SOUTH RICHMOND BMP, STATEN ISLAND, NY

CHAPTER 4: PRECIPITATION, WATERSHED, AND TIDE GATE ANALYSIS

Staten Island Bluebelt

Introduction

In order to effectively plan for the future, DEP has studied how climate change coupled with population growth could affect its wastewater collection systems and wastewater treatment infrastructure. Rising sea level, higher flows due to increasing population, more intense storms, and elevated surface temperatures are all factors that DEP has considered which could potentially affect the city's drainage infrastructure, wastewater collection system, and treatment operations. Table 1 summarizes the potential impacts associated with climate change on drainage infrastructure.

Table 1: Potential Impacts on Watersheds

Sea Level Rise	Air Temperature Variations	Precipitation Variations
• Physical inundation • Changed hydraulics • Changed influent wastewater characteristics • Change in energy use or pumping requirements • Saltwater intrusion • Impact on storm surge elevations • Increased operation and maintenance requirements • Shifting of inundation zones • Flooding of pump stations (especially if not watertight)	• Change in energy use • Increased operation and maintenance requirements • Increased occurrence of days greater than 90°F and impact on energy use • Increased probability of electrical grid failure	• Changes in the frequency of street flooding • Change in combined sewer overflow quantities, frequency, and water quality • Changes in stormwater discharge quantities, frequency, and water quality • Material strain • Increased operation and maintenance requirements • Increased frequency of emergency management actions

Excerpted from New York City Panel on Climate Change (NPCC) report entitled *Climate Risk Information*, issued February 2009. The NPCC issued a report in 2013 updating the projections used for its 2009 report. The changes to the projections would not alter the recommendations of this study.

The present study assesses the potential risks and impacts associated with changing precipitation patterns and sea level rise. It also evaluates adaptation strategies to improve resiliency in the face of climate change. The study was conducted in three phases:

Phase 1: Precipitation Analysis

The first phase of the study had two objectives. The first objective was to assess whether the rainfall intensity-duration-frequency (IDF) relationships used for sewer design have changed significantly since their original development during the first half of the 20th century. Sixty years of rainfall data have been collected since the development of the rainfall statistics currently used in sewer design. Analysis of this longer, more complete data set would inform the City's existing operations and assist in planning for the future. The second objective was to evaluate whether the typical rainfall year used for combined sewer overflow (CSO) Long-Term Control Plan (LTCP) development is representative of the 'average annual baseline' or if it should be revised in light of new rainfall data. The complete rainfall records from gauges throughout the New York City region through 2012 were examined to complete this phase of the study.

Phase 2: Watershed Analysis

The second phase of the study used hydrologic and hydraulic computer modeling to simulate how potential future rainfall and tides may affect drainage characteristics and the frequency and volume of CSOs. For this phase of the study, the projected future precipitation and tide data were applied using computer simulation modeling to a selected planning area, the Flushing Bay watershed, to compare CSO volume and frequency under current and future climate conditions. In addition, an analysis of potential changes in flood frequency and volume was conducted. Finally, the models were modified to simulate simplified adaptation strategies in order to assess their relative potential for mitigating the negative effects of climate change. The Flushing Bay watershed was chosen as a sample case study because it is representative of the city as a whole in a number of critical ways, and therefore feasible adaptation strategies developed for this watershed may be applicable citywide.

Phase 3: Tide Gate Analysis

The final phase of the study assessed the effectiveness, cost, and benefits of installing tide gates at stormwater outfalls to prevent storm surge inundation in adjacent communities. A preliminary, static analysis was performed to determine the viability and impacts of tide gate installations at 211 DEP-owned stormwater outfalls in New York City. The screening analysis looked at the local topography of the community upstream of each associated outfall and compared it to the elevations of typical tidal events to see whether the installation of a tide gate would provide flood protection.

Right-of-Way Bioswale

Phase I: Precipitation Analysis

Precipitation is the driving factor for peak flows in the sewer system; the system is designed and built to collect and convey runoff generated by a specific rainfall intensity called the design storm event. While the sewers themselves consistently function as designed, the weather is not always cooperative. Real temporal and spatial rainfall patterns can vary significantly from the design storm, resulting in sewer backups, surface flooding, and combined sewer overflows (CSO). Thorough analysis of precipitation data is therefore critical to assessing system functionality and planning for the future.

A fresh examination of regional rainfall data was conducted to determine if drainage and CSO Long Term Control Planning (LTCP) should be based on revised statistics, to identify a new typical rainfall year to be used for CSO LTCP modeling efforts, and to develop a means of modeling projected future precipitation conditions in the city's urban watershed. The analysis found that current drainage planning tools remain suitable for design, but that future modeling efforts should employ a different year of rainfall data based on recent historical data and projected changes in precipitation.

Rainfall Data Collection

Rainfall data were obtained from the Northeast Regional Climate Center at Cornell University. All data were subject to quality checks prior to delivery. Data were requested for the ten stations shown in Figure 1 and described in Table 2, which are the stations in and around New York City with the longest records. The longest available record comprises daily rainfall data at Central Park where data records commence in 1876, and only 3 years contain missing data. Newark also has a long daily record, commencing in 1897; however, daily data at stations other than Central Park were not used in the study as hourly data provides the most comprehensive record for short durations. Hourly observations began in 1948, and four stations also provided 15-minute data beginning in 1972.

Figure 1: Rainfall Stations with Long Records of Hourly Data Around New York City

Table 2: Available Rainfall Records

Type of data	Station name	Record length	15 -minute data availability
Daily	Central Park, NY	1876-2011	None
Hourly	Ave V, Brooklyn, NY	1948-1976	None
Hourly	Westerleigh, NY	1948-1992	None
Hourly	White Plains, NY	1948-1992	1982-1992
Hourly	Rahway, NJ	1948-2003	1984-2000
Hourly	Central Park, NY	1948-2011	None
Hourly	Newark Airport, NJ	1948-2011	None
Hourly	Mineola, NY	1948-2011	1972-2010
Hourly	Little Falls, NY	1948-2011	1984-2000
Hourly	LaGuardia Airport, NY	1948-2011	None
Hourly	JFK Airport, NY	1949-2011	None

Spatio-temporal Trend Analyses of New York City Rainfall Data

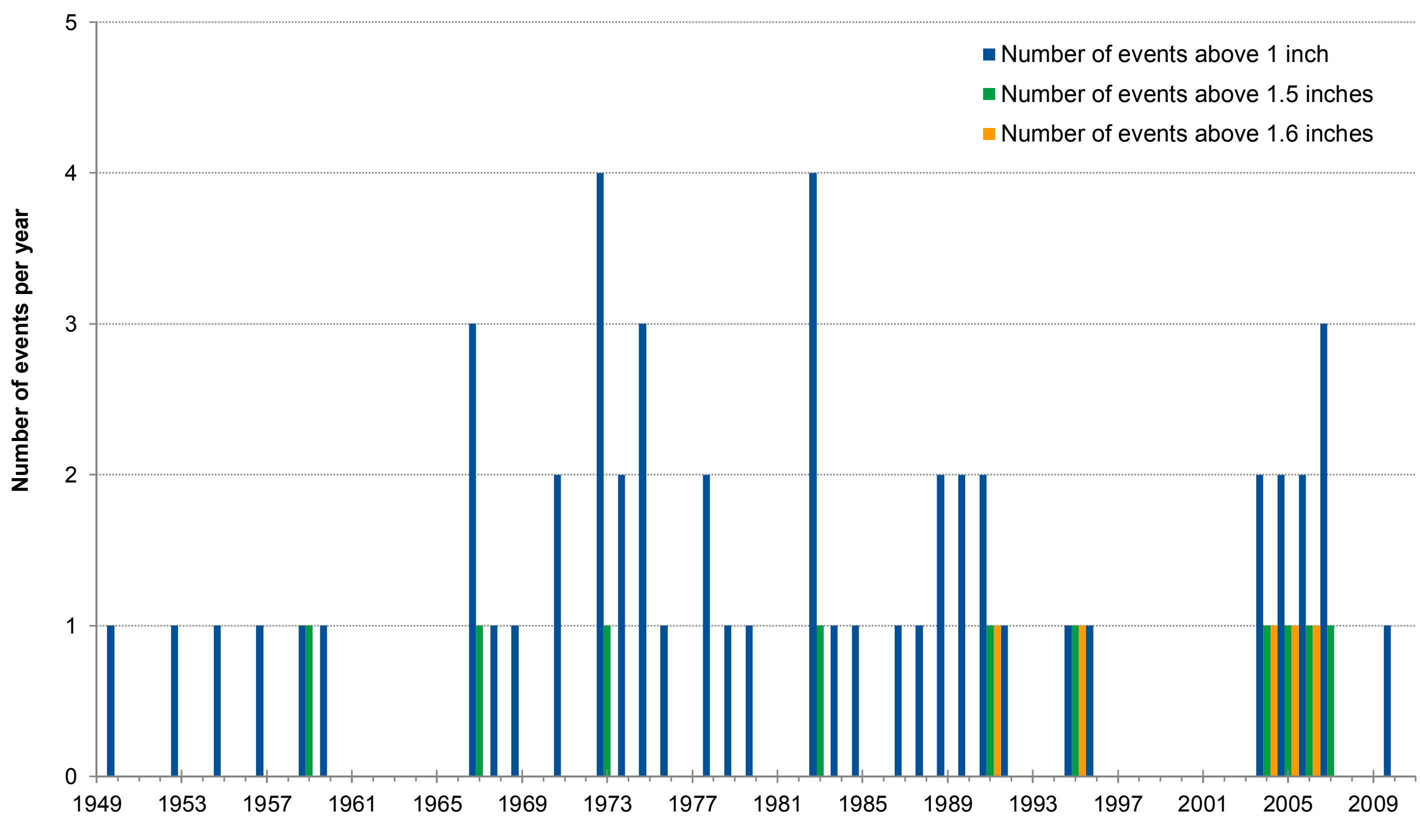
No single station can necessarily be considered representative of the entire city; rainfall within the city shows a strong spatial variation as storms tend to be localized. Locations in the southwest part of the city tend to receive higher rainfall; however, none of the stations in the southwest part of the city have sufficiently complete data, and using data from the gauges at Central Park and the three airports (JFK, Newark, and LaGuardia) for the period 1969-2010 provides the most complete spatial and temporal coverage (at the time of the analysis, data for 2011 and 2012 were not yet available). The period 1969-2010 is the longest period for which near complete datasets are available across these stations. This period is long enough to reliably estimate events of 10-year return periods or greater frequency, and includes the most recent cluster of recent extreme rainfall events to hit New York City in the 1990s and 2000s (Figure 2).

Since 1990, all of the following have occurred:

- three of the five largest precipitation events to occur at JFK;
- four of the five largest precipitation events to occur at LaGuardia and Newark; and
- all five of the largest precipitation events to occur at Central Park.

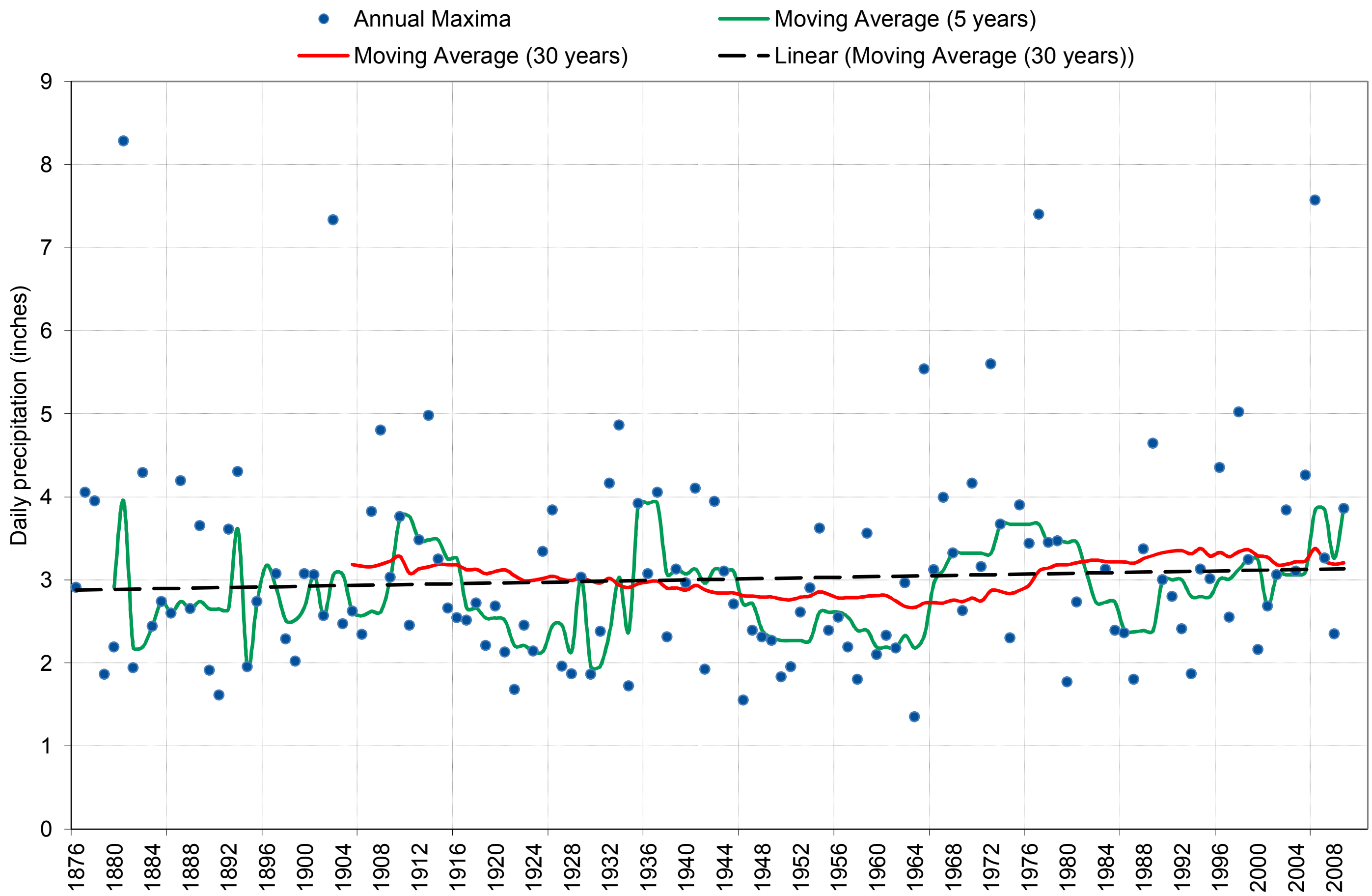
While these statistics would seem to suggest a dramatic shift in the rainfall climate towards more extreme rainfall events, it is difficult to draw very definitive conclusions. Analysis of the rainfall data shows that historically there have been similar clusters of large events, such as in the late 1880s and 1970s. The strong peak in the 5-year moving average illustrates the cluster of large storms in the 1970s (Figure 3). Similarly, the 30-year moving average (period recommended for climatological standard normals) shows a cyclic nature, with a decrease in daily precipitation from the beginning of the record to 1970,

Figure 2: Number of Large Rainfall Events Each Year since 1948



Number of large rainfall events occurring in each year since 1948, based on hourly data at Central Park. Data provided by the Northeast Regional Climate Center.

Figure 3: Trend Analysis of Daily Data from Central Park Rain Gauge



Annual maxima from hourly precipitation data at Central Park. Data provided by the Northeast Regional Climate Center.

and then an increase, reflecting the clusters of large events in the 1970s and the last two decades. Overall, the data show a gradual trend towards increased rainfall which is consistent with the recent observations of large precipitation events. It is difficult to predict rainfall trends and although global and regional climate models suggest increased precipitation, they do not provided clarity particularly regarding rainfall intensities used to size smaller sewer systems. Sewer systems are conservatively designed to capture large volumes of water very quickly to minimize street flooding in the interest of public safety. With future rain data collected in the coming years, it will be much clearer whether this increasing trend is real and statistically significant.

Intensity Duration Frequency Curves

With long records of rainfall, statistical methods can be applied to estimate the probability of a storm event with a specific intensity and duration occurring in a given year; this is referred to as the storm's return frequency. The rainfall intensity over a spectrum of durations from 5 minutes to 24 hours for storms with varying return frequencies are compiled into useful charts referred to as intensity-duration-frequency (IDF) curves.

IDF curves are one of the most common and useful tools for sewer design. The standard sewer design criterion in New York City is to use the intensity-duration values for a storm with a 5-year return frequency (i.e., a 20 percent chance of occurrence in any given year) to calculate how large the sewer pipes need to be sized to appropriately manage stormwater. The peak sewer design flow for a drainage area can be estimated using a runoff coefficient based on land use and imperviousness, the rainfall intensity value taken from the IDF curves, and the size of the contributing drainage area. The design of combined sewers also accounts for sanitary flows.

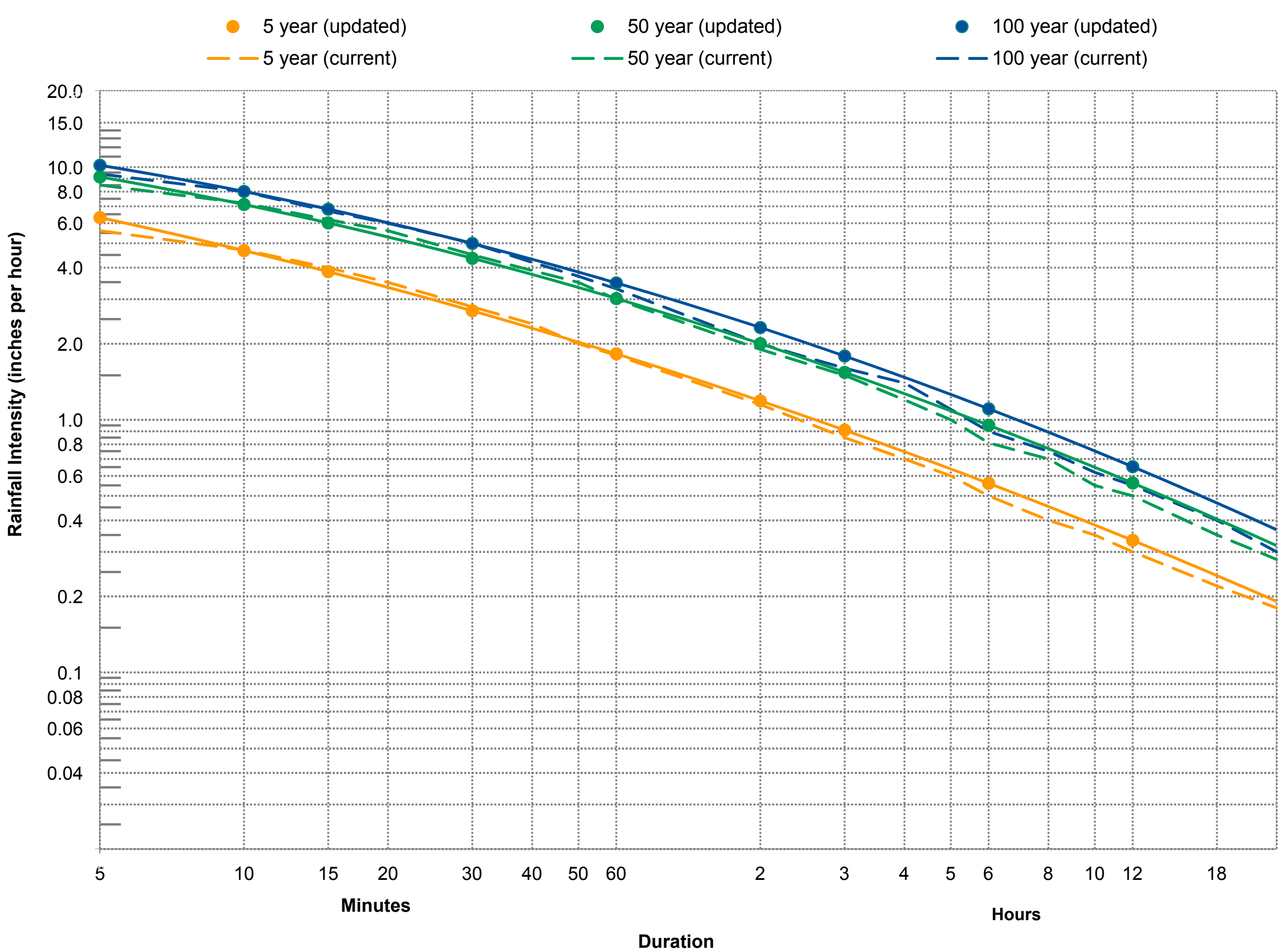
The city's current 5–year sewer design standard is fairly robust and conservative when compared to standards for other municipalities. Nevertheless, it is necessary to track rainfall patterns over time to see if the characteristics of a 5-year storm have changed.

The current sewer design standard is based on IDF curves derived from rainfall data from the period 1903 to 1951. To accurately estimate the peak design flow for sewers, it is important to analyze whether rainfall patterns, and the derived IDF curves, show a shift over time when the analysis includes additional data that have been collected over the past 60 years. The original IDF curves were also based on data from a single rain gauge (believed to be Central Park) but are applied to drainage systems throughout the five boroughs.

A single IDF curve is necessary for ease of use and consistency for sewer design, yet the IDF curve needs to be representative of conditions across the entire city. A full set of IDF curves was developed for each of the four stations using the 1969-2010 data. As the source data are hourly, intensities for durations less than one hour were derived using published scaling factors and validated through analysis of the 15-minute data at Mineola. The highest point from the IDF curve generated for each of the four stations was then used to generate a single curve. This conservative approach recognizes that the data used does not include stations in the southwest of the city where rainfall is highest; adopting the higher values acknowledges and compensates for this omission.

For the majority of the city's sewer network, depending on the size of the collection area, it takes up to 100 minutes for stormwater to reach an outfall. As shown in the IDF curve (Figure 4), the intensities for a storm with a 5-year return period are not significantly different between the current and updated curves for durations (or travel time) between 5 and 100 minutes. In other words, for durations relevant to sewer design (up to 100 minutes), the expanded, more recent data record revealed no discernible trend toward more intense rainfall, and the current IDF curves can remain the basis of drainage design for now. However, for the longer durations, (2 hours and greater), the computed rainfall intensities are larger based on the updated curve, reflecting the more recent trends in increased rainfall intensity. In order to more definitively recognize emerging trends in precipitation intensity due to future climate change, DEP will periodically review rainfall trends and assess implications for stormwater infrastructure, as appropriate.

Figure 4: Comparison of Current and Updated Intensity-Duration-Frequency (IDF) Curves



Typical Rainfall Year

Based on the revised statistics developed for the IDF, historical data was assessed to develop a "typical year" to represent average annual conditions for LTCP modeling. These models provide information about how stormwater runoff and sanitary wastewater move and consequently discharge into waterbodies, and are used as quantitative tools to understand impacts on water quality. For each year and station, five rainfall parameters were calculated: annual rainfall depth, July rainfall depth, November rainfall depth, number of very wet days, and average peak storm intensity. The number of very wet days was chosen to be the number of days with more than two inches of rainfall.

The statistics were examined to find the year and station which is closest to the mean of all four stations for all five climate parameters, both for current conditions and future conditions considering climate change. Based on current climate statistics (1969-2010) the 2008 record from JFK airport was found to be the most representative year overall.

The future most typical years were then identified by shifting the mean of the distribution by change factors based on climate projections from the New York City Panel on Climate Change (NPCC) *Climate Risk Information* report (2009)[1]. Both central and precautionary estimates, which are described in detail below under Phase 2, were used for the development of the change factors, based on the middle and upper ranges of the climate projections, respectively. Changes in rainfall intensity were not available from the NPCC, and therefore research findings from Forsee et al. (2010) were used as a proxy. JFK 2005 was found to be the most typical future year using the central estimate for climate change, while LaGuardia 2006 is the most typical year using the precautionary estimate (Table 3).

As a result of this analysis, data from JFK Airport in 2008 is now the selected as the "typical" rainfall year and will be used for LTCP modeling. Furthermore, to account for more extreme years that may become the norm in the future with climate change, the time series used for LTCP modeling has been expanded to ten years--including 2005 and 2006--to test the robustness of various CSO mitigation approaches under a range of average and extreme conditions.

Table 3: Precipitation Values for Selecting Historical Years Representing Baseline and Future Scenarios[1]

Parameter	Baseline		Future Central		Future Precautionary	
	Aggregate Statistic (1969-2010)	Best Fit Annual Time Series JFK 2008	Target Value (Change Factor)	Best Fit Annual Time Series JFK 2005	Target Value (Change Factor)	Best Fit Annual Time Seres LGA 2006
Annual Depth (in)	45.5	46.3	47.8 (+5%)	48.5	50.1 (+10%)	54
July Depth (in)	4.3	3.3	4.5 (+4.5%)	5.2	4.9 (+14%)	6
November Depth (in)	3.7	3.3	3.8 (+3.5%)	4	4.3 (+17%)	5.8
Number of days >2 in	2.4	3	2.8 (+17%)	3	3.2 (+33%)	4
Average Intensity (in/hr)	0.15	0.15	0.18 (+18%)	0.16	0.2 (+32%)	0.2

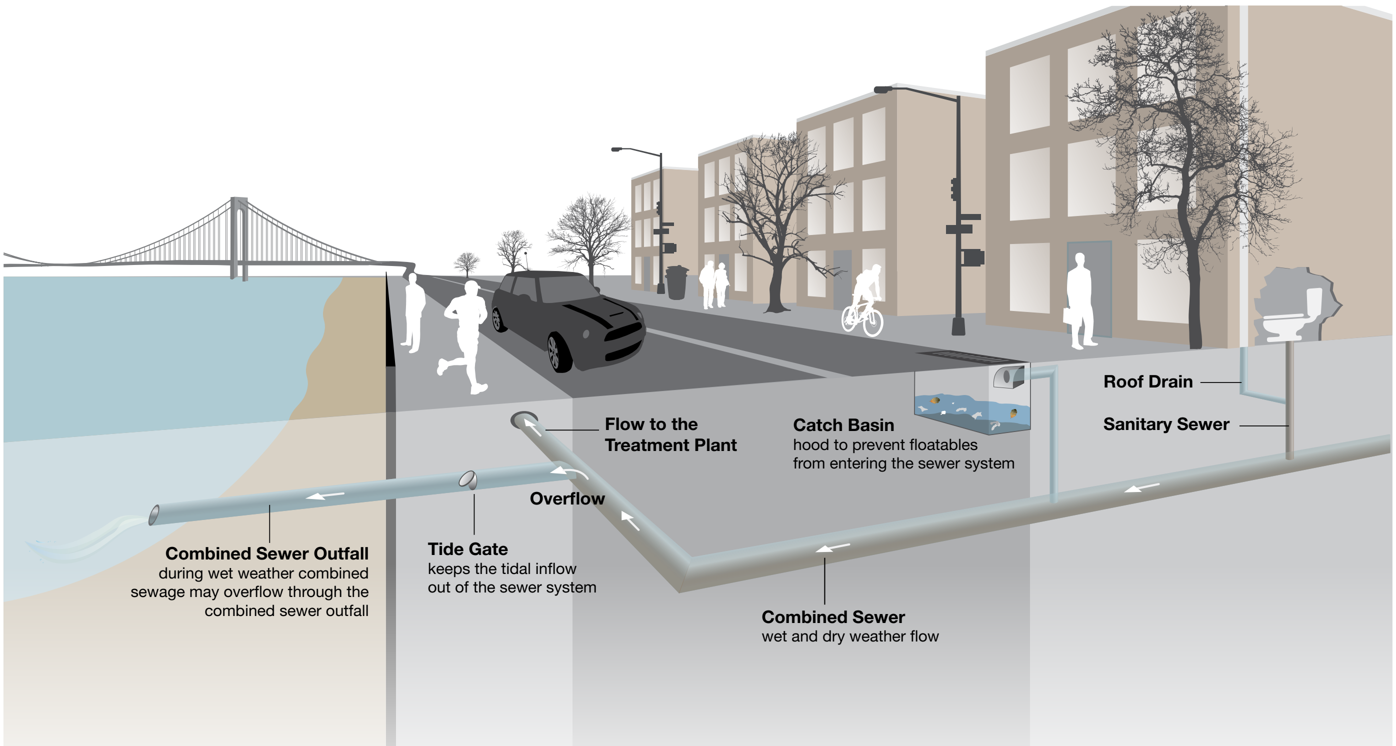
[1] The NPCC issued a report in 2013 updating the projections used for its 2009 report. The changes to the projections would not alter the recommendations of this study.

Phase II: Watershed Analysis

As a highly urbanized area, New York City's watersheds have both natural and engineered features to convey stormwater from the city's streets, sidewalks and properties to nearby waterways or wastewater treatment facilities when it rains. Approximately 60 percent of New York City's sewer system is combined, meaning that it handles sanitary waste from homes and businesses as wells as stormwater from streets and rooftops. Combined sewers (Figure 5) are common to older, more developed US cities and are designed to receive significant amounts of stormwater to prevent local flooding which can also result in combined sewer overflows (CSO) during significant rain events. Watershed analyses are conducted to understand the sensitivity of the wastewater infrastructure to changes in the system; therefore, for this study a representative watershed was evaluated under two possible future climate scenarios.

CSO mitigation is an ongoing process, including the development of Long Term Control Plans (LTCP). LTCP projects typically involve sewer and wastewater treatment plant upgrades, and the implementation of green infrastructure, which work together to increase the capacity of the sewer system and reduce the amount of stormwater flowing into the sewers. The planning areas for which LTCPs are being developed can span the service areas of multiple treatment plants, and can contain numerous pumping stations and several major CSO outfalls. With a sewer system so large, the City uses extensive computer simulation models of the sewer network and historical rainfall records to understand how much CSO is generated annually, and to determine how CSO mitigation projects will reduce CSOs upon implementation.

Figure 5: Combined Sewer System



For this study, DEP sought a representative watershed to demonstrate the impacts of climate change, and the robustness of current and future infrastructure to absorb these changes. The candidate watersheds were based on the planning areas used by DEP's LTCP program (Figure 6). The general considerations for choosing a representative watershed were as follows:

1. Infrastructure: Consideration was given to which wastewater treatment plants were associated with the watershed, and whether there were regional CSO facilities (such as at Paerdegat Basin or Flushing Bay), pump stations, and tide gates in the drainage area.

2. Drainage Area Characteristics: The selection process weighed the benefits of selecting an open water planning area versus a confined tributary, or a large drainage area versus a smaller one. In addition, the amount of combined sewer area, the housing density, and risk of storm surge inundation were considered. The verified sewer backup and street flooding complaint database from a 10-year period were evaluated as evidence of one type of flood risk in the drainage area.

3. Expected Investments and Projected CSO Reductions: DEP's CSO program includes a long list of capital commitments and construction projects, and it was agreed that the planning area selected should include a significant amount of future investment.

   The green and grey infrastructure investments and associated CSO reductions reported in the NYC Green Infrastructure Plan were considered, as were the presence of "Tier I Outfalls" (essentially the 10-15 largest CSOs citywide).

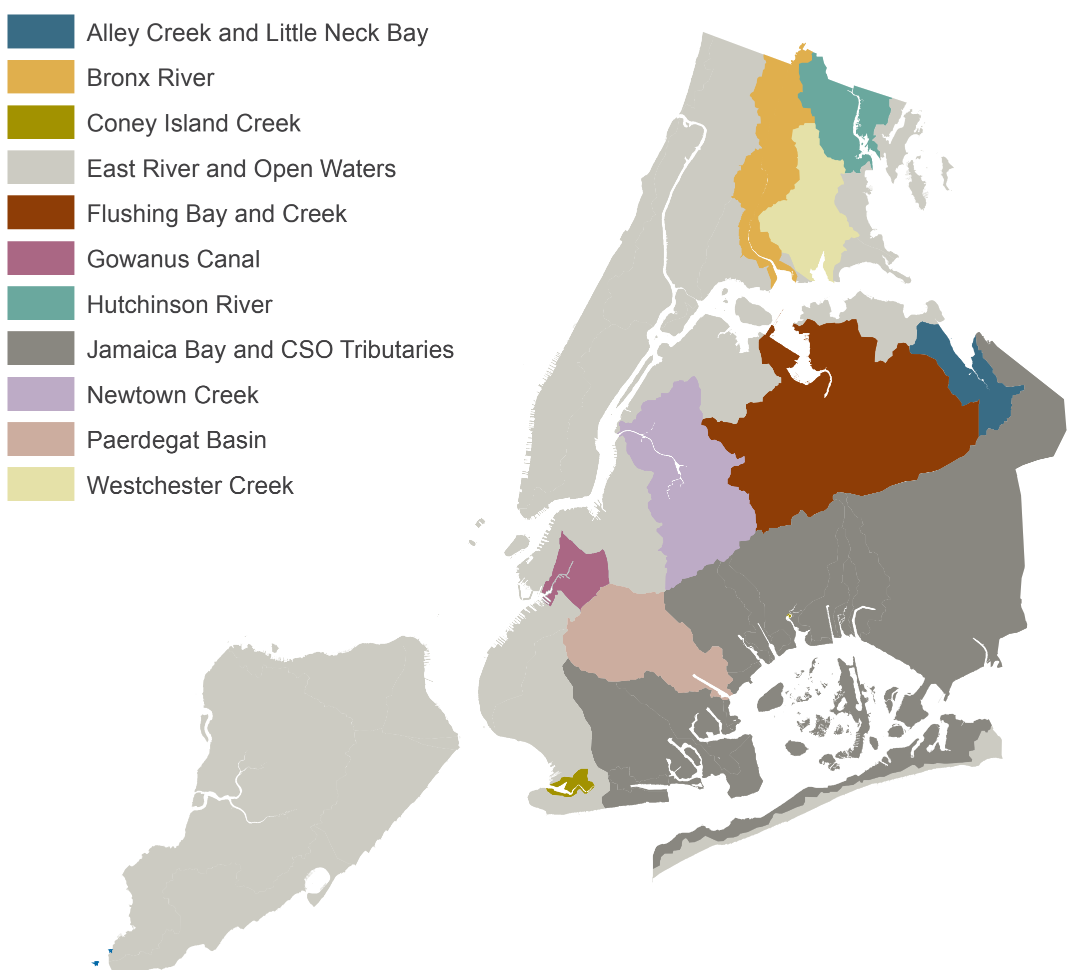
Based on these criteria, the Flushing Bay watershed was selected for further analysis for a conceptual sensitivity test of system response to two future climate scenarios, as it is broadly representative of the city's watersheds. To conduct this sensitivity test, an existing watershed (model InfoWorks CS) for Flushing Bay was used and modified to reflect the project needs for baseline and future population, sea level rise, and precipitation changes.

Two future scenarios, which are representative of projections for the 2050s, were defined. The 2050s represents a timescale of interest to DEP for the planning, design and operation of infrastructure, representing the planned life of much of the City's wastewater infrastructure. Two future scenarios representing two degrees of severity were used, since climate projection are wide-ranging due to uncertainty in future greenhouse gas emission levels and variations between climate models themselves. These future scenarios are coupled with a 'baseline' scenario, representing current conditions, to better understand the potential change in system responses. These scenarios are defined below.

- Current or Baseline: This is the scenario against which future scenarios are compared to quantify change, and it is intended to reflect the climate and operational conditions of the present or recent past.
- Future Central Estimate: This scenario represents the climate conditions near the middle range of 2013 projections published by the New York City Panel on Climate Change (NPCC) for the 2050s and assumes a 5 percent increase in annual precipitation and about 10 inches of additional sea level rise. An increase of 18 percent in precipitation intensity was assumed based on research findings from Forsee et al. (2010).
- Future Precautionary Estimate: This scenario represents a more severe change that could occur by the 2050s and includes a 10 percent increase in annual precipitation and 24 inches of additional sea level rise. It is at the upper end of the middle range of 2013 climate projections published by the NPCC for the 2050s. An increase of 32 percent in precipitation intensity was assumed based on research findings from Forsee et al. (2010).

The analysis showed that CSO discharges and local flooding will likely increase under future climate conditions in response to potential increases in precipitation volume and intensity. Overall annual rainfall volume is the most important driver of increased CSO volume, with the greatest changes at outfalls with large tributary areas because more runoff flows into those parts of the sewer system. Projections show that CSO increases at individual outfalls are consistent under both future scenarios, with increases from baseline between 5 and 47 percent for the future central scenario, and 9 and 46 percent for the future precautionary scenario. A number of the CSO catchments show a decrease in CSO spill between the Future Central and Future Precautionary scenarios. While the difference between the two estimated values is small, it is likely due to the large rise in tidal levels between the two scenarios, leading to 'tide locking' of the outfalls on a more regular basis. The differences between the future scenarios range from -11.9 to 14.8 percent, with no significant outliers. The relative consistency of the observed changes between the CSO catchments can be interpreted to suggest that there are not necessarily any specific elements or infrastructure within the CSO system that is

Figure 6: New York City Watersheds



at greater risk than others; rather, the system is generally susceptible to changes to the conditions for which they were designed, and size of the catchment area will dictate changes in CSO volumes.

In addition to the Future Central and Precautionary scenario analyses, which included future changes to rainfall, sea level, and dry weather flow, the individual impacts of rainfall and sea level projections were also reviewed. The intent of these analyses was to understand the relative contribution of changes in sea level and rainfall in the projected changes in CSO discharges. For each future scenario, two additional modeling runs were performed—one with the projected rainfall for that scenario with baseline tides, and another with baseline rainfall and projected tides. This analysis confirmed that changes in future rainfall have a far greater impact on CSO performance than does sea level rise.

Analysis of surface water drainage focused on a synthetic intense rainfall event for baseline, future central, and future precautionary climate scenarios. This event incorporates the intense rainfall in a 6-minute duration meant to simulate the type of flash flooding event that occurs during summer thunderstorms. The total rainfall volume for the baseline flooding event was increased uniformly in each 6-minute time step by 18 and 32 percent to simulate larger volumes of rainfall under the future central and future precautionary scenarios, respectively.

The incidence of surface flooding under the baseline, future central and future precautionary flooding events were analyzed in terms of surface flooding volumes, the normalized flood volume over each CSO catchment area, and the site-specific flood rates measured as a percentage of the local pipe full capacity. These are all important metrics for the management of surface flooding, although total flood volumes are the key consideration. The normalized volumes help understand the relative distribution of flooding within the watershed, and the pipe full capacity analysis helps identify areas where storm intensity in excess of the design storm would likely cause flooding in the system. It should be noted that the watershed sensitivity analyses considered only the 'combined' system, and did not examine the separate storm sewer network.

It should also be noted that the model selected for this study was not built with sufficient resolution to accurately evaluate site-specific flood extents and depths; however, results showed that there is an increase in flood volumes from baseline to future scenarios at the catchment scale. For example, an 18 percent increase in intensity under the future central scenario could result in doubling of flood volumes compared to baseline, whereas a 32 percent increase in intensity under the future precautionary scenario could result in flood volumes that are three times greater than the baseline. This demonstrates the importance of rainfall intensity to the surface drainage performance of the system. Additionally, the analysis suggests that potential flooding is largely localized, at least within the Flushing Bay watershed. As noted earlier, the city's drainage infrastructure is designed manage the 5-year storm event. For this analysis, when the intensity (and volume) of that design event is increased, it resulted in increased potential surface flooding impacts, which is not surprising due to the fact that the system was not designed to accommodate these larger flows.

In order to address the future projected climate changes, a range of adaptation strategies were investigated. Key findings from the analysis of adaptation strategies showed that 'source control' type options, designed to delay or prevent stormwater entering the sewer system, provide a comprehensive approach to improving system resilience. Source control can be achieved through either temporary retention or infiltration, either of which serves to reduce peak flows and consequently reduce or prevent impacts associated with flooding and CSO spills which, by definition, occur during event peaks. Green infrastructure was considered throughout this evaluation, and demonstrated benefits for both flooding and CSO overflows. It is both logical and evident from the results of this analysis that the more stormwater inflow to the sewers can be reduced, the more the load on the system is reduced, and impacts avoided.

New York City is already committed to implementing green infrastructure to capture the first inch of rainfall on 10 percent of impervious surfaces in combined sewer areas by 2030. This approach will result in reduced CSOs and improved water quality. As the green infrastructure system is built out, it could produce a gradual increase in stormwater system resilience, in parallel to the anticipated gradual increase in rainfall due to climate change. While the construction of green infrastructure is an effective solution to manage rainfall and reduce CSOs, in other areas, where feasible and based on local land use and sewer configuration, local disconnection or separation of the sewer system (conveying stormwater separately from sanitary sewage flows) could be more effective. Accordingly, DEP will augment existing combined sewers with high-level storm sewers in certain areas near the water's edge around the city. The benefit of this approach is similar to source controls in that it reduces stormwater flows into the combined sewer system.

Sewer outfall with tide gate on Shellbank Basin in Howard Beach, Queens

Phase III: Tide Gate Analysis

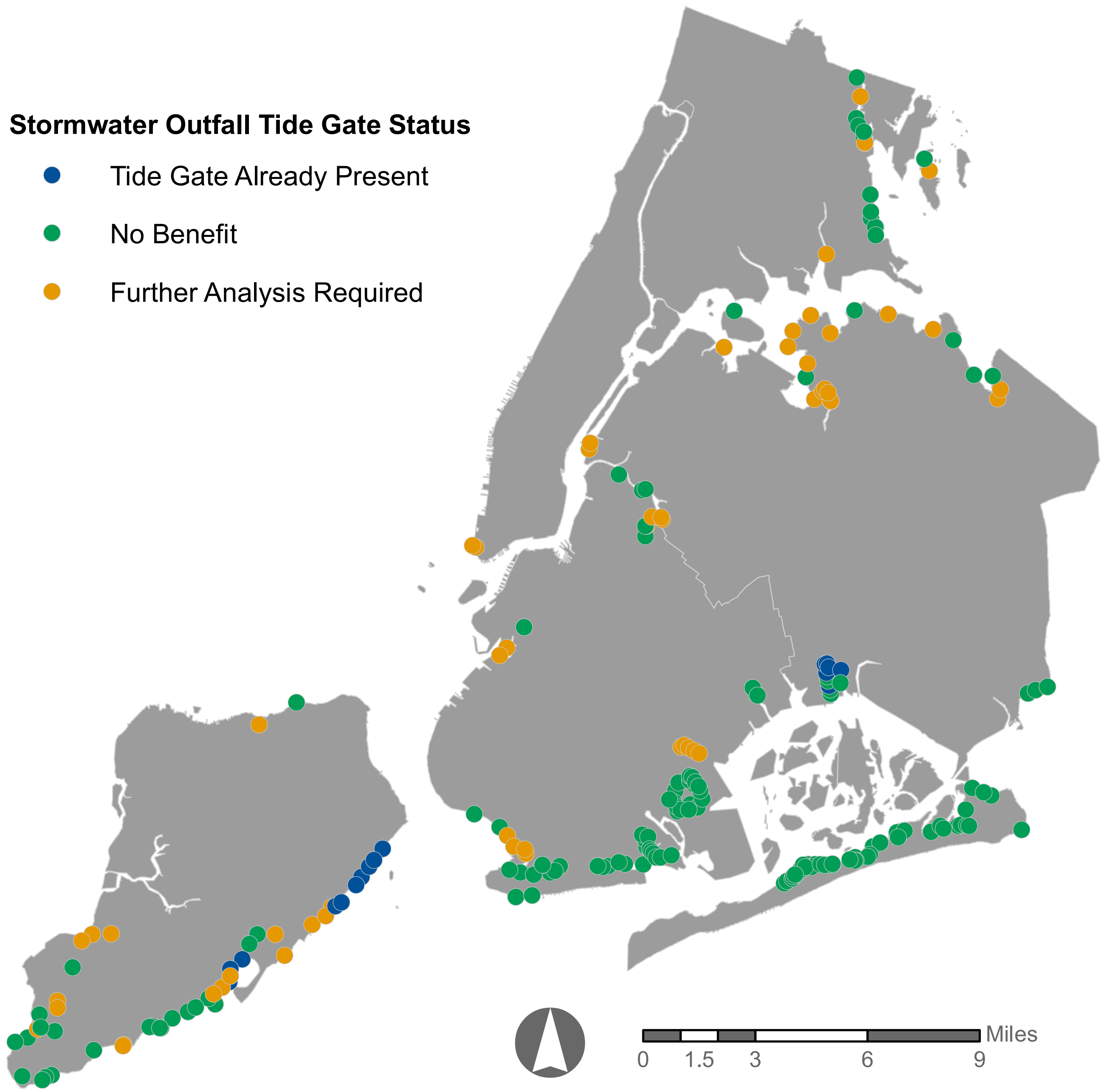
Tide gates prevent salt water from entering the combined sewer system and disrupting operations at wastewater treatment plants. While the combined system is equipped with tide gates, separate stormwater outfalls are not always equipped with tide gates, and therefore DEP sought to determine where additional tide gates might improve the functioning of the system during a storm surge event. A preliminary, static analysis was performed to determine the viability and impacts of tide gate installations at 211 DEP owned stormwater outfalls in New York City.

This analysis looked at the local topography of the community upstream of each associated outfall and compared it to the elevations of typical tidal events to see if the installation of a tide gate would provide flood protection to the communities directly adjacent to the associated shoreline. It should be noted that tide gates are effective in communities and areas where a seawall or similar flood protection measure are installed in tandem with the tide gate.

Of the 211 DEP-owned stormwater outfalls that were analyzed, it was determined that 152 outfalls would have no benefits from tide gate installation, while 59 required further analysis (Figure 7). For Coney Island and the Rockaways, tide gates have no benefit for the community due to the flat and low-lying topography of the surrounding communities. These conditions create a situation where a tide gate would not open during high tide events coinciding with certain rainfall events. Alternatively, for the south shore of Staten Island, the elevation of the communities is so high above the typical high tide that tide gates would also have a minimal impact.

The analysis demonstrated that tide gates must be analyzed on a case-by-case basis at each outfall to examine the hydraulics of the local drainage system, the surrounding topography of the community, and the typical tidal elevation along the associated shoreline. The installation of a seawall or other flood barrier is critical to the ability of a tide gate to benefit the community. The outfalls identified by this study as requiring further analysis necessitate dynamic modeling to determine the effectiveness and functional operation of tide gates during rainfall events. Additionally, each outfall needs to be assessed to determine the size of the area and types of assets that would potentially benefit from tide gate installation. Installing tide gates at every outfall in the city would be neither cost-effective, nor would it provide effective flood mitigation, adding costs for maintenance and replacements, and in some cases, potentially exacerbating flooding conditions.

Figure 7: Stormwater Outfalls Assessed for Tide Gate Analysis



Conclusion

New York City's drainage system is robust, and has provided excellent service to its residents for generations; however, projected changes in climate may pose new challenges. More intense precipitation patterns and a rise in sea level can contribute to increased frequency of CSO discharges, and a greater risk of local street flooding. Improving the city's wastewater and sewer systems will enhance the ability of the existing infrastructure to cope with environmental changes. DEP is actively addressing these issues and will continue to implement a number of its programs that are already underway, and where opportunities exist will seek to expand these programs.

This study is an important step in planning for the future because it specifically addressed the question of how global climate change is likely to affect New York City. It provides a basis for continuing existing efforts such as the Green Infrastructure Program, CSO Long-Term Control Plans, Bluebelt drainage program, and building out storm sewers in areas with limited drainage systems. In addition, this study, although focused on watershed-level impacts, produced results that are directly applicable to efforts to protect the DEP's entire wastewater infrastructure.

The analysis of watershed-level impacts on the collection system began with a comprehensive analysis of the complete available record of precipitation, including for the 60-year period since the Department's sewer design guidelines were formulated. The study reached the important conclusion that the current design documents, the IDF curves, need not be changed at this time, but should be revisited periodically in the future. The data analysis also selected the 2008 JFK data record as the typical year to be used for LTCP modeling, replacing the previous model year which was no longer the most representative of current New York City conditions. This analysis was the basis for projecting potential future rainfall conditions, under which the watershed was evaluated.

The representative watershed study of the drainage system indicated that changes to precipitation in New York City would increase the frequency of CSO discharges and the amount of local street flooding, while the increase in sea level would have little effect in the selected study area. Tide gates on stormwater outfalls were another specific element of the drainage infrastructure evaluated. A comprehensive analysis found that they can be an important feature in local flood protection, but only if they are used as part of a total engineering solution.

The study confirms the efficacy of the city's current green infrastructure approach, outlined in *PlaNYC*, especially the target of modifying impervious surfaces of city streets with bioswales, local infiltration or local storage, targeted separation of sewers, and regional Bluebelt-type designs. In fact, a clear result of the analysis was that the careful integration of green and traditional grey-infrastructure modifications will provide the largest benefit with the least cost. Additionally, other DEP initiatives such as adoption of new design standards for wastewater facilities and the recommended strategies for hardening wastewater infrastructure, as discussed in detail in Chapters 2 and 3, will further improve the city's resiliency in the face of future climate change. The data analysis of precipitation, the computer modeling of the sewer system of the Flushing Bay watershed, and the examination of critical pieces of system infrastructure all provide a foundation uppon which DEP can build future efforts to respond to climate change and sea level rise.

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