NYC WASTEWATER RESILIENCY PLAN

CLIMATE RISK ASSESSMENT AND ADAPTATION STUDY

NYC Environmental Protection

Michael R. Bloomberg
Mayor
Carter H. Strickland, Jr.
Commissioner

October 2013

Cover photograph: Newtown Creek Wastewater Treatment Plant, Brooklyn, New York

Carter H. Strickland, Jr.
Commissioner

Dear Friends:

The New York City Department of Environmental Protection (DEP) is proactively planning for climate change, from reducing greenhouse gas emissions to preparing for the impacts of extreme weather to drinking water and wastewater infrastructure. When Hurricane Sandy hit in October 2012, DEP was already in the process of studying the potential impacts of storm surge and sea level rise, to consider measures to protect the low-lying wastewater treatment plants and pumping stations that help drain our streets and keep our waterways and beaches clean for the enjoyment of millions of New Yorkers. After Sandy's surge caused damage to wastewater facilities, resulting in millions of gallons of untreated and partially treated wastewater spilling into the harbor, DEP quickly reacted to repair damage and to develop resiliency measures—such as elevating and flood-proofing equipment—to ensure the highest levels of protection from future storms.

presents a comprehensive assessment of facilities at-risk from future storms, potential costs, and suggested measures to protect critical equipment and reduce the risk of damage and loss of services. The report follows the recent release of Mayor Bloomberg's , which committed the City to harden its wastewater treatment plants and pumping stations. With 14 wastewater treatment plants and 96 pumping stations, prioritizing the most at-risk facilities included an extensive and in-depth assessment of the height of critical assets in relation to projected flood heights.

In determining the benefits of resiliency measures and the level of acceptable costs, DEP considered not only the value of wastewater assets, but also the population and critical facilities in the service areas and potential impacts on beaches. Resiliency measures were then selected based upon costs and level of risk reduction. The result is a portfolio of strategies that will be "shovel ready" for funding opportunities and implementation as part of planned capital projects.

Investing in our wastewater infrastructure today will ensure the continuity of critical services well into the future. By implementing these strategies along with initiatives to improve energy reliability, build green infrastructure, improve and expand drainage infrastructure, and promote redundancy and flexibility of our water supply, DEP will continue to be a leader in proactive planning for climate change, to ensure the resiliency of New York City's water resources.

Sincerely,

Carter H. Strickland, Jr.
Commissioner

ACKNOWLEDGMENTS

The was developed by the Department of Environmental Protection in collaboration with a dedicated team of consultants.

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We would also like to thank Radley Horton (Columbia University), Steve Moddemeyer (CollinsWoerman), Richard Palmer (University of Massachusetts Amherst), and Diego Rosso (University of California Irvine) for their expert feedback.

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NEWTOWN CREEK WASTEWATER TREATMENT PLANT VISITOR CENTER, BROOKLYN, NEW YORK

EXECUTIVE SUMMARY

The New York City Department of Environmental Protection (DEP) owns and operates one of the largest wastewater collection and treatment systems in the world, with 14 wastewater treatment plants and 96 pumping stations that convey stormwater and wastewater. The City's wastewater treatment plants (WWTP) utilize advanced biological and chemical processes to treat on average 1.3 billion gallons of wastewater per day, using state-of-the-art technology that removes between 85 and 95 percent of pollutants before discharging the treated water into the city's waterways. During wet weather, these treatment plants can disinfect two times their dry weather capacity. This immense system protects the environment and the health of more than eight million New Yorkers, and DEP is committed to ensuring its continued performance and reliability.

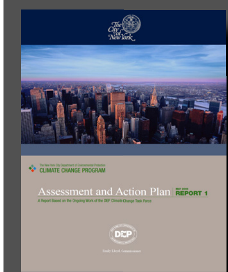
Many of the City's wastewater treatment plants and pumping stations are low-lying and necessarily located close to the waterfront in order to discharge treated wastewater and for efficient sludge handling. This waterfront dependency creates challenges that were plainly evident when a number of facilities experienced extensive damage during Hurricane Sandy. Flooding risk is likely to increase over time, as climate change brings more extreme storm surge events and continued sea level rise in the next several decades.

All 14 wastewater treatment plants and 60 percent of pumping stations are at risk of flood damage.

As such, DEP has taken a proactive stance in assessing its infrastructure risks and setting forth a framework to implement protective measures. Since 2008, DEP has been investigating the impacts of climate change on its infrastructure, not only for wastewater facilities, but also for drinking water supply and stormwater management.

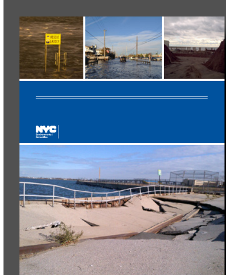
Building upon previous studies, this climate risk assessment and adaptation study sets forth cost-effective strategies for reducing flooding damage to wastewater infrastructure and safeguarding public health and the environment. This comprehensive study examined buildings and infrastructure at DEP's 96 pumping stations and 14 wastewater treatment plants, identifying and prioritizing infrastructure that is most at risk of flood damage. Through the study, DEP developed a set of recommended design standards and cost-effective protective measures tailored to each facility to improve resiliency in the face of future flood events.

April 2007
Mayor Bloomberg released PlaNYC, the City's long-term sustainability plan to accommodate a growing population, enhance the quality of life for all New Yorkers, and address climate change. The 2007 report entitled laid out PlaNYC's 127 goals, including reducing the city's greenhouse gas emissions by more than 30 percent by 2030.

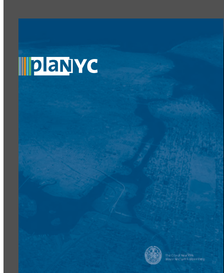


May 2008
DEP began implementing climate change resiliency measures after developing and issuing its Climate Change Assessment and Action Plan. This plan established the framework for subsequent studies to understand the linkages between climate change and specific service areas such as drinking water supply and delivery, stormwater management, and wastewater collection and treatment.

February 2011
DEP began a detailed Climate Risk Assessment and Adaptation Study for representative wastewater treatment plants, pumping stations, and drainage areas to evaluate the impacts of projected changes in temperature, precipitation, storm surge, and sea level.



October 2012
The potential impact of storm surge and sea level rise were demonstrated when Hurricane Sandy swept over New York City on October 29th, 2012. The surge caused extensive flooding and resulted in over $95 million in damage at 10 wastewater treatment plants and 42 pumping stations.



June 2013
Mayor Bloomberg released , outlining more than 250 recommendations to protect neighborhoods and infrastructure from future climate events. The results of DEP's Climate Risk Assessment and Adaptation Study were incorporated into the report's Water and Wastewater chapter.

The study produced a number of key results: All 14 wastewater treatment plants and 60 percent of pumping stations (58 out of 96) are at risk of flood damage. The study estimates that equipment valued at more than $1 billion is at risk and requires additional protection. It is unlikely that this high damage cost would be incurred during a single storm surge event, as flood heights tend to vary across New York City depending on storm characteristics; however, some at-risk equipment may incur repetitive damage from multiple storm surge events over time. Considering the entire range of surge heights up to and including the 100-year flood with 30 inches of sea level rise, the cumulative damages over the next 50 years may exceed $2 billion if no protective measures are put in place.

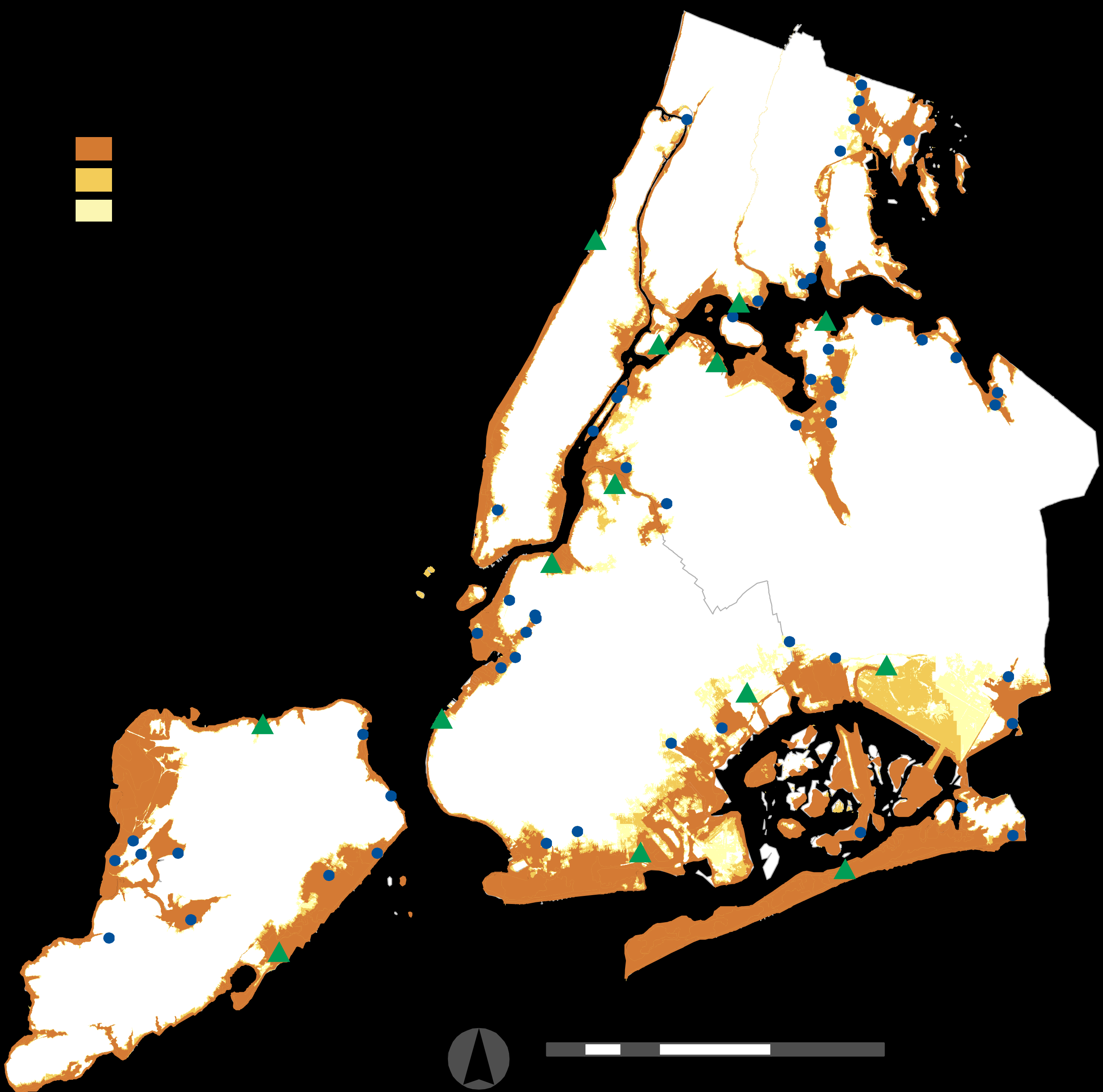
The recommended protective measures, totaling $315 million in improvements, are costly but critical. Increased resiliency not only reduces damage to DEP's assets, but also enables rapid recovery of full service to the community following a flood event, reduces risk of sewer backup into homes, and reduces the likelihood of the release of untreated sewage into the environment. DEP will prioritize these measures as part of planned capital projects and with an eye toward other proposals for engineered barriers or wetlands as part of the broader coastal protection initiatives described in *A Stronger, More Resilient New York.*

Wastewater infrastructure valued at over $1 billion is at risk if no protective measures are implemented. Over 50 years, cumulative damages could exceed $2 billion.

KEY FINDINGS

What is at risk?

Wastewater Facilities At-Risk of Storm Surge Inundation

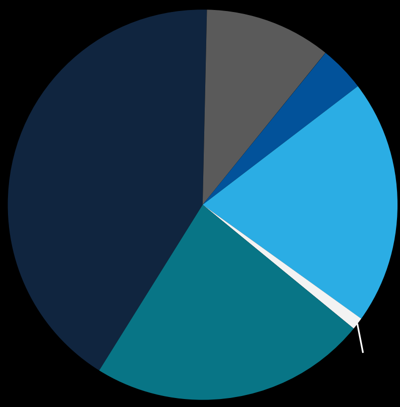


Source: FEMA; CUNY Institute for Sustainable Cities

How should it be mitigated?

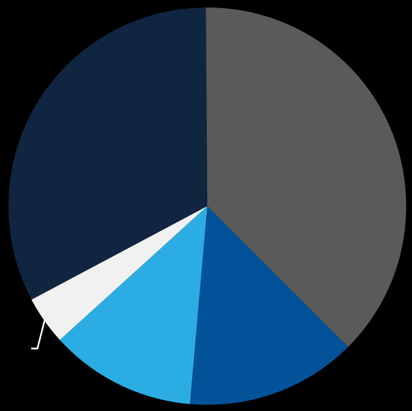
Adaptation Strategies

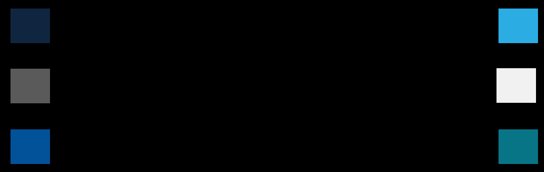
Pumping Stations



Wastewater Treatment Plants

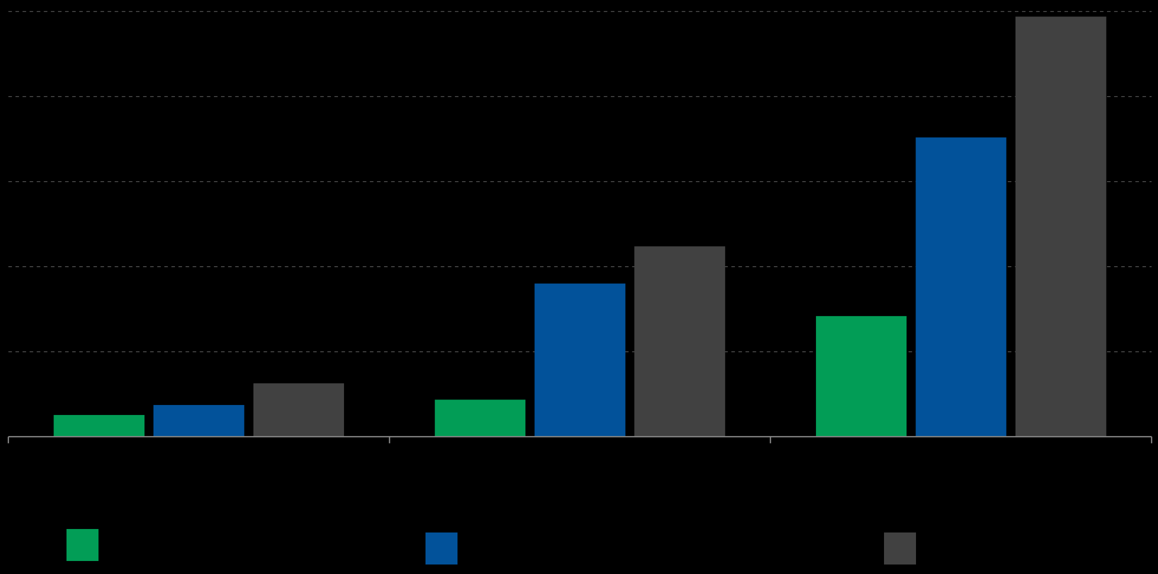
Note: All facilities are already equipped with backup generator power





What is the cost?

Summary of Estimated Costs for Wastewater Infrastructure



HIGH WATER MARK AT HUNTS POINT WASTEWATER TREATMENT PLANT

Hurricane Sandy was a devastating coastal flood event that left many New Yorkers without homes, electricity, and their livelihoods. The damage to DEP's wastewater treatment plants and pumping stations alone has been estimated to exceed $95 million. The inundation experienced at these facilities during the storm was unprecedented, forcing many of DEP's staff to work around the clock in difficult conditions through the surge and in the days that followed to maintain or restore service.

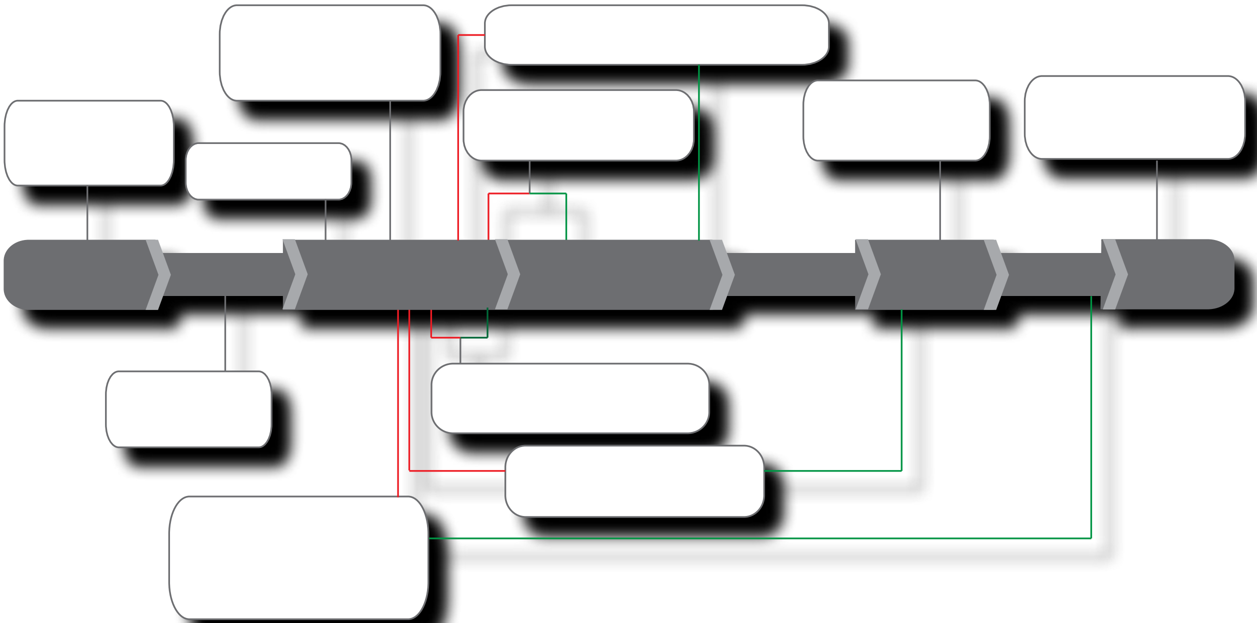
The surge also provided DEP with a unique and unprecedented example of risks at its wastewater facilities. To improve protection and response in the future, staff rigorously documented flood depths, providing valuable information regarding the impacts of flooding on site.

Of particular note, most of the damage experienced during Sandy was to electrical equipment that supplies power throughout the plants. Failure of this electrical equipment endangered many treatment processes. Fortunately, DEP implemented its Storm Preparedness Plan in advance so most facilities were able to retain some degree of power and operation using emergency generators. Only three facilities were non-operational as a result of the storm: Coney Island (two hours), North River (seven hours), and Rockaway (three days, although basic disinfection processes continued during this time). Many of the other plants experienced varying levels of flood damage to equipment and were forced to operate on their emergency generators for up to two weeks due to utility power outages.

Damage caused to wastewater infrastructure led to environmental impacts on surrounding waters. Partly due to power outages and plant inundation, and partly due to a large influx of floodwater into the sewer system, DEP reported that approximately 562 million gallons of untreated and diluted sewage that was mixed with stormwater and seawater was released into local waterways. The majority of this combined sewage overflow originated from the areas served by the Tallman Island, North River, Newtown Creek, Coney Island, and Rockaway plants. Advanced (secondary) treatment was also reduced at the Port Richmond, Oakwood Beach, Rockaway, Coney Island, and 26th Ward Wastewater Treatment Plants; however these plants were able to continue basic (primary) treatment to meet their permit requirements for pollutant removal.

Overall, given the severity of the storm, recovery was fairly quick. Just four days after the storm, DEP was treating 99 percent of all New York City wastewater; within two weeks, DEP had restored full treatment at all plants. DEP also enacted a number of emergency preparedness and response plans prior to the storm to protect its facilities, without which damage costs would have been much higher.

Timeline of Hurricane Sandy Impacts and Recovery



Out of the 96 pumping stations, 42 were affected by Sandy, with approximately half failing due to damage from floodwaters, the other half due to loss of power supply. Electrical equipment and power supply were found to be the systems at risk. Many of the pumping stations had to employ backup emergency generators during the surge. In addition, in some cases the main sewage pump motors were flooded which prevented the transfer of wastewater and stormwater.

DEP immediately put into action many of the lessons learned from Hurricane Sandy. At two facilities already in the midst of upgrades — the Manhattan Pumping Station and the Gowanus Pumping Station — a number of resiliency measures are being incorporated to address the risks identified during the storm. DEP is committing the time and money to include resiliency upgrades into these planned improvement projects, since combining upgrades is often less costly than performing them separately.

Hurricane Sandy provided an unprecedented example of flood risks at wastewater facilities.

Area Near the Rockaway Wastewater Treatment Plant

Pre-Hurricane Sandy (May 2008)

Source: NOAA

Post-Hurricane Sandy (November 2011)

Source: NOAA

The Rockaways experienced significant damage due to wave action during Hurricane Sandy. Waves swept away significant portions of beaches and inundated and battered homes and the nearby Rockaway Wastewater Treatment Plant. This facility and the surrounding community were amongst the hardest hit during Sandy's surge.

ELECTRICAL FEED AT OAKWOOD BEACH WASTEWATER TREATMENT PLANT

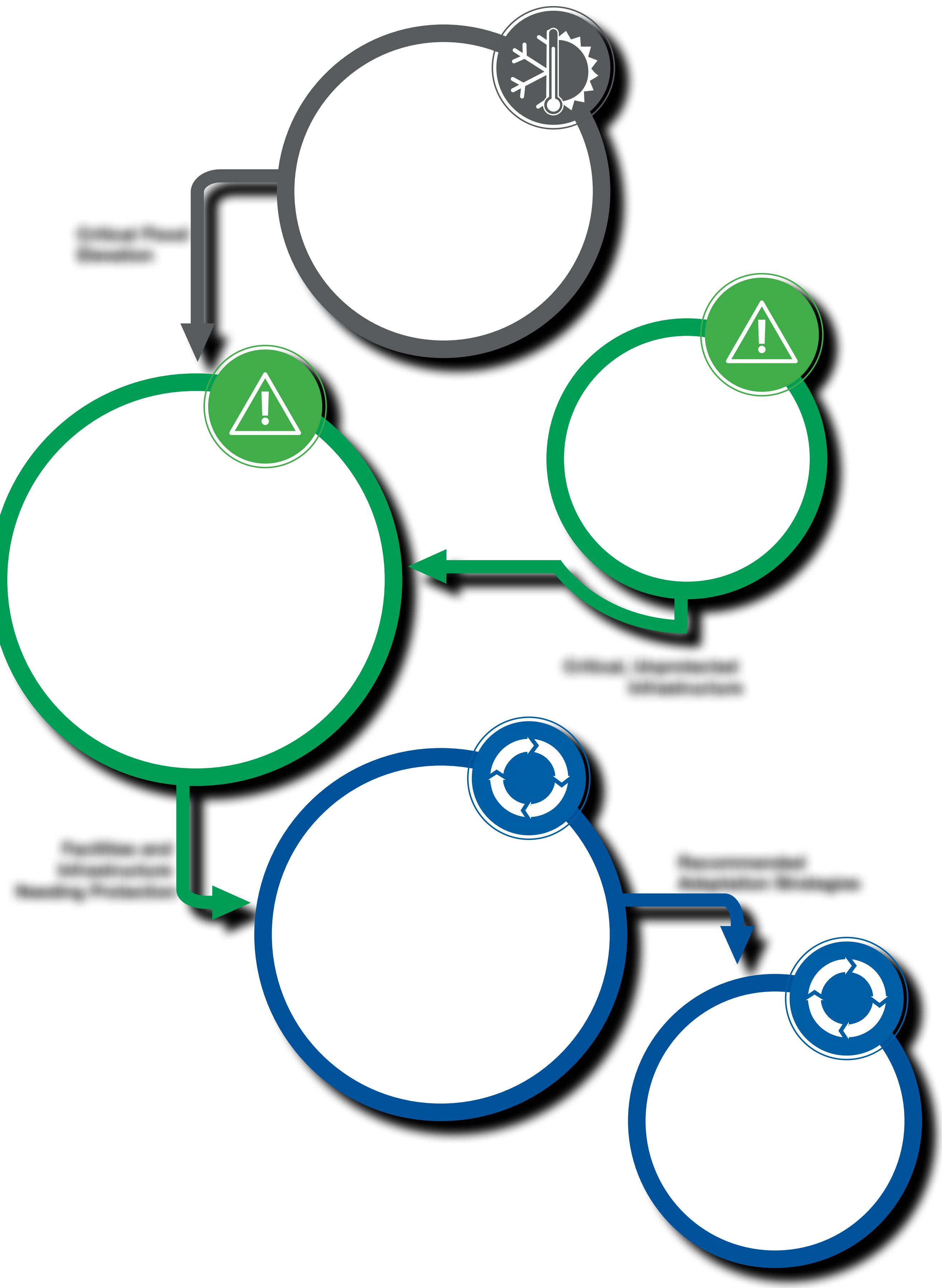
The used a unique framework to assess flood risk and identify appropriate protective measures. This framework can be applied as a prototype to protect a wide range of vital City infrastructure beyond wastewater facilities. As shown in the adjacent flowchart, the framework is comprised of three major modules:

CLIMATE ANALYSIS: What is NYC's climate likely to be in the future, especially in terms of storm surge and sea level rise? What conditions should NYC prepare for?
While climate science cannot predict when a surge will occur, current climate studies project that large surge events are likely to become more frequent in the future and will be exacerbated by sea level rise. The FEMA 100-year flood event was selected as the maximum surge assessed in this study. An additional 30 inches of flooding were also added to account for future sea level rise by the 2050s, the high end of the projections from the New York City Panel on Climate Change.

RISK ANALYSIS: Which infrastructure will be affected in flood events?
Potential risks at each facility were identified through site visits, analysis of facility blueprints, and interviews with facility personnel. Information about conditions during Hurricane Sandy also helped pinpoint specific risks and operational challenges. The elevations of flood pathways and infrastructure were then compared to the flood elevation defined in the Climate Analysis to determine which infrastructure is potentially at risk. Cost estimates for the replacement of at-risk equipment under emergency conditions, cleaning of facilities, and temporary power and pumping were developed, and then used as a metric to inform the prioritization of risks.

ADAPTATION ANALYSIS: What can be done to protect at-risk infrastructure from surges and how much will this cost?
DEP performed an extensive literature review of strategies being considered around the globe to protect against climate change and narrowed the list down to six measures that would work best for NYC's wastewater infrastructure. These protective measures were then evaluated for use at each wastewater facility. Strategy recommendations were made based on feasibility, effectiveness, and cost.

Climate Risk Assessment and Adaptation Framework



ELEVATED CONTROL PANELS AT 26TH WARD WASTEWATER TREATMENT PLANT

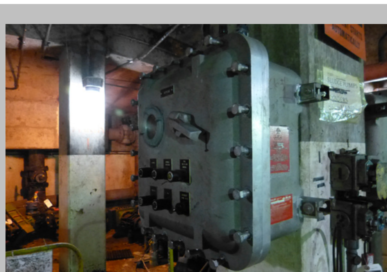
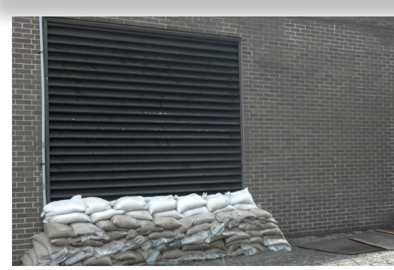
To increase the resiliency of wastewater treatment facilities against elevated flood levels, DEP is rapidly enacting a range of initiatives to implement the recommendations developed in the Climate Risk Assessment and Adaptation Study. One of these initiatives is to adopt new wastewater facility design standards that incorporate more robust measures than were formerly required.

Previous wastewater facility designs typically provided protection against the highest historically-recorded water height of nearby water bodies. However, with the new surge records set by Sandy and projected future sea level rise, the new design standards will account for the critical flood elevation used in the study: the FEMA 100-year flood elevation plus 30 inches of sea level rise.

To address the need for more robust protection, the design standard will incorporate appropriate protective strategies that were identified in the study as being highly effective for the site conditions of New York City's wastewater infrastructure. The portfolio of possible adaptation strategies includes six primary options, as follows: elevating equipment above the critical flood elevation, making pumps submersible and encasing electrical equipment in watertight casings, constructing a static barrier around a location, sealing structures with watertight windows and doors, sandbagging temporarily, and where feasible, providing backup power generation to pumping stations (treatment plants are already so equipped). Although these strategies may not necessarily keep the facility fully operational during a large storm event, the primary goal is to protect equipment from flood damage and reduce the time needed to return to normal operations following a flood event.

The new design standard will account for the critical flood elevation of the FEMA 100-year flood elevation plus 30 inches of sea level rise.

Each strategy has associated advantages and disadvantages relating to strategy effectiveness, cost, and complexity. For example, the higher the resiliency of the measure, the more thoroughly the strategy protects the facility during a flood event and the more risk the strategy can help avoid. However, strategies with higher resiliency are often more costly to implement. While the six strategies were all analyzed in the study and recommendations made for each wastewater facility, through the design standard, planners and designers will have the option to choose which strategy is implemented at a facility based on funding availability and more detailed site-specific analyses.

Adaptation Strategy		Resiliency/Effectiveness	Cost
	**Elevate Equipment** on pads or platforms, to a higher floor, to the roof, or to a new elevated building.		$$$$
	**Flood-Proof Equipment** by replacing pumps with submersible pumps and installing watertight boxes around electrical equipment		$$$
	**Install Static Barrier** across critical flood pathways or around critical areas.		$$$
	**Seal Building** with water-tight doors and windows, elevating vents and secondary entrances for access during a flood event.		$$
	**Sandbag Temporarily** around doorways, vents, and windows before a surge event.		$
	**Install Backup Power** via generators nearby or a plug for a portable generator.	Does not protect equipment, but ensures rapid service recovery	$$$

The adaptation strategies identified in this study were narrowed down from a comprehensive literature review of climate resiliency measures being implemented or considered in various locations around the world. These strategies will be incorporated into wastewater facility design moving forward to ensure more resilient plants and pumping stations.

CANNON STREET PUMPING STATION

As part of capital projects and subject to available funding, DEP will design and implement resiliency projects at the 58 pumping stations that are vulnerable to storm surge damage from a 100-year flood with 30 inches of sea level rise.

These pumping stations are situated across the five boroughs and vary greatly in their configurations. Some are located entirely underground, some have above ground structures, some are under streets and sidewalks, and others are in parks. Despite their diverse characteristics, the 58 pumping stations tend to have similar risks. The most common flood pathways were doorways, hatches, and pipe penetrations leading to areas containing electrical equipment and pump motors, which Hurricane Sandy showed were especially vulnerable. It is critical that these facilities be protected since at-risk pumping station infrastructure is valued at approximately $220 million.

Recommendations for resiliency improvements were made in close consultation with DEP's operating bureaus and predominately involve making pumps submersible and elevating electrical equipment on platforms or to higher floors, new buildings, and nearby roofs. Depending on space constraints, backup power generators or plugs to connect to portable generators were also frequently recommended to ensure rapid recovery in restoring service. The recommended strategies, which would cost a total of $128 million to implement, were specifically selected to protect equipment from flood damage and increase the likelihood of continued pumping during or immediately following a flood event.

Implementing $128 million in capital improvements at pumping stations would reduce equipment failures and potential damage by more than $700 million over the next 50 years.

While the implementation cost is steep, investing in resiliency measures at particularly low-lying pumping stations will protect them not just in a large flood, but also from less severe storms when flooding may occur.

Pumping Station Configurations


Avenue M: Under the sidewalk


37th Avenue: Under a park

40th Road: Small Building

Arlene Street: Above ground, no building


Bayswater Avenue: On a pier


Bush Terminal: Large building with outdoor equipment

New York's pumping stations vary greatly in size, configuration, and site characteristics. While their risks tend to be consistent, implementation of adaptive measures may vary depending on site specific constraints.

Pumping Stations At-Risk of Storm Surge Inundation

Source: FEMA; CUNY Institute for Sustainable Cities

The total value of risk avoided over 50 years if protective measures are implemented for all 58 pumping stations is $709 million, multiple times the total value of infrastructure that is at risk ($220 million). Although it is not likely that all at-risk equipment and facilities would be affected at once in a single storm event, the value of at-risk equipment is twice the total cost of implementing the recommended strategies ($128 million), lending strong economic support for implementation. Considering pumping stations also provide a critical service of transporting sewage and stormwater from homes, businesses, hospitals, and other facilities, implementing the recommended strategies makes sense both from an operational basis and from an economic basis.

Prioritizing pumping stations for capital improvements is an important aspect of planning since the required economic funding needs are greater than the available resources. In order to aid prioritization, a number of criteria were applied including operational, environmental, social and financial metrics. These metrics included historical flooding frequency at each pumping station, proximity to beaches and sensitive water bodies, population served, number of critical facilities served (e.g. hospitals, nursing homes, fire and police stations, etc.), and whether the particular pumping station is scheduled for improvements in DEP's 10-year capital plan. Based on the multiple criteria, the top 5 priority pumping stations are currently the Van Brunt, Howard Beach, Throgs Neck, Nautilus Creek, and 40th Road pumping stations.

DEP will upgrade pumping stations based on level of risk at the facility, level of service to the community, and whether the facility has other planned capital improvements.

Notes: Avenue V and Gowanus Pumping Stations are considered at-risk, but are already undergoing extensive protective upgrades and are not considered in this cost estimate.
1) All cost estimates are presented in 2013 US Dollars.
2) One-time replacement cost of at-risk equipment if no protective measures are in place and critical flood scenario occurs (i.e., current 100-year flood plus 30 inches). This estimate does not consider the probability of storm occurrence.
3) Repair/replacement costs that would be avoided over 50 years if protective measures are in place for storm surges up to and including the 100-year flood plus 30 inches. This estimate incorporates the probability of storm occurrence.

The city's wastewater treatment plants are large facilities spanning multiple elevations and flood zones, as seen at the Bowery Bay Wastewater Treatment Plant to the right. The plants also contain thousands of pieces of equipment, including pumps, motors, electrical power equipment, mechanical equipment, instrumentation, and controls. The facilities are also highly complex, with multiple buildings, tanks, and outdoor areas interconnected by tunnels, pipe work, and electrical conduits.

A site-specific analysis of each plant was required to ensure the nuances and layouts were adequately assessed. Each plant was visited to determine flood pathways and at-risk equipment. Common pathways documented were doorways, windows, vents, basement access ways, tunnels, and buried electrical conduits. These electrical conduits crisscross the plants and represent a significant risk as waterproofing sealant on conduits is difficult to maintain and monitor over time.

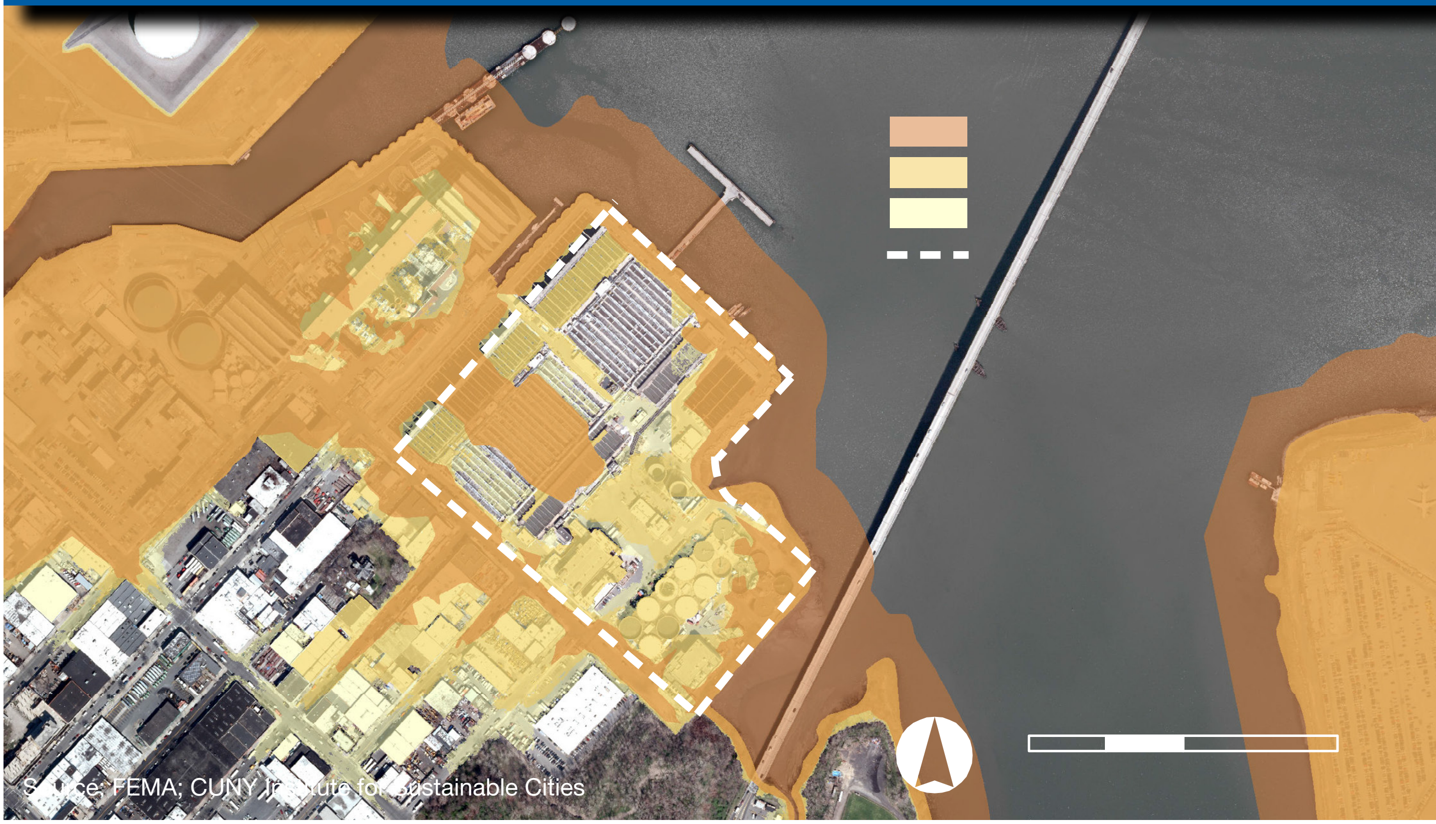
In total, infrastructure valued at $901 million is at risk at the City's wastewater treatment plants. While all 14 wastewater treatment plants are at risk from the 100-year flood with 30 inches of sea level rise, not all will be affected to the same degree. For example, the Jamaica

Infrastructure valued over $900 million is at risk in a large flood event, making these facilities prime targets for resiliency upgrades.

Wastewater Treatment Plant is located on relatively higher ground. Only one large piece of electrical equipment is at risk. This risk was already known to staff, who regularly sandbag around the infrastructure.

In contrast, the Rockaway Wastewater Treatment Plant was devastated during Hurricane Sandy and would be under more than 6 feet of water in a 100-year flood with 30 inches of sea level rise. This plant is also very close to the ocean, and could experience severe structural damage due to pounding waves. Low-lying plants such as the Rockaway Wastewater Treatment Plant can expect resiliency measures to provide protection in small and large flood events, making the case for adaptation strong even at higher costs.

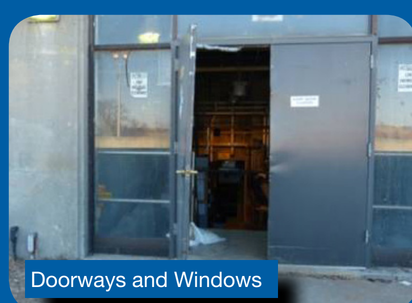
FEMA Flood Zones at Bowery Bay Wastewater Treatment Plant



Source: FEMA; CUNY Institute for Sustainable Cities

An aerial image of Bowery Bay Wastewater Treatment Plant is shown with the 2013 Advisory FEMA flood map and sea level rise projections overlaid. During the study, these maps provided flood elevation information which was then compared to the elevations of doorways, windows, and other flood pathways at the plant to see what areas and equipment would be vulnerable to flood damage.

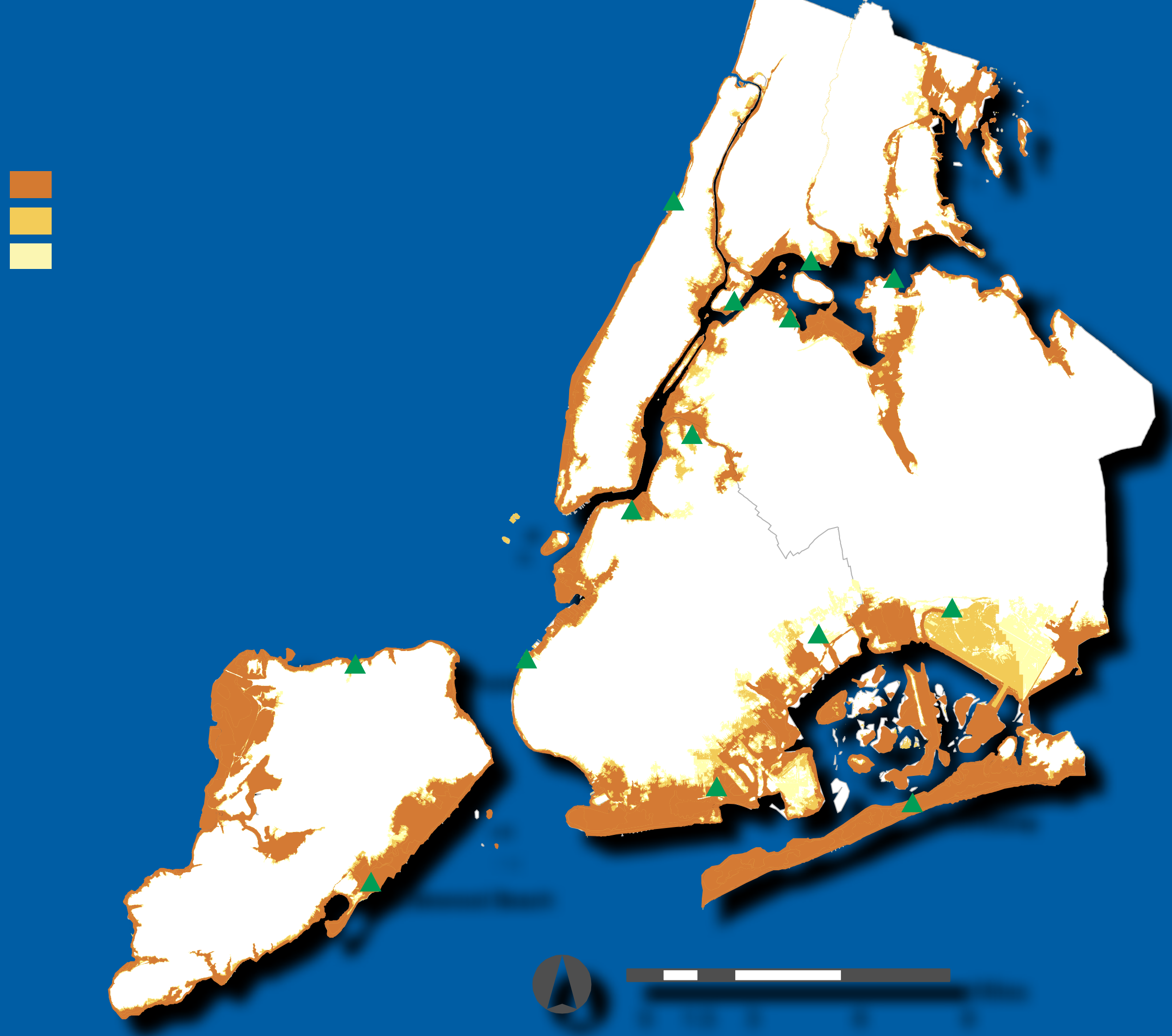
Potential Flood Pathways



Doorways and windows are easy to identify as flood pathways. However, understanding the often complex system of underground tunnels, pipes, and electrical conduits at wastewater treatment plants is much more difficult and requires the use of facility blueprints.

Wastewater Treatment Plants At-Risk of Storm Surge Inundation

Source: FEMA; CUNY Institute for Sustainable Cities



As with pumping stations, the total potential damage to the wastewater treatment plants is extremely high and warrants protection. The study associated and tailored strategies to each facility based on preliminary site feasibility assessments and a comprehensive cost-risk analysis. This quantitative assessment accounts for the cost to implement each strategy and the amount of risk each strategy could mitigate. For equipment that is critical to meeting a minimum required level of service by state law, strategies with high resiliency were selected to promote continuous service. For other equipment, recommended strategies provide a balance of resiliency and a good return on investment.

The study also identified a number of additional resiliency measures that are under consideration for implementation at wastewater treatment plants. These include:

Upgrading and retrofitting the plant generation systems to incorporate new technologies that allow for digester gas reuse and use as a backup power source during a flood event.

Establishing safe houses for staff during the storm with backup power and supplies.

Having electrical and mechanical contractors ready for immediate repairs following a flood event.

Quick references such as storm surge impact charts were also developed from this study, and will be distributed to plant operators to better inform emergency efforts before a surge event.

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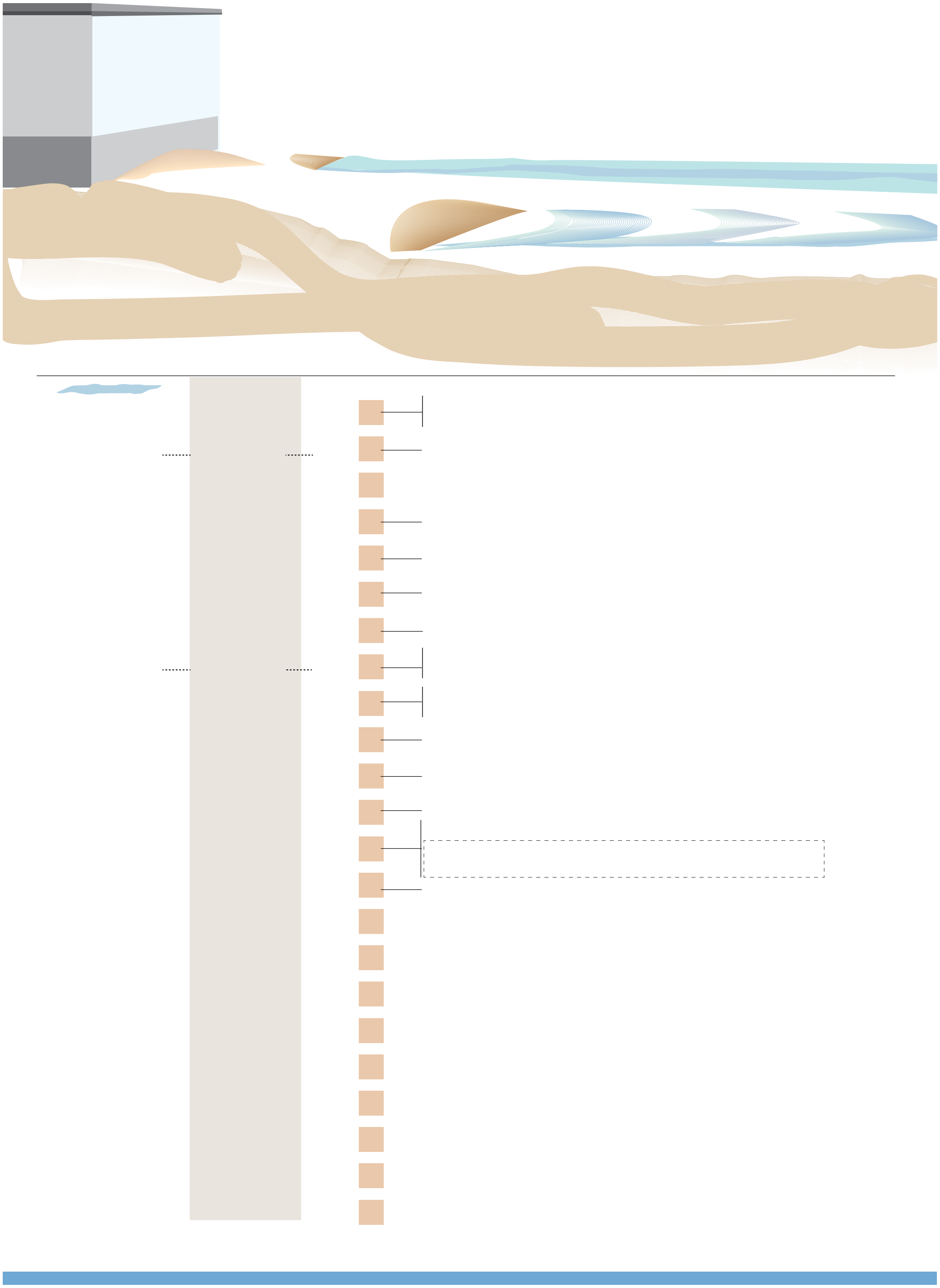
1) All cost estimates are presented in 2013 US Dollars.
2) One-time replacement cost of at-risk equipment if no protective measures are in place and critical flood scenario occurs (i.e., current 100-year flood plus 30 inches). This estimate does not consider the probability of storm occurrence.
3) Repair/replacement costs that would be avoided over 50 years if protective measures are in place for storm surges up to and including the 100-year flood plus 30 inches. This estimate incorporates the probability of storm occurrence.

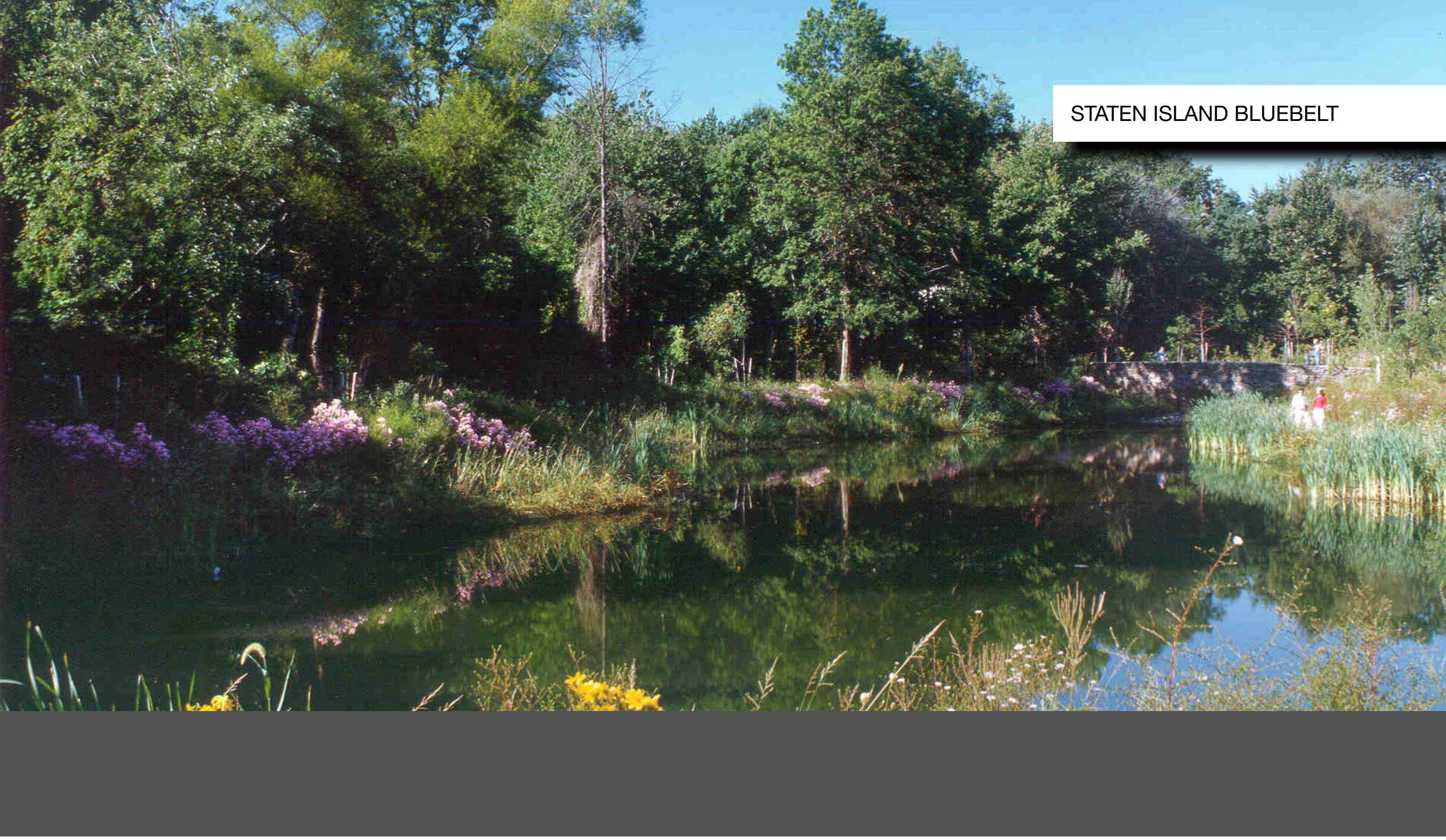
DEP plans to start protecting wastewater treatment facilities by implementing the six adaptation measures (presented in the Adopt New Design Standards section) as part of repairs and other planned capital improvements. As facilities are upgraded, the recommendations made through this study will be reassessed with detailed site analyses, and may be modified within the context of other capital improvements being made.

Timing with other capital improvements is especially important for resiliency upgrades, as the cost of implementing protective measures with other upgrades and at the end of equipment life spans often significantly reduces capital cost and may provide additional opportunities for improvement. Since water quality in New York City's waterways is vital to environmental and public health, DEP has also selected wastewater treatment plants that can affect bathing beaches as high priority for implementing protective measures. These plants include 26th Ward, Coney Island, Hunts Point, Jamaica, Oakwood Beach, and Rockaway.

In all, investing $187 million in a strategic mix of protective measures could improve resiliency at New York City's wastewater treatment plants and reduce risk by almost 85 percent. The damage costs avoided over 50 years from flood events, up to and including projected 100-year storms with 30 inches of sea level rise, is an estimated $1.76 billion. These estimates provide strong support for implementing protective measures as they will likely save the City more money as compared to the cost of repairs and disaster relief over time.



This storm surge placard provides a quick reference for operators to prepare their plant in advance of a surge event. The guidance enables an operator to rapidly locate at-risk locations based on storm surge warnings. Once at-risk areas are identified, plant staff may proactively protect locations at or below the forecasted surge levels.



DEP manages drainage system infrastructure with many elements that will last longer than 100 years, and must make sensible long-term plans that account for anticipated changes beyond its control. Among these important changes are rising sea level, increased population, elevated surface temperatures, and the possibility of more intense precipitation patterns. These factors could have an impact on wastewater treatment processes, the frequency of combined sewer overflow (CSO) events, and flooding on local streets. This study focused on the anticipated changes in rainfall and sea level from projected climate change, and assessed the alternatives available to mitigate these impacts.

This study included three phases:

Phase 1: *Precipitation Analysis*
Rainfall statistics are critical for design standards for city drainage systems; the goal of Phase 1 was to assess whether there have been changes to the rainfall intensity, duration, and frequency statistics, or IDF curves, that are used for sewer design. The study examined a longer, more complete rainfall dataset than has been used in the past to produce the revised IDF curves and to revisit the 'typical rainfall year' that is modeled for DEP's CSO Long-Term Control Plan (LTCP).

Phase 2: *Watershed Analysis*
In this phase of the analysis, a representative drainage area was assessed using hydraulic and hydrologic simulation models developed for the LTCP. These models were used to assess the potential impact of changes in sea level and precipitation on the performance of the drainage system, with particular attention on changes to CSO frequency and street flooding. Finally, the models were used to estimate the possible benefits of implementing combinations of green and grey infrastructure alternatives.

Phase 3: *Tide Gate Analysis*
The final phase of the study assessed the effectiveness, costs, and benefits of installing tide gates at stormwater outfalls to prevent storm surge inundation in adjacent communities.

Precipitation Analysis

Most of the city is served by a combined sewer system, and drainage pipes are large enough to carry both stormwater and sanitary flow for the majority of precipitation events. During dry weather, the pipes have ample capacity. This study sought to understand if there have been statistically relevant changes to wet weather patterns in New York City, and included an update of regional precipitation statistics to include an additional 50 years of data beyond the previous record.

The study determined that, although there have been some notable extreme events in recent years, the complete record shows no statistically significant trend towards more intense rainfall events over the longer historical record. IDF curves, one of the most common and useful tools for sewer design, were reassessed using historical rainfall data which revealed that the intensities for a storm with a 5-year return period are not significantly different between the current and updated IDF curves for durations (or travel time) up to 100 minutes. In other words, for durations relevant to sewer design, the expanded, more recent data record revealed no discernible trend toward more intense rainfall.

The relevance of this finding for DEP's current sewer design standards is that current drainage planning tools (IDF curves) remain suitable for design. However, to recognize any emerging trends in precipitation intensity due to future climate change, DEP will work with the Mayor's Office of Long-Term Planning and Sustainability and the New York City Panel on Climate Change to create a process to reassess precipitation data periodically and incorporate any advances in climate modeling. Based on any material emerging trends, DEP will assess implications for the sizing of stormwater detention systems, sewer site connections, and green infrastructure, as appropriate.

Historical rainfall data analysis did, however, result in a change in the 'typical year' to represent average annual conditions for LTCP modeling. Data from JFK Airport in 2008 is now used to represent the 'typical' rainfall year and will be used for modeling the efficacy of projects to reduce CSOs. Furthermore, to account for more extreme years that may become the norm in the future with climate change, the historical time series used for LTCP modeling has been expanded to ten years--including 2005 and 2006, which most closely fit the projections for future precipitation. The incorporation of additional years will be used to test the robustness of various CSO mitigation approaches under a range of average and extreme conditions.

Watershed Analysis

Watershed analysis is an integral component of DEP's planning for water quality projects to reduce the effects of CSOs, and is based on a simulation of the actual urban environment that considers how the system responds to precipitation events and fluctuations in tides. 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.

The analysis showed that CSO discharges and local flooding would 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 and potential effects on water quality. A detailed analysis of various solutions to address increased local flooding and CSO events showed that a combination of green infrastructure and grey infrastructure has the greatest benefit, but that adaptation strategies must be evaluated and implemented on a site-by-site basis in order to confirm feasibility, and compared on a cost-benefit basis with other proposed projects.

Already, DEP is implementing an ambitious Green Infrastructure Plan to build green infrastructure citywide to reduce CSO events. Continuing to implement the PlaNYC goal for green infrastructure is an important element of a strategy to adapt to climate change. Used in combination with cost-effective grey infrastructure practices, such as high-level storm sewers, these strategies will help to ensure that the city's wastewater system continues to provide a high level of service to the public and the environment, now and in the future.

Tide Gate Analysis

Tide gates prevent salt water from entering the combined sewer system and disrupting operations at wastewater treatment plants. Discharge points for stormwater pipes, however, are only occasionally fitted with tide gates. This portion of the study 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.

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. The results varied and are highly dependent on the engineering of the sewers in each area. It 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. In some cases, tide gates would yield benefits, but it would not be cost-effective or provide effective flood mitigation to install tide gates at every outfall in the city, adding costs for maintenance and replacements, and in some cases, potentially exacerbating flooding conditions.

The was a tremendous effort, with vital data sharing and intensive discussion between operators, risk analysts, climate specialists, and policy makers. The study greatly improved understanding of wastewater infrastructure risks and resulted in identification of a portfolio of robust adaptation strategies that will be incorporated in DEP design standards and capital planning. DEP has also established resources and institutional programs to help staff members understand the risks of climate change and continue to improve resiliency.

This study, therefore, does not mark the end of climate resiliency efforts at DEP. As New York City's climate continues to change, DEP is ready and committed to continue risk evaluations and pursue resiliency upgrades, not only in wastewater, but also for stormwater management, ecosystems management, and drinking water supply, as described in the report from Mayor's Special Initiative for Rebuilding and Resiliency. With a combination of hardened infrastructure and better emergency response, DEP is well positioned to better protect the City's water infrastructure and waterways on multiple fronts, and is committed to continue serving the public to create a stronger and more resilient New York City.

Additional Information

In addition to this document, DEP has developed a number of detailed public reports regarding the citywide risk framework and climate analyses used in this study, as well as facility-specific documents which serve as a valuable resource regarding lessons learned from Sandy and site-specific recommended adaptation strategies. Please see subsequent chapters for further details.

RESIDUALS HANDLING FACILITY, WARDS ISLAND WASTEWATER TREATMENT PLANT, MANHATTAN, NY

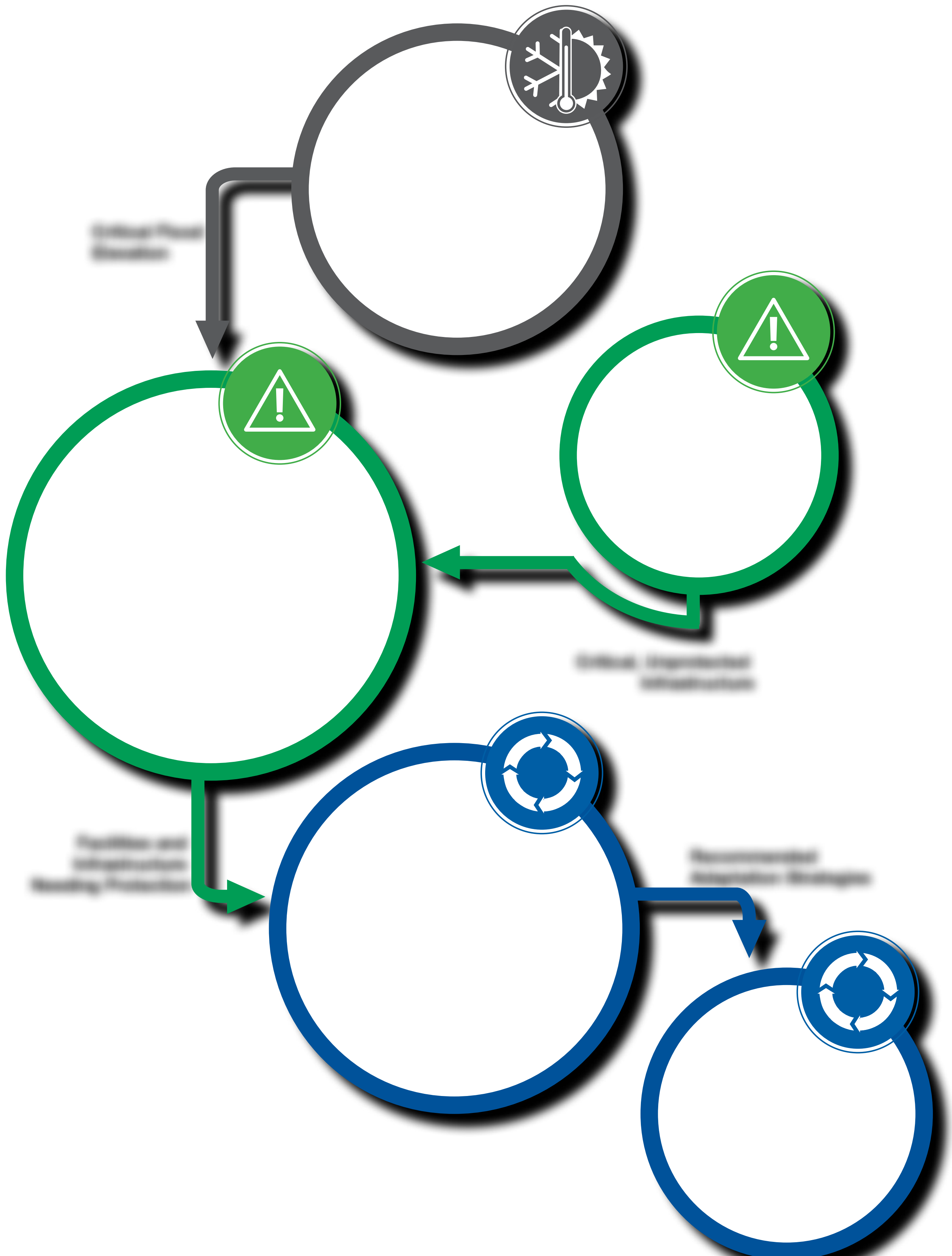
CHAPTER 1: CITYWIDE FRAMEWORK

The Climate Risk Assessment and Adaptation Study was developed as a planning level framework to assess the flood risk posed to wastewater infrastructure and to provide adaptation recommendations based on site feasibility and cost-benefit evaluation. This approach evaluates the cost of adaptation strategies against the value of risk avoided after strategy implementation.

The study yielded insight into the risk of DEP's wastewater infrastructure to flood damage, documented lessons learned from Hurricane Sandy, and provides a valuable framework that may be used as a prototype to protect a wide range of vital city infrastructure in New York and around the world.

The Citywide Resiliency Framework is summarized as a flowchart in Figure 1, and comprises three main analyses: 1) Climate Analysis, 2) Risk Analysis, and 3) Adaptation Analysis. These analyses build upon each other and are described in further detail in subsequent sections.

Figure 1: Climate Risk Assessment and Adaptation Framework



Climate Analysis

While climate science cannot predict when a storm surge will occur, current climate studies project that future storm surge events are likely to be exacerbated by sea level rise. The climate analysis in this study established the future storm surge conditions for which DEP should plan and prepare.

The March 2013 FEMA 100-year advisory base flood elevation (ABFE) plus an additional 30 inches for sea level rise was selected as the “critical flood elevation” against which DEP infrastructure would be assessed. This flood elevation was obtained for each wastewater facility location from online FEMA ABFE maps which provide flood levels accounting for specific local conditions, such as topography.

The 2013 ABFE maps were developed by FEMA to guide rebuilding efforts after Hurricane Sandy and were the most current flood elevations available at the time of the analysis. The ABFEs were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. The critical flood elevations in the updated maps are in most cases very similar to the ABFE maps, and are more conservative than the PWM elevations, and therefore more protective. Using the updated maps would not significantly affect the results of this analysis.

The additional 30 inches added to the ABFEs approximates future sea level rise in the 2050s, as projected by the New York City Panel on Climate Change. As shown in Table 1, 30 inches represents a high estimate of sea level rise[2]. The year 2050 was chosen to evaluate future conditions in the study in order to be consistent with DEP capital planning programs. Using a higher estimate for the analysis provides for more conservative design standards that will better protect wastewater infrastructure from future storm surge conditions.

Table 1: NPCC 2013 Climate Projections

Source: NPCC; for more details, see *Climate Risk Information 2013.*

[1]Baseline period for sea level rise projections is 2000-2004.

[2]The New York City Panel on Climate Change issued its final report in 2013, with slight changes to the high end estimate for sea level rise. The change of 1 inch to the projections would not alter the recommendations of this study.

Risk Analysis

The Risk Analysis sought to determine which facilities and infrastructure would be at risk from the critical flood elevation (100-year ABFE plus 30 inches of sea level rise), and how much damage DEP could expect to incur.

A detailed analysis of potential flood-related risks at each facility was conducted by walking through the facilities, documenting flood pathways for different buildings and plant areas, and interviewing operational staff to determine which infrastructure had been frequently subject to flooding during the facilities' active history. Of particular value was evaluating what flooded during Hurricane Sandy, which helped paint a picture of how floodwater moves throughout the facilities and the operational challenges that flooding creates. The most common flood pathways identified on site included doorways, outfall pipes, bulkheads, windows, vents, conduits, and tunnel systems. The site visit was accompanied by an analysis of facility blueprints to determine the height of a surge that would inundate the various flood pathways identified once a threshold elevation was overtopped (the sill of a door for example, or, in the case of pumping stations, the ground elevation). If the threshold elevation fell below the critical flood elevation, the location was determined to be at risk of flood damage.

An extensive assessment was performed on critical infrastructure within at-risk locations to determine the value of damage DEP could expect to incur in a large surge event. Pumps, motors, electrical equipment and controls, and other equipment necessary to meet basic (primary) treatment levels were of particular interest due to the receiving waterbody impacts.

DEP has an infrastructure database that catalogs the thousands of pieces of wastewater equipment at each treatment plant and pumping station. This database was reviewed and supplemented with information from inspections and drawing review pertaining to location, equipment resiliency, and equipment elevation with respect to the critical flood elevation. Replacement and repair costs were also developed for at-risk infrastructure. Total damage cost estimates for each plant location and pumping station considered the cost of replacement for infrastructure, and the cost to clean up the site and provide temporary power and pumping services, if necessary.

ASSESSING WASTEWATER INFRASTRUCTURE USING TRIPLE BOTTOM LINE ANALYSIS

Flood damage not only comes in the form of needing to replace equipment and clean a site, but also includes damages from extended loss of service. New York City's pumping stations convey millions of gallons of sewage from homes, businesses, hospitals, and other important buildings to treatment facilities, ensuring sewage does not back up into basements, which could pose a health risk. Similarly, wastewater treatment plants provide an invaluable service by treating sewage to protect water quality in New York's waterways. Without the treatment plants running, sewage would degrade the environment and contaminate beaches.

Thus, flood damage not only presents an economic burden, but also has significant social and environmental costs. Considered together, all three of these costs provide a more holistic assessment of damage from flood surge and can guide adaptation decision-making more appropriately for a service-driven agency such as DEP. Because it considers financial, social, and environmental consequences, this relatively new method of assessment is called Triple Bottom Line Analysis.

Quantifying the value of social and environmental damages is much more challenging than developing the cost estimates for replacing damaged equipment. For example, how does one determine the cost of damage to water ecosystems from sewage, the loss of wildlife and plant matter, and the loss of recreational uses of these ecosystems? How can we quantify the cost of health impairments in New Yorkers exposed to sewage: the medication, the sick leave from work, and the stress that results?

Answering these questions with monetary value is complex. As such, during the Risk Analysis, the environmental and social costs of flood damage at each wastewater facility were analyzed from a qualitative perspective using various metrics. DEP anticipates using these metrics within the broader set of criteria to inform implementation schedules and prioritization of capital upgrades for wastewater infrastructure.

More specifically, since water quality in New York City's waterways is highly important to the environment and public health, during the study DEP looked at each wastewater treatment plant and determined what level of impact it might have on nearby bathing beaches. Those treatment plants that can heavily affect bathing beaches were deemed higher priority for adaptation measures.

Pumping stations were prioritized based on operational, environmental, social, and financial metrics. These metrics included historical flooding frequency, proximity to beaches and sensitive waterbodies, tributary area population, facility size, number of critical facilities (hospitals, schools, etc.) potentially affected by failure of the wastewater infrastructure, and whether the facility is scheduled for improvements in DEP's 10-year capital plan.

Adaptation Analysis

For the Adaptation Analysis, a number of adaptation strategies were selected through a broad literature review of strategies in use or being considered in municipalities around the world to harden infrastructure. The strategies that were determined to be most applicable to New York City wastewater facilities included sealing a building with watertight windows and doors, elevating equipment, making pumps submersible, encasing electrical equipment in watertight casings, constructing a static barrier across doors and other access ways, temporary sandbagging, and providing backup power generation to pumping stations where feasible (wastewater treatment plants are already equipped with backup power). The purpose of these strategies is to prevent damage during a flood event and to minimize the recovery time needed to reestablish normal operations. It was assumed that any strategy would need to be operated and maintained for 50 years.

Each strategy has advantages and disadvantages associated with cost, logistics of implementation, effectiveness, and failure potential. The failure potential is the probability that the strategy will fail during a flood event, as estimated from manufacturer details, site observations, and engineering judgment. The resiliency level and failure potential are directly related — the higher the resiliency level, the better the strategy for protecting infrastructure during a flood event and the lower the failure potential. Table 2 summarizes the resiliency level, failure potential, and explanation of the residual risk for the adaptation strategies considered in this study.

The failure potential was a key quantitative metric used to select a recommended strategy for each at-risk plant location and pumping station. The strategy recommendations were also based on feasibility, the importance of the infrastructure in a location, and a cost-risk analysis. Feasibility was established during the site visits, when it was easy to see whether certain strategies could be implemented given site specific configurations and conditions.

For locations containing important infrastructure needed for the plant to meet basic (primary) treatment requirements, the feasible strategy with the lowest failure potential was recommended. As a result, flood-proofing and elevating equipment were often recommended for these locations. For instances where all critical infrastructure could not be elevated or flood-proofed due to site or infrastructure constraints, a second strategy was recommended to block flood pathways into the at-risk location. As a result, in many cases the cost of protecting these primary locations was high since multiple strategies were recommended to increase redundancy; however, since the infrastructure being protected serves such a pivotal role in protecting the environment and public health, the non-monetary benefits (social and environmental) outweigh the monetary costs.

Strategy selection for locations which contained pumps, motors, and electrical equipment that are not essential to meeting basic permit requirements were required to be cost-effective. Strategy selection for these locations was therefore based on feasibility and return on investment. To determine

Table 2: Adaptation Strategies

which strategy was most cost-effective, the cost of implementing and maintaining any strategy was compared to the anticipated benefit of implementing that strategy in terms of the resulting damage that would be avoided. The anticipated value of damage avoided accounts for the resiliency level of the strategy and includes the value of at-risk infrastructure in the location as estimated in the Risk Analysis. Future storms and surges are associated with a probability of occurrence based on historical storms and the likelihood that any storm will occur during any given year. Naturally, the bigger the surge, the less likely it is to occur in any given year; thus, the 100-year flood has a 1 percent chance of occurring in any given year and a 2-year flood event has a 50 percent chance of occurring in any given year.

The anticipated value of damage avoided also depends on the elevation of the location and how frequently surges are likely to reach that elevation. Certain low-lying locations are more likely to be frequently flooded over 50 years, so anticipated damage may be multiple times the value of at-risk infrastructure (as it may need to be replaced several times). Likewise implementing an adaptation strategy at these locations can protect the equipment through multiple floods, so the anticipated damage avoided may be very high over 50 years. Given that the benefits are higher than the cost of implementation, the strategy would be recommended due to its good return on investment.

In contrast, locations at high elevations may only be affected by very large storms such as the 100-year flood, which tend to occur infrequently. If strategies are implemented at these locations, they may protect against a surge that may or may not occur in the next 50 years. Therefore, the expected risk avoided at such locations will be much lower. If the risk avoided is lower than the cost to implement the strategy, the adaptation measure will not have a good expected return on investment, and would not be recommended.

An understanding of expected damage avoided provides insight into why some locations do not warrant protection at this time. These locations were often at higher elevations that would not be flooded frequently, and often contained fewer pieces of equipment, that were typically not critical to meeting primary treatment requirements. Therefore, the cost to protect a building by sealing doors or constructing a barrier could not be justified economically for these locations.

Programmatic Solutions

To ensure continued progress towards more resilient wastewater infrastructure, and to ensure that the resiliency concepts developed during this study are translated into feasible projects to harden facilities, DEP has established a number of programmatic steps which will be executed in the next few years.

- Maintain a portfolio of “shovel ready” projects that can be further developed when funding opportunities arise or when potentially at-risk assets are due for maintenance or replacement;
- Incorporate climate change and extreme weather considerations in risk assessment exercises designed to allocate funding and prioritize capital projects;
- Revise engineering design standards to accommodate anticipated increases in sea level and storm intensity;
- Include critical flood elevations in asset management databases; place storm surge guidance in visible locations within the wastewater treatment plants; and refine emergency response plans to improve disaster preparedness and recovery based on risk assessment and feedback from operating staff.

With the proper institutional mechanisms in place, DEP will be at the forefront of climate-resilient infrastructure planning, and will be able to make informed decisions about wastewater infrastructure upgrades and emergency response.

WARDS ISLAND WASTEWATER TREATMENT PLANT, MANHATTAN, NY

CHAPTER 2: WASTEWATER TREATMENT PLANTS

The New York City Department of Environmental Protection (DEP) own and operates 14 wastewater treatment plants. These facilities are highly complex, with a number of different treatment processes that collectively remove between 85 and 95 percent of pollutants in the 1.3 billion gallons of wastewater generated in New York City each day. Treatment plants keep waterways and bathing beaches clean and are fundamental to protecting the environment and public health. As such, DEP is committed to ensuring their continued performance and reliability.

One of DEP's priorities in the coming years will be hardening its wastewater infrastructure to increase resiliency against flood damage. Many of the City's wastewater treatment plants are located within close proximity to the waterfront and are at risk from flooding, as was evident during Hurricane Sandy. Given that this risk is likely to increase over time with sea level rise, DEP performed the 2013 Climate Risk Assessment and Adaptation Study to identify treatment plant risks and protective measures which will reduce flood damage and the time needed to restore normal operating conditions following a flood event.

The study revealed that all 14 wastewater treatment plants are at risk of flood damage during the critical flood event (the 100-year flood plus 30 inches of sea level rise), totaling over $900 million of at-risk infrastructure. The recommended protective measures, totaling $187 million in improvements, are also costly but will significantly reduce risk to the equipment, environment, and public health.

DEP plans to implement the protective measures systematically through capital projects in the coming years, with added consideration given to those plants whose failures will most likely affect bathing beaches. This chapter provides additional information regarding individual wastewater treatment plants, their risks, and which measures DEP may implement in the future to protect them.

Wastewater Treatment Plants

Wastewater Treatment Plant Estimated Costs