WARDS ISLAND WASTEWATER TREATMENT PLANT, MANHATTAN, NY

CHAPTER 2: WASTEWATER TREATMENT PLANTS

Introduction

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.

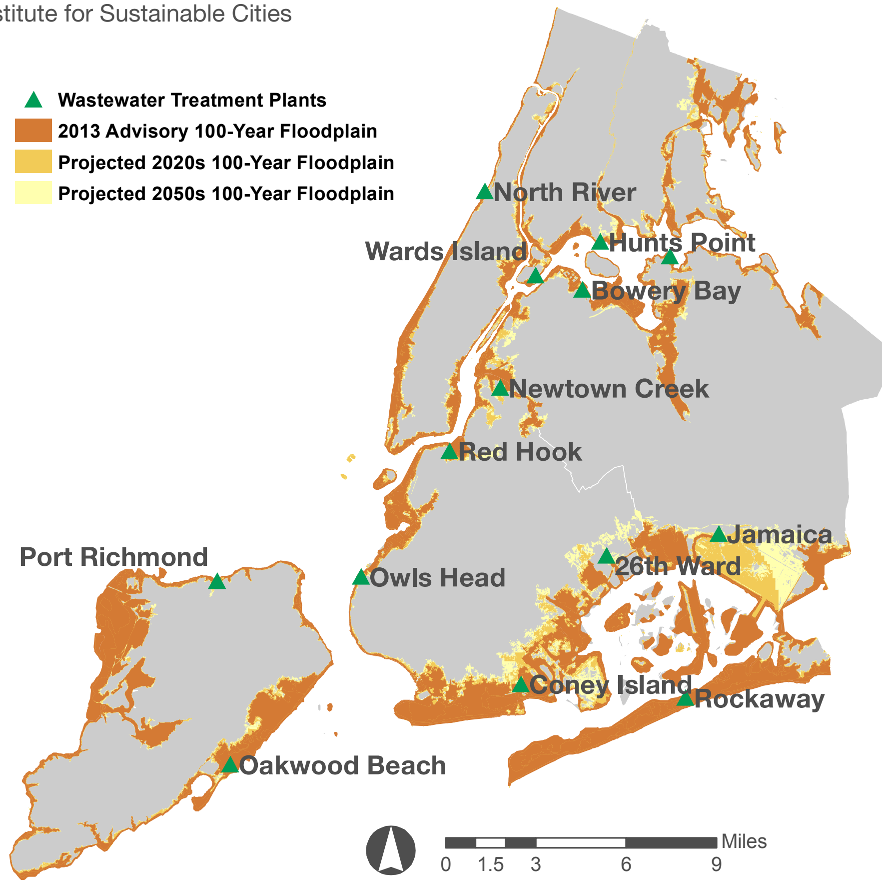
One of DEP's priorities in the coming years will be hardening its wastewater infrastructure to increase resiliency against flood damage. Many of the City's wastewater treatment plants are located within close proximity to the waterfront and are at risk from flooding, as was evident during Hurricane Sandy. 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

Source: FEMA; CUNY Institute for Sustainable Cities



Wastewater Treatment Plant Estimated Costs

Wastewater Treatment Plant	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]
Wastewater Treatment Plants with Greatest Potential for Affecting Beaches			
26th Ward	$8.18	$82.42	$79.45
Coney Island	$15.48	$84.95	$349.81
Hunts Point	$24.28	$201.36	$246.44
Jamaica	$0.21	$1.70	$0.46
Oakwood Beach	$5.33	$20.97	$44.28
Rockaway	$15.12	$49.28	$198.10
Subtotal	**$68.61**	**$440.67**	**$918.55**
All Other Wastewater Treatment Plants			
Bowery Bay	$40.26	$112.60	$69.03
Newtown Creek	$8.85	$28.79	$9.13
North River	$17.15	$94.10	$445.79
Owls Head	$11.01	$48.41	$158.81
Port Richmond	$10.39	$54.85	$60.36
Red Hook	$18.56	$67.38	$24.95
Tallman Island	$11.02	$45.18	$32.80
Wards Island	$1.48	$8.73	$40.46
Subtotal	**$118.74**	**$460.04**	**$841.32**
Wastewater Treatment Plants Citywide	**$187 M**	**$901 M**	**$1,760 M**

26th Ward Wastewater Treatment Plant

PLANT DESCRIPTION

The 26th Ward Wastewater Treatment Plant is located on a 57.3 acre site at the intersection of Flatlands and Van Siclen Avenues in southeastern Brooklyn, Community District 5. The plant abuts Flatlands Avenue on the north, Van Siclen Avenue to the west and Shore Parkway to the south; Hendrix Creek separates the site from the land to the east. General plant characteristics for 26th Ward can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +13.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.4 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	85
Maximum Wet Weather Flow (MGD)	170
Number of Residents Served	283,428
Discharge Waterbody	Jamaica Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+13.5 ft NAVD88 (+12.9 ft Brooklyn Sewer Datum)
Hurricane Sandy Flood Elevation	+12.6 ft NAVD88 (+12.0 ft Brooklyn Sewer Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	Yes

FEMA Flood Zones near 26th Ward Wastewater Treatment Plant

2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Electrical conduits in the basement of the Main Building provided a pathway for floodwaters during Hurricane Sandy.

A basement access way leading to the Primary Sludge Gallery would be a flood pathway during the critical flood event.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at 26th Ward. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Basement access ways with windows, low-lying doorways, and electrical conduits represent the most common flood pathways found on site. In addition, since the plant has a relatively flat terrain, several areas may be flooded by up to 5 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment that are needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 1,239 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

In particular, the Digester and Thickener Galleries contain numerous large sludge pumps below ground that would be at risk via a number of doorways and the tunnel system which connects the galleries to the at-risk Chlorination Building. During Hurricane Sandy, these galleries experienced several feet of flooding, and warrant additional protection.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power, would be approximately $82.4 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at 26th Ward. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements, and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over the 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

For many of the locations at 26th Ward containing at-risk, large pumping operations below ground, protecting flood pathways into the basements and tunnel system with barriers, sandbags, or watertight doors was recommended.

Furthermore, in locations such as the Primary and Return Sludge Galleries which contain critical pumps needed for basic treatment, additional protection is recommended. Since these pumps are large and the necessary overhead space is limited at these locations, elevating these pumps would not be realistic. Instead, it is recommended that the pumps be replaced with submersible pumps, preferably at the end of their life cycle to reduce costs.

In total, the cost to implement all recommended strategies at 26th Ward is $8.2 million. While this cost is high, the potential damage cost that a large surge may impose totals $82.4 million. Furthermore, since 26th Ward

*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $79.5 million, which is almost ten times the cost of implementation.

This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering that they would also minimize service disruptions in Brooklyn during flood events, reduce sewage bypasses, and protect public health.

Table B: 26th Ward Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Air Process Gallery	Sandbag	$132,000	$724,000	$369,000	Moderate-Low
BNR Building	No Action Required	$0	$139,000	$0	No Protection
Chemical Handling	No Action Required	$0	$49,000	$0	No Protection
Chlorination Building (Old)	Flood-proof Equipment and Construct Barrier	$1,201,000	$1,093,000	$3,132,000	High
Chlorine Contact Tanks	Elevate Equipment	$14,000	$270,000	$90,000	Very High
Dewatering Building	Sandbag	$697,000	$43,567,000	$31,399,000	Moderate-Low
Digester Gallery	Sandbag	$105,000	$753,000	$654,000	Moderate-Low
Final Settling Tanks	No Action Required	$0	$2,294,000	$0	No Protection
Fire Pump Station	No Action Required	$0	$335,000	$0	No Protection
Instrument Maintenance	No Action Required	$0	$604,000	$0	No Protection
Main Building	Flood-proof Equipment and Seal Building	$1,879,000	$11,815,000	$9,268,000	Moderate
Primary Sludge Gallery	Flood-proof Equipment and Construct Barrier	$3,500,000	$5,083,000	$1,660,000	High
Return Sludge Gallery	Flood-proof Equipment and Seal Building	$287,000	$3,426,000	$1,064,000	Moderate
Sludge Transfer	Sandbag	$158,000	$6,092,000	$2,274,000	Moderate-Low
Substation Building	No Action Required	$0	$46,000	$0	No Protection
Thickener Gallery	Construct Barrier	$212,000	$6,044,000	$29,544,000	High
Waste Gas Burners	No Action Required	$0	$86,000	$0	No Protection
Total for All 17 At-Risk Locations		**$ 8.2 M**	**$ 82.4 M**	**$ 79.5 M**	

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

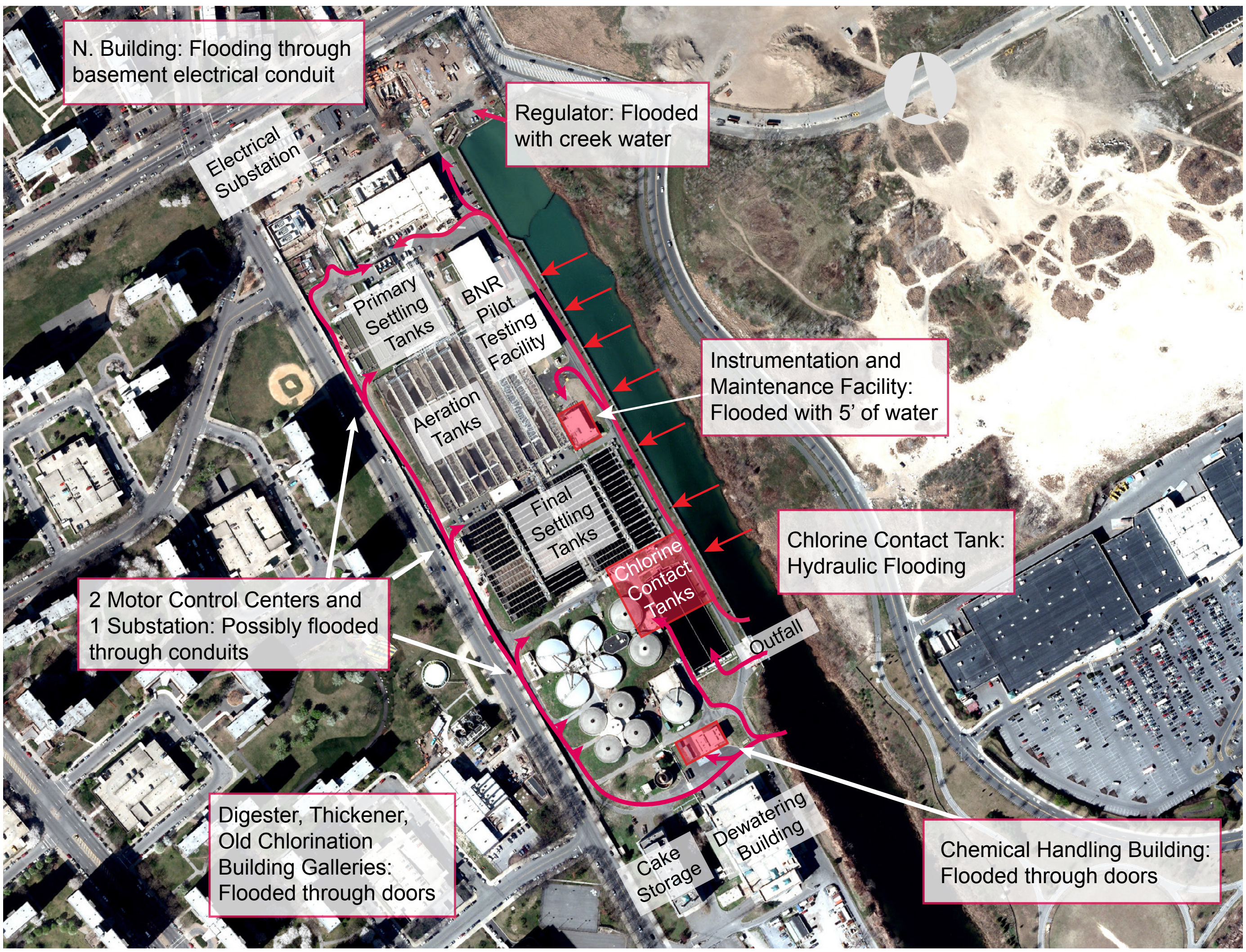
HURRICANE SANDY IMPACTS

26th Ward experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters from Hendrix Creek overtopped the plant walls and backed up into the plant through the outfall discharge pipe. The backflow of water through the plant's outfall caused water to build up in the adjacent Chlorine Contact Tanks, eventually causing them to overflow.

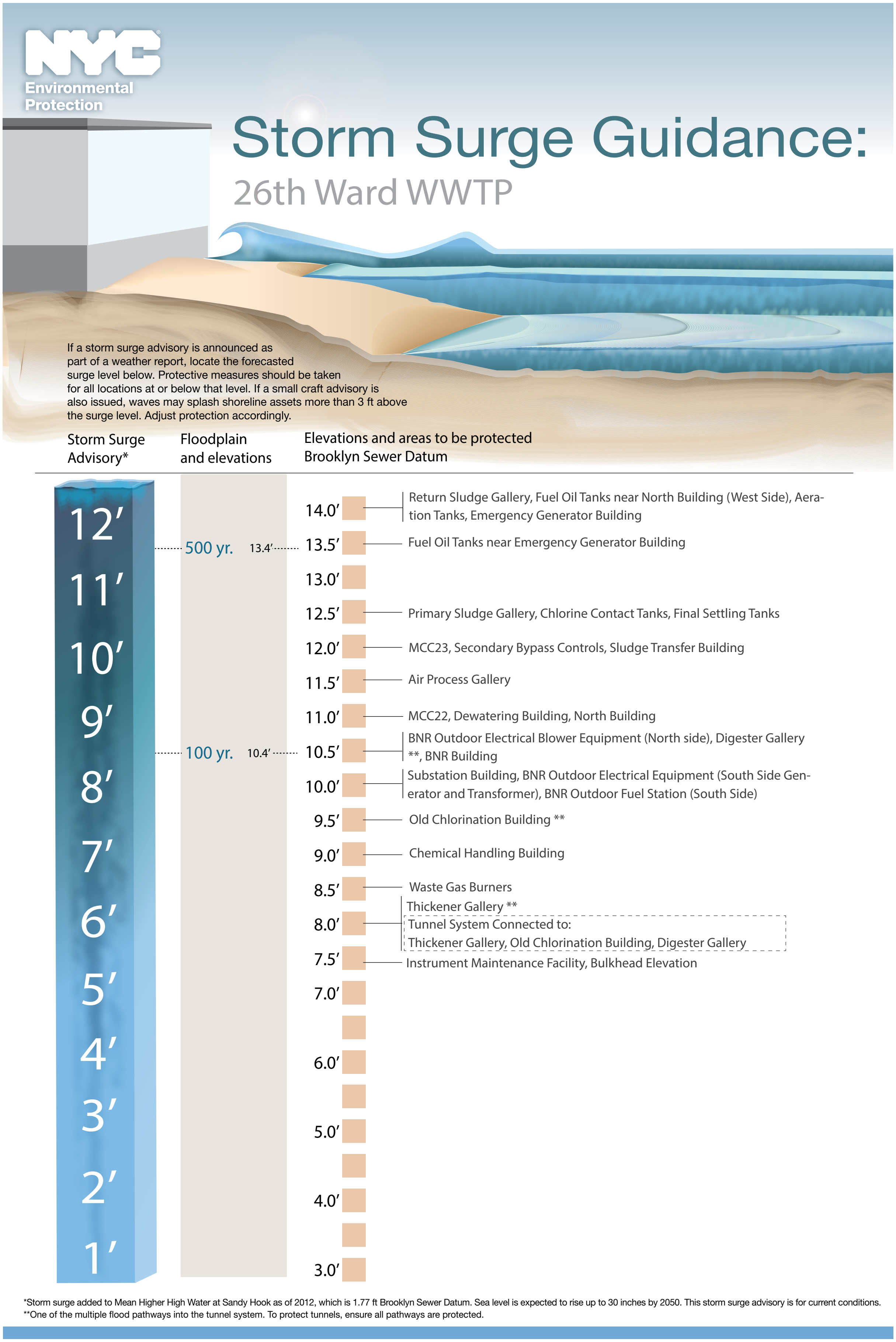
Storm surge also overtopped the plant sea wall and traveled via the West and East Road, flooding a number of plant locations and limiting plant access during the storm. Flooding occurred in the Digester and Thickener Galleries, Old Chlorination Building, Return Activated Sludge Gallery, Chemical Handling Building, electrical stations along West Road, and in the parking lot just north of the Dewatering Building. In addition, the motor control center in the Instrumentation and Maintenance Facility was flooded. The plant dock was also damaged.

Fortunately, overland floodwater did not reach any of the exterior doors of the Main Building, where raw sewage is initially pumped into the plant for treatment. However, the basement experienced flooding through an electrical channel. In all, none of the main sewage pumps were damaged, and the plant was able to continue pumping and performing basic wastewater treatment during the storm.

Plant staff worked actively before, during, and after the storm to protect the plant and bring it back to normal operation. Electrical power was proactively shut off throughout the plant during the storm surge, except in the North Building, to prevent short circuiting as the water level continued to rise. After the storm, all flooded areas were dewatered and flooded motors and electrical equipment were cleaned, dried, and repaired or replaced depending on their condition.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Bowery Bay Wastewater Treatment Plant

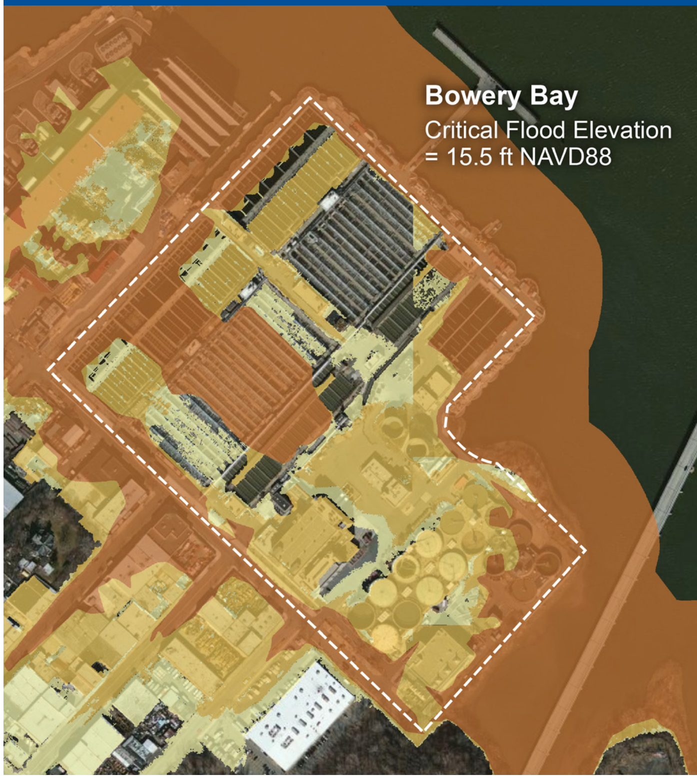
PLANT DESCRIPTION

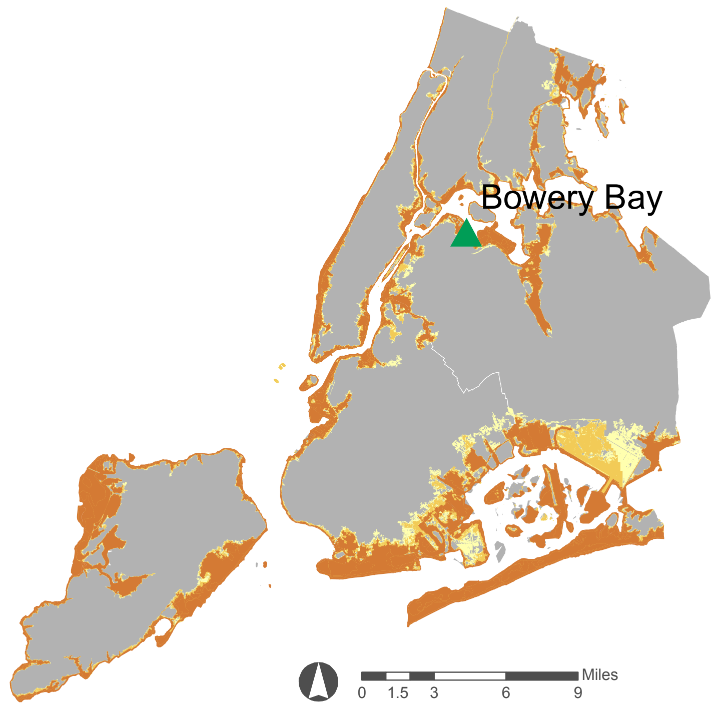
The Bowery Bay Wastewater Treatment Plant is located on a 34.6 acre site along Berrian Boulevard in the north-western section of Queens, Community District 1. The plant abuts the Rikers Island Channel to the north and east, Berrian Boulevard to the south and Steinway Street to the west. General plant characteristics for Bowery Bay can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +15.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +8.5 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	150
Maximum Wet Weather Flow (MGD)	300
Number of Residents Served	848,328
Discharge Waterbody	Upper East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+15.5 ft NAVD88 (+13.9 ft Queens Datum)
Hurricane Sandy Flood Elevation	+11.6 ft NAVD88 (+10.0 ft Queens Datum)
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Bowery Bay Wastewater Treatment Plant



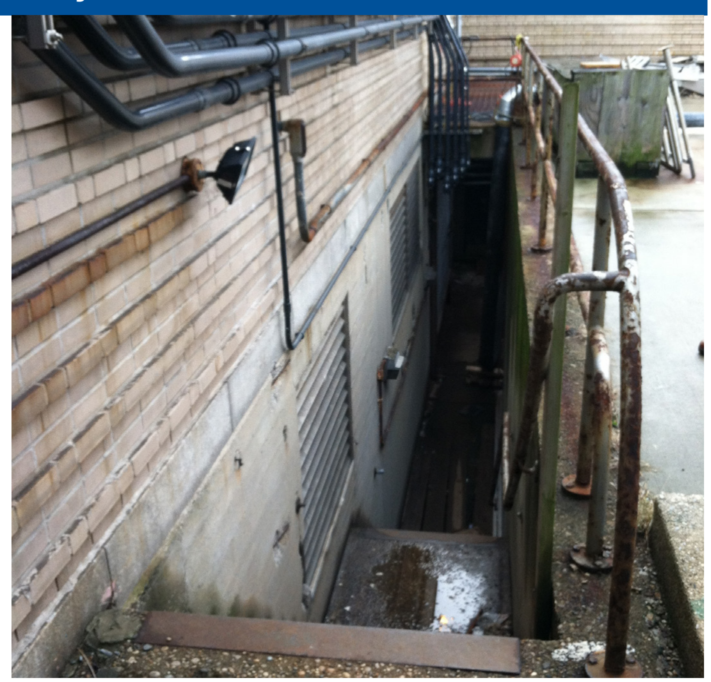


2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Typical hatch at grade level leading to tunnel system



Stairway at grade leading to the Main Building

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Bowery Bay. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation.

Since the plant has a relatively flat terrain, several areas may be flooded by up to 5 feet of water during the critical flood event. In addition, there is an extensive underground tunnel system that connects several locations and can convey water throughout the plant if not properly protected.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 1,215 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $112.6 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Bowery Bay. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the areas at Bowery Bay contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen that protect openings into the plant areas. In addition, since Bowery Bay is susceptible to flood damage from an interconnected tunnel system, sealing doors and hatches leading to the tunnel is recommended. Providing more robust coverings and seals would greatly reduce this risk and prevent floodwaters from entering the tunnel system, traveling throughout the plant, and damaging target pieces of equipment in basements.

In total, the cost to implement all recommended strategies at Bowery Bay is $40.3 million. While this cost is high, the potential damage cost that a large surge may impose totals $112.6 million. Furthermore, since Bowery Bay is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $69 million, which is nearly twice the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering that they would also minimize service disruptions in Queens during flood events, reduce sewage bypasses, and protect public health.

*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: Bowery Bay Adaptation Strategy Recommendations

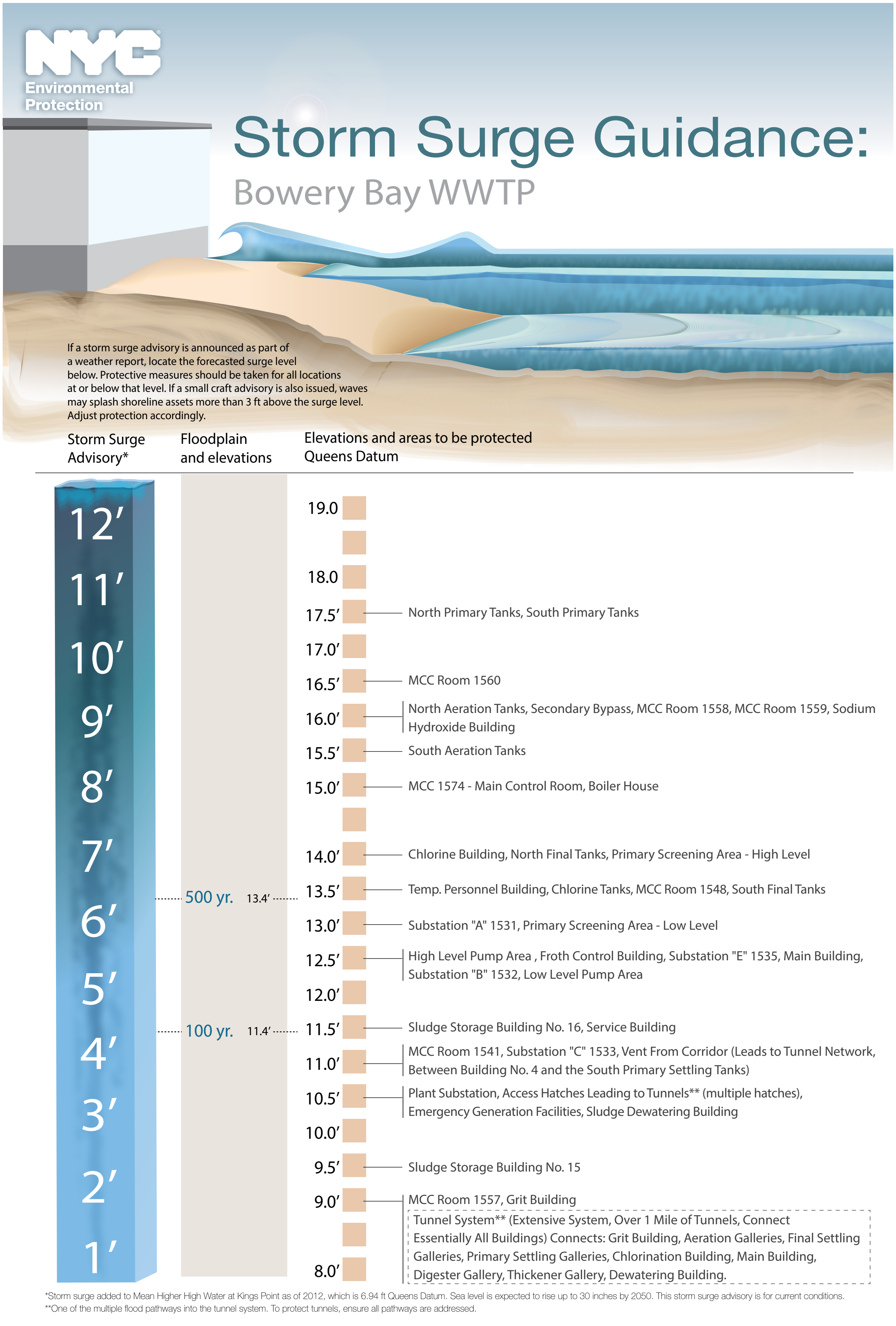
Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Chlorine Tanks	Elevate Equipment	$236,000	$446,000	$124,000	Very High
Emergency Generation Facilities	Elevate Equipment and Construct Barrier	$964,000	$5,940,000	$5,644,000	Very High
Grit Building	Seal Building	$557,000	$3,318,000	$6,683,000	Moderate
Main Building	Construct Barrier	$1,427,000	$37,313,000	$12,761,000	High
MCC Room 1541	Sandbag	$132,000	$902,000	$575,000	Moderate-Low
MCC Room 1548	Sandbag	$132,000	$902,000	$216,000	Moderate-Low
Plant Substation	Elevate Equipment and Construct Barrier	$1,150,000	$7,494,000	$7,149,000	Very High
Primary Screening Area - Lower Level	Flood-proof Equipment and Sandbag	$314,000	$405,000	$121,000	Moderate
Service Building	Elevate Equipment and Sandbag	$791,000	$742,000	$372,000	Moderate
Sludge Dewatering Building	Flood-proof and Elevate and Construct Barrier	$3,419,000	$15,315,000	$12,641,000	High
Sludge Storage Building No. 15	No Action Required	$0	$861,000	$0	No Protection
South Final Tanks	No Action Required	$0	$3,966,000	$0	No Protection
Substation "A" 1531	Elevate Equipment and Seal Building	$563,000	$3,131,000	$947,000	High
Substation "B" 1532	Elevate Equipment and Seal Building	$563,000	$3,131,000	$1,221,000	High
Substation "C" 1533	Elevate Equipment and Seal Building	$563,000	$3,131,000	$2,122,000	High
Substation "E" 1535	Elevate Equipment and Seal Building	$535,000	$3,131,000	$1,219,000	High
Tunnels And Corridors	Flood-proof and Elevate and Seal Building	$28,918,000	$21,263,000	$17,230,000	High
Digester Gallery	No Action Required	$0	$768,000	$0	No Protection
Fire Pump House	No Action Required	$0	$446,000	$0	No Protection
Total for All 19 At-Risk Locations		**$ 40.3 M**	**$ 112.6 M**	**$ 69.0 M**	

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

HURRICANE SANDY IMPACTS

Bowery Bay experienced minor flooding as a result of Hurricane Sandy, as depicted in the figure below. During the peak of the storm, water overtopped the plant bulkhead and northern access road which parallels the Rikers Island Channel. However, the water from the storm surge stopped just short of entering into any of the plant's process or electrical buildings. The storm surge caused minor damage to several temporary contractor office trailers, several storage sheds, and the barge dock. Plant staff took precautions ahead of the storm, which included sandbagging buildings and other routine emergency preparation procedures outlined in the plant's Wet Weather Operations Plan. The plant maintained electrical power and continued normal wet weather operation throughout the storm.

Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Coney Island Wastewater Treatment Plant

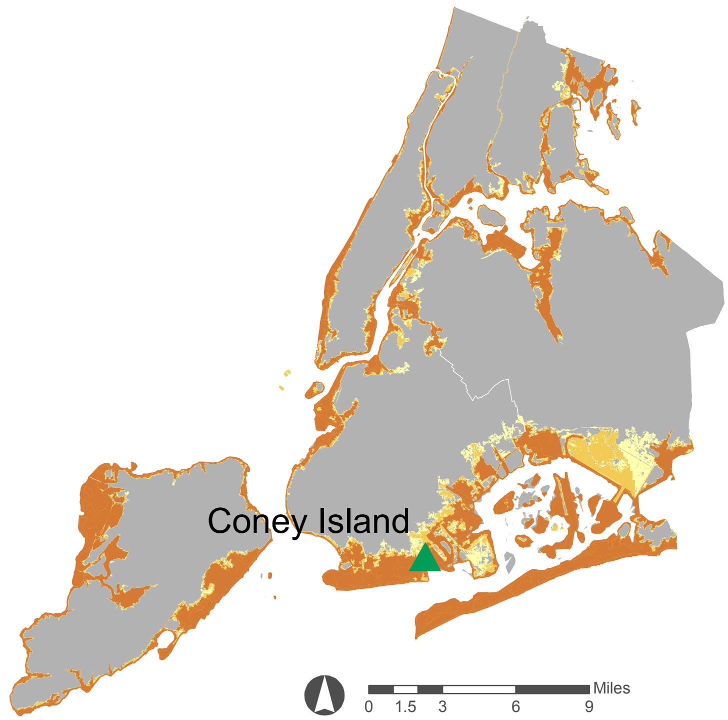
PLANT DESCRIPTION

The Coney Island Wastewater Treatment Plant is located on a 30 acre site along Knapp Street in south central Brooklyn, Community District 15. The plant abuts Avenue Y to the north, Coyle Street to the west, Voorhies Avenue to the south and Rockaway Inlet/Shell Bank Creek to the east. General plant characteristics for Coney Island can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +15.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.4 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	No
Design Dry Weather Flow (MGD)	110
Maximum Wet Weather Flow (MGD)	220
Number of Residents Served	596,326
Discharge Waterbody	Jamaica Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+15.5 ft NAVD88 (+14.02 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Elevation	+10.1 ft NAVD88 (+8.62 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	Yes

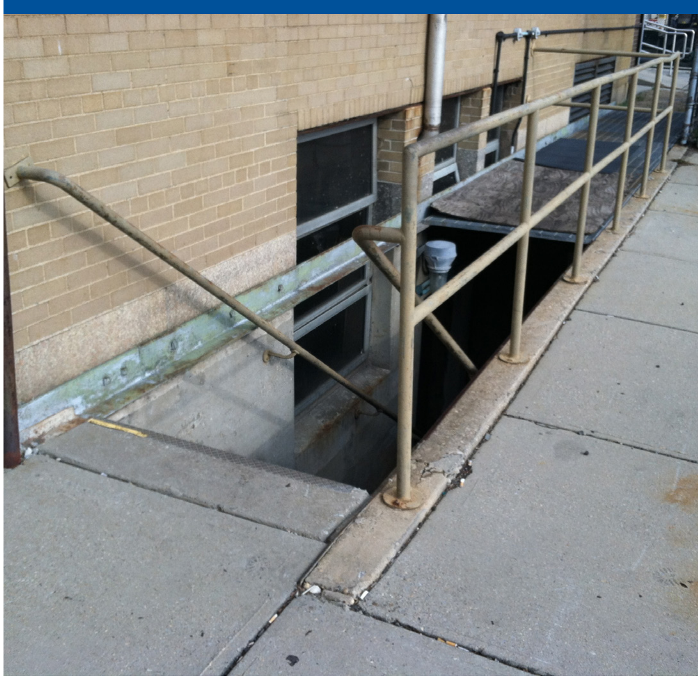
FEMA Flood Zones near Coney Island Wastewater Treatment Plant



2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways



Access stairway to the basement and gas booster room of the Pump and Power Building

Sinkholes developed near the Sludge Storage Area after Hurricane Sandy. Groundwater may present a flood risk during the next critical flood event

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Coney Island. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain, most plant buildings would be flooded by three or more feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 1,204 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Of particular note, the Main Electrical Substation, which provides power to a significant portion of the plant; the main sewage pumps in the Pump and Blower Building which bring sewage into the plant; and the tunnel system which connects numerous buildings on site, are all at risk. Fortunately, most of the tanks would be protected from direct inundation, but may spill over as water backs up into the plant from the outfall during a large flood.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $84.9 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Coney Island. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Given that Coney Island is susceptible to flood damage from an interconnected tunnel system (Tunnel A), constructing static barriers around grates and providing stop logs on doorways leading to the tunnel is recommended to minimize spreading of floodwater.

Locations containing equipment critical for primary treatment operations, particularly the main pumps, screens, and disinfection equipment, also warrant protective measures. Since most of the equipment is relatively large and below ground, elevating equipment from this underground area is challenging. Flood-proofing the equipment is recommended instead, and in locations where not all infrastructure can be flood-proofed, additional strategies which block flood pathways can provide added levels of protection.

Finally, key outdoor electrical components that are below the critical flood elevation should either be elevated or have a barrier constructed around them. If flood waters penetrate these areas, power should be turned off.

*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Primary treatment process equipment can be operated with emergency generators as was done during Hurricane Sandy.

In total, the cost to implement all recommended strategies at Coney Island is $15.5 million. While this cost is high, the potential damage cost that a large surge may impose totals $84.9 million. Furthermore, since Coney Island is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $349.8 million, which is 23 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering that they would also minimize service disruptions in Brooklyn during flood events, reduce sewage bypasses, and protect public health.

Table B: Coney Island Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Administration Building	No Action Required	$0	$1,109,000	$0	No Protection
Digesters	Seal Building	$622,000	$8,138,000	$37,692,000	Moderate
Distributed Equpment	No Action Required	$0	$265,000	$0	No Protection
Grit Building	Flood-proof Equipment and Construct Barrier	$2,685,000	$5,133,000	$25,341,000	High
Hypo Building	Flood-proof Equipment and Seal Building	$1,027,000	$1,524,000	$6,766,000	Moderate
IRE Building/Storage Garage	No Action Required	$0	$81,000	$0	No Protection
Main Electrical Substation	Construct Barrier	$617,000	$10,771,000	$52,648,000	High
Odor Control Building	Seal Building	$594,000	$2,892,000	$12,519,000	Moderate
Old Power House	No Action Required	$0	$306,000	$0	No Protection
Plant Maintenance Building	No Action Required	$0	$318,000	$0	No Protection
Primary Screening Building	Flood-proof Equipment and Construct Barrier	$3,702,000	$4,579,000	$9,319,000	High
Pump and Power Building	Flood-proof Equipment and Construct Barrier	$4,675,000	$18,853,000	$86,788,000	High
Sludge Storage Building	Construct Barrier	$212,000	$1,112,000	$5,434,000	High
Thickener Building	Construct Barrier	$482,000	$22,783,000	$111,378,000	High
Tunnel A	Flood-proof Equipment and Construct Barrier	$409,000	$251,000	$1,221,000	High
Distributed Power	Elevate Equipment	$460,000	$6,833,000	$706,100	Low
Total for All 16 At-Risk Locations		**$ 15.5 M**	**$ 84.9 M**	**$ 349.8 M**	

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

HURRICANE SANDY IMPACTS

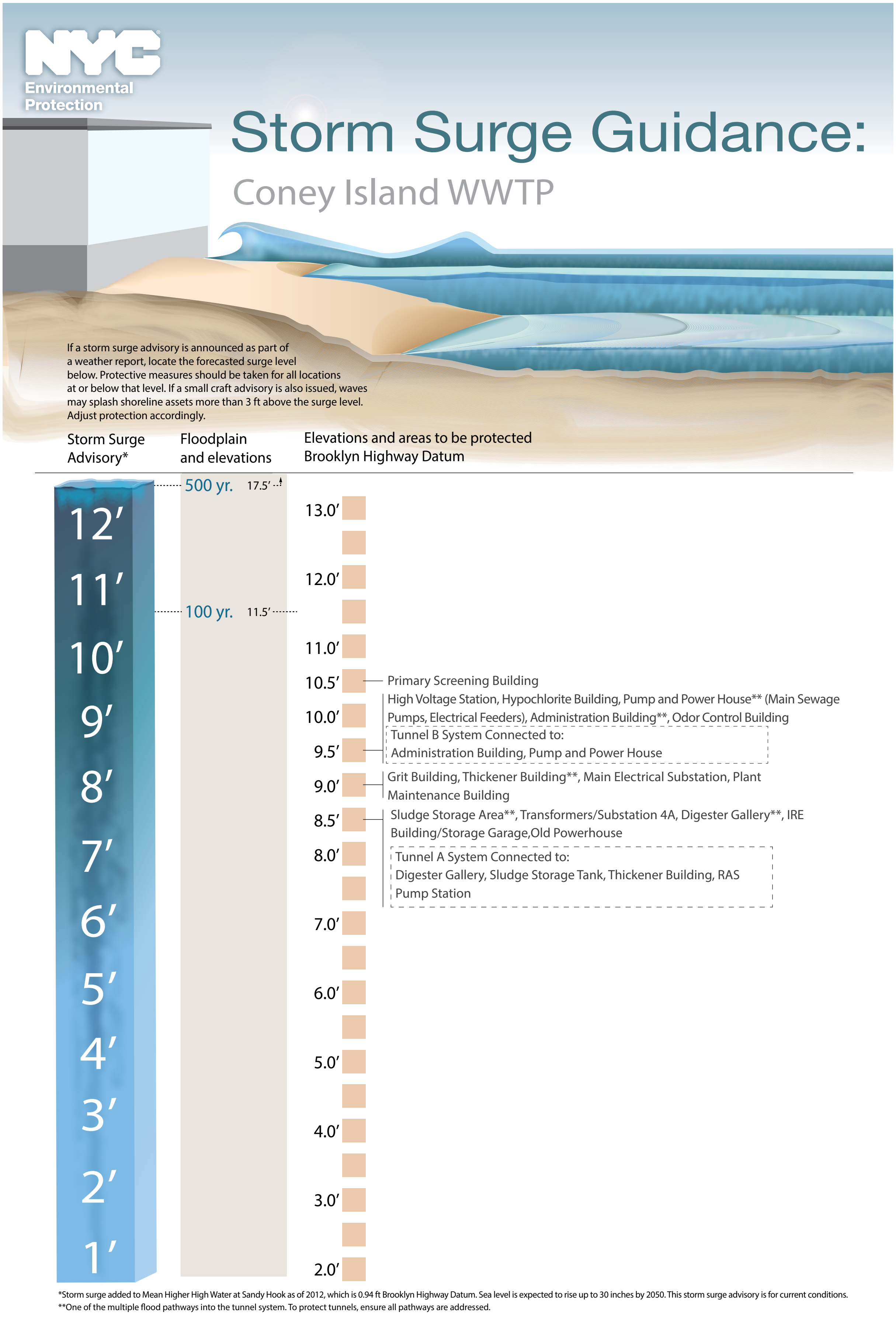
Coney Island experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, water from the adjacent Rockaway Inlet/Shell Bank Creek overtopped the banks behind the Sludge and Digester building complex, flooded Knapp Street and flowed through the main wastewater treatment plant parking lot and into low-lying buildings. There was extensive damage to the Storage Garage, located at grade level, which contained spare parts and other equipment. Over 1 foot of water filled the lower levels of the Sludge Storage/Digester Gallery, the Pump and Power House Building, and the Primary Screening Building, compromising mechanical and electrical equipment. Water spilled out of the Chlorine Contact Tanks and a tunnel which spans Knapp Street, connecting the Sludge Storage/Digester Gallery on the east side with the Thickener Building on the west side, also filled with water.

Three of the five main electrical feeds from Con Edison were lost during the storm event and the remaining two lines were shut down the next day for four hours. In addition, since the elevation of the plant discharge outfall was overwhelmed by the storm surge, treated wastewater backed up within the plant.

The storm event resulted in several sinkholes causing the ground around the buildings to settle. A ground penetrating radar survey performed after Hurricane Sandy revealed numerous areas in the parking lot adjacent to the Storage Garage that require geotechnical restoration.

The plant staff took precautions ahead of the storm, which included sandbagging low-lying buildings, relocating some of the portable equipment, filling chemical tanks, ensuring emergency power equipment was operational, closing certain inflow pipes to reduce inflow of combined sewage to the plant, and other procedures outlined in their Wet Weather Operations Plan. Despite the damage, the plant maintained normal wet weather operation through the storm event.

Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Hunts Point Wastewater Treatment Plant

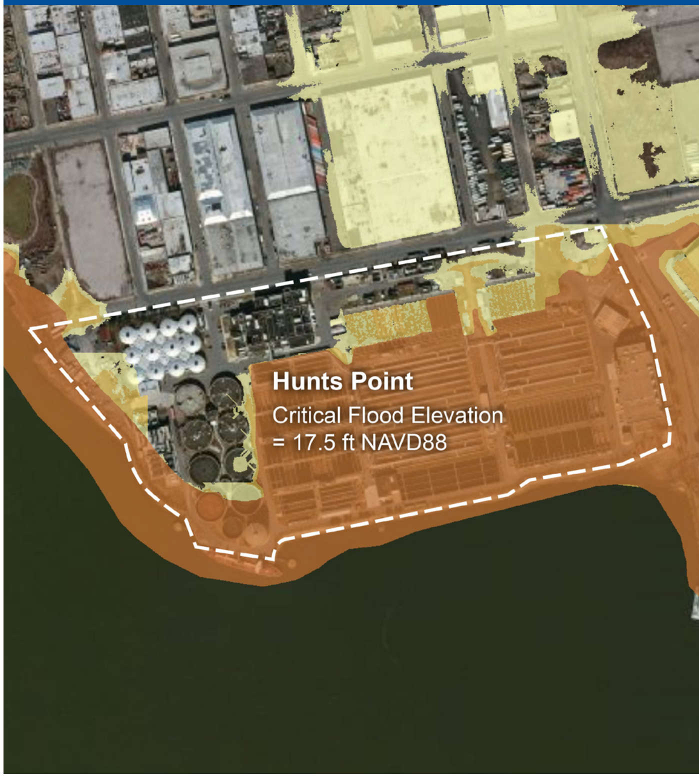
PLANT DESCRIPTION

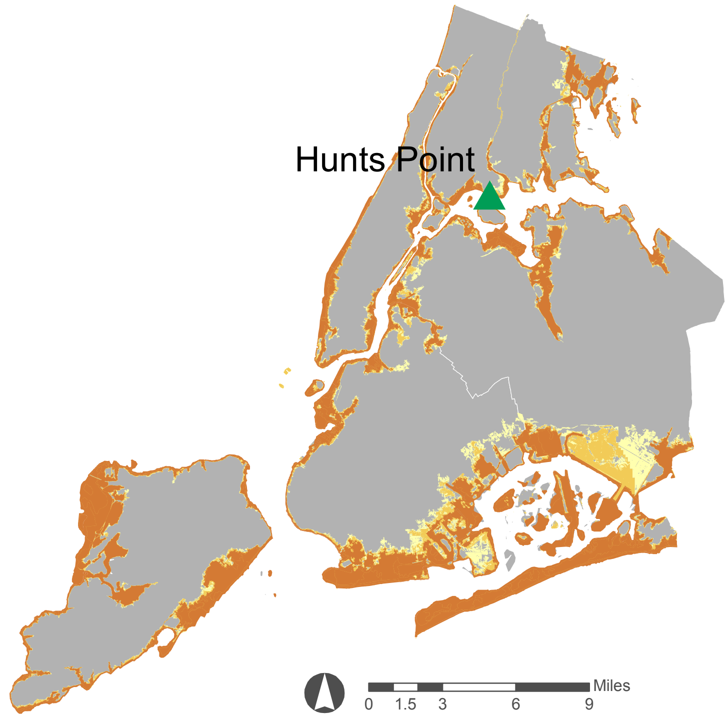
The Hunts Point Wastewater Treatment Plant is located in the Hunts Point section of the Bronx, on the shore of the upper East River. The plant abuts Ryawa Avenue on the north, Halleck Street to the east, and the East River separates the site from the land to the west and south. General plant characteristics for Hunts Point can be found in Table A.The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +17.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +8.2 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	200
Maximum Wet Weather Flow (MGD)	400
Number of Residents Served	684,569
Discharge Waterbody	Upper East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+17.5 ft NAVD88 (+16.0 ft Bronx Sewer Datum)
Hurricane Sandy Flood Elevation	+10.2 ft NAVD88 (+8.7 ft Bronx Sewer Datum)
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	Yes

FEMA Flood Zones near Hunts Point Wastewater Treatment Plant





2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

The overhead grate above the Aeration Gallery is a potential flood pathway to the sludge pumps.

Access doors to the Sludge Storage Tanks next to the East River

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Hunts Point. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since parts of the plant are situated at a relatively low elevation, a number of areas would be flooded by up to 7 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 3,782 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

The Aeration Galleries and the Electrical Substations contain some of the most expensive pieces of equipment that are at risk at the plant. The Aeration Gallery houses a series of large sludge pumps below ground, and the Electrical Sustations contain equipment used to transmit power throughout the plant. This equipment, therefore, is not only expensive to replace, but is fundamental to the plant's funcitonality.

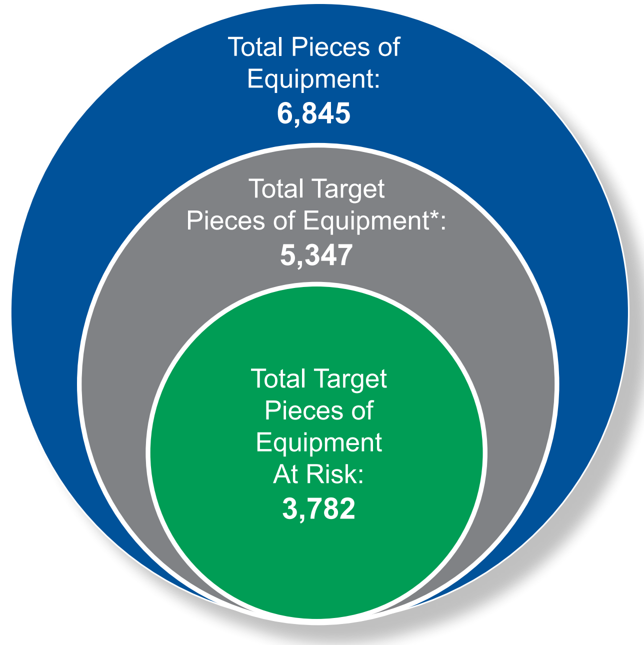
Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $201.4 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Hunts Point. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements. When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide.

In total, the cost to implement all recommended strategies is $24.3 million. While this cost is high, the potential damage cost that a large surge may impose totals $201.4 million. Furthermore, since Hunts Point is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $246.4 million, which is ten times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering that they would also minimize service disruptions during flood events, reduce sewage bypasses, and protect public health.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: Hunts Point Adaptation Strategy Recommendations

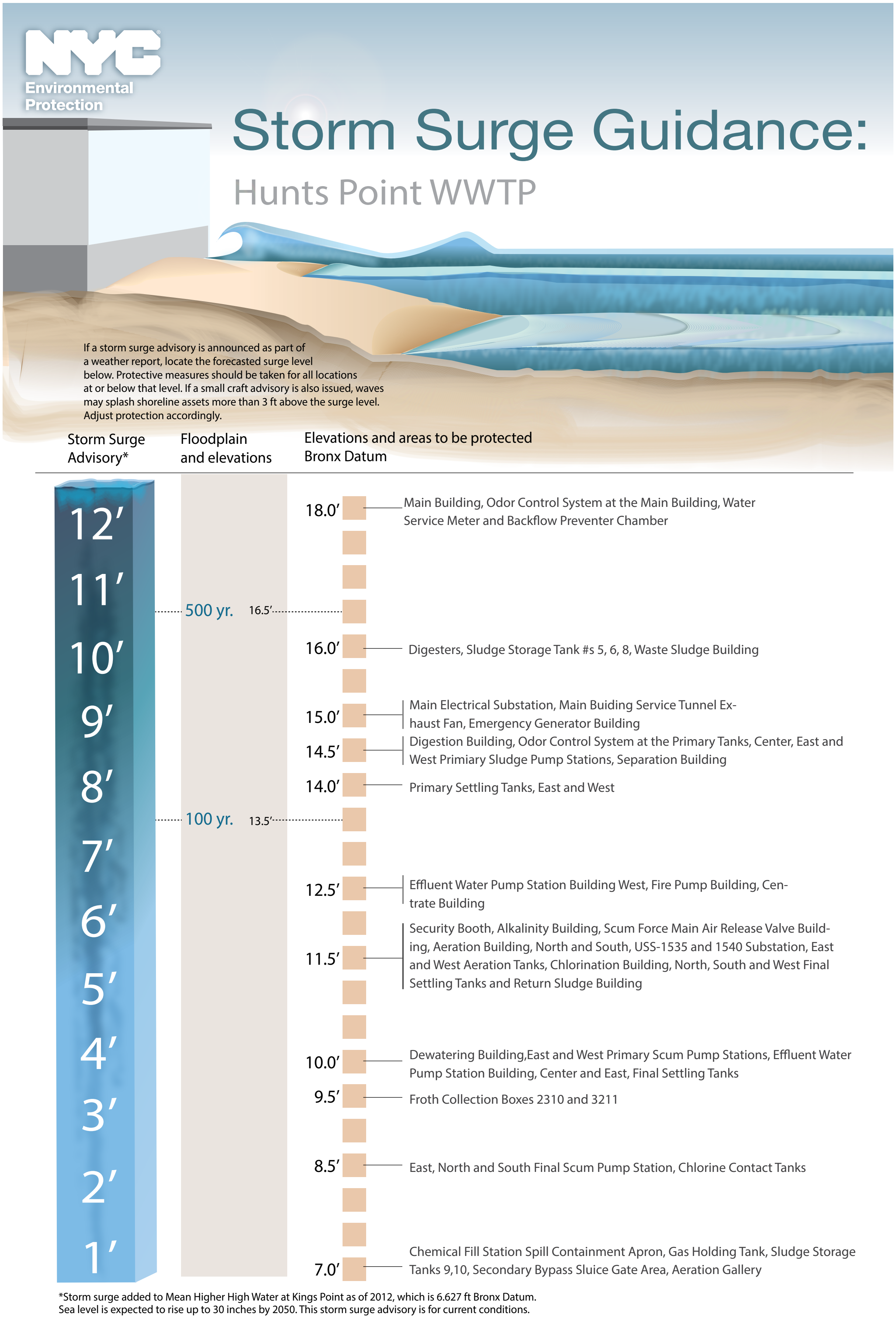
Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Aeration Building – North	Seal Building	$318,000	$1,477,000	$2,186,000	Moderate
Aeration Building – South	Seal Building	$318,000	$1,273,000	$1,887,000	Moderate
Aeration Gallery	Flood-proof Equipment and Construct Barrier	$745,000	$9,168,000	$44,980,000	High
Aeration Tank - East	Elevate Equipment	$2,036,000	$8,627,000	$13,212,000	Moderate-Low
Aeration Tank - West	Elevate Equipment	$4,363,000	$18,251,000	$28,295,000	Moderate
Alkalinity Building	Seal Control Room	$299,000	$5,398,000	$7,323,000	Moderate
Centrate Building	Sandbag	$103,000	$1,820,000	$1,255,000	Moderate-Low
Chlorination Building	Elevate Equipment	$1,636,000	$2,359,000	$4,045,000	Very High
Chlorine Contact Tank	Elevate Equipment	$142,000	$525,000	$2,700,000	Very High
Dewatering Building	Seal Building	$597,000	$42,718,000	$75,305,000	Moderate
Digestion Building	Sandbag	$103,000	$6,674,000	$2,434,000	Moderate-Low
Effluent Water Pump Station Building - Center	Elevate Equipment and Seal Building	$594,000	$1,413,000	$4,508,000	Moderate
Effluent Water Pump Station Building - East	Elevate Equipment and Construct Barrier	$1,258,000	$1,152,000	$3,953,000	High
Effluent Water PS Building – West	Elevate Equipment and Construct Barrier	$1,229,000	$1,093,000	$1,010,000	High
Final Scum Pump Station - East	Elevate Equipment and Construct Barrier	$248,000	$1,613,000	$7,906,000	High
Final Scum Pump Station - North	Elevate Equipment and Seal Building	$400,000	$1,376,000	$6,414,000	Moderate
Final Scum Pump Station - South	Seal Control Room	$269,000	$1,548,000	$7,164,000	Moderate
Final Settling Tank - East	No Action Required	$0	$1,718,000	$0	No Protection
Final Settling Tank - North	No Action Required	$0	$2,178,000	$0	No Protection
Final Settling Tank - South	No Action Required	$0	$2,264,000	$0	No Protection
Final Settling Tank - West	No Action Required	$0	$13,629,000	$0	No Protection
Fire Pump Building	No Action Required	$0	$53,000	$0	No Protection
Froth Collection Boxes 3210 and 3211	No Action Required	$0	$789,000	$0	No Protection
Gas Holding Tank	No Action Required	$0	$135,000	$0	No Protection
Main Electrical Substation	Flood-proof Equipment and Construct Barrier	$1,252,000	$54,982,000	$14,633,000	High
Primary Scum PS - East	Elevate Equipment	$1,234,000	$1,342,000	$2,883,000	Very High
Primary Scum PS - West	Elevate Equipment	$1,145,000	$1,338,000	$2,874,000	Very High
Primary Settling Tank - East	Elevate Equipment	$1,452,000	$2,481,000	$1,171,000	Moderate
Primary Settling Tank - West	Elevate Equipment	$2,835,000	$4,287,000	$2,169,000	High
Primary Sludge PS – Center	Sandbag	$102,000	$368,000	$135,000	Moderate-Low
Primary Sludge PS – East	No Action Required	$0	$58,000	$0	No Protection
Primary Sludge PS – West	No Action Required	$0	$58,000	$0	No Protection
Return Sludge Building	No Action Required	$0	$1,395,000	$0	No Protection
Separation Building	No Action Required	$0	$290,000	$0	No Protection
Sludge Storage Tanks #9, 10	No Action Required	$0	$2,103,000	$0	No Protection
USS-1535 Substation	Seal Building	$799,000	$2,692,000	$3,986,000	Moderate
USS-1540 Substation	Seal Building	$799,000	$2,714,000	$4,015,000	Moderate
Total for All 37 Locations At-Risk		**$ 24.3 M**	**$ 201.4 M**	**$ 246.4 M**	

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

HURRICANE SANDY IMPACTS

Hunts Point experienced minor flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters entered the plant from the East River. Storm surge overtopped the plant wall located along the southern shoreline and flooded the roadways. The West Effluent Water Building flooded and many electrical components, including motors, were damaged. Equipment in the storage buildings behind the South Final Settling Tanks was also damaged. The plant maintained normal wet weather treatment operation during and after the storm.

Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Jamaica Wastewater Treatment Plant

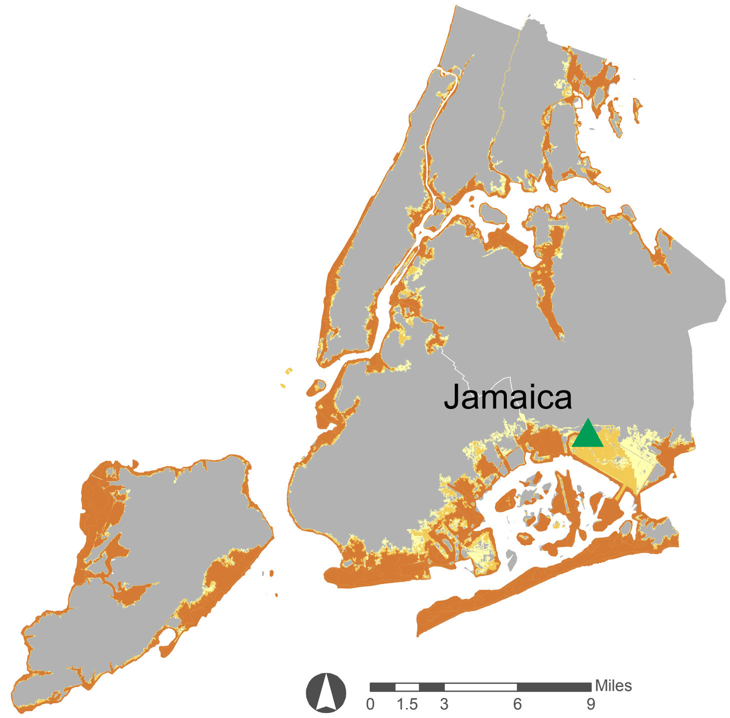
PLANT DESCRIPTION

The Jamaica Wastewater Treatment Plant is located on a 26 acre site adjacent to the western end of John F. Kennedy Airport in southwestern Queens, Community District 10. The plant is situated between the Nassau Expressway to the north, 130th Street to the west, 155th Avenue to the south and 134th Street to the east. General plant characteristics for Jamaica can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +13.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.4 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes (Not currently in use)
Design Dry Weather Flow (MGD)	100
Maximum Wet Weather Flow (MGD)	200
Number of Residents Served	728,123
Discharge Waterbody	Jamaica Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+13.5 ft NAVD88 (+11.9 ft Queens Highway Datum)
Hurricane Sandy Flood Elevation	Not Flooded
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	Yes

FEMA Flood Zones near Jamaica Wastewater Treatment Plant



2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

The Unit Substation adjacent to the Return Sludge Pump Station #3 would be flooded at grade level during the critical flood event.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Jamaica. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation.

Since the plant is located on relatively high terrain, there is only one area that would be at risk during the critical flood event - the outdoor Unit Substation (USS 1533). Water in the 100-year flood event with 30 inches of sea level rise would be able to travel along one of the plant roads to this substation and enter through the fence.

An assessment of the infrastructure in this area revealed the substation contains large electrical equipment which supplies energy to a number of important sludge pumps. All other equipment throughout the plant, even those located in basements or the tunnel system, are not at risk because the flood pathways leading to these areas are not within reach of the critical flood.

Table B lists the Unit Substation as the only area of the plant containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace the Unit Substation, plus clean the plant and provide temporary power would be approximately $1.7 million.

ADAPTATION STRATEGIES

The critical flood event would only result in half a foot of flooding near the Unit Substation; therefore, sandbagging around the Substation is recommended. This strategy is regularly employed at the Substation, already as staff know this area has the greatest potential for flooding. This option can be implemented as needed prior to large flood events. It is also affordable and provides an adequate level of protection for the Substation.

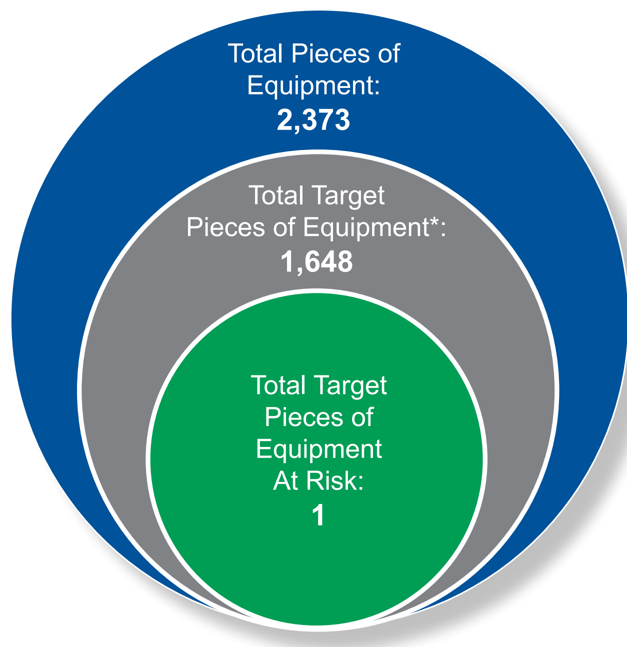
Table B presents a cost comparison for the Unit Substation at Jamaica. In this table, the cost of supplying sandbags over the course of 50 years is compared to the total damage which would be incurred in a single large flood event, and the total damage which could be avoided over the course of 50 years given the frequency of flood events which could effect the Substation.

While sandbagging does not provide the highest possible level of resiliency, given the low risk, and the low cost associated with sandbagging, this option is suitable for the Substation.

Sandbagging will certainly reduce the plant's risk by preventing floodwaters from entering and damaging the target equipment. However, as time progresses, plant staff should continue to monitor this area and may consider building a more permanent barrier around the Substation if the need arises.

In total, the cost to implement the recommended strategy at Jamaica is $0.2 million. While the cost to protect the one location is high, the potential damage cost that a large surge may impose totals $1.7 million. Because the frequency of large flood events which could affect the Substation is relatively low, the risk avoided over the next 50 years is only $0.5 million, less than the potential damage cost incurred in a single large flood event. However, it is important to note that the risk avoided is still twice the cost of implementation.

This favorable cost comparison provides strong economic support for using sandbags along the substation to minimize service disruptions in Queens during flood events, reduce sewage bypasses, and protect public health.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: Jamaica Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Unit Substation (USS 1533) - Adjacent to Return Sludge Pump Station #3	Sandbagging	$213,000	$1,700,000	$460,000	Moderate-Low
Total for 1 At-Risk Location		**$ 0.2 M**	**$ 1.7 M**	**$ 0.5 M**	

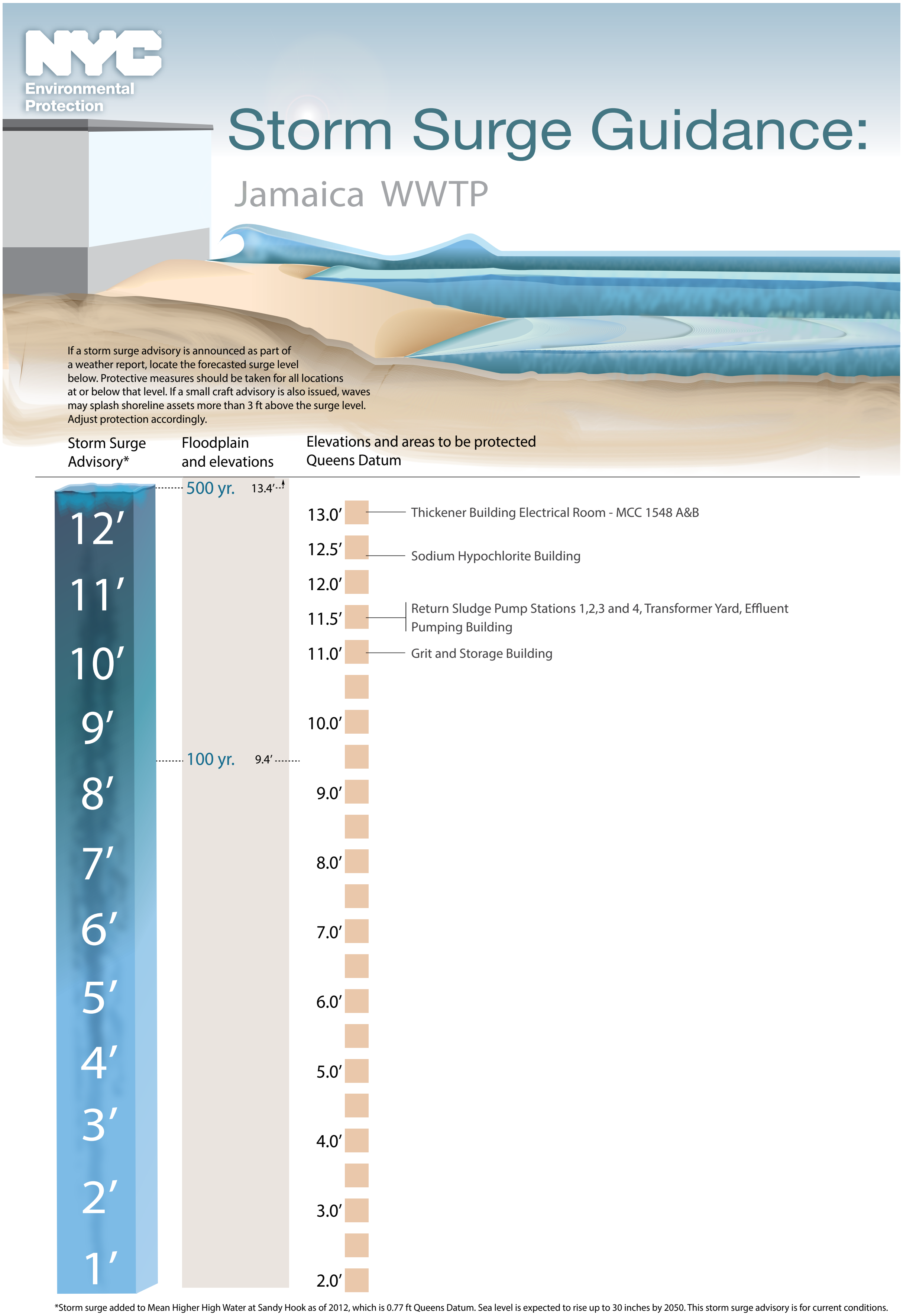
1) All cost estimates are presented in 2013 US Dollars
2) One-time replacement cost of at-risk equipment if no protective measures are in place and critical flood scenario occurs (i.e., current 100-year flood plus 30 inches). This estimate does not consider the probability of storm occurrence
3) Repair/replacement 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 Unit Substation (USS 1533) is currently protected with sandbags.

HURRICANE SANDY IMPACTS

Jamaica experienced no flood damage as a result of Hurricane Sandy, as floodwaters did not reach the plant. Plant staff took precautions ahead of the storm by sandbagging critical areas of the plant and implementing other procedures outlined in their Wet Weather Operations Plan. The plant received little precipitation and electrical power was continuous during and after the storm event. All primary treatment equipment operated throughout the storm and the plant maintained normal wet weather treatment operations. The only minor damage sustained was from wind, which tore off the siding of a temporary office building on site.

The Jamaica Wastewater Treatment Plant did not sustain any damage due to flooding during Hurricane Sandy.



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.

Newtown Creek Wastewater Treatment Plant

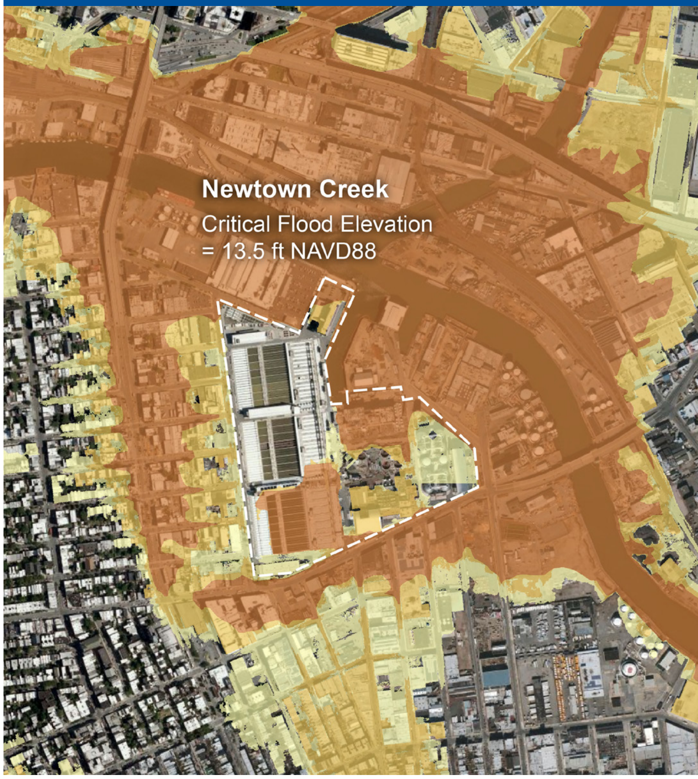
PLANT DESCRIPTION

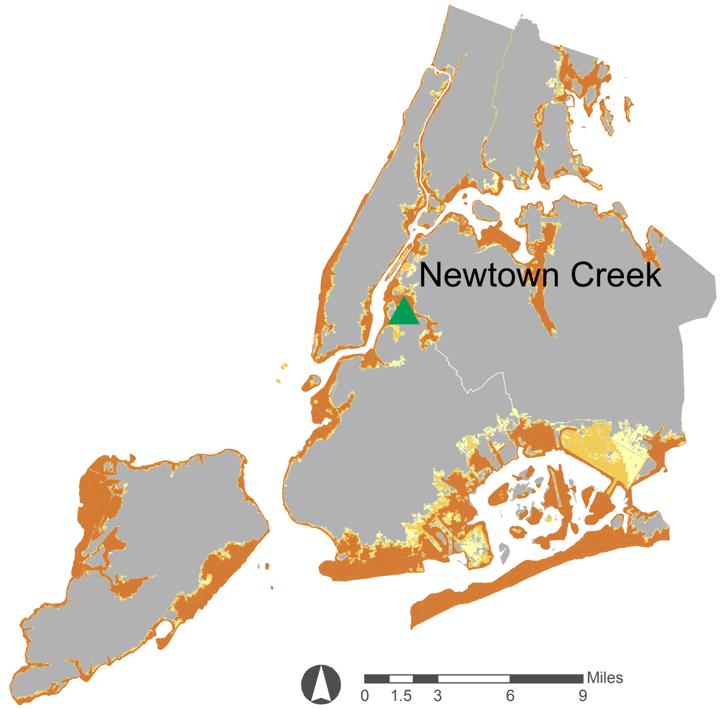
The Newtown Creek Wastewater Treatment Plant is located on a 53 acre site at 301 Greenpoint Avenue in northern Brooklyn, Community District 1. The plant abuts Provost Street on the west, Paidge Avenue on the northwest, Kingsland Avenue on the northeast and north, and Greenpoint Avenue on the south. Newtown Creek and Whale Creek Canal are to the north of the facility. General plant characteristics for Newtown Creek can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +13.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.3 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	No
Design Dry Weather Flow (MGD)	310
Maximum Wet Weather Flow (MGD)	700
Number of Residents Served	1,068,012
Discharge Waterbody	East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+13.5 ft NAVD88 (+12.0 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Elevation	+10.0 ft NAVD88 (+8.5 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Newtown Creek Wastewater Treatment Plant





2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Basement access and floor grates on the perimeter of the Main Building

Low-lying louvers along-side the Main Building

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Newtown Creek. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain, some areas may be flooded by nearly 4 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 381 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $28.8 million.

ADAPTATION STRATEGIES

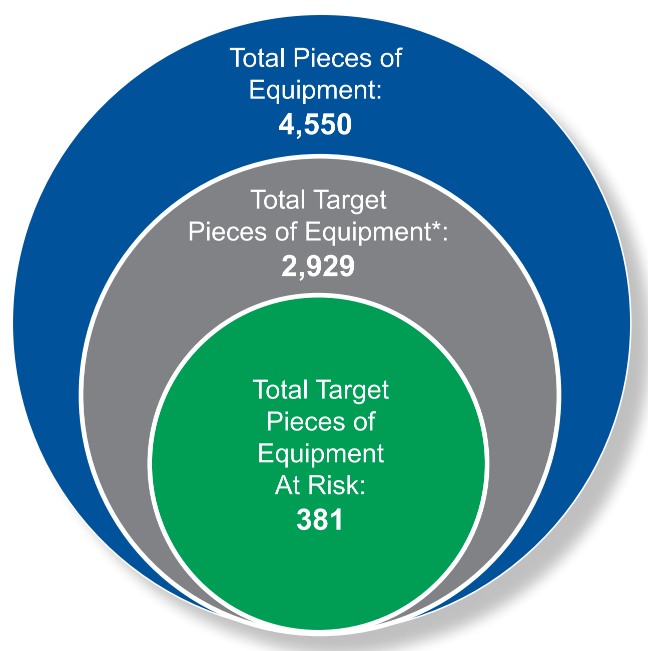
A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Newtown Creek. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency that the adaptation measure may provide to the selected location.

Since many areas at Newtown Creek contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen that protect openings into the plant areas. Given that Newtown Creek is susceptible to flood damage from an interconnected tunnel system, sealing doors and access ways leading to the tunnel is recommended. Providing more robust coverings and seals would greatly reduce this risk and prevent floodwaters from entering the tunnel system, traveling throughout the plant, and damaging target pieces of equipment.

The Main Building contains several rooms that are susceptible to flooding under the critical flood event, such as the Main Pump Room, Old Facility Room, and Electrical Substation area. It is recommended to seal the building with water-tight doors and windows and flood-proof target pieces of equipment to provide adequate protection during the critical flood event and smaller storms.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

In total, the cost to implement all recommended strategies at Newtown Creek is $8.9 million. While this cost is high, the potential damage cost that a large surge may impose totals $28.8 million. As the recommended strategies would also protect infrastructure during smaller storm events, the total value of risk avoided over a 50-year time span is estimated at the cost of $9.1 million. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering that they would also minimize service disruptions in Brooklyn during flood events, reduce sewage bypasses, and protect public health.

Table B: Newtown Creek Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Central Residuals Building	No Action Required	$0	$85,000	$0	No Protection
Centrifuge Building	Sandbag	$428,000	$6,916,000	$1,574,000	Moderate-Low
Digestion Building	Sandbag	$885,000	$6,453,000	$1,467,000	Moderate-Low
Disinfection Building	Flood-proof Equipment	$573,000	$565,000	$138,000	High
Grit Handling Building	Elevate Equipment and Construct Barrier	$2,136,000	$2,048,000	$547,000	Very High
Main Building – Electrical Substation	Seal Building	$785,000	$4,897,000	$3,524,000	Moderate
Main Building – Old Facilities	Flood-proof Equipment and Seal Building	$758,000	$607,000	$154,000	High
Main Building – Pump Room	Flood-proof Equipment and Seal Building	$1,174,000	$6,317,000	$1,492,000	Moderate
Solids Handling Facilities Service Building	Elevate Equipment	$27,000	$102,000	$27,000	Very High
Distributed Power and Controls	Elevate Equipment and Construct Barrier	$2,090,000	$803,000	$205,000	High
Total for All 10 At-Risk Locations		**$ 8.9 M**	**$ 28.8 M**	**$ 9.1 M**	

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

HURRICANE SANDY IMPACTS

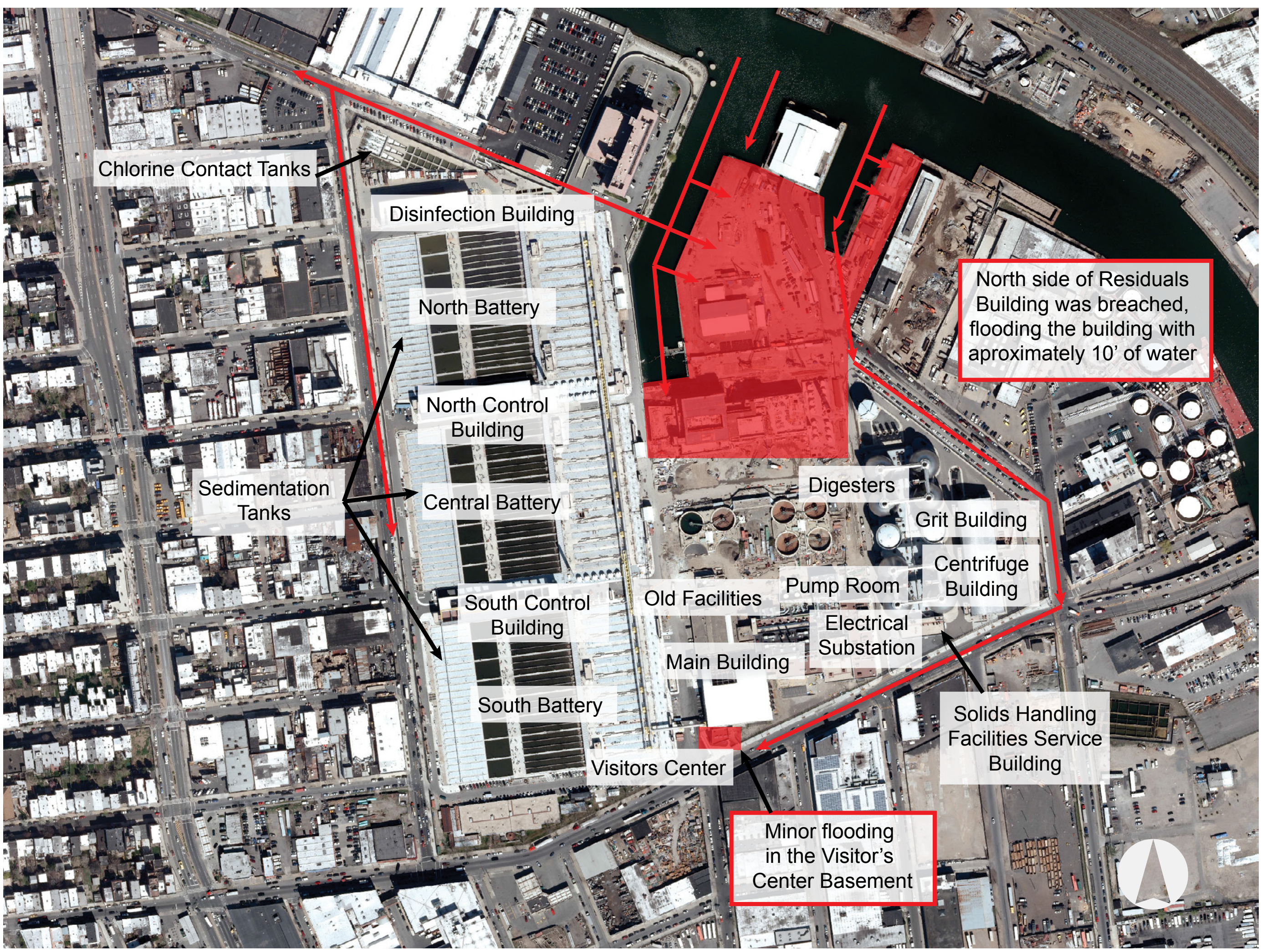
A significant area of Newtown Creek experienced flooding as a result of Hurricane Sandy, however damage was minor. During the peak of the storm, floodwaters entered the site from Whale Creek Canal and Newtown Creek over the bulkheads. Floodwaters inundated Paidge Avenue, Kingsland Avenue, and Greenpoint Avenue, leading up to the plant Visitor's Center. Water reached the doorway of the Visitor's Center but did not breach the entrance. However, there was minor flooding in the basement of the Visitor's Center, as water backed up through the drain system and electrical conduits. These valves were shut during the storm to minimize additional flooding.

Water also flooded internal Road D and reached a low-lying doorway with direct access to the plant's interconnected tunnel system at the north side of the Central Residuals Building, flooding the building with approximately 10 inches of water. The plant effluent structure was flooded with one foot of water, causing flooding in a number of treatment tanks.

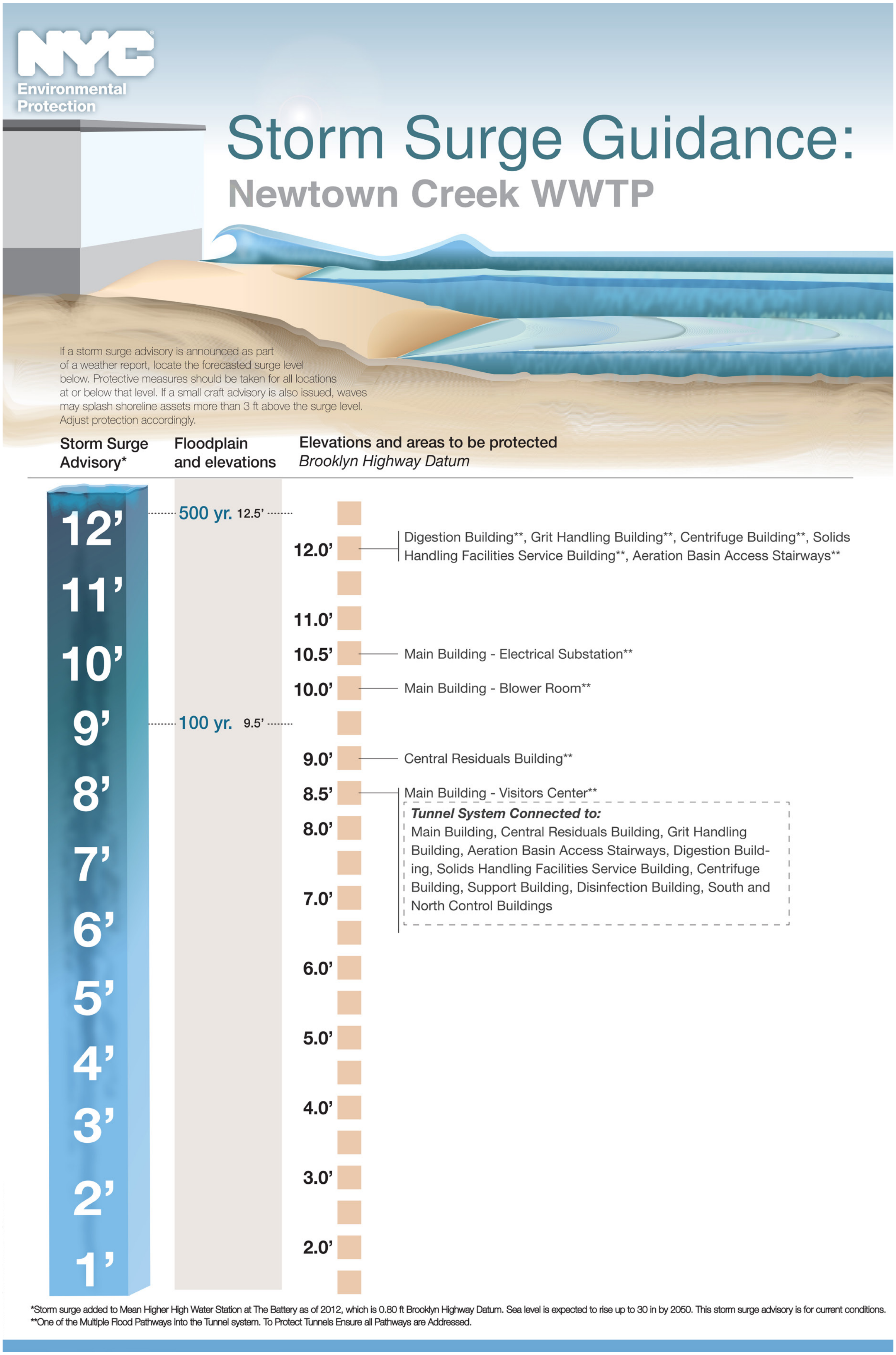
The nature walk surrounding the plant also flooded, however plant staff placed sandbags at critical flood pathways which prevented floodwaters from entering the nearby Support Building. Likewise, flooding of the Central Residuals Building was prevented by sandbagging the doorway at the north side of the building.

Due to local power outages, the plant was powered by emergency generators for three days during and following the storm. When power was restored, the plant continued operation with no evident damage to critical equipment or facilities.

The only significant damage to Newtown Creek's treatment process occurred offsite during the storm. The Manhattan Pump Station, where sewage from some sections of Manhattan is screened and then pumped to Newtown Creek, experienced significant flooding and damage. During Hurricane Sandy, several feet of floodwater surrounded and entered the pumping station and sewage backed up into the dry wells, damaging pump motors.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

North River Wastewater Treatment Plant

PLANT DESCRIPTION

The North River Wastewater Treatment Plant is located on a two-story, 28 acre site at the intersection of Riverside Drive and West 135th Street on the west side of Manhattan, New York. The plant abuts Riverside Drive on the east and the Hudson River on the west, and lies between 135th and 145th Streets. General plant characteristics for North River can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +12.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.3 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Type	Activated Sludge
Dewatering Facilities	No
Dry Weather Flow (MGD)	170
Wet Weather Flow (MGD)	340
No. Residents Served	588,772
Discharge Waterbody	Hudson River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+12.5 ft NAVD88 (+10.8 ft Manhattan Datum)
Sandy Flood Elevation	+9.7 ft NAVD88 (+8.0 ft Manhattan Datum)
Sandy Flooding	Major
Top Priority for Beach Impacts	No

FEMA Flood Zones near North River Wastewater Treatment Plant

2013 Advisory 100-Year Floodplain

Projected 2020s 100-Year Floodplain

Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Arched windows around the perimeter of the ground level (EL 5) are considered pathways for flooding.

Expansion joints are flood pathways as experienced during Hurricane Sandy.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at North River. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant is located on the first and second floors of a building adjacent to the Hudson River, all critical equipment located on the first floor is low-lying and may be flooded by nearly 6 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 2,251 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $94.1 million.

ADAPTATION STRATEGIES

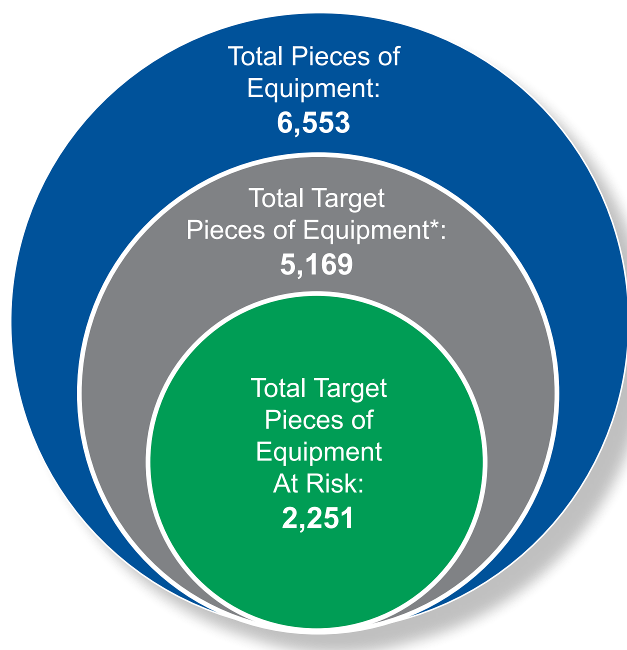
A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at North River. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since the first floor elevation (EL 5) at North River contains critical infrastructure, flood-proofing is recommended since it provides a high degree of protection. In areas of the first floor where not all infrastructure could be flood-proofed, sealing the openings to the building is recommended. Fortifying the manhole covers, driveway entrance, and arch openings along the perimeter of the building will greatly reduce the plant's risk and prevent floodwaters from entering the first floor, traveling throughout the plant, and damaging target pieces of equipment.

In total, the cost to implement all recommended strategies at North River is $17.2 million. While this cost is high, the potential damage cost that a large surge may impose totals $94.1 million. Furthermore, since North River is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $445.8 million, which is 26 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Manhattan during flood events, reduce sewage bypasses, and protect public health.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: North River Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
EL 5	Flood-proof Equipment and Seal Building	$17,155,000	$94,100,000	$445,787, 000	Moderate
Total for 1 At-Risk Location		**$ 17.2 M**	**$ 94.1 M**	**$ 445.8 M**	

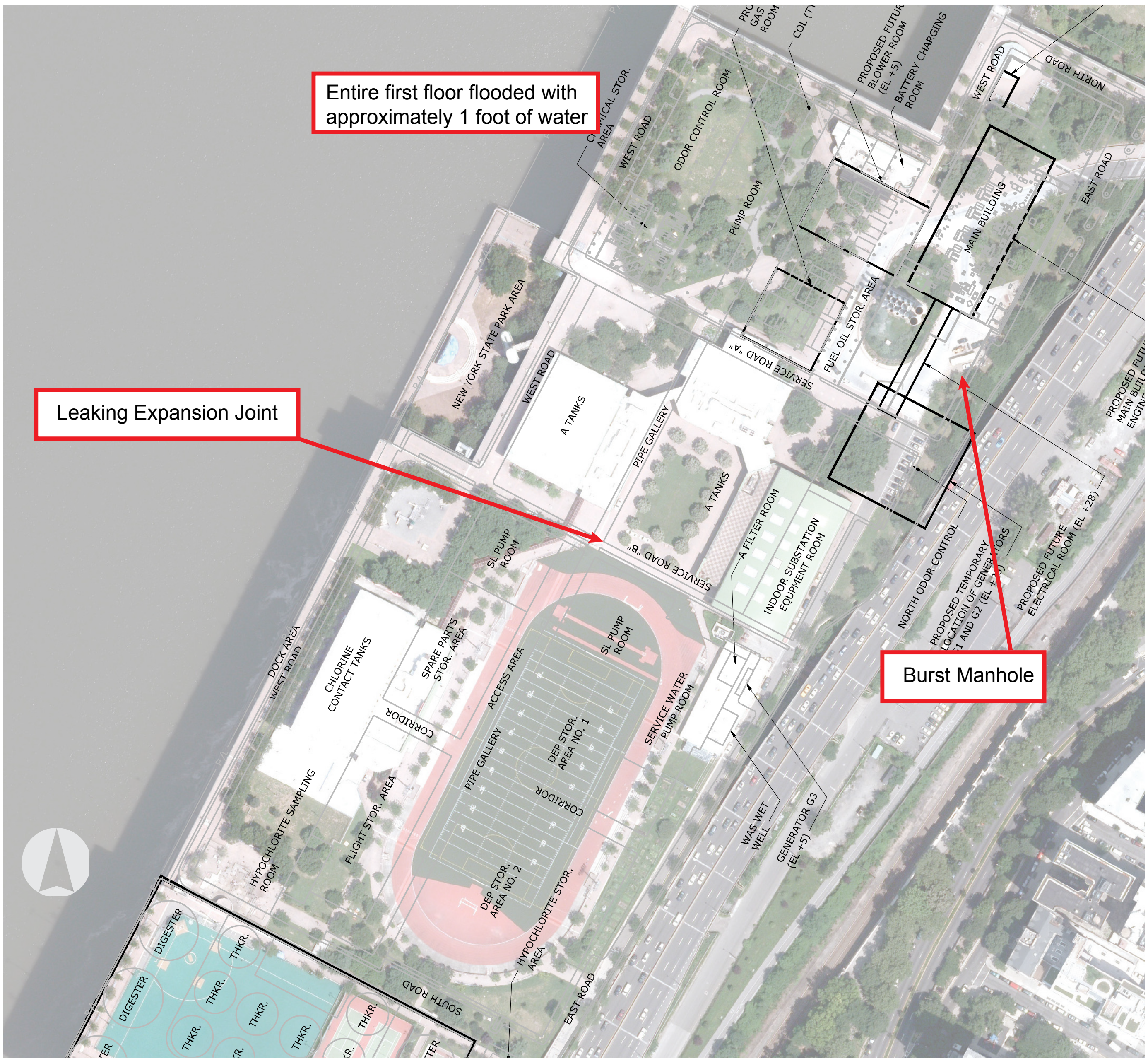
1) All cost estimates are presented in 2013 US Dollars
2) One-time replacement cost of at-risk equipment if no protective measures are in place and critical flood scenario occurs (i.e., current 100-year flood plus 30 inches). This estimate does not consider the probability of storm occurrence
3) Repair/replacement 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

North River Wastewater Treatment Plant

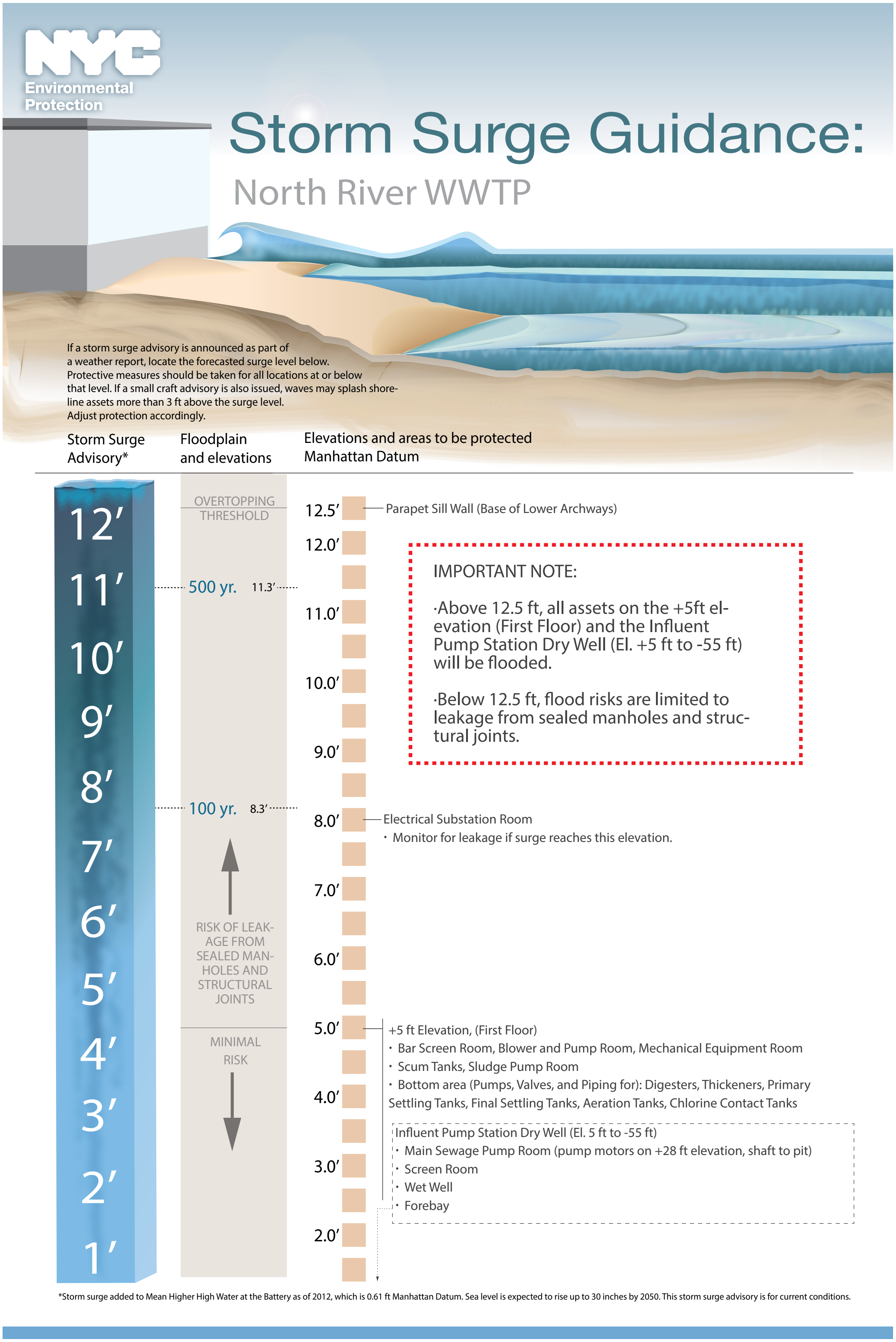
HURRICANE SANDY IMPACTS

North River experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, as depicted in the figure below, floodwater forced its way through a manhole that ruptured on the first floor and through expansion joints near the Thickeners, which flooded the first floor of the plant with one foot of water. Fortunately, the engines that supply power to the main wastewater pumps are located on the second floor, and were not damaged. The Electrical Substation has raised doors, yet it flooded with less than 1 inch of water through cracks and other small pathways in the walls. Plant staff monitored the water level in the Electrical Substation throughout the storm and contacted Con Edison as a precautionary measure in case power to the plant had to be shut down.

The plant did not lose power; however, certain critical components were proactively shut down for up to 7 hours to prevent short circuiting in case the water level continued to rise. Water flooded the low-lying areas of the building first, including the Raw Influent Pump Dry Well through the first floor stairwells. It was at this point that plant staff turned off the electricity in critical plant areas. Once it was safe to restore power to the facility, a single pump was used to empty the dry well, and maintenance was performed on the remaining pumps when the dry well was emptied. After the storm, floodwater on the first floor flowed out of the plant through the ruptured manhole and through the various drains and sump pumps.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Oakwood Beach Wastewater Treatment Plant

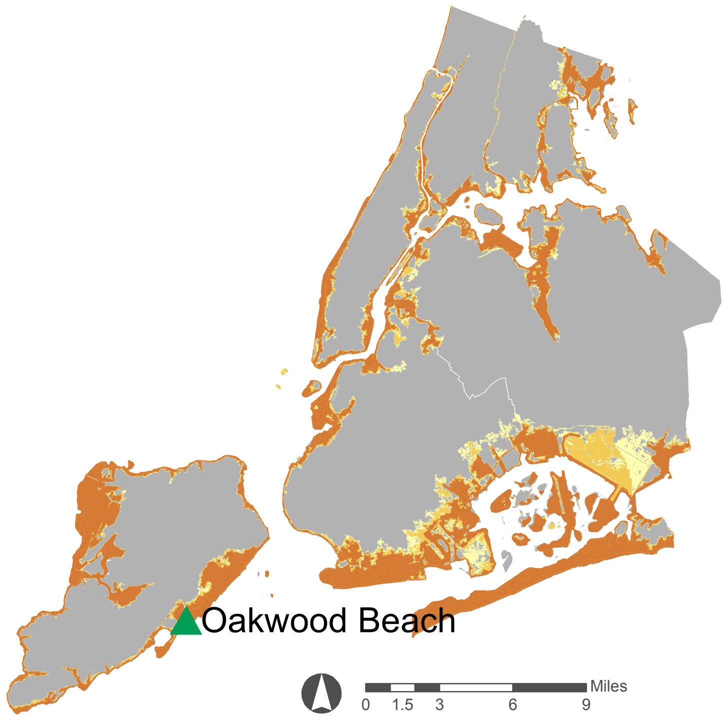
PLANT DESCRIPTION

The Oakwood Beach Wastewater Treatment Plant is located on an approximately 27 acre site at 751 Mill Road in southern Staten Island, Community District 3. The plant abuts the Gateway National Recreational Area to the west, a residential area to the east, and the Lower New York Bay to the south. General plant characteristics for Oakwood Beach can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +16.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +1.8 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	40
Maximum Wet Weather Flow (MGD)	120
Number of Residents Served	244,918
Discharge Waterbody	Lower New York Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+16.5 ft NAVD88 (+14.4 ft Staten Island Highway Datum)
Hurricane Sandy Flood Elevation	+13.1 ft NAVD88 (+11.0 ft Staten Island Highway Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Oakwood Beach Wastewater Treatment Plant



- 2013 Advisory 100-Year Floodplain
- Projected 2020s 100-Year Floodplain
- Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Floor grate outside of the Maintenance Building

A window at the Sludge Storage Building was one of the main areaways for floodwater to enter during Hurricane Sandy.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Oakwood Beach. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain, a few areas may be flooded by up to 5 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment that are needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 353 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $21 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Oakwood Beach. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

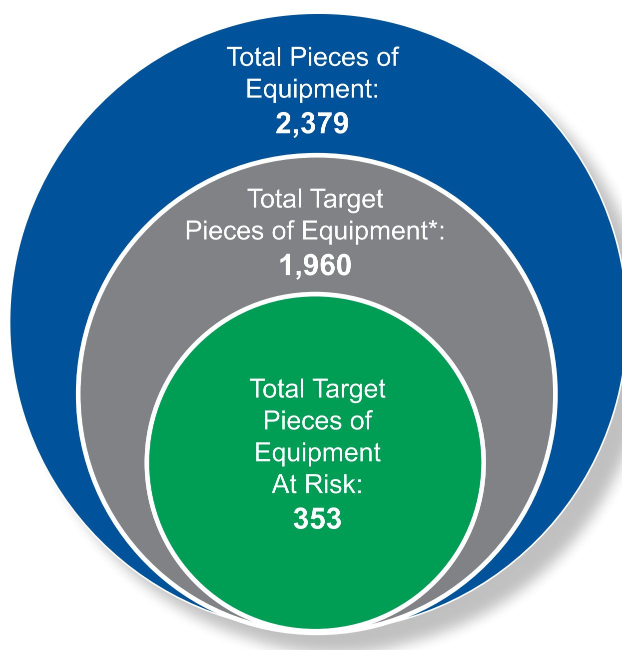
When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the at-risk areas at Oakwood Beach contain critical infrastructure, often elevating equipment was chosen as the recommended strategy since it provides a high degree of protection. In locations where not all infrastructure could be elevated, additional strategies were chosen such as constructing static barriers to protect openings into the plant areas.

In addition, Oakwood Beach is susceptible to flood damage from an interconnected tunnel system that has key at-risk flood pathways at the Sludge Storage Building. While flood-proofing and elevating equipment within the Sludge Storage Building would offer a high level of protection, constructing a static barrier around the areaways and sealing the doorways and windows to prevent damage at the Main Building and Treatment Building is also recommended.

In total, the cost to implement all recommended strategies at Oakwood Beach is $5.3 million. This cost is relatively low considering that the potential damage cost that a large surge may impose totals $21 million. As the recommended strategies would also protect infrastructure during smaller storm events, the total value of risk avoided over a 50-year time span is estimated at $44.3 million, which is eight times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Staten Island during flood events, reduce sewage bypasses, and protect public health.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: Oakwood Beach Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Chlorine Building	Elevate Equipment and Seal Building	$1,265,000	$1,189,000	$3,701,000	High
Dewatering Building	Sandbag	$966,000	$8,926,000	$2,831,000	Moderate-Low
Diesel Generator	Elevate Equipment	$454,000	$1,193,000	$4,982,000	Very High
Existing Substation	Construct Barrier	$212,000	$3,525,000	$13,984,000	High
Maintenance Building	No Action Required	$0	$824,000	$0	No Protection
Meter Building	Elevate Equipment and Construct Barrier	$328,000	$395,000	$443,000	High
Microstrainer Building	Elevate Equipment and Construct Barrier	$1,101,000	$1,250,000	$6,202,000	High
Sludge Pump Building	No Action Required	$0	$51,000	$0	No Protection
Sludge Storage Building	Flood-proof and Elevate	$522,000	$3,024,000	$11,082,000	Low
Transformer Enclosure	Construct Barrier	$482,000	$594,000	$1,058,000	High
Total for All 10 At-Risk Locations		**$ 5.3 M**	**$ 21.0 M**	**$ 44.3 M**	

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

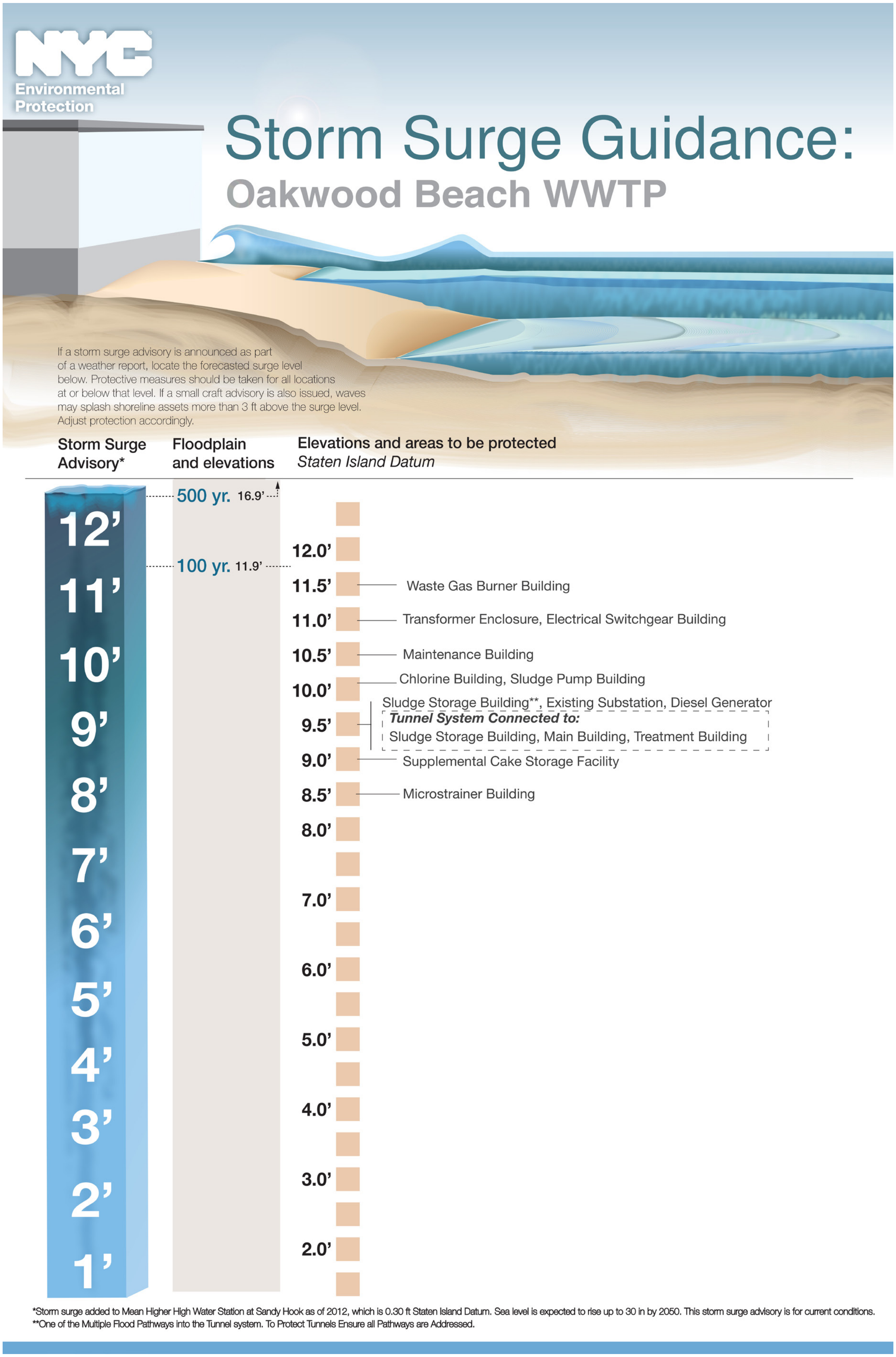
HURRICANE SANDY IMPACTS

Oakwood Beach experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters entered the site from the Lower New York Bay through the surrounding drainage canal and natural areas. Rising floodwaters surrounded the site on all sides, flooding the north lot storage yard with over 6 feet of water and the guard house at the north entrance with 3 feet of water. Vehicular access was obstructed for up to 5 hours.

The main disruption to the plant occurred when water entered the areaways and doorways of the Sludge Storage Building and spilled into the connected basements of the Main Building and Treatment Building through a tunnel. Roughly 8 inches of water accumulated in basements of the Sludge Storage Building, Main Building, Treatment Building, and connecting tunnel; however, equipment in these areas continued to function since they are elevated on concrete pads above the finished floor level. Sump pumps in the basements helped to contain rising floodwater. Other areas affected by the flood included the Sludge Pump Building, Chlorine Building, existing Electrical Switchgear Building, Emergency Generator, and the Microstrainer Building. Flooding of these areas resulted in damage to the electrical equipment, pumps, and motors. Processed water in the Chlorine Contact Tank and Effluent Channel overflowed even though they are above the Hurricane Sandy flood elevation. The overflow from the Effluent Channel flooded the Meter Building basement, resulting in partial damage to electrical equipment and the Chlorine Transfer Pumps.

Plant staff worked actively before, during, and after the storm to protect the plant and bring it back to normal operation. Power from one of the plant's two electrical service feeders was lost during the storm, forcing operators to partially operate on emergency generators and suspend power to the aeration blowers for a period of time. Sandbags were placed ahead of the storm to protect the low-lying temporary substation and temporary electrical generator. When power was restored, the plant resumed normal wet weather treatment with no apparent damage to critical equipment.

Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Owls Head Wastewater Treatment Plant

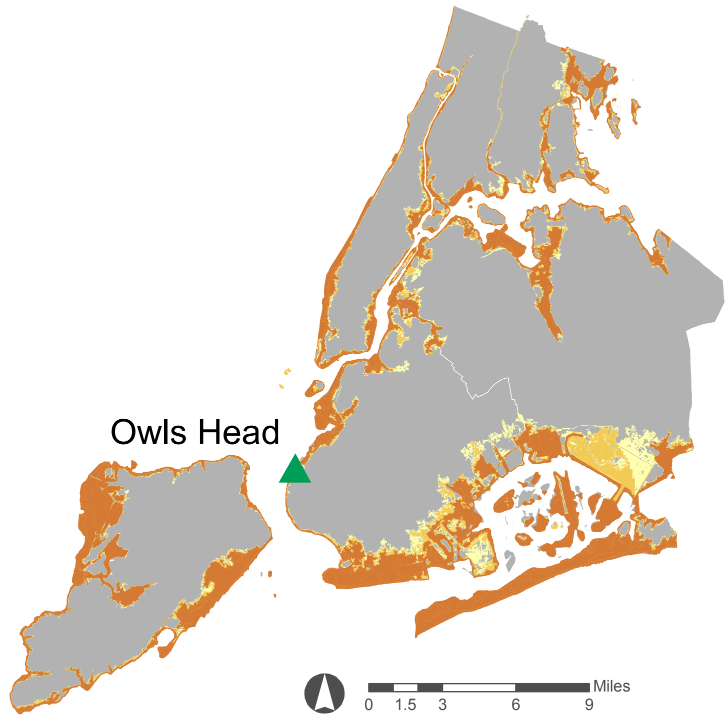
PLANT DESCRIPTION

The Owls Head Wastewater Treatment Plant is located at the intersection of Bay Ridge Avenue and Shore Road in west Brooklyn, Community District 10. The plant abuts Shore Parkway to the east and is bound by the Upper Bay on the north, west and south. General plant characteristics for Owls Head can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +14.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.3 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	No
Design Dry Weather Flow (MGD)	120
Maximum Wet Weather Flow (MGD)	240
Number of Residents Served	758,007
Discharge Waterbody	Upper New York Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+14.5 ft NAVD88 (+13.0 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Elevation	+13.5 ft NAVD88 (+12.0 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Owls Head Wastewater Treatment Plant



2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

A pathway for flooding is around the perimeter of the Administration Building.

Floor grates near the Generator Room may allow floodwater to enter.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Owls Head. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain, some areas may be flooded by up to 4 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 762 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $48.4 million.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Owls Head. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

The Main Electrical Substations and Substations #2 and #4 in particular require robust protection as the extent of flooding ranges from 4 inches at the substations to 2 feet at the Main Electrical Substation. It is recommended that equipment be elevated and a static barrier be installed around the exterior of the Substations to protect the power feeds. Likewise, the Chlorine Contact Tanks may potentially flood during the critical flood event and elevating equipment may provide adequate protection. In addition, equipment located on the first floor and basement of the Chlorination Building is at-risk, with floodwater depth expected to reach approximately 4.5 feet under the critical flood scenario. It is recommended that electrical equipment be relocated to the second floor of the building, chemical tanks on the first floor to be filled prior to the event to prevent buoyancy issues, and for floor drains to be equipped with check valves to prevent water intrusion.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location. Since many of the at-risk areas at Owls Head contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen that protect openings into the plant areas. In addition, since Owls Head is susceptible to flood damage from an interconnected tunnel system, it is recommended to flood-proof and elevate equipment within the tunnel system to provide adequate protection

*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

In total, the cost to implement all recommended strategies at Owls Head is $11 million. While this cost is high, the potential damage cost that a large surge may impose totals $48.4 million. Furthermore, since Owls Head is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $158.8 million, which is 14 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Brooklyn during flood events, reduce sewage bypasses, and protect public health.

Table B: Owls Head Adaptation Strategy Recommendations

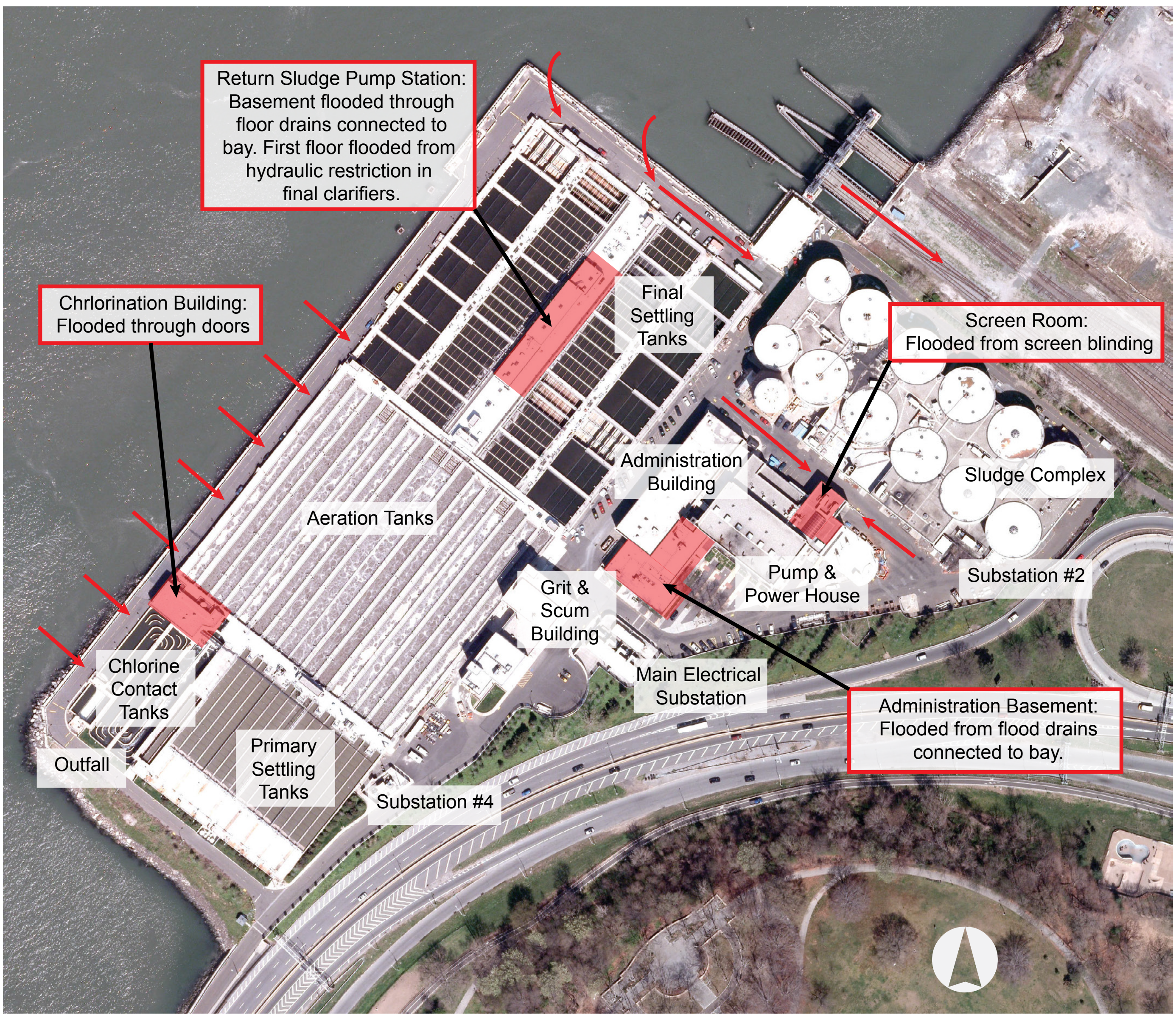
Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Administration Building	No Action Required	$0	$314,000	$0	No Protection
Chlorine Contact Tanks	Elevate Equipment	$45,000	$121,000	$69,000	Very High
Chlorination Building	Elevate Equipment and Seal Building	$1,284,000	$2,426,000	$12,031,000	High
Electrical Substation #2	Elevate Equipment	$394,000	$3,745,000	$1,210,000	Very High
Electrical Substation #4	Elevate Equipment and Construct Barrier	$1,146,000	$3,518,000	$1,379,000	Very High
Grit and Scum Building	Flood-proof Equipment	$34,000	$12,000	$12,000	High
Grit and Scum Tunnel	Flood-proof Equipment	$320,000	$733,000	$3,591,000	High
Main Electrical Substation	Elevate Equipment and Construct Barrier	$1,146,000	$4,271,000	$3,054,000	Very High
Primary Tank Tunnel	Flood-proof and Elevate	$3,218,000	$3,746,000	$18,382,000	High
Pump and Blower Building – Blower Room	Flood-proof Equipment and Seal Building	$2,963,000	$15,926,000	$71,289,000	Moderate
Solids Handling Complex	Seal Control Room	$460,000	$13,603,000	$47,795,000	Moderate
Total for All 11 At-Risk Locations		**$ 11.0 M**	**$ 48.4 M**	**$ 158.8 M**	

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

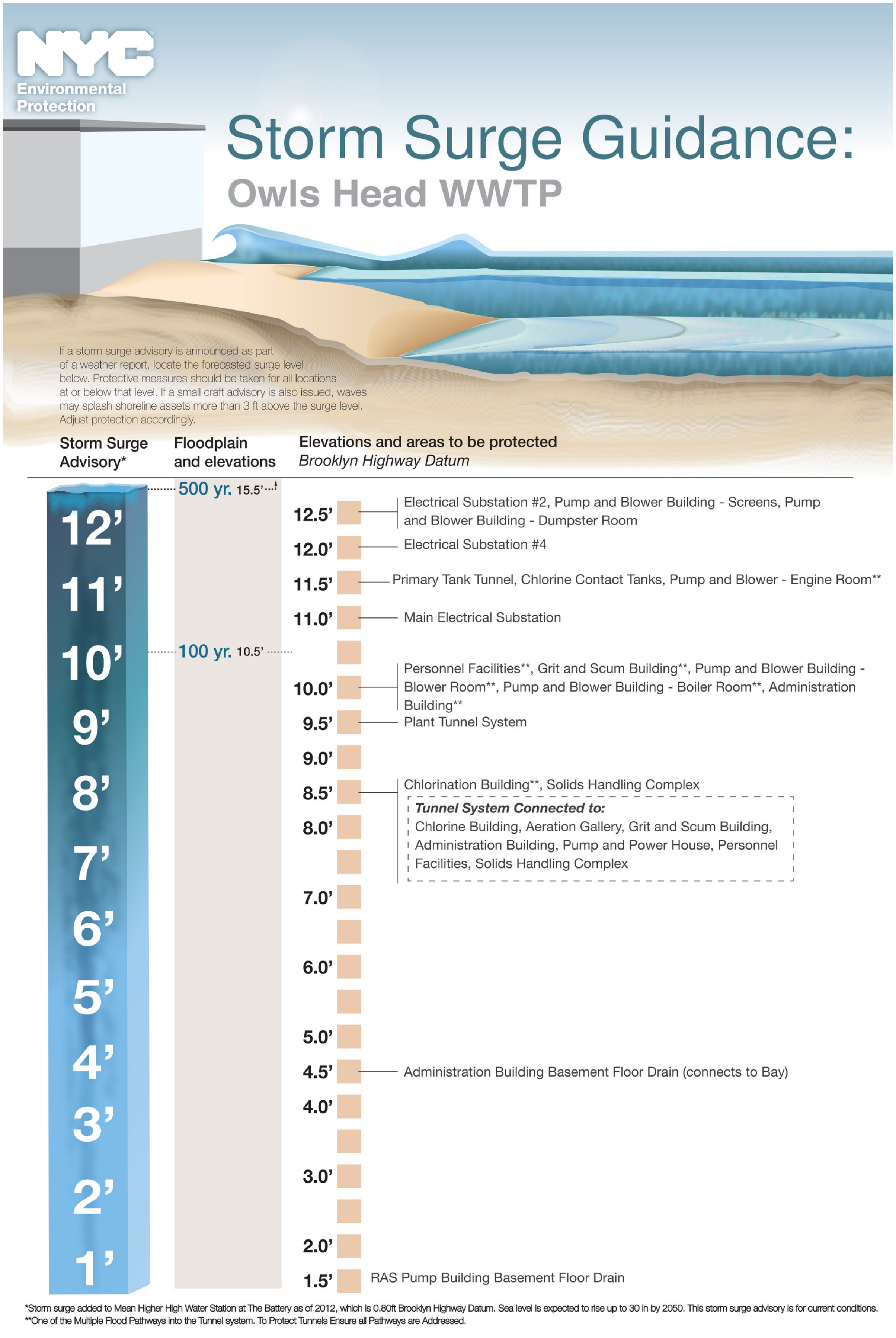
HURRICANE SANDY IMPACTS

Owls Head experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters rapidly entered the site over the bulkhead at the north and west sides of the plant. Additional flooding occurred overland as flow breached the railroad yard to the north, covering roadways around the Solids Handling Facility and Administration Building. Overland floodwater did not reach any of the exterior doors of the Administration Building, but the building's basement was flooded through a floor drain that backed up from the bay. Floodwater entered the plant's tunnel system which connects several buildings including the Chlorination Building and the Administration Building; however, flooding was confined to the Chlorination Building and did not reach the plant's main pumping equipment. Chemical-feed equipment for wastewater disinfection that is located in the basement of the Chlorination Building was flooded when sump pumps were unable to keep up with the rising water levels. Due to the high storm surge levels, both entrances to the plant were blocked which prevented staff from entering or exiting the site for two days after the storm.

Plant staff took precautions ahead of the storm which included sandbagging low-lying areas such as the Chlorination Building, Machine Shop, and Storage Room in the Administration Building. The plant lost power during the storm, but maintained normal wet weather operations using back-up generators. Plant staff successfully protected the Motor Control Centers located on the first floor of the disinfection facilities by opening the interior doorways to allow water to drain into the basement. The plant's ability to pump wastewater was uninterrupted during the storm event since the Pump and Blower Building and the plant's main pumping equipment were protected ahead of the storm.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Port Richmond Wastewater Treatment Plant

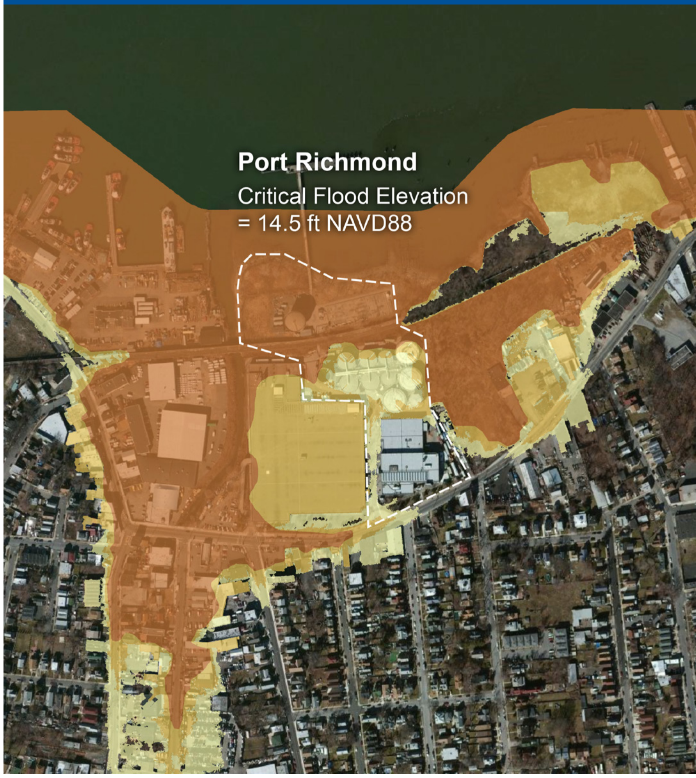
PLANT DESCRIPTION

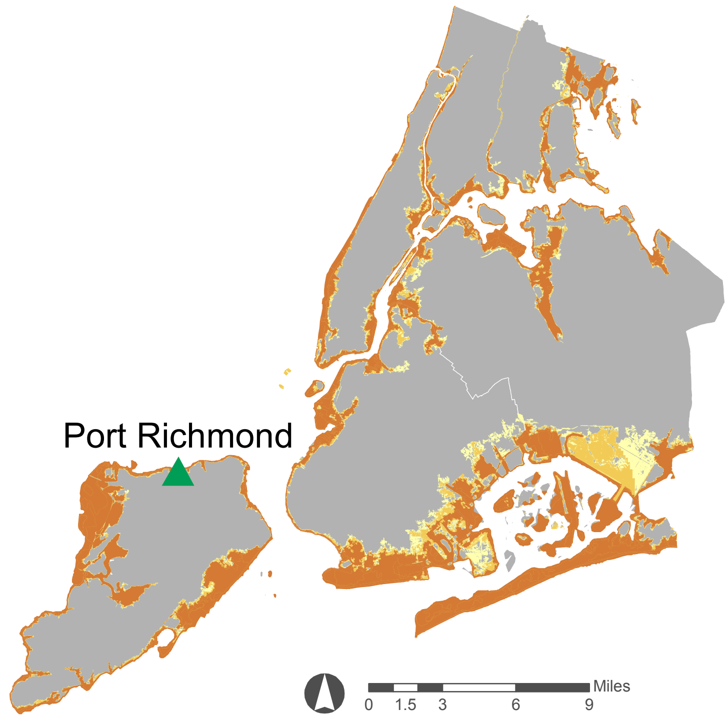
The Port Richmond Wastewater Treatment Plant is located at the intersection of Richmond Terrace and Bodine Street on the north side of Staten Island, NY. The plant abuts Richmond Terrace to the south, a creek to the west, and the Kill Van Kull waterway to the north. General plant characteristics for Port Richmond can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +14.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +1.9 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	No
Design Dry Weather Flow (MGD)	60
Maximum Wet Weather Flow (MGD)	120
Number of Residents Served	198,128
Discharge Waterbody	Kill Van Kull
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+14.5 ft NAVD88 (+12.4 ft Staten Island Datum)
Hurricane Sandy Flood Elevation	+12.1 ft NAVD88 (+10.0 ft Staten Island Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Port Richmond Wastewater Treatment Plant





2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Entrance to Main Building

Chlorine Contact Tanks are potentially at risk of flooding during a large storm event.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Port Richmond. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain, a few areas may be flooded with nearly 4 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 536 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power would be approximately $54.8 million.

ADAPTATION STRATEGIES

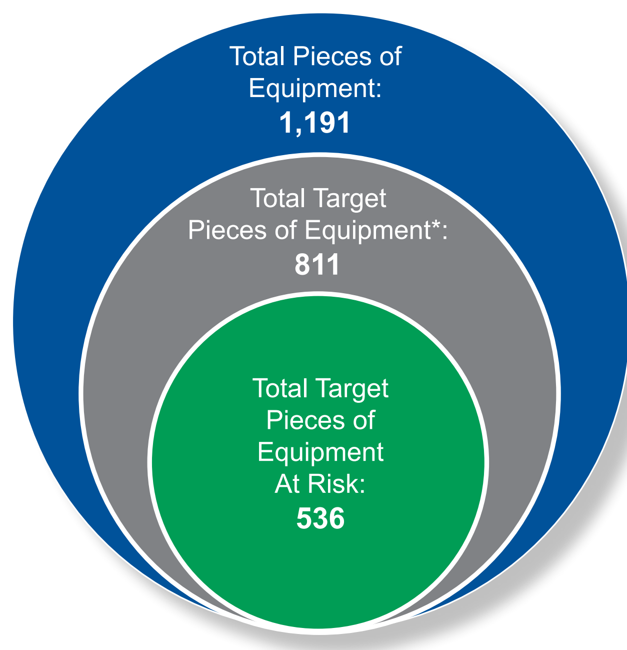
A combination of recommended strategies to reduce damage and recovery time after a surge event were proposed for each at-risk location at Port Richmond. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the at-risk areas at Port Richmond contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen to protect openings into the plant areas. The Chlorine Contact Tanks, as the closest structure to the Kill Van Kull waterway, is the most at-risk from storm surge. In order to provide uninterrupted primary treatment operations, it is recommended to elevate the equipment around the Chlorine Contact Tanks to protect against floodwaters. It is also recommended to seal the building that houses the raw sewage pumps, and flood-proof equipment associated with raw sewage pumping and primary settling, to reduce the risk of flooding.

In total, the cost to implement all recommended strategies at Port Richmond is $10.4 million. This cost is relatively low considering that the potential damage cost that a large surge may impose totals $54.8 million. As the recommended strategies would also protect infrastructure during smaller events, the total value of risk avoided over a 50 year time span is estimated at $60.4 million, which is almost 6 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Staten Island during flood events, reduce sewage bypasses, and protect public health.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

Table B: Port Richmond Adaptation Strategy Recommendations

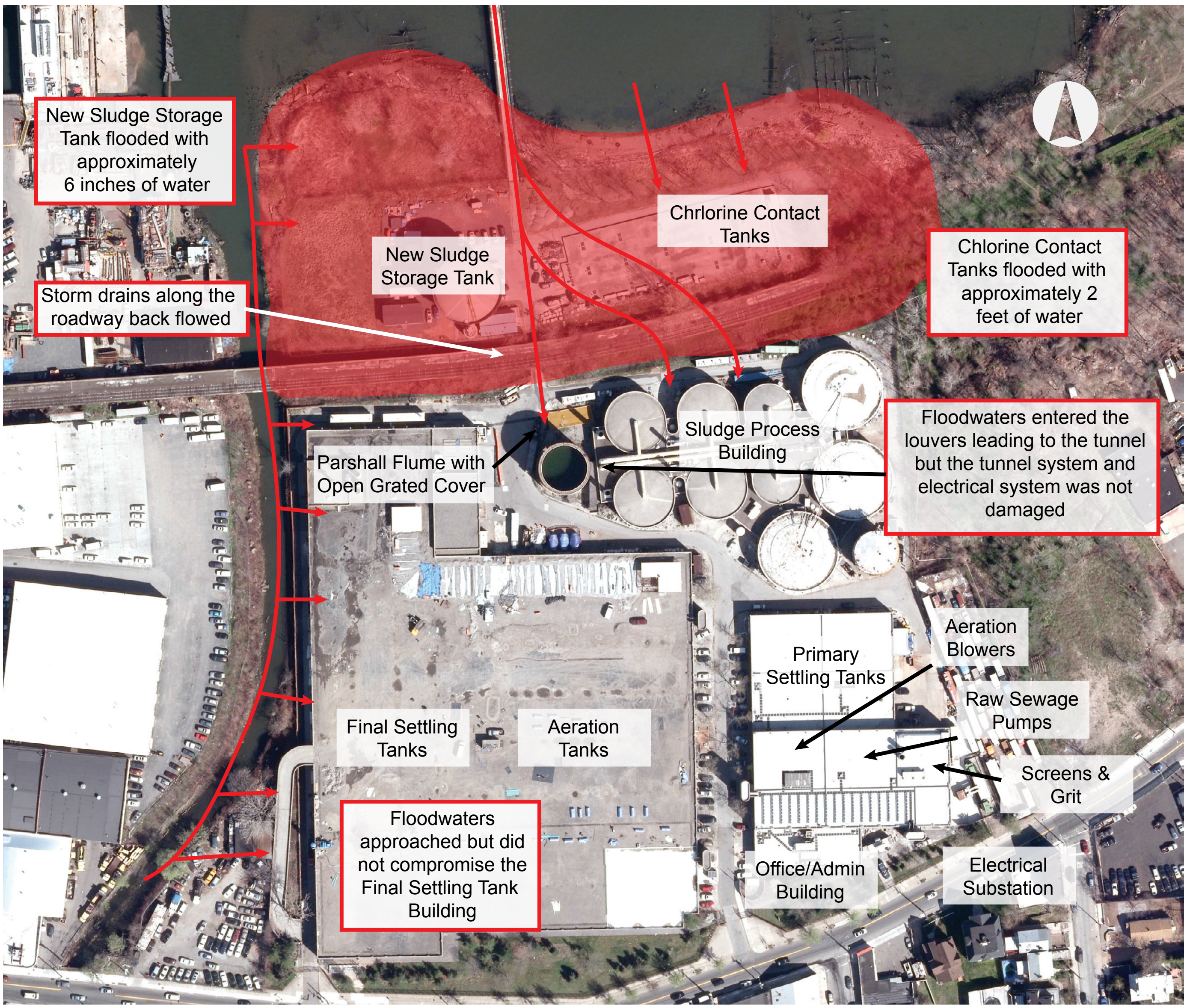
Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Aeration Blowers	Sandbag	$213,000	$1,371,000	$363,000	Moderate-Low
Chlorine Contact Tanks	Elevate Equipment	$63,000	$73,000	$380,000	Very High
Distributed Equipment	No Action Required	$0	$410,000	$0	No Protection
Electrical Substation	Elevate Equipment and Construct Barrier	$1,834,000	$6,129,000	$4,129,000	Very High
New Sludge Storage Tank	Construct Barrier	$347,000	$4,278,000	$20,920,000	High
Office / Admin Building	Construct Barrier	$482,000	$2,623,000	$776,000	High
Primary Settling Tank	Flood-proof Equipment	$2,214,000	$3,983,000	$974,000	High
Raw Sewage Pumps	Flood-proof Equipment and Seal Building	$2,127,000	$9,145,000	$2,204,000	Moderate
Screens and Grit	Flood-proof Equipment and Construct Barrier	$1,898,000	$9,761,000	$3,723,000	High
Service Tunnel 1 and 2	No Action Required	$0	$83,000	$0	No Protection
Sludge Process Building	Seal Building	$659,000	$14,851,000	$23,503,000	Moderate
Sludge Pumping Station	Seal Building	$557,000	$2,143, 000	$3,389,000	Moderate
Total for All 12 At-Risk Locations		**$ 10.4 M**	**$ 54.8 M**	**$ 60.4 M**	

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

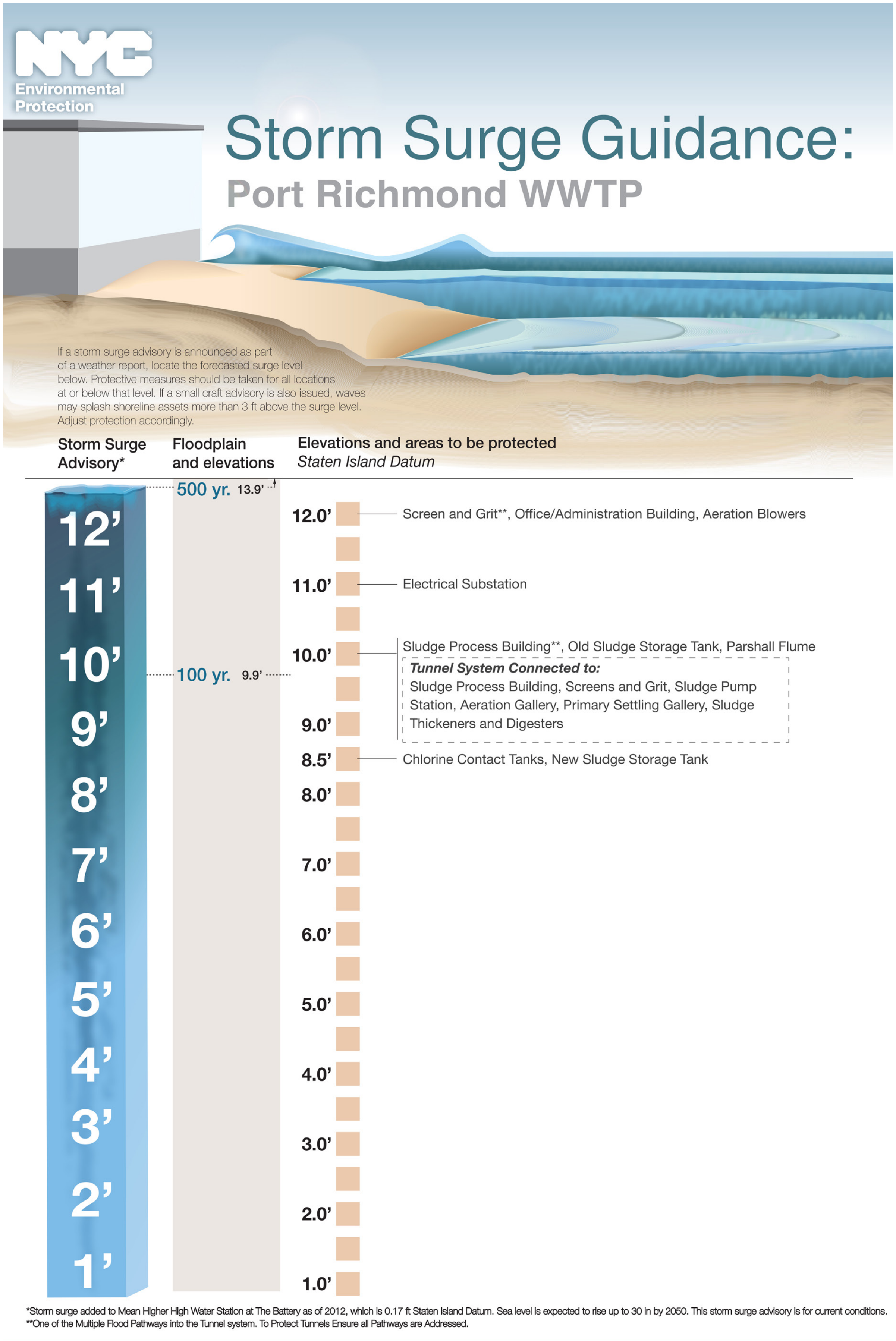
HURRICANE SANDY IMPACTS

Port Richmond experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters entered the site from the Kill Van Kull over the sea wall along the waterway. As water levels in the Kill Van Kull began to rise, initial flooding occurred due to backflow through storm sewers to the roadway adjacent to the new Sludge Storage Tank and Thickeners. Floodwaters also approached the Final Settling Tanks Building from the creek bank to the west of the plant, although water did not compromise the structure. Vehicular access was obstructed on the west side of the plant due to floodwaters. Floodwaters also entered the underground tunnel system through various pull-boxes and manholes, but significant flooding within the tunnel system was avoided. One power feed was lost, causing one of the boilers to shut down, but the flood levels did not reach levels that would immediately damage Motor Control Centers and other electrical equipment.

The plant staff worked actively before, during, and after the storm to protect the plant and quickly resume normal operation. Just prior to the hurricane, plant staff placed sandbags at multiple locations on the site. Sandbag placement at the New Sludge Storage Facility provided adequate protection and only allowed a minimal amount of water to enter the building, protecting pumps and most electrical equipment. Large intake louvers to the heaters located on the west side of the Sludge Process Building were also protected with sandbags, which prevented water from entering the tunnel system. Power was out for three days, and the on-site generator was used to power the primary treatment facilities during that time.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Red Hook Wastewater Treatment Plant

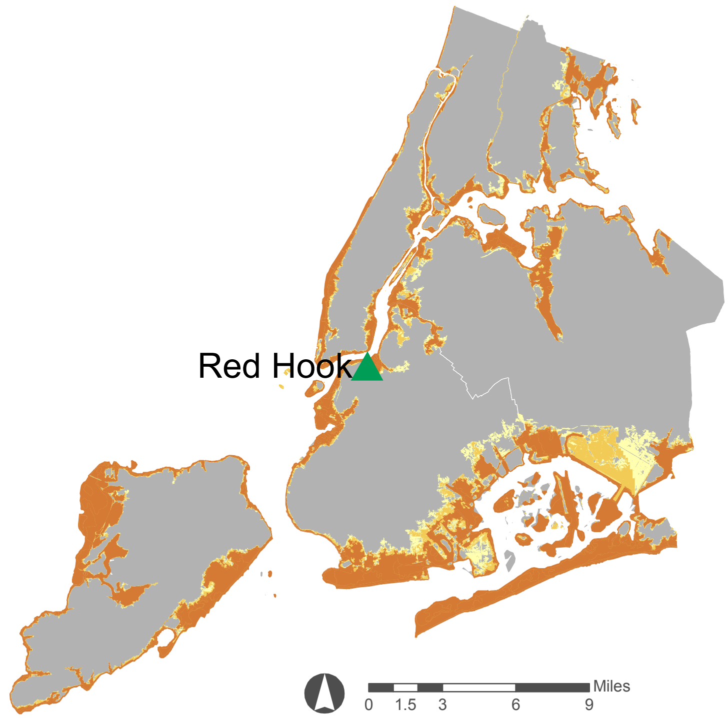
PLANT DESCRIPTION

The Red Hook Wastewater Treatment Plant is located at the former Brooklyn Navy Yard in northwestern Brooklyn, Community District 6. The plant abuts the Lower East River on the north, West Street to the west, Ship Ways to the south, and the East Way and the Lower East River to the east. General plant characteristics for Red Hook can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +14.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.3 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	60
Maximum Wet Weather Flow (MGD)	120
Number of Residents Served	192,050
Discharge Waterbody	Lower East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+14.5 ft NAVD88 (+13.0 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Elevation	+11.7 ft NAVD88 (+10.2 ft Brooklyn Highway Datum)
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	No

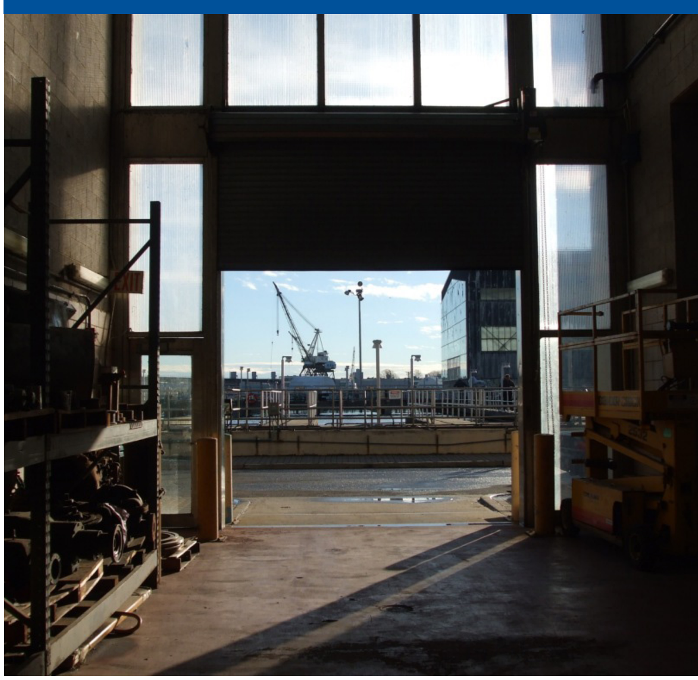
FEMA Flood Zones near Red Hook Wastewater Treatment Plant



- 2013 Advisory 100-Year Floodplain
- Projected 2020s 100-Year Floodplain
- Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways



Rollup doors at the Main Building

Fencing surrounding the outdoor Electrical Substation

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Red Hook. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation.

While much of the plant was unaffected during Hurricane Sandy, because the critical flood elevation is approximately 3 feet higher than the recorded Sandy elevation, most of the plant is projected to be flooded in the critical flood event. Most locations will be flooded with a foot of water or less; however, the Truck Loading Area and Ferric Chloride Storage Area may be flooded with up to 6 feet of water.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 1,281 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment. Of particular concern are many of the pumps which convey sewage and sludge through the plant. This equipment is located below ground in the tunnel system, which is at-risk through a number of pathways, including vaults, conduits, and the Solids Handling Facility near the northern seawall that flooded during Hurricane Sandy.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power, would be approximately $67.4 million.

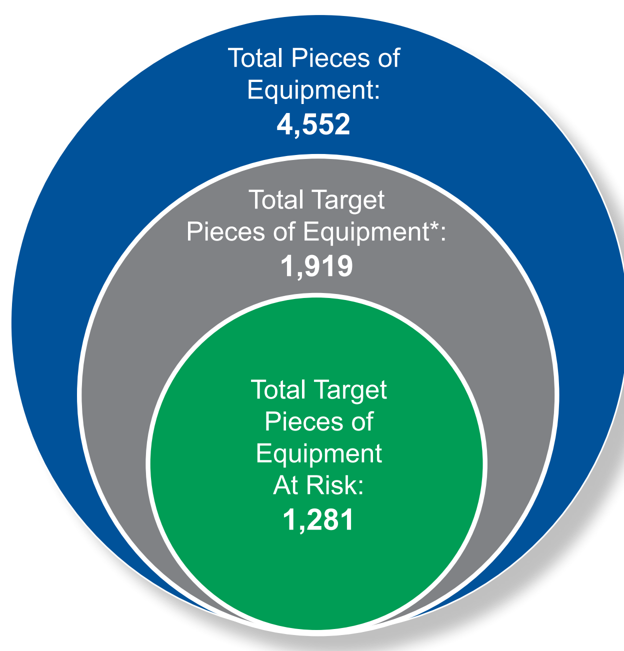
ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Red Hook. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the at-risk areas at Red Hook contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen that protect openings into the plant areas. Given the space constraints within basements and the tunnel system, it is recommended that the transfer pumps be replaced with submersible pumps at the end of their life cycle. In the interim, as applicable depending on location, the infrastructure can be effectively protected by sandbagging, providing watertight doors, or constructing barriers across flood pathways. In particular, the Thickener and Centrifuge Buildings can be protected to reduce the likelihood of flooding in the tunnels.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

In total, the cost to implement all recommended strategies at Red Hook is $18.6 million. While this cost is high, the potential damage cost that a large surge may impose totals $67.4 million. As the recommended strategies would also protect infrastructure during smaller storm events, the total value of risk avoided over a 50-year time span is estimated at $25 million, which is 33 percent more than the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Brooklyn during flood events, reduce sewage bypasses, and protect public health.

Table B: Red Hook Adaptation Strategy Recommendations

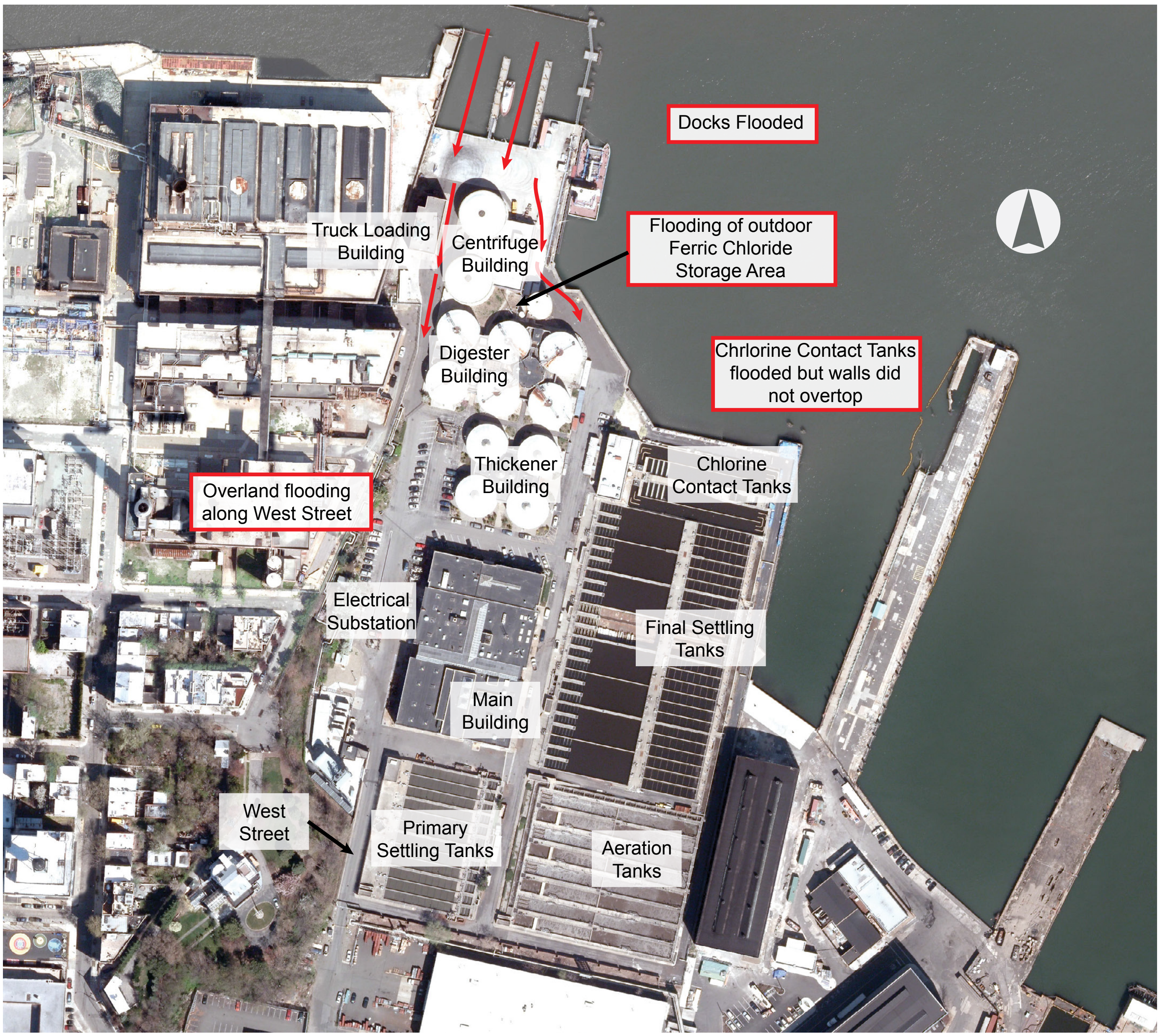
Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Aeration Tanks	No Action Required	$0	$301,000	$0	No Protection
Chlorine Contact Tanks	Elevate Equipment	$44,000	$24,000	$11,000	Very High
Centrifuge Building	Sandbag	$320,000	$5,061,000	$1,571,000	Moderate-Low
Chlorination Building	Elevate Equipment	$511,000	$651,000	$220,000	Very High
Digester Building	Seal Building	$557,000	$7,068,000	$2,324,000	Moderate
Electrical Substation	Elevate Equipment and Construct Barrier	$993,000	$8,220,000	$3,842,000	Very High
Main Building	Elevate Equipment and Seal Building	$8,896,000	$33,561,000	$11,998,000	High
Primary Settling Tank	Flood-proof Equipment and Construct Barrier	$5,891,000	$4,635,000	$2,448,000	Very High
Thickener Building	Flood-proof Equipment and Seal Building	$1,352,000	$7,299,000	$2,536,000	High
Truck Loading Building	No Action Required	$0	$556,000	$0	No Protection
Total for All 10 At-Risk Locations		**$ 18.6 M**	**$ 67.4 M**	**$ 25.0 M**	

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

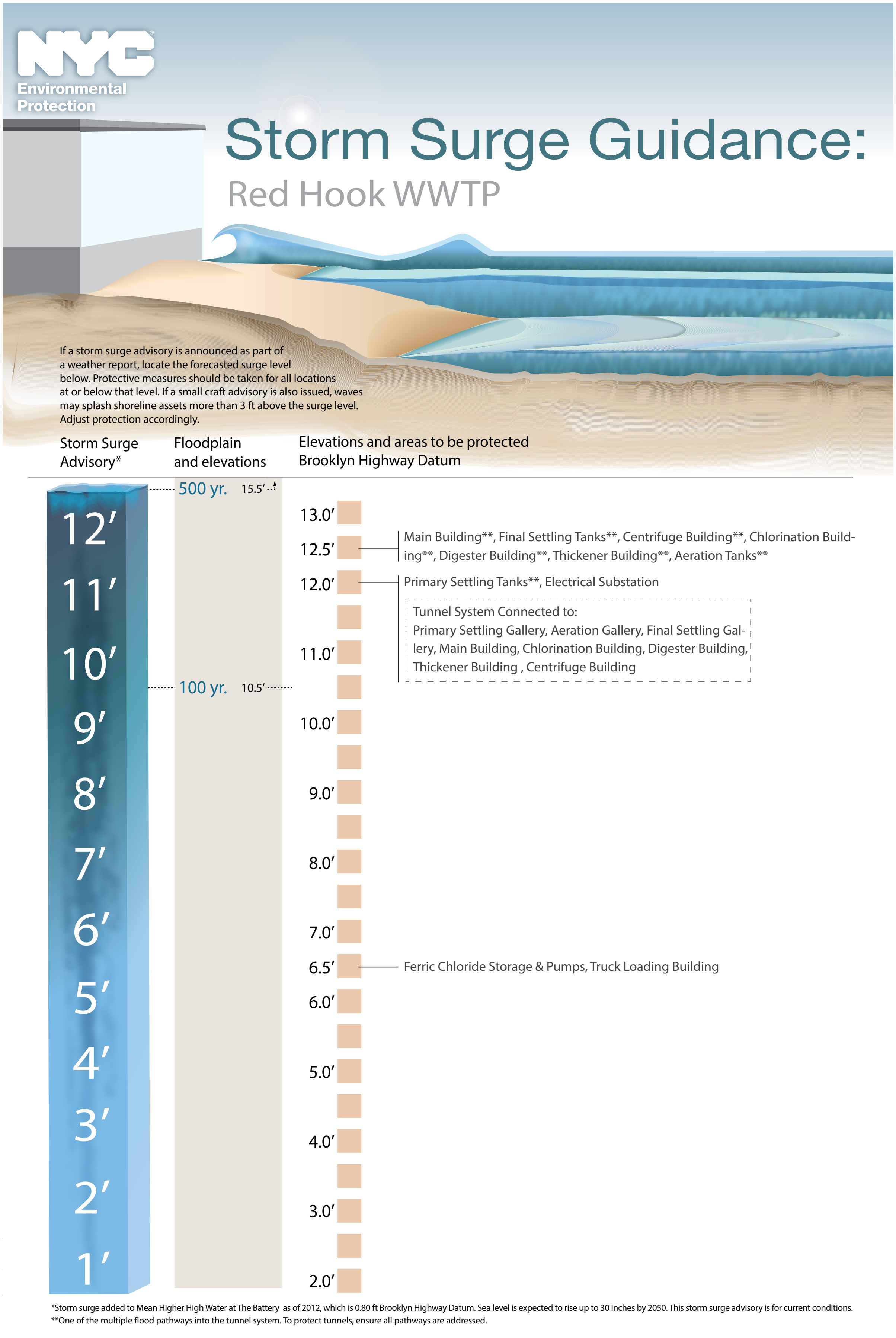
HURRICANE SANDY IMPACTS

Red Hook experienced minor flooding as a result of Hurricane Sandy. During the peak of the storm, floodwaters entered the plant from the northern seawall, flooding the barge docks and the Ferric Chloride Storage Area with over 3.5 feet of flood water. Overland flooding occurred along West Street near the Sludge Storage Tanks, Gas Holder Tank, and Sludge Digester Building near the Digester and Thickener Tanks. Floodwaters did not reach the Main Building or Solids Handling Facility, both of which contain numerous pumps and electrical equipment.

Floodwater that entered through the plant outfall caused build up in the Chlorine Contact Tanks, but did not overtop the tank walls. The plant staff worked actively before, during, and after the storm to protect the plant by sandbagging doors in locations at the north end of the plant, including the Sludge Storage Tanks, Dewatered Sludge Truck Loading Building, Centrifuge Building and Digester Building. Critical equipment needed to perform basic (primary) treatment at the plant was not damaged.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Rockaway Wastewater Treatment Plant

PLANT DESCRIPTION

The Rockaway Wastewater Treatment Plant is located on Beach Channel Drive on the south side of Rockaway, NY. The plant abuts Rockaway Freeway to the south, Beach Channel Drive to the north, and lies between Beach 108th Street and Beach 104th Street. The plant is located between two waterbodies, Jamaica Bay to the north and the Atlantic Ocean to the south. General plant characteristics for Rockaway can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +14.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +2.4 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	No
Design Dry Weather Flow (MGD)	45
Maximum Wet Weather Flow (MGD)	90
Number of Residents Served	90,474
Discharge Waterbody	Jamaica Bay
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+14.5 ft NAVD88 (+12.9 ft Queens Datum)
Hurricane Sandy Flood Elevation	+11.4 ft NAVD88 (+9.8 ft Queens Datum)
Hurricane Sandy Flood Damage	Major
High Likelihood to Impact Beaches	Yes

FEMA Flood Zones near Rockaway Wastewater Treatment Plant

2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Rollup doors on the Sludge Storage Building adjacent to Jamaica Bay are potential pathways for flooding as experienced during Hurricane Sandy. The Sludge Storage Building is also an access point into the plant's interconnected tunnel system.

Rollup doors at the Electrical Substation Building

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Rockaway. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation.

Since the plant has a relatively flat terrain and it is located between two waterbodies, several areas may be flooded by up to 7 feet of water during the critical flood event. There is also an extensive underground tunnel system that connects all locations (except the Electrical Substation and the Heating Plant) that can convey water throughout the plant if not properly protected. The main at-risk pathways to the tunnel are doorways in the new and old Sludge Storage Buildings, which will require robust protection. Lastly, a number of open tanks would be flooded during the critical flood, and could contribute to cleanup costs on site.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 689 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power, would be approximately $49.3 million.

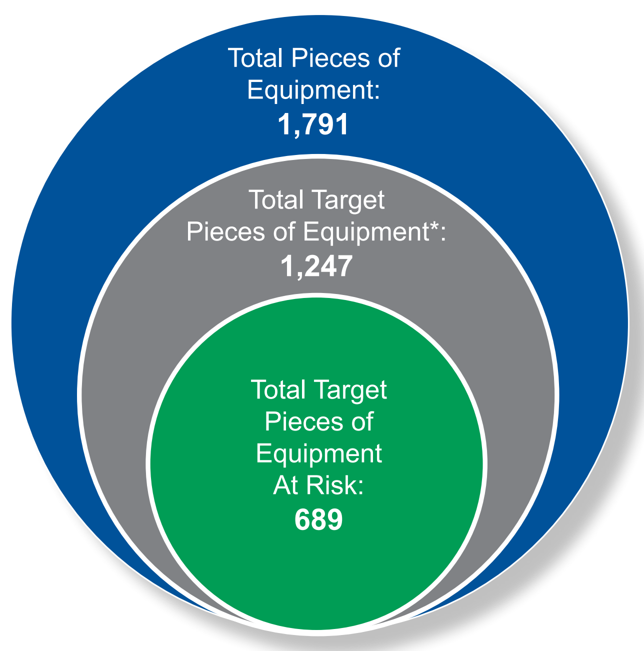
ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Rockaway. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the at-risk areas at Rockaway contain critical infrastructure, often elevating equipment was the chosen strategy since it provides a high degree of protection. In locations where not all infrastructure could be elevated, additional strategies were chosen that protect openings into the plant areas. For example, since Rockaway is susceptible to flood damage from an interconnected, underground tunnel system, constructing barriers around grates and hatches leading into the tunnel is recommended. These barriers, combined with watertight doors and windows in buildings with basements leading to the tunnels, will greatly reduce the plant's risk and prevent floodwaters from traveling throughout the plant, and damaging target pieces of equipment. In addition, when replacing old pumps, plant staff may consider installing submersible pumps to provide further resiliency.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

DEP is also investigating the feasibility and logistics of converting Rockaway into a pumping station, amongst other alternatives, which may reduce the need to fund substantial capital projects to heavily protect and reinforce many of the buildings and equipment on site. Regardless of the alternative selected, some resiliency upgrades will likely be needed at Rockaway.

If all recommended resiliency upgrades are implemented at the Rockaway Wastewater Treatment Plant, the total cost of implementation is $15.1 million. While this cost is high, the potential damage cost that a large surge may impose totals $49.3 million. Furthermore, since Rockaway is at a relatively low elevation, smaller flood events could affect this site. As the recommended strategies would also protect infrastructure during these smaller events, the total value of risk avoided over a 50-year time span is estimated at $198.1million, which is more than 13 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Queens during flood events, reduce sewage bypasses, and protect public health.

Table B: Rockaway Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Chlorination Building	Elevate Equipment	$2,048,000	$1,729,000	$8,900,000	Very High
Chlorine Contact Tanks (N. of Beach Channel Dr.)	Elevate Equipment	$58,000	$127,000	$660,000	Very High
Electrical Substation	Elevate Equipment and Construct Barrier	$1,604,000	$4,558,000	$23,453,000	Very High
Final Setting Tanks	No Action Required	$0	$1,382,000	$0	No Protection
Heating Plant	Elevate Equipment	$37,000	$1,169,000	$815,000	Low
Main Sewage Pump Station	Seal Building	$751,000	$5,135,000	$23,778,000	Moderate
New Digester Building	No Action Required	$0	$1,139,000	$0	No Protection
New Sludge Storage Building	Seal Building	$493,000	$404,000	$1,872,000	Moderate
Old Digester Building	Sandbag	$158,000	$1,569,000	$662,000	Moderate-Low
Primary Scum Building	Flood-proof and Elevate	$2,142,000	$2,872,000	$14,270,000	High
Pump and Compressor Building	Elevate Equipment and Seal Building	$2,594,000	$9,694,000	$48,094,000	High
Return and Waste Sludge Pump Building	Elevate Equipment and Seal Building	$3,147,000	$8,248,000	$40,822,000	High
Sludge Thickener Building	Seal Building	$1,332,000	$7,300,000	$33,804,000	Moderate
Tunnels	Construct Barrier	$752,000	$3,957,000	$967,000	High
Total for All 14 At-Risk Locations		**$ 15.1 M**	**$ 49.3 M**	**$ 198.1 M**	

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

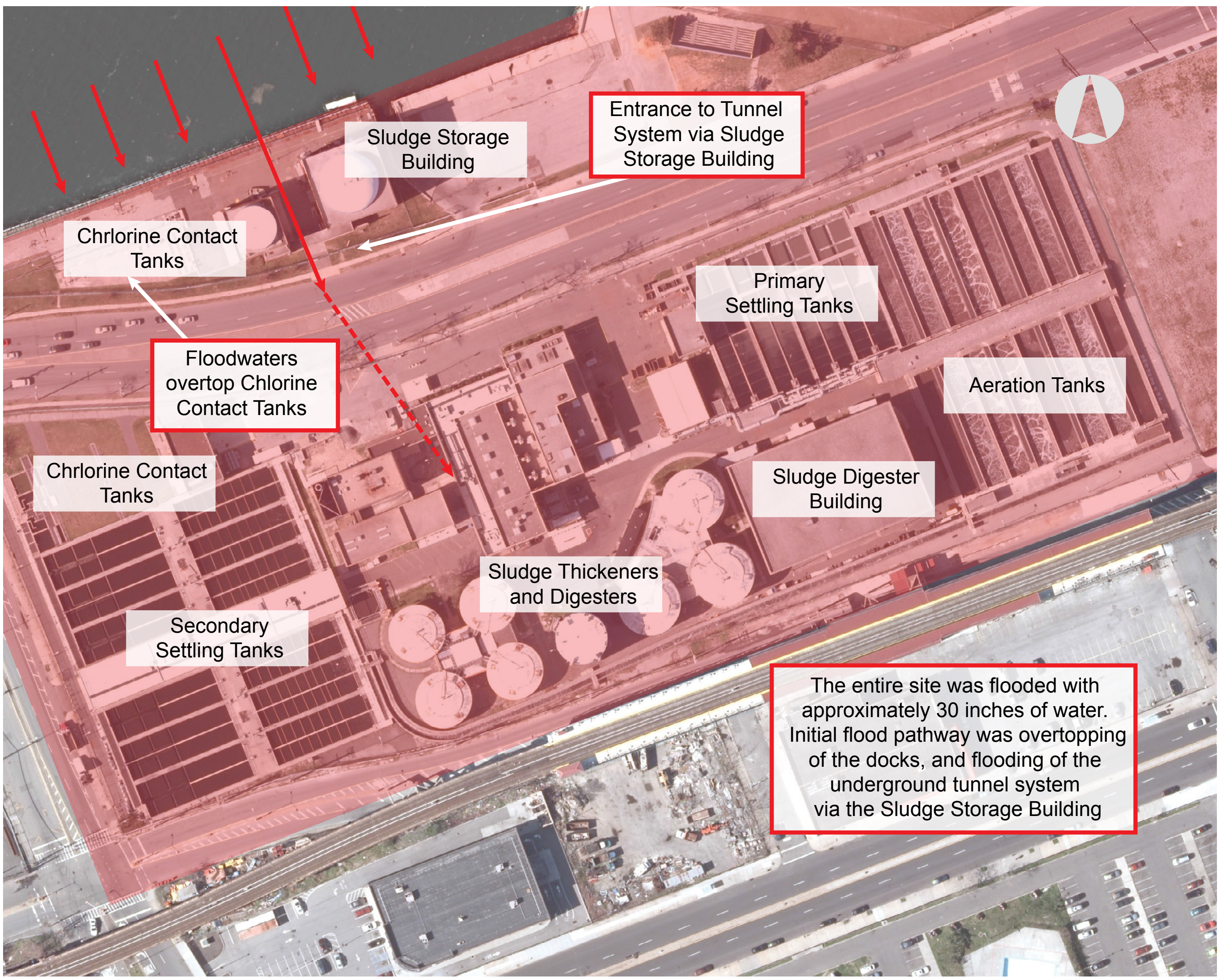
HURRICANE SANDY IMPACTS

Rockaway experienced major flooding as a result of Hurricane Sandy. During the peak of the storm, storm surge water from Jamaica Bay entered the plant by overtopping the dock on the north side of the plant. Initially, water flooded the underground tunnel system via doorways and conduits in the Solids Storage Facility, and as the storm progressed, floodwater traveled over Beach Channel Drive and into the plant, flooding the entire site with approximately 30 inches of water. Due to the plant's interconnected underground tunnel system, all equipment located in the basement levels of plant buildings endured significant damage. The main sewage pumps and their control systems were damaged, aeration piping in basements was detached from its supports, numerous motors and sludge transfer pumps were submerged, and electrical equipment and conduits in the tunnels were exposed to floodwaters (which willl likely advance their corrosion over time). Plant staff took precautions ahead of the storm by placing sandbags at all doorways and rollup doors, but due to numerous access ways into the tunnel system, and the significant amount of floodwater that entered the plant, the sandbags were not adequate to protect the buildings.

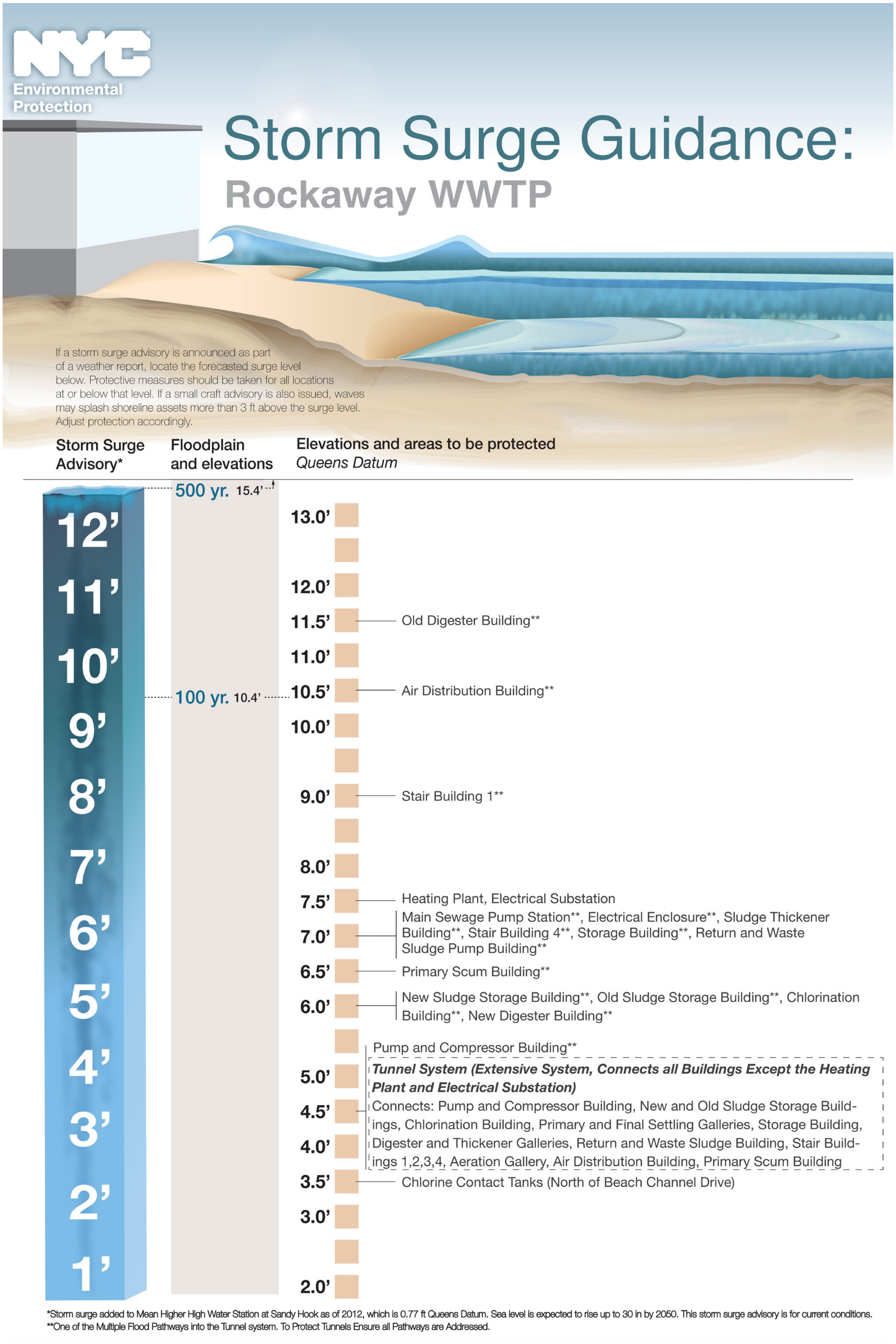
Following the flood event, major dewatering and temporary pumping operations were required. In addition, major equipment replacement and repair commenced.

Based on the flood damages incurred during this storm surge, it is evident that a comprehensive adaptation plan will be required to protect the plant under the critical flood elevation, which is approximately 3 feet higher than the elevation experienced during Hurricane Sandy.

DEP is also investigating the feasibility and logistics of converting Rockaway into a pumping station, amongst other alternatives, which would reduce the need to fund substantial capital projects to heavily protect and reinforce many of the buildings on site.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Tallman Island Wastewater Treatment Plant

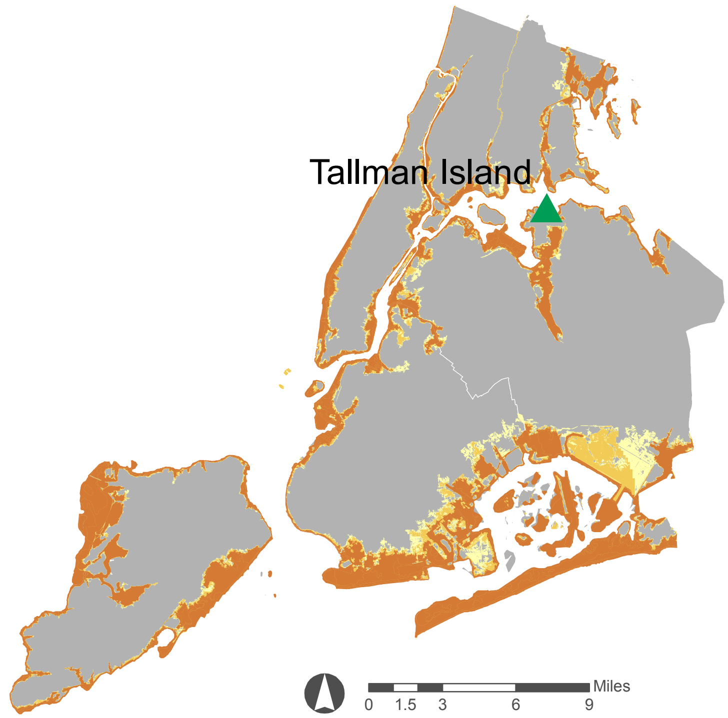
PLANT DESCRIPTION

The Tallman Island Wastewater Treatment Plant is located on a 31-acre site at 127-01 Powell's Cove Boulevard, College Point, in north central Queens, Community District 7. The plant abuts Powell's Cove Boulevard and residential areas to the south, a marina and boatyard to the west, Powell's Cove to the east, and the East River to the north. General plant characteristics for Tallman Island can be found in Table A. The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater at the plant may reach +15.5 feet NAVD88. In contrast, the typical high tide elevation nearby is +8.5 feet NAVD88.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	80
Maximum Wet Weather Flow (MGD)	120
Number of Residents Served	410,812
Discharge Waterbody	East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	+15.5 ft NAVD88 (+13.9 ft Queens Highway Datum)
Hurricane Sandy Flood Elevation	+10.1 ft NAVD88 (+8.5 ft Queens Highway Datum)
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	No

FEMA Flood Zones near Tallman Island Wastewater Treatment Plant



2013 Advisory 100-Year Floodplain
Projected 2020s 100-Year Floodplain
Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways

Grate and windows leading to the basement of the Sludge Thickener Building and tunnel system

Basement access ways into the Chlorine Building

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood event at Tallman Island. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation. Since the plant has a relatively flat terrain on the north, some areas may be flooded by up to 7 feet of water during the critical flood event.

An infrastructure-level assessment identified whether certain pieces of equipment needed to meet basic levels of service are located in plant areas that are at risk. There is a total of 773 target pieces of equipment located in these at-risk facilities that are below the critical flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment. Of particular note, various critical pumps are located in the basements of a number of buildings, including the Preliminary Sludge Pump Station, Digesters, North and South Thickener Buildings, and Grit Building, all of which are connected by a tunnel system. In addition, both the Final Settling and Chlorination Tanks would be flooded.

Table B provides a complete list of plant areas containing critical equipment at risk in the 100-year flood with 30 inches of sea level rise. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power, would be approximately $45.2 million.

ADAPTATION STRATEGIES

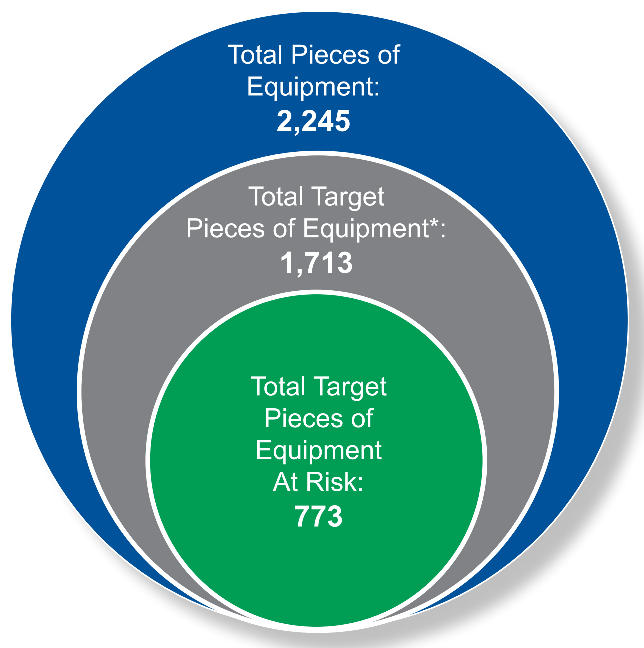
A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Tallman Island. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of damage potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

Since many of the at-risk areas at Tallman Island contain critical infrastructure, often elevating and flood-proofing were chosen as strategies since they provide a high degree of protection. In locations where not all infrastructure could be elevated or flood-proofed, additional strategies were chosen that protect openings into the plant areas.

The Chlorine Building, in particular, requires robust protection as it would experience several feet of flooding under the critical flood event and contains numerous pieces of equipment needed to disinfect wastewater. As such, waterproofing chemical feed pumps and sealing the building with water-tight windows and doors is recommended. Likewise, the Grit Building and Thickener Building are also key locations that require several protection measures, since they have thresholds below the critical flood which lead to the tunnel system.



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

In total, the cost to implement all recommended strategies at Tallman Island is $11 million. While this cost is high, the potential damage cost that a large surge may impose totals $45.2 million. As the recommended strategies would also protect infrastructure during smaller storm events, the total value of risk avoided over a 50-year time span is estimated at $32.8 million, which is approximately three times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Queens during flood events, reduce sewage bypasses, and protect public health.

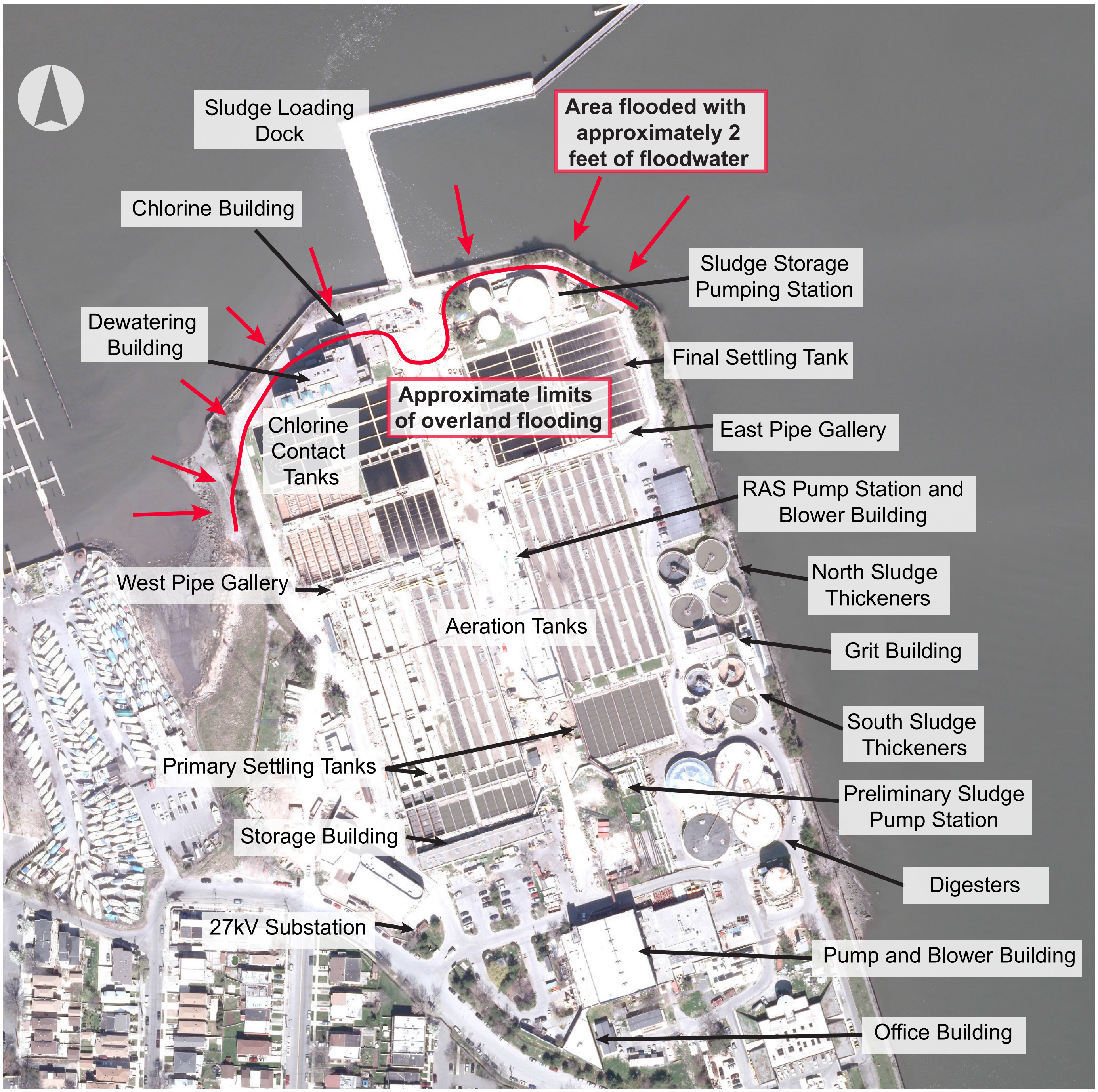
Table B: Tallman Island Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Chlorine Building	Flood-proof Equipment and Seal Building	$1,792,000	$1,298,000	$6,372,000	High
Chlorine Contact Tanks	Elevate Equipment	$37,000	$84,000	$28,000	Very High
Dewatering Building	Seal Control Room	$460,000	$11,023,000	$3,799,000	Moderate
Final Settling Tank	No Action Required	$0	$2,162,000	$0	No Protection
Grit Building	Sandbag	$320,000	$542,000	$190,000	Low
Mixed Flow Pump Station	Flood-proof and Elevate and Construct Barrier	$846,000	$1,550,000	$5,045,000	High
Sludge Storage Tanks	Construct Barrier	$347,000	$2,833,000	$7,037,000	High
South and North Thickener Buildings	Seal Building	$804,000	$12,163,000	$4,531,000	Moderate
Storage Building	Flood-proof and Elevate and Seal Building	$6,417,000	$13,521,000	$5,800,000	Very High
Total for All 9 At-Risk Locations		**$ 11.0 M**	**$ 45.2 M**	**$ 32.8 M**	

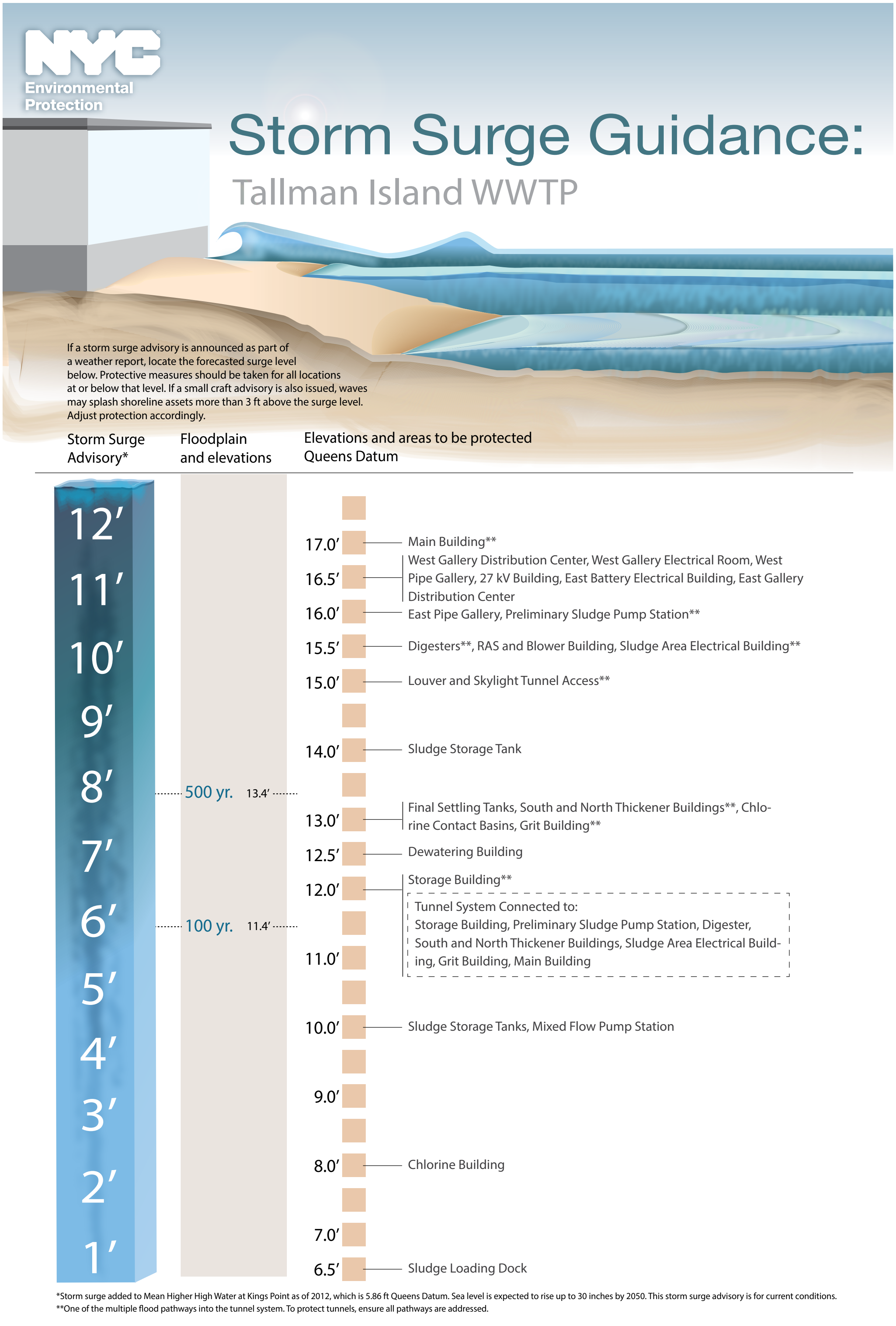
1) All cost estimates are presented in 2013 US Dollars
2) One-time replacement cost of at-risk equipment if no protective measures are in place and critical flood scenario occurs (i.e., current 100-year flood plus 30 inches). This estimate does not consider the probability of storm occurrence
3) Repair/replacement 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

HURRICANE SANDY IMPACTS

Tallman Island experienced minor flooding as a result of Hurricane Sandy. During the peak of the storm, floodwater submerged the sludge loading dock and inundated the roadway along the north end of the plant along the waterfront. Rising waters also encroached upon the central plant roadway, and approached the doorway of the Sludge Storage Building and some transformers mounted on pads next to the building; however, no damage was incurred. Floodwaters did enter the Chlorine Building through a few doors and basement access ways. However, flooding was reduced by plant staff who took precautions ahead of the storm by placing temporary slide gates and sandbags coupled with concrete traffic barriers across flood pathways. In addition, the sump pumps within the Chlorine Building maintained operation during the flood and no equipment in the building was significantly affected. While the plant did not endure significant flood damage, the wooden boardwalk surrounding the plant was severely damaged in the areas where the storm surge overtopped the perimeter bulkhead.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.

Wards Island Wastewater Treatment Plant

PLANT DESCRIPTION

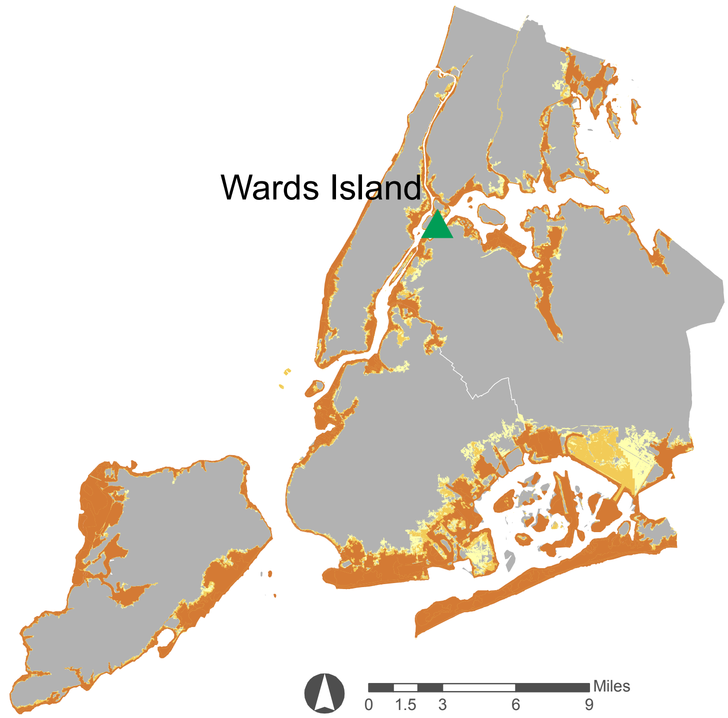
The Wards Island Wastewater Treatment Plant is located on the southwest side of Randall’s and Wards Island between the Harlem and East Rivers. The plant occupies approximately a quarter of the island’s total land area and is part of the borough of Manhattan, Community District 11. The plant abuts the New York City Fire Department Training Academy on the north and Hell Gate Circle to the south and west. The East River separates the site from Queens to the east.

Before entering the plant, sewage is pumped and screened at the Manhattan and Bronx Grit Chambers. The Manhattan Grit Chamber is at the eastern end of 110th Street in Manhattan, next to the FDR Drive. The Bronx Grit Chamber is located in the Bronx at 158 Bruckner Blvd, adjacent to 133rd Street. General plant characteristics for Wards Island can be found in Table A.

Table A: Wastewater Treatment Plant Characteristics

Characteristic	Value
Plant Type	Activated Sludge
Dewatering Facilities	Yes
Design Dry Weather Flow (MGD)	275
Maximum Wet Weather Flow (MGD)	550
Number of Residents Served	1,061,558
Discharge Waterbody	Upper East River
Critical 100-year Flood Elevation + 30 inches of Sea Level Rise	Wards Island and Manhattan Grit Chamber: +17.5 ft NAVD88 (+15.8 ft Manhattan Highway Datum) Bronx Grit Chamber: +14.5 ft NAVD88 (+13.0 ft Bronx Datum)
Hurricane Sandy Flood Elevation	+10.7 ft NAVD88
Hurricane Sandy Flood Damage	Minor
High Likelihood to Impact Beaches	No

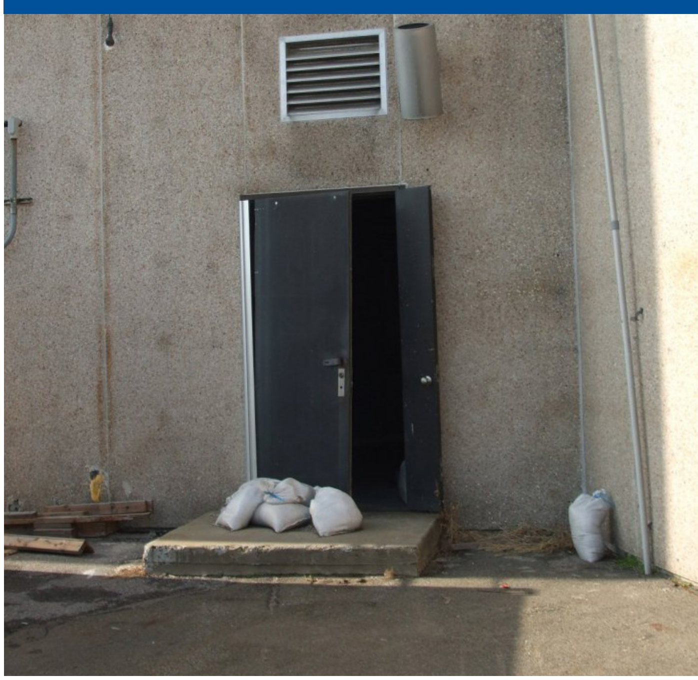
FEMA Flood Zones near Wards Island Wastewater Treatment Plant



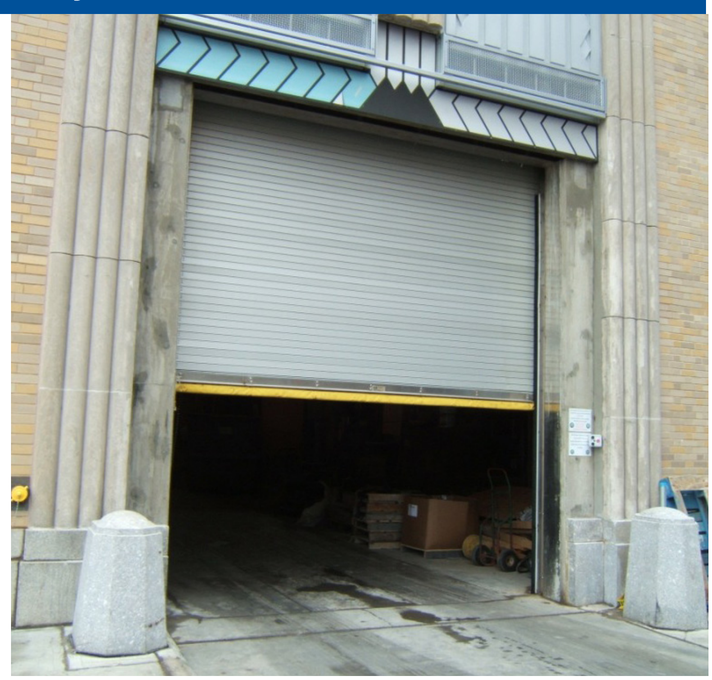
- 2013 Advisory 100-Year Floodplain
- Projected 2020s 100-Year Floodplain
- Projected 2050s 100-Year Floodplain

Source: FEMA; CUNY Institute for Sustainable Cities

Flood Pathways



Access door leading to the equipment rooms in the Sludge Storage Tank Building



This rollup door at the Manhattan Grit Chamber was a pathway for flooding during Hurricane Sandy and may be flooded during the critical flood event.

The critical flood elevation used in the analysis is the FEMA March 2013 advisory base flood elevation (ABFE) with 30 inches of projected sea level rise. The ABFE maps were developed to guide rebuilding efforts after Hurricane Sandy, and were replaced by the FEMA Preliminary Work Maps (PWM) in June 2013. Although it was not feasible to reassess all wastewater facilities using the PWMs, the critical flood elevations are in most cases very similar to the ABFE maps, and using the updated maps would not affect the results of this analysis. In the critical flood scenario, based on the 100-year flood event (from the ABFE) with 30 inches of sea level rise, floodwater my reach +17.5 feet NAVD88 at Wards Island and the Manhattan Grit Chamber and +14.5 feet NAVD88 near the Bronx Grit Chamber. In contrast, the typical high tide elevation nearby is +2.26 feet NAVD88.

RISK ASSESSMENT

A risk assessment was performed in two steps to determine the potential level of damage DEP might expect under the critical flood scenario at Wards Island. First, as part of the building-level assessment, potential flood pathways were identified at each location of the plant and determined to be at risk if located below the critical flood elevation.

Since the plant is at a relatively high elevation, only one area, the Sludge Storage Tanks, may be flooded by up to 6 feet of water during the design flood event. However, since the Manhattan Grit Chamber is at a relatively low elevation it may be flooded by up to 8 feet during the critical flood event. These areas are listed in Table B and were found to be at risk in a 100-year flood with 30 inches of sea level rise.

An infrastructure-level assessment identified what pieces of equipment needed to meet basic levels of wastewater pollutant removal are located in the Sludge Storage Tanks and Manhattan Grit Chamber. There is a total of 46 target pieces of equipment located in these at-risk facilities that are below the design flood elevation and are at risk of flooding. This equipment includes pumps, motors, electrical equipment, and other infrastructure associated with primary treatment. Immediately following a large flood event, the cost to replace this infrastructure, plus clean the plant and provide temporary pumping and power, would be approximately $8.7 million.

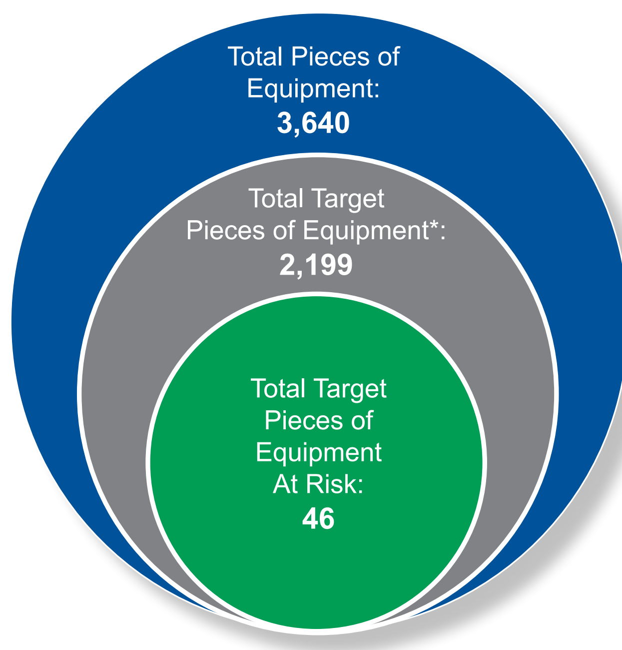
It was also found that the Bronx Grit Chamber may be flooded by approximately 6 inches of water under the critical flood event; however, since the infrastructure within the facility is high enough to be above the critical flood event, it is not considered at risk.

ADAPTATION STRATEGIES

A combination of recommended strategies to reduce damage and recovery time after a surge event was proposed for each at-risk location at Wards Island. Strategy selection was based on a feasibility analysis accounting for current site configurations and DEP's existing database (as of 2/7/2013) of active infrastructure, as well as a cost-risk analysis which compares the cost of implementing the strategy to the potential damage avoided. Strategy selection also accounted for the importance of infrastructure within a location for meeting basic treatment requirements.

When resiliency upgrades are planned, the proposed recommendations should be evaluated with consideration to other ongoing capital improvements and may be modified to account for new and changing site conditions and infrastructure.

Table B lists all plant locations containing target at-risk equipment, recommended planning-level strategies and the associated cost of implementation, cost of dam-



*All components needed to meet basic (primary) level of treatment and all electrical equipment, motors, and pumps

age potentially incurred during an individual storm, risk avoided over a 50-year time span, and level of resiliency the adaptation measure may provide to the selected location.

The two main rooms that need protection at the Manhattan Grit Chamber are the electrical room and generator room, both of which can be sealed with watertight doors and windows. Since some equipment does not reside in these rooms, this equipment should be flood-proofed individually. Likewise, the Wards Island Sludge Storage Tank contains a control room which can be sealed to protect valuable electrical equipment. Plant staff might also consider flood-proofing assets outside the electrical room to provide even higher resiliency.

In total, the cost to implement all recommended strategies at Wards Island and the Manhattan Grit Chamber is $1.5 million. While this cost is high, the potential damage cost that a large surge may impose totals $8.7 million. As the recommended strategies would also protect infrastructure during smaller storm events, the total value of risk avoided over a 50-year time span is estimated at $40.5 million, which is 27 times the cost of implementation. This favorable cost comparison provides strong economic support for implementing robust adaptation strategies, especially considering they would also minimize service disruptions in Manhattan during flood events, reduce sewage bypasses, and protect public health.

Table B: Wards Island Adaptation Strategy Recommendations

Location	Recommended Protective Measure	Cost of Protective Measures ($M)[1]	Damage Cost for Critical Flood without Protection ($M)[1,2]	Cumulative Risk Avoided Over 50 Years ($M)[1,3]	Resiliency Level
Manhattan Grit Chamber	Flood-proof Equipment and Seal Building	$1,017,000	$4,489,000	$20,839,000	Moderate
Wards Island Sludge Storage Tank	Seal Control Room	$460,000	$4,238,000	$19,620,000	Moderate
Total for 2 At-Risk Locations		**$ 1.5 M**	**$ 8.7 M**	**$ 40.5 M**	

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

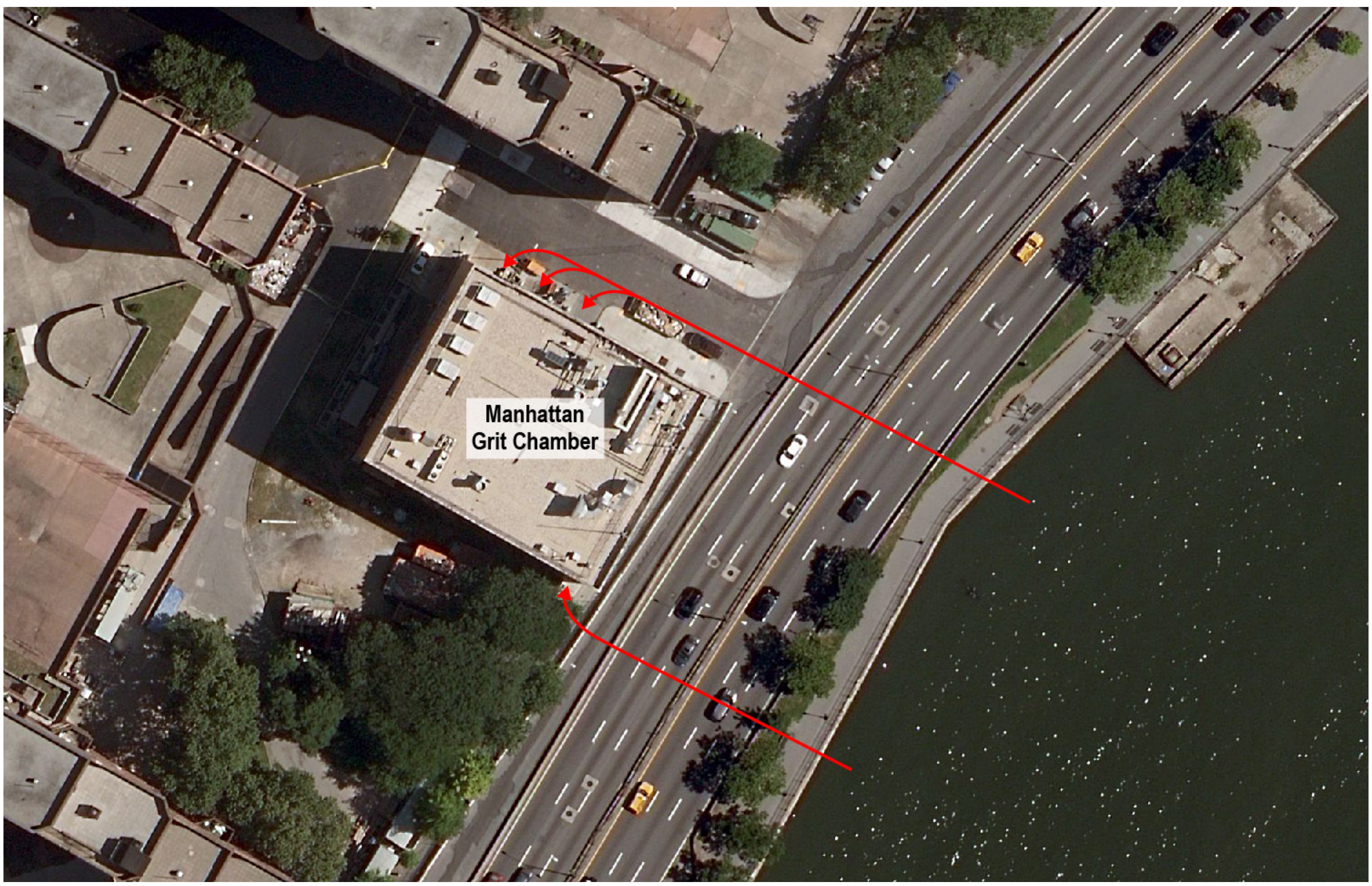
HURRICANE SANDY IMPACTS

Wards Island experienced minor flooding as a result of Hurricane Sandy. During the peak of the storm, water overtopped the eastern seawall near the Sludge Storage Tanks, which resulted in a small amount of flooding on the roadway. The water from the storm surge reached up to approximately 3 steps (21 inches) alongside the Chlorination Basin, but did not compromise the system. Plant staff took precautions ahead of the storm, that included sandbagging low-lying areas such as the doorway to the Sludge Storage Tanks, which successfully prevented floodwater from entering the structures.

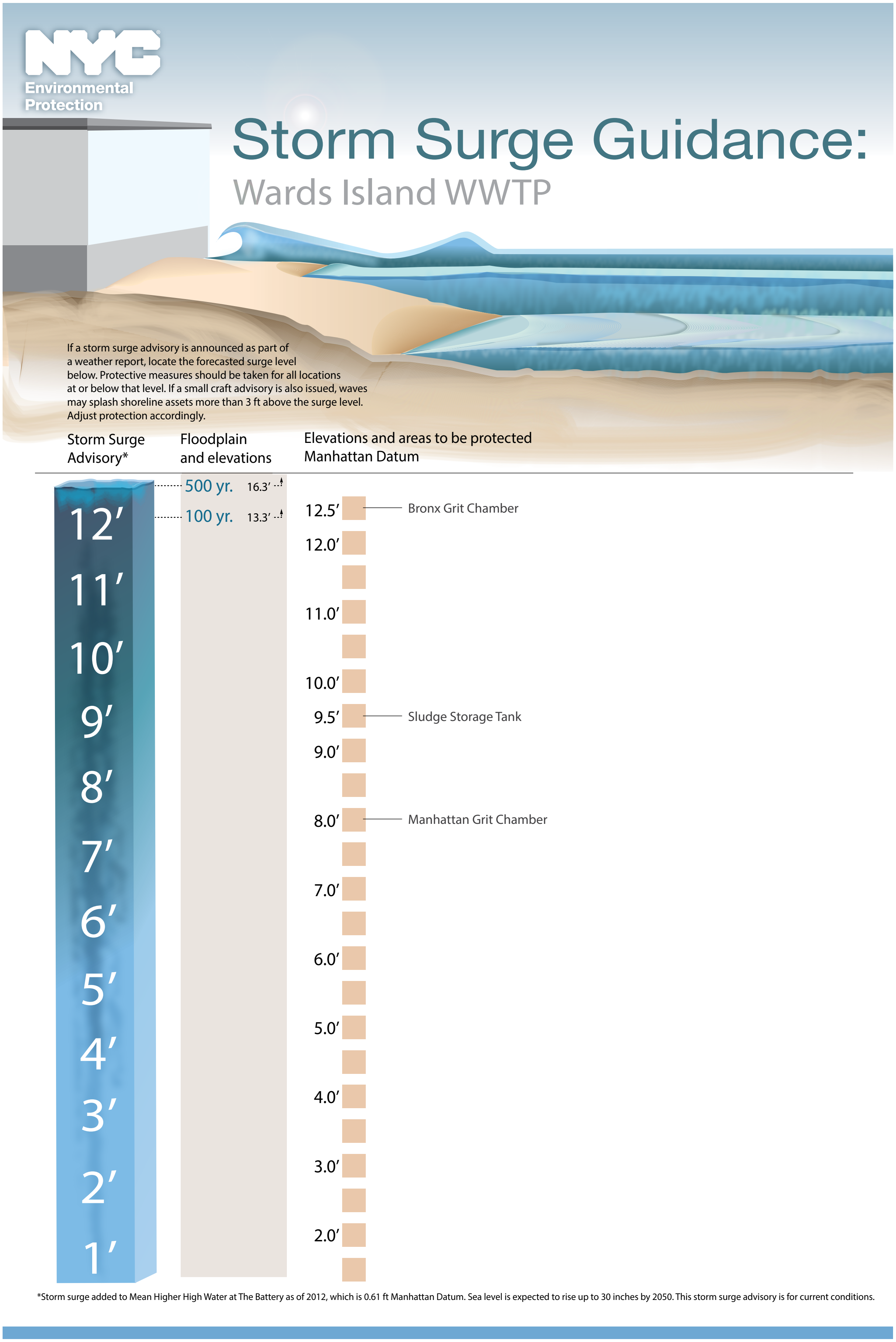
Greater impact was experienced across the river at the Manhattan Grit Chamber facility, which screens half the wastewater inflow before it enters the Wards Island Wastewater Treatment Plant. Water from the storm surge reached approximately 2 feet along the eastern exterior wall. While a concrete barrier provided protection along certain flood pathways, floodwaters still managed to penetrate the building via a rollup door and access door at grade. Fortunately, plant staff were able to protect the electrical room and emergency generator rooms at grade by opening floor hatches, which redirected flow to the basement.

However, had the storm surge reached the lower window sills and filled the basement, valuable electrical equipment including motor control centers for grit screening and associated backup power, may have been compromised.

The Bronx Grit Chamber experienced no flood damage as a result of Hurricane Sandy.



Flood pathways and areas flooded during Hurricane Sandy are highlighted in red.



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.