland; Copenhagen; and Washington, DC. Deep-dive research was also conducted on Rotterdam as an innovation spotlight, given the city's forward-looking mechanisms and extensive experience in stormwater management. Deep-dive research includes information on the city's regulatory and political environment, incorporation of climate change projections in stormwater initiatives, KPIs and metrics, challenges, and successes to date. To bolster the desk research for each of the chosen cities, targeted interviews were conducted with nine out of the 10 cities named, including Seattle; Portland; Copenhagen; Washington, DC; Cincinnati; St. Louis; Charleston; and Rotterdam. These interviews provided clear insight into the governance structure of each city, implementation processes for stormwater initiatives, and successes and challenges to date.

4.3 City Research Template

To ensure streamlined information was collected for each city, the team developed a structure for the deep-dive studies. For each city, relevant background information was collected, including size, population, regular weather patterns, surrounding bodies, and climate change projections. This provided context for each city, especially when analyzed in comparison to New York City.

The regulatory and political environment of each city was then studied, to gain a clear understanding of implementation processes and compliance requirements. This included key stakeholders in stormwater management, stormwater regulations currently in place, and the landscape for policy approval processes.

Once the context of the city was established, each researcher looked into key initiatives undertaken by each city, focusing on the top three initiatives based on ranking: governance, integrated planning, and green infrastructure. For each of the three types, more detail on progress-to-date, strategies around climate change integration, best practices, and challenges were compiled. For climate change integration, many of the interviews provided further detail on barriers to implementation.

Beyond the key initiatives, each researcher then identified the most successful solutions, as well as any failed strategies, with regard to rainfall magnitude, building water retention, public/private innovation, pumping infrastructure, stormwater fee, nuisance flood protection, and raising road levels. A main priority of DEP was to gain a clear understanding of all stormwater management projects and initiatives that have been implemented in U.S. cities, and this allowed researchers to take account of all that has been done. Since KPIs is an area that has not yet been explored by DEP, the researchers were tasked to identify metrics already being applied in the 10 cities, beyond water quality assessments.

To gain a clear understanding of future plans, the researchers also determined whether each city had a roadmap for integrating climate change projections in their stormwater management strategies, if they have not yet done so. Funding strategies from both private and public sources were investigated as well, to help DEP unlock capital that has not yet been tapped.

4.4 Framework for Identifying Relevant Best Practices

Based on desk research and interviews conducted with subject matter experts from the 10 target cities, the researchers then identified the strongest recommendations that were considered transferable to New York City. Best practices related to data collection, modeling, funding mechanisms, and market mechanisms were given priority, as well as projects under the top three initiatives identified in the force-ranking exercise: cooperative governance, integrated planning, and green infrastructure. The research team then interviewed DEP and other agency representatives to identify what would make the largest impact in the context of New York City. Factors that determined transferability to New York City included prioritization by DEP, current governance and organizational structures, regulatory requirements, and previous successes and failures.

4.5 Challenges

While modern stormwater management and climate change science have relatively long histories, this study revealed that the practice of combining them is nascent. This somewhat limited the researchers' ability to collect reliable data on performance and effectiveness, as many programs that intended to incorporate climate change projections have either been recently implemented or remain in the planning stage. Hard data are simply not available in many cases, which is emblematic of the larger challenge of climate change: whether a city effectively accounts for future changes may not be conclusively established for many years. To account for this, this assessment focused less on quantitative assessment of the city's programs and more on a qualitative assessment to identify best practices.

5 Findings

5.1 Overview

The findings from national best practices identified in this section should be considered for developing an Integrated Stormwater Management Plan for New York City. All principal initiatives outlined through the research of national best practices—data collection, modeling, innovative funding mechanisms, market mechanisms, green infrastructure, and cooperative governance—are necessary for an Integrated Plan that will properly addresses the complex and interconnected dimensions of stormwater management. Through the research conducted on best management practices, it is evident that some cities prosper in specific areas compared to others, but none excel in all components. By integrating the aforementioned principal initiatives into a formal New York City Stormwater Management Integrated Plan, the city should expect to (1) maintain compliance with the Clean Water Act, (2) balance regulations, (3) maintain a reasonable level of debt relative to service costs, (4) keep rates affordable, and (5) meet alternative objectives, as demonstrated in the respective analyses. Findings identified in the following sections are from both the capstone team's desk research and interviews with officials in the studied cities.

5.2 Data Collection

Data collection emerged as a key feature of cities' stormwater management programs. Various data collection practices were observed, including estimating the volume of stormwater managed by specific types of projects; collecting real-time data using Smart Sewer systems; and extensively cataloging infrastructure systems. Three cities—Seattle, Cincinnati, and Portland—were found to have robust practices in this regard.

5.2.1 Cincinnati

Cincinnati's current system of combined sewers, which carry both wastewater and stormwater, often gets overwhelmed during heavy storms and extreme rain events, discharging wastewater into surrounding water bodies and private property. To comply with the federal Consent Decree to curb raw sewage from waterways and reduce bypasses and backups by at least 85%, the Metropolitan Sewer District (MSD) has invested in Smart Sewer technology. Officially known as Wet Weather Operational Optimization, the solution was 95% more cost effective[81] than spending on larger green infrastructure projects. The project costs $0.01 per gallon of overflow reduced, as compared to the $0.23 for green stormwater controls and about $0.40 per gallon for larger pipes and storage tanks. The Smart Sewer SCADA system allows MSD to measure rainfall, flow rates, and storage volumes in real time, and to open and close valves that control water flow throughout the system depending on current capacity. According to a report by the City of Cincinnati, "MSD is the first sewer system in the country to use real-time flow monitoring and controls to minimize storm releases," saving over $10 million that would have gone towards overflow reduction and controlling 400 million gallons of sewage[82]. The system was also relied upon during a period of Ohio River flooding, in which it isolated large volumes of river intrusion and redirected more concentrated wastewater to a treatment plant.

The Smart Sewer system has significantly improved the legacy flow monitoring program, reducing flow monitoring management costs from $3.5-4.5 million per year, to $2.2 million in the first year of implementation, and $2.7 million in the current year.[83] While MSD is taking the lead on this project, the City of Cincinnati is involved in the capacity of implementing the Smart Sewer technology throughout the city. The timeline for implementation is stated to be around four to five years, beginning with the identification of areas that are most affected by stormwater and expansion of existing technology.[84]

5.2.2 Portland

To assist with monitoring of its sewer and stormwater system, Portland has created an extensive catalogue of the city's grey infrastructure. Portland's sanitary and stormwater system is made up of two different aspects—a combined sewer system, which serves approximately 1/3 of the population, and a separate sewer system and drywells, which makes up the other 2/3 of the system.[85] In 2013, Portland's grey stormwater and wastewater infrastructure were valued at $13.2 billion.[86] This includes over 885 miles of pipes for the combined sewer system and over 1,000 miles of pipes for the separate system, as shown below in Table 5-1. To keep this system running, Portland's Bureau of Environmental Services has comprehensive condition data of almost the entire sanitary sewer collection system. The conditions range from high risk of failure to very good condition. Through this cataloguing, the Bureau was able to create a proposed investment strategy to address the pipes at highest risk of failure, valued at $225 million.[87] Finally, the Bureau of Environmental Services has established levels of service—they want to be able to sustain a 25-year storm for the combined sewer system without system failure and to sustain a five-year storm for the separate sanitary system without system failure.[88]

Portland catalogued its system using a geographical information system (GIS) database tool, which allowed it to map and prioritize areas in the sanitary and combined sewer system. It allows them to see pipes that need spot repairs or whole pipe replacement. This database includes pipe condition, pipe grade, pipe defects, consequences of pipe failure, likelihood of pipe failure, estimated cost, and prioritization.[89]

In addition to the combined sewer system cataloguing, Portland created and currently maintains an MS4 facility inventory and maintenance database.[90] This includes 769 public vegetated stormwater management facilities (green infrastructure), 464,740 lineal feet of roadside ditches, and 98,716 lineal feet of culvert pipe.[91]

Portland uses a risk-based asset management approach to evaluate and implement capital upgrades, which was mandated by City Council.[92] They use a triple bottom line approach to assess the consequences of failure to meet levels of service, which includes economic, environmental, and social aspects.[93]

Table 5-1: Estimated Replacement Value of Portland Sewer System[94]

System	Inventory	Estimated Replacement Value
Combined Sewers	885 miles of pipe & access structures	$5.0 billion
Sanitary Sewers	1,000 miles of pipe & access structures	$4.1 billion
Stormwater system*	1,900 water quality facilities & 454 miles of pipe	$1.9 billion
Wastewater Treatment	2 plants & 97 pump stations	$2.2 billion
Total		$13.2 billion

* Estimated replacement value does not include the value of the nearly 9,000 Underground Injection Controls (UICs).

5.2.3 Seattle

The City of Seattle measures stormwater management projects, principally green stormwater infrastructure (GSI) projects, through four segments: (1) Required by Stormwater Code, (2) Utility-Led and Funded Retrofit Projects, (3) Utility-Incentivized Retrofit Projects, and (4) Non-Utility Led/Funded Projects.[95] For measuring the gallons of stormwater managed through GSI, Seattle used data from city project records, stormwater code-related plans, RainWise program data, and partner-reported data to generate a baseline from 2000-2012.[96] The baseline calculations found that 100.5 million gallons were managed from 2000-2012 through GSI projects, leading to the city's 2020 goal of 400 million gallons managed.[97] Further, Seattle uses present and future budgetary considerations to determine how the 2020 goals will be distributed among the four aforementioned segments (see Appendix 4). The city found that diversifying their GSI portfolio, through pursuit of additional gallons managed via cross-sector partnerships and non-utility funded projects, is necessary to meet the 400 million gallons target.[98]

5.3 Modeling

Some cities support their stormwater management programs and decision making with modeling. Practices observed ranged from technical three-dimensional modeling to qualitative scenario-based models. Six cities—Cincinnati, Copenhagen, Rotterdam, Seattle, Portland, and Washington, DC—were found to have robust practices in this regard.

5.3.1 Cincinnati

The Cincinnati Area Geographic Information System (CAGIS) is an award-winning shared-services organization that provides data-driven solutions to the city's local government, based on land and infrastructure information on Cincinnati. Through CAGIS online, street, topography, and property base maps, as well as aerial photographs from 1996 to 2016, are made publicly available to all users.

Because of its proximity to rivers, Cincinnati is heavily challenged by flooding and landslide risks. To build city resiliency, Cincinnati' created GIS maps[99] with plots of flooding and landslide potential, as well as disaster preparedness. The map of flooding and landslide potential covers the city of Cincinnati, indicating the 100-year flood boundary, areas with high landslide potential, and the floodway boundaries of the city (see Figure 5-1). The disaster preparedness is concerned "with all natural and manmade hazards including international and domestic acts of terrorism and homeland security functions," mapping police stations, fire stations, and warning sirens around Hamilton County.

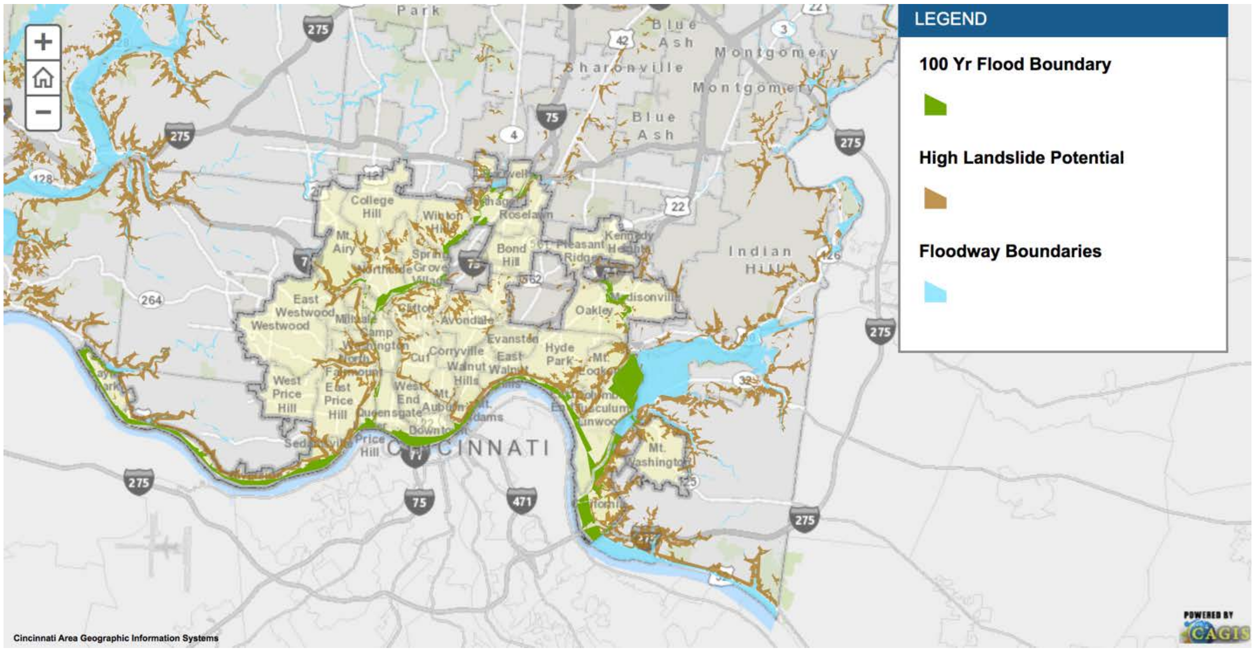


Figure 5-1: Flooding and Landslide Potential Map

Separately, for the Lick Run Project, the city took inventory of (1) existing soils, (2) existing land use, (3) historic stream network, (4) topography, (5) tree canopy cover, (6) existing stream network, (7) impervious surface, (8) hillsides, and (9) neighborhood using three-dimensional maps, to inform green infrastructure development (see Figure 5-2).[100] By plotting and modeling this data, the city was able to determine the historic and current state of the watershed, including the rate of water infiltration in the soil, the natural water flow given natural land and water features, and natural threats to development, including landslides and erosion. Specifically, for water infiltration in soil, Cincinnati determined that "soils classified as 'Group C' or 'Group D,' which cover most of the Lick Run Watershed, contain fine particles like clay and silt. These materials have slow rates of water infiltration, which increase the volume of stormwater runoff generated during rain events. MSD is incorporating specialized soils within green infrastructure projects to increase rates of water infiltration."[101]

With a robust understanding of the natural systems, the city was able to raise awareness with the community and introduce stakeholders to potential challenges and opportunities associated with the project. The collection of visual preference data then helped the exploration of alternative solutions, the assessment of the types of green infrastructure most appropriate for the watershed, and the identification of areas in which to implement these solutions.

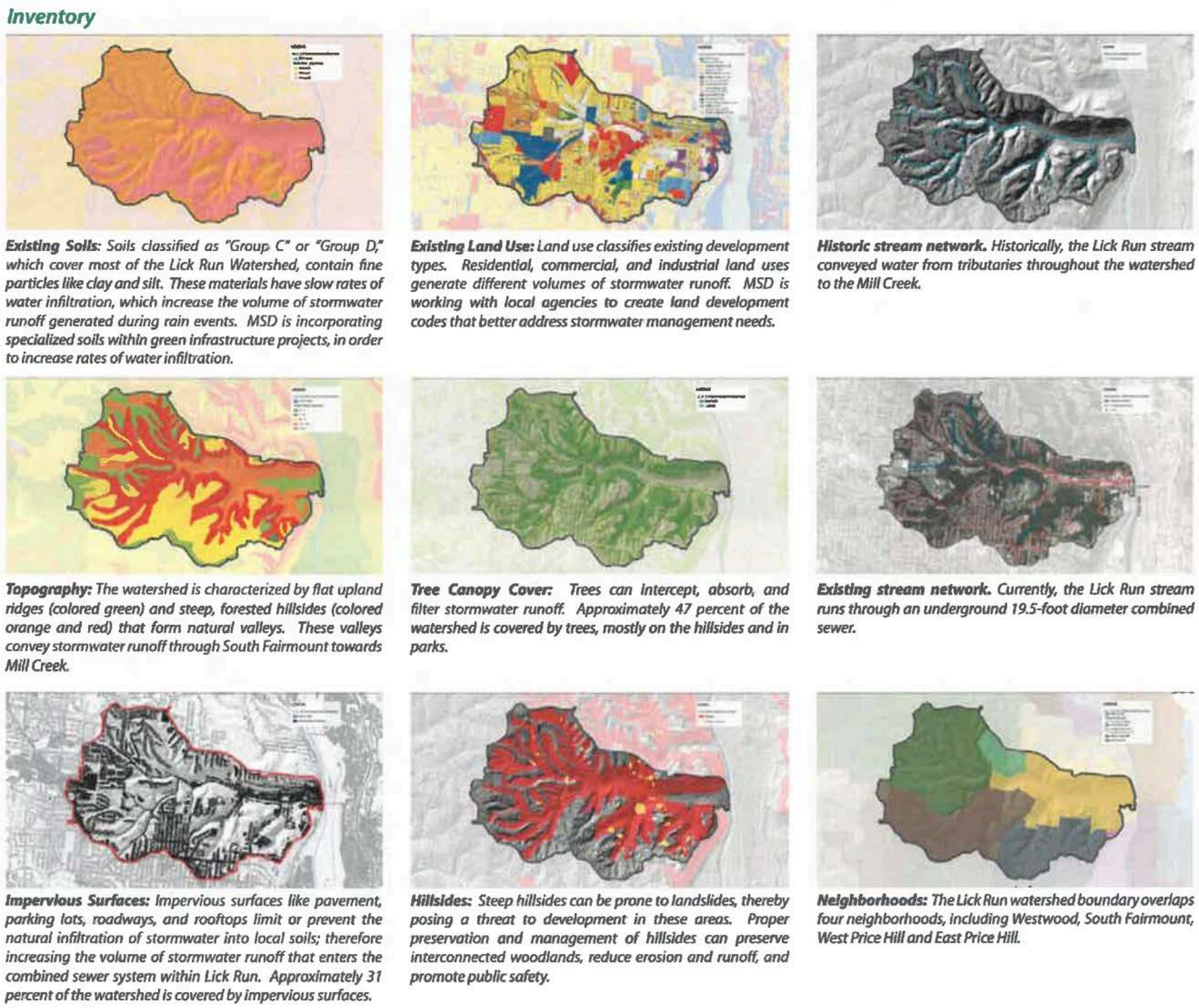


Figure 5-2: Historical vs. Existing Landscape of Lick Run Watershed

5.3.2 Copenhagen

According to Lykke Leonardsen, Head of Resilient and Sustainable City Solutions for Copenhagen, the utility companies, along with the people and agencies implementing these programs are responsible for monitoring progress and risk mitigation. This has been difficult to measure directly and has led to success defined as "lack of damage."[102] The city is divided into cloudburst branches and, once a branch is complete, risk reduction has been accomplished for that specific area. The city does not believe that areas without risk do not exist; its approach has focused on diminishing the risk as much as possible through green infrastructure.

Various forms of projects can be used to mitigate stormwater. The combination of cloudburst roads, detention streets, green streets, central retention areas, and cloudburst pipes is used to achieve optimal results for a city (see additional detail in Appendix 5). These pilot projects are investigated through various forms such as GIS surface hydrology, 1D and 2D hydraulic modelling, flood vulnerability, risk mapping, combined surface and sewer modelling, and landscape analysis.[103]

The Lådegåds-Åen catchment was selected as a prototype due to its high susceptibility to flooding and sea level rise. The extensive analysis on these projects led to the Copenhagen Cloudburst Formula. This model can be universally adapted for mitigating cloudbursts through green infrastructure, which integrates traffic, urban planning, and a hydraulic analysis with comprehensive investment strategies that bring co-benefits to the city (see Figure 5-3).[104] Green infrastructure is on the surface and visible, low-tech, and interactive. This solution addresses both climate adaptation and the limitations of urban space.[105] In order for co-creation to exist, not only do the city and utility companies need to be involved, the participation of small business, citizens, and non-public actors are also needed. They play a vital role in designated areas to remodel cityscape, adapting squares, streets, lakes, and parks to better cope with future cloudbursts.[106]

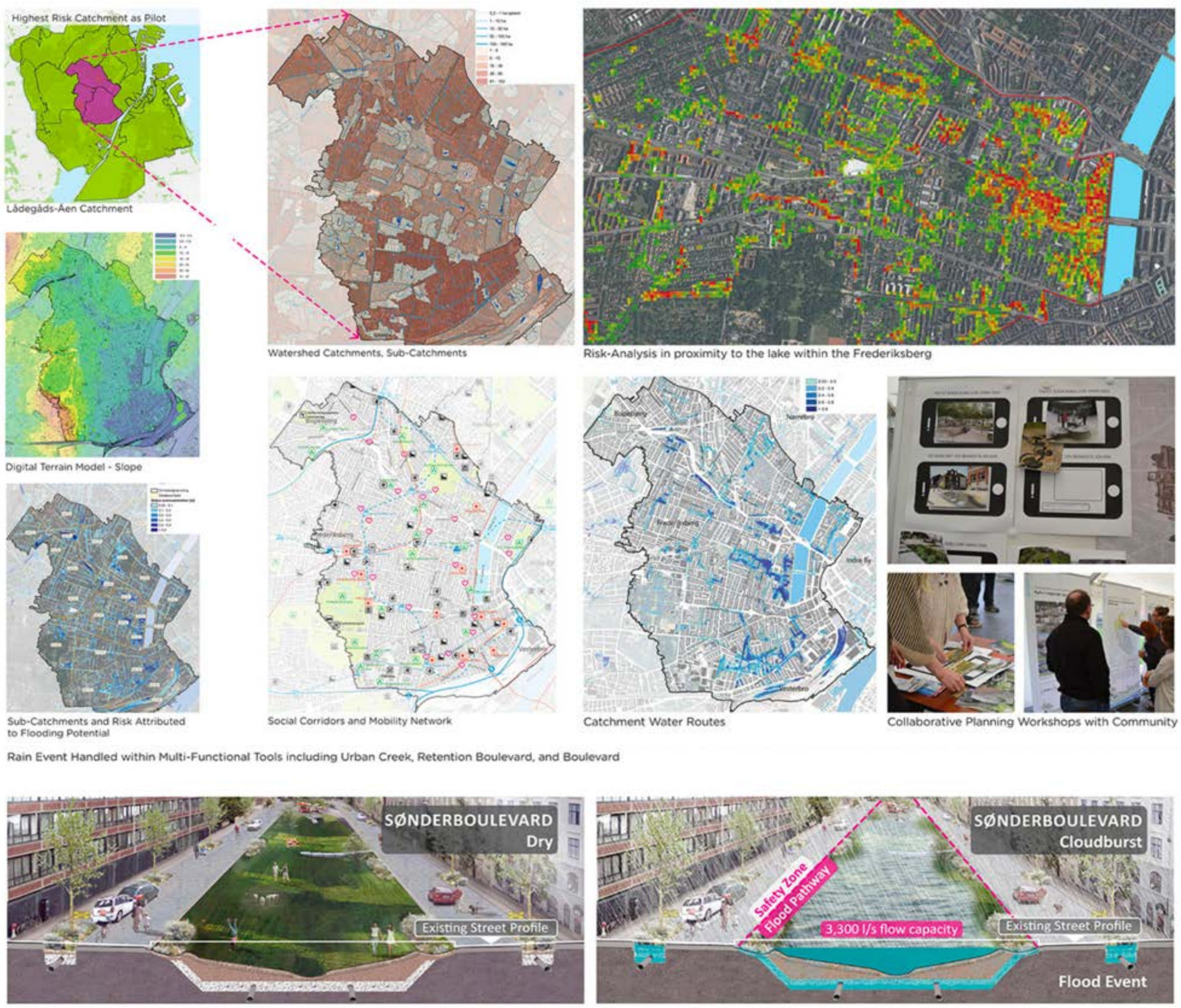


Figure 5-3: Lådegåds-Åen catchment analysis[107]

5.3.3 Portland

Portland is working with the University of Washington Climate Impact Group on Regional Climate Models (RCMs). The group is currently researching climate models on the Western United States and Eastern Pacific. These models will be able to estimate future rainfall intensities on the local and sub-daily levels, which is crucial for stormwater management planning. Previous models were only able to estimate inches of rain per month, but this local and downscaled model will allow the City of Portland to plan for large rainfall events. The Bureau of Environmental Services is also coordinating with Portland State University on future large-scale meteorological patterns, which will allow them to incorporate atmospheric rivers in their stormwater planning.[108]

In addition to this, the city is working on qualitative scenario-based models or "a structured discussion process" on climate change to identify driving forces, identify crucial uncertainties, develop scenarios, discuss implications, and develop adaptive strategies.[109] This approach includes "bottom-up" thinking and stress testing (see Figure 5-4), which focuses on vulnerabilities in the system, rather than potential problems found by future forecasts.[110] These scenario-based models will allow Portland to grapple with the large uncertainties associated with climate change in a meaningful way. This is because there is a large amount of uncertainty with current climate change models, which limits their usefulness for planning and decision-making.[111] The system requires long-term, accurate, and precise thinking in order to cope—making it nearly impossible to include potentially inaccurate future climate change data. This model will allow Portland to build robustness in the system and prepare the city for a number of possible future events.

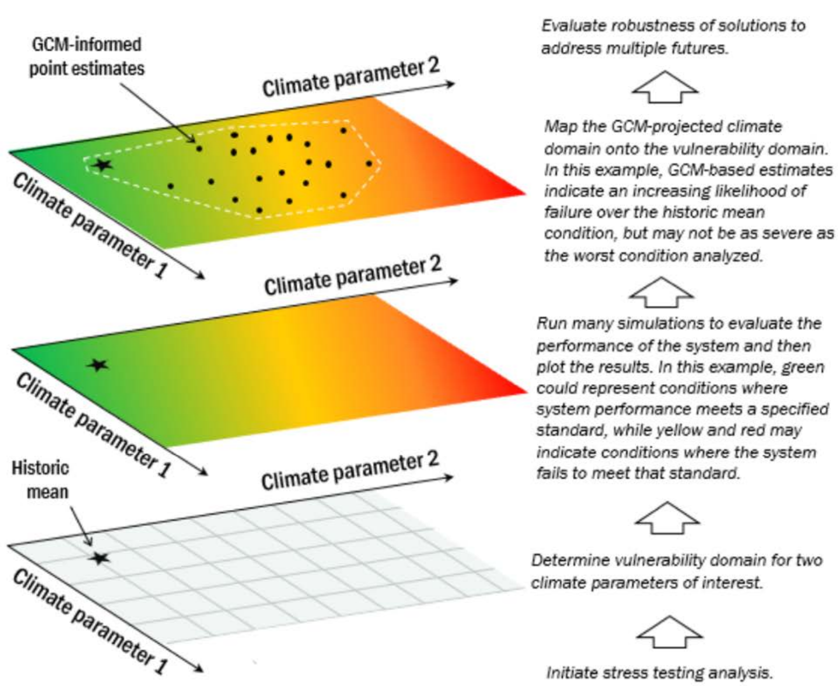


Figure 5-4: Schematic illustration of vulnerability domain for stress testing[112]

5.3.4 Rotterdam

Rotterdam has created a three-dimensional model of the city and its water systems that allows it to understand and prioritize stormwater investments.[113] Its model captures the city's aboveground topography and built environment, combining that with representations of its sewer system, groundwater, and surface water system.[114] Using this model, it is able to simulate the impacts of intense rainfall. The city then assigns a risk level of flooding from rainfall to each building by letter grade (A: safest, B-E: less safe) in partnership with Blue Label[115] and makes this information available to the public.[116] A sample of the property rating is shown below in Figure 5-5 and a sample report is available in Appendix 6. It also tracks the rating of properties over time[117] and evaluates the risk of flooding at a neighborhood level,[118] as shown below in Figure 5-6. This model has also proven successful as a tool to communicate flooding risks to community and local leaders[119] to help in building consensus and move efforts forward.

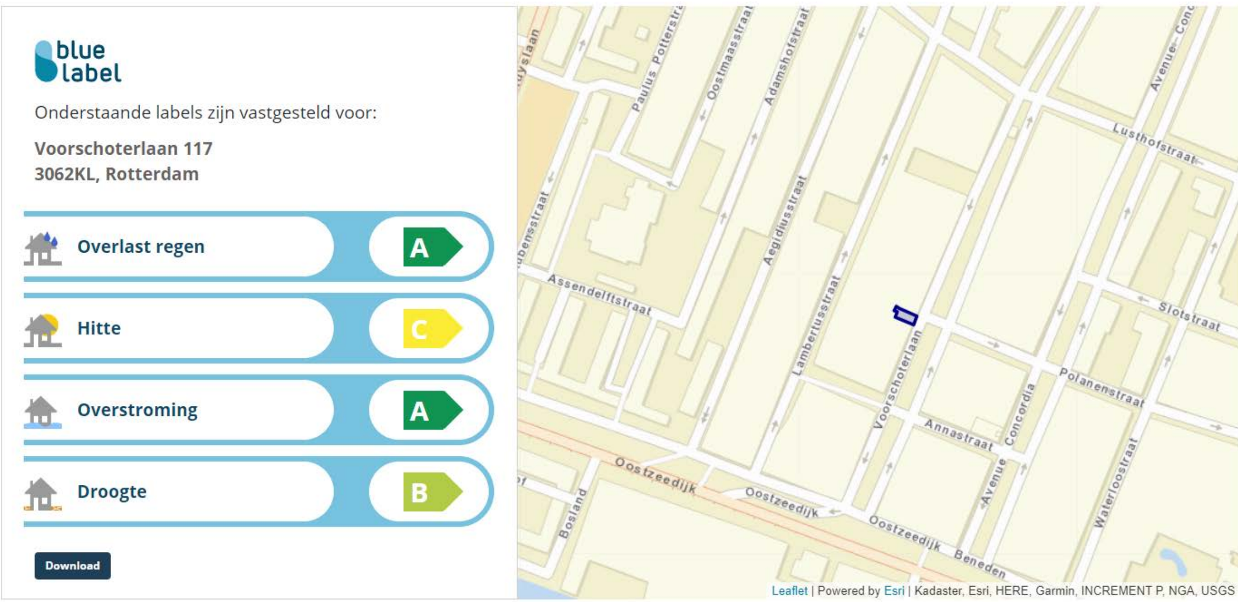


Figure 5-5: Sample Blue Label climate change risk ratings[120]

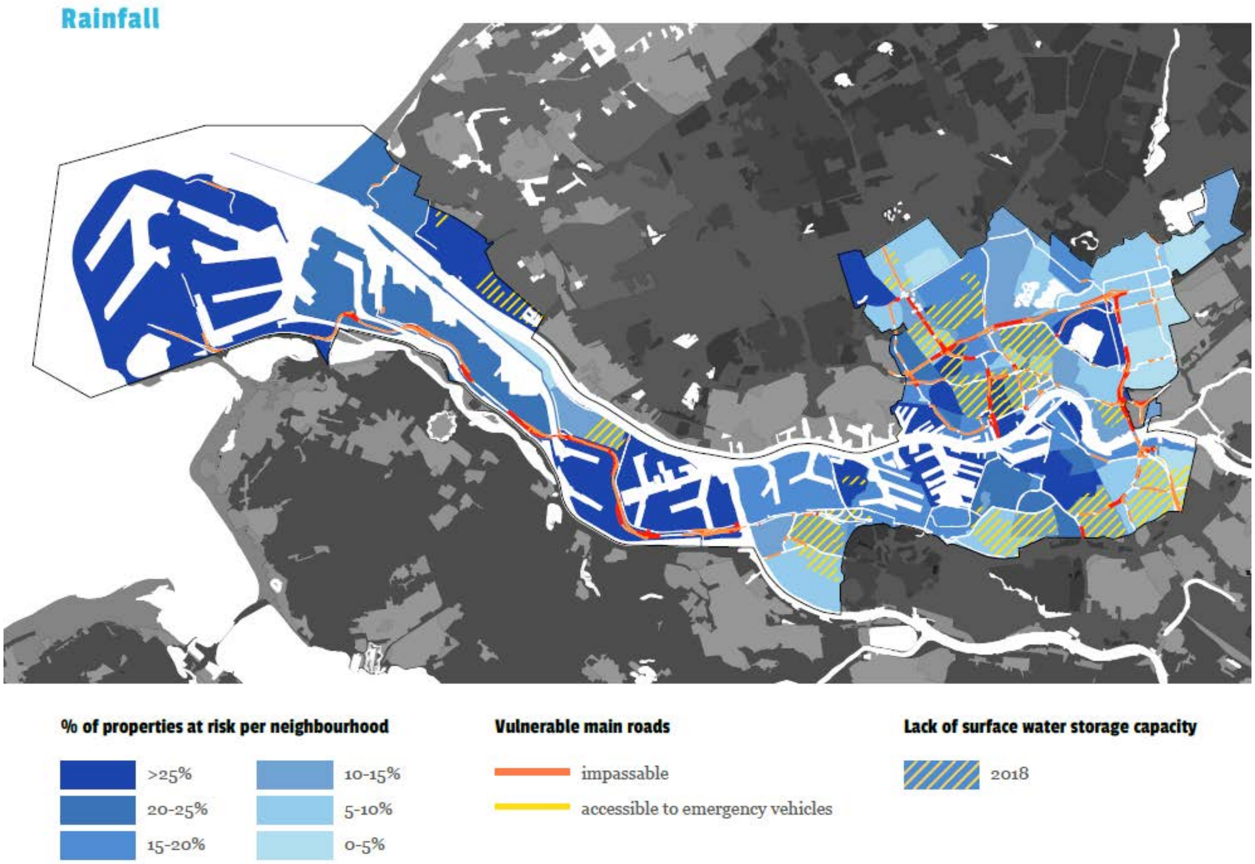


Figure 5-6: Assessment of neighborhood flood risk from rainfall in Rotterdam[121]

5.3.5 Seattle

According to an interview with the Seattle Public Utility (SPU), Seattle is no longer relying solely on NOAA rainfall data and projections for modeling.[122] Instead, Seattle assembled a group of climate scientists to model project sizing, design, capacity, upgrades, and resiliency in order to speed up their modeling and projecting processes. With regard to their modeling of precipitation impact for resiliency, Seattle has followed DEP's Cloudburst study. Through 100-year and Seattle's 1,000-year storm equivalent models, the city uses surface modeling of overland flows and identifies areas of high nuisance flooding risk, according to an interview with SPU. These areas are not necessarily assessed for infrastructure buildouts, rather they are modeled to understand where Seattle can increase resiliency in low-lying areas through design guidelines or development standards in the future.

For project sizing and design, Seattle uses models of climate scenarios for future predictions of climate change to generate a climate perturbed intensity, duration, and frequency (IDF) curve.[123] These perturbed IDF curves are used for determining size of infrastructure based on the life of the infrastructure, for example, CSO tank oversizing. Additionally, the city uses growth and development predictions, climate perturbed storm series, and sea level projections to run models of future conditions and understand present and future capacity needs, according to an interview with SPU.

Seattle uses pollutant load evaluation methods to measure stormwater management projects. These load modeling results helped determine which stormwater projects would be included in their Long-Term Control Plan (LTCP), as a part of their Consent Decree with EPA.[124] Using existing information and a simple pollutant load model (PLM) spreadsheet, the city estimated the pollutant load reductions for each candidate stormwater project. The PLMs are evaluated based on local stormwater runoff study data and local precipitation data, not calibration toward site-specific conditions.[125] The evaluations were made based on pre-project and post-project components. Pre-project factors are based on observed rainfall and runoff relationships, as well as estimated concentrations of pollutants in stormwater runoff. The post-project components of the PLM model consider the pre-project concentrations of runoff volumes, while applying stormwater project performance estimates to each of the candidate projects.[126] Finally, the modeled performance of each project depends on three key factors: (1) the pollutant removal achieved in the stormwater project by virtue of improved water quality, (2) the fraction of average long-term stormwater runoff volume receiving treatment, known as capture efficiency, and (3) pollutant removal achieved in the stormwater project by virtue of surface runoff reduction via infiltration and/or evapotranspiration.[127]

5.3.6 Washington, DC

Washington, DC currently has an open data mapping system that is publicly available online. The data serves multiple purposes, with transparency and education as the main objectives. DC's data tracking is extremely thorough. Presently, one of their most useful mapping data sets track all green infrastructure projects in the District in extensive detail, collecting data for each project on project type, drainage area, storage and retention volume, location coordinates, drainage basin and sewer shed impacted.[128] Matthew Espie of the DC Department of Energy & Environment (DOEE) discussed how this data allows for tracking of key measurement data, while also providing information to citizens and private investors on the success of green infrastructure projects in the district.[129] The District also has a live flood inundation mapping system (FIM). "The District will use the FIM as part of a comprehensive, risk-analysis initiative to prepare for possible flood events and inform flood-mitigation strategy and emergency-management plans and operations. Flood depths will be used to estimate physical, economic, and social impacts, including future risk attributed to sea-level rise."[130]

According to Nick Bonard of the DOEE, DC is looking to greatly improve their data management and mapping capabilities with a brand new $5 million 3D mapping system.[131] The system will allow for continued and improvements on data collection practices. The main reason for this investment is that the new system will allow them to test the capacity of their existing and proposed infrastructure to withstand varying storm events. Essentially, the system will allow the DOEE to plan infrastructure updates by running them through the mapping system to test if they produce the desired outcome whether it is related to stormwater retention, water quality, or an unrelated metric.[132]

5.4 Funding Mechanisms

Creativity in securing funding sources amongst tight municipal budgets emerged as a key characteristic of cities' stormwater management programs. Practices observed ranged from traditional bond sales and environmental impact bond sales to stormwater fees. The funding approaches of seven cities—Cincinnati, Copenhagen, Houston, Miami, Portland, Seattle, and Washington, DC—are highlighted herein.

5.4.1 Cincinnati

The City of Cincinnati recently restructured their sewer/stormwater fee[133] to an equitable storm drainage service charge, encouraging onsite stormwater retention on commercial and residential properties, and discourage runoff. Through the restructuring, the city hopes to incentivize the use of permeable surfaces that help absorb water during storm events and reduce sewage backup and flash foods. Formerly, Cincinnati's Sewer District was funded by a charge that was a fixed percentage of each person's water bill, unrelated to the amount of stormwater runoff from a property. The fee was based solely on the size and use of the property, creating no incentive for property owners to manage the stormwater that fell on their land.

The city recently restructured the fee, now basing it on the amount of impervious surface on the property or the property's contribution to stormwater runoff in the city. It is collected from all property owners in the City of Cincinnati, not including undeveloped land and street rights-of-way. Further detail on the new fee structure is available in Appendix 7.

The change aims to more strongly incentivize water management and decentralized stormwater solutions across the city. While the City of Cincinnati owns this recommendation, they work with the Planning Department and the Building Inspection Department to encourage permeable solutions on both private and public properties. Costs are approximated at $230,000,[134] associated with designing, enacting, and implementing the new fee structure. These are offset by benefits amounting to $400,000,[135] associated with the avoided cost of centralized wastewater management infrastructure. Implementation time is estimated at one to two years and will require establishing a system to measure pervious and impervious surfaces around the city.

5.4.2 Copenhagen

Most funding for Copenhagen projects comes from utility water fees. Residents pay about $5 per cubic meter. The utility company contributes funds to projects such as roads, which are used in the hydraulic pattern to flow water into the harbor and mitigate flooding. Projects are financed through water charges from the utility and urban space improvements can be financed through the income tax and property tax.[136] Utility companies work together with the City Council to finalize projects that can impact the future of Copenhagen. In order for the utility company to finance projects such as these, the city of Copenhagen and the Danish government passed a specific law to allow funding for stormwater management by utility companies for projects such as cloudburst road.[137]

5.4.3 Houston

In August 2018, Harris County (the county in which Houston is located) voters approved a $2.5 billion bond issuance to provide funding for improving flood control.[138] The Harris County Flood Control District (HCFCD) aims to achieve two goals with the bond: "to assist with recovery after previous flooding events (including Harvey) and to make our county more resilient for the future."[139] The county developed a prioritization framework[140] to select projects funded by the bond proceeds based on current readiness, timeline of other funding, clear impact on drainage problems, and community benefits.[141] The projects covered by this bond were selected by the HCFCD[142] prior to issuing the bond, but the HCFCD acknowledges that the bond will not cover the total cost of the projects[143] and may adjust the list in the future.

5.4.4 Miami

In November 2017, voters in Miami approved a $400 million dollar general obligation bond, the "Miami Forever Bond".[144] The citizens of Miami gave their government permission to increase their taxes and borrow money in order to pay for the public projects across the city to mitigate sea level rise.[145] The projects will fall within five categories, "which align with the City's most pressing needs: Sea-Level Rise and Flood Prevention, Roadways, Parks and Cultural Facilities, Public Safety and Affordable Housing."[146] The government prioritizes the inclusion of public opinion in their project funding decisions, and created a "Citizens Oversight Board" and bond task force in order to oversee the project management and ensure transparency through the execution process.[147] About one year after the approval, the city government announced the first round of approved projects under the bond totaling $58 million.[148] The bond has an interactive mapping program that allows citizens to look at projects that have either been proposed, approved, are under construction, or completed.[149]

5.4.5 Portland

Portland finances stormwater management services through a variety of ways including public utility fees, bond sales, and EPA grants. Public utility fees are raised on developed properties and system development charges on new developments.[150] The city charges stormwater, sewer, water and Superfund fees (sanitary volume and impervious areas). The stormwater fee is dependent on the type of development, but can range from $4.33 per dwelling unit per month in on-site charges to $19.27 per user account per month in off-site charges.[151] The Willamette River/Portland Harbor Superfund charges $0.09 per 100 cubic feet of water consumption for sanitary volume, $0.24 per 1,000 square feet of impervious area per month, and all Portland residents are subject to the Superfund charges (see Appendix 8 for other fees).[152] In addition, the City of Portland and State of Oregon have agreed to provide $24 million in funding to clean up across the entire Willamette River/Portland Harbor Superfund site after the EPA placed the site on the Superfund National Priorities List.[153] Portland's massive CSO capital improvement project has raised rates significantly over the past two decades[154], with an average of 7.4%[155] from Fiscal Year 2018/19 to Fiscal Year 2019/2020.[156] Portland also finances CSO and other capital improvements through bond sales. These bond repayment terms vary from 20-30 years, with 1/3 of the Bureau's annual budget allocated to debt payments.[157] Finally, between 2002 and 2014, the U.S. EPA granted Portland $3.4 million to fund over 30 innovative public and private projects through the EPA's

Innovative Wet Weather Program.[158] These projects are intended to demonstrate sustainable, low-impact stormwater management solutions and typically include green infrastructure projects.[159]

5.4.6 Seattle

The city of Seattle charges a fee for stormwater management services (billed as a separate line item on King County property tax statements) to property owners, based on each property's estimated impacts on citywide drainage systems[160]. For wastewater, SPU collects fees of metered water usage through their combined (wastewater and drainage) utility bill. Drainage charges are based on property owners' characteristics contributing to stormwater runoff. These two rates are set to recover SPU's treatment component, expenses, and recover payments to facilities that treat the wastewater transported by SPU's system.[161] Although the drainage and wastewater systems are funded through separate rate structures, they share common infrastructure, debt financing, financial budgeting and reporting systems, as well as administrative and maintenance services.[162]

5.4.7 Washington, DC

In 2016, Washington, DC issued a $25 million dollar Environmental Impact Bond through DC Water and Sewer Authority, as well as investors Goldman Sachs and Calvert Foundation.[163] The Environmental Impact Bond (EIB) was the first in U.S. history dedicated to funding green infrastructure to improve DC's water quality by managing stormwater runoff and CSOs.[164] As the largest social impact bond investment in the U.S., the EIB has a 30-year term with a mandatory tender in the fifth year, a 3.43% coupon rate, and over 100 candidates trained for jobs in green infrastructure through a complementary DC Water program.[165] The bond uses a financing technique that allows for the costs of building green infrastructure to be covered by DC Water, while the risks of managing stormwater runoff are shared between DC Water and the bond investors.[166] The bond will also help to stimulate the creation of local jobs and support economic development as DC Water is simultaneously launching a Green Jobs Initiative with training and certification opportunities for residents of DC.[167] If the planning associated with the bond is successful, the new green infrastructure from this bond will allow for the capture of about 650,000 gallons of water each year.[168]

5.5 Market Mechanisms

Cities can also advance their stormwater management programs through market mechanisms such as cap and trade programs. One city, Washington, DC, was found to have robust practices in this regard.

5.5.1 Washington, DC

In May 2016, Washington, DC launched a Stormwater Retention Credit (SRC) trading program aimed at incentivizing Green Infrastructure (GI) in the district.[169] This program works in conjunction with the Stormwater Management Regulations passed by the district in January 2014, requiring large development projects to install stormwater retention projects based on the volume of stormwater runoff and the size of the land disturbance of their development.[170] The SRC program allows for developments regulated under this law to comply for up to 50% of their retention requirements by purchasing stormwater credits from GI projects from other entities. Since the regulation passed in 2014, the SRC trading program has approved 79 green infrastructure projects amounting to 3,994,213[171] credits which presently sell on the market for about $2 each.

The program actively uses government policies to benefit stormwater runoff and water quality. The policies in place regulate Stormwater Retention Volume (SWRv) for regulated sites based on site size rather than the need for retention specific to a drainage basin or sewer system impacts.[172] The SRC trading program allows the DOEE to target areas where more retention is necessary, while still complying with a policy that has retention requirements with differing priorities. This means that the government can prioritize the certification of GI SRCs in areas that drain into the MS4 and will therefore have a great impact on runoff and water quality.[173] Developments that would have otherwise installed onsite retention for non-priority sewer or drainage basins, can now purchase the SRCs from projects that have more substantial impacts on the District's higher priority areas.

The program was not an immediate success for the DOEE. Matthew Espie stated that it took multiple attempts to get the program to pass, as they ran into problems with the development community.[174] During the first attempt to pass the policy, many stakeholders felt that the regulations were too stringent and would be almost impossible to comply with. Standards set by the original policy required high levels of water retention per GI project or SRC credit. The policy met significant opposition with the community who would oversee implementing, designing, and building this infrastructure, as they felt incapable of delivering. This ultimately led to a failed attempt and allowed the DOEE to rethink their policy. Before proposing the policy again, the DOEE provided free training and professional development programs to the development community.[175] This increased confidence in the development community to meet the standards set by the policy and allowed the policy to be passed.

Attracting private investment is a key component of this program, although it was not prioritized during the program's launch. A couple of years into the program's launch, it became evident to policy makers that they would not be able to create a substantial market for the program without private investment.[176] The barrier to attracting investors was their fears of not making a return on their investment.[177] To solve this, the DOEE set aside $11 million, raised through stormwater fees to launch the "SRC Price Lock Program." The funds allowed the DOEE to set an SRC price for one year that they would guarantee to pay to investors should they fail to sell their credits.[178] This program allowed private investors to invest in SRC projects with confidence, knowing that they would always have a way to sell the credits in which they have invested. Additionally, to further incentivize investment in green infrastructure that drains to the MS4, the Price Lock Program only applies to SRCs within the MS4.[179] After the Price Lock Program launched in late 2017, the SRC program had its two most successful years.[180]

SRC buyers and sellers have access to an online marketplace where they can buy or sell credits. The DOEE first certifies the seller and the number of credits they are selling. From there the buyer and seller can negotiate the sale and the DOEE acts as a third-party to oversee the transaction and ensure credit upkeep every three years.[181] Current SRC sellers ranged from the French Embassy, to corporations and individual landowners.[182] Sellers list the number of credits they have for sale and the asking prices are currently averaging about $2 per credit.

5.6 Cooperative Governance

Stormwater management is a multi-sectoral undertaking and some cities adopt cooperative governance models as a result. Practices observed including creating inter-jurisdictional and inter-agency governmental partnerships. Four cities— Cincinnati, Miami, Portland, and Seattle—were found to have robust practices in this regard.

5.6.1 Cincinnati

As a result of the three 100-year rainstorms that hit Cincinnati in 2017, and the $50 million spend on storm-related issues, the Cincinnati Mayor and City Manager's office created an Extreme Weather Task Force to "evaluate policy recommendations to prepare and minimize future storm damages." Members of the task force include nine different municipal departments in charge of identifying storm-related risks, proposing appropriate solutions, and developing cross-departmental projects to address relevant issues. Most of their focus is on landslide mitigation, flooding properties, and infrastructure damage. In partnership with the City Office of Environment and Sustainability, the task force helped assess neighborhood vulnerability and created a heat-island map based on data gathered from the City Resilience Index (CRI) program, sponsored by Arup and the Rockefeller Foundation. Based on this data, the task force was then able to identify opportunities for an informational resource hub for city residents, create a green jobs program to implement recommended solutions, and develop regulations and incentives for greener development.[183]

5.6.2 Miami

The Miami area is comprised of several different large municipalities their own governments, budgets and priorities. For this reason, Miami chose to create a governmental partnership, the "Greater Miami & the Beaches" (GM & B).[184] This partnership includes, Miami-Dade County, the City of Miami, and the City of Miami Beach. While each municipality has its own fully functioning government, they chose to partner in an effort to band government policies on important and overlapping issues that affect all their residents. After engaging many stakeholders with varying needs and interests, GM & B created the Resilient 305 strategy. The plan has three main goal areas, Places, People and Pathways and over 50 actions identified for impact.[185] In order to oversee project implementation, Miami put together a team they refer to as "PIVOT," comprised of senior administrative staff, and a Chief Resilience Officer from each of the partner localities.[186] The strategy and projects associated with it are funded by The Miami Foundation as well as in-kind support from the participating entities.[187]

5.6.3 Portland

In 2005, Portland created the "Portland Watershed Management Plan," stressing the importance of an integrated approach when maximizing limited resources to meet multiple objectives.[188] This includes multi-bureau cooperation and integrating the activities and plans of multiple city bureaus—such as the Department of Transportation's Transportation System Plan and the Parks Department's Parks 2040 Plan—to meet stormwater goals and other interests.[189] The plan treats stormwater as a resource, and focuses on proper resource management rather than solving to a minimum permit standard, like MS4.[190] The Bureau of Environmental Services representatives believe that by focusing on stormwater this way, cities can go above and beyond minimum permitting standards.[191]

In addition to this, the city relies on a multitude of stakeholders to make the “Portland Watershed Management Plan” work. First, the city council and mayor were cited as large partners and supporters of the city’s innovative stormwater goals. They pushed stakeholders to implement the Watershed Management Plan through green infrastructure projects in the Grey to Green initiative.[192] The city also relies on regional governing bodies—such as the Metro Regional Government, soil and water conservation districts, and state watershed groups—to aid in funding through property taxes, bonds, state funding, and fundraising, as well as help implement in-stream and green infrastructure goals.[193] Finally, Portland relies on non-governmental stakeholder such as community members and developers.

Portland currently engages its citizens through programs like the Community Watershed Stewardship Grant, where up to $12,000 is awarded to fund projects that improve watershed health;[194] and the Community Visioning Project, where Portland engages the community to help with its strategic plans.[195] The city also works with developers to meet their development permit requirements to integrate green infrastructure into any project over 500 square feet.[196] Portland’s Bureau of Planning is also streamlining its building and land development regulations including: identifying areas for improvement in city code that would not require major policy changes, and a review of Portland’s current regulatory framework to achieve its goals (see Figure 5-7).[197]

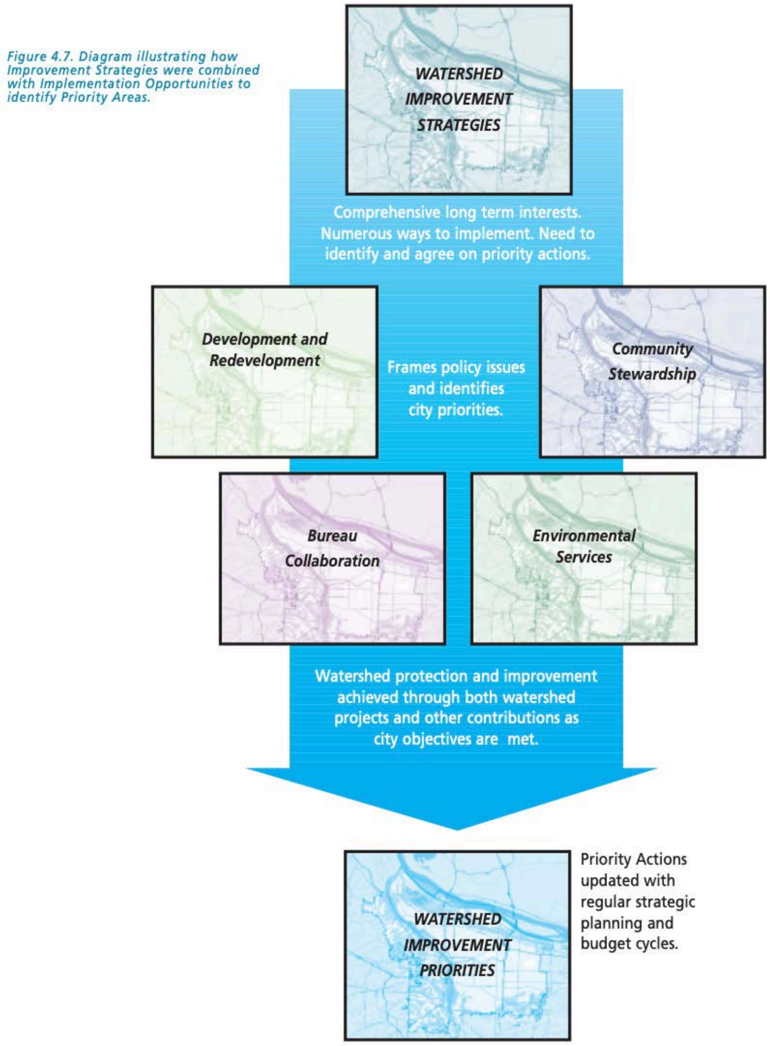


Figure 5-7: Identification of Priority Areas for Watershed Improvement[198]

5.6.4 Seattle

The city of Seattle has worked with various agencies, such as the Seattle Department of Transportation (SDOT) and Department of Parks and Recreation (Parks), along with several community groups, businesses, and non-profits in order to expand their stormwater management practices.[199] For example, the SPU and SDOT have incorporated green stormwater infrastructure (GSI) into multi-modal corridors, minor paving projects, and sidewalk projects; designing roadside GSI in specific neighborhoods; street tree planting and retention; and removal of impervious surface during capital projects.[200] These impervious removals are most often replaced by permeable pavements or green landscape.[201] Parks has contributed to the stormwater management in Seattle through retrofitting and converting existing landscaped areas into rain gardens; investing in rainwater capture and reuse systems for irrigation; and decommissioning and removing imperviable areas in parks.[202] In most cases, the decommissioning of impermeable pavements is from parking lots or excessive concrete in park spaces that are converted to extend park space.[203]

In regard to community-based, voluntary approaches, SPU has worked with businesses and non-profits to create the "Green Infrastructure Partnership" (GrIP) in order to facilitate voluntary adoption of GSI. Further, SPU created the "Right Place, Right Project" initiative to clarify the process for developing stormwater infrastructure beyond the stormwater code guidelines.[204] According to an interview with SPU, these partnerships have substantially streamlined the process of managing stormwater and have led to cost sharing and savings.

5.7 Green Infrastructure

Green infrastructure has emerged as a key means by which cities achieve their stormwater management goals. Practices observed include developing targeted green infrastructure programs and implementation strategies. Three cities—Cincinnati, Portland, and Seattle—were found to have robust practices in this regard.

According to the EPA, green infrastructure is a "cost-effective, resilient approach to managing wet weather impacts that provides many community benefits."[205] Rather than moving water away from the built environment, this type of infrastructure "reduces and treats stormwater at its source while delivering environmental, social, and economic benefits."[206] It is a critical component of the stormwater management solutions, not only for its effective water management outcomes, but also for its significant positive impacts on communities. Some examples of green infrastructure include downspout disconnection, rainwater harvesting, rain gardens, planter boxes, bioswales, permeable pavements, green streets and alleys, green parking, green roofs, urban tree canopy, land conservation.

Types of green infrastructure that have appeared most often in this study include green roofs, bioswales, and permeable pavements. Green roofs use growing media and vegetation to facilitate rainfall infiltration and evapotranspiration on top of the built environment. They are a cost-effective solution in urban areas where land values are high, and on large buildings where stormwater management costs are likely to be high.[207] Bioswales are vegetated, mulched, or xeriscaped channels that act as rain gardens in long narrow spaces. They are often placed in between a sidewalk and curb to help move stormwater away from the street.[208] Permeable pavements are made of pervious concrete, porous asphalt, or permeable interlocking pavers that can infiltrate, treat, and/or store stormwater as it falls on the ground. This is a cost-effective solution, especially in areas with high land values and high probability for flooding or icing.[209]

5.7.1 Cincinnati

Cincinnati, with its geography, hilly topography, and soil types, is much more prone to exacerbated sewer overflow problems compared to many other U.S. cities. Much of this overflow is attributed to stormwater (combined sewer overflows) rather than sewage (sanitary sewer overflows), with the highest levels occurring during rain events. To combat this issue, the city has implemented numerous green infrastructure projects.

MSD's Project Groundwork focuses on developing green infrastructure to help capture about 120 million gallons of stormwater runoff during a typical year of rain (41 inches).[210] The project covers multiple green infrastructure initiatives, including rain gardens, bioswales, stream restoration, and stormwater detention basins. Hamilton County, OH, after dealing with approximately 14 billion gallons of combined sewer overflow annually,[211] has begun working on a green infrastructure program that seeks to be the first of its size and scope in the nation. In fact, "the project won the U.S. Water Alliance's 2014 U.S. Water Prize for 'its green infrastructure strategy to reduce water pollution, beautify neighborhoods and help spark economic development.'"[212]

To balance both grey and green infrastructure in ways that are both cost effective and sustainable, the county is working with MSD staff, the Sierra Club, the Cincinnati Department of Transportation and Engineering, the Cincinnati Parks Department, the Hamilton County Planning Department, and others. MSD is working with the Hamilton County Stormwater District, consisting of more than 40 local governments, to develop county-wide stormwater standards. They have also created a Green Interchange Task Force, with members including state and local government representatives, MSD, the Ohio EPA, the Ohio Department of Transportation, and the Cincinnati Parks Department, to address stormwater runoff from roadways. As one of the first steps towards the initiative, the task force will assist with evaluating and implanting green infrastructure solutions for major Interstate 75 highway construction projects over the next 10 years.

A large portion of the 14 billion gallons of sewer overflow in Hamilton County originates from the lower stretch of the Mill Creek as it approaches the Ohio River,[213] an area of land that covered 40,000 acres. Within Lower Mill Creek is the Lick Run Watershed, an area that covers about 2,900 acres and is home to the largest CSO (by volume) in Hamilton County. Every year, 1.5 billion gallons of raw sewage and stormwater overflows into Mill Creek from the Lick Run Watershed. Focusing on Lick Run, a part of Lower Mill Creek that[214] on Cincinnati's west side, would eliminate 369 million gallons of Combined Sewer Overflow.[215] This was the impetus for MSD's Lick Run Project, part of the Lower Mill Creek Partial Remedy, which aims to ensure that 88% of the flows during a typical year of rain reaches the Mill Creek treatment plant or is discharged to the Mill Creek through the Valley Conveyance System (VCS).[216] The total cost of the Lower Mill Creek Partial Remedy was estimated at $244 million (in 2006 dollars). The implementation of this green infrastructure project was done in lieu of building a deep, underground storage tunnel to carry the increased stormwater levels in the city, saving Cincinnati approximately $200 million.[217] According to Diana Christy, Interim Director of the MSD, this has been one of the city's biggest stormwater-related successes to date.[218]

5.7.2 Portland

Portland has several green infrastructure programs that it has implemented through requirements and incentives. The city's stormwater manual requires that projects with more than 500 square feet of impervious surfaces comply with pollution-reduction and flow-control standards, and use green infrastructure as the primary measure to achieve these standards.[219] In 2011, Portland City Council passed the Green Buildings Measure, which requires eco-roofs on all new city-owned facilities and roof replacements on buildings larger than 500 square feet.[220] In 2008, the city budgeted $50 million in stormwater management fees to invest in its green infrastructure program.[221] Between 2008 and 2012, the city offered education, planning aid, and a $5 per square foot incentive to build an eco-roof for property owners and developers.[222] This initiative created over 20 acres of eco-roofs across 390 roofs that manage millions of gallons of stormwater each year.[223] Portland also created a tree planting program, which provides a one-time credit on a utility bill for residences and businesses, and cut out concrete sidewalk space to plant trees; a green streets program, which uses curb extensions to build rain gardens along streets; and a percentage for green project, which provides grants to residents for sustainable stormwater projects.[224] Finally, the City of Portland has an Innovative Wet Weather Program which funds over 30 private and public projects that effectively manage stormwater. These projects feature downspout disconnection, infiltration planters, pervious pavement, and more.[225]

5.7.3 Seattle

In Seattle's Green Stormwater Infrastructure Implementation Strategy 2015-2020 plan, the city displays various types of GSI tools (i.e., bioretention, stormwater cisterns, infiltration trenches, green roofs, etc.) and their respective benefits (see Appendix 4). The city lists three principal drivers for the use of GSI: (1) regulatory requirements, (2) community benefits, and (3) citywide environmental protection and equity goals.[226] Several of Seattle's regulations require GSI, especially in any new developments, for example, Low Development Impact Code Integration (LID), City of Seattle's "Plan to Protect the Waterways," stormwater code, and the King County CSO Consent Decree.[227] In a report co-authored with the EPA, the Seattle Public Utility analyzed numerous community benefits to GSI, for example, air pollutant reductions, mental health, job impacts, potable water conservation, avoided costs of water treatment, and more.[228] Additionally, Seattle found that GSI can assist in achieving their climate preparedness goals outlined in the city's Climate Action Plan, such as energy and GHG savings from reduced water treatment and the use of compost in bioretention soils resulting in increased soil carbon and sequestration.[229]

6 Recommendations and Conclusions

6.1 Recommendation #1: Create an Inter-agency Task Force Aimed at Preparing Stormwater Management for Climate Change

To bring forth an improved governance framework that capitalizes on interagency relationships, DEP should build on existing pathways. Currently, there is no New York City Stormwater Task Force unto itself, and the existing MS4 permit group of agencies are focused on compliance with DEC and EPA mandates. This new task force will look beyond existing mandates to incorporate climate change projections into the city's stormwater management.

Many of the elements necessary for evaluating the impacts of increased precipitation, intensified cloudbursts, and greater likelihood of flooding already exist, with sewers and stormwater as focal points. The capstone team recommends that, in addition to DEP, this same task force consist of the following city agencies and other public and private stakeholders required for consensus building and those directly involved in stormwater infrastructure:

- New York City Department of City Planning
- New York City Department of Education
- New York City Department of Parks and Recreation
- New York City Department of Sanitation
- New York City Department of Transportation
- New York City Department of Sanitation
- New York City Mayor's Office of Sustainability
- New York State Department of Environmental Conservation

Today, DEP is accountable to DEC, the regulator, with regard to permits for, and performance of, stormwater management and compliance. However, since the department does not have direct managerial control over agencies that control the efforts, this task force can help improve inter-agency collaboration. It also opens opportunities for unlocking capital, since these agencies have competing funding priorities and long-term capital plans. Moving forward, the task force should be involved in reviewing the future plans of agencies as they related to climate change-driven stormwater issues.

By strengthening interagency relationships and initiatives, the task force will facilitate the discovery of co-benefits and consensus building. It also better positions DEP for improved education and awareness building around stormwater management. Furthermore, it makes the case for mandated participation of agencies that impact stormwater and runoff, or expose DEP to compliance risk. Legal pathways for enforcing participation in this task force should be explored, as agencies who impact stormwater have obligations to comply.

For this recommendation to have the highest likelihood of success, the support of both OMB and the Mayor's Office is necessary. Learning from the successful implementation of previous green infrastructure initiatives in New York City, where flexibility was maintained by deferment of grey infrastructure into green infrastructure, OMB made the final decision that allowed for the tradeoff.

In that case, 'governance' rendered successful because one agency, DEP, controlled the entire capital budget. The involvement of the Mayor's Office is critical to establishing priority projects, emphasizing stormwater management as a citywide issue, and ensuring recognition of priorities by other partner agencies. When the city as a whole is held accountable, the burden of compliance gets amortized over a larger capital base and organization of agencies.

However, even if partner task force agencies with immense capital projects divert millions of dollars to managing stormwater, it is important to note that the necessity of the initiative can still be called into question. The researchers anticipate that accruing capital from partner agencies' budgets may be a challenge to implementing this recommendation, which the following recommendation aims to address.

6.2 Recommendation #2: Fund Stormwater Projects Through a New York City Environmental Impact Bond and Other Innovative Sources

To incorporate the identified best practices, DEP needs to identify new sources of funding. Additionally, any new funding requests for city funding must be vetted and reviewed by OMB. The newly established task force can help facilitate funding opportunities and link those items back to regulatory requirements. Per the advice of DEP's leadership, regulatory-mandated programs typically acquire funding even in the face of stiff competition. Tying objectives to regulatory mandates—such as water quality benefits, flood reduction, or conservation—should be a part of this new task force's governance process. However, current capital structure timelines may not always align or provide the opportunities needed for swift action. Therefore, the development of an Environmental Impact Bond and exploration of other potential fees should be a primary objective of the task force in creating a new funding mechanism.

For most New York City agencies, agency infrastructure is financed by general obligation bonds, and debt service against those bonds is recovered through tax revenue. However, the city's sewer system is financially self-sustaining, because of the New York City Municipal Finance Authority Act of 1984. Capital improvements to the water/sewer systems are funded by bonds issued by the New York City Water Authority; DEP is tasked with the operation of that system. All expenses for the water and sewer system, including the debt service owed on the bonds issued by the New York City Water Finance Authority, are recovered through user fees, according to the rates set by the Water Board. Therefore, issuance of new bonds solely by the New York City Water Finance Authority would have a detrimental impact to rates and is not a viable option.

The established task force should recognize stormwater as a city-wide issue, and other agencies should incorporate key findings from the CCATF—the case for issuing a new special Environmental Impact Bond through OMB, where stormwater is named a top priority.[230] In this case, the debt could be recoverable through tax revenue and amortized over a much larger pool, to divert impact from water and sewer rates. If this is not an option at the city scale, OMB can coordinate with DEC to issue a similar bond structure at the New York State level, in order to partly fund New York City stormwater projects that mitigate climate risk. However, DEC has not issued an environmental bond since 1996.

If a bond structure is pursued and the task force agencies are aligned on this mission, it can be framed not only as an Environmental Bond, but also as a Green Bond. There are many precedents for Green Bonds, but one of the most relevant to this recommendation is the partnership between the Chesapeake Bay Foundation and Quantified Ventures. The latter provided support to counties in the Chesapeake Bay Watershed in issuing Environmental Impact Bonds that specifically focused on stormwater. This included the first-ever Environmental Impact Bond issued by the Washington, DC Water and Sewer Authority, which financed green infrastructure that addressed stormwater-induced sewage overflows into local rivers. The Chesapeake Bay Foundation used a ‘Pay for Success’ financing model to support projects that achieved environmental and socio-economic goals. Successful projects that were financed through the bond and achieved their goals received higher repayments to reflect their value to the city. If a project fell short of its goals, repayments were lower. This model allows Environmental Impact Bond investors who care about environmental outcomes to share project risks with the cities and municipalities who implement them. This structure also provides verification of outcomes, so that both investors and cities can measure the project’s impacts and highlight those impacts to constituents.

The timing of this recommendation is extremely optimal. Today, many investors care as much about social and environmental returns as they do financial. Many specific Environmental, Social, and Corporate Governance (ESG) funds have been established to finance Green Bonds. New York City is currently well-positioned to attract investors because of the visibility of the city’s brand, and the recent upgrade of the city’s $38 billion outstanding general obligation bonds to an Aa1 credit rating—the second highest level, as reported by Moody’s and Standard and Poor’s (S&P). There has arguably never been a better time to attract investors for municipal bonds in New York City; furthermore, an added ESG or ‘green’ component could broaden the audience of investors.

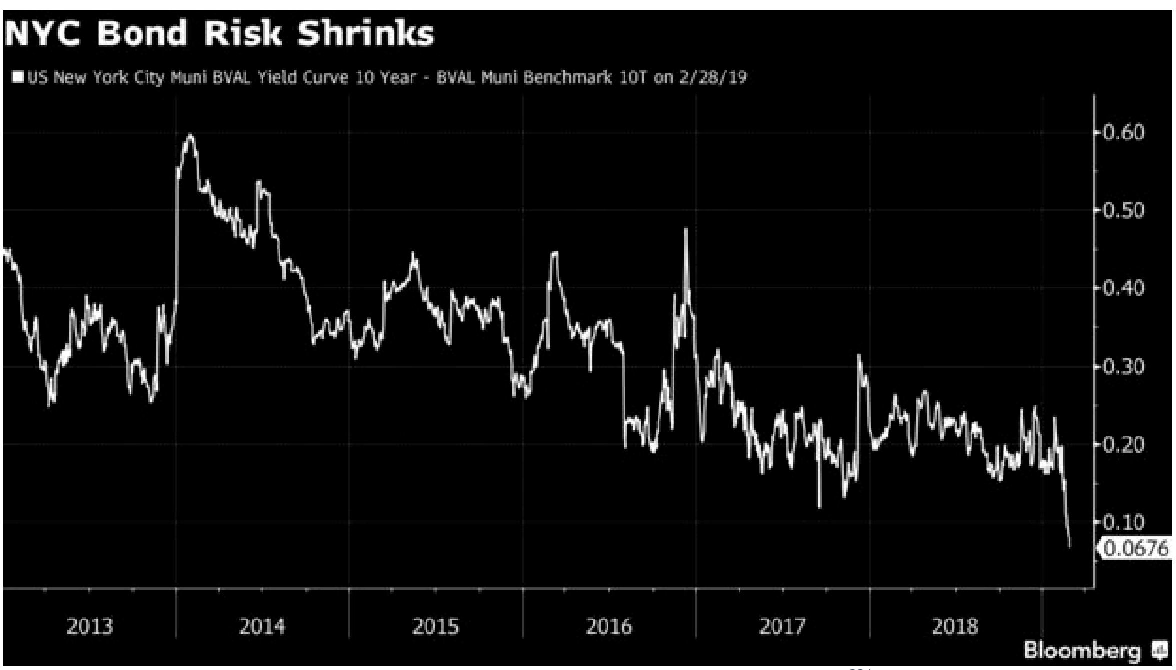


Figure 6-1: New York City Bond Yield Curve 2013-2018[231]

If DEC or OMB raised a $10 billion Environmental Impact Bond, then the servicing of the bond could be provided through a newly established ‘Stormwater Board’ governance structure, comprised of many city or state agencies. While future bonds of this type could address other issues facing the city, the initial bond should focus on stormwater to ensure that it does not face competition from other project types.

This Stormwater Board can be folded into the responsibilities of the task force. Funding can be allocated to stormwater projects as the bond's primary purpose; however, adding other applicable priorities within an ESG context (e.g., healthcare, air quality, flood protection for affordable housing or at-risk housing, as per the precedent set by Miami) to provide a more well-rounded platform would attract the most investors, as well as create the most competitive interest rates and lowest possible escalations back to New York City or State residents, via taxation.

The researchers also identified a stormwater fee as a potential source of additional funding necessary to addressing the growing challenges of climate change on New York City. This has been pursued by several the cities studied during this capstone project. Cincinnati, Houston, Seattle, Portland, and Washington, DC have all implemented stormwater fees in some fashion; most take the form of either a charge based on an estimation of the amount of impervious surface on a property, or a flat usage fee. Installing pervious surfaces or other water retention schemes lowers the impact of this fee, either through a direct reduction in the fee or provision of a credit.[232] The fee can potentially provide benefits: it could incentivize property owners to reduce runoff through installations of green infrastructure, and could provide funding for the collecting agency outside of capital projects.

A stormwater fee could also be used to anchor a program like Washington, DC's Stormwater Retention Credit trading program. Despite possible benefits, there is not yet strong empirical evidence of the success of incentivizing green infrastructure, and implementation of a fee must be carefully studied to ensure that it does not introduce additional burdens to challenged communities. DEP will conduct a rate study in 2020 to evaluate the impacts of a stormwater fee and, based upon the results of that study, it could potentially provide a steady stream of funding necessary to help New York City cope with the expanded challenges of climate change on its stormwater system.

6.3 Recommendation #3: Implement Best Practices Identified in City Case Studies

The New York City Environmental Impact Bond not only provides a timely option for impact investors, but also helps DEP take the lead in adapting stormwater management practices to climate change projections. The best practices mentioned in the Findings section can be limited in funding, constrained by regulations and compliance measures, and need further citywide cooperation. Through this new funding and task force structure, New York City can be positioned as a leader in funding and cooperative governance mechanisms for stormwater management. Additionally, the new funding allows DEP to invest in projects beyond compliance and regulation capital projects, including modeling, stormwater data collection, and green infrastructure. These projects will allow the city to better understand where and how new projects can be deployed to mitigate the effects of extreme rainfall events. The cities studied during the course of this research offer many examples of innovative initiatives that New York City can look to as it considers how to improve its stormwater management in the face of climate change. In particular, the following best practices appear promising:

- Installation of a Smart Sewer SCADA system, as done in Cincinnati, to measure and control the flow of rainfall through the city's sewer system in a proven, cost-effective manner
- Development of a risk-based asset management strategy, in line with Portland's, to plan deployment of capital upgrades by using a triple bottom-line approach that accounts for the consequences of failures
- Development of a three-dimensional model of the city and its water systems, as done in Rotterdam, to evaluate the risks of intense future rainfalls on different areas of the city, and use that model to perform risk assessments for neighborhoods.

6.4 Conclusion

The latter half of the twentieth and beginning part of the twenty-first centuries have been a story of progress for how cities in the U.S. deal with stormwater: the Clean Water Act paved the way for substantial reductions in pollution carried through runoff, and subsequently improved the quality of cities' waters. New York City has seen impressive improvements, with the current quality of its surrounding waters at its best in over a century.[233] However, climate change presents a challenge to this hard-won progress; the existing infrastructure and governance systems that shaped the city's stormwater program will be threatened by future precipitation events that bring greater, more frequent rainfall. New York City's task is to now ensure a balance between these two sets of obligations.

New York City is not alone in facing this issue; the research completed by this capstone team has identified that, while many efforts are new, cities are beginning to blend their approaches towards managing the existing and emerging challenges of stormwater. Domestically, Portland, Seattle, and Washington, DC, all provide examples of innovative ideas on how to incorporate climate change into stormwater management, while both Copenhagen and Rotterdam offer impressive approaches to water management in their unique regulatory environments. Cities are taking action, and New York City should build on its leading efforts through learning from its peers.

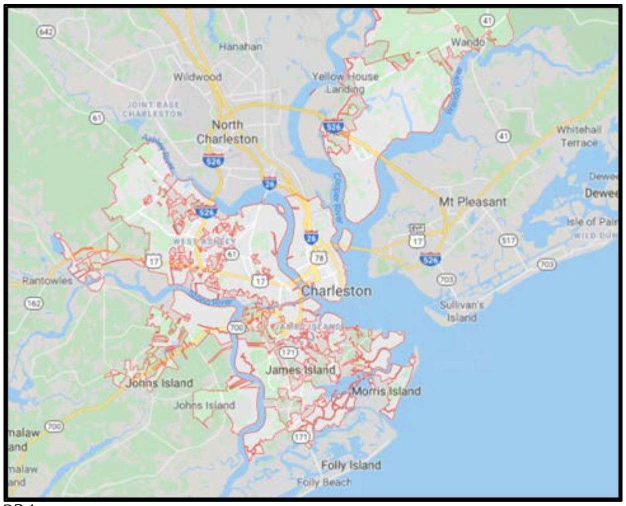
As a first step towards confronting the challenges posed by climate change to the city's stormwater system, New York City should look towards redefining its governance approach and create a task force aimed at improving agency and public coordination of stormwater efforts. To be effective, this body must have financial support, and an Environmental Impact Bond and other potential new sources can create funding streams dedicated to managing stormwater. After the new body is in place and has a mandate to focus on stormwater and has a specific funding source, New York City can begin adapting its stormwater system to climate change by following the examples of cities identified in this report. These recommendations will set the city on a path towards a stormwater system that is prepared for future challenges.

Appendix

Appendix 1

This Appendix contains case studies of all the targeted cities identified in the Methodology section above.

Charleston, SC



[234]

Demographics	
Total City Size	127.53 square miles[235]
Population	136,208[236]
Surrounding Water Bodies	Atlantic Ocean, Rivers, Wetlands
Water Management System	
Sewer System Type	Separate
Sewer Capacity	800 miles[237]
Expected Climate Impacts	
Current Annual Precipitation Levels	~51in[238]
Projected Precipitation Levels	~54.7in[239]
Planning Time Horizon	2050 (Scenario 8.5)[240]

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	Charleston Stormwater Department	Utility Fee
Surface water quality	Charleston Water System	Utility Rates & Fees
Wastewater treatment	Charleston Water System	Utility Rates & Fees
Drinking water supply	Charleston Water System	Utility Rates & Fees
Sewers & stormwater	Charleston Stormwater Department, Charleston Water System	Utility Fee

Regulatory Environment:
Charleston has support for stormwater that extends to the Governor of South Carolina. The threat to Charleston from flooding has just recently carved out $10 million of the Governor's executive budget to relieve flooding in the city's medical district.[241] This is in addition to unanimous voting from city council in 2018 to increase revenue towards their stormwater fund. The Mayor and City Council has stated that flooding and drainage is the city's number one priority.[242] Along with funding and support, Charleston officials created a dedicated Stormwater Department in 2018 to address stormwater projects and various long-term capital improvement projects.[243]

Successful Initiatives:

1. **Grey Infrastructure:** Charleston has been focusing heavily on flood mitigation through various grey infrastructure projects. Their top initiative is an on-going infrastructure project called the Spring-Fishburne Drainage Improvement Project. Designed in 2009, the 5-phase project is aimed at relieving flooding in Charleston's downtown area through surface collection, new shafts, and 12 feet diameter tunnel that will ultimately pipe 120,000 gallons per minute out to the Ashley River.[244] Additional sunny-day flooding is proving problematic in the city's medical district. Flooding issues has spurred the above mentioned $10 million in funds towards connecting the medical district to the Spring-Fishburne project in the next 2 years. To protect Charleston's rich history from expected sea level rise, funds have also been allocated by City Council to raise approximately 1000 feet of Charleston's Low Battery wall.[245] Work on the Battery wall is expected to begin January of 2020

2. **Dutch Dialogues Charleston**: This is a collaborative effort involving Dutch and International water experts to develop an integrated approach towards mitigating climate threats to Charleston. From January to April of 2019, project research, data compiling, past learnings, impact analysis, and mapping took place. From May through Sept, various workshops and teams were created which formulated a clear integrated resiliency plan for the city. Past learnings from the Dutch, along with experts in multidisciplinary fields helped to produce a 250-page report which outlines areas of concern, findings, and actions to make Charleston better versed against climate change.[246]

3. **Capital Improvement Plan:** The funding and resources are aligning to start proactively addressing capital improvement projects. The Charleston Stormwater Department is focusing on future projects with the creation of a Project Prioritization Tool. The tool analyzes projects by amount of water managed and combines quantitative CBA analysis with qualitative social impact measures. Project costs versus amount of water managed is meshed with a qualitative rating system help in uniform decision making for city stakeholders

Challenges:
Charleston's Stormwater Department is less than a year old and is faced with frequent tidal flooding and rain events that are projected to get worse.[247] The city is working to build momentum towards a proactive stormwater maintenance plan. This means first, addressing needed rehabilitation of pipes and below ground infrastructure, then systematically working through every drainage system in the city. The 2009 created Spring-Fishburne project has already proven challenging as it has extended its estimated completion timing and budget over multiple iterations.[248] Ensuring community engagement towards the project's progress is vital as all work is happening underground and unseen to the public.

Cincinnati, OH

Demographics	
Total City Size	79.52 square miles[249]
Population	302,605[250]
Surrounding Water Bodies	Ohio River and Licking River[251]
Water Management System	
Sewer System Type	40% combined; 60% separate[252]
Sewer Capacity	3,300 miles[253]
Expected Climate Impacts	
Current Annual Precipitation Levels	3.37 inches per month (average)[254]
Projected Precipitation Levels	30% increase in heavy rainfall
Planning Time Horizon	"Next few decades"

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	MSD & SMU	Utility Fee[255]
Surface water quality	GCWW	Water Works Enterprise Fund[256]
Wastewater treatment	MSD	Utility Fee[257]
Drinking water supply	GCWW	Water Works Enterprise Fund[258]
Sewers & stormwater	MSD & SMU	Utility Fee[259], Stormwater Rate[260], Stormwater Management Fund[261]

Regulatory Environment:
Cincinnati has two main government bodies overseeing the city's stormwater management. The first is the Metropolitan Sewer District of Greater Cincinnati (MSD) governed by a 50-year agreement between the City of Cincinnati and Hamilton County. MSD serves 800,000 people in 33 separate political jurisdictions over 400 square miles within Hamilton County, and is managed by the City of Cincinnati. MSD oversees collection and treatment of wastewater for 43 of the 49 political subdivisions in the county. MSD operates seven major wastewater treatment plants, and 3,000 miles of piles – of which 2/3 are sanitary; the rest are combined sewers, handling both stormwater and wastewater.[262]

The Cincinnati Stormwater Management Utility (SMU) is a division of Greater Cincinnati Water Works (GCWW), which separated from MSD in July 2016. Unlike MSD, which manages both wastewater and stormwater, SMU focuses on capturing, controlling, and conveying stormwater runoff. They manage 300 miles of storm sewers, approximately 30,500 inlet and intake structures, more than 6,000 storm sewer manholes, the Mill Creek Barrier Dam, and four pump stations.[263]

Successful Initiatives:

1. **Project Groundwork:** As one of the top five combined sewer overflow (CSO) dischargers in the country, MSD has successfully curbed overflow through extensive green infrastructure. Under Project Groundwork, MSD implemented the Lick Run Project, saving the city $200 million dollars in what would have been spent on grey infrastructure—specifically, a deep, underground storage tunnel.[264]

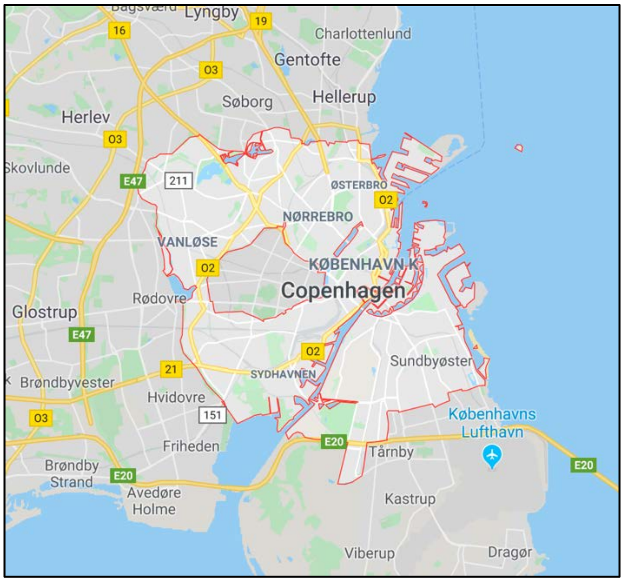
2. **Stormwater Fee Restructuring:** With a former fee structure that did not incentivize water management on properties around the city, SMU recently announced rate updates and service charges for 2019. The fee restructuring tacks on a charge to each water bill, based on the amount of impervious surface on a property, and the amount of runoff from the property. By moving away into a method that ties in metrics related to stormwater management, Cincinnati is laying the groundwork for decentralized stormwater management throughout the city.[265]

3. **Smart Sewer SCADA System:** MSD was recently awarded the top prize in a national Best Water Projects contest for its "Smart Sewers." The system has saved tens of millions of dollars in capital investments to meet MSD's Consent Decree obligations to keep raw sewage mixed with stormwater out of waterways. The system uses sensors in the sewers, computerized controls, and gates/valves within the sewers that can redirect excess water flows to parts of the system that are not inundated or operating at capacity.[266]

Challenges:
According to an interview with Diana Christy, Interim Director of the MSD, a challenge that Cincinnati has faced is duplication of stormwater fees and confusion among city residents, as a result of the city's governance structure. While the SMU implements a rate based on the amount of impervious surface on a property, MSD continues to bill a separate fee based on the amount of water used by a property. Since MSD's sewer bill helps fund Project Groundwork, which is intrinsically linked to stormwater management, some confusion arises from the dual bill.

Another challenge specific to MSD is regarding KPIs—while they can measure reduction and overflow volume, they are not able to measure sewer capacity and water removal rates specific to stormwater.

Copenhagen, Denmark



Demographics	
Total City Size	48.75 square miles[267]
Population	1,333,888 (2019)[268]
Surrounding Water Bodies	Faces Oresund Sound to the East
Water Management System	
Sewer System Type	Combined & Separate
Sewer Capacity	1,100 km of main sewer and approx. 300 km of service pipes[269]
Expected Climate Impacts	
Current Annual Precipitation Levels	Average annual rainfall is 1164 mm[270]
Projected Precipitation Levels	25-55% more by 2100[271]
Planning Time Horizon	20 years (Cloudburst Management Plan)

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	HOFOR (Greater Copenhagen Utility) in compliance w/ City of Copenhagen[272]	Public Utility Fee, Taxes, Private Financing[273]
Surface water quality	HOFOR/City	Fee/Taxes/Private[274]
Wastewater treatment	BIOFOS/City	Fee/Taxes/Private[275]
Drinking water supply	HOFOR/City	Public Utility Fee[276]
Sewers & stormwater	HOFOR/City	Fee/Taxes/Private[277]

Regulatory Environment:

The City of Copenhagen Government (City Council) supports the city's Cloudburst Management Plan 2012 (20-year plan) and Climate Adaptation Plan 2011 (14-year plan). Copenhagen's climate challenges are addressed by the City Council and legislation alongside planning are integrated with utility companies, private companies, and the citizens resulting in a co-creation and meta-governance.[278] Some of the challenges addressed due to climate change are extreme rainfall; affected groundwater and capacity; higher sea levels; higher temperatures and heat island effect.[279] Copenhagen has a co-financing scheme for the $1.5 Billion USD combined cloudburst and stormwater solution cost. The Hydraulic Function can be financed thorough water charges from the utility, while funds for urban space improvements can be financed through the municipal budget (income tax and property tax). Private citizens can invest in backflow valves and local drainage of stormwater.[280]

Successful Initiatives:

1. **Surface Solution:** These Blue/Green Infrastructure solutions integrate urban planning, hydraulic analysis, sound analysis, and traffic. There are over 300 citywide pilot projects including cloudburst roads, detention streets, green streets, central retention areas, urban canals and cloudburst pipes.[281]

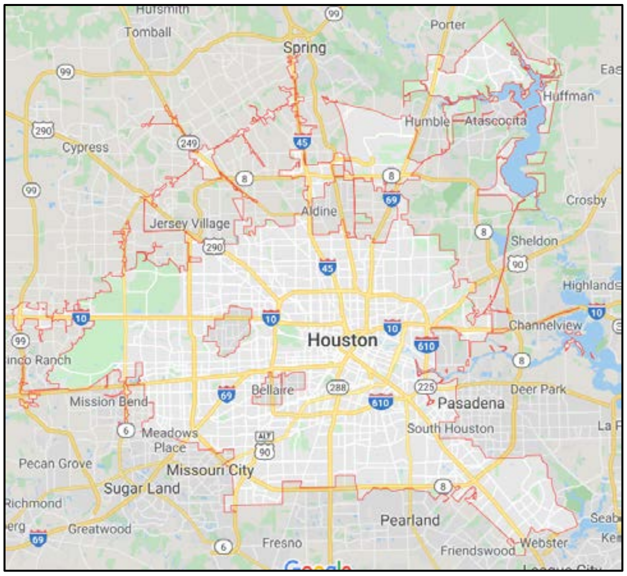
2. **Hydraulic Solution:** City-wide hydraulic patterns to channel water into harbor and reduce impacts of pluvial flooding. Four large cloudburst pipes will be built below ground to discharge water into Copenhagen Harbor and the surrounding city lakes acting as retention basins.[282] The model established can be universally applied for flood mitigation strategies.[283]

3. **Meta-Governance and Co-Creation:** Both private and public ideas, knowledge, and resources are merged to come up with solutions to better cope for future cloudbursts. Citizens, small businesses and other nonpublic actors work together to adapt the city scape in terms of streets, lakes, parks, and squares.[284] The City Council steers and initiates these integrated urban space projects which enhance public value through the outcomes and collaborative innovations.[285]

Challenges:

Some of the challenges posed with meta-governance and co-creation were unclear definitions and solutions by all parties involved, therefore not all preferences could be accommodated and conflicting interests and turf fights arose.[286] Major damages over the next 100 years were predicted at $2.3 billion while major rainfall events in a six-year span period, the largest being in 2011, left the city with about $900 million in damages. Using almost half the sum already, lead to reassessment of overall damage costs in the Copenhagen Climate Adaptation Plan.[287]

Houston, TX



Demographics	
Total City Size	665[288] square miles
Population	2,325,502[289]
Surrounding Water Bodies	Gulf of Mexico
Water Management System	
Sewer System Type	Combined
Sewer Capacity	--
Expected Climate Impacts	
Current Annual Precipitation Levels	45.3[290] in
Projected Precipitation Levels	--
Planning Time Horizon	--

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection, water quantity	HCFCD	Regional tax
Surface water quality	HCFCD	Regional tax
Wastewater treatment	City	Local taxes
Drinking water supply	City	Fee
Sewers & stormwater	City	Local taxes, stormwater fee

Regulatory Environment:
The Harris County Flood Control District is responsible for permit responsibility related to stormwater[291] and is part of a joint task force that includes the City of Houston, Harris County, and the Texas Department of Transportation tasked with cooperating on Phase I permit requirements. In this arrangement, HCFCD oversees flood management and prevention and the City of Houston oversees construction of storm sewers and street drainage.[292] The federal government, through the Army Corps of Engineers and the Federal Emergency Management Agency,[293] is supports Houston's flood control efforts, especially in wake of 2017's Hurricane Harvey.

Successful Initiatives:

1. **Bond Issuance:** Voters approved a $25 billion bond issuance in August 2018 that will be used "to assist with recovery after previous flooding events (including Harvey) and to make our county more resilient for the future."[294]

2. **Stormwater Fee:** Voters approved a 2010 initiative to enhance the city's drainage infrastructure by creating a "Dedicated Pay-As-You-Go Fund for Drainage and Streets"[295] named Rebuild Houston. It aggregates funding from four sources: property taxes, developer impact fees, third-party funds and grants, and a drainage utility fee;[296] the drainage utility fee makes up the largest source of contributions.[297] The drainage fee is assessed to property owners and is based on the amount of impervious surface area on their property.[298]

3. **Green Infrastructure Plans:** As part of its recovery from Hurricane Harvey, Houston commissioned a study on the possibilities of green infrastructure to address the city's drainage challenges. That process produced a number of recommendations on how to incentivize green infrastructure in the city: development rules, property tax abatements, recognition programs, and improved permitting.[299] The city will now further study these recommendations to develop implementation plans, with a goal of putting them into service from 2020 to 2022.[300]

Challenges:
Climate change does not appear to be a future issue for Houston; the city has regularly experienced precipitation events that exceed the 100-year and 500-year daily rainfall totals in the past twenty years.[301] The city has also grown rapidly in the past half century, so that now as much as 40-50% of the county may be in the 500-year floodplain.[302] At the same time, the city imposes a cap on revenue that challenges its ability to meet its infrastructure needs.[303]

Miami, FL

Demographics	
Total City Size	7.63 square miles
Population	91,718[304]
Surrounding Water Bodies	Atlantic Ocean Biscayne Aquifer Gulf of Mexico
Water Management System	
Sewer System Type	Separate[305]
Sewer Capacity	8,723 miles of pipe[306]
Expected Climate Impacts	
Current Annual Precipitation Levels	61.93" / year[307]
Projected Precipitation Levels	Drought & Increased Heavy Downpours – location & season dependent[308]
Planning Time Horizon	50 years

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	Miami Dade Water & Sewer	Utility Fees & Bonds
Surface water quality	Miami Dade Water & Sewer	Utility Fees & Bonds
Wastewater treatment	Miami Dade Water & Sewer	Utility Fees
Drinking water supply	Miami Dade Water & Sewer	Utility Fees
Sewers & stormwater	Miami Dade Water & Sewer	Utility Fees

Regulatory Environment

The Miami Dade Water and Sewer Department oversee all functions associated with drinking water, wastewater and water conservation throughout the County. The County is comprised of 34 incorporated municipalities[309] including the city of Miami Beach. While each municipality has its own governing body, all municipalities work together towards resiliency strategies especially those related to sea level rise and stormwater management.

Miami has placed significant emphasis on education for the public on the city's risks associated with climate change, and what they can do to help. The success of this educational effort was seen when the residents voted to increase their own taxes to fund the Miami Forever Bond.

Successful Initiatives:

1. **The Miami Forever Bond:** Miami voters passed the $400 million dollar general obligation bond in November 2017.[310] The bond increases taxes for citizens and allows the City to borrow money to fund sea level rise mitigation projects throughout the city. The City government created a "Citizen Oversight Board" as well as a "Bond Task Force" to oversee the project management of the bond and ensure transparency.[311]

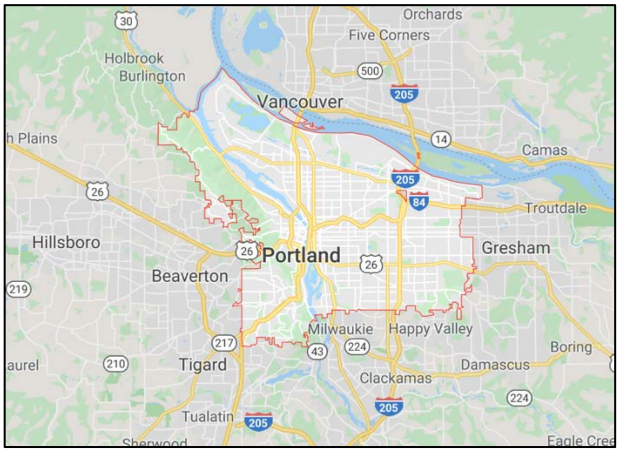
2. **Greater Miami & The Beaches:** Miami is comprised of multiple small municipalities, each with their own governing bodies, budgets and priorities. This partnership allows for the alignment of governmental efforts and the creation and implementation of the "Resilient 305" strategy. The plan address the impacts of sea level rise and stormwater management for the greater Miami area with overarching goal areas of "Places, People and Pathways".[312] A joint team comprised of senior staff and CRO's from each municipality called "PIVOT" oversees the strategy implementation.[313]

3. **Miami Beach Rising Above:** Miami Beach created a resiliency strategy called MB Rising Above. The strategy focuses on resiliency strategies for sea level rise and stormwater management.[314] Projects implemented to date include pump stations, raising roads, elevating sea walls and replacing aging infrastructure.[315] The City sees this as a beginning to integrated planning in which they are incorporating blue and green infrastructure and consulting experts from varying backgrounds. Monthly utility fees and stormwater bonds are covering costs. The City also launched an app in conjunction with this program to allow residents and visitors to take a walking tour of the projects implemented.[316]

Challenges:

The biggest challenge facing Miami is mostly due to their location and elevation. Miami has found ways to raise awareness, drive investment, raise funds and work together between municipalities and government agencies for success. While they still look to continuously improve in all of these areas, they are mostly challenged by the amount of time they have to make all of these changes before it is too late.

Portland, OR



Demographics	
Total City Size	145 square miles
Population	653,115 (2018)[317]
Surrounding Water Bodies	Columbia and Willamette Rivers
Water Management System	
Sewer System Type	Combined (33%) and Separate (66%)[318]
Sewer Capacity	--
Expected Climate Impacts	
Current Annual Precipitation Levels	37 inches[319]
Projected Precipitation Levels	Same annual average with wetter winters and more intense storms[320]
Planning Time Horizon	50 years[321]

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	Bureau of Environmental Services	Public Utility Fees
Surface water quality	Bureau of Environmental Services & Portland Water Bureau	Public Utility Fees
Wastewater treatment	Wastewater Group - Bureau of Environmental Services	Public Utility Fees
Drinking water supply	Portland Water Bureau	Public Utility Fees
Sewers & stormwater	Bureau of Environmental Services	Public Utility Fees

Regulatory environment:
Portland's City Council is large partner and supporter of the City's stormwater goals. Between 2007 and 2009, City Council approved a green street resolution, which encouraged green street facilities in private and public development; a grey to green initiative, which budgeted $50 million in stormwater management fees to invest in green infrastructure to complement the City's conventional pipe investments; and approved a climate action plan.[322]

Successful Initiatives:

1. **Eco-roofs & Green Infrastructure:** Portland's stormwater manual requires that projects with more than 500 square feet of impervious surfaces comply with pollution-reduction and flow-control standards and uses green infrastructure as a primary measure to achieve this. Portland was also able to develop a program between 2008 and 2012 where the City offered education, planning aid, and a $5 per ft2 incentive to build an eco-roof for property owners and developers. This initiative created over 20 acres of eco-roofs that can manage millions of gallons of stormwater each year. The program also included green streets and tree-planting.[323]

2. **CSO Infrastructure:** In 2011, Portland completed its largest public works investment in its history -- 20-year project that added new infrastructure, including "Big Pipes" to the sewer system. The system went from being able to manage 1/10 inch of rain to more than an inch before a CSO event occurs. The Bureau of Environmental Services maintains an in-depth catalogue of this grey infrastructure. Under the CSO program, there was also a downspout disconnection program, which disconnected roof drains from combined sewers, removing more than 1.2 billion gallons of stormwater annually from the CSS.[324]

3. **Modeling:** Portland is currently working with the University of Washington Climate Impact Group on regional rainfall climate models that will be able to estimate future rainfall intensities on the local and sub-daily levels, which is very important for stormwater planning and resiliency.[325] The City is also working on scenario-based models or a "structured discussion process" on climate change to identify driving forces, identify critical uncertainties, develop scenarios, discuss implications, and develop adaptive strategies.[326]

Challenges:
Uncertainty of future rainfall patterns, calibrating down-scale climate change models, and high rates for customers

Rotterdam, The Netherlands

Demographics	
Total City Size (square miles)	113.1 square miles[327]
Population	634,660[328]
Surrounding Water Bodies	River Maas, North Sea
Water Management System	
Sewer System Type	Combined
Sewer Capacity *(if available)*	--
Expected Climate Impacts	
Current Annual Precipitation Levels	30.8 in[329]
Projected Precipitation Levels	2.75 in/hr (2050)[330]
Planning Time Horizon	2050, 2100

Water Governance: tasks, responsibility, and funding

Task	Organization	Funding Method
Floodwater protection	Water Board	Regional tax
Surface water quality	Water Board	Regional tax
Wastewater treatment	Water Board	Regional tax
Drinking water supply	Utility	Fee
Sewers & stormwater	City	Local tax

Regulatory Environment:
The 2009 Water Act consolidated water legislation at the national level and delineated the responsibilities of water authorities at different levels.[331] Two additional policies, the 2012 Delta Act[332] and the 2016 National Climate Adaptation Strategy,[333] tasked the national government the responsibility of planning to adapt the country to the effects of climate change. This is supplemented with efforts at the regional level, where 23 Water Boards are responsible for maintaining water levels and water quality.[334] The city government is responsible for maintenance of sewer systems and prevention of flooding from rainfall.[335] Water management is integrated with spatial planning at the national level[336] through the Ministry of Infrastructure and the Environment and at the city level through a Water Assessment performed on new developments.[337]

Successful Initiatives:

1. **Data-driven Goals:** To understand the city's climate risks and determine how to prioritize action, Rotterdam has developed a three-dimensional computer model of the city's topography and water system. This model was developed in conjunction 3Di Water Management[338] and uses the city's aboveground elevation, sewer system, groundwater, and surface water system[339] to predict the impacts of intense rainfall. This model is used to analyze the level of flooding risk from intense rainfall at the city, neighborhood, and individual property level.[340]. Buildings are assigned a letter grade that identifies their flooding risk (A: safest, B-E: less safe) and makes this information available to the public.[341]

2. **Integrated Management:** Rotterdam views the problem of water management as something that requires holistic management and has put in place policies that address it across various city agencies. It has established a city-wide goal of being climate proof by 2025[342] while also preparing for longer term changes[343] and put in place cross-cutting policies to support that. Water management is integrated with urban planning: the permitting process for new development entails co-review by both the local spatial development authority and the water authority to ensure that both agencies have the ability to evaluate the development's impact on their system[344][345]. The city has also balanced its approach to intervention in stormwater control, acknowledging that sewer infrastructure is costly and that investing in efforts to defer stormwater from sewers may produce a better outcome.[346] The city also views its response to climate change as an opportunity, both to add to the city's economy[347] and to improve quality of life[348] for residents.

3. **Infrastructure:** Rotterdam's focus for its stormwater infrastructure involves a three-step approach:[349] capturing water, storing water, and then draining water. To support this approach, the city has pursued both gray and green infrastructure projects. It established 2030 targets of 800,000 square meters of green roofs in the city and a minimum of 50% of municipal buildings with green roofs.[350] The city also offers incentives to its residents who pursue water retention projects on their properties.[351][352] Marquee projects, like the Benthemplein water square capable of retaining over 2 million liters of rainwater[353] and the Museumpark garage capable of storing 10 million liters of rainwater,[354] supplement the city's green infrastructure initiatives.

Challenges: Despite the shared political consensus of the Dutch water management authorities, it is sometimes hard to communicate the need for action to all stakeholders. The country's historic excellence in managing water has made it challenging for the public and political leadership to understand that climate change will mean upsetting the balance that exists today.[355] Rotterdam's leadership has found that using data and modeling can be a persuasive tool to overcome this lack of clarity.[356] The city has also found that, while marquee pilot projects can bring attention to the city's challenges, it can be difficult to expand on those projects and scale up.[357]

Seattle, WA

Demographics	
Total City Size	83 square miles[358]
Population	747,300[359]
Surrounding Water Bodies	Lake Washington, Lake Union, Puget Sound, Duwamish[360]
Water Management System	
Sewer System Type	2/3 Combined 1/3 Separate[361]
Sewer Capacity	1,421 miles (pipes)[362]
Expected Climate Impacts	
Current Annual Precipitation Levels	37.5 in[363]
Projected Precipitation Levels	+5% annually +22% intensity[364]
Planning Time Horizon	2050[365]

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	King County WLRD[366]	Surface Water Management Fee
Surface water quality	Seattle Public Utility[367]	Ratepayers and Bonds
Wastewater treatment	King County WTD[368]	Ratepayers
Drinking water supply	Seattle Public Utility	Ratepayers and Bonds
Sewers & stormwater	Seattle Public Utility	Ratepayers and Bonds

Regulatory Environment

Seattle's stormwater code addresses drainage control review requirements, on-site stormwater management, erosion control requirements for projects during construction, flow control and stormwater treatment requirements, and how the city enforces their stormwater code. The city's stormwater code is a mixture of items required by regulators discretionary decisions from the City Council over time.[369] The Seattle Public Utility has dedicated most of its resources to CSO upgrades over the last decade, which has resulted in high rates and less focus on building resiliency around flooding. The stormwater code is focused more on overall annual precipitation, not extreme events or resiliency.[370]

According to Seattle Public Utilities, for a project to be considered 'Green Stormwater Infrastructure' it must provide a function in addition to stormwater management such as water reuse, providing greenspace and/or habitat in the City[371] (examples include bioretention, rain gardens, vegetated roofs, etc.). The City of Seattle's Stormwater Code contained in Seattle Municipal Code (SMC 22.800-22.808) "requires projects to implement On-site Stormwater Management BMPs, which include Green Stormwater Infrastructure."[372]

Successful Initiatives:

1. Incorporating climate change projections through project sizing and design, determining system capacity, and identification of at-risk areas to build resilience.[373]

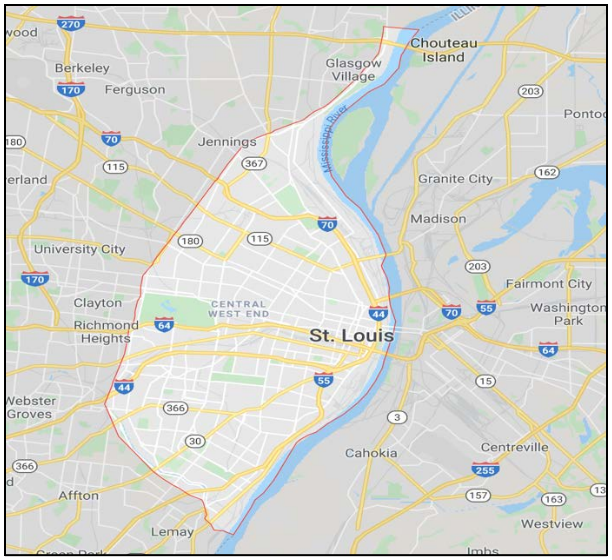
2. Engagement with various agencies for shared resources; for example, cautionary agreements with DOT, community-based PPPs for retrofits, and Office of Sustainability and Environment for climate projections.[374]

3. Value-based health outcomes and co-benefits as substitute for monetary KPIs. Strong emphasis on triple bottom line assessments[375]. The Seattle Public Utility has co-authored a report with the EPA on the benefits of green stormwater infrastructure, which provides economic and health benefits to various projects.[376]

Challenges

Compliance standards and procedures are not flexible enough to combat climate change projections and do not consider resilience. Not enough focus on flooding impacts.[377] Further, legal constraints limit options for alternative compliance approaches for the city's stormwater code.[378] As rates have gone up and income inequality grows,[379] legal requirements and rate pressures often limit the investment potential in stormwater projects.[380]

St. Louis, MO



Demographics	
Total City Size (square miles)	62[381] square miles
Population	302,838[382]
Surrounding Water Bodies	Missouri River, Mississippi River, Meramec River[383]
Water Management System	
Sewer System Type	--
Sewer Capacity	3,000 miles for stormwater[384]
Expected Climate Impacts	
Current Annual Precipitation Levels	39 inches[385]
Projected Precipitation Levels	+40% increase[386]
Planning Time Horizon	2037[387]

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	N/A	--
Surface water quality	MSD	Regional Tax[388]
Wastewater treatment	MSD	Regional Tax
Drinking water supply	City of St. Louis Water Division	Rates set by Board of Alderman[389]
Sewers & stormwater	MSD	Regional Tax

Regulatory Environment

The sewer system, in terms of wastewater, in St. Louis is the 4th largest in the United States.[390] Overflows, principally combined sewer overflows, are a significant at the center of the Metropolitan St. Louis Sewer District's (MSD) work. The MSD spent $2.7 billion to eliminate approximately 380 overflow events from 1992 to 2012, and these costs are expected to continue growing with a projected $4.7 billion in spending over the next 23 years.[391] Stormwater funds are generated through flat fees on each MSD bill and property taxes that raise $20-$25 million annually.[392] Governance decisions are primarily based on a rate commission, comprised of various stakeholders in the area, that meet every five years to balance regulations and budgetary priorities.[393] The EPA's consent decree with the MSD drives much of the city's stormwater management practices; for example, the department allocates a certain amount of money toward green infrastructure projects every year without knowing how much they will allocate in future years.[394] Much of the focus at the MSD in regard to stormwater management is on water quality.[395]

Successful Initiatives:

1. Partnership with USGS to monitor small streams and open channels.[396]
2. Applying smart utilities to efficiently manage stormwater assets.[397]
3. Stormwater retention requirement have been in place since the late 1980's. They are getting more stringent and improving runoff rates.[398]

Challenges:

The greatest challenge for dealing with stormwater management is surcharging the stormwater system or open channel flooding from creeks.[399] Further, the lack of funding to build infrastructure to deal with this flooding makes the problem harder to manage. Stormwater practices have not been formally approved by ratepayers; in fact, the community has rejected capital improvements in several votes.[400]in

St. Louis is currently using rainfall data from 2013 instead of future projections for climate change in regard to their project designing.[401]

Washington, DC

Demographics	
Total City Size	61.05 square miles
Population	702,455
Surrounding Water Bodies	Anacostia River Chesapeake Bay Potomac River Rock Creek
Water Management System	
Sewer System Type	Separate (2/3) Combined (1/3)
Sewer Capacity	364 MGD
Expected Climate Impacts	
Current Annual Precipitation Levels	40.78" / year
Projected Precipitation Levels	Increase in Time & Intensity of extreme events (1"-2"); 15 yr storm increase from 5.3" to 6.8"[402]
Planning Time Horizon	10 – 50 years

Water Governance: Tasks, Responsibility, and Funding

Task	Organization	Funding Method
Floodwater protection	DOEE	Utility Rates & Fees; Bonds
Surface water quality	DOEE	Utility Rates & Fees; Bonds
Wastewater treatment	DC Water	Utility Rates & Fees
Drinking water supply	DC Water	Utility Rates & Fees
Sewers & stormwater	DC Water & DOEE	Utility Rates & Fees

Regulatory Environment

In Washington, DC, management of water resources, utilities and stormwater is a shared task between the Department of Energy and Environment (DOEE) and DC Water & Sewer (DC Water). In 1996, DC Water elected a Board of Directors and became financially independent from the DC government, allowing them to set their own budgets and rates while raising funds through capital markets.[403] The DOEE focuses on water quality within the district, while DC Water is the water utility for the district, delivering drinking water and managing wastewater treatment.[404]

The DOEE is very active in the community and works with sister agencies to provide free training, meetings and oversight of stormwater pollution prevention plans (SWPPP).[405] Additionally, the DOEE runs targeted outreach and education programs to teachers, students, businesses, district employees, homeowners and developers through community wide programs such as their RiverSmart Homes and RiverSmart Communities programs.[406]

Successful Initiatives:

1. **Storm Water Retention Credit Trading:** The DOEE launched a Stormwater Retention Credit (SRC) trading program in May 2016.[407] The program allows for entities regulated under DC's Stormwater Management Regulations to comply with up to 50% of their retention requirements by purchasing storm water credits from green infrastructure projects sold by other developments.[408] DC was able to attract private investment by launching a "SRC Price Lock Program".[409]

2. **Environmental Impact Bond:** DC Water issued a $25 million Environmental Impact Bond in September 2016, the first of its kind.[410] The bond allows DC to finance green infrastructure projects throughout the district, while limiting financial risk to DC Water. With a main goal of improving water quality through storm water management, the green infrastructure implemented through this bond, will allow for the capture of an additional 650,000 gallons of storm water runoff annually.[411]

3. **Data Collection and Mapping:** The Department of Energy and Environment has prioritized data collection, mapping, transparency, and accessibility of this information to the public. DC has an extensive data set used to map all green infrastructure projects throughout the district, which is used to assess impact on specific sewer systems and watersheds.[412] DC has set aside $5 million to purchase a new 3D mapping system that they plan to have functional over the next 3 – 5 years.[413] The system will allow them to test system capacity for specific rain events as well as test the impacts of proposed infrastructure projects on storm water management.[414]

Challenges:

While DC has state of the art green infrastructure programming, they still struggle with gathering data on these projects beyond meeting their required water quality standards. When asked if they have data on storm water retention of their projects and how each project influences water quality, they had general numbers, but no specific data. For example, they have a standard set of water retention amounts for projects like planting a single tree, but cannot use this data with high levels of accuracy[415] for future planning and implementation.

Appendix 2

This Appendix contains a table summarizing the potential impacts on infrastructure in New York City identified as a part of the 2019 NPCC report.

Table 2. Potential infrastructure impacts from heavy downpours[416]

Infrastructure sector	**Component**	**Impact**
Energy (electricity)	Production	Equipment damage from flooding
	Transmission and distribution	Increase in number and duration of local outages from flooded and corroded equipment
Transportation	Roadways	Declining serviceability of roadways due to flooding conditions
		Increased travel delay from increased congestion during street flooding
	Transit	Increase in pumping capacity and associated increased energy use to remove excess water to prevent flooding
Telecommunications	Supplies	Equipment flooded and stored materials damaged
	Equipment	Excessive precipitation flooding equipment
Water supply	Quantity	Uncertain changes in precipitation producing variability and unpredictable water supplies
	Distribution	Pressure changes in water distribution system
	Quality	Impact on water quality from increased turbidity
Waste	Closed landfills	Unexpected leaching of contaminants where precipitation penetrates the surface of closed landfills
	Marine transfer stations	Marine transportation impeded

	Curbside refuse	Increased damages to curbside refuse containment and releasing refuse, increasing public health concerns
Sewer	Quality	Hydraulic capacity of sewers and wastewater treatment plants exceeded owing to increased flows
		Combined sewer overflow facility capacity is overwhelmed, and pollutants discharged into sewer systems and waterways
		Sewer backups
		Treatment capacity of treatment plants exceeded from dilution from increased flows
		Decline in water quality reflected in Clean Water Act standard variances
Social infrastructure	Hospitals	Equipment flooded and stored materials damaged
	Parks and public spaces	Reduction in vegetation from washouts and flooding of root systems

Appendix 3

This appendix contains a rough order-of-magnitude (ROM) economic risk analysis of New York City from climate-driven precipitation impacts. Input data are denoted by regular formatting and calculations are bold and highlighted. As mentioned in section 5, both the CRPS and Copenhagen sources quantified the net present value (NPV) of the costs of heavy downpour impacts. A discount rate was therefore not used in this analysis.

NYC Cloudburst Resiliency Planning Study (CRPS)

South Queens Study Area		**NYC**	
Land area (square miles)	5	Land area (square miles)	303
Population	110,000	Population	8,623,000
Land area (as a % of NYC total)	**1.7%**	Population Density	28,496
Population (as a % of NYC total)	**1.3%**		
Population density	**22,000**		
% Less dense than NYC	**22.8%**	**NYC Total Estimated Risk**	
Avoided costs	Net present value (NPV)	Avoided costs	ROM NPV
Risk costs	**$ 310,000,000**	**Risk costs**	**$ 23,038,222,725**
Physical damages	$ 185,000,000	Physical damages	**$ 13,748,616,788**
Output loss	$ 125,000,000	Output loss	**$ 9,289,605,938**
Social costs ($M)	**$ 290,000,000**	**Social costs ($M)**	**$ 22,733,363,636**
Injuries	$ 90,000,000	Injuries	**$ 7,055,181,818**
Mental stress and anxiety	$ 200,000,000	Mental stress and anxiety	**$ 15,678,181,818**
Environmental costs	**$ 20,000**	**Environmental costs**	**$ 1,486,337**
Water quality	$ 20,000	Water quality	**$ 1,486,337**
TOTAL	$ 600,020,000	**TOTAL**	**$ 45,773,072,699**

Copenhagen Climate Adaptation Plan

Copenhagen		**NYC**	
Land area (square miles)	34.07	Land area (square miles)	303
Population	602,481	Population	8,623,000
Land area (as a % of NYC total)	**11.3%**	Population Density	28,496
Population density	**17,683.62**	100-year storm event (inches/hc	3.3
% less dense than NYC	**37.9%**		
100-year storm event (inches/hour)	2.2	**NYC Total Estimated Risk**	
% Less storm intensity than NYC	**32.3%**		
NPV cost of torrential rain (next 100 yrs)	$ 2,200,000,000	ROM NPV	**$ 33,266,847,272**

Appendix 4

This appendix contains information on green stormwater infrastructure in Seattle from the city's Green Stormwater Infrastructure in Seattle Implementation Strategy 2015-2020.[417]

Table 11. Six-Year Budgeted Totals (2015 - 2020)

	Capital Investment	Est. Gallons managed	Operations + Maintenance	NOTES
Seattle Public Utilities				
Right-of-Way Water Quality Projects	$15M	42M		Combined sewer overflow projects; Swale on Yale phase II construction
Right-of-Way Partnering for Creek Protection Projects	$28M	27M-48M		Venema Project; Natural Drainage Systems Partnering via the Integrated Plan
Additional Partnering on Others' Projects (uncontrolled CSO basins)	$3M	6M		Funding available to assist others' beyond Code retrofit projects (agencies and community)
RainWise (voluntary incentives)	$11.7M	26.6M		RainWise
Sub-Total	$57.7M	102M-123M	$5M	
King County Wastewater Treatment Division (WTD)				
Right-of-Way CSO prevention projects	$92.4M	32M-64M		Combined sewer overflow projects
RainWise (voluntary incentives)	$2.6M	5.9M		RainWise
Sub-Total	$95M	38M - 70M	$1.8M	
Seattle Department of Transportation				
Street tree planting	$.4M	<1M		Currently funded through 2015
Sub-Total	$.4M	<1M	TBD	
Seattle Parks Department				
Denesmore Pilot Project	$.2M	<1M		Funded with Department of Ecology grant
Sub-Total	$.2M	<1M	TBD	
Seattle Waterfront Office				
Right-of-way bioretention	.92M	3.3M		2,800 sq. ft. of bioretention (bottom area)
Street trees	$1.26M	.3		885 new street trees
Pervious cycle track	$.2M	.6M		40,000 sq. ft. of pervious cycle track
Sub-Total	$2.38M	4.2M	TBD	

Table 14. Projected Gallons Managed with GSI Anually in 2020 (in millions)

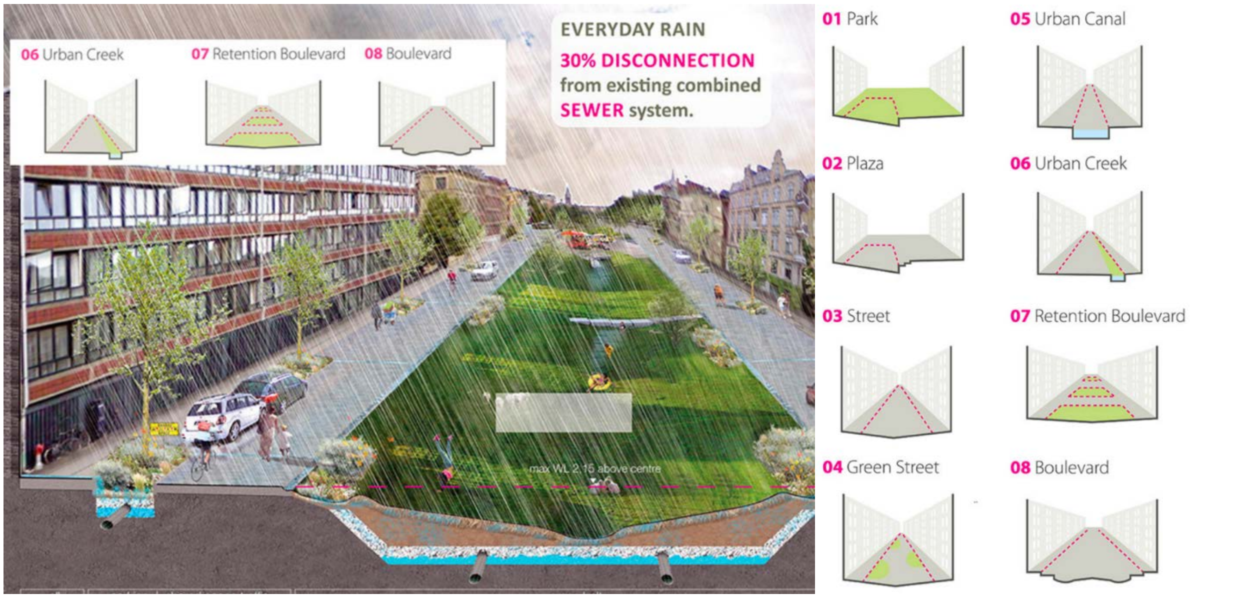
	Gallons Managed 2012 Baseline	Funded initiatives through 2020	Projected Increase by 2020	Projected Total in 2020
Required by Stormwater Code Developer Led & Funded (Public & Private)				
Special Projects, ie: Waterfront	--	bioretention; pervious cycle track; street trees	4.2	4.2
Parcels, ROW, single-family residential, trails and sidewalks	8.7	private development; public projects in the right-of-way, Parks, or building parcels	94.8	103.5
Subtotal	8.7		99	107.7
Utility-Led & Funded Retrofit Projects (in the public right-of-way)				
Seattle Public Utilities	67	right-of-way water quality projects and creek protection projects	75-96	142-163
King County WTD	0	right-of-way projects to prevent combined sewer overflows	32-64	32-64
Subtotal	67		107-160	174-227
Utility-Incentivized Retrofits (on parcels)				
Seattle Public Utilities and King County WTD	2.5	RainWise rebate program; SPU and WTD partnering on others' projects; Green Grants; ReLeaf	33	35.5
Subtotal	2.5		33	35.5
Voluntary Retrofits, Developer Led & Funded (Public & Private)				
Community-Led	10.4	grant-funded; voluntary green roofs and other installations; Depave pilots;	2	12.4
SDOT capital projects & programs beyond Code	1.9	Street tree planting (2015 only); Others TBD, pending transportation levy	1	2.9
Parks operational retrofits and capital projects beyond Code	10	Capacity-building pilot pending funding by WA Department of Ecology; Parks facilities	1	11
Subtotal	22.3		4	26.3
Total	100.5		243-296	344-397

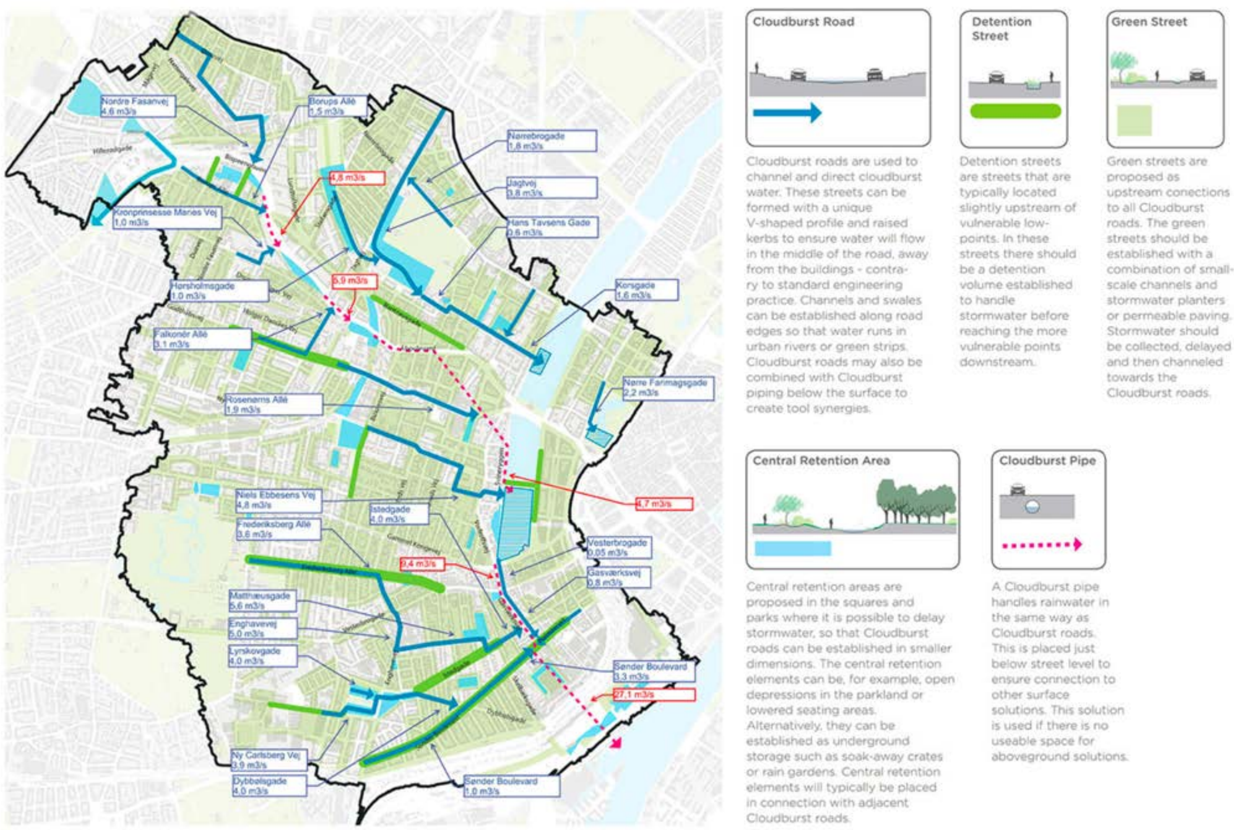
GSI Tool	How it Works	Benefits
Permeable Paving	SOAKS IN	• Manages runoff and maintains a durable driving surface for cars and people • Can add visual interest/design detail
Green Roofs	SLOWS, EVAPORATES	• Adds more green space to your property • Adds habitat for birds and beneficial insects • Improves air quality • Has potential for LEED™ credits • May be designed for food production
Depaving (Photo Courtesy of Sustainable Seattle)	SLOWS, SOAKS IN	• Frees up underutilized paved space for trees, plantings, and other uses, including GSI • Allows stormwater to soak into the ground where it falls instead of picking up and carrying pollutants into creeks and waterways • Can restore habitats for birds, insects, and other wildlife
Tree Canopy	SLOWS, EVAPORATES	• Tree planting and care is easy and fun • Mature trees improves air quality • Trees offer cool shade in summer and protect against harsh wind in winter • Adds beauty and green space to urban areas
Compost & Mulch	SLOWS, SOAKS IN	• Mulching is easy • Amending soil with compost helps rain soak in and builds healthier landscapes • Saves money by reducing need for irrigation, fertilizers and pesticides

GSI Tool	How it Works	Benefits
Bioretention	SOAKS IN, SLOWS, CLEANS	• Can manage large amounts of runoff • Can be designed to calm traffic • Adds beauty, habitat, and green space • Protects against future flooding risks due to climate change • Can be used for Green Factor requirements
Rain Gardens	SOAKS IN, SLOWS, CLEANS	• Manages runoff from roofs, paths, driveways • Adds beauty and habitat to your property • No technical knowledge is required for routine maintenance
Stormwater Cisterns	SLOWS, STORES + REUSES	• Easy to design, install, and maintain • During winter, cistern slowly releases water to yard or side sewer to make room for more • During summer, water can be used for irrigation and can reduce overall water use
Dispersion	SLOWS, SOAKS IN	• Manages runoff from roof, paths and driveways • Inexpensive in settings with sufficient space
Dry Well/ Infiltration Trench	SLOWS, SOAKS IN	• Manages runoff from roof, paths and driveways • Inexpensive in settings with sufficient space
Biofiltration	SLOWS, CLEANS	• Cleans large amounts of runoff • Can add beauty and habitat to a range of sites

Appendix 5

This Appendix contains parts of the Cloudburst Toolkit[418] developed by Copenhagen as a part of the Copenhagen Cloudburst Formula.





Appendix 6

This Appendix contains a sample report generated using the Blue Label software that has partnered with the City of Rotterdam to provide information on climate risks of properties to the city and its residents. Users input the post code and house number into the service, and it returns a rating on four categories: Nuisance Rain Flooding, Heat, Surface Water Flooding, and Drought. The service is available at the following link: https://bluelabel.net/.

De waterkwetsbaarheidsscan

Onderstaande labels zijn vastgesteld voor:

Voorschoterlaan 117
3062KL, Rotterdam

Overlast regen	A
Hitte	C
Overstroming	A
Droogte	B

Wat is een klimaatlabel?

BlueLabel voor elk gebouw in Nederland een label A t/m E bepaald. Een A-labelbetekent dat het gebouw niet kwetsbaar is en een E-label betekent dat het gebouw zeer kwetsbaar is.

De klimaat labels zijn bepaald op basis van tal van openbare gegevens van uw woning ofpand en simulatiemodellen. De labels zijn bepaald gebruik makend van de standaard voorgeschreven stresstesten van de Nederlandse overheid. Mocht u twijfelen over de juistheid van uw label dan kunt u contact opnemen met BlueLabel of navraag doen bij uw gemeente.

Wat kunt u met het label?

U kunt voor uw eigen woning checken hoe uw woning scoort op de vier klimaatthema's. U kunt daarna ook bepalen wat u kunt doen om een hoger label te krijgen of om beter voorbereid te zijn.

	Overlast regen	Hitte	Droogte	Overstroming
A	Geen water	< 38°	< 1 m	< 20 cm
B	< 5 cm	38° - 40°	1 – 2 m	20 - 50 cm
C	5 - 10 cm	40° - 42°	2 – 4 m	50 – 200 cm
D	10 - 23 cm	42° - 44°	4 – 8 m	200 – 500 cm
E	> 23 cm	> 44°	> 8 m	> 500 cm
	Verschil maximale waterdiepte en drempelhoogte (uitgaande van een hevige bui van 53 mm/75 min)	De gevoelstemperatuur op een hele warme zomerdag rondom uw woning (peildatum 1 juli 2015)	De diepste grondwaterstand in de zomer rondom uw woning	De hoogte van het water in uw huis als gevolg van een dijkdoorbraak (gebaseerd op kaarten Europese Richtlijn Overstromingsrisico's)

Gegenereerd om 11/18/2019, 11:18:33 AM
https://bluelabel.net/bluelabel-order-results/?req_code=252b8cf1-0a1e-11ea-83d7-001dd8b723bb

blue label

De waterkwetsbaarheidsscan

Het **Overlast regen** label geeft inzicht in het risico dat er water in uw woningstroomt bijeen hevigebui. Alsu in een appartement of flat woont, dan gaat het om de begane grond. Als uw woningeen C of lager danadviseren we u om na te gaan of er rondom uw huis laaggelegen plekken zijn waar regenwater naar binnen kan stromen, denk daarbij aan inrit van garage of kelderraam. Ook kunt u bij uw gemeente informeren naar concrete plannen om uw buurt of straat klimaatbestendig te maken.

Het **Hitte** label geeft inzicht in de gemiddelde gevoelstemperatuur op hele warme zomermiddag (peildatum 1 juli 2015) in een straal van 10 meter rond uw woning. De gevoelstemperatuur bepaald hoe comfortabel mensen zich voelen. Het hittelabel zegt mogelijk iets over het comfort in uw woning, zeker als deze niet goed is geïsoleerd. De hittestress kan worden verlaagd door meerschaduw te creëren. Zonnewering of schaduwdoeken helpen, maar bomen werken nog verkoelender. Daarnaast helpt wind om de gevoelstemperatuur te verlagen.Heeft u geen eigen tuin, informeer dan bij uw gemeente wat zij doen om uw omgeving groener en verkoelender te maken.

Het **Overstroming** label geeft aan hoe hoog het water in uw woning kan komen te staan bij een dijkdoorbraak. De kans op een dijkdoorbraak is weliswaar klein, maar niet nul. De waarden van uw label zijn gebaseerd op overstromingskaarten die zijn gepubliceerd in het kader van de Europese Richtlijn Overstromingsrisico's. Voor meer achtergrond informatie verwijzen we u naar https://ruimtelijkeadaptatie.nl/stresstest/bijsluiter/overstroming/. Heeft een C label of lager? Check dan eens https://www.crisis.nl/wees-voorbereid/overstroming/

Het **Droogte** label geeft aan hoe diep het grondwater rond uw woning staat in de zomer. Scoort u een C over lager dan betekent dat dat het grondwater tot meer dan 2 m kan zakken, waardoor planten verdrogen. Scoort u een E dan betekent dat ook de bomen met diepere wortels watertekorten kunnen krijgen.

Meer informatie: bluelabel.net

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https://bluelabel.net/bluelabel-order-results/?req_code=252b8cf1-0a1e-11ea-83d7-001dd8b723bb

Appendix 7

This Appendix contains the calculation methodology for Cincinnati's stormwater fee.[419]

As of July 1, 2019, the city divided properties into class A, B, and C, depending on the size of the property. To compute for stormwater runoff, they also developed an Area Range Number based on the total square footage of lots or parcels, an Intensity Development Factor based on the use of the property, and an Equivalent Runoff Unit based on the parameters used in the stormwater management utility rate.

The class descriptions are as follows:

Class A: One- and two-family residential properties, **10,000 square feet or less** in land area (approximately 0.23 acres), pay $6.90 monthly.

Class B: One- and two-family residential properties, **10,001 square feet or more** in land area (approximately 0.23 acres), pay $9.66 monthly.

Class C: All other properties within the city, including three- and four-family apartments, institutional, commercial, industrial and agricultural, pay a variable service charge based upon existing land use and the area of the property. The formula used to calculate this charge is as follows:

The Area Range Numbers are assigned by the utility division to calculate storm drainage service charges, and are as follows:

Lot or parcel area in square feet	Area Range Number
0 to 2,000	1
2,001 to 4,000	2
4,001 to 6,000	3
6,001 to 8,000	4
8,001 to 10,000	5
10,001 to 12,000	6
12,001 to 14,000	7
14,001 to 16,000	8
16,001 to 18,000	9
18,001 to 20,000	10
continues in 2,000 increments	continues

The Intensity Development Factors (IDF) are runoff coefficients or percentages of impervious coverage on or in the property, and are as follows:

Land Use	**IDF**
Commercial	0.85
Industrial	0.75
Multi-family	0.60
Transportation	0.50
Institutional	0.40
Residential up to 10,000 s.f.	0.25
Residential 10,001 s.f. or larger	0.20
Agriculture	0.08
Park	0.05
Undeveloped	0.00

Finally, the Equivalent Runoff Unit represents one unit of stormwater runoff and has been determined by Cincinnati's Stormwater Management Utility to be $6.90 per month.

The final stormwater service charge is calculated as follows:

(Area Range Number) *x* (Intensity Development Factor) *x* (charge per 1 Equivalent Runoff Unit)

Appendix 8

This Appendix contains the different stormwater fees[420] implemented by the city of Portland.

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Rate Name	Rate	Unit Type
A) Sanitary Sewer System User Service Charges and Discounts		
1) Residential Users		
1a) Sanitary Sewer Services	$11.08	per 100 cubic feet of water consumption
1b) Low Income Discount	-$37.37	per month for eligible single family ratepayers only
1c) Extremely Low Income Discount	-$59.80	per month for eligible single family ratepayers only
2) Non-Residential, Commercial, Industrial, and Institutional Users		
2a) Special Meter Charge	$40.00	per special meter bill
2b) Sanitary Sewer Services	$10.904	per 100 cubic feet of water consumption
2c) Clean Water Discharge	$1.150	per 100 cubic feet of discharged clean water
2d) Publicly-Owned Drinking Fountain or Single-Pass Waste Fountain	$0.001	per 100 cubic feet of discharged water
3) Industrial Extra-Strength Discharger		
3a) Biochemical Oxygen Demand	$0.831	per pound (allowable concentration - 300 mg/liter)
3b) Suspended Solids	$1.096	per pound (allowable concentration - 350 mg/liter)
3c) Extra Strength Additional Sample	$310.00	per composite sample
B) Drainage/Stormwater Management User Service Charges and Discounts		
1) Residential Users		
1a) Single Family and Duplexes		
1ai) Off-Site Charge	$19.27	per user account per month
1aii) On-Site Charge	$10.39	per user account per month
1b) 3-Plex and 4-Plex Residences		
1bi) Off-Site Charge	$8.03	per dwelling unit per month
1bii) On-Site Charge	$4.33	per dwelling unit per month
1c) Developments of 5 or More Units		
1ci) Off-Site Charge	$8.03	per 1,000 square feet of impervious area per month
1cii) On-Site Charge	$4.33	per 1,000 square feet of impervious area per month
2) Non-Residential Users		
2a) Off-Site Charge	$8.46	per 1,000 square feet of impervious area per month
2b) On-Site Charge	$4.56	per 1,000 square feet of impervious area per month
C) Discounts		
Clean River Rewards - user fee discounts as much as 100% of the monthly on-site stormwater management charge for private on-site facilities that manage stormwater runoff, and 100% of the monthly on-site stormwater management charge for Drainage District residents and businesses.		
D) Willamette River/Portland Harbor Superfund Charges		
1) Sanitary Volume Component	$0.09	per 100 cubic feet of water consumption
2) Impervious Area Component	$0.24	per 1,000 square feet of impervious area per month
Note: These rates apply to all users, residential and non-residential. The impervious area component is calculated for the following classes of residential users based on the following class-average values of impervious area:		
Single Family and Duplex Residences	*2,400*	*square feet of impervious area per parcel*
3-Plex and 4-Plex Residences	*1,000*	*square feet of impervious area per unit*
E) System Development and Connection Charges		
1) Sanitary System		
1a) Development Charge	$6,917.00	per equivalent dwelling unit
2) Stormwater Management System		
2a) Single Family or Duplex Residence	$1,159.00	per parcel
2b) 3-Plex Residential Development	$1,338.00	per parcel

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Rate Name	Rate	Unit Type
2c) 4-Plex Residential Development	$1,835.00	per parcel
2d) All Other Developments		
2di) Impervious Area Component	$242.00	per 1,000 square feet of impervious area
2dii) Frontage Component	$7.69	per linear foot of frontage
2diii) Trip Generation Component	$4.21	per daily vehicle trip
3) Connection Charges		
3a) Line Charge	$1.87	per square foot within the zone of benefit
3b) Branch Charge	$6,967.00	per branch used
3c) Wyes and Tees	$318.00	per wye or tee used
4) Sanitary Sewer Conversion Charges		
4a) Residential (Single Family, Duplex, 3-Plex, and 4-Plex)		
4ai) Branch Charge	$6,967.00	per branch used
4b) Commercial (All Other Users)		
4bi) Simple Sewer Extensions	$3.18	per square foot
4bii) Complex Sewer Extensions	$6.53	per square foot
5) System Development Charge Exemptions		
5a) Affordable Housing	Qualified affordable housing developments will be exempt from all or part of required sanitary and stormwater system development charges.	
5b) Accessory Dwelling Units	Qualified Accessory Dwelling Units (ADUs) will be exempt from required sanitary and stormwater system development charges.	

Fee Name	Unit Fee	Unit Type
F. Building Plan Review Fees Based on Type of Review		
1) One or Two Family Residential Structures	$639	per application
2) Revisions/Recheck Fees for Residential Permits	$213	per application
3) Structures Auxiliary to or Interior Modifications of One or Two Family Residential Dwelling Units Submitted on a Separate Application	$213	per application
4) Tenant Improvements In and Additions to Commercial Buildings		
4a) Environmental Review	$426	per application
4b) Source Control Review	$426	per application
5) Commercial Buildings (other than those listed in other categories above)		
5a) Environmental Review	$1,278	per application
5b) Source Control Review	$639	per application
6) Commercial Permit Revisions/Recheck with Management Approval (Additional Checksheet Required)		
6a) Environmental Review	$426	per review
6b) Source Control Review	$426	per review
7) Over-the-Counter Hourly Rate, Billable in 15 Minute Increments for a Maximum of One Hour.		
7a) Environmental Review	$213	per hour
7b) Source Control Review	$213	per hour
8) Commercial Stormwater Facility Inspection		
8a) Up to Two Facilities	$1,171	per application
8b) Each Additional Facility	$213	per facility

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Fee Name	Unit Fee	Unit Type
9) Residential Stormwater Facility Inspection	$586	per application
10) Fee for Major Projects Group (Assigned by Bureau of Development Services)	$20,000	per project
G. Land Use Review Fees		
1) Adjustment Review		
1a) Existing House/Duplex	$311	per application
1b) All Other Projects	$389	per application
2) Central City Master Plans	$2,333	per application
3) Comprehensive Natural Resource Management Plan & Amendments		
3a) Type I	$700	per application
3b) Type II	$1,400	per application
3c) Type III	$2,333	per application
4) Comprehensive Plan Map Amendment w/Zone Map Amendment		
4a) Tier A	$1,128	per application
4b) Tier B	$1,128	per application
4c) Tier C	$1,750	per application
5) Conditional Use		
5a) Type Ix	$233	per application
5b) Type II	$311	per application
5c) Type III – New	$933	per application
5d) Type III – Existing	$467	per application
6) Design/Historic Resource Review		
6a) Tier D	$428	per application
6b) Tier F	$428	per application
6c) Tier G	$1,633	per application
7) Environmental Review/River Review		
7a) Resource Enhancement/PLA/Public Rec Trails	$622	per application
7b) Existing House/Duplex	$661	per application
7c) All Other Projects	$1,633	per application
8) Environmental Review Protection Zone	$1,750	per application
9) Environmental Violation Review/River Review Violation		
9a) Type II Required	$933	per application
9b) Type III Required	$933	per application
9c) Columbia South Shore Plan District (CSSPD)	$933	per application
9d) CSSPD, Undividable Lot with Existing Single Dwelling Unit	$933	per application
9e) Undividable Lot with Existing Single Dwelling Unit	$933	per application
10) Greenway		
10a) Existing House Duplex or Simple Non-Residential or Mixed Use	$661	per application
10b) All Other Projects	$1,633	per application
11) Impact Mitigation Plan		
11a) Amendment (Minor)	$2,333	per application
11b) Implementation	$2,333	per application
11c) New/Amendment (Major)	$2,333	per application
11d) Amendment (Use)	$2,333	per application
12) Land Division Review		
12a) Type Ix	$622	per application

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Fee Name	Unit Fee	Unit Type
12b) Type IIx	$1,400	per application
12c) Type III	$4,044	per application
13) 2 to 3 Lot Land Division with Concurrent Environmental Review	$1,400	per application
14) 4 or More Lot Land Division with Concurrent Environmental Review	$5,832	per application
15) Land Division Amendment Review (All Types)	$311	per application
16) Land Division Final Plat Review/Final Development Plan Review		
16a) If Preliminary Was Type Ix with No Street	$311	per application
16b) If Preliminary Was Type Ix or IIx with a Street	$700	per application
16c) If Preliminary Was Type IIx with No Street	$350	per application
16d) If Preliminary Was Type III	$1,400	per application
17) Lot Consolidation	$350	per application
18) Master Plan		
18a) Minor Amendments to Master Plans	$700	per application
18b) New Master Plans or Major Amendments to Master Plans	$2,333	per application
19) Non-Conforming Situation Review	$233	per application
20) Planned Development Bonus Review	$2,955	per application
21) Planned Development Review – All Other	$2,955	per application
22) Planned Development Amendment	$467	per application
23) Planned Unit Development Amendment	$467	per application
24) Statewide Planning Goal Exception	$778	per application
25) Zoning Map Amendment	$1,477	per application
26) Other Unassigned Reviews		
26a) Type I/Ix	$194	per application
26b) Type II/IIx	$350	per application
26c) Type III	$583	per application
27) Early Assistance, Written Info Only	$311	per application
28) Early Assistance, Meeting and Written Info	$467	per application
29) Pre-Application Conference	$1,400	per conference
30) Public Works Inquiry (Written Info Only)	$50	per inquiry
31) Hourly Rate for Land Use Services	$156	per hour
32) Lot Confirmation		
32a) Sites without Buildings	$233	per application
32b) Sites with House(s) or Duplex(es)	$233	per application
32c) Sites with Other Development	$233	per application
33) Property Line Adjustment		
33a) Site without Buildings	$233	per application
33b) Sites with House(s) or Duplex(es)	$544	per application
33c) Sites with Other Development	$1,128	per application
34) Property Line Adjustment with Lot Confirmation		
34a) Site without Buildings	$233	per application
34b) Sites with House(s) or Duplex(es)	$544	per application
34c) Sites with Other Development	$1,128	per application

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Fee Name	Unit Fee	Unit Type
35) Remedial Action Exempt Review		
35a) Remedial Action Exempt Review - Conference	$1,400	per conference
35b) Remedial Action Exempt Review - Simple	$933	per review
35c) Remedial Action Exempt Review - Complex	$2,488	per review
H. Industrial Waste Discharge Fees		
1) Permit Base Fee by Permit Type*		
1a) CIU	$2,796	per permit
1b) SIU	$2,330	per permit
1c) NSIU	$1,331	per permit
1d) NDCIU	$200	per permit
2) Unit Fees		
2a) Alternative Discharge Control Mechanism	$77	per year
2b) Construction Dewatering Permit	$230	per unit
2c) Service Fee per Occurrence**	$130	per unit
*The total permit fee is comprised of the base fee plus actual costs for enforcement and monitoring as well as a DEQ SIU fee, if applicable. **This fee is applied to such discharges not otherwise addressed in an Industrial Waste Discharge permit, in addition to other applicable charges.		
I. Street Use Permit Fees		
1) Access Permit		
1a) Type 1	$0	per permit
1b) Type 2 - Minimum	$1,341	per permit
1c) Type 2 - Additional per Day	$467	per day
2) Sewer Connection Fees: Connections to Existing Laterals or Extensions of Laterals from Sewer Mains to Property Lines; Sewer or Lateral Extensions More Than 100 Feet in Length Are Deemed a Public Improvement.	$241	per connection
3) Sewer Tap Fees		
3a) Mainline Sewer and Manhole Tap	$419	per tap
3b) Wye and Tee, and Standard Manhole (Rate per Installation, All Materials Provided by the Contractor)	$815	per installation
3c) City Inspection of Insert-A-Tee installed by Permittee	$122	per inspection
3d) Complex Sewer Connection Permit	$1,628	per connection
4) Short Sewer Extension		
4a) Up to 50 Feet - Minimum	$600	per permit
4b) 51 to 100 Feet - In Addition to Minimum	$400	per permit
5) Residential Infill Permit	$3,000	per permit
6) Basic Sewer Extension	$3,000	per permit
7) PW Permit: *Calculator to establish base cost plus additional cost for factors per ENB-4		
7a) Project Manager (Per Hour)	$160	per hour
7b) Construction Manager (Per Hour)	$140	per hour
7c) Engineering Technician (Per Hour)	$124	per hour
7d) Inspector (Per Hour)	$137	per hour
7e) Revegetation (Per Hour)	$146	per hour
7f) Maintenance (Per Hour)	$188	per hour

BES Fiscal Year 2019-2020 Rate Ordinance Exhibit A

Fee Name	Unit Fee	Unit Type
8) Complex Permit	Full Cost Recovery	per permit
9) Revegetation Inspection	$1,076	per permit
10) Construction Warranty Fee	$748	per permit
11) Permit Reactivation Fee	$500	per application
12) Street Vacation	$300	per application
13) Hourly Rate for Revegetation Natural Area Services	$146	per hour
J. Source Control Manual and FOG Fees		
1) Source Control Manual Fees - Special Circumstances Advanced Review Application Fee	$100	per application
2) FOG Variance Request Processing Fee	$250	per application
K. Stormwater Management Manual Fees		
1) Special Circumstances Application Fee	$100	per application
2) Offsite Management Fee	$3.70	per SF
3) Post-Issued Permit Offsite Management Fee	$7.40	per SF
4) Manufactured Stormwater Treatment Technologies Application Fee		
4a) Application Review Fee	$5,000	per application
4b) Third-Party Water Quality Review Fee	$3,000	per application

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