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June 26, 2015

Mr. Michael Moriarty
Director, Mitigation Division
FEMA Region 2
290 Broadway
New York, NY 10007

Re: Appeal of FEMA's Preliminary Flood Insurance Rate Maps for New York City

Dear Mr. Moriarty:

The City of New York respectfully submits the attached appeal of FEMA's January 2015 Preliminary Flood Insurance Rate Maps (FIRMs). This appeal demonstrates several errors that were made in the development of the Preliminary FIRMs that undermine their accuracy. The City relies on its FIRMs to provide a technically accurate picture of *current* flood risk in order to prudently communicate risk, guide building code requirements, and inform residents of the flood insurance premiums they can expect to pay. The City also uses its FIRMs as the basis for understanding *future* flood risk, in consultation with sea level rise projections, in order to inform project standards for coastal defense and related infrastructure. Accuracy of the FIRMs is, therefore, critically important.

In preparation for FEMA's statutory 90-day appeals period, the City systematically reviewed the underlying modeling used to produce FEMA's Preliminary FIRMs for New York City. Based on this review, the City is concerned that FEMA has made clear errors in its modeling that need to be addressed. As described in depth in the attached submission, FEMA has made two fundamental errors: 1) the flood models were insufficiently validated; and 2) tidal effects were misrepresented. These errors must be corrected.

The City takes flood risk very seriously. Even before Hurricane Sandy hit in 2012, the City was focused on better understanding its risk to flooding. In 2007, the City, aware that FEMA's 2007 FIRMs may not have adequately reflected New York City's flood risk, formally requested that FEMA update its maps and provided detailed topographical data to FEMA. Further, the City took action to understand the effects of climate change on the city. In 2008, the City convened the first New York City Panel on Climate Change (NPCC) to analyze future risks, including that of sea level rise and coastal flooding.

The City did not stop at simply understanding the threats of climate change, but instead moved aggressively to address those threats. In June 2013, the City released its comprehensive climate resiliency plan, *A Stronger, More*

Resilient New York. In April 2015, the City expanded and accelerated its commitment to addressing the risks of climate change and other 21st century threats through the release of *One New York: The Plan for a Strong and Just City.* At the core of both plans is a comprehensive approach to building the community, social, and economic resiliency of our neighborhoods; upgrading our buildings to be more resilient to the impacts of climate change; adapting infrastructure like transportation, telecommunications, water, and energy to withstand severe weather events; and strengthening our coastal defenses against flooding and sea level rise. The City's goal continues to be to ensure that FEMA's flood maps provide a representation of *current* flood risk based on sound scientific and technical analysis, so that appropriate building codes (freeboard requirements, for example) and other measures meant to address *future* flood risk can be appropriately implemented. To ensure that we invest wisely in the areas of the City at greatest risk and reach the City's resiliency goals, the City must have a scientifically accurate assessment of flood risk. This assessment starts with accurate FEMA FIRMs.

However, FEMA's January 2015 Preliminary FIRMs are not accurate. The impact of the technical and scientific errors identified in the City's analysis is significant. Specifically, FEMA's Preliminary FIRMs *overstate* Base Flood Elevations (BFEs) by more than 2 feet in many areas across New York City and *misrepresent* the Special Flood Hazard Area (SFHA) by 35 percent, unnecessarily putting approximately 26,000 buildings and 170,000 residents in the SFHA. This overestimation would have three important consequences. First, homeowners in the SFHA who invest in their homes could end up building or rebuilding to excessive heights at extra cost, with additional impacts on neighborhood character. Second, many homeowners in the SFHA would be asked to pay flood insurance premiums based on incorrect BFEs, causing an affordability challenge. And third, many homeowners that would otherwise not be in the SFHA, would be required to pay for flood insurance at higher rates, further exacerbating that affordability challenge.

Climate change continues to be the challenge of our generation and conveying this risk accurately is paramount. Inaccurate FIRMs would undermine the credibility upon which many other efforts are built and would require unnecessary spending. Because of this, the City urges FEMA to correct and reissue the Preliminary FIRMs.

As always, the City remains committed to working collaboratively with FEMA to ensure that we accurately assess and convey flood risk. We would be pleased to discuss this appeal with you at your convenience.

Sincerely,

Daniel A. Zarrilli

APPEAL OF FEMA'S PRELIMINARY FLOOD INSURANCE RATE MAPS FOR NEW YORK CITY

June 26, 2015

Submitted to FEMA Region II

By the City of New York

Mayor's Office of Recovery and Resiliency

Tables

Figures

Figures (continued)

Figures (continued)

Appendices

Acronyms and Abbreviations

ADCIRC	ADvanced CIRCulation
BFEs	Base Flood Elevations
CFR	Code of Federal Regulations
ET	Extratropical
FEMA	Federal Emergency Management Agency
FIRMs	Flood Insurance Rate Maps
FIS	Flood Insurance Study
GEV	Generalized Extreme Value
JPM-OS	Joint Probability Method-Optimal Sampling
LiMWA	Limit of Moderate Wave Action
m/s	Meters per Second
MSL	Mean Sea Level
NAVD88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NTDE	National Tidal Datum Epoch
PFIRMs	Preliminary Flood Insurance Rate Maps
Q-Q	Quantile-Quantile
RAMPP	Risk Assessment Mapping and Planning Partners
RMSE	Root-Mean-Square Error
SFHA	Special Flood Hazard Area
SWAN	Simulating WAves Nearshore

USC	United States Code
WHAFIS	Wave Height Analysis for Flood Insurance Studies

1.0 INTRODUCTION

On January 30, 2015[1], the Federal Emergency Management Agency (FEMA) issued Preliminary Flood Insurance Rate Maps (FIRMs) with proposed Based Flood Elevations (BFEs) and Special Flood Hazard Area (SFHA) boundaries for New York City. The new or modified flood hazard information is based on a coastal flood study conducted by FEMA Region II for portions of coastal New York and coastal New Jersey. FEMA Region II initiated a 90-day appeal period on March 31, 2015, following the issuance of the Preliminary FIRMs (PFIRMs). In accordance with Title 44 of the Code of Federal Regulations (CFR) Sections 67.5 and 67.6 and 42 United States Code (USC) Section 4104, New York City's PFIRMs are eligible for appeal because the City of New York (the City) is in possession of knowledge and information that indicate: (1) the BFEs being proposed by FEMA with respect to identified areas having special flood hazards are scientifically or technically incorrect; and (2) the designations of identified SFHAs are scientifically or technically incorrect.[2]

Based on the findings described in this document, the City is appealing the designations of the BFEs and SFHA boundaries defined in the PFIRMs. The City has identified two primary sources of bias errors in the storm surge and offshore wave models and methodology that have resulted in incorrect BFEs and SHFA boundaries: (1) insufficient extratropical storm model validation; and (2) misrepresentation of tidal effects for extratropical storms. As required by the National Flood Insurance Program (NFIP) regulations and explained further in FEMA guidance documents[3], the City is providing extensive data, analyses, formulae, modeling, and explanations for each basis of appeal in the subsequent sections of this document.

As a participant in FEMA's NFIP since 1974[4], the City seeks to continue working with FEMA to manage New York City's floodplain, using updated maps that are the most technically correct maps possible, free of scientific errors. Because of the impacts the errors in FEMA's PFIRM coastal analysis have on informed decision making associated with the management of flood risk, the City is demonstrating its commitment to the NFIP by creating a new coastal analysis based on corrected, alternative methodologies and submitting it to FEMA within the 90-day appeal period. ARCADIS staff led by Hugh J. Roberts, as well as Perry Rhodes of ATCS and Don Resio of the University of North Florida, supported the City's scientific and technical analyses.

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[1]The initial Preliminary Flood Insurance Rate Maps were released by FEMA in December 2013. Updated versions for some panels were released in January 2015. The final versions for all panels, regardless of release date, are the subject of this document and are herein referred to as the 2015 Preliminary Flood Insurance Rate Maps or PFIRMs.

[2]Scientifically incorrect" means "[t]he methodology(ies) and/or assumptions which have been utilized are inappropriate for the physical processes being evaluated or are otherwise erroneous." 44 CFR §59.1. "Technically incorrect" means "[t]he methodology(ies) utilized has been erroneously applied due to mathematical or measurement error, changed physical conditions, or insufficient quantity or quality of input data." Id.

[3]See 42 USC §§4101b & 4104; 44 CFR §§67 & 68: FEMA, Appeals, Revisions, and Amendments to National Flood Insurance Program Maps: A Guide for Community Officials, December 2009; FEMA, Criteria for Appeals of Flood Insurance Rate Maps, November 30, 2011.

[4]On June 28, 1974, New York City joined the Emergency Program of the NFIP with the adoption of Flood Hazard Boundary Maps. On November 16, 1983, the City adopted the first FIRM with a detailed flood study.

This section provides an overview of FEMA's PFIRM coastal analysis and introduces the technical and/or scientific incorrectness in the analysis. The bases for appeal are then discussed to show "that alternative methods or applications result in more correct estimates of base flood elevations, thus demonstrating that FEMA's estimates are incorrect (44 CFR §67.6)."

1.1 OVERVIEW OF FEMA COASTAL ANALYSIS

FEMA's PFIRMs for New York City (subsequently referred to as the 2015 PFIRMs) were generated based on a coastal storm analysis and updated topographic information for portions of FEMA Region II in New York and New Jersey. The Flood Insurance Study (FIS) and other associated documentation that supported the release of the 2015 PFIRMs were assembled by FEMA and FEMA's contractor, Risk Assessment, Mapping, and Planning Partners (RAMPP), and are referenced throughout this document. Though many of these documents are dated prior to 2015, they comprise the supporting documentation for the FIS associated with the 2015 PFIRMs.

In the 2015 PFIRM coastal analysis, FEMA performed numerical simulations using the ADvanced CIRCulation (ADCIRC) (Luettich and Westerink 2004) and Simulating WAves Nearshore (SWAN) (SWAN 2006) numerical models and conducted statistical analysis using a Joint Probability Method-Optimal Sampling (JPM-OS) scheme (Resio 2007; FEMA 2008; Toro et al. 2010; Niedoroda et al. 2010) and extreme value theory. ADCIRC and SWAN were coupled (ADCIRC+SWAN) to simulate water surface elevations due to the combination of astronomical tide, storm surge, and waves for two main types of storm events: extratropical (ET) and tropical storms. FEMA chose 30 historical ET storms and generated 159 synthetic tropical storms to produce a data set of peak water levels throughout the study area for the recurrence analysis. Generally, the ET storms with the largest storm surge residuals at gage locations in New York and New Jersey were selected for the study, including the ET storms of November 25, 1950; March 29, 1984; October 31, 1991; and December 11, 1992.

As part of the FEMA modeling approach, each synthetic tropical storm surge was made to coincide with one random tide (for a total of 159 tropical storm simulations) and each ET storm surge was made to coincide with two random tides (for a total of 60 ET storm simulations), equaling a combined total of 219 storm tide simulation events (FEMA 2014a). A storm tide is defined herein as the combination of storm surge and astronomical tide. The peak storm tide elevations for each of the 219 simulation events at each ADCIRC+SWAN node were then applied in FEMA's recurrence analysis for determination of percent-annual-chance stillwater elevations at given return frequencies throughout the study area. A statistical analysis was performed for ET storms and tropical storms separately and then combined to define total 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations. Return interval stillwater elevations due to ET storms were computed by applying an L-Moment estimator to the Generalized Extreme Value (GEV) distribution, and return interval stillwater elevations due to tropical storms were calculated using a non-parametric frequency distribution based on the storm probability developed as part of the JPM-OS method (FEMA 2014b).

The resulting BFEs mapped in the 2015 PFIRMs include flood hazards comprised of 1-percent-annual-chance stillwater elevations and wave-induced setup, which were updated from the effective FIRMs for New York City released in 2007 (hereafter 2007 FIRMs). The Battery in Lower Manhattan (National Oceanic and Atmospheric Administration [NOAA] gage 8518750), a well-known location central to New York Harbor with measured water level data available since 1932, provides an example location to highlight the differences in stillwater elevations between the 2015 PFIRMs and the 2007 FIRMs. Table 1-1 lists the 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations at The Battery. Figure 1-1 shows the New York City area and NOAA gage locations, including The Battery.

Table 1-1. 2007 FIRM and 2015 PFIRM percent-annual-chance stillwater elevations at The Battery (FEMA 2007b; FEMA 2013).

Annual-Chance Stillwater Elevation at The Battery				
	10%	2%	1%	0.2%
2007 FIRMs (feet, NAVD88)	6.4	7.9	8.6	10.8
2015 PFIRMs (feet, NAVD88)	6.9	9.9	11.3	14.9
Increase from 2007 FIRMs to 2015 PFIRMs (feet)	0.5	2.0	2.7	4.1

Figure 1-1. Location map and NOAA gages in the New York City area.

Table 1-1 demonstrates that percent-annual-chance stillwater elevations from the 2015 PFIRMs significantly changed relative to the 2007 FIRMs. Specifically, the 1-percent-annual-chance stillwater elevation increased by 2.7 feet at The Battery. Changes in stillwater elevations resulted in changes to the SFHA boundaries between the 2007 FIRMs and 2015 PFIRMs throughout New York City, as shown on Figure 1-2. Variations in the SFHA boundaries are most substantial near Rockaway Peninsula, Jamaica Bay, Lower Manhattan, Newtown Creek, and Staten Island.

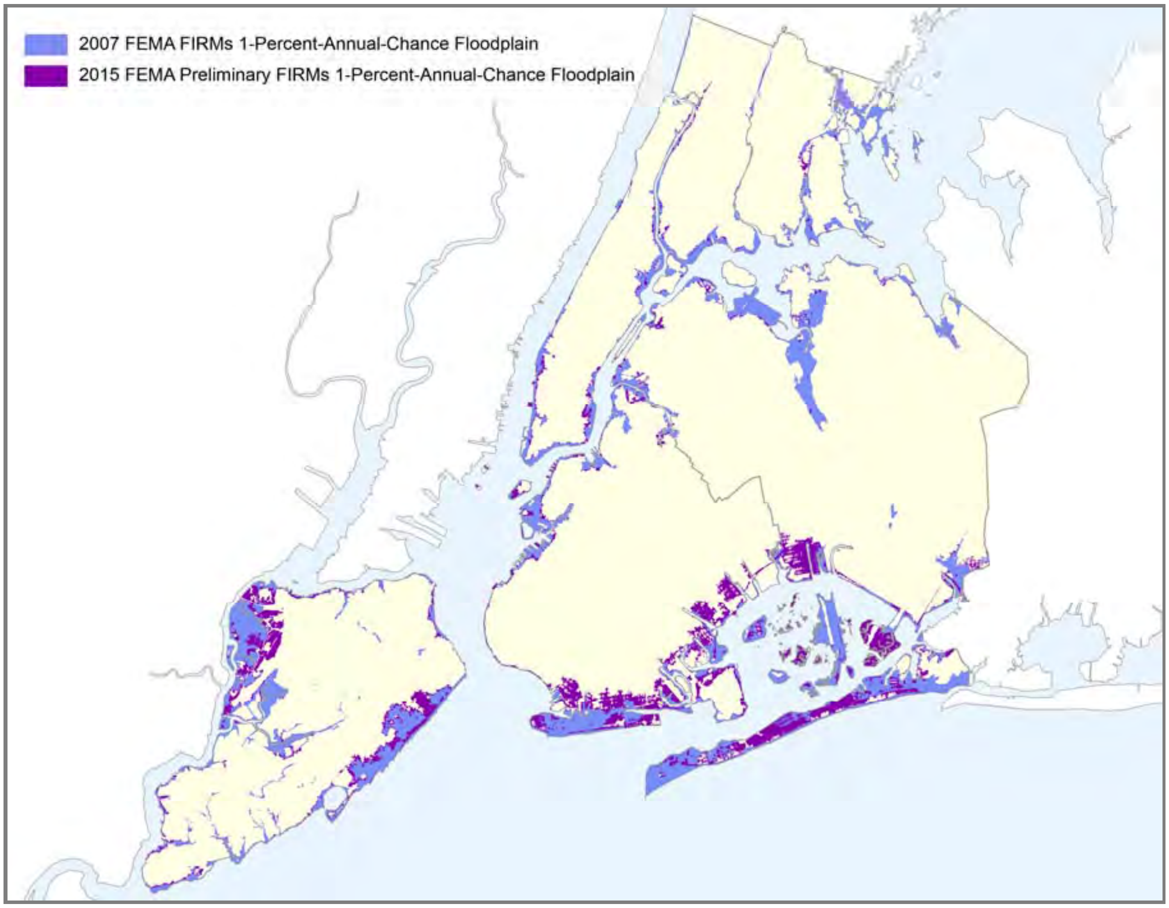


Figure 1-2. Citywide comparison of the 2007 FIRM and 2015 PFIRM 1-percent-annual-chance floodplains.

Tangible effects of the changes in the floodplain between the 2007 FIRMs and 2015 PFIRMs in New York City are listed in Table 1-2, including percent increases in residents, buildings, residential homes, and constructed floor area in the floodplain. One- to four-family homes (a subset of buildings in which one to four families reside) show the largest percent increase (120 percent), while the number of New York City residents in the floodplain (based on 2010 population numbers) increases to 400,000 from 218,000 in the 2007 FIRMs.

Table 1-2. Changes in residents and buildings in the 1-percent-annual-chance floodplain from the 2007 FIRMs to the 2015 PFIRMs.

1-Percent-Annual-Chance Floodplain*			
	2007 FIRMs	**2015 PFIRMs**	**Change (%)**
Residents	218,000	400,000	83%
Buildings	36,000	71,500	99%
1-4 Family**	26,000	57,400	120%
Floor Area (square feet)	377,000,000	532,000,000	42%

*Rounded for clarity

**A subset of the total number of buildings

1.2 BACKGROUND

New York City staff met with FEMA Region II staff on several occasions to discuss the findings of studies conducted by the City during their review of the 2015 PFIRMs. As part of the City's technical review of FEMA's PFIRM coastal analysis, the City discovered that FEMA's percent-annual-chance stillwater elevations for New York City were more heavily influenced by ET storms than tropical storms. Figure 1-3 demonstrates this trend at The Battery in Lower Manhattan. The red line on Figure 1-3 indicates the ET storm contribution to the total percent-annual-chance stillwater elevations, the blue line indicates the tropical storm contribution, and the black line indicates the combined values that form the total percent-annual-chance stillwater elevations. The 60 peak storm tide elevations from ET storm simulations are plotted over the ET storm frequency curve, with the 1950 ET storm data points shown as red squares. In order statistics, rare events dominate the tail of the exceedance probability curve, i.e., low frequencies. In the study area, ET storms reach the coast more frequently than tropical storms and there is no notable stratification in the order magnitudes of storm-associated extreme water levels (Walton 2000) between the two types of events. Therefore, tropical events are statistically more rare and significant at the tail of the exceedance curve. When combining statistics for both tropical storms and ET storms, it is expected that the contribution of tropical storms to the lower frequencies in the combined frequency curve should be considerable. However, for all percent-annual-chance values ranging from the 10 to 0.1 percent in FEMA's PFIRM coastal analysis, as shown on Figure 1-3, the ET storm statistics are predominant.

Note that the stillwater elevations on Figure 1-3 are in reference to mean sea level (MSL). In general, throughout this document, elevations are reported in either MSL (e.g., Figure 1-3) or North American Vertical Datum of 1988 (NAVD88) (e.g., Table 1-1). The reason for reporting in both datums is that ADCIRC+SWAN is set up with MSL as the datum, while FEMA mapping products like PFIRMs use NAVD88. Accordingly, most figures and tables in this document reference MSL, with the exception of those reporting revised stillwater elevations used for mapping or those comparing FEMA numbers reported in NAVD88.

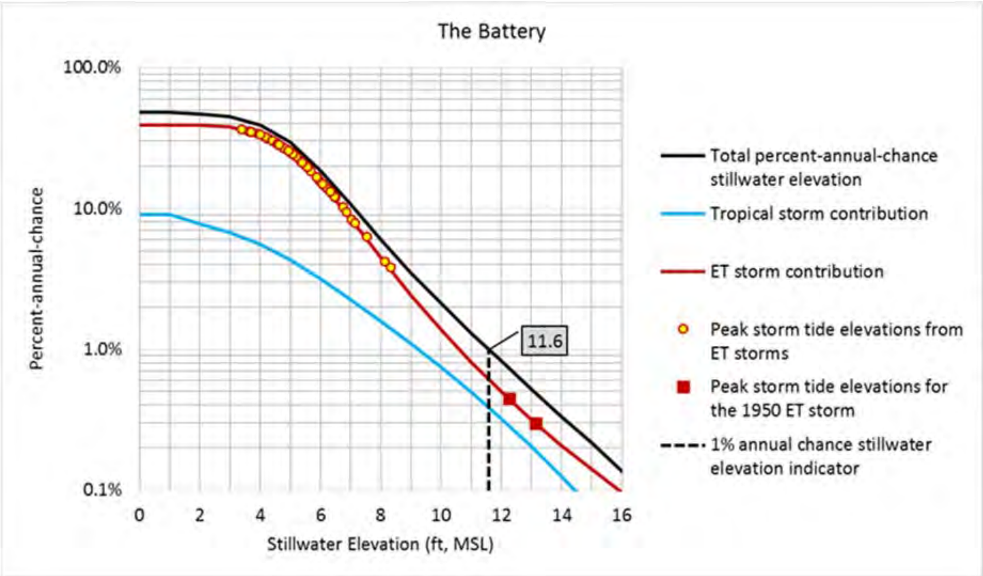


Figure 1-3. Contributions of tropical and ET storms to the total percent-annual-chance stillwater elevations at The Battery.

The trends for ET, tropical storm, and combined statistics shown on Figure 1-3 prompted the City to examine FEMA's overall approach more closely. This further analysis revealed that the two storm tide peaks from the FEMA 1950 ET storm simulations had outsized impacts on the ET frequency curve for low frequencies. Because of this, a simulation of the 1950 ET storm was performed under historical tide conditions using FEMA's ADCIRC+SWAN configuration. As shown on Figure 1-4, review of the simulation results revealed that the peak of the simulated storm tide elevation is 4.1 feet higher than the observed peak storm tide elevation at The Battery due to the meteorological inputs to the ADCIRC+SWAN model.

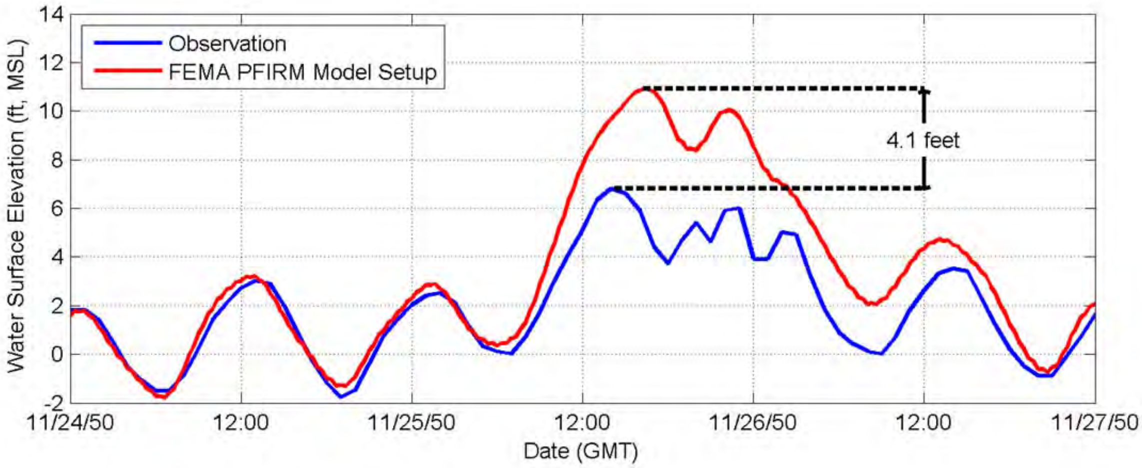


Figure 1-4. Comparison of 1950 ET storm observed water levels (feet, MSL) to simulated water levels (feet, MSL) at The Battery using the FEMA model configuration.

The overestimation in storm tide elevations for the 1950 ET storm due to the meteorological inputs to the ADCIRC+SWAN model was also recognized by FEMA as a potential technical issue that required further evaluation. Therefore, FEMA conducted an independent analysis described in the memorandum released by FEMA on March 31, 2015, with the subject heading *Investigation of Issues Regarding the Coastal Flood Hazard in New York Harbor* (RAMPP 2015). The memorandum evaluated the "impact of strong extra-tropical storms on the frequency analysis of stormwater levels and the uncertainty associated with the storm surge elevations computed in the surge study." The findings in FEMA's memorandum showed the peak storm tide level was overestimated by 4.2 feet in the FEMA simulations, which FEMA attributed to the meteorological forcing applied in the model.[5] [6] Yet FEMA concluded in the memorandum that "the differences in New York Harbor for the 1950 storm were unremarkable and well within the range of uncertainty of typical coastal flood study determination of the statistical flood levels."

The overestimation of the 1950 ET storm, however, remains a concern and is best demonstrated on Figure 1-5, which illustrates the impacts of the overestimation of the 1950 ET storm surge (meteorological

[5]Note that the FEMA analysis, and thus the City's analysis, adjusted the historical NOAA observed water levels (blue line on Figure 1-4) to account for sea level rise that has occurred from the time of the storm to the mid-point of the 1983-2001 National Tidal Datum Epoch (NTDE) such that all data were relative to the current epoch.

[6]The 0.1-foot difference in overestimation of the 1950 storm for the FEMA analysis and the City's analysis is believed to be due to slight differences in either model outputs or possibly differences in the values (e.g., number of decimal places) used to convert observed data to the mid-point of the 1983-2001 National Tidal Datum Epoch.

condition impacts only) on the percent-annual-chance stillwater elevations at The Battery. The Battery was selected as a representative location to illustrate findings to parallel the March 2015 FEMA memorandum, which also referenced The Battery as a representative location to quantify and illustrate findings. Similar to Figure 1-3, Figure 1-5 shows the frequency curves for tropical storms (blue line), ET storms (red line), and combined statistics (black line). However, the ET and combined curves on Figure 1-5 differ from those on Figure 1-3 in that the two FEMA-simulated 1950 ET storm tide peaks were reduced by 4.1 feet to demonstrate the impacts on percent-annual-chance stillwater elevations as a result of removing the overestimation of the 1950 ET storm surge (Figure 1-4). Again, the 60 peak storm tide elevations from ET storm simulations are plotted over the ET storm frequency curve, with the 1950 ET storm data points shown as red squares.

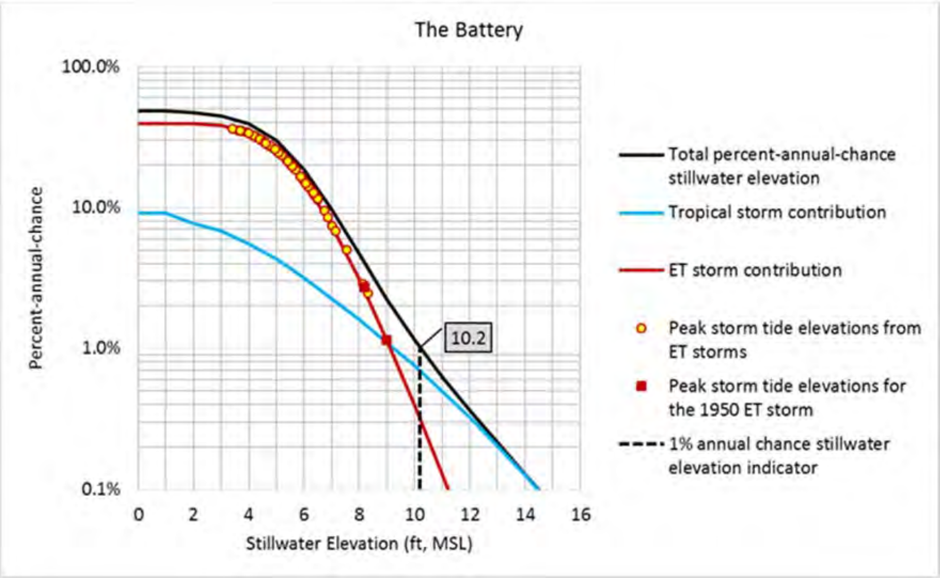


Figure 1-5. Contributions of tropical and ET storms to the total percent-annual-chance stillwater elevations at The Battery, with the overestimation of the 1950 ET storm removed.

On its own, this 4.1-foot reduction in peak 1950 ET storm tide elevations has a substantial impact on the shape of the ET and combined curves, especially for the low-frequency stillwater elevations, including the 1-percent- through 0.2-percent-annual-chance values used by FEMA for development of the 2015 PFIRMs. The overestimation of the 1950 ET storm thus has a distorting impact on the percent-annual-chance stillwater elevations. When the overestimation of the 1950 ET storm is corrected, the frequency curve of tropical storms contributes more weight to the combined frequency curve for low frequencies, as expected. Additionally, as highlighted by the dashed vertical lines, the 1-percent-annual-chance stillwater elevation reduces by approximately 1.4 feet near The Battery, from 11.6 feet to 10.2 feet MSL.

As mentioned earlier, FEMA asserted the impact of the 1950 ET was “unremarkable.” However, as shown on Figure 1-5, the overestimation of the 1950 ET storm is in fact remarkable; the effect on the 1-percent-annual-chance stillwater elevation at The Battery is greater than 1 foot, which is the increment in which BFEs are mapped. This finding led the City to further evaluate all ET storms to determine if the 1950 ET storm alone was the source of error or if broader-reaching scientific and technical errors existed in FEMA’s PFIRM coastal analysis. The City’s analysis revealed that many of the simulated ET storms, including the 1950 ET storm, have overestimated storm tides as a result of a scientifically and technically incorrect model validation. Consequently, the overestimation of the 1950 ET storm pointed to, and illustrates, the broader scientific and technical errors that form the bases for appeal and are summarized in Section 1.3 and described in detail in Sections 2 and 3 of this document.

As part of the City's evaluation of ET storms, the City additionally noted that the two random tides selected by FEMA for the 1950 ET storm were two higher high tides that coincided closely with the peak storm surge. This coincidence causes the already overestimated peak storm tide (due to the meteorological conditions alone) to be even higher for both 1950 ET storm simulations. The 4.1-foot reduction illustrated on Figure 1-5 accounted for an overestimation of storm surge related to meteorological conditions only. By additionally removing the bias in the selection of tidal conditions, further changes in simulated peak storm tide elevations for the 1950 ET storm were expected. However, the City again recognized that this was likely not an error associated with the 1950 ET storm alone. This concern led the City to evaluate the selection of the two random tides used in model production for all ET storms more closely. As summarized in Section 1.3 and described in detail in Sections 2 and 4, the City asserts that, in addition to FEMA improperly validating the ADCIRC+SWAN model, the methodology for incorporating tides into the return interval analysis for ET storms is scientifically and technically incorrect.

1.3 SUMMARY OF BASES FOR APPEAL

As a result of the assessments and discussions between FEMA and the City described in Section 1.2, the City conducted a detailed assessment of FEMA's PFIRM coastal analysis and identified two primary sources of technical and scientific errors[7] that have resulted in incorrect BFEs and SHFA boundaries: (1) insufficient ET storm model validation; and (2) misrepresentation of tidal effects for ET storms. The City's findings show that the errors in the FEMA analysis are remarkable and revisions to FEMA's analysis are required in order to properly determine BFEs and SFHA boundaries in the study area.

Due to the time limitations of the 90-day appeal period and the background information described in Section 1.2, ET storms alone are the sole focus of this appeal. The City suspects that there may be similar improvements that could be made to FEMA's methodologies for determining the contribution of tropical storms in the total percent-annual-chance stillwater elevations and welcomes further discussion with FEMA related to tropical storms, including further evaluation of the impact of Hurricane Sandy, a historic tropical storm in the study area.

[7]The proposed BFEs, base flood depths, SFHA zone designations, or regulatory floodways are said to be technically incorrect if at least one of the following is true:

- The methodology was not applied correctly.
- The methodology was based on insufficient or poor-quality data.
- The application of the methodology included indisputable mathematical or measurement errors.
- The methodology did not account for the effects of natural physical changes that have occurred in the floodplain.

The proposed BFEs, base flood depths, SFHA zone designations, or regulatory floodways are scientifically incorrect if the methodology used is inappropriate or incorrect, or if the assumptions made as part of the methodology are inappropriate or incorrect (FEMA 2011a).

1.3.1 SUMMARY OF FEMA'S INSUFFICIENT MODEL VALIDATION

The 2015 PFIRMs are scientifically and technically incorrect because FEMA's model validation for ET storms was insufficient, which resulted in (1) overestimation of peak storm tide levels used in the recurrence analysis and (2) biased high percent-annual-chance stillwater elevations. FEMA Region II's methodology to define the most appropriate model setup was inconsistent with FEMA-issued guidance by not evaluating the current state of knowledge related to wind drag coefficients and formulations as part of the model validation. This methodology error led to the overestimation of peak storm tide levels for ET storms. Additionally, the overestimation of ET storm tide levels led to an indisputable bias (mathematical error) in FEMA's determination of percent-annual-chance stillwater elevations.

The FEMA model validation described in the PFIRM coastal analysis documentation shows model simulations that compared poorly to observation data in the New York City area for all three ET storms used in model validation. The poor comparisons to observation are problematic for multiple reasons. First, FEMA did not evaluate various wind drag formulations and wind speed multipliers as part of the model validation, though FEMA guidance recommends doing so (FEMA 2007a). Hence critical model parameters were not evaluated, and model biases associated with those parameters were not minimized as part of model validation. Instead, the model biases were incorrectly categorized by FEMA as unbiased random errors. A second concern is that FEMA had 30 historical ET storms available for model validation yet only made use of three ET storms. A scientifically and technically sound model validation would have made use of all available observation data or, at minimum, a sufficiently large subset of available data to validate the ADCIRC+SWAN model with a high level of confidence. FEMA's FIS documentation shows that the model was not validated for ET storms with a high level of confidence. In fact, one of the three ET storms was removed from the validation set because FEMA's validation simulations did not "reveal good agreement" during the peak storm tide portions of the simulation (FEMA 2014c). Accordingly, as part of FEMA's PFIRM coastal analysis, a large enough set of ET storms should have been included in the model validation to reveal good agreement for all simulated ET storms. The limited set of storms used by FEMA in model validation was insufficient for FEMA to adequately understand the drivers causing the difference in simulated and observed water levels and thus make necessary model adjustments. For comparison purposes, it is worth noting that the 2007 effective FIRMs coastal analysis was based on validating 13 ET storms (FEMA 2007b), setting a precedent for validating models with considerably more storms than FEMA used as part of the 2015 PFIRM coastal analysis.

As described later in this document, the City included all 30 ET storms as part of the City's model validation and found that the model systematically overestimated peak storm tides across all ET storms when applying the FEMA model setup. The City conducted hundreds of ADCIRC+SWAN simulations to demonstrate that, with the proper application of an alternative wind drag formulation and wind speed multiplier, simulated peak storm tide elevations compare significantly better to observed water levels across all 30 ET storms. These model improvements significantly reduce the model bias present in FEMA's model setup and address FEMA's mathematical errors in the determination of percent-annual-chance stillwater elevations.

1.3.2 SUMMARY OF FEMA'S MISREPRESENTATION OF TIDAL EFFECTS

The 2015 PFIRMs are also scientifically and technically incorrect because of errors associated with FEMA's insufficient selection of only two random tides coincident with ET storms. The inclusion of only two tidal conditions for each of the ET storms resulted in an overly small sample and introduced a high level of uncertainty. Storm surge coincides with a tidal phase randomly in nature and, therefore, to combine a random process with an extremal distribution requires a sufficient number of coincidences to minimize the randomness and determine the expected value. Two tide phases per ET storm are insufficient for representing the impacts of tides on the total water levels, particularly for low-frequency storms defining the tail of an extremal distribution. The misrepresentation introduces a high level of random error, and ultimately bias, into the ET storm sample set, which is both unnecessary and statistically unjustifiable. The City's review and assessment of FEMA's methodology for the PFIRM coastal analysis revealed that the inclusion of only two random tides has caused a biased high estimation of the total water level displacement compared to the expected displacement due to tides. Section 2.2 describes the notable bias, including the resulting mathematical error in FEMA's determination of percent-annual-chance stillwater elevations. Section 4 describes the steps taken by the City to remove the resulting bias by incorporating thousands of tidal conditions for each ET storm into the recurrence analysis.

Given the importance of tides in the total water levels in this region and the biases found in FEMA's analysis, FEMA's PFIRM coastal analysis is scientifically and technically incorrect due to FEMA's consideration of only two tide phases for each of 30 ET storms. This is particularly surprising considering that FEMA's coastal analysis completed in the early 1980s, and implemented as part of the effective 2007 FIRMs, took into account 42 ET storms coinciding with 250 different tide phases (FEMA 2007b). In other words, the 2007 FIRMs were based upon consideration of 10,500 combined ET storm tide conditions or 175 times more combined ET storm tide conditions than the 60 simulations included in the PFIRM coastal analysis.

1.3.3 SUMMARY OF IMPACTS OF SCIENTIFIC AND TECHNICAL ERRORS

With a properly validated ADCIRC+SWAN model for ET storms and a sufficient number of tidal phases to properly account for effects of tides on ET storm tide elevations in an extremal analysis, the City generated new statistics for ET and total percent-annual-chance stillwater elevations. This statistical analysis used the GEV distribution with L-Moments, consistent with FEMA, but incorporated 3,816 tide phases for each of the 30 ET storms, for a total of 114,480 ET storm tide elevations included in the statistical analysis for each location. The large number of storm tide scenarios was included by using superposition of surge-only simulations (i.e., without any tides) and tide-only simulations. Nonlinear effects between tides and surge were accounted for by running all 30 ET storms coupled with four tide phases and comparing the simulated peak storm tide elevations with the peak storm tide elevations calculated using linear storm tide superposition.

The City's new coastal analysis resulted in significant changes in stillwater elevations for the study area compared to FEMA's PFIRM coastal analysis. As is demonstrated in Section 5, changes in stillwater elevations and starting wave conditions lead to changes to BFEs and SFHA boundaries. Changes in the 1-percent-annual-chance stillwater elevations from FEMA's PFIRM analysis to the City's analysis are shown on Figure 1-6. Table 1-3 shows the changes to the 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations at six NOAA gage stations within the study area. Changes to the 1-percent-annual-chance floodplain extents (SFHA boundaries) between the 2015 PFIRMs and the City's analysis are shown on Figure 1-7. Table 1-4 shows revised estimates of buildings, residents, one- to four-family homes, and constructed floor area in the 1-percent-annual-chance floodplain based on the City's new coastal analysis described within and a comparison of these estimates to those created based on the 2007 FIRMs and 2015 PFIRMs.

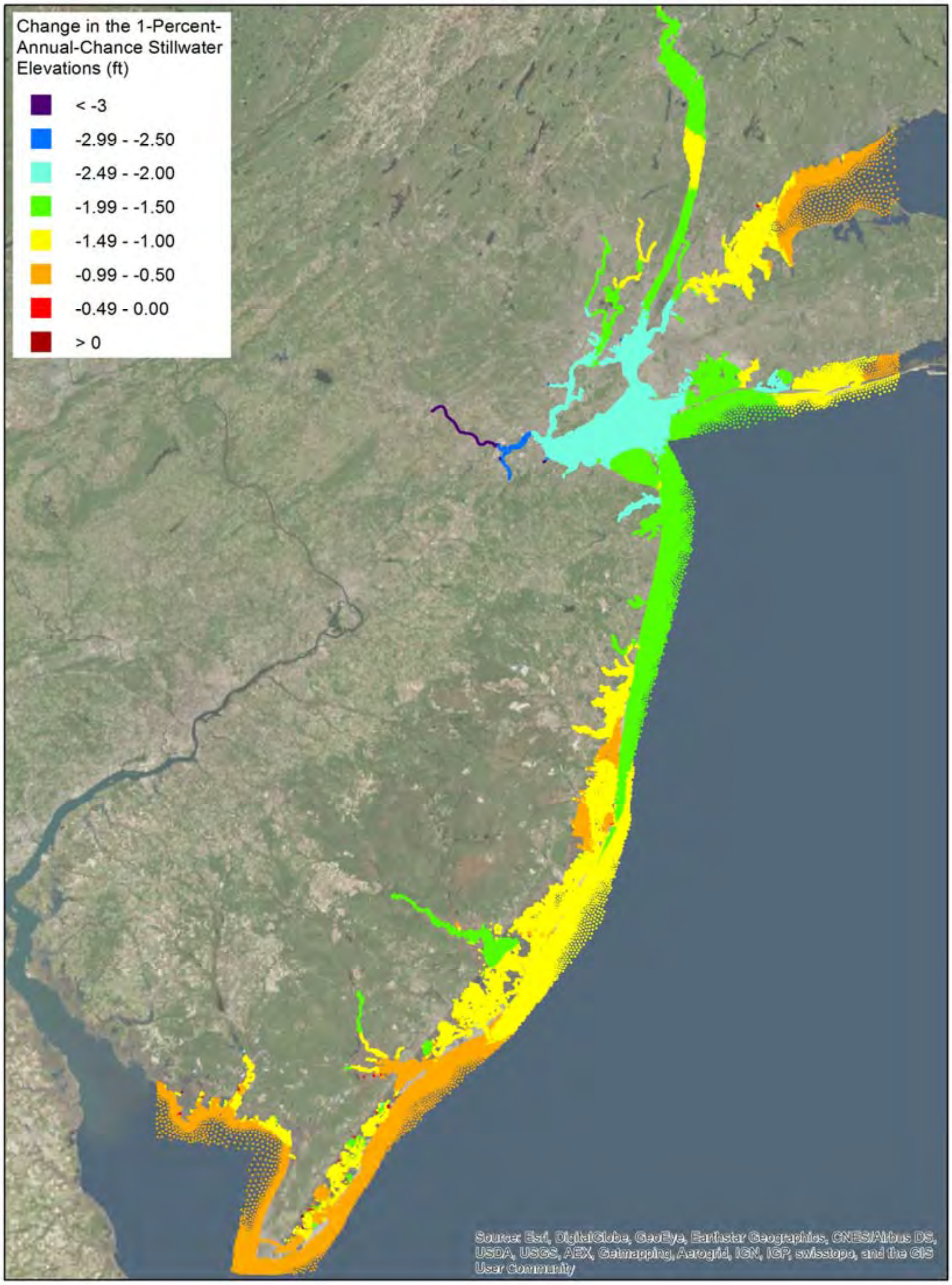


Figure 1-6. Difference (feet) in 1-percent-annual-chance stillwater elevations between the 2015 PFIRMs coastal analysis and the City's analysis in the study area.

Negative values represent decreases in PFIRM stillwater elevations. Values are shown for water bodies only.

Table 1-3. 2015 PFIRMs and City Analysis percent-annual-chance stillwater elevations (feet, NAVD88) at NOAA gage stations.

Location	Analysis	10%	2%	1%	0.2%
The Battery	2015 PFIRMs	6.9	9.9	11.3	14.9
	City's Analysis	6.1	8.0	9.2	12.7
Kings Point	2015 PFIRMs	9.7	11.9	12.7	14.5
	City's Analysis	9.4	11.0	11.6	13.2
Willets Point	2015 PFIRMs	9.8	12.0	12.9	14.7
	City's Analysis	9.5	11.1	11.7	13.3
Sandy Hook	2015 PFIRMs	7.2	9.9	11.1	14.4
	City's Analysis	6.3	8.1	9.3	13.2
Atlantic City	2015 PFIRMs	5.9	7.9	8.8	12.1
	City's Analysis	5.5	6.9	7.9	12.1
Cape May	2015 PFIRMs	5.8	7.3	7.9	9.3
	City's Analysis	5.4	6.6	7.2	9.1

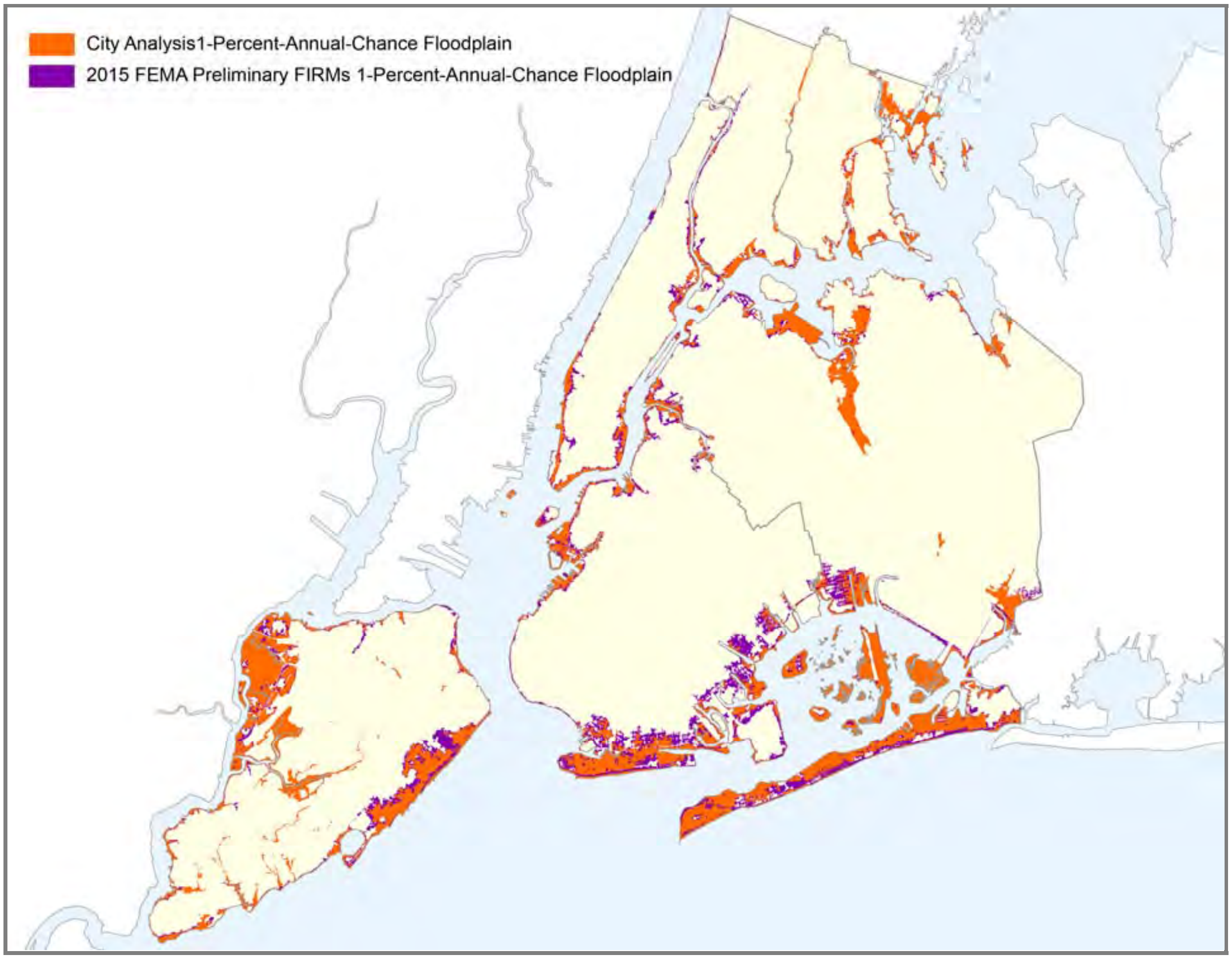


Figure 1-7. **Citywide comparison of the 2015 PFIRMs coastal analysis and the City's analysis 1-percent-annual-chance floodplains.**

Table 1-4. **Changes in residents and buildings in the 1-percent-annual-chance floodplain between 2007 FIRMs, 2015 PFIRMs, and the City's analysis.**

1-Percent-Annual-Chance Floodplain*					
	2007 FIRMs	2015 PFIRMs	City's Analysis	Change from 2007 FIRMs to City's Analysis % increase	Change from 2015 PFIRMs to City's Analysis (% decrease)
Residents	218,000	400,000	230,000	6%	(43%)
Buildings	36,000	71,500	45,000	25%	(37%)
1-4 Family**	26,000	57,400	42,000	38%	(27%)
Floor Area (Square Feet)	377,000,000	532,000,000	383,000,000	2%	(28%)

*Rounded for clarity

**A subset of total number of buildings

1.4 SUMMARY OF APPEAL REQUIREMENTS MET

The City's new coastal analysis described within demonstrates a need for FEMA to revise and reissue the FIRMs due to technically and scientifically incorrect PFIRM stillwater elevations. Incorrect stillwater elevations resulted in incorrect BFEs and SFHA boundaries in the 2015 PFIRMs. Sections 2 through 5 describe the City's new coastal analysis conducted to determine correct stillwater elevations, while meeting the following federal requirements (44 CFR §67.6):

- For technically incorrect errors, which are both methodological and mathematical in nature, the City has applied the same methods as FEMA but with itemized changes;
- For scientifically incorrect errors, alternative analyses utilizing correct methods or assumptions have been conducted and documented;
- For all errors, technical analysis and explanation have been included to document changes indicating why the City's alternative methods should be accepted as correct;
- Documentation of all locations where the City's stillwater elevations are different from FEMA's is included; and
- In order to meet FEMA data submission requirements, the City's new coastal analysis (documented herein), revised SFHA zone boundaries based on the City's stillwater elevations, and all applicable FIS report tables including the Transect Data Table are included in this submission to FEMA.

The City is providing stillwater elevations that are scientifically and technically correct and free of mathematical errors. Subsequent steps in FEMA's mapping process, such as the determination of variation in stillwater elevations overland, Wave Height Analysis for Flood Insurance Studies (WHAFIS) simulations, wave runup, erosion, and primary frontal dune assessments, are not included in the City's analysis. The City would appreciate the opportunity to consult with FEMA on FEMA's process to address the above-mentioned subsequent steps.

In addition to this document, the City is submitting to FEMA all data required as part of the appeal on a separate hard drive. The data included in the submittal are described in Section 6 and provide information necessary to complete the requisite mapping processes to revise BFEs and SFHA boundaries throughout the region following the City's new coastal analysis providing corrected stillwater elevations.

2.0 BASES FOR APPEAL AND PATH FORWARD

FEMA' s PFIRM coastal analysis documentation includes extensive details for many elements of the statistical analysis, but the methodology is deficient in the treatment of ADCIRC+SWAN validation and the treatment of tides in the analysis of ET storms. Additionally, mathematical errors are present in FEMA's determination of percent-annual-chance stillwater elevations due to FEMA's incorrect categorization of model- and methodology-related biases as unbiased random errors. This section provides a detailed review of the technical and scientific errors in FEMA's PFIRM coastal analysis to define the bases for this appeal.

Prior to presenting the detailed assessment, it is important to clarify the difference between certain principles, as these principles are important in understanding the insufficient nature (i.e., the scientific and technical incorrectness) of FEMA's PFIRM coastal analysis:

- <u>The average weight of an individual event in a sample set versus the ranking position of the event in order statistics (David and Nagaraja 2003)</u>: When evaluating a data set, the significance of an individual data point differs depending on the evaluation approach. For example, though the average weight of the 1950 ET storm out of 30 ET storms is 1/30, its significance as a top-ranked event, i.e., the rarest event in order statistics, is considerably more remarkable in the recurrence analysis, particularly for low frequencies;

- <u>Standardization of a method versus accuracy of model outputs</u>: A standardized analysis is necessary for each step of a coastal analysis, but accuracy should not be sacrificed unnecessarily for standardization. For example, a standard kinematic analysis method to derive meteorological fields as model inputs does not mean the model outputs are accurate; validation is indispensable, and analysis methods should be revised as necessary;

- <u>Statistical characterization of differences between simulated and observed peak water levels for an overall storm suite compared to deviations in individual storms</u>: The differences between simulated and observed data should be assessed across all available data in a given dataset. In addition to evaluating the performance of a storm suite as a whole, each individual storm must be assessed to adequately measure the "goodness of fit" of model simulation results. Biases in the simulation of each individual storm should be understood and improved upon where possible in order to validate both the individual storms and the storm suite as a whole;

- <u>Unbiased random error (i.e., epistemic uncertainty, which, in the joint probability integral, assumes that errors are distributed symmetrically around a mean error of zero at each surge level) versus systematic bias (Taylor 1999)</u>: Random errors and biases do not impact analysis results in the same manner. Two sources of independent, unbiased random errors can be added together, and no increased bias will be produced by this summation. On the other hand, any system bias directly produces a deviation between results containing such a bias and an actuarially sound estimate. The magnitude of an epistemic uncertainty cannot be used as a measure for the impacts of a systematic bias on the expected hazard level; and

- Epistemic uncertainty versus aleatory uncertainty (Matthies 2007): As noted in FEMA's March 2015 memorandum, "epistemic uncertainty represents uncertainty that results from imperfect knowledge about storms, their climatology, and their effects, and aleatory uncertainty is that uncertainty that for all practical purposes cannot be known in detail or cannot be reduced." For instance, the aleatory uncertainty due to the random coincidence of tides and storm surge would affect the actuarially sound estimation of the expected hazard level in instances where only a small number of tidal phases are considered in the ET storm sample set.

2.1 INSUFFICIENT MODEL VALIDATION

In FEMA's PFIRM coastal analysis, the numerical models were validated with observed water surface elevations from the following historical tropical and ET storms (FEMA 2014c):

- 1938 Hurricane (September 21, 1938)
- 1944 Hurricane (September 14-15, 1944)
- Hurricane Donna (September 12, 1960)
- Hurricane Gloria (September 26-27, 1985)
- ET Storm March 29, 1984
- ET Storm October 31, 1991
- ET Storm December 11, 1992

Of the three ET storms selected for model validation, none compared well with historical data in the New York City area. It should be noted that the October 31, 1991, ET storm was included in FEMA's initial set of validation storms, but the model validation failed to match observations with a high level of accuracy and was removed from the set of validation storms (FEMA 2014c). Additionally, for the other two ET storms used in model validation (March 1984 and December 1992), storm tide elevations were consistently overestimated at all gage locations throughout New York and New Jersey and for all observed high water marks measured north of Monmouth County, New Jersey, as shown on Figure 2-1 and Figure 2-2. Although FEMA guidance does not document accuracy requirements for model validation, FEMA's PFIRM coastal analysis documented a specific criterion for reproducing water levels as part of model validation (FEMA 2014c): "Based on past and ongoing FEMA surge studies and consultation with the project team, an acceptable criterion for evaluating model performance was established where 70 percent or more of the peak water level comparisons have a difference of less than 1.5 feet."

Inspection of Figures 2-1 and 2-2 and review of FEMA's PFIRM coastal analysis validation documentation (FEMA 2014c) result in the conclusion that FEMA only considered the above-mentioned criterion when evaluating the study area as a whole and did not consider the criterion for specific regions such as the New York City area. Of the eight high water marks and gage peaks adjacent to New York Harbor and New York City for the 1992 ET storm, only four (or 50 percent) meet the criterion of 1.5 feet. Of the 13 high water marks and gage peaks in this region for the 1984 and 1992 ET storms combined, only nine (or 69 percent) meet the criterion of 1.5 feet.

Given the poor comparison of simulated and observed peak storm tides for the two storms included in FEMA's final ET storm validation set, simulations of additional ET storms under historical tidal conditions were necessary to adequately validate the model. Yet FEMA did not make use of the additional 27 historical ET storms as part of the validation process. As discussed in Section 1.3.1, a sufficiently large number of the ET storms, and preferably all 30, should have been simulated by FEMA as part of the validation process, considering measured data for these comparisons were readily available. The City therefore conducted the ET storm validation exercise that FEMA should have completed as part of the PFIRM coastal analysis and simulated each of the 30 ET storms, considering historical tidal conditions. The City's simulated peak storm tide elevations were compared to NOAA observations. The NOAA gages selected for comparison were located in New York and New Jersey, as well as outside the direct study area, in order to evaluate the region as a whole. These NOAA gages selected for comparison are shown on Figure 2-3 and include Chesapeake Bay Bridge Tunnel, Virginia (#8638863); Lewes, Delaware (#8557380); Cape May, New Jersey (#8536110); Atlantic City, New Jersey (#8534720); Sandy Hook, New Jersey (#8531680); Bergen Point West Reach, New York (#8519483); The Battery, New York (#8518750); Willets Point, New York (#8516990); Kings Point, New York (#8516945); and Montauk, New York (#8510560).

The Battery had NOAA records available for all 30 events; Cape May, New Jersey, had records available for all events except the October 20, 1961, storm; the other stations had data available for 4 to 27 of the storm events. In total, 215 observed peak water levels were available for comparison among the 30 storms and 10 gage locations. As with FEMA's PFIRM coastal analysis, the City adjusted NOAA observation data to match water levels at the mid-point of the 1983-2001 National Tidal Datum Epoch (NTDE).

All 30 ET storms were simulated using historical tidal conditions and FEMA's PFIRM coastal analysis ADCIRC+SWAN configurations. When possible, no modifications were made to the ADCIRC+SWAN input files obtained from FEMA; the model mesh, bathymetry, Manning's roughness values, wind fields, a Garratt wind drag formulation with a 0.0035 cap, a 1.04 wind speed multiplier, etc., were all unchanged from FEMA's PFIRM coastal analysis. Some storms required that advection terms were turned off in the ADCIRC model in order to maintain model stability; however, the impact of turning off model advection had minimal impact on the final maximum water surface elevation, as discussed in Section 3.2.

To quantify the model skill at simulating storm tide peak elevations, the quantiles of the 215 simulated storm tide peaks were calculated and compared to the quantiles of observed storm tide peaks using a GEV distribution function. Figure 2-4 is a quantile-quantile (Q-Q) plot showing the quantiles of simulated results (vertical axis) using FEMA's PFIRM coastal analysis model setup (including the original 1950 ET storm meteorological conditions) versus the quantiles of NOAA observations adjusted to the mid-point of the 1983-2001 NTDE (horizontal axis). The blue crosses are the 215 data points, the black line is the 1:1 line, and the red line illustrates the slope and intercept to fit the 215 data points. The Q-Q comparison results in a root-mean-square error (RMSE) of 0.49 foot and a slope of 1.239. The notable deviation of the data points from the 1:1 line (or best-fit line) clearly demonstrates that the model results using FEMA's PFIRM coastal analysis model setup overestimate storm tide elevations, especially those above approximately 6 feet MSL. The model bias demonstrates that FEMA made a technical and scientific error by not validating ADCIRC+SWAN to an acceptable degree.

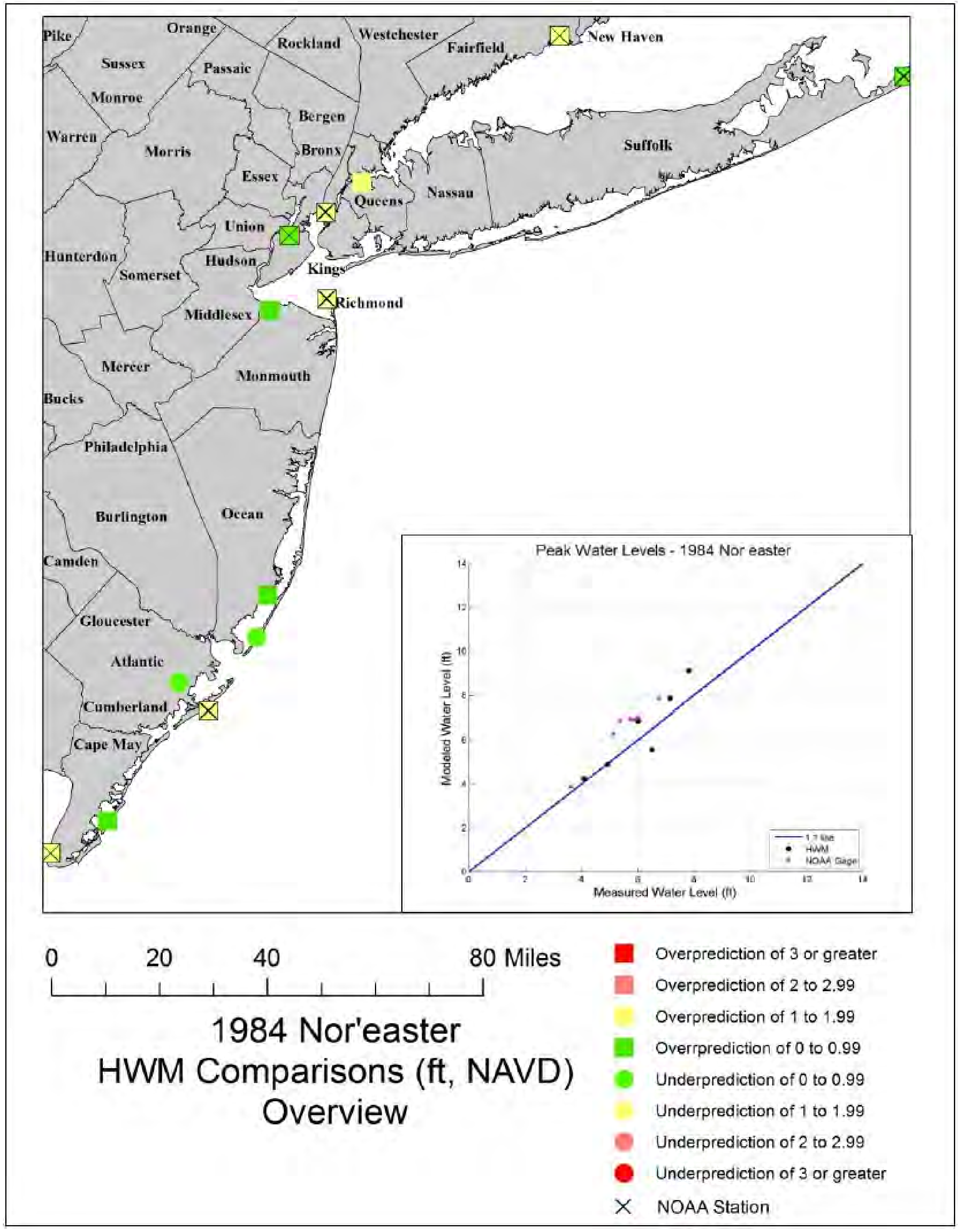


Figure 2-1. FEMA's peak storm tide elevation (feet) comparisons for the 1984 ET storm (FEMA 2014c) for high water marks and gages.

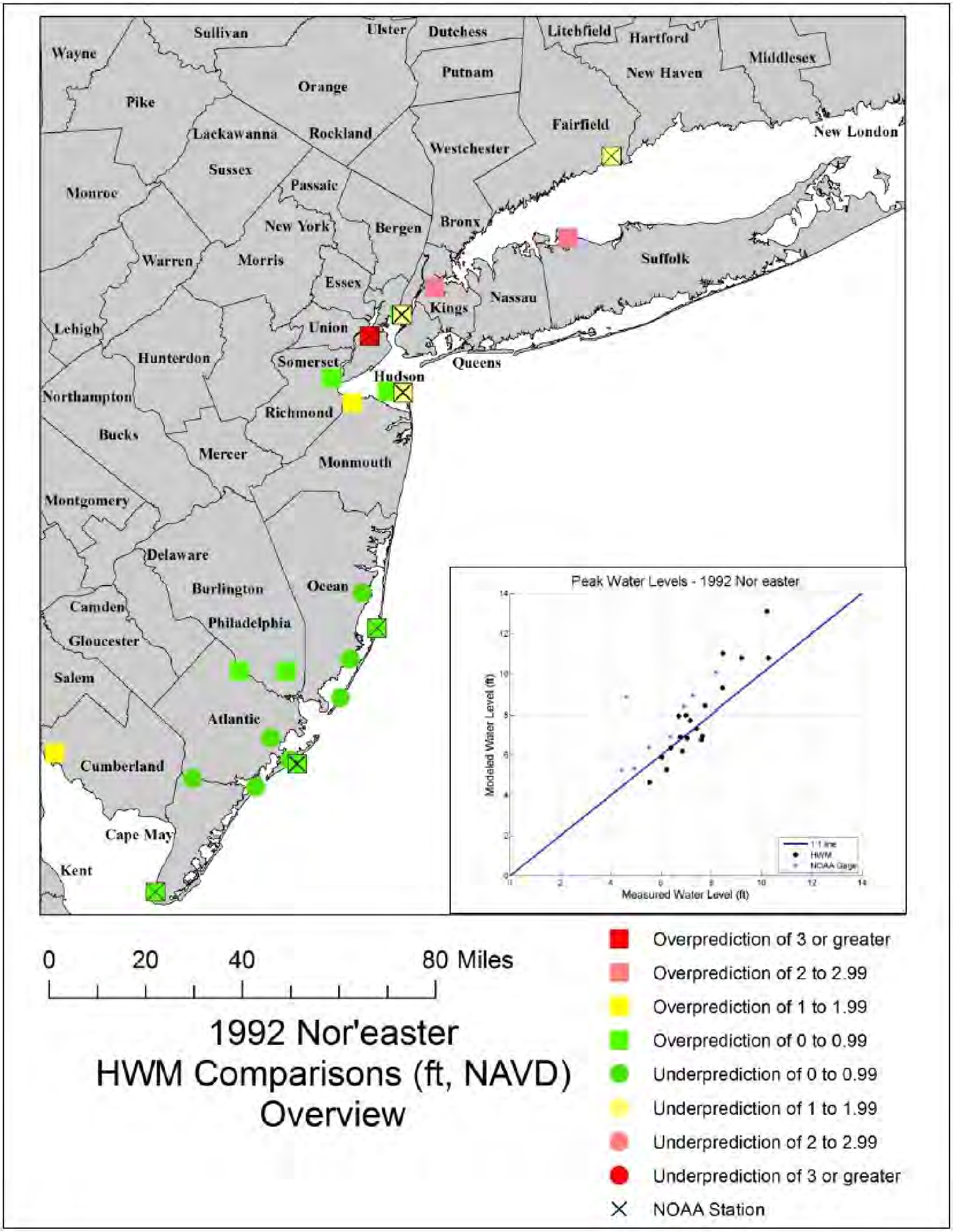


Figure 2-2. FEMA's peak storm tide elevation (feet) comparisons for the 1992 ET storm (FEMA 2014c) for high water marks and gages.

Figure 2-3. NOAA gage locations used in the City's model validation.

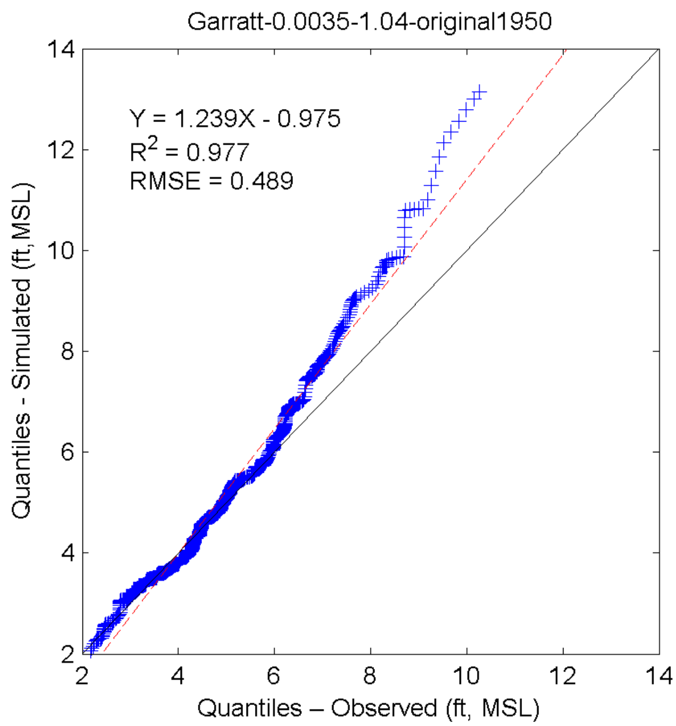


Figure 2-4. Q-Q plot comparing observed and simulated peak storm tides at NOAA gage stations using the FEMA ADCIRC+SWAN model setup and original 1950 ET storm.

Values are in feet, MSL. Black: 1:1 line; red dash line: linear regression line; blue crosses: quantile data points.

It should be noted that, following FEMA's PFIRM coastal analysis, FEMA's March 2015 memorandum (RAMPP 2015) documented an additional analysis of potential errors and biases in ADCIRC+SWAN simulations beyond the initial model validation efforts documented by FEMA (FEMA 2014c). As described in the March 2015 memorandum, normalized residuals were computed by subtracting tides from the total water levels for selected ET storms at selected model output locations and compared with the residuals computed from NOAA observations (Figure 2-5). The conclusion of the analysis was that no model bias existed. Specifically, the March 2015 memorandum concluded that "these sensitivity analyses reinforce the conclusion that the normalized residuals for the ETSs have no bias and a standard deviation of 21 percent. When taken in the context of all the data shown…the residual for the November 1950 ETS at the Battery gauge is relatively unremarkable."

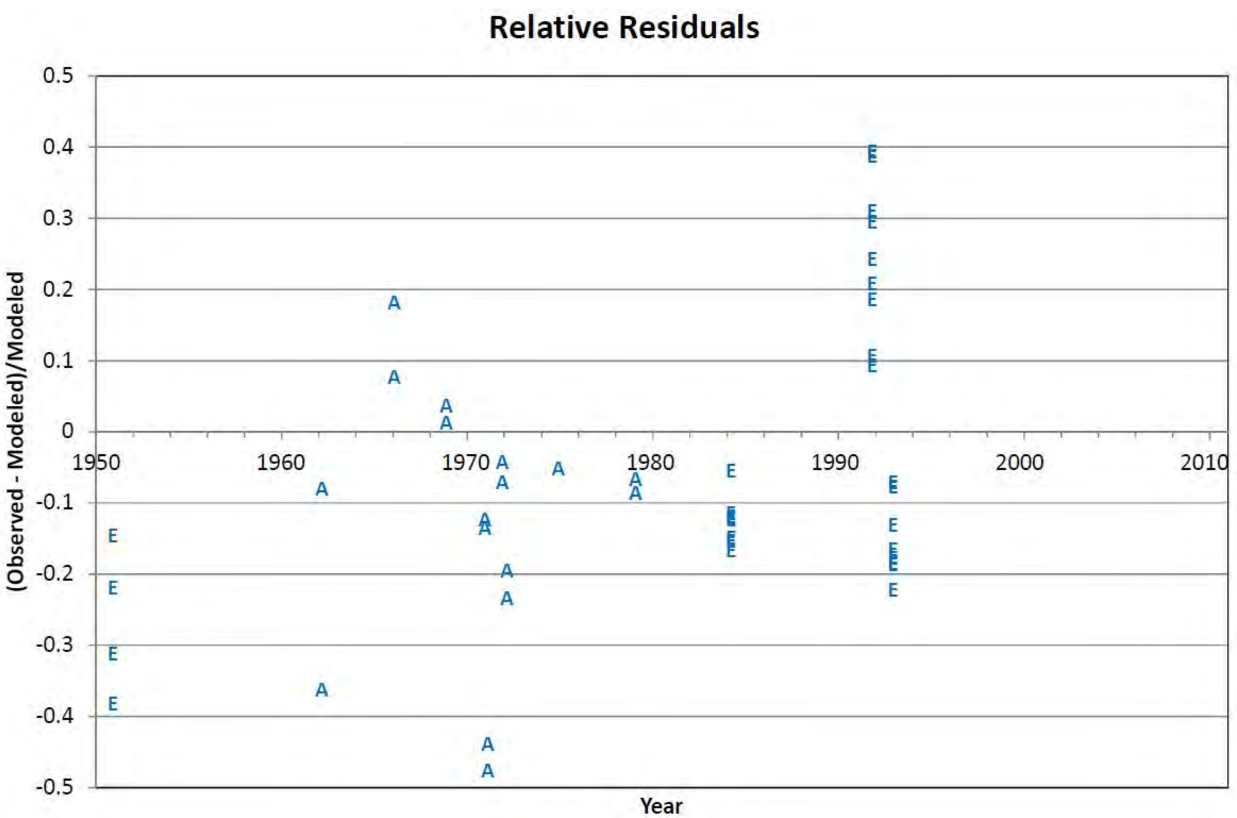


Figure 2-5. FEMA scatter diagram showing relative residuals.

E (exact) is used to indicate data with correct tide phase, and A (approximate) is used to indicate tide residuals obtained using random tide phases (RAMPP 2015).

The City's findings illustrated on Figure 2-4 contradict FEMA's assertion in the March 2015 memorandum that no bias exists for the simulation of ET storms. The analysis described in the FEMA memorandum shows little effort to objectively separate the random errors in the comparisons from the bias characteristics of ET storms. As discussed in the introduction of this section, unbiased random error and bias are distinctly different and should be treated as such. Ultimately, FEMA's conclusion is not reliable because of the use of normalized residuals to assess model performance, which creates a nonlinear ordinate axis (one in which small deviations in small surges appear to be the same magnitude as large deviations in large surges). Such an analysis cannot be used to examine overall error bias accurately.

Additionally, the FEMA memorandum describes the assessment of select normalized data at select locations. Instead, a scatter plot of measured and modeled peaks with an RMSE, or more appropriately a Q-Q plot such as Figure 2-4, should have been created to objectively and clearly document the model performance across all 30 ET storms for multiple locations in the study area. Unlike a plot of normalized residuals, a Q-Q plot displays the data in a manner that clearly illustrates bias if present. Additionally, a Q-Q plot can be created with minimal additional effort. Thus, the comparisons to measured data from all of the storms would have been straightforward and would have clearly shown the problem in FEMA's model validation.

Additionally, FEMA's PFIRM coastal analysis and subsequent memorandum do not objectively evaluate model bias because the analyses ignore the fact that equal amounts of underestimation of low to moderate storm tide elevations and overestimation of high storm tide elevations do not create an unbiased comparison overall. The FEMA (RAMPP 2015) conclusion that simulated and observed differences in New York Harbor for the 1950 ET storm are unremarkable does not take into account that the simulation of the 1950 storm includes a very significant overestimation of the highest modeled ET storm tide elevations and, in the FEMA normalized residual analysis, is essentially offset by a significant underestimation in the simulation of the relatively moderate 1991 ET storm. This offset is best illustrated on Figure 2-5. Though the normalized residuals analysis implies limited bias from an arithmetic standpoint, from a statistical perspective, the bias for storms of different intensities can significantly alter the frequency curve for percent-annual-chance stillwater elevations, which is obscured in FEMA's normalized residual analysis. Overestimation for the highest storm and underestimation for a moderate storm actually result in further overestimation of stillwater levels for low-frequency events, e.g., 1-percent-annual-chance events.

Lastly, as noted previously, the only ET storm with significant model underestimation in FEMA's PFIRM coastal analysis is the 1991 storm, as shown on Figure 2-5. Unlike the surge responses in the other 29 ET storms that were driven by direct wind forcing, the ADCIRC+SWAN model results indicate that storm tide elevations in the 1991 storm were driven by wave radiation stresses from the large offshore waves propagating toward the coast. The underestimation of the 1991 ET storm additionally indicates that the wave radiation stresses were not fully captured in FEMA's PFIRM coastal analysis ADCIRC+SWAN model. As shown on Figure 2-6 and in Appendix A, the winds were blowing offshore during the time of major surge generation, meaning that winds did not drive surge into the harbor for the days leading up to the peak storm tide and that FEMA's assumption that the cause of the underestimation was the meteorological forcing is likely incorrect. Ultimately, this is a relatively minor issue but worth noting due to the unique nature of the 1991 storm simulation and the fact that FEMA did not invest adequate time and effort to understand the biases in the simulation of the 1991 ET storm and improve upon the individual simulation and treatment of the ET storm suite as a whole. Hence, beyond the fact that normalized residuals should not be used to assess model performance in general, the 1991 ET storm model underestimation should not be considered an offset to the model overestimation of the majority of wind-driven surges (i.e., different physical processes are the causes of under- and overestimation). Regardless, even with the incorporation of all 30 ET storms including the 1991 ET storm, FEMA's PFIRM coastal analysis model shows a clear bias high (Figure 2-4).

In summary, FEMA's technical and scientific error of insufficiently validating the model for ET storms resulted in the overestimation of model peak storm tide elevations during FEMA's ET production simulations and a bias that was unaccounted for in the determination of stillwater elevations. Had FEMA conducted an adequate model validation for all 30 ET storms (or at least a sufficiently large subset of ET storms) and objectively quantified model performance for the entire ET storm set (e.g., Q-Q plots), the biases in FEMA's model production and determination of percent-annual-chance stillwater elevations could have been avoided. The steps taken by the City to improve model performance and remove systematic biases are described in Section 3.

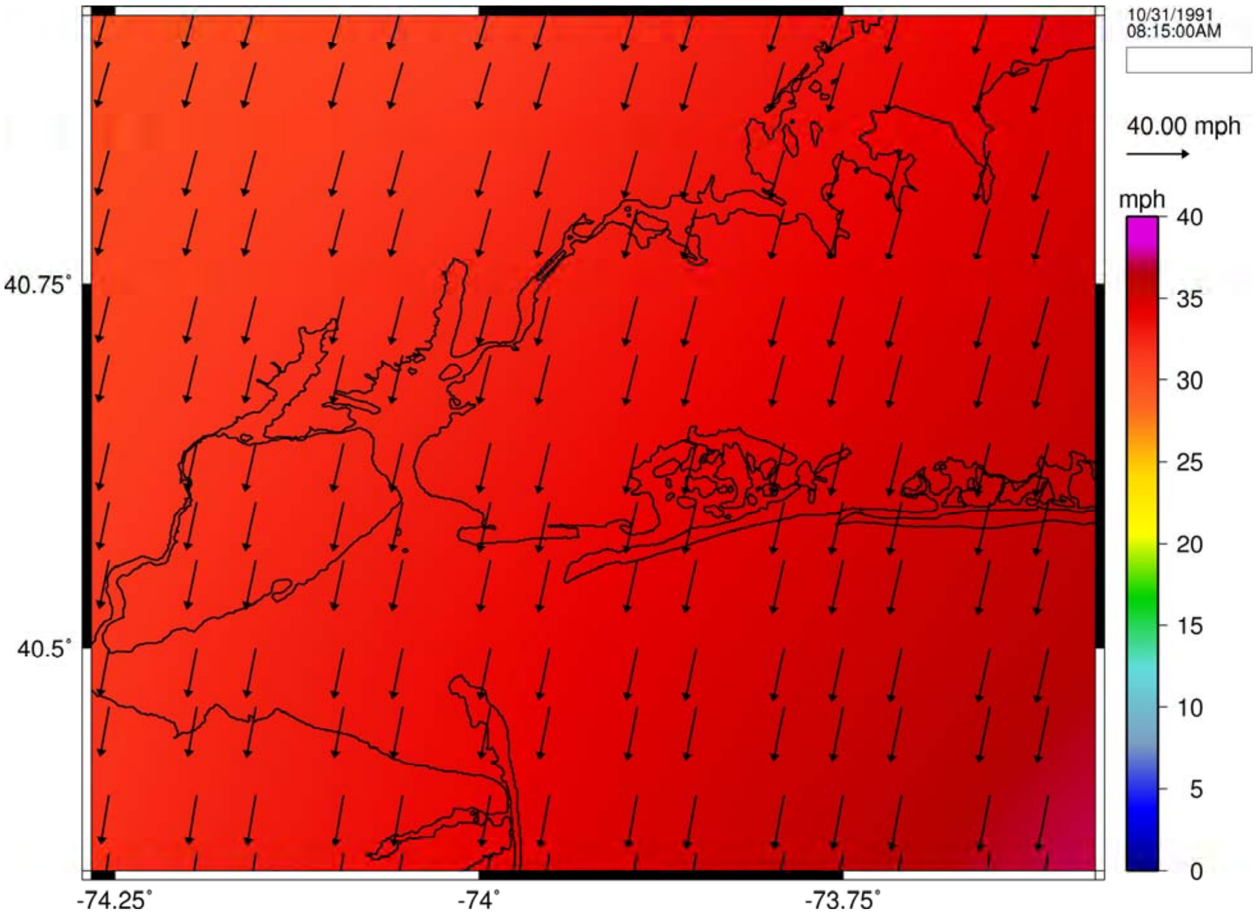


Figure 2-6. 1991 ET storm wind speed and direction during peak storm tide elevations at The Battery.

2.2 MISREPRESENTATION OF TIDAL EFFECTS

As noted in Section 1.3.2, the methodology to include tidal effects in FEMA's PFIRM coastal analysis introduced variability in the total water levels, which created substantial bias that was unaccounted for in FEMA's determination of stillwater elevations. While storm tide is overestimated for most ET production storms due to the model setup described in Section 2.1, the method of considering only two random tides in FEMA's PFIRM coastal analysis introduced additional unjustifiable bias due to aleatory uncertainty. For instance, the two random tides selected for the 1950 ET storm happened to be two higher high tides in coincidence with the peak storm surge, which caused the already overestimated water levels to be even higher. Furthermore, the technical error in FEMA's analysis related to tide selection goes beyond the 1950 ET storm. For all 30 ET storms, only considering two random tides for each storm introduced unjustifiable and unnecessary random variability and ultimately bias to the system.

In order for the City to investigate potential bias in the total stillwater elevations resulting from FEMA's use of only two tides for ET storms, it was necessary to establish the mean value of all possible tide-associated displacements for all storms in the storm set. The term displacement is herein defined as the difference between the peak storm surge and the peak storm tide (which is induced by the coincidence of a tide with a storm event). In the sensitivity study described in this section of the document, the displacement was estimated at The Battery assuming a linear superposition scheme, with the nonlinear interaction of surge and tide ignored. As discussed in Section 4 of this document, nonlinear effects on the peak storm tide elevation are shown to reduce peak storm tide elevations at The Battery and, therefore, a linear superposition is a conservative assumption for this site.

The City estimated the average displacement and median displacement caused by the encounters of a tide time series and surge-only time series using FEMA's PFIRM coastal analysis ADCIRC+SWAN outputs. Note that the surge-only water levels in this case were calculated as the surge residual by subtracting the corresponding NOAA predicted tides from the FEMA simulated storm tide total water levels. In order to evaluate FEMA model outputs directly, FEMA PFIRM model simulation data were used in this analysis rather than the City's simulations described in subsequent sections. For a given time series of surge elevations, the average tidal displacement is expressed as:

$$\langle \delta_\eta \rangle = \left\{ \frac{1}{N} \sum_{n=1}^{N} max_{0 \to T} [tide(t + \phi_n) + surge(t)] \right\} - \eta_{surge.max}$$

where:

$\langle \delta_\eta \rangle$ is the average tidal displacement;
N is the number of tidal phases considered;
t is the time;
T is the total duration of the time series;
ϕ_n is the initial phase of the nth tide sample; and
$\eta_{surge.max}$ is the maximum of surge-only water levels.

The average displacement produced by an individual storm depends on (1) the relative magnitude of the water level displacements caused by tides and storm surge and (2) the duration of the storm surge at given levels of displacement.

A 123-day (October 1 through February 1) interval of tidal prediction at The Battery (NOAA 8715750) was downloaded from the NOAA website and used to characterize tides. To estimate the expected tidal displacement and its standard deviation, estimated surge residuals of each ET storm were combined with a tide time series that was shifted by equal time increments of 20 minutes over the entire range of the tidal record.

The estimated mean displacement for each of the 30 ET storms is plotted on Figure 2-7 against the peak residual of each storm. A linear relationship was initially tested to depict the dependence of the mean displacement on the peak residual; however, a linear fit produced physically unrealistic, negative mean displacements at very large surges. This is unrealistic because the maximum value of two time series combined with random phases must be larger than the value of either of the time series alone, as can be shown in the linear superposition of sine waves in a wave spectrum.

To provide an improved estimation of displacements at higher surge elevations for parametric curve fitting, the 1950 ET storm was selected as a reference storm on which to base the development of synthetic storm surge data points to guide the general shape of large synthetic storms. Because this storm was a long-duration storm with the highest surge residual on record, it is likely slightly conservative to choose the 1950 ET storm as the basis for the general storm shape. Synthetic storm surges were created for five additional storms with peak surge levels higher than the peak surge residual of the 1950 ET storm by *m* feet, where *m* equals 1.0 to 5.0 feet; the surge level at each time step was calculated to be:

$$\eta_{m,i} = R\eta_{1950,i}$$

where $R = \dfrac{\eta_{m,\max}}{\eta_{1950,\max}}$

with

$\eta_{m,i}$ is the surge-only value for the m[th] additional storm at time step i

R is the ratio of the maximum surges in the m[th] additional storm to the 1950 storm

$\eta_{1950,i}$ is the surge-only value for the 1950 storm at time step i

$\eta_{m,\max}$ is the maximum surge for the m[th] additional storm

$\eta_{1950,\max}$ is the maximum surge for the 1950 storm

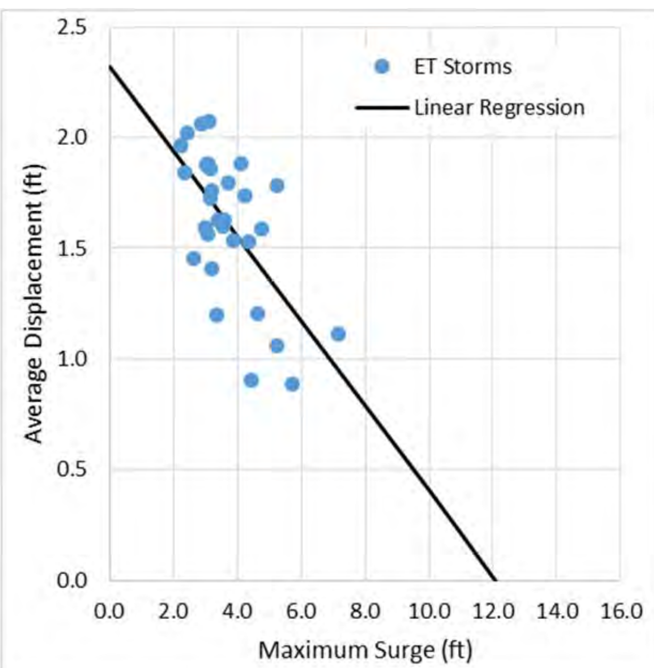


Figure 2-7. Linear regression fit of displacements due to tides for the 30-ET-storm set.

As shown on Figure 2-8, the 30 ET storms (blue dots) combined with the 5 synthetic storms (red dots) confirm that an exponential fit to the data produces a more realistic representation for surge levels above 6 feet than the linear regression of only the 30 ET storms shown on Figure 2-7. Figure 2-7 and Figure 2-8 show that the expected average displacement varies systematically with the surge magnitude. For the largest ET surge residual in FEMA's PFIRM coastal analysis (the 1950 ET storm), the average displacement caused by the tides is approximately 1.1 feet, as shown on Figure 2-8. The best-fit exponential equation for all data shown on Figure 2-8 is as follows:

$$\langle \delta_\eta \rangle = 2.373 exp\left(-0.110 \times \eta_{surge.max}\right)$$

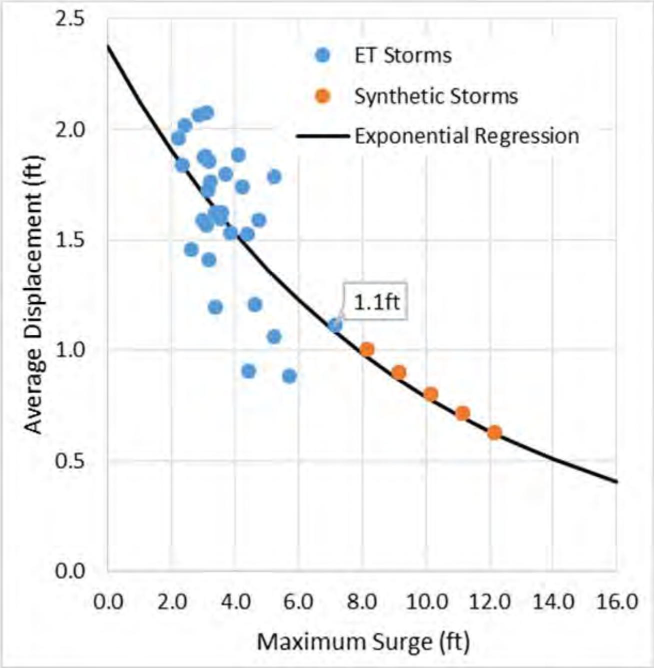


Figure 2-8. Calculated average displacement due to tides for the 35-storm set. (30 ET simulations plus 5 synthetic storms.)

In this figure, the red dots represent the synthetic storms.

The standard deviation around the expected tidal displacement for each storm was additionally estimated and plotted on Figure 2-9. As shown on the figure, in contrast to the relationship between expected tidal displacement and the peak surge level, the standard deviation increases with an increasing peak surge level, although it remains less than 1 foot for the largest peak surge among the actual ET storm set. For example, for a 9-foot surge, the expected storm tide would be 9.0 feet ± 0.9 foot; for a 10-foot surge, the expected storm tide would be 10.7 feet ± 1.1 feet.

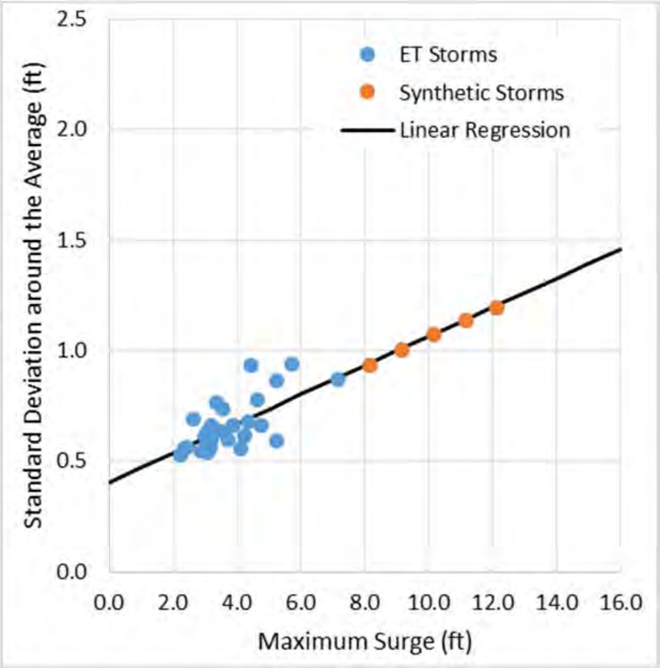


Figure 2-9. Variation of the standard deviation around the mean displacement for the 35-storm set.

The estimate of the average displacement was added to surge residuals to obtain the total water level for each storm, and total water levels were then compared to those used in FEMA's PFIRM coastal analysis (e.g., the 60 simulated ET storms). Figure 2-10 shows a Q-Q plot of FEMA's 2015 PFIRM storm tide elevations (vertical axis) based on two random tide selections for each storm and the expected storm tide elevations (horizontal axis) based on the average displacement discussed in this section. Similar to Figure 2-4, the blue crosses are the data points, the black line is the 1:1 line, and the red line illustrates the slope and intercept to fit the displacement data points. The Q-Q comparison results in an RMSE of 0.58 foot and a slope of 1.085. The figure shows a persistent, increasing deviation from the 1:1 line, with FEMA's 2015 PFIRMs biased high compared to the expected values. For the largest storm in the set, the deviation is greater than 1 foot. The fact that FEMA's under-sampling of tide phases (i.e., two per ET storm) produced a value significantly higher than the expected storm tide elevations despite the fact that linear superposition at The Battery is a conservative assumption indicates that FEMA's methodology for selection of random tides is scientifically and technically incorrect and biased high.

Prior to model production, FEMA should have conducted a similar assessment to understand the model bias associated with consideration of only two tidal conditions per ET storm. The Q-Q analysis is a fundamental tool in determining both the "goodness of fit" and the needed corrections to a set of values to remove bias. More tidal conditions should have been considered, as was done for the 2007 FIRMs and the City's new coastal analysis (described in Section 4 of this document).

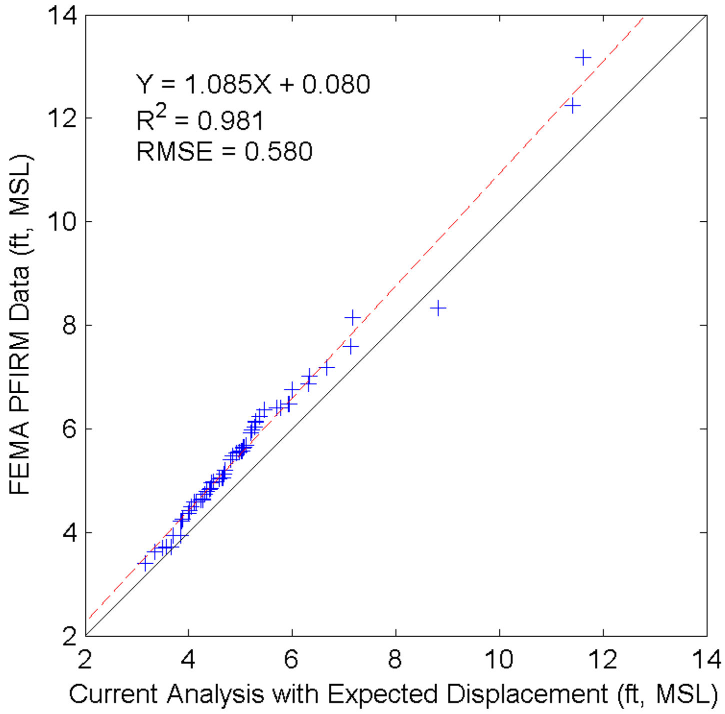


Figure 2-10. Q-Q plot of FEMA estimated tide displacements for the two random tides compared to the estimated mean over all phases.

Values are in feet, MSL. Black: 1:1 line; red dash line: linear regression line; blue crosses: data points.

2.3 SUMMARY OF IMPROVEMENTS – PATH FORWARD

Both insufficient model validation and inadequate consideration of tidal effects for ET storms resulted in percent-annual-chance stillwater elevations that are biased high and scientifically and technically incorrect due to FEMA's methodological and mathematical errors. Ultimately, the delineation of BFEs and SFHA boundaries are also scientifically and technically incorrect due to the errors present in FEMA's stillwater elevations. Subsequent sections of this document concentrate on improvements made by the City (i.e., a new coastal analysis and improved flood hazard data) to correct for errors and determine scientifically and technically correct stillwater elevations. The City's analysis described in detail in subsequent sections includes the following:

- Model setup improvements were tested for alternative wind drag formulas and wind speed multipliers, and a scientifically and technically correct model setup was selected following the sufficient validation of all 30 ET storms selected by FEMA. See Section 3;

- As part of the model setup improvement analysis, the 1950 ET storm was further examined, and the 1950 ET "reanalysis" meteorological conditions described in FEMA's March 2015 memorandum were carried forward in the City's new coastal analysis. See Section 3;

- Using a validated model with an updated wind drag formula and wind speed multiplier, production simulations were conducted for the 30 ET storms without tides (surge only) to separate the storm surge signal from astronomic tides. Additionally, one long-term, tide-only simulation was completed. See Section 4;

- A total of 120 ET storm tide simulations were completed, combining each of the 30 ET storms with four selected tidal conditions representing low to high tide for spring and neap tide cycles to determine the effects of nonlinear interaction between surge and tide in the study area. See Section 4;

- Surge-only simulations, tide-only simulations, and nonlinear interactions were combined to construct 114,480 storm tide data points at each ADCIRC+SWAN node for recurrence analysis. See Section 5; and

- A recurrence analysis was completed at each location using the 114,480 storm tide samples to determine scientifically and technically correct percent-annual-chance stillwater elevations. See Section 5.

3.0 EXTRATROPICAL STORM VALIDATION

FEMA's stillwater elevations and thus the 2015 PFIRMs are scientifically and technically incorrect because the ET storm production simulations were completed using a model that did not undergo sufficient model validation, which resulted in biased high peak storm tide levels used in the recurrence analysis.

This section presents the steps taken by the City to sufficiently validate the 30 ET storms included in FEMA's PFIRM coastal analysis. Section 3 is outlined below:

- Section 3.1 describes the reproduction of the 1950 ET storm simulation to ensure that the ADCIRC+SWAN setup used by the City was consistent with the setup used by FEMA;

- Section 3.2 includes a Q-Q plot that demonstrates that the inclusion of the 1950 ET storm reanalysis meteorological conditions improved the comparison of simulated and observed peak elevations in the City's analysis, which is consistent with FEMA's findings (RAMPP 2015);

- Section 3.3 discusses updates to ADCIRC+SWAN that significantly improved simulation runtime and stability without adversely impacting model solutions;

- Section 3.4 outlines the simulation parameters that controlled the transfer of wind forcing from the atmosphere to the water surface and that were tested during the City's model validation. This section also describes the steps taken as part of the City's model validation, specifically model adjustments for wind drag formulation and wind speed multiplier parameters. For each model setup, all 30 ET storms were simulated and Q-Q plots were created. A Garratt-based wind drag formulation with a coefficient cap of 0.002 and a 1.00 wind speed multiplier was determined to be the most appropriate model setup for the production simulations of ET storms in the study area because the setup most closely replicated historical observations; and

- Section 3.5 summarizes the model validation improvements and the ways in which these improvements addressed the scientific and technical insufficiencies and inaccuracies of FEMA's PFIRM coastal analysis.

3.1 REPRODUCTION OF FEMA'S 1950 EXTRATROPICAL STORM SIMULATION

The 1950 ET storm was selected to test the City's model setup and confirm consistency with FEMA's PFIRM coastal analysis. The City's simulation used FEMA's PFIRM coastal analysis model setup including the FEMA model mesh, bathymetry, Manning's roughness values, wind drag with a 0.0035 cap, a 1.04 wind speed multiplier, etc. For the purposes of testing model reproduction, both the City's and FEMA's simulations made use of the original 1950 ET meteorological conditions.

Figure 1-4 and Figure 3-1 show the simulated storm tide and observed storm tide from the analyses conducted by the City and FEMA (RAMPP 2015), respectively. Inspection of the two figures shows very similar model results, as expected. The peak storm tide value at The Battery is approximately 11.0 feet MSL in FEMA's March 2015 memorandum (RAMPP 2015) and 10.9 feet MSL in the City's reproduction analysis[8]. Both studies adjust historical observations to MSL at the mid-point of the 1983-2001 NTDE.

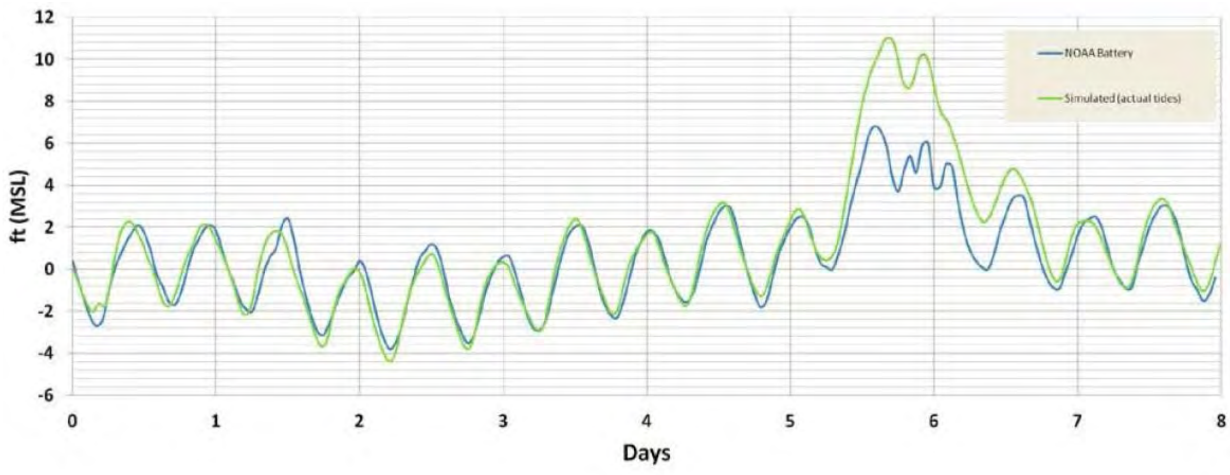


Figure 3-1. FEMA's simulation of the 1950 ET storm with historical (actual) tides compared to NOAA observed water levels at The Battery (RAMPP 2015).

3.2 EVALUATION OF 1950 EXTRATROPICAL STORM REANALYSIS

Prior to validating the ADCIRC+SWAN model setup for all 30 ET storms, the 1950 ET storm was assessed to determine which version of the 1950 ET storm meteorological conditions was most appropriate for inclusion in the City's new coastal study.

The overestimation of the 1950 ET storm, as shown on Figure 1-4 and Figure 3-1, was recognized by FEMA as a potential technical deficiency in the FEMA approach that required further evaluation. This resulted in the March 2015 memorandum evaluating "the impact of strong extra-tropical storms on the frequency analysis of storm water levels and the uncertainty associated with the storm surge elevations computed in the surge study" (RAMPP 2015). FEMA attributed the overestimation of the 1950 storm to the meteorological forcing applied to the model. Specifically, according to FEMA's memo, the "results showed that uncertainty about the offshore wind conditions is by far the most likely source of the relatively high computed maximum surge heights in New York Harbor" (RAMPP 2015).

As part of the March 2015 memorandum, FEMA conducted simulations of seven alternate meteorological representations of the 1950 ET storm to assess the variability in the computed maximum surge elevations. That analysis revealed that the original 1950 ET storm meteorological representation resulted in modeled peak values that were higher than observed elevations at all of the NOAA stations analyzed, including Willets Point, The Battery, Sandy Hook, and Atlantic City. The seven alternate meteorological representations that were simulated produced peak storm tide values that compared more closely than

[8]The 0.1-foot difference in simulation of the 1950 storm for the FEMA analysis and the City's analysis is believed to be due to slight differences in model outputs.

the original 1950 ET storm to observed peak values, with the exception of the alternate representation that increased wind speeds by 10 percent overall.

The alternate meteorology that best compared to observations as described in the FEMA March 2015 memorandum (RAMPP 2015) was the reanalysis meteorology, which represented a "complete reanalysis of the storm carried out in an attempt to discover the differences in the storm structure and speed of propagation that would affect the computed maximum surge height at the Battery Park gauge while maintaining the fit of the wind and pressure measurements available" (RAMPP 2015). The reanalysis meteorology is a "reasonable representation of the storm climate in the recent past," similar to the original 1950 ET storm meteorological forcing (RAMPP 2015). It should be noted that, while the reanalysis meteorology produced simulated peak values closer to observed values, the peak values remained 1.0, 2.5, and 1.5 feet higher than observed peak water levels at Willets Point, The Battery, and Sandy Hook, respectively, in the FEMA March 2015 analysis.

Similar to the FEMA March 2015 analysis, by applying the reanalysis meteorological forcing for the 1950 ET storm, the City's reproduction of the historical 1950 ET storm yielded a significant reduction in modeled water level and compared more closely to the observed data than the original 1950 ET meteorological conditions. A Q-Q plot generated using all simulated peak storm tides (with the 1950 reanalysis meteorological conditions) and observed peak storm tides is shown on Figure 3-2. A comparison of Figure 3-2 to Figure 2-4 shows improvement in the overall simulation results when including the reanalysis meteorological conditions rather than the original meteorological conditions, although only 5 out of the 215 records changed. The inclusion of the reanalysis meteorological conditions resulted in an RMSE of 0.40 foot and a slope of 1.193 in comparison to a 0.49-foot RMSE and a slope of 1.239 from the simulations with the original 1950 storm wind forcing.

Note, however, that, although the original1950 ET storm simulation exhibited a significant overestimation of peak storm tide values compared to observations and the reduction of the overestimation of the 1950 ET storm resulted in significant changes to percent-annual-chance stillwater elevations (Figure 1-5), the model overestimation associated with the 1950 ET storm was not the only factor contributing to the overall FEMA model bias. As shown by the bias on Figure 3-2, errors beyond the improvement of the 1950 ET storm meteorological conditions (from original to reanalysis) were the cause for the overall bias in FEMA's PFIRM coastal analysis.

Nevertheless, the 1950 reanalysis meteorological conditions reduce bias for the overall storm suite compared to the original meteorological conditions. Accordingly, all subsequent City analyses (those described in the remainder of the document unless otherwise noted) use the 1950 reanalysis meteorological conditions. In the steps taken by the City to validate and revise/improve the ADCIRC+SWAN model setup for all 30 ET storms, the 1950 reanalysis meteorological conditions were applied.

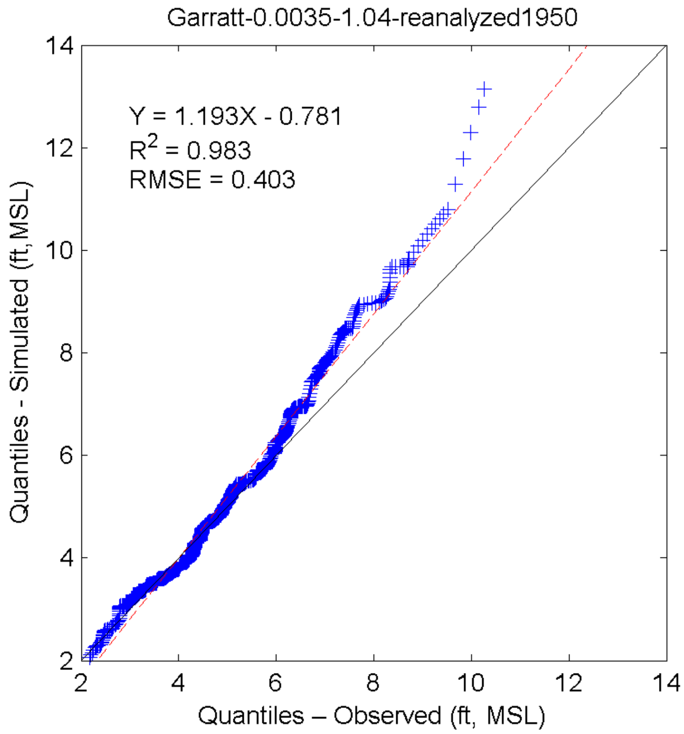


Figure 3-2. Q-Q plot comparing observed and simulated peak storm tide at NOAA gage stations using the FEMA ADCIRC+SWAN model setup and reanalysis 1950 ET storm.

Values are in feet, MSL. Black: 1:1 line; red dash line: linear regression line; blue crosses: quantile data points.

3.3 ADCIRC+SWAN STABILITY AND RUNTIME IMPROVEMENTS

During the review of FEMA's PFIRM coastal analysis, it was determined that ADCIRC+SWAN runtime and stability could be significantly improved without adversely impacting model solutions by making updates to the model setup. The City recognizes that limiting the changes to the FEMA ADCIRC+SWAN model setup is ideal, aside from those changes necessary for model validation and the development of a corrected, alternative methodology. However, it should be noted that the changes described in this section of the document are not bases for appeal. Rather, these items are model improvements that were necessary to complete and document the City's new coastal analysis within FEMA's 90-day appeal period, i.e., they maintained or improved the quality of the modeling solution while providing considerable model stability and runtime benefits. Had the City maintained FEMA's original setup, the appeal analyses could not have been completed within the required appeal period because of model instabilities and runtimes related to FEMA's model setup.

The following adjustments were made to ADCIRC+SWAN for all simulations described in subsequent sections of this document unless otherwise noted. The simulations described in Sections 2.1, 3.1, and 3.2 do not include these model changes, with the exception of select storms that required ADCIRC advection terms to be turned off for some of the 30 ET storms, as mentioned in Section 2.1.

1. The release version 50 (v50.99.15) of the ADCIRC+SWAN code was selected for this study. Various features added to the code since version 49 (v49.00), which was selected for the FEMA study, were critical to aid in providing an on-time deliverable for this project and enhancing efficiency when dealing with large datasets, such as the fully implemented Unidata netCDF library, which tremendously reduced the ADCIRC+SWAN output file size and the time required to write the data to a hard drive for submission to FEMA. The revised code version improved model runtime and substantially reduced file size for the data provided to FEMA as part of this appeal.

2. The ADCIRC solver was adjusted from an explicit solver with a 2-second time step to an implicit solver with a 1-second time step to improve model stability. In general, an implicit solver is more stable than an explicit solver. For ADCIRC specifically, an implicit solver is often more time intensive than an explicit solver for individual simulations but also more stable, meaning simulations are less likely to fail with an implicit solver. The simulations described in Sections 2.1, 3.1, and 3.2 demonstrated that the FEMA ADCIRC+SWAN mesh was prone to instabilities. Accordingly, an implicit solver and reduced time step were selected to address instability concerns. As demonstrated for the 1950 ET (with reanalysis meteorological conditions), the change in solver and model time step had a very limited impact on simulated peak storm tide elevations, as shown on Figure 3-3.

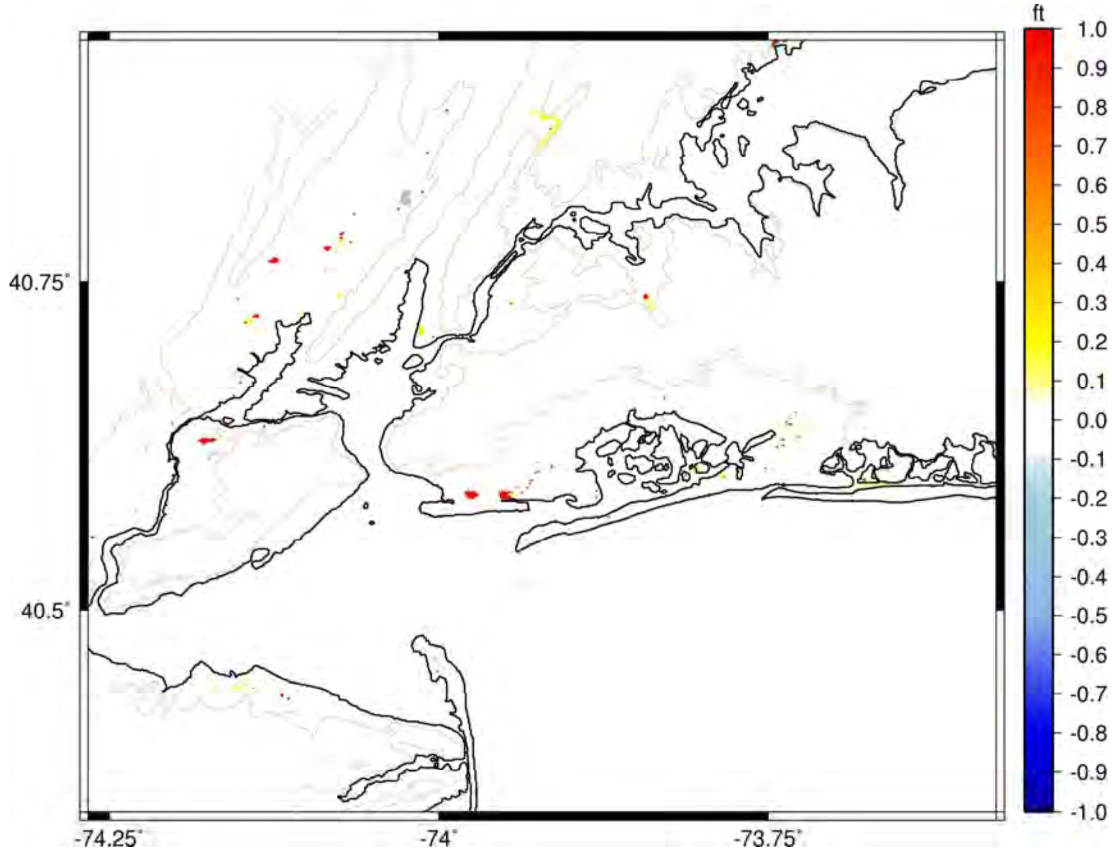


Figure 3-3. Maximum storm tide elevation differences (feet) for the 1950 ET reanalysis due to changing to an implicit solver and a 1-second time step.

Warm colors denote areas where peak values increased with the implicit solver and 1-second time step. Dark red and blue contours mark differences in wetting and drying fronts between the two simulations.

3. ADCIRC advection terms were turned off to improve model stability. The City found that the primary cause of model instabilities in FEMA's model setup was advection terms, which typically stem from the offshore boundary location in the North Atlantic. Instabilities outside the study area, particularly in the Caribbean Sea, occurred for numerous model simulations. Turning off ADCIRC advection parameters resulted in a considerably more stable model, and those storms that failed to run to completion with advection terms on all reached completion successfully with advection terms off. Figure 3-4 shows the change in peak storm tide elevations for the 1950 ET reanalysis meteorological conditions. Turning advection terms off lowered peak storm tide levels by 0.1 to 0.2 foot for much of the New York City area for the 1950 ET reanalysis meteorological conditions. However, the model impacts of turning off advection parameters varied with each ET storm. Of the storms simulated by the City with and without advection terms on, the greatest absolute differences were seen for the 1950 ET reanalysis meteorological conditions, nearly all storms showed less than 0.1 foot differences for the majority of the harbor, and many storms showed an increase in peak storm tide levels with advection terms off.

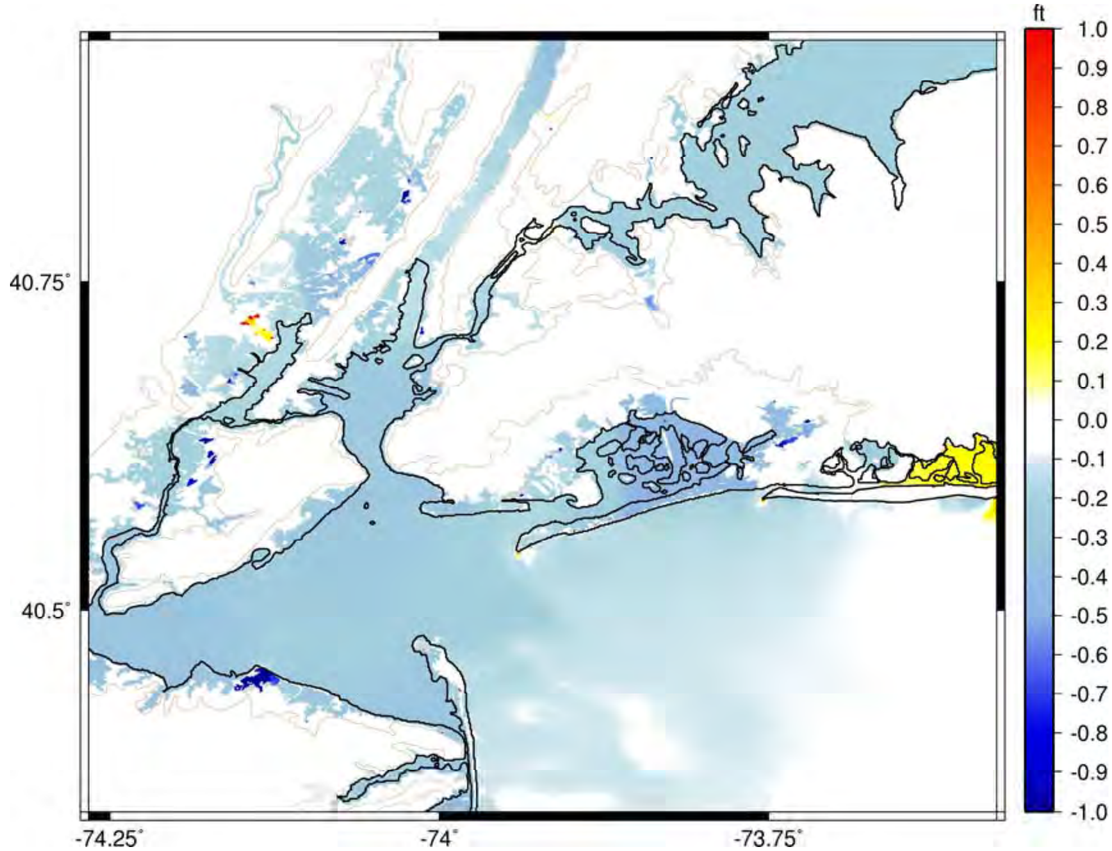


Figure 3-4. Maximum storm tide elevation differences (feet) for the 1950 ET reanalysis due to turning off advection terms.

Cool colors denote areas where peak values decreased with advection terms turned off. Dark red and blue contours mark differences in wetting and drying fronts between the two simulations.

4. SWAN model courant parameters were turned on to provide improved SWAN model results, including stable peak wave periods. Though this model setup was unavailable at the time of FEMA's PFIRM coastal analysis, the City thought it prudent to make use of these parameters to improve SWAN simulation results, particularly given that all 30 ET storms were simulated for each analysis. In this way, the final set of ET storms used in the determination of percent-annual-chance stillwater elevations were simulated consistently for all of the study area and included reliable peak wave period outputs.

5. The SWAN model wet node convergence criteria were adjusted from 99 percent to 95 percent, significantly reducing model runtime. As shown on Figure 3-5, for the 1950 ET storm reanalysis, which is representative of all ET storms in this instance, the FEMA PFIRM SWAN model convergence criteria were rarely, if ever, met by FEMA during the PFIRM coastal analysis. Instead, during FEMA's simulations, SWAN iterated 20 times (the maximum number of iterations as was set in the SWAN code), achieving the level of accuracy following the 20th iteration and not the accuracy set by the SWAN convergence criteria. Figure 3-5 shows that, by setting the convergence criteria to 95 percent, fewer model iterations (top plot) were necessary to provide nearly the same accuracy with each time step of the simulation (bottom plot). The change in SWAN convergence criteria decreased model runtimes by more than 30 percent. Figure 3-6 shows that the changes to the SWAN setup, both the courant parameters and the change in convergence criteria, resulted in minor changes in the simulated peak storm tide elevations.

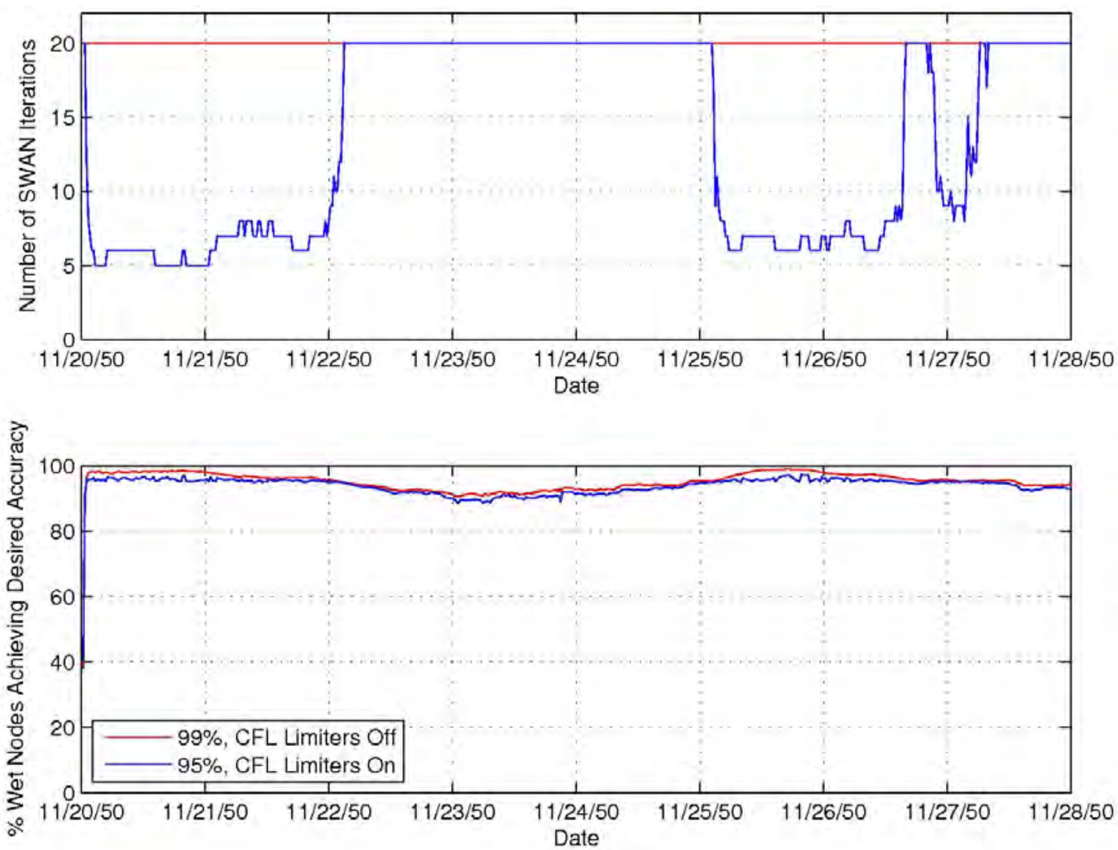


Figure 3-5. SWAN model iterations and accuracy for 99 percent (red line on both plots) and 95 percent convergence criteria (blue line on both plots) for the 1950 ET reanalysis.

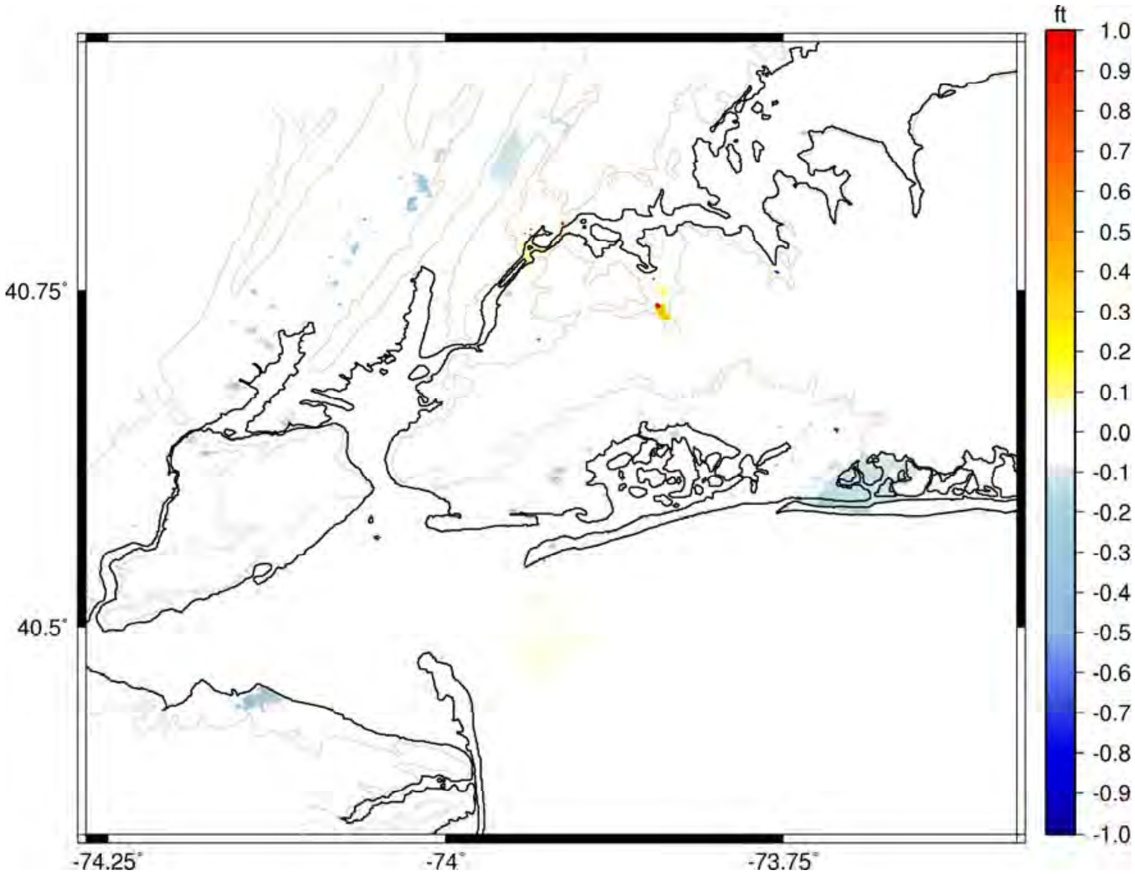


Figure 3-6. Maximum storm tide elevation differences (feet) for the 1950 ET reanalysis due to changes in the SWAN model setup for courant parameters and convergence criteria.

Warm colors denote areas where peak values increased with the changes to SWAN model setup. Dark red and blue contours mark differences in wetting and drying fronts between the two simulations.

In summary, of the five model changes described, each resulted in simulated peak storm tide elevation changes of generally 0.1 foot or less, while improving model stability and runtime considerably. These impacts are on the order of, and in most areas less than, the impacts described by FEMA (2014d) related to the surface directional effective roughness length parameter. FEMA's error in setting the surface directional effective roughness length parameter was described to have "little impact based on differences less than 0.1 foot for the majority of the study area...[and] isolated differences of plus and minus 0.5 foot in back bay areas, and in rare locations differences reached upwards of 1.0 foot" (FEMA 2014d). Accordingly, the effects of these model changes had little impact based on FEMA's own criteria for the PFIRM coastal analysis. Because of the relatively minor impacts on results and considerable runtime improvements, the five model adjustments were made for all simulations described in subsequent sections of this document unless otherwise noted.

3.4 WIND DRAG COEFFICIENT AND WIND SPEED MULTIPLIER SELECTION FOR EXTRATROPICAL STORMS

Winds are the primary driving force for a storm-induced rise of water level. To further assess the potential cause of FEMA's PFIRM coastal analysis model bias and improve model validation, a review of the wind stress parameters that control the transfer of wind forcing from the atmosphere to the water surface was performed. Two fundamental parameters that significantly influence wind stress in ADCIRC+SWAN are a wind drag coefficient and a wind speed multiplier. In 1977, the wind drag coefficient was found to be a function of neutral wind speed (Garratt). A wind speed multiplier scales wind speeds uniformly by a set factor across the model domain. A wind speed multiplier can be applied to calibrate a model or to incorporate a wind speed conversion factor. For the City's analysis, Manning's roughness values, horizontal eddy viscosity, and surface directional effective roughness length parameters remain unchanged from those set by FEMA (FEMA 2014e).

3.4.1 WIND DRAG COEFFICIENT AND FORMULATION OVERVIEW

In the 2007 Coastal Guidelines update, FEMA specifically discussed the importance of the wind drag formulation in coastal modeling and the need to potentially consider different formulations for tropical and ET events, as excerpted below (FEMA 2007a):

"The surface stress distribution resulting from storm induced wind is computed through application of some specified wind drag formulation that includes empirical coefficients. Selection of an appropriate formula and coefficients is extremely important because the shear stress is proportional to the square of the windspeed. A formulation/coefficient that is appropriate for extratropical events may not be appropriate for tropical storms. A versatile numerical model should provide the user with capability to specify parameters for a given formulation, including reductions in the presence of vegetation. Based on current research progress, it may soon be a standard procedure to consider allowing the wind stress to be capped at the highest windspeeds, owing to reduction in sea surface roughness during extreme events."

The City reviewed wind drag coefficient-related publications to determine wind drag formulations that could be applicable in the study area and over the range of wind speeds encountered during ET storms, i.e., storms with winds less than 30 meters per second (m/s). Figure 3-7 illustrates the variation of wind drag coefficients with respect to a wind speed at 10 meters elevation, including the Garratt (1977) publication adopted by FEMA's PFIRM coastal analysis. All publications were published prior to FEMA's PFIRM coastal analysis except for Holthuijsen et al. (2012) and are potentially applicable for ET storms in New York and New Jersey. The works of Powell et al. (2003) and Holthuijsen et al. (2012) involved direct field measurements using wind sondes, while the works of Donelan et al. (2004) and Bye and Jenkins (2006) were experimental and theoretical, respectively, and were not developed specifically for tropical cyclones and hurricanes. Powell (2006) reanalyzed the data in Powell et al. (2003) and presented a similar variation but with a smaller drag coefficient cap of 0.0021. Holthuijsen et al. (2012) reviewed data from previous publications including Powell et al. (2003) and Garratt (1977) and showed that all data sets are consistent at high wind speeds but suggest a relatively small drag coefficient for low wind speeds. Note that the formulations shown on Figure 3-7 have been simplified from those in literature and represented using linear functions to demonstrate the first-order difference in trend and magnitude.

Though simplified, the formulations, other than the Garratt (1977) formulation, provide essential agreement on an acceptable maximum drag coefficient.

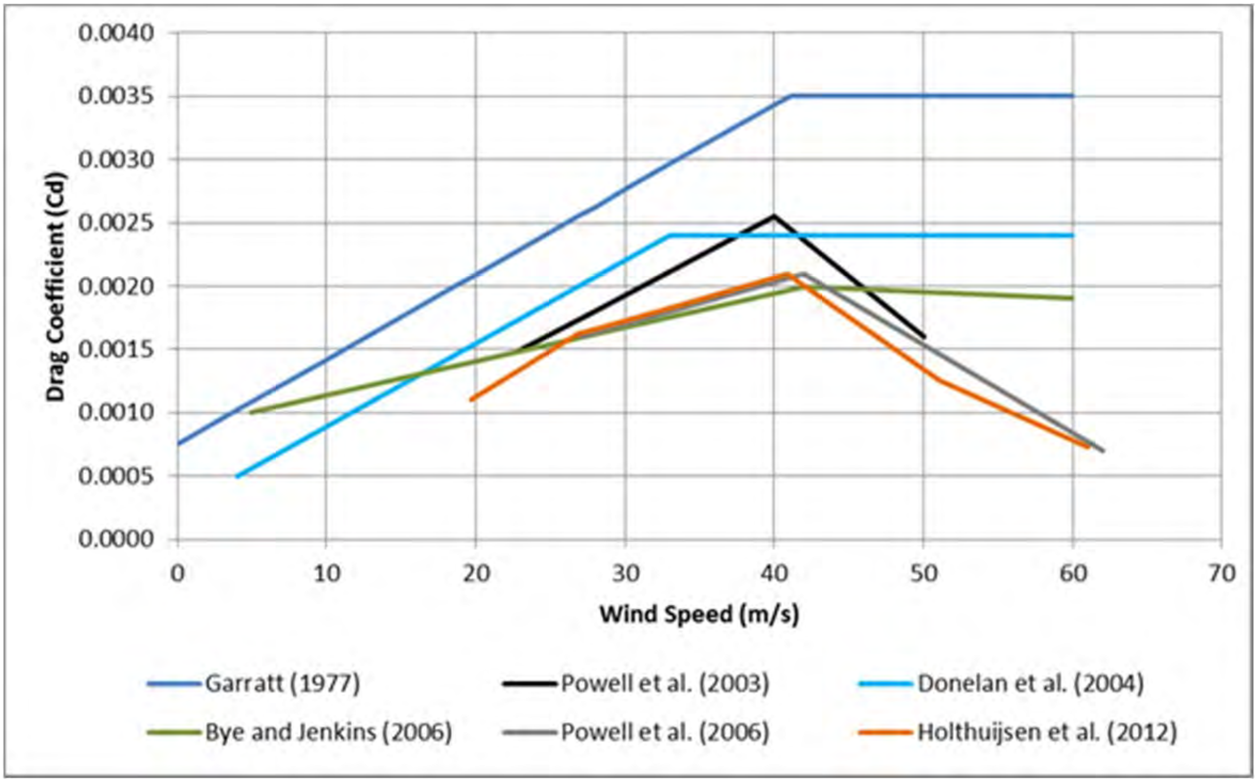


Figure 3-7. Reviewed wind drag coefficient formulations.

The wind drag coefficient cap varies from 0.002 to 0.0035, with all formulations demonstrating a cap of 0.0026 or less, with the exception of Garratt (1977). Figure 3-7 also shows that the Garratt (1977) formulation has a wind drag coefficient for all wind speeds that is higher than the other formulations reviewed. It is also important to recognize that a higher wind drag coefficient and cap will transfer more wind energy from the atmosphere to the water in the model, thus producing higher storm surge.

Regardless of which wind drag formulation is the default in ADCIRC+SWAN or applied in other coastal flood hazard studies, it is important to select a technically appropriate formulation that is properly balanced with other ADCIRC+SWAN parameters in this specific study (i.e., Manning's roughness values, horizontal eddy viscosity, surface directional effective roughness length parameter, and wind speed multiplier) to produce unbiased storm tide elevations for all ET storms in New York and New Jersey. Section 3.4.2 discusses the analysis and selection of the most appropriate wind drag coefficients and formulation, as well as the wind speed multiplier.

3.4.2 WIND DRAG COEFFICIENT AND WIND SPEED MULTIPLIER SELECTION

FEMA's PFIRM coastal analysis made use of the ADCIRC+SWAN default wind drag coefficient formulation for both tropical and ET storms, i.e., the Garratt formulation with a 0.0035 wind cap (FEMA 2014c; FEMA 2014e). However, as is clear from the excerpt from the FEMA Atlantic Ocean and

Gulf of Mexico Coastal Guidelines Update (FEMA 2007a) and the Q-Q plots showing significant model bias on Figures 2-4 and 3-2, FEMA should have selected an appropriate formula and coefficients for ET storms. Not doing so resulted in a scientific and technical error that could have been avoided and that left the modeling methodology biased high, rather than having been validated to be unbiased.

Of the wind drag formulations presented in Section 3.4.1, it is important to understand which formulation would be most applicable in the study area for ET storms. In order to select the technically appropriate wind drag formulation and wind speed multiplier, four wind drag formulations and two wind speed multipliers were applied for all 30 ET storm simulations. Table 3-1 summarizes the alternative model setups that incorporate various combinations of the wind drag formulation and the wind speed multiplier.

Table 3-1. Wind drag formulations and wind speed multiplier simulated with each of the 30 ET storms.

Model Setup	Wind Drag Formulation	Wind Drag Description	Wind Speed Multiplier
FEMA PFIRM	Garratt 0.0035	Default in ADCIRC, cap at 0.0035 at 40 m/s	1.04
Alternative 1	Garratt 0.0020	Cap at 0.002 at 20 m/s	1.04
Alternative 2	Garratt 0.0020	Cap at 0.002 at 20 m/s	1.00
Alternative 3	Donelan 0.0024	Cap at 0.0024 at 33 m/s	1.04
Alternative 4	Bye-Powell 0.0026	Cap at 0.0026 at 42 m/s	1.04

Note that Alternatives 1 and 2 adopt the Garratt (1977) formulation but decrease the wind drag coefficient cap from 0.0035 to 0.002 based on the more recent (than 1977) published data, such as Powell (2006), that were available at the time of FEMA's PFIRM coastal analysis. Alternative 3 applies a linear approximation of the Donelan formulation. Alternative 4 is a combination of Bye and Jenkins (2006) for winds speeds less than 26 m/s and Powell et al. (2003) for wind speeds greater than 22 m/s. Figure 3-8 shows all four functions of the wind drag coefficient that were implemented in ADCIRC+SWAN for testing by the City.

In addition to changing the wind drag formulation and wind speed multiplier, all four alternatives in Table 3-1 include the removal of the lower limit of the bottom friction coefficient. Manning's roughness values, horizontal eddy viscosity, etc., remain the same as those set by FEMA. The removal of the bottom friction lower limit can reduce model damping for deep water columns and low Manning's roughness values. Removal of the bottom friction lower limit has been found to produce results that compare better to observation in other ADCIRC-based studies. This method was applied for the FEMA FIS initially completed in 2008 for Coastal Texas (FEMA 2011b), by Dietrich et al. (2011) for the hindcast of Hurricane Gustav, and by Hope et al. (2013) for the hindcast of Hurricane Ike.

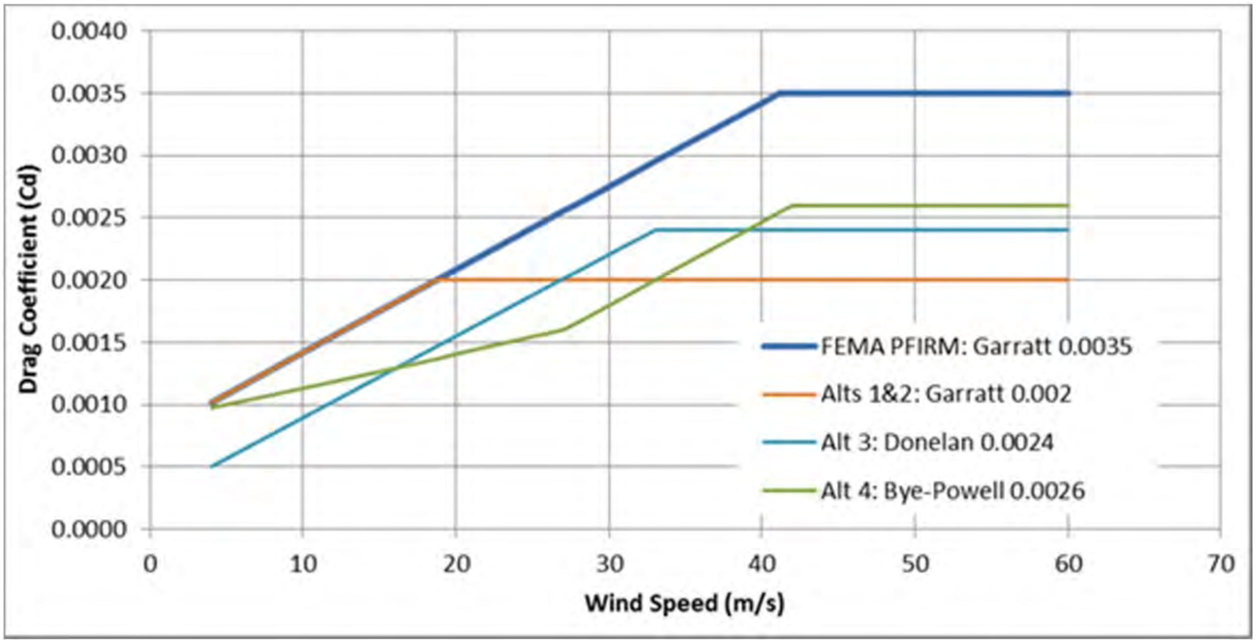


Figure 3-8. Alternative wind drag coefficient formulations tested.

Figures 3-9 through 3-12 show the water surface elevation simulation results for each of the alternative wind drag formulations and wind speed multipliers at Willets Point, The Battery, Sandy Hook, and Atlantic City NOAA gage locations as compared to the observed water levels during the 1950 ET storm event. As previously mentioned, each of the alternative drag formulations were applied for all 30 ET storms; however, the 1950 ET storm was selected as a representative storm on Figures 3-9 through 3-12 to be consistent with other figures in the report that highlight the 1950 ET storm. The NOAA observed data were again adjusted to MSL at the midpoint of the 1983-2001 NTDE in order to account for the sea level change since the time of each storm. For the 1950 ET storm, relative to the FEMA PFIRM model setup (Garratt 0.0035 formulation), all four alternatives offer improved simulation results compared to observed water levels. Note that all five simulations (the four alternatives and the FEMA PFIRM model set up) applied the 1950 ET storm reanalysis meteorological conditions.

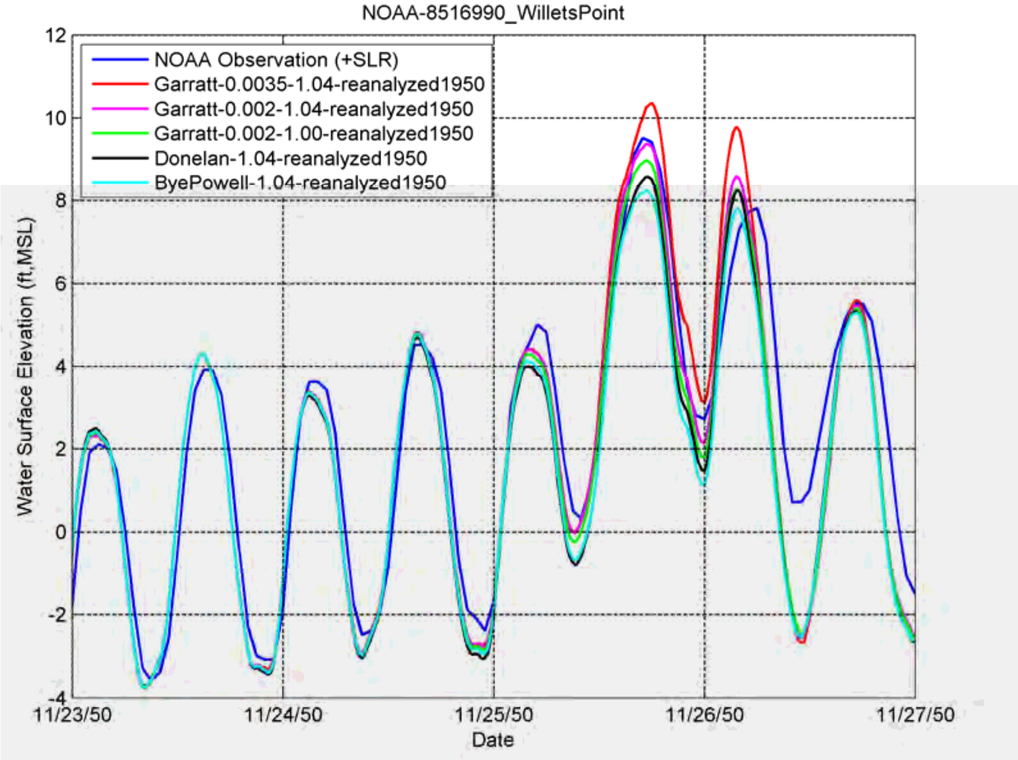


Figure 3-9. Water surface elevation (feet, MSL) at the Willets Point, New York, NOAA gage for the 1950 ET storm.

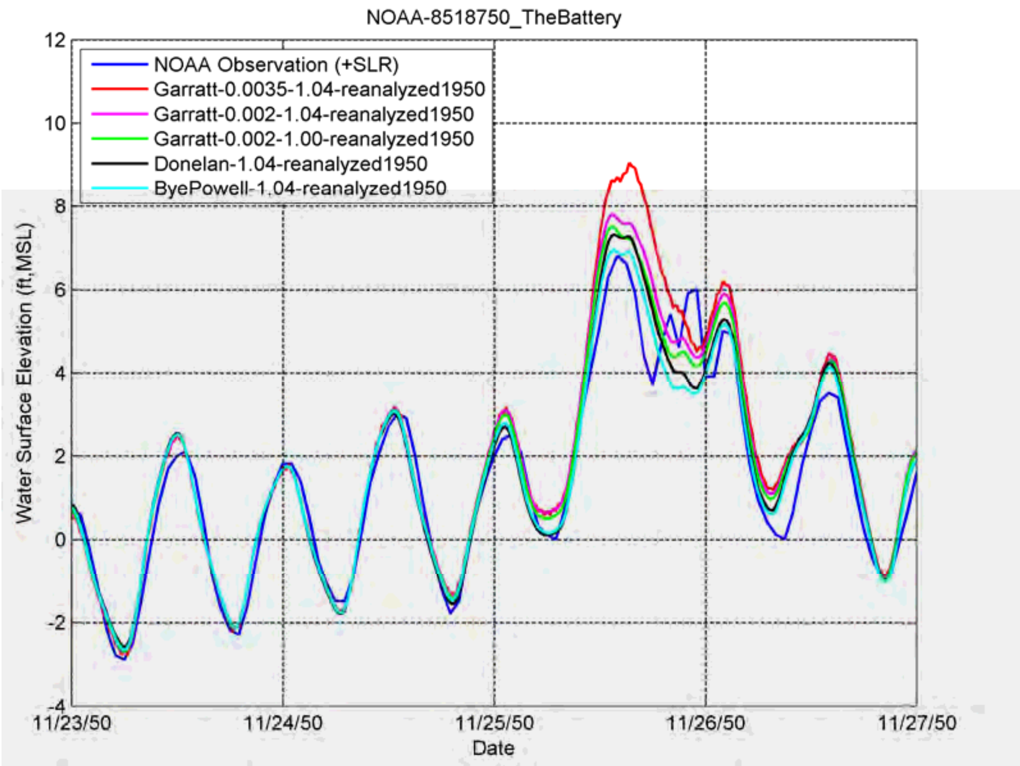


Figure 3-10. Water surface elevation (feet, MSL) at The Battery, New York, NOAA gage for the 1950 ET storm.

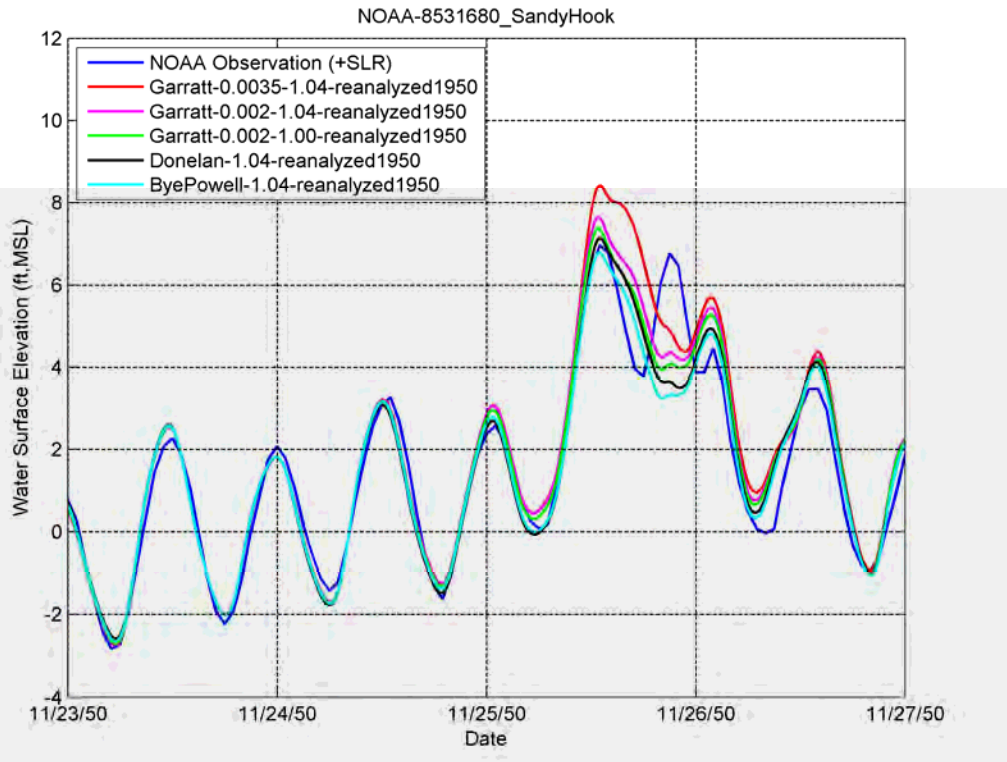


Figure 3-11. Water surface elevation (feet, MSL) at the Sandy Hook, New Jersey, NOAA gage for the 1950 ET storm.

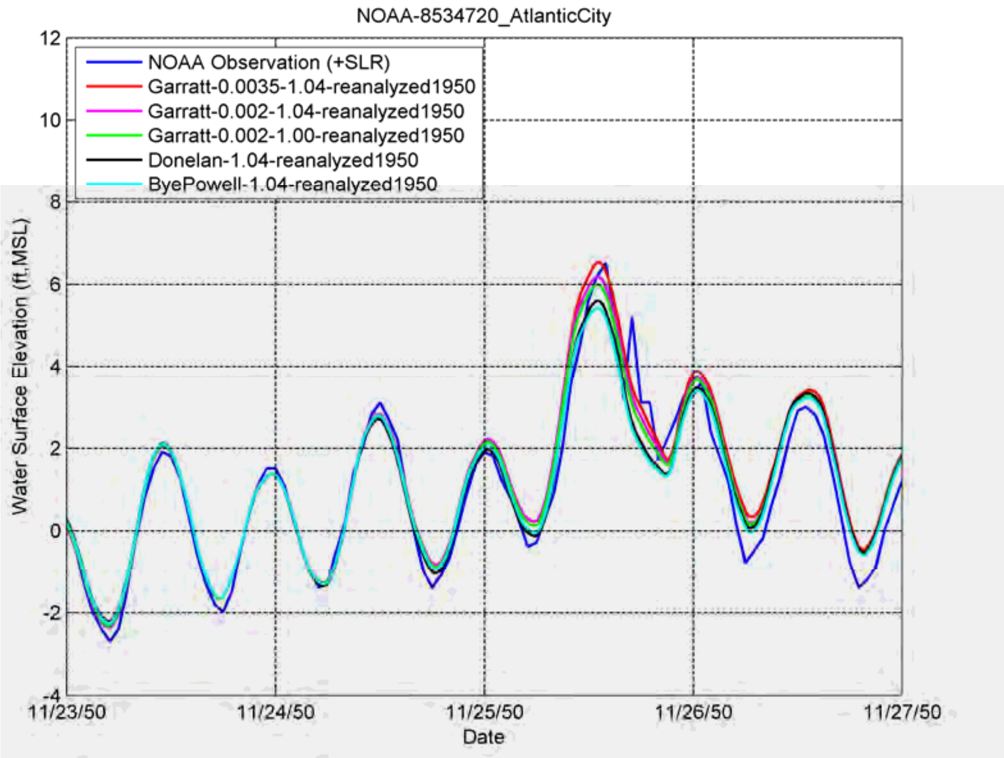


Figure 3-12. Water surface elevation (feet, MSL) at the Atlantic City, New Jersey, NOAA gage for the 1950 ET storm.

In addition to the 1950 ET storm, the model setup alternatives show improvement for the other ET storms as well, each to a different degree. Q-Q plots were created based on the same 215 data points described in Section 2 to demonstrate the improvement in model performance and the reduction in bias overall, particularly for low-intensity storm simulations. The Q-Q plots (Figure 3-13) show that Alternatives 1, 2, and 3 reduced the RMSE for the entire storm suite from 0.40 foot (Figure 3-2, which was the FEMA PFIRM model setup using the reanalysis 1950 ET storm) to 0.25 foot (Alternative 1), 0.24 foot (Alternative 2), and 0.35 foot (Alternative 3). Alternative 4 (the Bye-Powell formulation) resulted in an overall low estimation of storm tide and was consequently removed from consideration. When considering the RMSE for high-intensity storms only (those producing peak storm tides greater than 6 feet MSL or 8 feet MSL), the improvements due to the use of alternative model setups were even more remarkable in comparison to the FEMA PFIRM model setup. For instance, the Alternative 2 model setup produced model results with an RMSE of 0.24 foot (for peak storm tides greater than 6 feet) and 0.37 foot (for peak storm tides greater than 8 feet) for the high-intensity storms compared to an RMSE of 0.83 foot (for peak storm tides greater than 6 feet) and 1.37 feet (for peak storm tides greater than 8 feet) using the FEMA PFIRM model setup. The RMSEs for each model setup can also be found in Table 3-2.

Alternative 2, i.e., the Garratt 0.002 with a wind speed multiplier of 1.00, resulted in the least biased model results while still providing conservative (potentially overestimated) storm tide elevations. Therefore, rather than using the default model setup used by FEMA, the Garratt 0.002 formulation with a wind speed multiplier of 1.00 was determined as the most appropriate model setup for the production simulations of ET storms in the study area, which are described in Section 4.

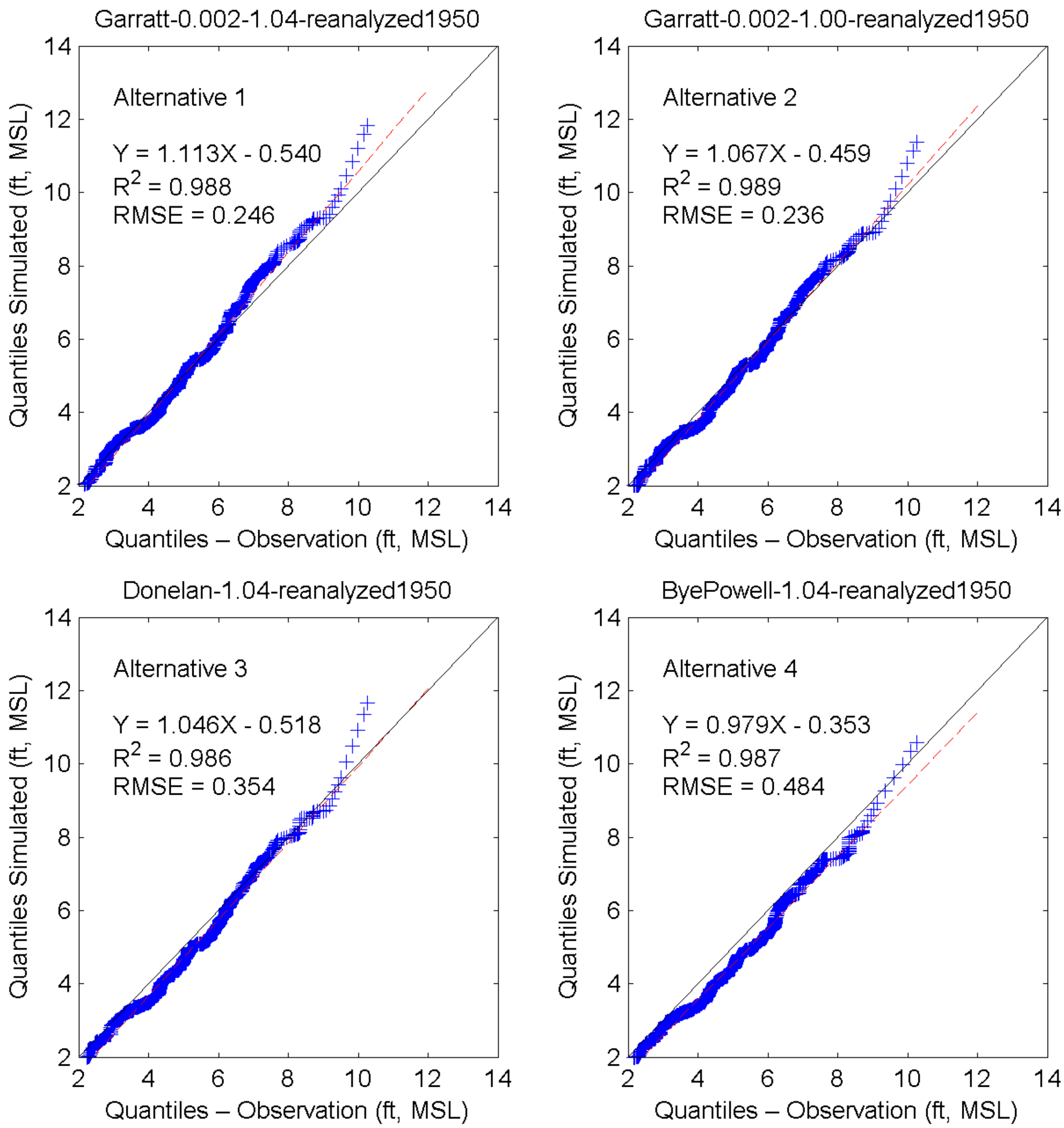


Figure 3-13. Q-Q plot comparing observed and simulated peak storm tide at NOAA gage stations using various ADCIRC+SWAN model setups and reanalysis 1950 ET storm.

Values are in feet, MSL. Black: 1:1 line; red dash line: linear regression line; blue crosses: quantile data points.

Table 3-2. Q-Q slope and RMSE (feet) values for various ADCIRC+SWAN model setup alternatives.

Model Setup	Figure Label	Slope	RMSE (all)	RMSE (>6 feet)	RMSE (>8 feet)
FEMA PFIRM original 1950	Garratt-0.0035-1.04-original1950	1.239	0.49	1.03	1.86
FEMA PFIRM reanalysis 1950	Garratt-0.0035-1.04-reanalyzed1950	1.193	0.40	0.83	1.37
Alternative 1	Garratt-0.002-1.04-reanalyzed1950	1.113	0.25	0.44	0.67
Alternative 2	Garratt-0.002-1.00-reanalyzed1950	1.067	0.24	0.24	0.37
Alternative 3	Donelan-1.04-reanalyzed1950	1.046	0.35	0.26	0.44
Alternative 4	ByePowell-1.04-reanalyzed1950	0.979	0.48	0.44	0.54

3.5 SUMMARY OF IMPROVED SIMULATION OF EXTRATROPICAL STORMS

Section 3 discussed the steps taken by the City to sufficiently validate the 30 ET storms included in FEMA's PFIRM coastal analysis and illustrated FEMA's scientific and technical errors that caused their modeling methodology to be biased high, which led to biases that were unaccounted for in FEMA's determination of stillwater elevations. FEMA's methodological and mathematical errors ultimately led to inaccurate BFEs and SFHA boundaries. The key steps and findings described in Section 3 can be summarized as follows:

- The inclusion of the reanalysis meteorological conditions improved the comparison of simulated and observed peak elevations, as demonstrated by a Q-Q plot and RMSE values. All subsequent analyses made use of the 1950 reanalysis wind and pressure fields;
- ADCIRC+SWAN changes made for this analysis significantly reduced simulation runtime and enhanced stability without adversely impacting model solutions;
- The FEMA default model setup and four alternative wind drag formulations and wind speed multipliers were tested and evaluated to examine model bias and reduction of RMSE; and
- A Garratt-based wind drag formulation with a coefficient cap of 0.002 and a wind speed multiplier of 1.00 was determined to be the most technically appropriate model setup for the production simulations of ET storms because it produced the most accurate model results compared to observation data.

4.0 EXTRATROPICAL STORM PRODUCTION

In addition to the errors described in Section 3, FEMA's 2015 PFIRMs are scientifically and technically incorrect because of methodological errors associated with FEMA's insufficient selection of only two random tides coincident with ET storms, which resulted in mathematical errors in FEMA's determination of stillwater elevations and hence inaccuracies in BFEs and SFHA boundaries. The inclusion of only two tidal conditions for each of the ET storms resulted in an overly small sample and introduced a high level of uncertainty that is mathematically expected to produce a bias toward higher values. Section 2.2 describes the notable bias that was not properly assessed or accounted for by FEMA as part of the PFIRM coastal analysis.

In order to address model bias resulting from the small sample size for ET storms, the validated model setup presented in Section 3 was applied to ET storm production simulations for generating a large number of storm tide samples, which then informed the ET storm statistical analysis. However, it was not feasible to simulate each of the 30 ET storms combined with a large number of tides in the 90-day appeal time frame. Instead, linear superposition of surge-only (ET storms simulated without tides) time series and a time series of tidal levels were applied to construct a large number of storm tides. The approach additionally accounted for the effects of nonlinear interaction between surge and tides. The nonlinear effects were integrated into the linear superposition by comparing the peak of simulated storm tides and the peak of linearly superposed storm tides. To do so, 30 ET storms were simulated with surge and waves only ("surge only"), one tide-only simulation was carried out for a 2-month range (October 1, 2010, through November 30, 2010), and 120 storm tides were simulated by fully coupling each of the 30 ET storms with four tidal phases. In total, 150 ADCIRC+SWAN ET storm simulations and one ADCIRC tide simulation were performed to build the database of peak storm tide elevations for statistical analysis, as discussed in Section 5.

4.1 SURGE-ONLY SIMULATIONS

Surge-only simulations were performed to inform water level response due to wind-forced surge and waves. These simulations employed the validated wind drag formulation discussed in Section 3.4, i.e., the Garratt wind drag coefficient with a 0.002 cap and a wind multiplier of 1.00. The other model setup parameters and files, including the mesh, bathymetry, and Manning's roughness coefficients used, were identical to those in FEMA's PFIRM coastal analysis, with the exception of the model setup adjustments noted in Section 3. Also, as discussed in Section 3, the City's storm suite included the 1950 ET reanalysis meteorological conditions. An example surge-only simulation output is shown on Figure 4-1. For each of the 30 ET storms, the durations to the peaks were also calculated to determine the initial tidal phase for surge-tide coupled simulations, which are described in Section 4.3.

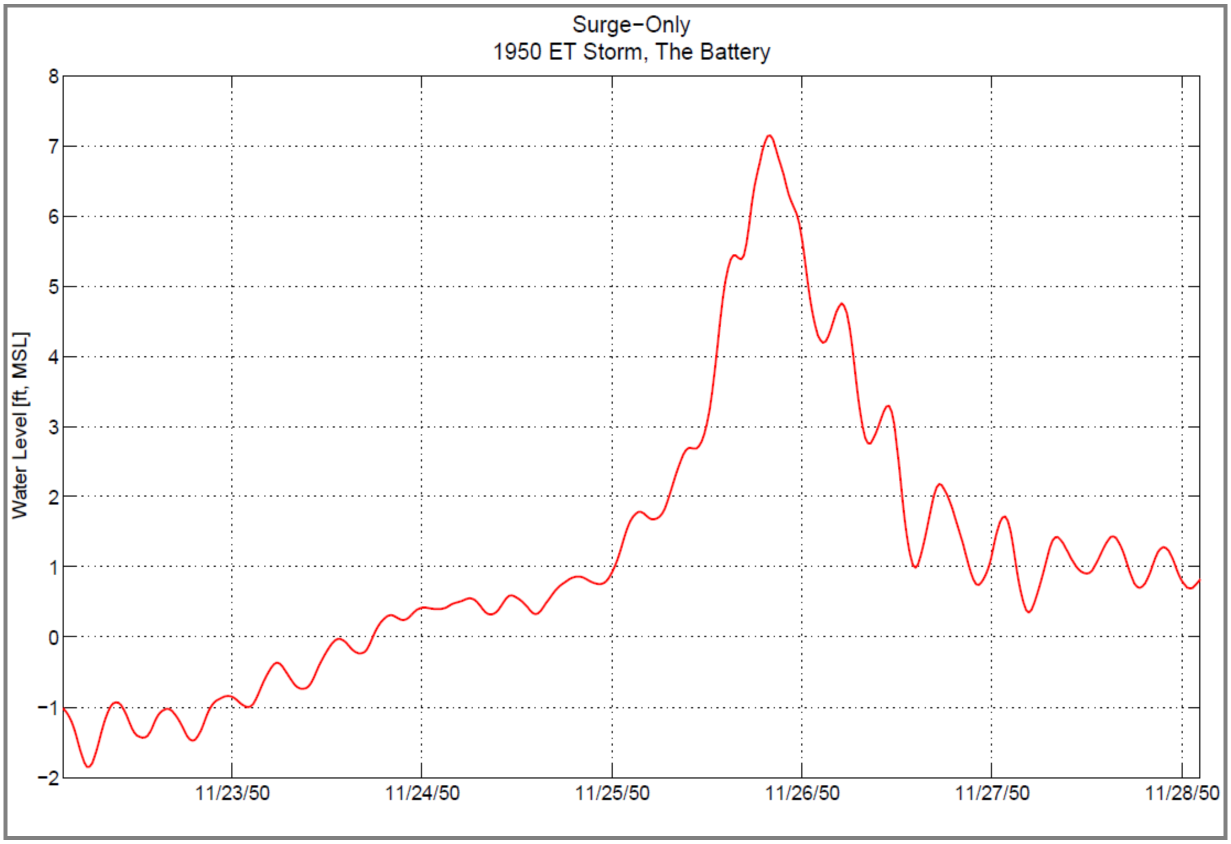


Figure 4-1. Surge only for the 1950 ET reanalysis storm at The Battery. Values are in feet, MSL.

4.2 TIDE-ONLY SIMULATIONS

To construct storm tide records, a tidal prediction (a time series of tidal elevations with no wind forcing) is needed. The tidal prediction data were downloaded for NOAA stations at The Battery and Kings Point. It was determined that the 2-month tidal period (October and November) is representative of the range of tidal elevations expected for the non-tropical season, as shown on Figure 4-2. Due to the MSL seasonal variation, the mean tidal level for October and November is slightly higher than the mean of the entire non-tropical season, making use of those 2 months a conservative estimation. Figure 4-3 shows the comparison of simulated tidal elevations with NOAA predicted tides for The Battery and Kings Point.

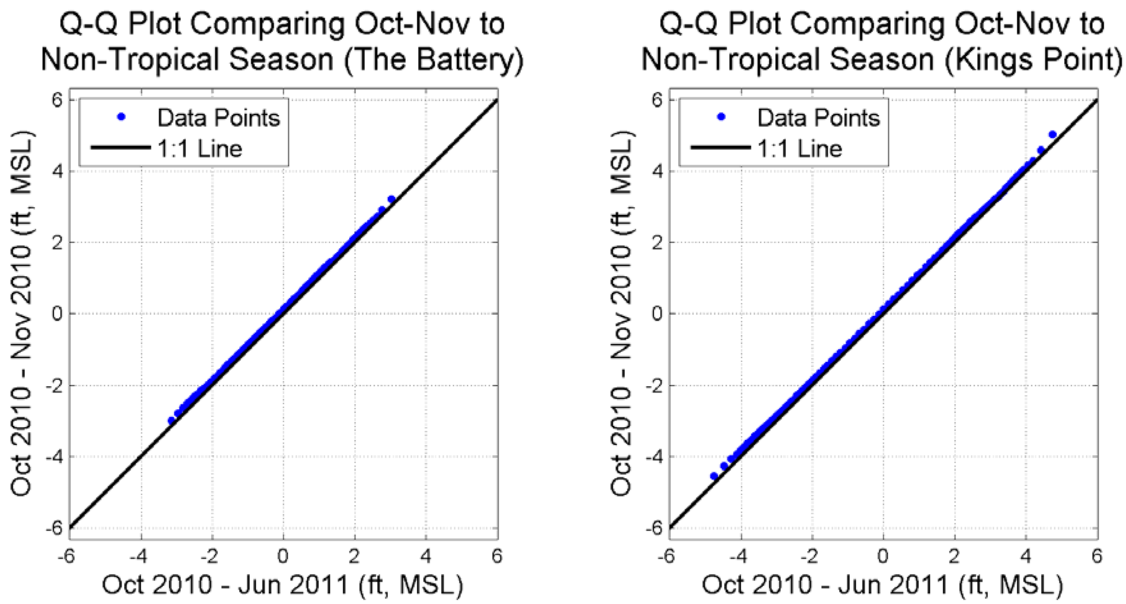


Figure 4-2. Q-Q plot comparing tides in October and November 2010 to non-tropical season.

Elevations are in feet, MSL.

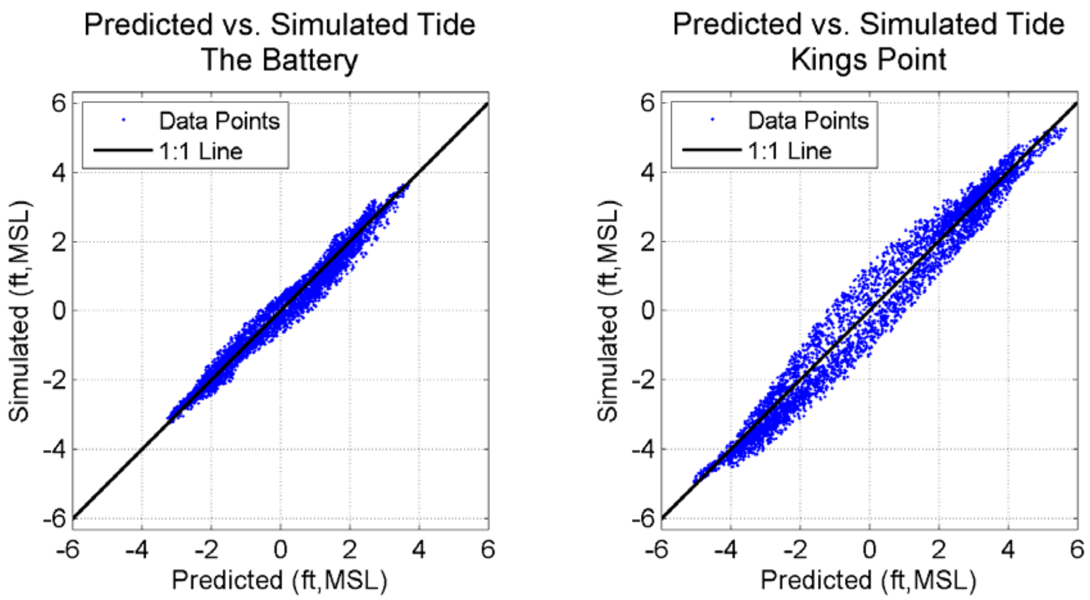


Figure 4-3. The scatter plot of ADCIRC simulated tides versus NOAA predicted tides at The Battery and Kings Point.

Elevations are in feet, MSL.

4.3 EFFECTS OF NONLINEAR INTERACTION AND SUPERPOSITION OF STORM SURGE AND TIDES

As discussed in Section 2, FEMA's selection of only two random tides to coincide with the 30 ET storms was insufficient to reproduce the effects of combined surge and tides. However, it is very costly and time consuming to carry out the number of ADCIRC+SWAN simulations necessary for a sufficient sample size.

Linear addition of surge and tide is a computationally efficient method to bracket the possibility of surge and tides. In the study area, tidal amplitudes are relatively large, with a great diurnal range of 5.1 feet at The Battery and 7.8 feet at Kings Point (NOAA). Because these tidal magnitudes are similar to storm surge magnitudes, the nonlinearity of the interaction between tide and surge is important to quantify using "physically realistic methods" (FEMA 2014a).

FEMA guidance recommends that the nonlinearities can only be accounted for by hydrodynamic considerations. In a common FEMA approach, "a small number of storms are simulated around a set of tide assumptions with differing amplitudes and phases. These additional simulations are used to provide guidance for simple adjustments that are made to the large set of [linear] computations" (FEMA 2007a). In fact, the linear addition of surge and tide, with the quantification of nonlinearities, was adopted for the 2007 effective FIRM coastal study performed for the New York City area, specifically "total stillwater elevations were determined by combining each stillwater elevation with the complete range of local tidal conditions and accounting for nonlinearities in the combination" (FEMA 2007b).

In order to quantify the nonlinear interactions between surge and tide, storm tides were simulated for each ET storm with both wind forcing and tidal forcing for four selected tidal phases. To maintain the number of simulations at a manageable number yet fully inform the range of incidents, the NOAA tidal predictions at NOAA stations in the study area were examined to evaluate the difference in tidal phase and tidal amplitude among stations. All stations exhibit mixed semi-diurnal tides, and there are minor tidal phase shifts between stations, with the exception of Kings Point, which has a phase shift of more than 3 hours compared to nearby stations. Table 4-1 shows the tidal phase shift between gage locations, with The Battery as a point of reference. Because the tidal phases at most gages are similar, the tidal phases for storm tide simulations were based on the NOAA tidal predictions at The Battery and Kings Point.

Table 4-1. Phase lag between The Battery and adjacent tide gages averaged over all tides October 1 through November 30, 2010.

Location	Lag (hours)
The Battery	0
Kings Point	3.4
Sandy Hook	- 0.4
Atlantic City	- 0.8

Source: NOAA predicted tides.

The tidal phases for storm tide simulations were determined by aligning the expected high/low tide with the peak of the storm surge for each of the 30 ET storms. Because the tides at The Battery and Kings

Point show a 3.4-hour phase difference, four tides were selected based on the Kings Point tidal prediction for 13 ET storms, and four tides were selected based on The Battery tidal prediction for the other 17 ET storms. For both gage locations, four tides were selected to reflect higher high water to lower low water during spring and neap conditions for the selected 2-month period. The selected tides at The Battery and Kings Point are shown on Figure 4-4 and Figure 4-5. The initial tidal phase for each ET storm was then determined based on the duration of high storm surge levels calculated from the surge-only simulation time series.

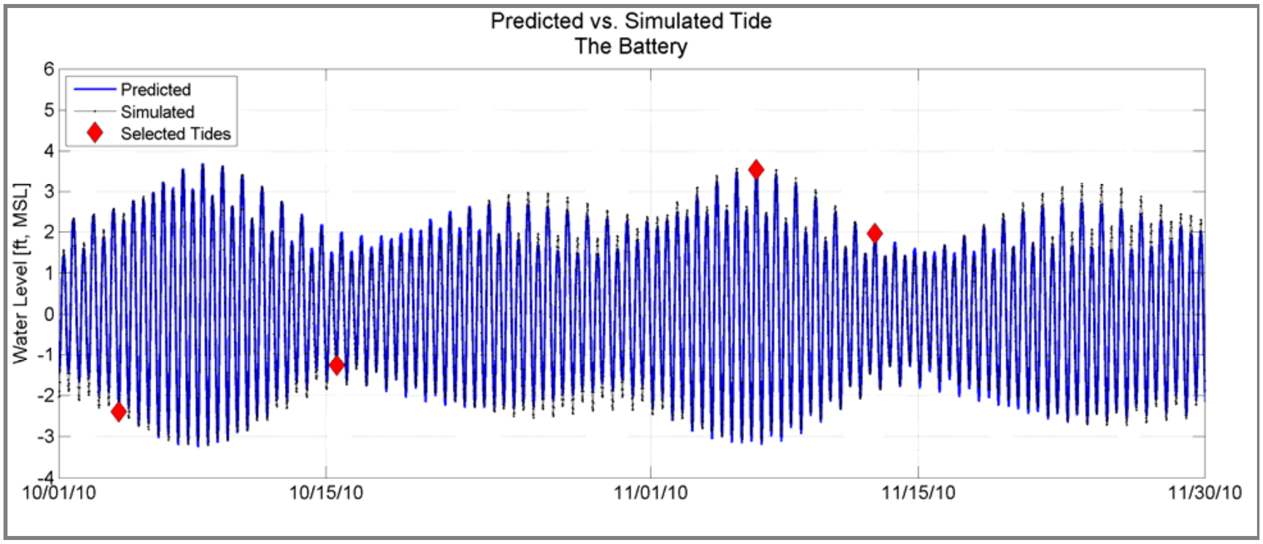


Figure 4-4. Tides selected for the simulation of combined storm tide at The Battery from the October 1 through November 30, 2010, tidal period.

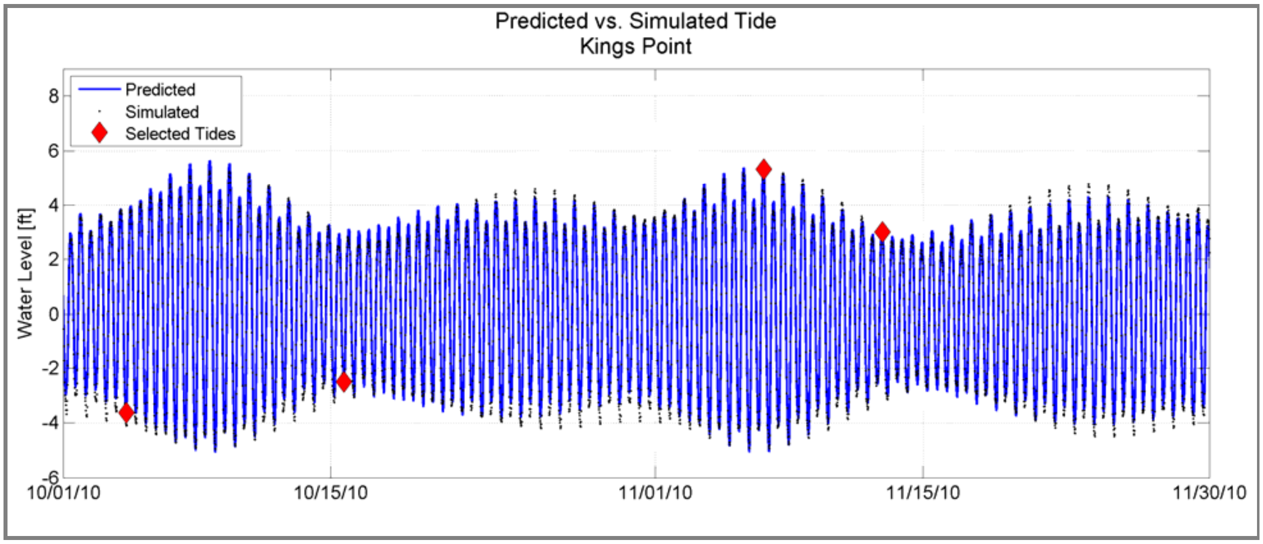


Figure 4-5. Tides selected for the simulation of combined storm tide at Kings Point from the October 1 through November 30, 2010, tidal period.

In total, 120 storm tides were simulated. Figure 4-6 shows the difference in the time series of water levels between the tide-only simulation, surge-only simulations, storm tide simulations, and linearly superposed storm tide (i.e., surge + tide) at The Battery. Figure 4-6 also shows that the addition of the tide-only time series and the surge-only time series resulted in a 0.7-foot higher peak elevation at The Battery than the peak elevation of the simulated storm tide due to the nonlinear interaction of surge and tides. Contrary to The Battery, the nonlinear effects at Kings Point resulted in a superposition storm tide peak that was 0.6 foot lower than the peak of simulated storm tide, as shown on Figure 4-7.

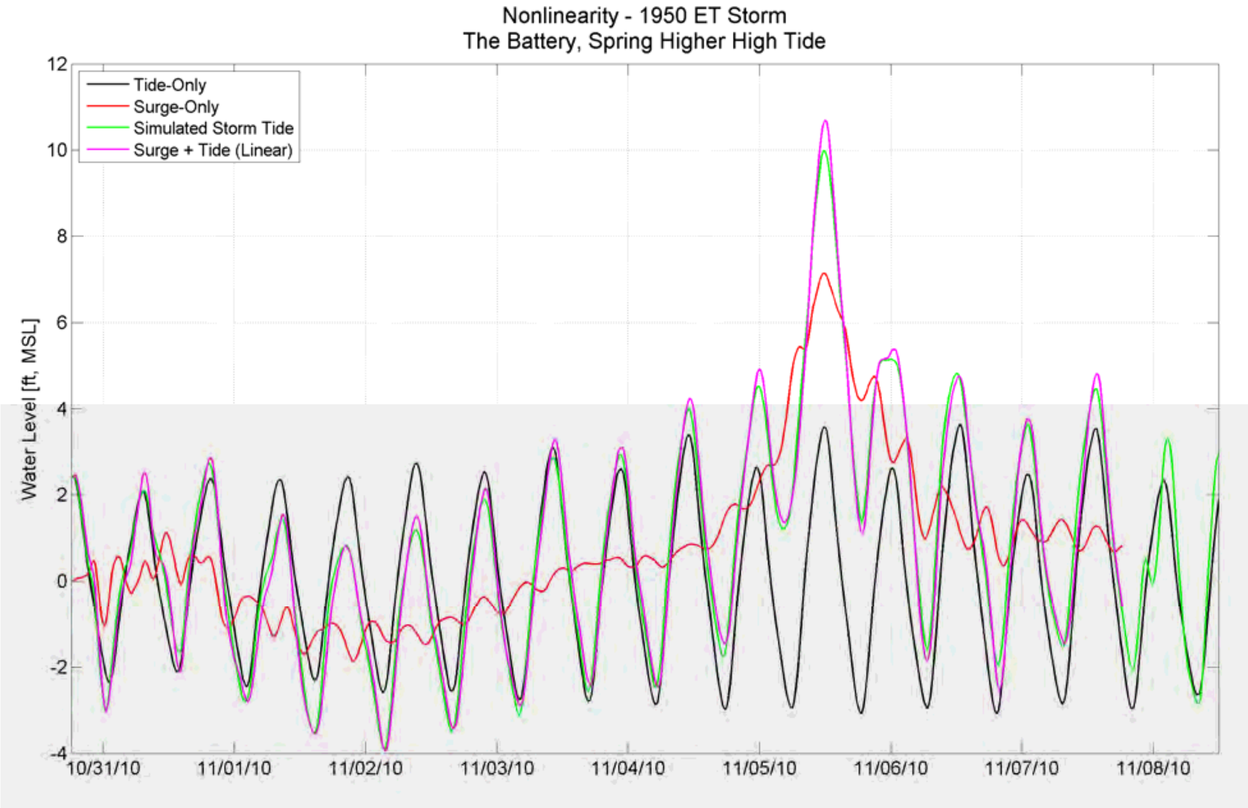


Figure 4-6. Storm tide, surge-only and tide-only simulations and linearly superimposed surge and tides at The Battery for the 1950 reanalysis ET storm with a spring higher high water tide phase.

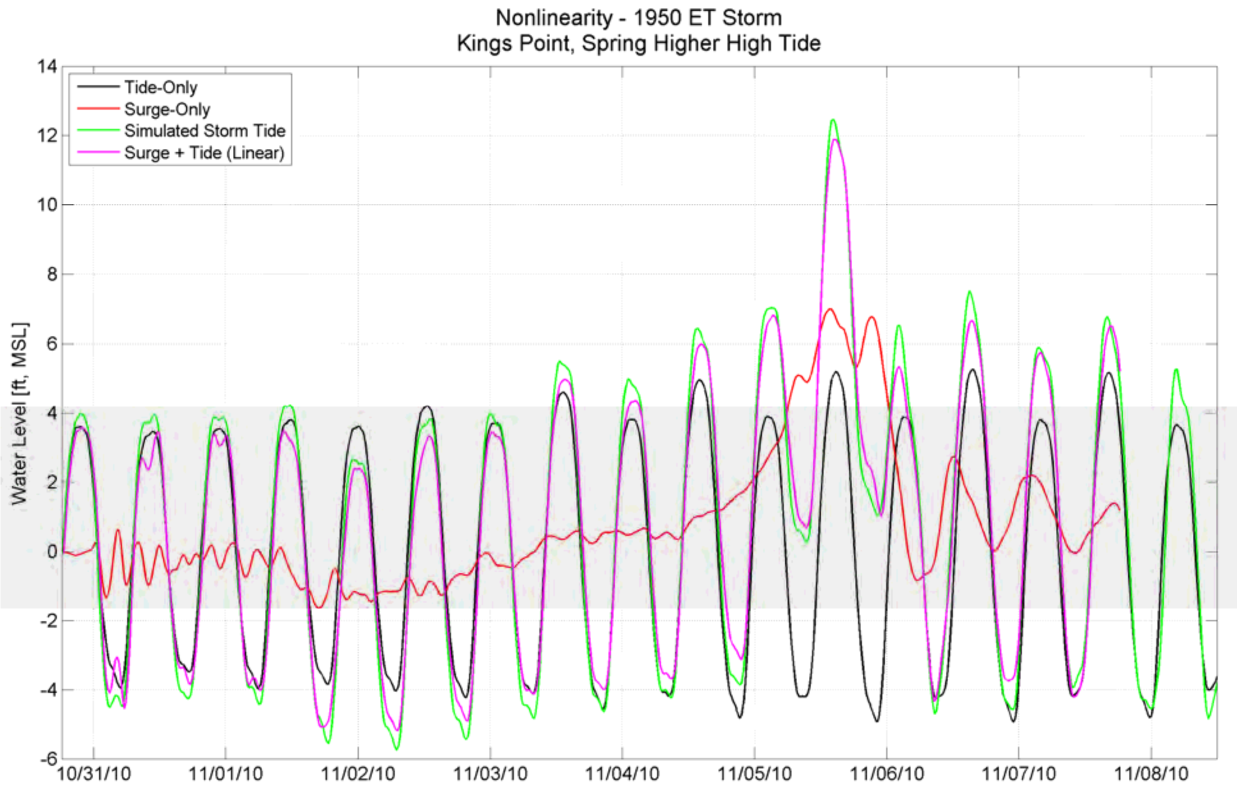


Figure 4-7. Storm tide, surge-only and tide-only simulations and linearly superimposed surge and tides at Kings Point for the 1950 reanalysis ET storm with a spring higher high water tide phase.

At each ADCIRC+SWAN node, 120 peak elevations from the simulated storm tides were extracted and compared with the peaks of linearly superposed storm tides. A linear regression relationship between the data sets was found. Figure 4-8 and Figure 4-9 plot the relationship for The Battery and Kings Point, respectively. The plots depict that a significant linear relationship exists with a correlation coefficient (R^2) of 0.993 at The Battery and 0.956 at Kings Point. The slope of the linear regression line at The Battery is slightly larger than 1.0, which indicates the linear superposition of surge and tide results in an estimate higher than the actual storm tide peak elevation. However, the slope at Kings Point is lower than 1.0, indicating an underestimation of the storm tide peak elevation. Similar relationships were computed for the entire model domain. Correlation coefficient values associated with those relationships are high throughout the study area (Figure 4-10), demonstrating a good overall fit. The significant linear relationship was used in the City's new coastal analysis to adjust the peak of linearly superposed storm tides to account for the effect of nonlinear interactions.

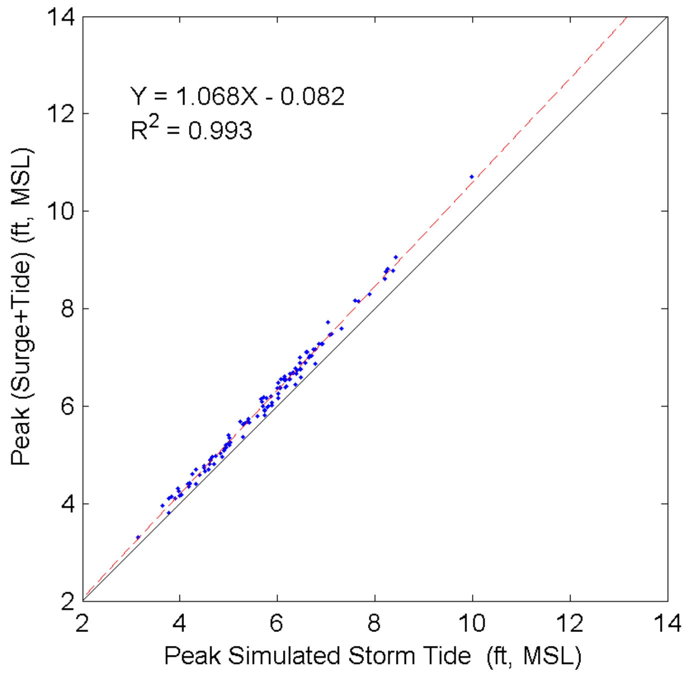


Figure 4-8. Peaks of simulated storm tide elevations versus peaks of linearly superposed storm surge + tide elevations at The Battery for all 120 storm tide simulations.

Black: 1:1 line; red dash line: linear regression line; blue dots: data points.

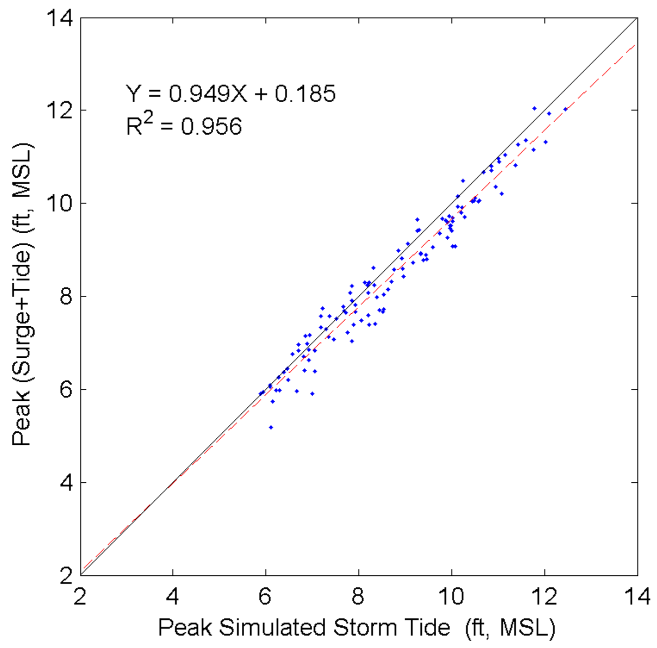


Figure 4-9. Peaks of simulated storm tide elevations versus peaks of linearly superposed storm surge + tide elevations at Kings Point for all 120 storm tide simulations.

Black: 1:1 line; red dash line: linear regression line; blue dots: data points.

The surge-only simulation outputs, tide-only simulation outputs, and nonlinear effects discussed above were combined to create thousands of storm tides without the limitations associated with simulating ADCIRC+SWAN for a large number of tidal conditions. For each ET storm, the surge-only time series was added to a time series of tides at each node to determine the peak storm tide elevation over the duration of the time series (the peak storm tide does not necessarily coincide with the peak surge-only elevation). The process of combining the two time series started at the beginning of the time series of tides and was replicated 3,816 times by marching the tide-only time series forward 20 minutes and summing the two time series again until the end of the tide-only time series. In total, 114,480 peak storm tides (3,816 tides for 30 ET storms) were obtained by extracting the maximum of those superposed storm tides. The linear regression relationship was then applied to those peaks to account for the nonlinear effects. The resulting peaks that include consideration of nonlinear surge and tide interactions were utilized in the statistical analysis for determining percent-annual-chance stillwater levels for multiple frequencies. This method ensured a sufficiently large sample size and an adequate consideration of nonlinear effects.

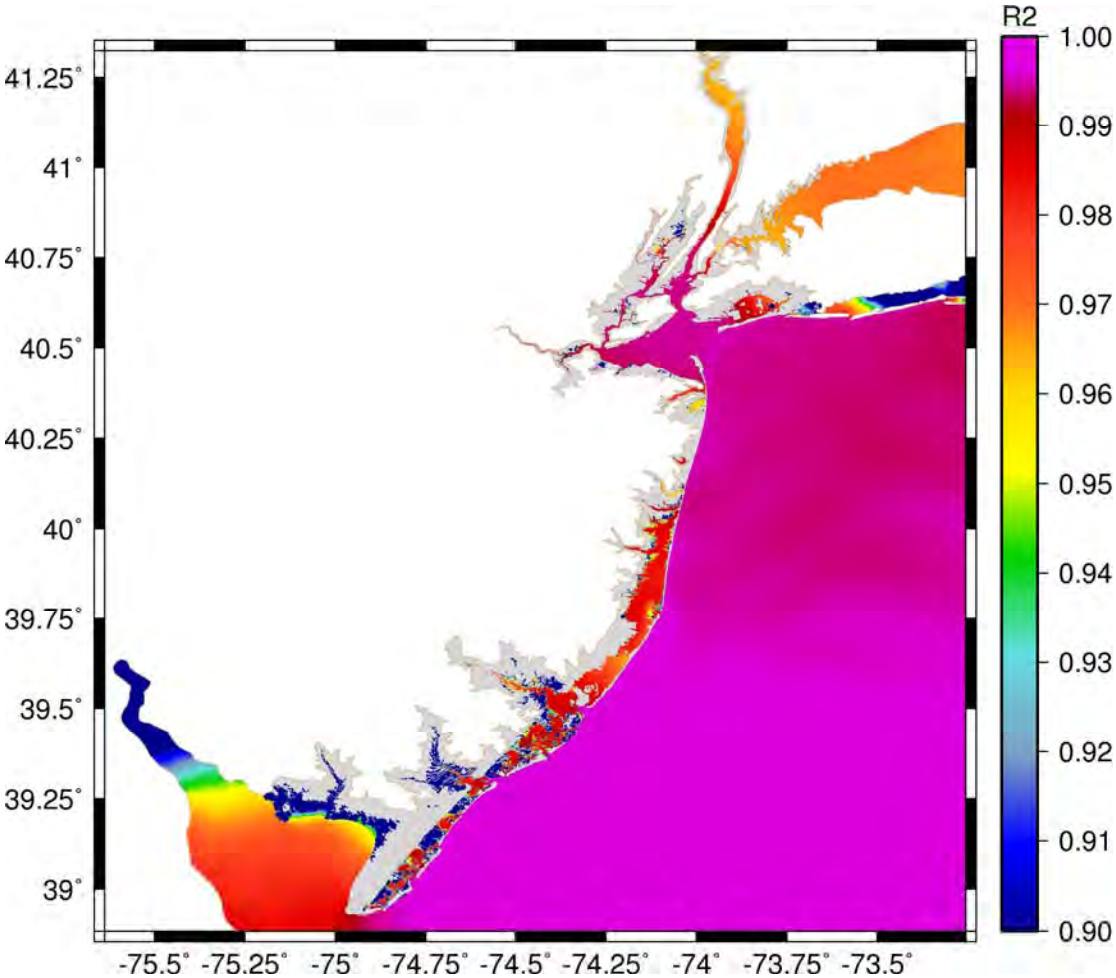


Figure 4-10. Regional map of the correlation coefficient (R^2) between the peaks of simulated and linearly superposed storm tide elevations.

4.4 SUMMARY OF EXTRATROPICAL STORM PRODUCTION SIMULATIONS

Section 4 discussed the methods and results associated with the production of ET storm simulation outputs that were used in the statistical analysis of percent-annual-chance stillwater elevations. The production of ET storm simulations can be summarized as follows:

- Surge-only simulations were completed for all 30 ET storms with the Garratt 0.002 cap wind drag formulation and 1.0 wind multiplier. The 30 storms included the 1950 ET storm reanalysis meteorological conditions;

- A tide-only simulation was completed for the October 1 through November 30, 2010, period, from which tides at multiple phases were extracted to construct storm tide records;

- Storm tide simulations were completed for four tide phases aligned with the peak surge elevation for each of the 30 ET storms, generating 120 storm tide simulations used to evaluate the effects of nonlinear surge and tide interactions in the superposition of storm tides; and

- A total of 114,480 storm tide peak values were calculated for each location in the ADCIRC+SWAN mesh by linearly adding surge for each of the 30 ET storms onto 3,816 tide phases and then adjusted to agree with the nonlinear surge and tide interaction relationship found in the regression analyses.

5.0 REVISED STILLWATER LEVELS, WAVE CONDITIONS, AND SFHA BOUNDARIES

Based on the model validation described in Section 3 and the production simulations and superposition described in Section 4, thousands of storm tide peak values were created and included in the ET storm statistical analysis for each nodal location in the ADCIRC+SWAN mesh. As discussed in this section, both ET and combined percent-annual-chance stillwater elevations were calculated throughout the study area using the same approach as FEMA's PFIRM coastal analysis. Additionally, based on the revised stillwater elevations and SWAN model outputs, updated 1-percent-annual-chance starting wave conditions have been calculated for each of FEMA's transects in New York City, and SFHA boundaries and select BFEs have been approximated based on 1-percent-annual-chance starting stillwater elevations.

5.1 EXTRATROPICAL STORM STATISTICS

The ET storm statistics were reproduced using 114,480 storm tide peak values created based on the superposition of surge-only and tide-only elevations, with an adjustment of nonlinear interaction between surge and tide. Superposed storm tide elevations were created at every ADCIRC+SWAN node within the study area, as described in Section 4.3. As with the FEMA analysis, the dataset at each node was fit to the GEV distribution function using an L-Moment estimator. Exceedance annual rates for the same elevations as used for tropical storms (0 to 36 feet, with an increment of 1 foot) were calculated and combined with the exceedance annual rates for tropical storms to determine the combined total stillwater elevations at given return intervals. The methodology used by FEMA to statistically combine tropical storm and ET storm percent-annual-chance stillwater elevations is believed to be reasonable and thus was adopted in this analysis. Because there was insufficient time to consider a reanalysis of the tropical storms and for the purposes of providing combined tropical and ET statistics, the tropical storm contributions to combined percent-annual-chance stillwater elevations were assumed to be reasonable and thus were adopted in this analysis. As mentioned in Section 1.3, though the focus of this appeal is ET storms, the City welcomes further discussion with FEMA related to the treatment of tropical storms following FEMA's review of the City's new coastal analysis.

In the statistics calculations for ET storms, the City adopted the procedure developed in FEMA's PFIRM coastal analysis with three exceptions. First, the model validation-associated epistemic uncertainty was not included in the City's analysis. The standard deviation of 0.92 foot was originally used in FEMA's recurrence analysis for ET storms to account for uncertainty. The value of 0.92 foot was estimated as the standard deviation of the difference between modeled and measured peak elevations (or RMSE) for two validation ET storms (March 29, 1984, and December 11, 1992, as discussed in Section 2.1). In the FEMA analysis, the measured peak elevations included NOAA gage data and high water marks. However, in the City's analysis, all 30 ET storms that were used in the production simulation were thoroughly validated against observations at 10 NOAA gages. High water marks were not used in the City's model validation because high water marks were not readily available for all 30 ET storms and are not as reliable as those measurements collected from gages for the reasons outlined in the FEMA model validation documentation (e.g., high water marks may include surface waves, and datum conversions can be challenging) (FEMA 2014c). The City's modeled ET water surface elevation time series and peak elevations compare well with NOAA gage measurements, as described in detail in Section 3.4. As a result of using a more appropriate model setup, the RMSE of the modeled peak elevations was 0.24 foot for all data points in the City's new coastal analysis. In addition to a considerably smaller RMSE in the City's analysis, the Q-Q plot (Figure 3-13) showed that modeled results for the selected model setup slightly overestimated the actual peak elevations, indicating an appropriately conservative estimation. In other words, the validated ET storm model setup reliably provided a slightly conservative estimation of storm tide elevations used in the statistical analysis. Accordingly, a model validation-associated epistemic uncertainty of 0.24 foot was not included in the statistical analysis.

The second exception to FEMA procedures was that some ADCIRC+SWAN nodes that were included in FEMA's PFIRM statistical analysis were excluded from the City's analysis. Figure 5-1 shows the ADCIRC+SWAN nodes that were removed from the City's analysis because of fewer flood responses and thus less reliable superposition (e.g., nonlinear effects) and exceedance probabilities. The City's new model setup produced overall smaller storm tide elevations; therefore, some areas where prevailing ground elevation is high and/or model resolution is low were flooded less frequently in the City's model setup than in FEMA's.

The third exception was the conversion from MSL to NAVD88 used for each location. Both FEMA's and the City's statistical analyses produced percent-annual-chance stillwater elevations in MSL because the storm tide inputs used in the analysis codes were in MSL. In order to adjust the final percent-annual-chance stillwater elevations from MSL to NAVD88, the City initially attempted to apply the same datum adjustments at each ADCIRC+SWAN node as FEMA's PFIRM coastal analysis. The City calculated FEMA's adjustments by taking a difference between percent-annual-chance stillwater elevations provided by FEMA in both MSL and NAVD88. However, the City found that the datum adjustments at most locations varied between the return intervals for unknown reasons (e.g., the MSL to NAVD88 conversions for 1- and 0.2-percent-annual-chance stillwater elevations were different at the same location, and there was no clear documentation of the process FEMA used). As a result, the City used NOAA's VDatum software version 31 (http://vdatum.noaa.gov/) to determine datum adjustments between MSL and NAVD88 at all ADCIRC+SWAN node locations such that a consistent adjustment could be applied for all return intervals at each location. VDatum is a tool commonly used in datum conversion applications that was used by FEMA at different stages of the PFIRM coastal analysis.

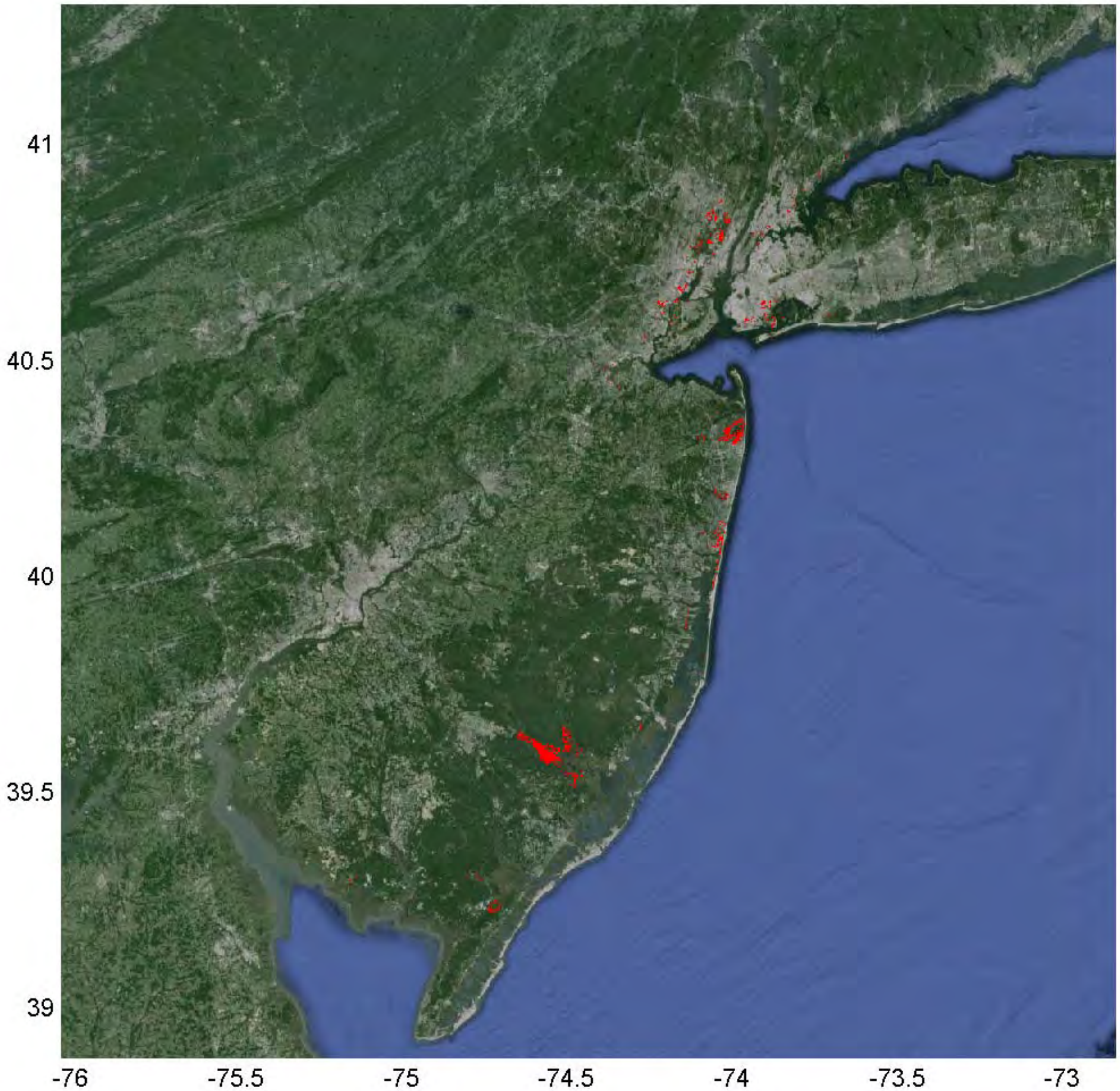


Figure 5-1. Areas excluded from the City's statistical analysis due to limited sample size.

5.2 REVISED STILLWATER ELEVATIONS

The City's revised ET storm statistical outputs combined with the tropical storm statistical outputs produced by FEMA resulted in revised total return stillwater elevations that correct FEMA's methodological and mathematical errors. Figure 5-2 shows the revised 1-percent-annual-chance stillwater elevations in the New York City area. Figure 5-3 shows reductions of over 2 feet in the 1-percent-annual-chance stillwater elevations between the City's analysis and FEMA's PFIRM coastal analysis. Similarly, 0.2-percent-annual-chance stillwater elevations and differences in stillwater elevations between the City's and FEMA's PFIRM coastal analyses are shown on Figures 5-4 and 5-5, respectively. Figures for the entire study area, including New Jersey, are provided in Appendix B. Stillwater elevations are shown in feet, NAVD88, and differences are shown in feet. Note that only those nodes flooded by all tropical and ET storms (referred to as “in water” nodes) are included on the figures.

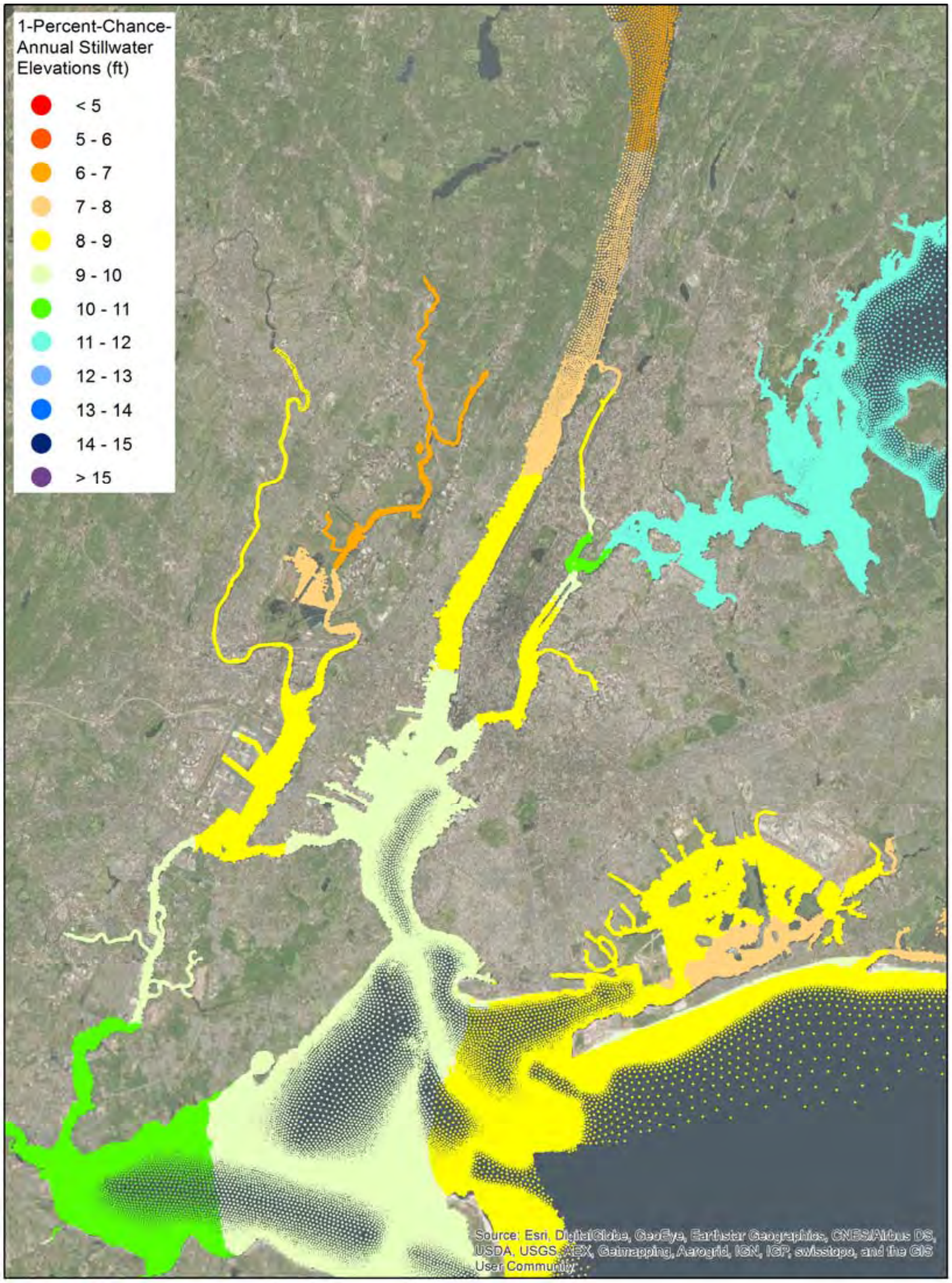


Figure 5-2. 1-percent-annual-chance stillwater elevations (feet, NAVD88) for the City’s analysis in the New York City area.

Values are shown for “in water” nodes only.

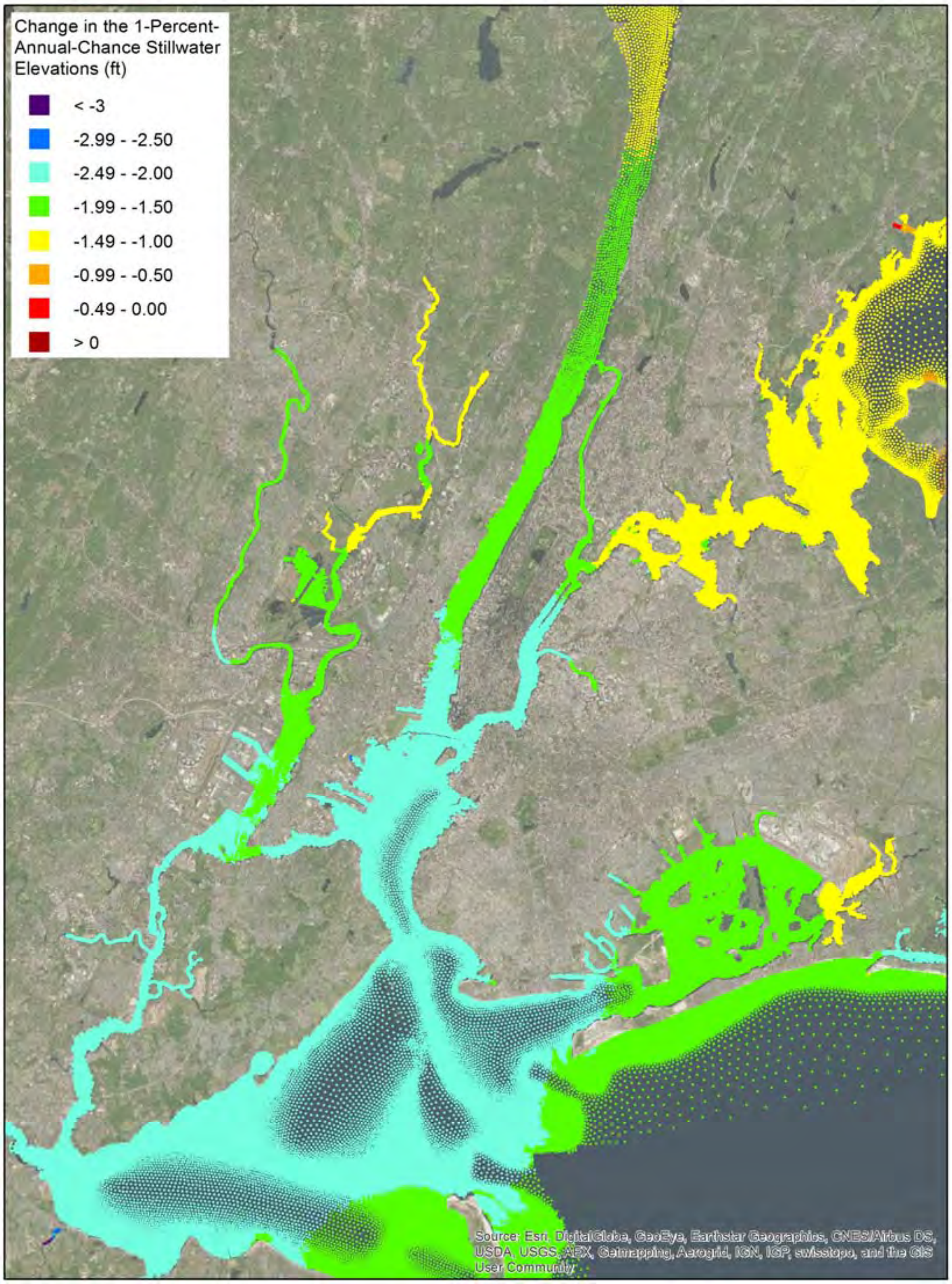


Figure 5-3. Difference (feet) in 1-percent-annual-chance stillwater elevations between FEMA's PFIRM coastal analysis and the City's analysis in the New York City area.

Negative values represent decreases in FEMA's stillwater elevations. Values are shown for "in water" nodes only.

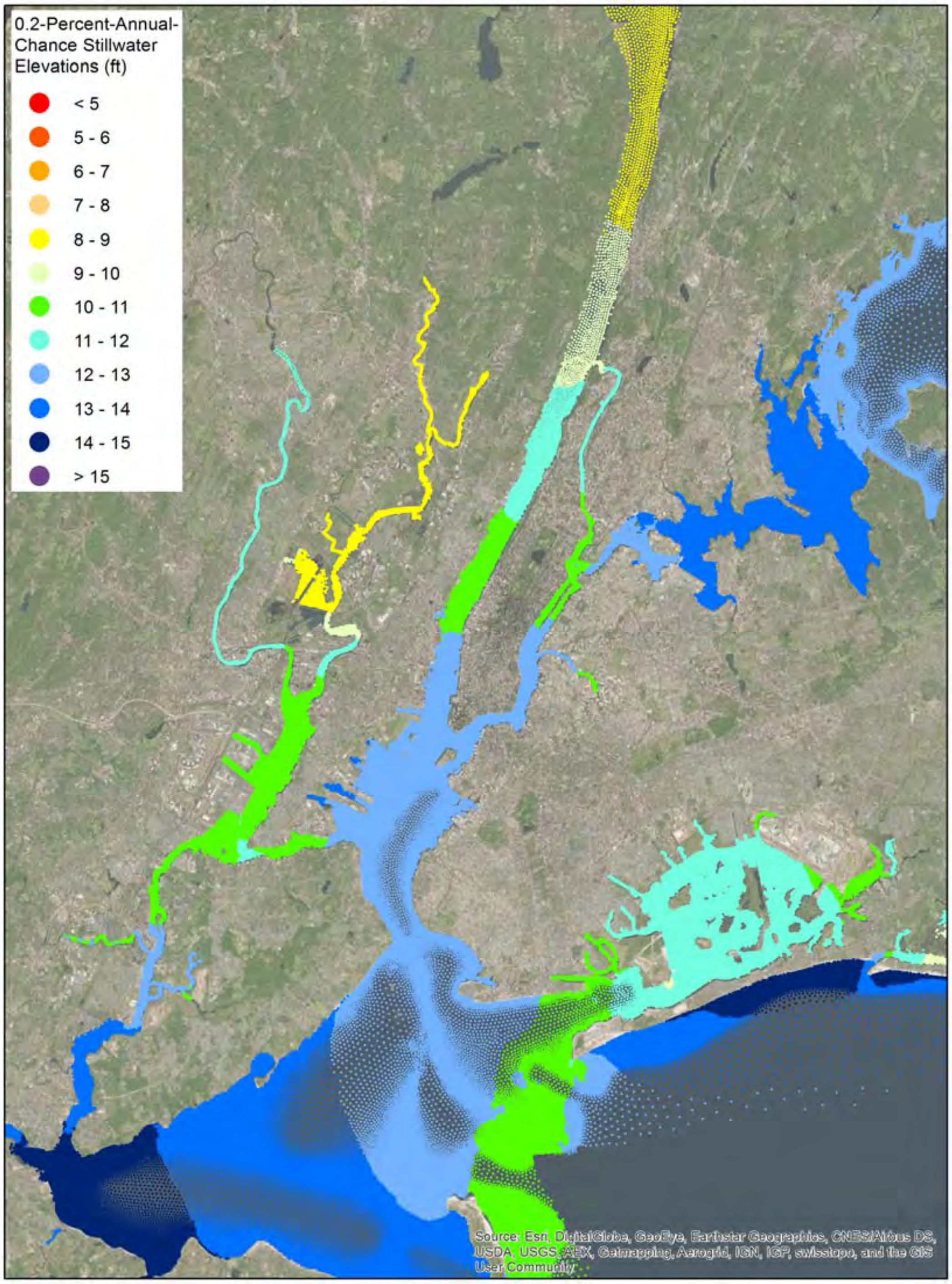


Figure 5-4. 0.2-percent-annual-chance stillwater elevations (feet, NAVD88) for the City's analysis in the New York City area.

Values are shown for "in water" nodes only.

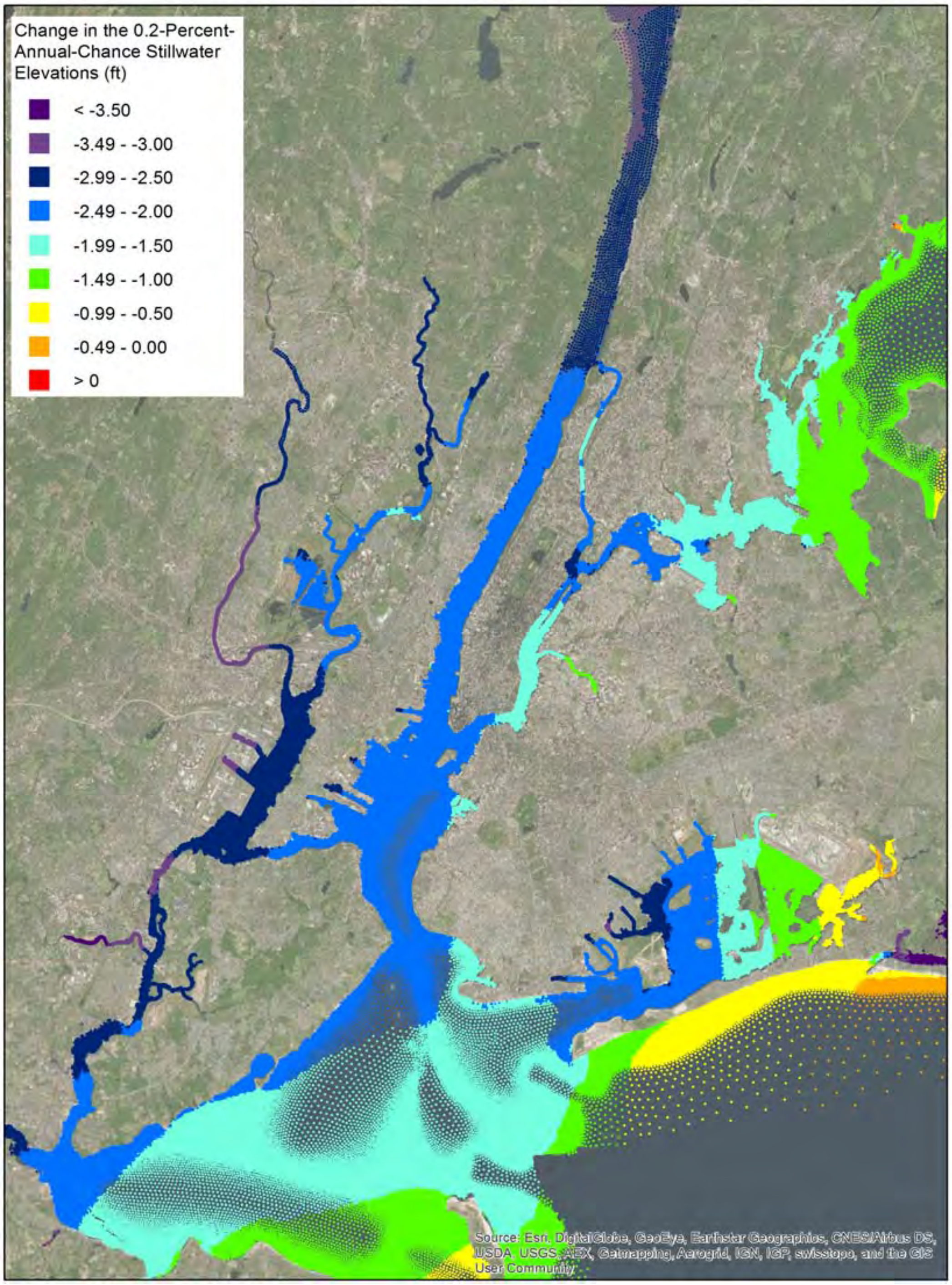


Figure 5-5. Difference (feet) in 0.2-percent-annual-chance stillwater elevations between FEMA's PFIRM coastal analysis and the City's analysis in the New York City area.

Negative values represent decreases in FEMA's stillwater elevations. Values are shown for "in water" nodes only.

Using similar methods as FEMA and those described in Section 5.1, percent-annual-chance stillwater elevations were calculated by the City for overland nodes as well. Overland nodes, defined to mean those nodes outside of tidally influenced areas in the ADCIRC+SWAN model and thus not wetted for all storms, are not included on Figures 5-2 through 5-5. As discussed in Section 5.1, percent-annual-chance stillwater elevations overland can be unreliable due to sample size limitations. As part of the City's analysis, 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations were calculated for all overland ADCIRC+SWAN nodes for which FEMA calculated stillwater elevations (based on the locations in the files provided by FEMA), with the exception of those shown on Figure 5-1. However, overland stillwater elevations calculated directly from the City's analysis were not applied in subsequent steps of the City's analysis.

Instead, "in water" stillwater elevations were used for subsequent steps described in this document because the selection of reliable overland stillwater elevations is largely dependent on judgment and is one of the initial steps in the mapping process. As described in Section 1.4, the City is providing scientifically and technically correct stillwater elevations free of mathematical errors. Subsequent steps in FEMA's mapping process, such as the determination of variation in stillwater elevations overland, WHAFIS simulations, wave runup, erosion, and primary frontal dune assessments, are not included in the City's analysis.

Stillwater elevations for each WHAFIS transect in New York City that was included in FEMA's PFIRM coastal analysis were extracted from the data shown on Figure 5-2, Figure 5-4, and the figures in Appendix B. For each transect, the City's revised 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations at the starting station are listed in the Transect Data Table in Appendix C. The stillwater ranges shown in the City's Transect Data Table are consistent with the stillwater ranges defined for each transect in FEMA's Transect Data Table (FEMA 2013a).

The City's revised "in water" and overland 10-, 2-, 1-, and 0.2-percent-annual-chance stillwater elevations in both MSL and NAVD88 are provided to FEMA on the hard drive submitted as part of this appeal.

5.3 REVISED SFHA BOUNDARIES

A 1-percent-annual-chance floodplain boundary was generated in a geographic information system based on the City's revised "in water" stillwater elevations discussed in Section 5.2. The City's mapping process included the creation of a stillwater elevation surface based on the projection of "in water" stillwater elevations inland. Along each WHAFIS transect in New York City (note that all 1,082 transects used by FEMA for the mapping process were applied here, rather than only the 311 listed in the Transect Data Table), the starting stillwater elevations such as those listed in Appendix C were applied to generate a triangular, irregular network, which was then converted to a raster. When required for mapping purposes, WHAFIS transects were extended inland and/or seaward. In some areas with limited or no WHAFIS transects, including portions of the East River and Harlem, additional transect lines (not WHAFIS model transects, rather simply lines for mapping) were added for the purposes of mapping floodplain extents or improving mapping quality.

The surface was then intersected with the FEMA topography raster. Similar to the mapping process used by FEMA (FEMA 2013b), the resulting floodplain boundary was smoothed to create a cleaner line, low lying areas not hydraulically connected were removed, and areas with narrow widths located above the stillwater elevation but surrounded by flooded areas were mapped within the floodplain. The results are the SFHA boundaries shown on Figure 5-6, Figure 5-7, and the figures in Appendix D that demonstrate the impact of the proposed changes as per FEMA criteria for appeals of FIRMs. Note that Figure 5-6, Figure 5-7, and the figures presented in Appendix D depict SFHA boundaries based on the projection of 1-percent-annual-chance stillwater elevations from the waterfront inland. Variations in stillwater elevation overland, wave runup, erosion, and primary frontal dune considerations are not included in the SFHA boundaries depicted. Consequently, in the case of dunes, for instance, there are dunes along the open coast areas that are shown as out of the City's SFHA; inclusion of erosion and primary frontal dune considerations will put those areas into the SFHA. WHAFIS transects are included on Figure 5-6, Figure 5-7, and the figures in Appendix D to denote those areas with SFHA boundaries that will likely require revisions to account for wave runup, erosion, and primary frontal dunes in the final determination of the SFHA boundaries.

Figure 5-6 shows example SFHA boundaries based on 1-percent-annual-chance stillwater elevations at the neighborhood scale for the City's analysis and FEMA's 2015 PFIRMs for a portion of Manhattan. The changes in SFHA boundaries resulting from the City's revised analysis are most noticeable near Hudson Yards and in Chelsea, Soho, and the East Village.

Another neighborhood significantly impacted by the changes in SFHA boundaries based on 1-percent-annual-chance stillwater elevations in the City's analysis is the Canarsie neighborhood in Brooklyn, as shown on Figure 5-7. The topography in the neighborhood is generally in the range between the 1-percent-annual-chance stillwater elevations determined by the City's analysis and those elevations determined by FEMA's PFIRM analysis, making the floodplain extents sensitive to the difference in stillwater elevations.

The City's methodology to create the representative SFHA boundaries made use of WHAFIS and other transects to define inland boundaries to ensure that the most appropriate "in water" percent-annual-chance stillwater elevations were applied overland with the correct orientation. In order to ensure that SFHA boundaries based on the City's methodology resulted in floodplain extents that were comparable to those using FEMA's mapping procedures, the City's methodology was first tested using FEMA's "in water" stillwater elevations and PFIRM boundaries. A visual comparison of the results showed that most differences between the areas delineated using the City's method were small, often attributed to differences in smoothing tolerances, stillwater variation overland, the effects of erosion, primary frontal dunes, and wave runup. Differences may have also been due to the extrapolation method used by FEMA at the edge of the 1-percent-annual-chance floodplain; extrapolation was described in FEMA documentation as a manual process largely based on experience and judgment.

The City's revised SFHA boundaries are provided to FEMA on the hard drive submitted as part of this appeal.

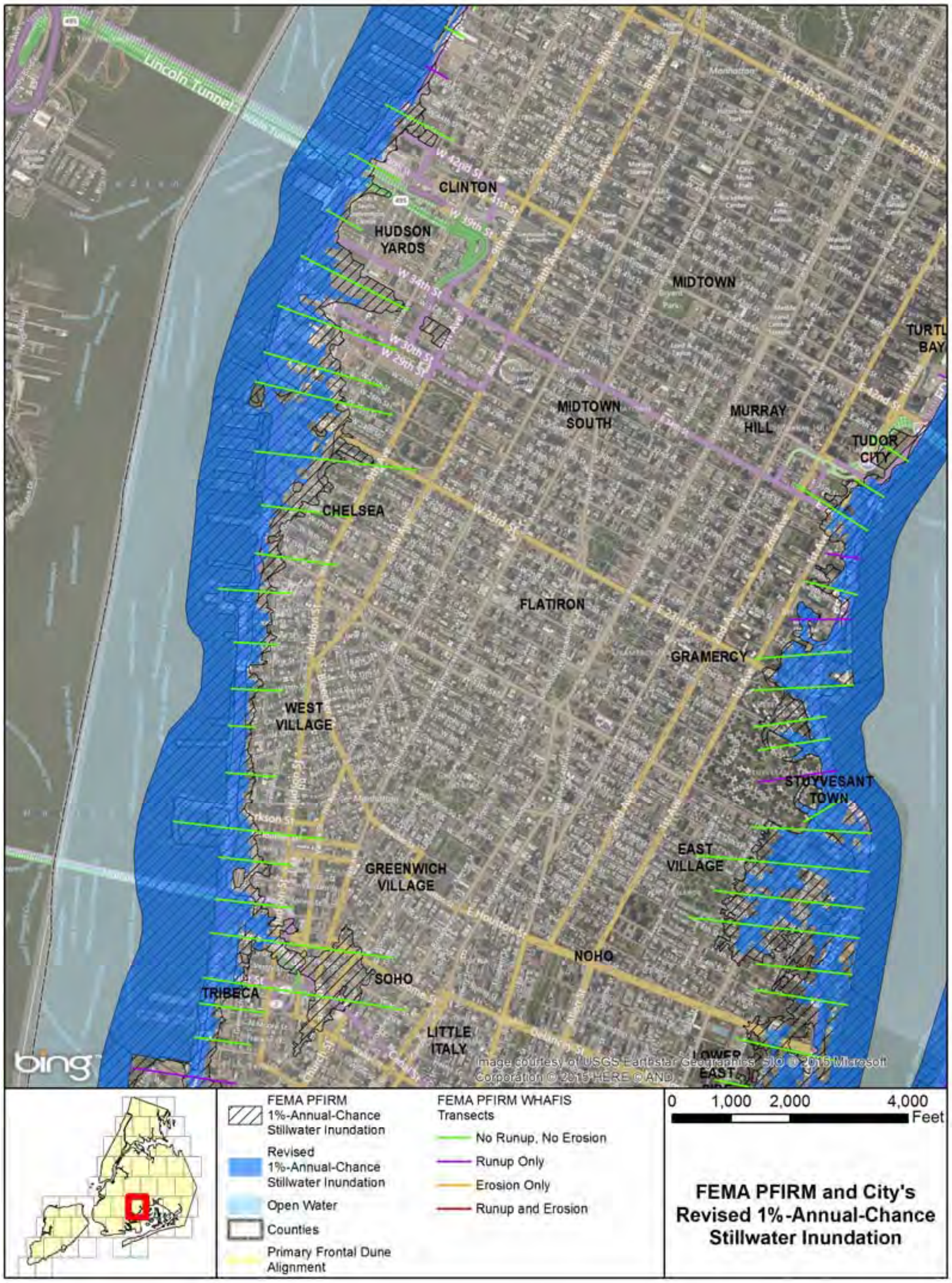


Figure 5-6. Comparison of the 1-percent-annual-chance floodplain extents between FEMA's PFIRM coastal analysis and the City's revised analysis for Lower and Midtown Manhattan.

FEMA PFIRM WHAFIS transects shown to indicate areas of runup and erosion, as discussed in Section 5.

Figure 5-7. Comparison of the 1-percent-annual-chance floodplain extents between the FEMA's PFIRM coastal analysis and the City's analysis for the Canarsie neighborhood in Brooklyn.

FEMA PFIRM WHAFIS transects shown to indicate areas of runup and erosion, as discussed in Section 5.

5.4 REVISED STARTING WAVE CONDITIONS

Wave conditions at the starting station of each transect corresponding to the City's 1-percent-annual-chance stillwater elevations were calculated. For consistency, FEMA's methodologies for calculating these conditions were maintained where possible. Thus, starting wave conditions were calculated for each WHAFIS transect at locations 2,500 feet offshore from that transect for open coasts or in the middle of the channel or bay for sheltered coasts (i.e., the locations for which FEMA lists starting wave conditions in the PFIRM analysis Transect Data Table).

At each wave location, the seven simulated storms with peak stillwater elevations closest to the 1-percent-annual-chance stillwater elevation were identified (the one closest and the next three higher and lower). Reviewed storms included tropical storms from FEMA's PFIRM coastal analysis and the City's revised ET storm tide simulations (the 120 simulations described in Section 4.3 that were used to evaluate the nonlinear interactions of storm surge and tides).While all four of the simulated tidal conditions for each ET storm were compared to the 1-percent-annual-chance stillwater elevation, only the closest storm tide for any given ET storm was used (i.e., the same ET storm for varying tides was not selected twice). This prevented lending extra weight to a single ET storm with multiple storm tide elevations close to the statistical stillwater elevation. Once the seven closest storms were selected at each location, the significant wave heights and mean wave periods occurring at the time of the peak storm tide elevation for each storm were extracted and averaged.

The resulting average of the seven wave conditions coincident with the peak storm tide closest to the 1-percent-annual-chance stillwater elevation offers a reasonable estimate of the wave heights and periods. Note that mean wave periods rather than peak wave periods were extracted for all storms, including ET storms, to be consistent with the more robust dataset from FEMA's PFIRM coastal analysis. Mean wave periods were used even though stable peak periods were available for ET storms simulated by the City. Mean periods were converted to peak periods by multiplying by 1.1. FEMA's PFIRM coastal analysis included a more detailed conversion from mean to peak periods, but a constant conversion factor was applied in the City's analysis because the points from which starting wave conditions were extracted were relatively sparse and consistently offshore. The factor of 1.1 was selected based on the range given in the U.S. Army Corps of Engineers Coastal Engineering Manual (Demirbilek and Vincent, 2002). It is also the recommended conversion factor in the EurOtop overtopping manual (Pullen et al., 2007), and it is slightly more conservative than the value advocated by Holthuijsen (2007) for wind waves, which is appropriate, because a 1-percent-annual-chance stillwater elevation is likely coincident with waves that include a combination of wind waves and swell.

Finally, the results on the Atlantic coast (e.g., Rockaway Peninsula) were compared to the 2007 FEMA Coastal Guidelines Update (FEMA 2007a), which includes a table of "Appropriate Wave Conditions for Runup Computations Pertaining to 1-Percent-Annual-Chance Event in Coastal Flood Map Projects" (Table D.2.8-2). The revised starting wave conditions along the Atlantic coast calculated for the City's study, which combines tropical and ET storm simulations, have significant wave heights and peak periods in the range of suitable for tropical and ET storms according to the guidelines, and further validate the estimates.

The revised starting wave conditions are listed in the Transect Data Table in Appendix C.

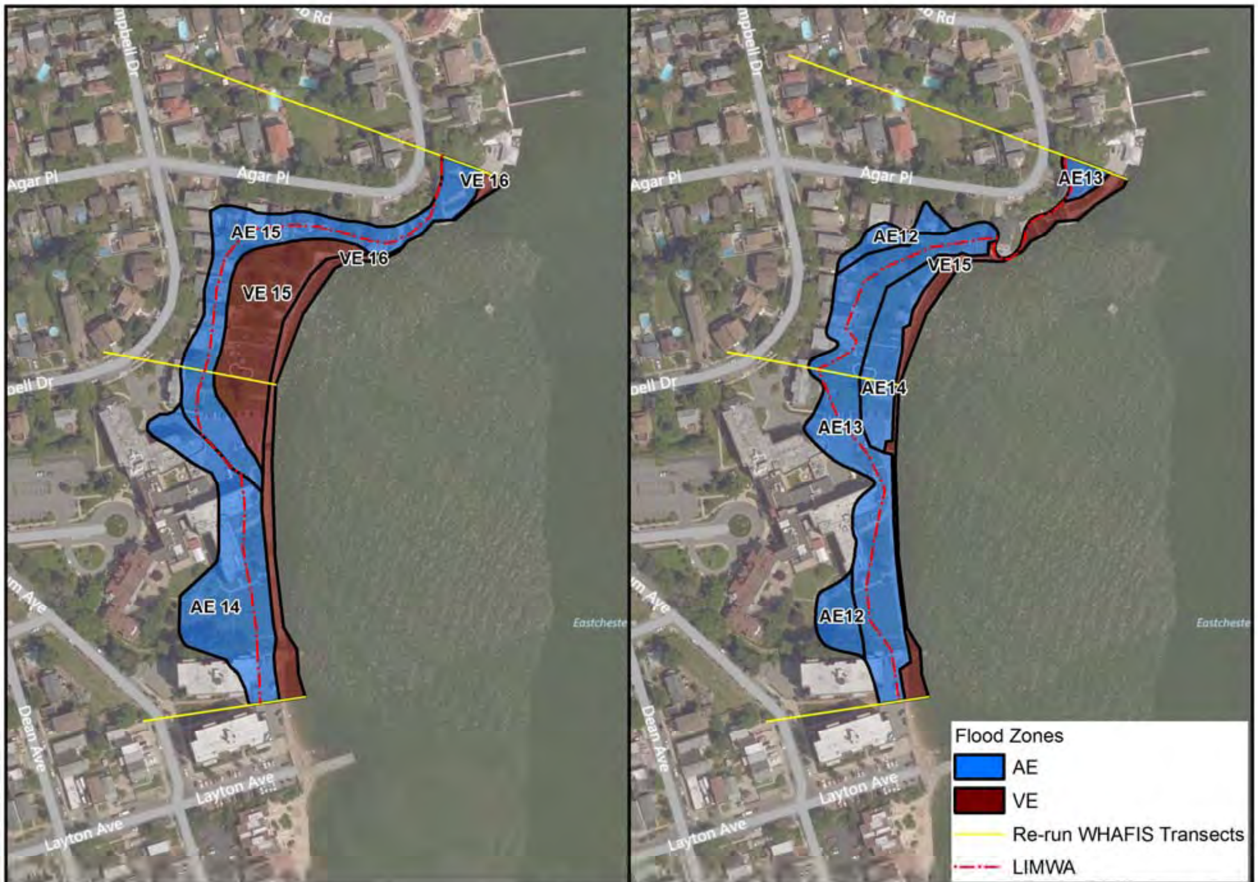
5.5 EXAMPLE REVISED BASE FLOOD ELEVATIONS

While not required for an appeal, in order to illustrate the impact the revised stillwater elevations and starting wave conditions have on BFEs in the study area, five example locations (one per borough) were selected to re-run select FEMA WHAFIS transects with revised stillwater elevations and starting wave conditions. Stillwater elevations along each transect were updated based on the difference between FEMA's and the City's starting stillwater elevations. The differences in the starting stillwater elevations were imposed at all locations along each transect, maintaining the magnitude of water level variation from FEMA's analysis. Starting wave conditions were also updated at the start of each transect.

Table 5-1 lists the selected locations, WHAFIS transect numbers, starting stillwater elevations, and starting wave conditions. FEMA's PFIRM coastal analysis involved a significant effort in surveying and developing WHAFIS transects throughout the domain, including vegetation and building conditions along each transect. Therefore, for the five example locations, only the hydraulic conditions were changed, while all other transect features were retained. The resulting BFEs in the five example locations and comparisons to FEMA's 2015 PFIRMs at each site are presented on Figures 5-8 through 5-12. Note that the BFEs in the City's analysis are only depicted between the WHAFIS transects that were tested. Additionally, none of the examined transects include wave runup, erosion, or primary frontal dune considerations. Flood zones such as AE and VE are shown on the figures, as well as the Limit of Moderate Wave Action (LiMWA).

Table 5-1. Starting 1-percent-annual-chance hydraulic conditions for example WHAFIS transects.

Transect Number	Borough	Description	Starting Stillwater Elevation (feet, NAVD88)	Starting Significant Wave Height (feet)	Starting Peak Period (seconds)
2260	Bronx	Throggs Neck	11.8	2.7	2.6
2270	Bronx	Throggs Neck	11.8	3.0	2.8
2280	Bronx	Throggs Neck	11.8	3.0	2.8
2940	Kings	S Brooklyn Marine Terminal	9.3	3.3	2.8
2950	Kings	S Brooklyn Marine Terminal	9.3	3.1	2.7
2955	Kings	S Brooklyn Marine Terminal	9.3	3.0	2.6
250	New York	Manhattan	8.9	2.8	2.6
260	New York	Manhattan	8.9	2.9	2.6
50160	Queens	Howard Beach	8.2	3.4	3.6
50170	Queens	Howard Beach	8.2	3.1	2.5
51000	Queens	Howard Beach	8.2	2.8	2.6
2880	Richmond	Tottenville	10.5	5.3	4.3
2890	Richmond	Tottenville	10.5	5.1	4.3
2900	Richmond	Tottenville	10.6	5.1	4.3



FEMA PFIRM 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations | **City Revised 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations**

Figure 5-8. Example SFHA boundary extent and BFE update for a location in Country Club, Bronx.

Bronx borough transects from Table 5-1 are shown in yellow. FEMA PFIRM mapping shown only for overland areas within the re-run WHAFIS transects.

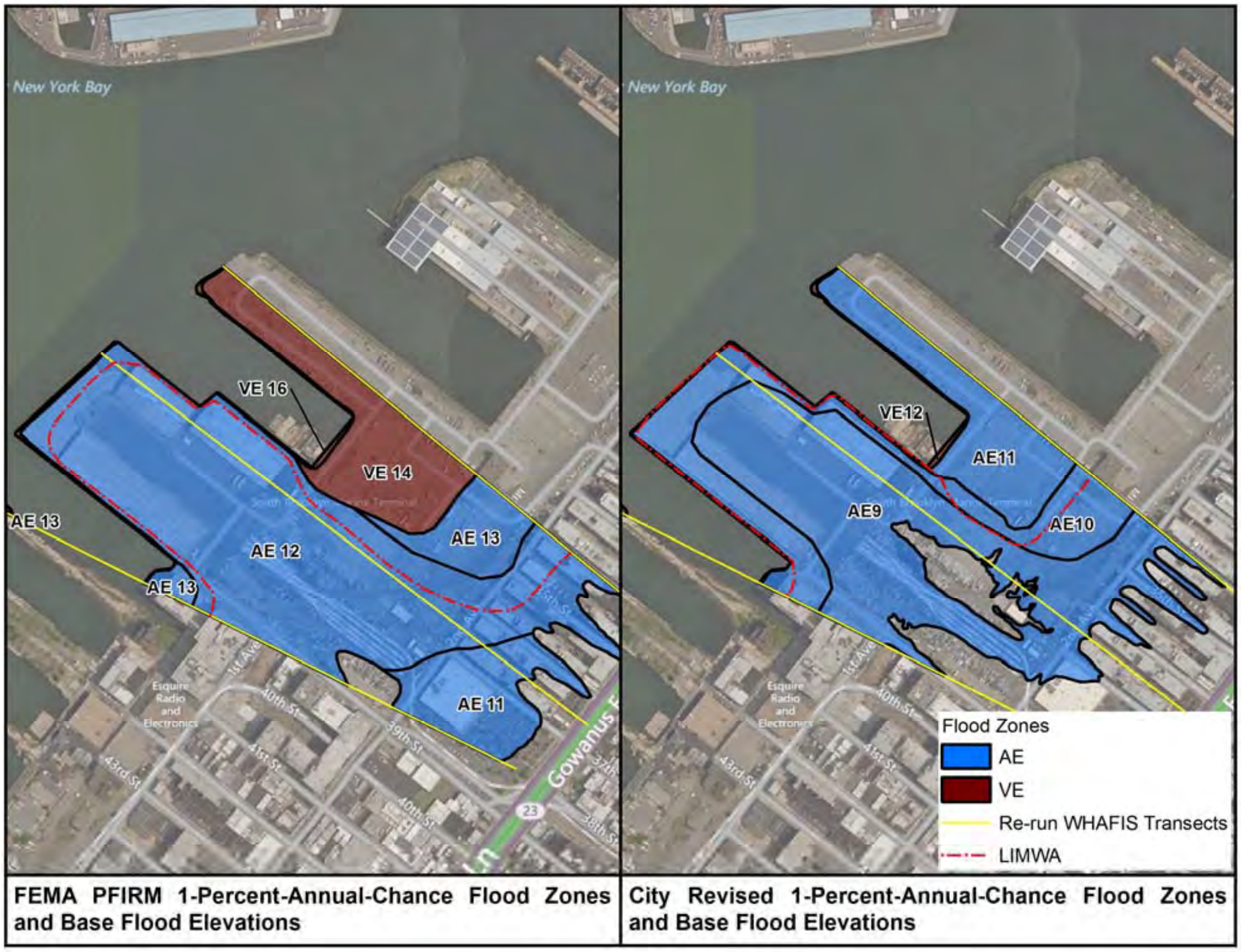


Figure 5-9. Example SFHA boundary extent and BFE update for a location in Sunset Park, Brooklyn.

Kings borough transects from Table 5-1 are shown in yellow. FEMA PFIRM mapping shown only for overland areas within the re-run WHAFIS transects.

FEMA PFIRM 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations	City Revised 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations

Figure 5-10. Example SFHA boundary extent and BFE update for a location in Peter Cooper Village/Stuyvesant Town, Manhattan.

New York borough transects from Table 5-1 are shown in yellow. FEMA PFIRM mapping shown only for overland areas within the re-run WHAFIS transects.

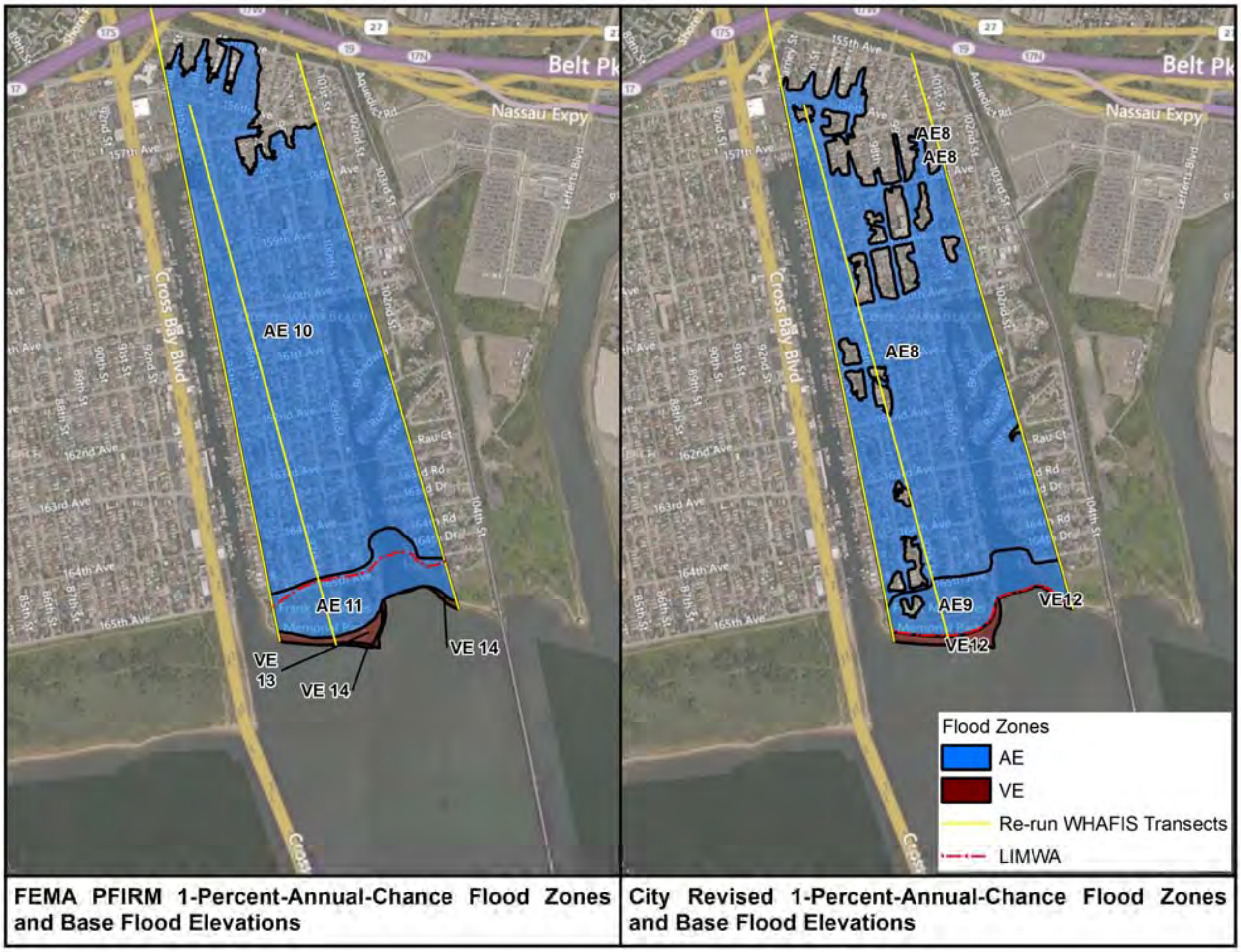
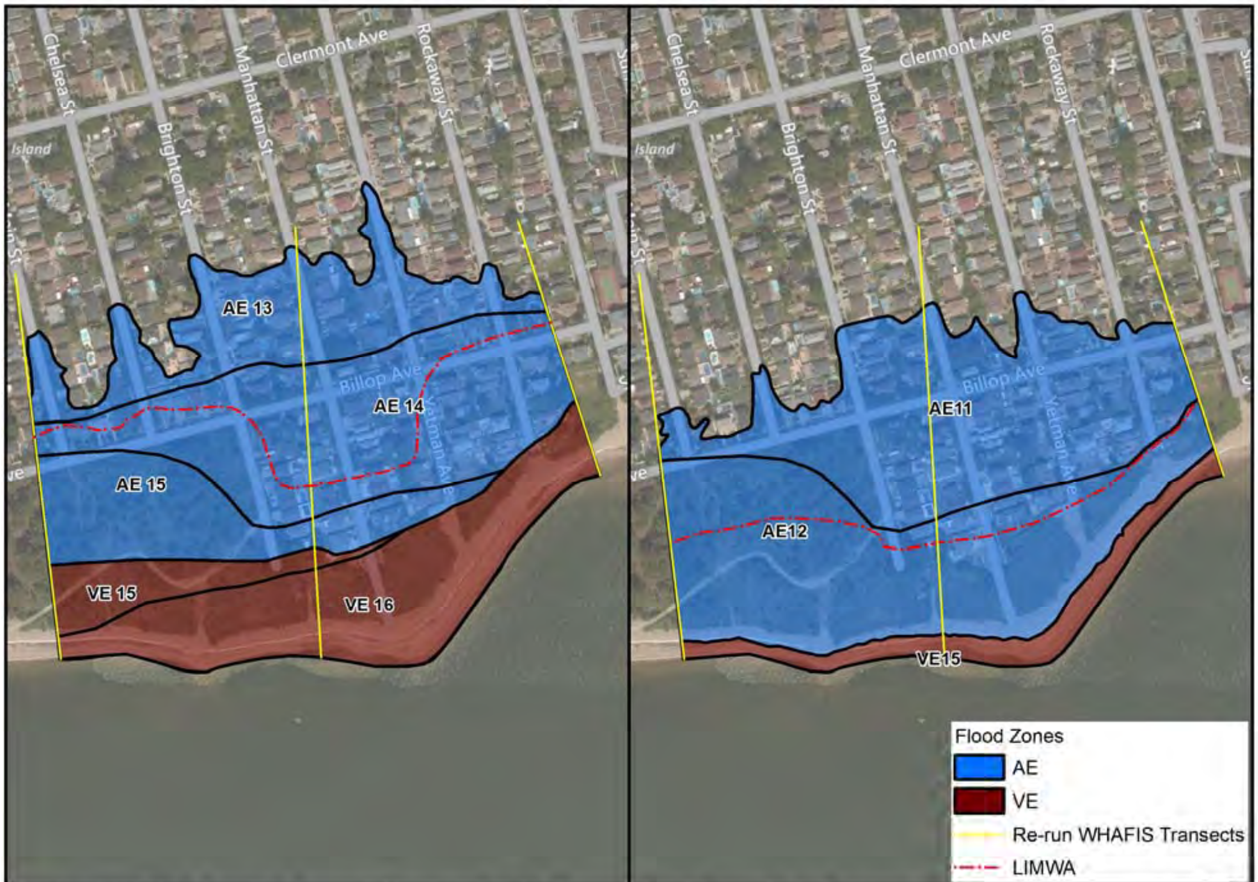


Figure 5-11. Example SFHA boundary extent and BFE update for a location in Howard Beach, Queens.

Queens borough transects from Table 5-1 are shown in yellow. FEMA PFIRM mapping shown only for overland areas within the re-run WHAFIS transects.



FEMA PFIRM 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations	City Revised 1-Percent-Annual-Chance Flood Zones and Base Flood Elevations

Figure 5-12. Example SFHA boundary extent and BFE update for a location in Tottenville, Staten Island.

Richmond borough transects from Table 5-1 are shown in yellow. FEMA PFIRM mapping shown only for overland areas within the re-run WHAFIS transects.

6.0 DATA SUBMITTAL

The data generated and used to assemble this report have been archived on a hard drive and delivered with this document. The archived data include compiled observation data, model simulations, statistical analysis, and the codes used to undertake critical pre- and post-processing activities. The data are categorized and structured in the order of report sections. Figure 6-1 shows the directory structure found on the hard drive. All directories and subdirectories are numbered for ease of navigation. Contents of each directory and their corresponding report sections are described in Table 6-1.

```
.
├── 01_ModelValidation
│   ├── 01_NOAAObservationData
│   ├── 02_FEMAConfiguration
│   ├── 03_SensitivityTesting
│   │   ├── 01_FEMAConfiguration
│   │   ├── 02_ImplicitSolver
│   │   ├── 03_withoutAdvection
│   │   └── 04_SWANLimiters
│   ├── 04_WindDragComparisons
│   │   ├── 01_Garratt0.0020cap_1.04multiplier
│   │   ├── 02_Donelan_1.04multiplier
│   │   ├── 03_ByePowell_1.04multiplier
│   │   └── 04_Garratt0.0020cap_1.00multiplier
│   └── 05_ADCIRCCode
│       ├── 01_FEMACode
│       ├── 02_v50Release
│       ├── 03_Donelan_windDrag
│       └── 04_ByePowell_windDrag
├── 02_Production
│   ├── 01_TidesOnly
│   ├── 02_SurgeWavesOnly
│   └── 03_TidesSurgeAndWaves
│       ├── 01_TidePhase01
│       ├── 02_TidePhase02
│       ├── 03_TidePhase03
│       └── 04_TidePhase04
├── 03_TidalSuperposition
│   ├── 01_LinearSuperpositionProduction
│   │   ├── 01_SuperpositionOutput
│   │   ├── 02_MergedSuperpositionOutput
│   │   └── 03_Code
│   └── 02_Nonlinearity
│       ├── 01_PeakStormTideExtraction
│       │   ├── 01_TidePhase01
│       │   ├── 02_TidePhase02
│       │   ├── 03_TidePhase03
│       │   ├── 04_TidePhase04
│       │   └── 05_Code
│       └── 02_NonlinearityCoefficients
│           ├── 01_Coefficients
│           └── 02_Code
├── 04_RecurrenceAnalysis
│   ├── 01_ExtratropicalStatistics
│   │   ├── 01_WaterNodes
│   │   ├── 02_LandNodes
│   │   └── 03_Code
│   └── 02_CombineExtratropicalandTropical
│       ├── 01_CombinedStats
│       └── 02_Code
├── 05_TransectTable
│   ├── 01_StartingSWEL
│   └── 02_StartingWaves
├── 06_Mapping
│   ├── 01_SWEL-GISFiles
│   └── 02_FloodPlainExtent
└── 07_BFERevision
    ├── 01_WHAFIS
    └── 02_RevisedBFE
```

Figure 6-1. Data submittal hard drive directory tree

Table 6-1. Data submittal summary sheet

Directory and Subdirectory	Data Files Description	Scripts/Model	Corresponding Report Section
01_ModelValidation	This directory contains data and files relevant to model validation. • The subdirectory "01_NOAAObservationData" has 10 NOAA gage water levels and associated MSL adjustments the midpoint of the 1983-2001 NTDE used for model validation. • "02_FEMAConfiguration" includes model inputs and outputs for 30 ET storm simulations using the original FEMA model configuration, including model inputs/outputs for both the original and reanalysis 1950 ET storm simulation. • "03_SensitivityTesting" contains model inputs and outputs for ADCIRC+SWAN stability and runtime improvement sensitivity tests, using the 1950 ET storm (19501125) as an example. • "04_WindDragComparisons" includes the simulations testing four alternative combinations of wind drag coefficient and wind speed multiplier. • "05_ADCIRCCode" contains various ADCIRC+SWAN model versions that were used for different simulations. • All simulation outputs include global water surface elevation time series (20-minute intervals), global maximum water surface elevations, global maximum wave heights, and global wave periods.	ADCIRC+SWAN	2.1 3.1 3.2 3.3 3.4
02_Production	• This directory contains all production simulation inputs and outputs that are used in the statistical analysis. • "01_TidesOnly" contains model inputs and outputs for the simulation of two months of tides (tide-only simulations). • "02_SurgeWavesOnly" contains model inputs and outputs for simulations of 30 ET storms excluding the effects of tides (surge-only simulations). • "03_TidesSurgeAndWaves" contains model inputs and outputs of 120 storm tide simulations for 30 ET storms coinciding with four specific tidal phases.	ADCIRC+SWAN	4.1 4.2 4.3

Directory and Subdirectory	Data Files Description	Scripts/Model	Corresponding Report Section
02_Production (continued)	• All simulation outputs include global water surface elevation time series (20-minute intervals), global maximum water surface elevations, global maximum wave heights, and global wave periods.	ADCIRC+SWAN	4.1 4.2 4.3
03_TidalSuperposition	This directory contains the scripts used to create the sample set for recurrence analysis, intermediate products and data files used in recurrence analysis. • "01_LinearSuperpositionProduction" includes data files archiving the peaks of linearly superposed storm tides and the codes used to generate those files. Tidesuperposition.F90 was written to 1) superpose storm surge time series (outputs in "02_Production\02_SurgeWavesOnly") onto tidal signals ("02_Production\01_TidesOnly") with varying tidal phases, 2) to pick the peak of the linear summation, and 3) to store the peaks for each tidal phase in individual NetCDF files (e.g. TideSurgeLS_Tide0001.nc). 3816 TideSurgeLS_Tide<#>.nc files are stored in the subdirectory "01_SuperpositionOutput". • CombineTides.F90 was written to combine the individual NetCDF files into one large NetCDF file (TideSurgeLS_Merged.nc) for the sake of computational efficiency. The merged NetCDF file is stored in the subdirectory "02_mergedSuperpositionOutput". • "02_Nonlinearity" contains scripts to examine the effects of nonlinear interaction between tides and surge, as well as the output data files from those scripts. In the subdirectory "02_Nonlinearity\01_PeakStormTideExtraction", PeakSearch.F90 was written to locate simulated peak storm tide elevations ("02_Production\01_TidesSurgeAndWaves") and the peak storm tide elevations of linearly superposed storm tides ("03_TidalSuperposition\01_LinearSuperpositionProduction"); the output files are stored in subdirectories corresponding to each of the four specific tidal phases. In the subdirectory	TideSuperposition.F90 CombineTides.F90 PeakSearch.F90 CheckNonlinearResponse.F90 LRcoefficient_updates.m	4.3

Directory and Subdirectory	Data Files Description	Scripts/Model	Corresponding Report Section
03_TidalSuperposition (continued)	"02_Nonlinearity\02_Noninearity", CheckNonlinearResponse.F90 was written to calculate the regression coefficients and correlation coefficients, and its direct output is nonlinearity_summary.csv. The output was reviewed using the MATLAB script "LRcoefficient_updates.m", and updated regression coefficients are stored in nonlinearity_summary_upd.csv, which was used to make the nonlinear adjustment.	TideSuperposition.F90 CombineTides.F90 PeakSearch.F90 CheckNonlinearResponse.F90 LRcoefficient_updates.m	4.3
04_RecurrenceAnalysis	This directory contains scripts used to calculate the return interval stillwater levels and the intermediate and final results. • "01_ExtratropicalStatistics\01_Water Nodes" and "01_ExtratropicalStatistics\01_Land Nodes" contain recurrence analysis results for "in water" nodes and overland nodes, respectively, land_3816_ETexcprob.csv, water_3816_ETexcprob.csv, water_3816_ETreturns.csv and land_3816_ETreturns.csv. • "01_ExtratropicalStatistics\code" includes ET_GEV_Offshore.F90, ET_GEV_Onshore.F90, and Combine_ET_TS.F90. These codes were revised from FEMA's versions and were used to compute the return values and exceedance rates. • "02_CombineExtratropicalandTropical" includes the script to combine ET and tropical responses (Combine_ET_TS.F90 revised from FEMA's version), its direct outputs, and return total stillwater elevations at given frequencies due to both tropical and ET storms: water3816_return_Combined.csv and land3816_return_Combined.csv, which are reported in MSL. • The recurrence analysis results were reviewed using the MATLAB script ReturnsRev.m. The file containing updated return interval stillwater elevations is Updated_return_CombinedRev.csv, which is reported in MSL. It was converted to NAVD88 using spatially varying datum conversion factors created using VDatum and saved as	ET_GEV_Offshore.F90 ET_GEV_Onshore.F90 Combine_ET_TS.F90 ReturnsRev.m	5.1 5.2

Directory and Subdirectory	Data Files Description	Scripts/Model	Corresponding Report Section
04_RecurrenceAnalysis (continued)	Updated_return_CombinedRev_NAVD.csv. The file containing spatially varying conversion factors is DatumConv_NOAAVDatum_updated.csv.	ET_GEV_Offshore.F90 ET_GEV_Onshore.F90 Combine_ET_TS.F90 ReturnsRev.m	5.1 5.2
05_TransectTable	This directory contains data and scripts used to create the transect data presented in Section 5 and Appendix D. • The 100-year stillwater elevations and wave conditions corresponding to the 100-year stillwater elevations at the starting station for each transect are included in “01_StartingSWEL” and “02_StartingWaves”, respectively.		5.2 5.3 5.4
06_Mapping	This directory contains a spatial exhibition of revised stillwater elevations and demonstrative mapping products. • In “01_SWELShapes”, point shape files are provided for "in-water" and overland points (nodes) with 1-percent-annual-chance and 0.2-percent-annual-chance stillwater elevations at nodal locations in the ADCIRC+SWAN mesh. Elevations are listed in feet, both in MSL (City100yrSWEL_MSLft_QA1) and in NAVD88 (City100yrSWEL_NAVD88ft_QA1). The elevation difference between FEMA's and the City's revised stillwater elevations are provided in the point shape files SWEL_QA1_Differences_LandPoint and SWEL_QA1_Differences_WaterPoint. Elevation differences are listed in feet. • In “02_FloodPlainExtent”, polygon shapefiles are included to illustrate the 1-percent-annual-chance flooding extents based on the City's revised "in-water" stillwater elevations, intersected with FEMA's 2010 topography. The directory also includes FEMA WHAFIS Transects adjusted for mapping with mapped stillwater elevations in NAVD88, an Excel file with Transect IDs and Node IDs corresponding to the nodal location used to determine stillwater elevation for mapping (as described in Section 5.3), and transects added for mapping based on stillwater elevation in NAVD88.		5.2 5.3

7.0 REQUEST TO REVISE AND REISSUE FIRMS

The City's new coastal analysis described within demonstrates a need for FEMA to revise and reissue the FIRMs due to technically and scientifically incorrect PFIRM stillwater elevations. Incorrect stillwater elevations resulted in incorrect BFEs and SFHA boundaries in FEMA's 2015 PFIRMs. As discussed in Section 1.4, the City's appeal demonstrates the following as part of federal requirements for appeal (44 CFR §67.6):

- To address FEMA's scientific and technical errors related to (1) an insufficient extratropical storm model validation and (2) the misrepresentation of tidal effects for extratropical storms, a new coastal analysis has been conducted by the City to develop new, scientifically and technically correct stillwater elevations. For scientific errors, the City's new coastal analysis, which employed corrected, alternative methodologies, is described within, and for technical errors, explanations of where FEMA's methodologies have been applied differently and mathematical errors have been addressed are documented and justified;

- The City's new and correct stillwater elevations are described in Section 5.2 and provided in digital form on a separate hard drive;

- Revised SFHA zone boundaries are provided in Section 5.3 and Appendix D based on the revised stillwater elevations determined by the City; and

- A revised Transect Data Table for all transects in New York City has been provided in Appendix C.

In addition to this document, the City is submitting all data required as part of the appeal to FEMA on a separate hard drive. The data included in the submittal are described in Section 6 and provide information necessary to complete the requisite mapping processes to revise BFEs and SFHA boundaries throughout the region following the City's new coastal analysis providing corrected stillwater elevations.

The City looks forward to a timely response to this appeal and the prompt revision and reissuance of FIRMs.

8.0 REFERENCES

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APPENDIX A

WIND VECTORS AND HYDROGRAPHS FOR THE 1991 EXTRATROPICAL STORM

Figures A-1 through A-4 show four snapshots of wind speed and direction that were input to the ADCIRC+SWAN model, as well as water surface elevation time series comparing simulated and observed storm tide elevations at The Battery and Sandy Hook NOAA gage locations. The time associated with each figure is labeled and also indicated as a vertical green line in each time series plot. These four snapshots were chosen at low and high tide for the two tidal cycles prior to observed peak storm tide elevations. As shown on the figures, the region experienced offshore winds before and during peak storm tide elevations. Due to the wind directions prior to the storm, the City believes that storm tide elevations in the 1991 storm were not a result of shoreward winds and instead were driven by wave radiation stresses from the large offshore waves propagating toward the coast. These wave radiation stresses are also believed to not be fully captured in FEMA's PFIRM coastal analysis ADCIRC+SWAN models, hence the underestimation at peak storm tide levels.

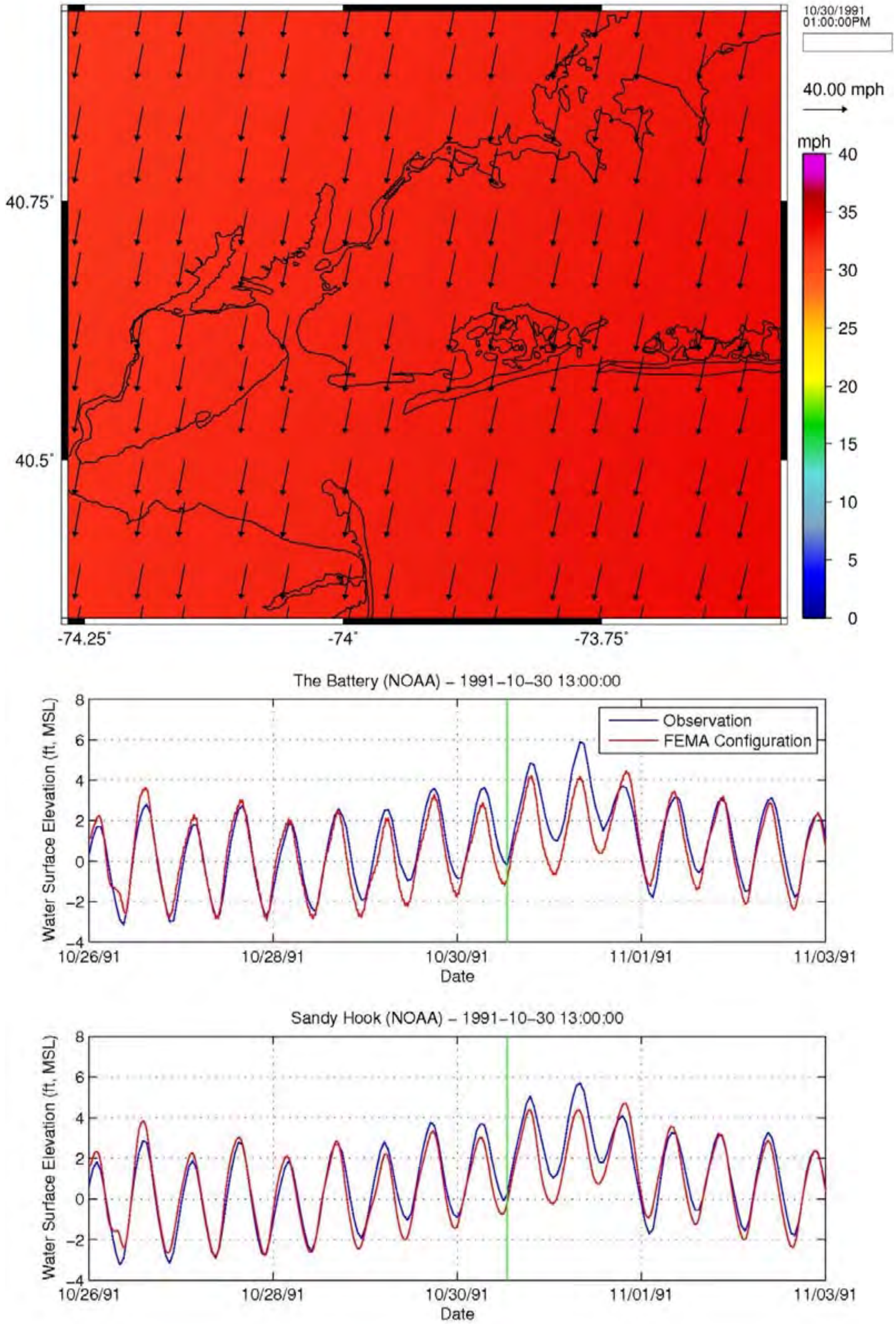


Figure A-1: Wind speed and direction at 10/30/1991 13:00GMT and water surface elevation time series at The Battery and Sandy Hook.

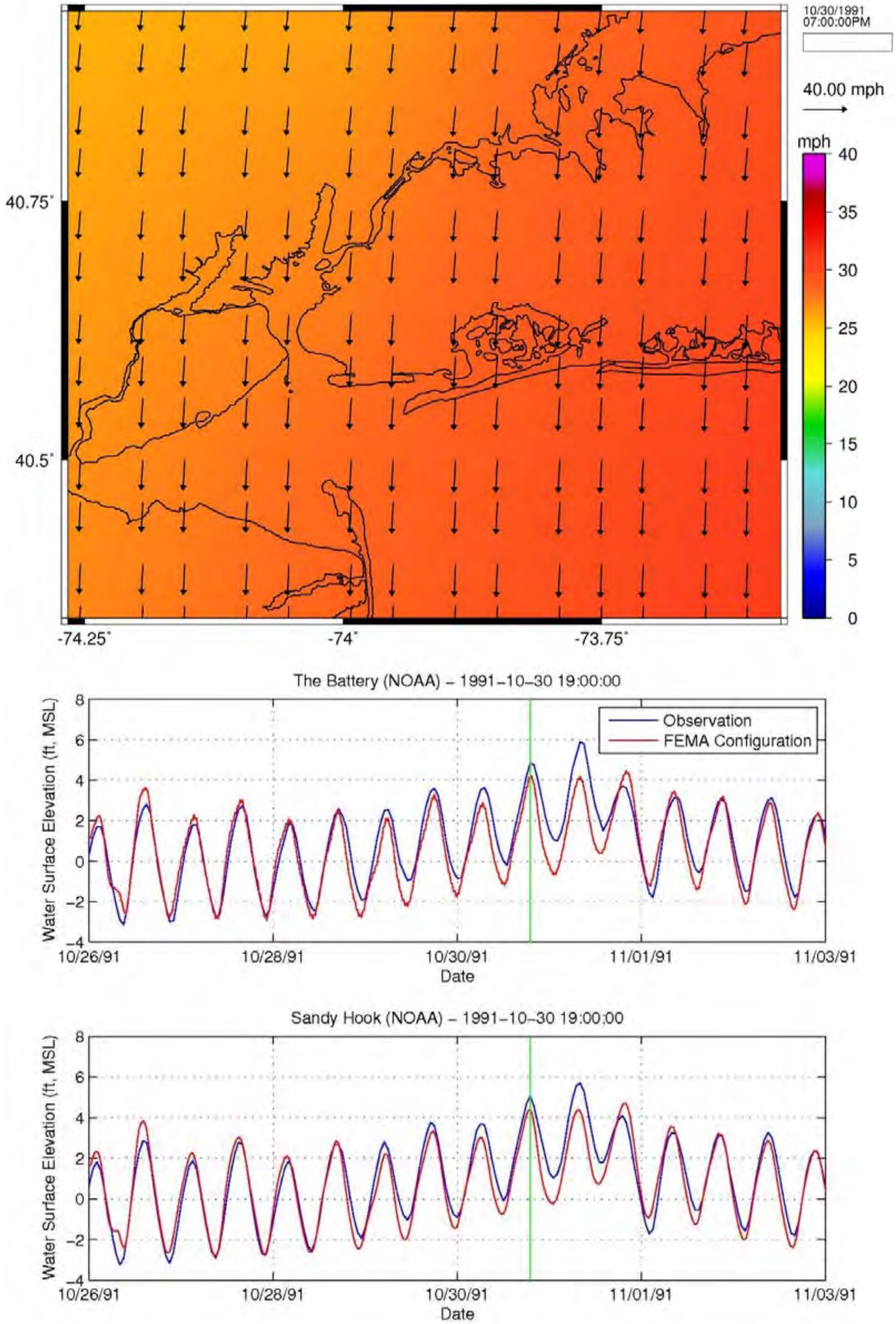


Figure A-2: Wind speed and direction at 10/30/1991 19:00GMT and water surface elevation time series at The Battery and Sandy Hook.

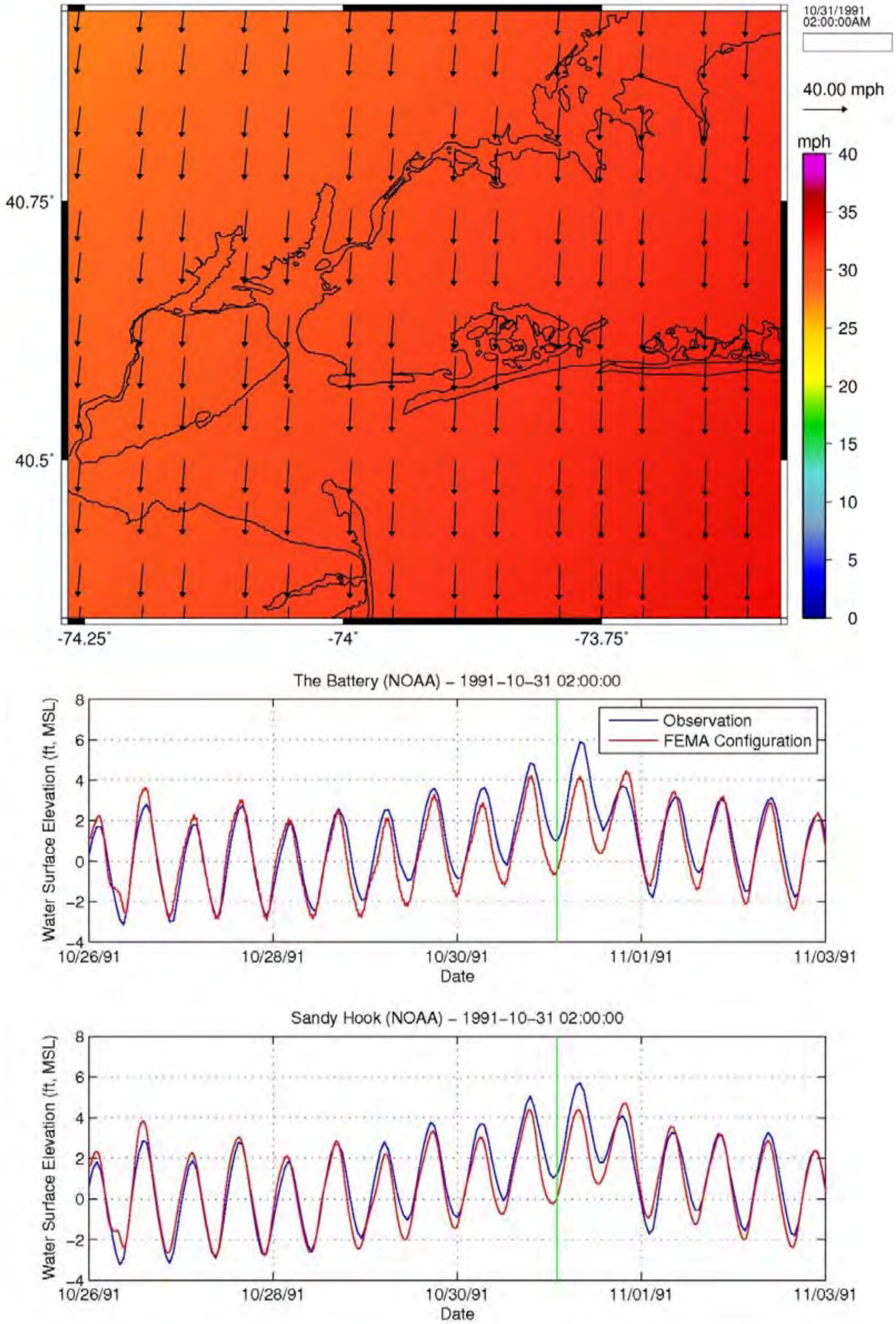
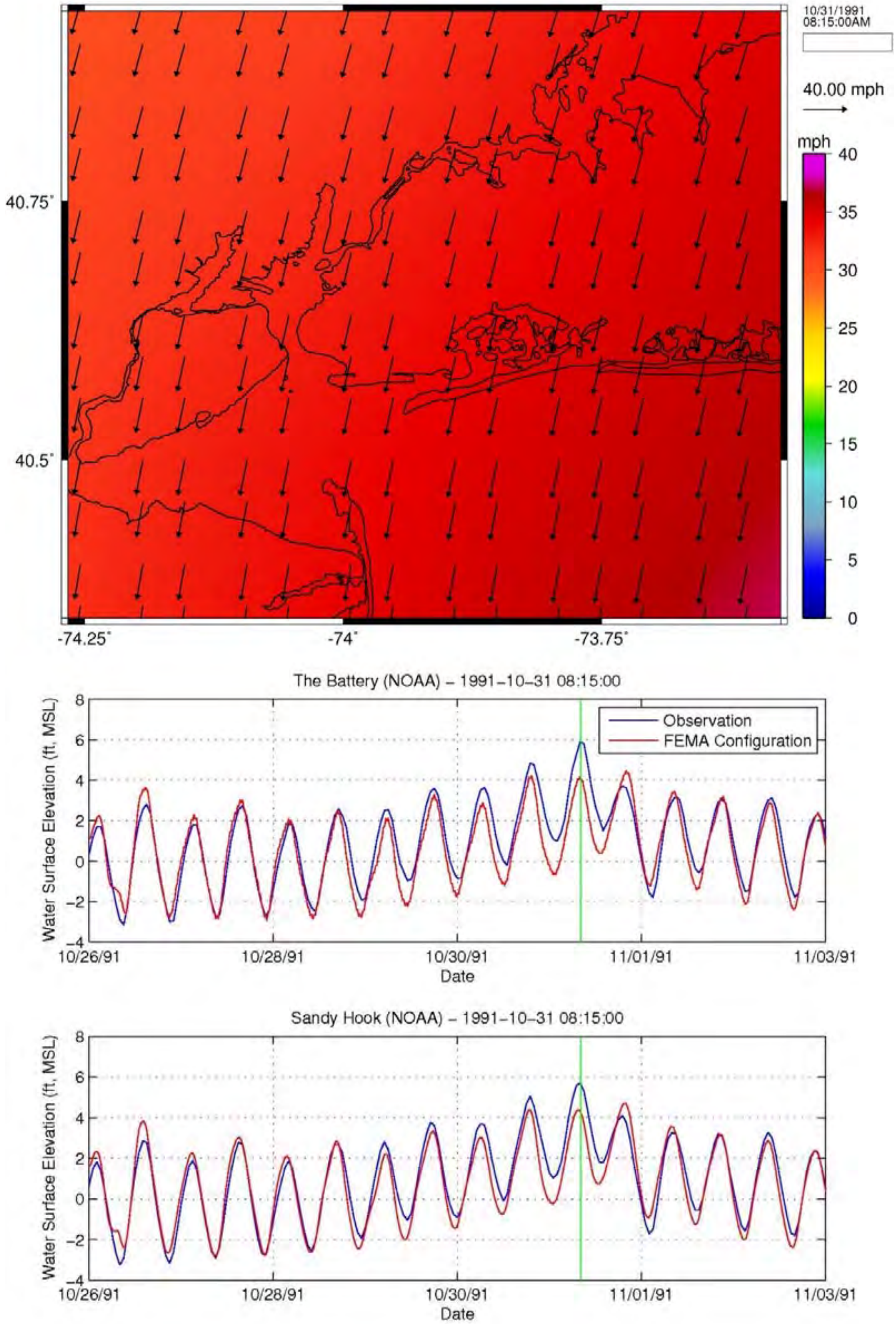


Figure A-3: Wind speed and direction at 10/31/1991 02:00GMT and water surface elevation time series at The Battery and Sandy Hook.



FigureA-4: Wind speed and direction at 10/31/1991 08:15GMT and water surface elevation time series at The Battery and Sandy Hook.

APPENDIX B

PERCENT-ANNUAL-CHANCE STILLWATER ELEVATIONS

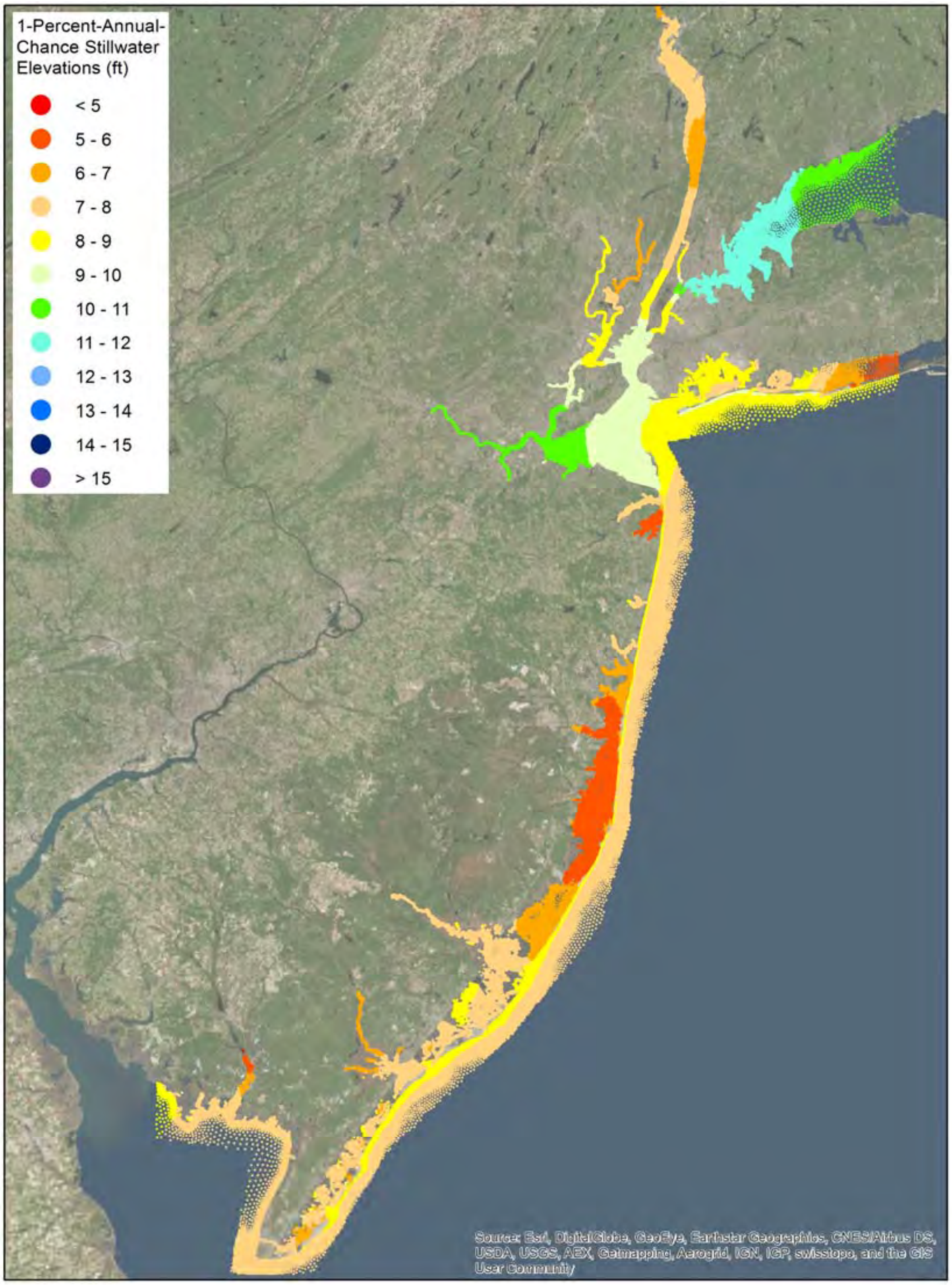


Figure B-1. 1-percent-annual-chance stillwater elevations (feet, NAVD88) for the City's analysis in the study area.

Values are shown for "in water" nodes only.

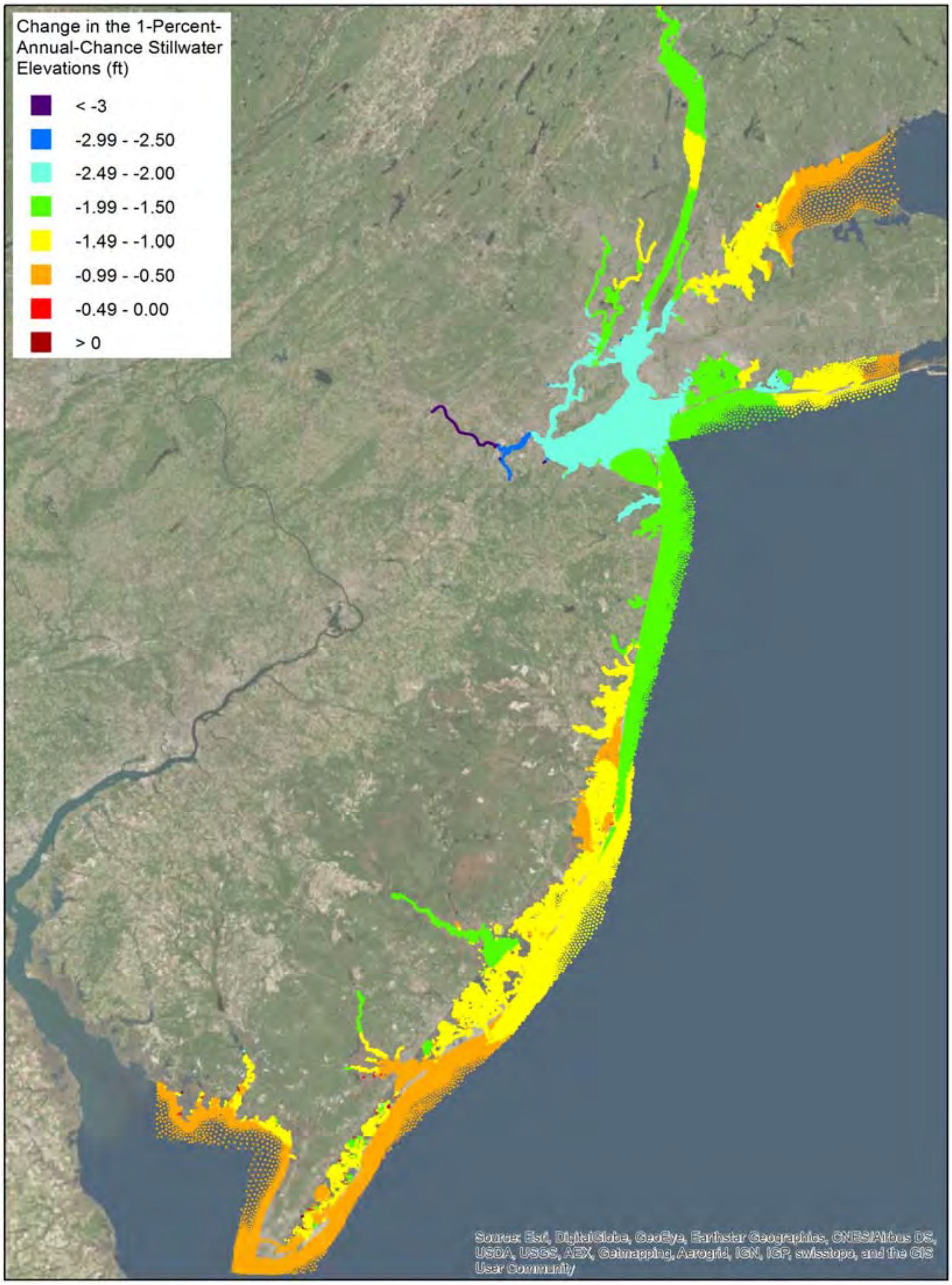


Figure B-2. Difference (feet) in 1-percent-annual-chance stillwater elevations between FEMA's PFIRM coastal analysis and the City's analysis in the study area.

Negative values represent decreases in FEMA's stillwater elevations. Values are shown for "in water" nodes only.

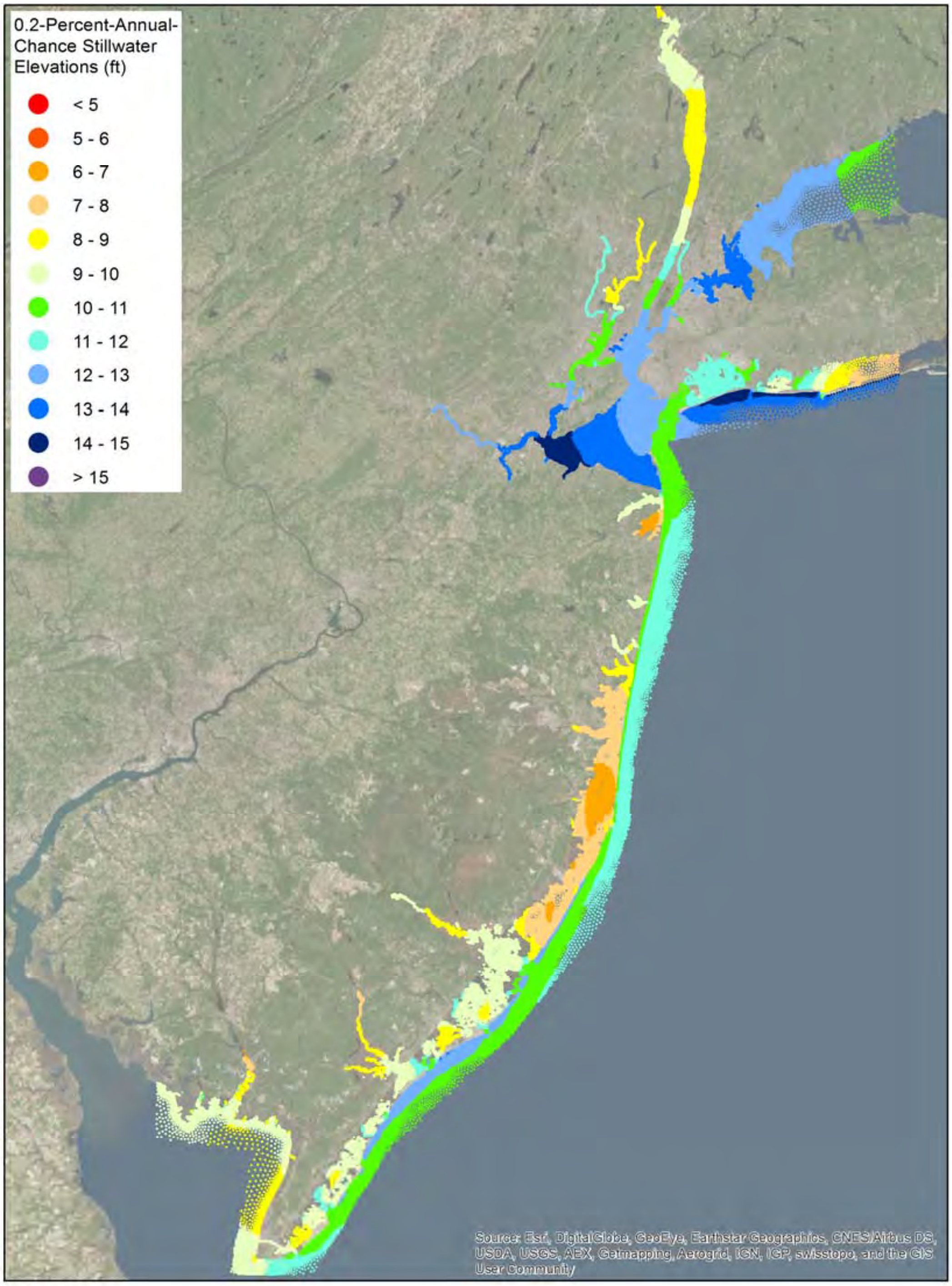


Figure B-3. 0.2-percent-annual-chance stillwater elevations (feet, NAVD88) for the City's analysis in the study area.

Values are shown for "in water" nodes only.

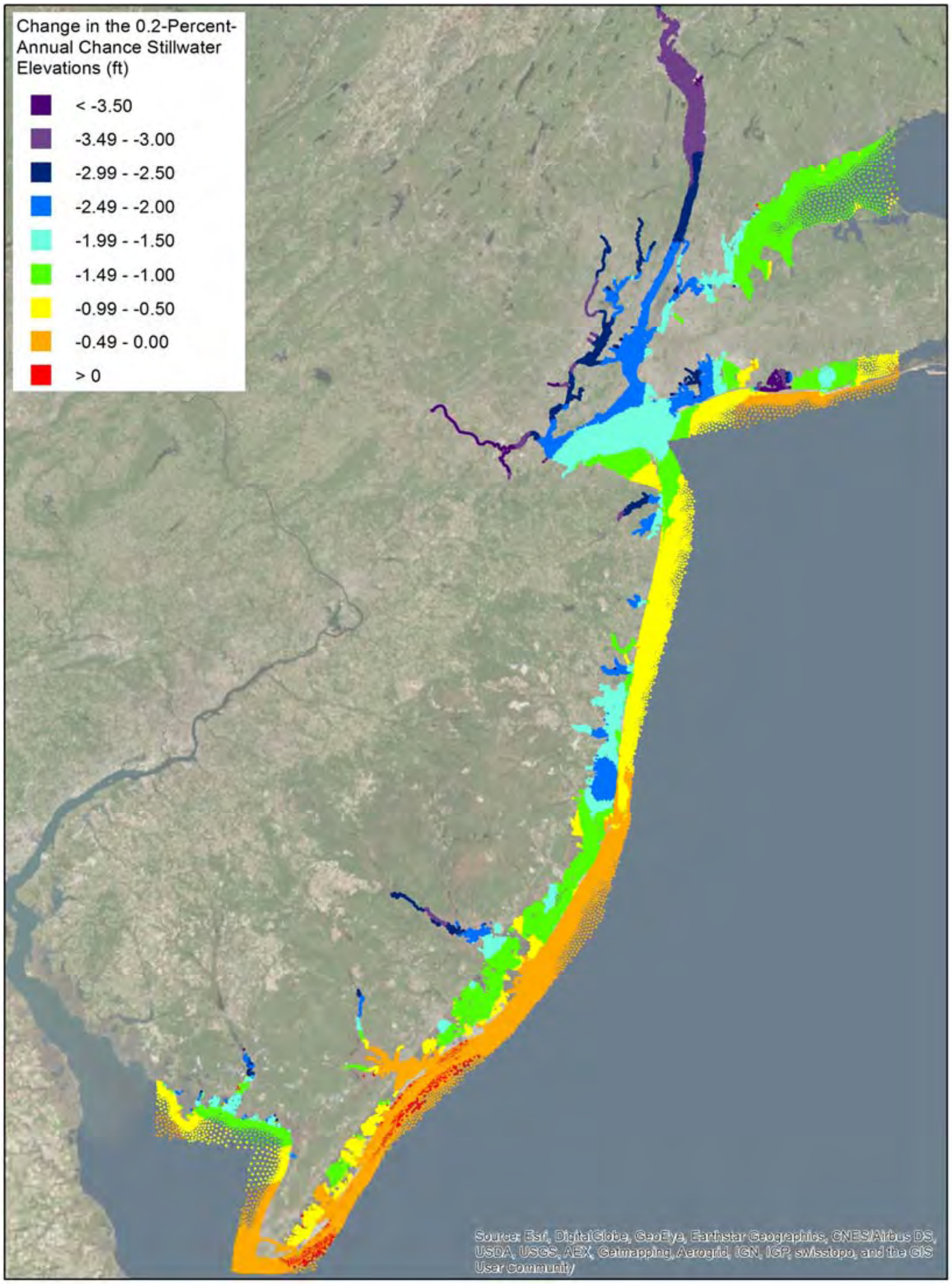


Figure B-4. Difference (feet) in 0.2-percent-annual-chance stillwater elevations between FEMA's PFIRM coastal analysis and the City's analysis in the study area.

Negative values represent decreases in FEMA's stillwater elevations. Values are shown "in water" nodes only.

APPENDIX C

TRANSECT DATA TABLE

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Bronx County, New York								
Long Island Sound	BX-1	N 40.882876 W 73.793188	2.71	2.94	9.4 -	11.1 11.1-11.2	11.7 11.6-11.7	13.1 -
Long Island Sound	BX-2	N 40.875510 W 73.785368	5.23	4.67	9.3 9.3-9.5	11 11-11.2	11.6 11.6-11.8	13 13-13.3
Long Island Sound	BX-3	N 40.867896 W 73.791576	5.24	4.58	9.3 9.2-9.5	11 11-11.3	11.6 11.6-12	13 13-13.6
Long Island Sound	BX-4	N 40.857657 W 73.788791	4.81	4.07	9.4 9.3-9.4	11 10.9-11.1	11.6 11.5-11.7	13.1 13-13.3
Long Island Sound	BX-5	N 40.853174 W 73.787539	3.93	3.58	9.4 -	11 -	11.6 11.6-11.7	13 12.9-13
Long Island Sound	BX-6	N 40.846334 W 73.782475	2.89	2.89	9.3 -	11 10.9-11	11.6 11.5-11.6	13 -
Long Island Sound	BX-7	N 40.840038 W 73.781424	3.85	3.32	9.4 -	11 -	11.6 -	13.1 -
Eastchester Bay	BX-8	N 40.840755 W 73.787536	2.20	2.39	9.4 -	11 -	11.6 -	13.2 -
Eastchester Bay	BX-9	N 40.849456 W 73.789833	2.05	2.48	9.4 -	11 10.9-11	11.6 -	13.1 -
Eastchester Bay	BX-10	N 40.850414 W 73.801881	2.23	2.37	9.4 9.3-9.4	11.1 10.9-11.1	11.7 11.4-11.7	13.2 13-13.2
Eastchester Bay	BX-11	N 40.859015 W 73.807876	1.98	2.18	9.4 -	11.1 -	11.7 -	13.2 -
Eastchester Bay	BX-12	N 40.853506 W 73.817070	1.72	2.10	9.5 -	11.2 -	11.8 -	13.3 -
Eastchester Bay	BX-13	N 40.847353 W 73.816165	2.31	2.41	9.5 -	11.2 -	11.8 11.7-11.8	13.3 13.1-13.3
Eastchester Bay	BX-14	N 40.840772 W 73.815333	2.68	2.56	9.5 -	11.2 -	11.8 -	13.3 -
Eastchester Bay	BX-15	N 40.836330 W 73.816310	2.97	2.77	9.5 -	11.2 -	11.8 -	13.3 -

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Eastchester Bay	BX-16	N 40.831840 W 73.815367	2.80	2.72	9.5 -	11.2 -	11.8 -	13.2 -
Eastchester Bay	BX-17	N 40.825977 W 73.814133	3.33	3.07	9.5 -	11.2 11.2-11.3	11.8 -	13.3 -
Eastchester Bay	BX-18	N 40.822950 W 73.806499	3.56	3.17	9.5 -	11.1 -	11.7 -	13.2 -
Eastchester Bay	BX-19	N 40.819079 W 73.804739	3.64	3.21	9.5 -	11.1 -	11.7 11.6-11.7	13.2 13.2-13.3
Long Island Sound	BX-20	N 40.815456 W 73.799164	3.65	3.13	9.5 9.5-9.6	11.1 11-11.1	11.7 11.6-11.7	13.2 13.1-13.3
Long Island Sound	BX-21	N 40.813471 W 73.801406	3.72	3.19	9.5 8.4-9.5	11.1 11-11.1	11.8 11.7-12	13.3 13.3-13.5
Long Island Sound	BX-22	N 40.811723 W 73.803529	3.66	3.16	9.5 -	11.2 -	11.8 11.7-11.8	13.3 13.2-13.3
Long Island Sound	BX-23	N 40.807911 W 73.794756	3.62	3.10	9.5 -	11.1 -	11.7 -	13.2 -
Long Island Sound	BX-24	N 40.804938 W 73.790269	3.81	3.13	9.5 -	11.1 11-11.1	11.7 11.6-11.7	13.2 13.1-13.2
East River	BX-25	N 40.809133 W 73.803045	2.31	2.59	9.4 9.4-9.5	11.1 -	11.7 11.7-11.9	13.2 13.2-13.4
East River	BX-26	N 40.812835 W 73.809719	2.30	2.55	9.5 -	11.1 -	11.7 -	13.3 -
East River	BX-27	N 40.813721 W 73.817371	2.22	2.43	9.4 9.3-9.4	11.1 11-11.1	11.7 11.6-11.7	13.3 13.2-13.3
East River	BX-28	N 40.813192 W 73.819875	2.30	2.43	9.4 9.2-9.4	11.1 11-11.1	11.7 11.6-11.7	13.3 -
East River	BX-29	N 40.811760 W 73.825350	2.38	2.47	9.4 -	11.1 10.9-11.1	11.7 11.6-11.7	13.3 13.3-13.6
East River	BX-30	N 40.808182 W 73.832188	2.29	2.41	9.5 9.3-9.5	11.2 10.9-11.3	11.8 11.5-11.9	13.3 13-13.3
East River	BX-31	N 40.810697 W 73.846372	3.02	2.60	9.4 -	11.1 10.8-11.1	11.7 11.5-11.7	13.2 13.1-13.2

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
East River	BX-32	N 40.809094 W 73.850006	2.32	2.30	9.4 -	11.1 11-11.1	11.8 11.7-11.9	13.3 -
East River	BX-33	N 40.805165 W 73.847739	2.46	2.61	9.4 -	11.1 11.1-11.2	11.7 11.7-11.8	13.2 13.2-13.4
East River	BX-34	N 40.804769 W 73.856471	2.70	2.70	9.4 -	11.1 -	11.7 -	13.2 13.2-13.4
East River	BX-35	N 40.809620 W 73.860589	2.47	2.49	9.4 -	11.1 -	11.7 -	13.2 13.2-13.3
East River	BX-36	N 40.810482 W 73.866440	2.46	2.48	9.4 -	11.1 -	11.7 -	13.3 -
East River	BX-37	N 40.802478 W 73.871062	2.78	2.71	9.4 -	11.1 10.8-12.5	11.8 11.6-11.8	13.3 13.2-13.3
East River	BX-38	N 40.802234 W 73.883391	2.51	2.64	9.4 9.3-9.4	11.1 10.6-11.1	11.7 11.4-11.7	13.2 13-13.2
East River	BX-39	N 40.806363 W 73.892463	2.13	2.16	9.2 -	10.9 10.7-10.9	11.6 11.5-11.6	13.1 12.9-13.1
East River	BX-40	N 40.804857 W 73.901251	1.89	2.28	9.1 8.8-9.1	10.9 10.6-12.5	11.5 11.2-11.5	13 12.8-13
East River	BX-41	N 40.798453 W 73.908958	2.27	2.21	9.1 -	10.8 10.3-10.8	11.4 11.2-11.4	12.9 12.8-13
Harlem River	BX-42	N 40.802539 W 73.927213	1.66	2.07	7.3 -	9 8.7-9.3	9.7 9.5-9.7	11.6 11.3-11.6
Hudson River	BX-43	N 40.880389 W 73.923785	3.94	3.17	5 -	6.6 -	7.5 -	9.7 9.6-9.7
Hudson River	BX-44	N 40.894006 W 73.918004	4.06	3.16	5 -	6.6 -	7.4 -	9.6 9.6-9.7
Hudson River	BX-45	N 40.902509 W 73.915161	4.03	3.15	4.9 -	6.6 -	7.4 -	9.5 -
Hudson River	BX-46	N 40.915050 W 73.910557	3.84	3.13	4.9 -	6.5 -	7.3 -	9.3 9.2-9.3
Long Island Sound	BX-47	N 40.856289 W 73.766650	6.00	4.35	9.3 9.2-9.3	10.9 10.7-10.9	11.5 11.4-11.7	13 12.8-13.5

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Long Island Sound	BX-48	N 40.851035 W 73.768842	5.25	4.01	9.3 -	10.9 -	11.5 -	13 -
Long Island Sound	BX-49	N 40.852594 W 73.771758	3.75	3.50	9.3 -	10.9 10.9-11	11.5 11.5-11.6	13 12.9-13.3
East River	BX-50	N 40.792101 W 73.874565	2.80	2.75	9.4 -	11.1 -	11.7 -	13.2 -
East River	BX-51	N 40.786214 W 73.882983	2.10	2.52	9.1 -	10.8 10.6-10.8	11.4 11.3-11.4	12.9 12.8-12.9
East River	BX-52	N 40.791346 W 73.892419	2.01	2.25	9 -	10.8 -	11.4 11.3-11.4	12.9 -
East River	BX-53	N 40.797559 W 73.886136	2.37	2.66	9.3 -	11 -	11.7 -	13.1 -
East River	BX-54	N 40.801180 W 73.896639	2.19	2.84	9.3 9.3-9.5	11 10.9-11	11.6 11.4-11.6	13.2 -
East River	BX-55	N 40.796870 W 73.897179	2.14	2.24	9.2 9.1-9.2	10.9 10.8-10.9	11.5 11.4-11.5	13 12.9-13

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Kings County, New York								
Jamaica Bay	K-1	N 40.650180 W 73.857295	3.11	2.66	5.9 -	7.5 7.4-7.6	8.3 8.3-8.5	10.8 10.5-11.1
Jamaica Bay	K-2	N 40.642913 W 73.861579	3.25	2.66	5.9 5.9-6	7.5 7.3-7.5	8.3 -	10.7 10.6-10.9
Jamaica Bay	K-3	N 40.637659 W 73.870611	3.17	2.70	5.9 -	7.5 -	8.3 -	10.5 10.4-10.5
Jamaica Bay	K-4	N 40.635459 W 73.877340	2.93	2.59	6 5.9-6.1	7.6 7.6-7.9	8.3 8.2-8.4	10.5 10.3-10.7
Jamaica Bay	K-5	N 40.631760 W 73.882391	2.52	2.51	6 -	7.6 -	8.3 8.1-8.3	10.5 10.3-10.7
Jamaica Bay	K-6	N 40.627664 W 73.888337	3.17	2.60	6 5.9-6	7.6 -	8.3 8-8.3	10.4 10.3-10.5
Jamaica Bay	K-7	N 40.622933 W 73.894580	3.06	2.63	6 -	7.6 -	8.4 8.2-8.5	10.4 10.3-10.8
Jamaica Bay	K-8	N 40.618794 W 73.895780	3.14	2.67	6 6-6.1	7.6 -	8.3 8-8.3	10.3 10.1-10.7
Jamaica Bay	K-9	N 40.608044 W 73.892504	3.23	2.73	6 6-6.4	7.5 7.3-8.2	8.2 8.1-8.7	10.2 10.2-11.1
Jamaica Bay	K-10	N 40.602728 W 73.883254	2.99	2.63	6 -	7.4 7.1-7.4	8.1 7.9-8.2	10.2 9.9-10.5
Jamaica Bay	K-11	N 40.593793 W 73.880519	2.87	2.65	6 -	7.4 -	8.1 -	10.1 10.1-10.6
Jamaica Bay	K-12	N 40.578895 W 73.883644	3.67	3.54	5.9 -	7.4 -	8 7.8-8	10.1 10-10.4
Dead Horse Bay	K-13	N 40.579371 W 73.896649	3.96	3.35	5.9 -	7.4 -	8.2 -	10.7 10.6-10.7
Dead Horse Bay	K-14	N 40.587565 W 73.899036	3.58	3.04	5.9 -	7.5 -	8.3 -	11 -
Dead Horse Bay	K-15	N 40.586948 W 73.906879	3.46	3.13	6 -	7.5 7.1-7.6	8.3 8-8.3	11 11-11.1

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Raritan Bay	K-16	N 40.582036 W 73.917709	3.74	3.45	6 5.9-6	7.6 7.3-8.2	8.4 8.2-8.5	11.1 11-11.4
Raritan Bay	K-17	N 40.583425 W 73.923126	4.02	3.51	6 5.9-6	7.6 7.3-8.2	8.5 8.3-8.7	11.2 11.2-11.6
Raritan Bay	K-18	N 40.583473 W 73.928895	4.43	3.75	6 -	7.6 7.3-8.1	8.5 8.3-8.7	11.2 11.2-11.8
Raritan Bay	K-19	N 40.575543 W 73.937167	5.72	4.88	6 -	7.6 7.6-8	8.5 8.1-8.7	11.2 10.9-11.5
Raritan Bay	K-20	N 40.574959 W 73.947220	6.82	5.48	6 -	7.7 7.2-7.9	8.6 8-8.8	11.6 11-12.2
Raritan Bay	K-21	N 40.574173 W 73.957374	7.26	5.6	6.1 -	7.8 -	8.8 8.1-8.8	12 10.9-12.2
Raritan Bay	K-22	N 40.573203 W 73.967783	8.19	5.90	6.1 -	7.9 7.3-8	8.9 7.9-8.9	12.3 10.5-12.5
Raritan Bay	K-23	N 40.572069 W 73.976340	8.32	5.63	6.2 6.2-6.3	8 7.3-8	9 7.9-9.1	12.4 10.9-12.6
Raritan Bay	K-24	N 40.571304 W 73.985245	8.10	5.45	6.2 5.9-6.2	8 7.5-8.1	9 7.8-9.2	12.4 10.6-12.7
Raritan Bay	K-25	N 40.570384 W 73.994383	8.26	5.89	6.2 5.9-6.2	8 7.6-8	9 8.6-9.1	12.4 11.8-12.5
Raritan Bay	K-26	N 40.572728 W 74.004156	8.31	5.92	6.2 5.8-6.2	8 7.7-8	9.1 8.8-9.1	12.5 12.3-12.6
Raritan Bay	K-27	N 40.576794 W 74.012480	7.68	4.82	6.2 -	8 8-8.1	9.1 8.2-9.3	12.5 11.2-13
Lower New York Bay	K-28	N 40.590029 W 73.998578	4.10	3.11	6.2 6.2-6.3	8 -	9.2 8.1-9.2	12.7 11.1-12.7
Lower New York Bay	K-29	N 40.595454 W 74.002996	4.64	3.32	6.2 -	8.1 -	9.2 9-9.3	12.7 12.6-12.7
Lower New York Bay	K-30	N 40.600945 W 74.011295	5.59	3.88	6.2 -	8.1 -	9.2 -	12.7 12.6-12.7
Lower New York Bay	K-31	N 40.603748 W 74.022831	6.09	3.98	6.3 -	8.2 -	9.3 9.1-9.3	12.8 12.8-13.1

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Upper New York Bay	K-32	N 40.610985 W 74.036792	5.67	3.96	6.3 -	8.1 -	9.2 9.2-9.3	12.6 -
Upper New York Bay	K-33	N 40.619585 W 74.041365	5.12	3.87	6.2 -	8.1 -	9.2 -	12.4 -
Upper New York Bay	K-34	N 40.627366 W 74.041565	4.97	3.79	6.2 -	8.1 -	9.2 -	12.5 -
Upper New York Bay	K-35	N 40.634525 W 74.039003	4.46	3.40	6.2 -	8.2 -	9.3 9.2-9.3	12.6 12.4-12.6
Upper New York Bay	K-36	N 40.642177 W 74.036170	4.29	3.30	6.2 -	8.2 -	9.3 8.9-9.3	12.7 12.5-12.7
Upper New York Bay	K-37	N 40.645337 W 74.026905	3.53	2.98	6.2 -	8.1 8-8.1	9.3 9.2-9.3	12.8 12.7-12.8
Upper New York Bay	K-38	N 40.650947 W 74.024463	3.58	2.97	6.2 -	8.1 -	9.3 9.1-9.3	12.8 12.5-12.8
Upper New York Bay	K-39	N 40.657654 W 74.018838	3.32	2.80	6.2 6.1-6.2	8.1 -	9.3 9.2-9.3	12.8 12.6-12.8
Upper New York Bay	K-40	N 40.660150 W 74.007926	2.63	2.55	6.1 -	8 7.8-8	9.2 9-9.2	12.9 12.7-12.9
Upper New York Bay	K-41	N 40.667702 W 74.004180	2.34	2.36	6.1 5.8-6.1	8 7.7-8	9.2 8.2-9.2	12.9 11.9-12.9
Upper New York Bay	K-42	N 40.670684 W 74.018672	3.45	2.81	6.2 6-6.2	8.1 7.9-8.1	9.3 8.6-9.3	12.9 12.4-12.9
Upper New York Bay	K-43	N 40.676241 W 74.017878	3.48	2.86	6.2 -	8.1 7.9-8.1	9.3 8.9-9.3	12.9 12.6-12.9
Upper New York Bay	K-44	N 40.683167 W 74.013571	2.69	2.61	6.2 6.1-6.4	8.1 7.9-8.1	9.3 9.1-9.3	12.8 12.6-12.8
East River	K-45	N 40.687110 W 74.005415	2.57	2.51	6.1 -	8 8-8.1	9.2 8.7-9.2	12.7 12.4-12.7
East River	K-46	N 40.693747 W 74.001117	3.09	2.65	6.1 -	8 7.9-8	9.2 9.1-9.2	12.7 12.6-12.7
East River	K-47	N 40.699626 W 73.997517	3.27	2.67	6 -	7.9 7.8-7.9	9.1 8.7-9.1	12.7 12.6-12.7

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TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
East River	K-48	N 40.705170 W 73.987400	3.14	3.06	5.9 -	7.7 7.5-7.7	8.8 8.7-8.8	12.3 12.1-12.3
East River	K-49	N 40.705888 W 73.973068	2.63	2.70	5.9 5.7-5.9	7.7 7.2-8.6	8.8 8.5-8.9	12.3 12.1-12.4
East River	K-50	N 40.714219 W 73.968382	2.78	2.63	5.9 -	7.7 -	8.8 -	12.2 -
East River	K-51	N 40.722032 W 73.962987	2.85	2.63	5.9 -	7.7 7.4-7.7	8.8 8.6-8.8	12.1 11.9-12.1
East River	K-52	N 40.729474 W 73.961207	2.81	2.60	6 6-6.1	7.8 7.7-7.8	8.8 7.9-8.8	12.2 11.1-12.2
East River	K-53	N 40.736815 W 73.960049	2.66	2.51	6 -	7.8 -	8.8 8-8.8	12.1 11.2-12.1
Jamaica Bay	K-54	N 40.616812 W 73.870376	3.08	2.50	6 5.9-6	7.5 7.4-7.5	8.2 8.1-8.2	10.3 10.2-10.3
Jamaica Bay	K-55	N 40.596268 W 73.859579	3.09	2.59	5.9 5.8-5.9	7.4 7.3-7.4	8.1 8-8.1	10.3 9.8-10.3

[1]Stillwater elevations include the contribution from wave setup.

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TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
New York County, New York								
East River	NY-1	N 40.793831 W 73.913812	2.10	2.15	9 7.2-9	10.7 9.2-10.7	11.3 9.8-11.4	12.8 11.1-13.1
East River	NY-2	N 40.781691 W 73.929639	2.05	2.02	7.8 7.8-7.9	9.5 9.4-9.5	10.2 10.1-10.2	11.8 11.6-11.8
East River	NY-3	N 40.785609 W 73.939519	1.95	2.23	7.7 5.1-7.7	9.5 9-11.2	10.2 10-10.2	12 12-12.2
East River	NY-4	N 40.779837 W 73.943466	2.26	2.28	7.7 -	9.4 -	10.2 10.1-10.2	11.9 11.8-11.9
East River	NY-5	N 40.774289 W 73.943270	2.11	2.18	7.3 -	9 -	9.6 -	11.6 -
East River	NY-6	N 40.772969 W 73.940171	2.17	2.19	7.5 7-7.5	9.2 9-9.3	10 9.3-10	11.8 11.3-11.9
East River	NY-7	N 40.749979 W 73.966252	2.33	2.39	6.1 -	7.9 -	8.9 -	12.1 -
East River	NY-8	N 40.743089 W 73.971655	2.80	2.56	6 -	7.9 -	8.9 8.6-8.9	12.1 12-12.1
East River	NY-9	N 40.737477 W 73.972616	2.81	2.58	6 5.7-6	7.9 -	8.9 8.6-8.9	12.1 12.1-12.3
East River	NY-10	N 40.731894 W 73.973573	2.89	2.60	6 -	7.8 -	8.8 8.5-8.8	12.1 -
East River	NY-11	N 40.724087 W 73.972177	2.81	2.62	5.9 5.9-6.4	7.7 7.5-7.7	8.8 8.6-8.8	12.1 12.1-12.2
East River	NY-12	N 40.716408 W 73.974358	2.80	2.64	5.9 5.7-5.9	7.7 7.6-7.7	8.7 8.5-8.7	12.1 12-12.3
East River	NY-13	N 40.710420 W 73.979459	2.68	2.77	5.9 -	7.7 -	8.7 8.5-8.7	12.1 12-12.1
East River	NY-14	N 40.709185 W 73.987873	3.14	3.06	5.9 5.7-5.9	7.7 -	8.8 8.7-8.8	12.3 12.3-12.5
East River	NY-15	N 40.708799 W 73.997024	3.10	2.77	5.9 5.8-5.9	7.8 -	9 8.8-9	12.5 -

[1]Stillwater elevations include the contribution from wave setup.

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TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
East River	NY-16	N 40.705313 W 74.003819	3.18	2.63	6 5.8-6	7.9 7.8-7.9	9.1 8.8-9.2	12.7 12.7-12.8
East River	NY-17	N 40.701590 W 74.010682	3.10	2.66	6.1 6.1-6.6	8 -	9.2 8.6-9.2	12.7 12.7-12.8
Upper New York Bay	NY-18	N 40.702983 W 74.017383	3.86	3.20	6.1 -	8.1 -	9.3 9-9.3	12.9 12.7-12.9
Hudson River	NY-19	N 40.709054 W 74.018613	3.71	3.04	6.1 6.1-6.5	8 7.3-8	9.2 8.4-9.2	12.5 12-12.8
Hudson River	NY-20	N 40.715891 W 74.017227	3.61	2.99	6 -	8 -	9.1 8.6-9.1	12.4 12-12.4
Hudson River	NY-21	N 40.722252 W 74.012398	3.44	2.92	6 -	7.9 7.8-7.9	9.1 8.1-9.1	12.5 12.3-12.5
Hudson River	NY-22	N 40.729533 W 74.014233	3.31	2.90	6 5.9-6	7.9 -	9 8.8-9	12.3 12.1-12.3
Hudson River	NY-23	N 40.735728 W 74.010684	3.27	2.89	6 -	7.8 -	9 8.8-9	12.3 12.2-12.3
Hudson River	NY-24	N 40.742069 W 74.009242	3.25	2.89	5.9 -	7.8 -	8.9 8.8-8.9	12.2 12-12.2
Hudson River	NY-25	N 40.750050 W 74.009229	3.48	2.99	5.9 5.9-6.1	7.7 7.5-7.7	8.8 8.5-8.8	11.9 11.7-11.9
Hudson River	NY-26	N 40.755928 W 74.006425	3.73	3.22	5.8 5.8-5.9	7.7 -	8.7 8.1-8.7	11.8 11.5-11.8
Hudson River	NY-27	N 40.763002 W 74.001275	3.64	3.18	5.8 -	7.7 -	8.8 8.5-8.8	11.8 11.4-11.8
Hudson River	NY-28	N 40.767894 W 73.996609	3.57	3.12	5.8 -	7.6 -	8.7 -	11.8 11.6-11.8
Hudson River	NY-29	N 40.773962 W 73.993331	3.51	3.14	5.7 -	7.5 -	8.6 8.3-8.6	11.6 11.4-11.6
Hudson River	NY-30	N 40.781047 W 73.988345	3.29	3.17	5.6 -	7.5 -	8.5 -	11.4 11.1-11.4
Hudson River	NY-31	N 40.787199 W 73.984194	3.26	3.13	5.6 -	7.4 -	8.4 -	11.3 11.3-11.4

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Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Hudson River	NY-32	N 40.797037 W 73.977270	3.49	3.39	5.5 -	7.3 -	8.3 -	11.1 -
Hudson River	NY-33	N 40.818234 W 73.961908	3.62	3.41	5.4 -	7.1 7.1-7.3	8.1 7.9-8.1	10.8 10.3-10.8
Hudson River	NY-34	N 40.826015 W 73.957987	3.77	3.45	5.4 -	7.1 -	8 7.9-8	10.5 10.2-10.5
Hudson River	NY-35	N 40.833945 W 73.950475	3.69	3.47	5.2 -	7 -	7.9 -	10.5 10.4-10.5
Hudson River	NY-36	N 40.845426 W 73.946225	3.58	3.14	5.2 -	6.9 -	7.9 7.9-8	10.4 10.2-10.4
Hudson River	NY-37	N 40.859698 W 73.937985	3.60	3.13	5.1 -	6.8 -	7.7 -	10 -
Hudson River	NY-38	N 40.869369 W 73.932182	3.77	3.24	5.1 -	6.8 -	7.7 -	10.1 9.7-10.1
East River	NY-39	N 40.692651 W 74.014019	3.03	2.62	6.1 -	8 -	9.2 -	12.7 -
Upper New York Bay	NY-40	N 40.684656 W 74.026236	4.27	3.33	6.2 -	8.2 8.1-8.2	9.3 8.9-9.3	12.8 12.7-12.8
Upper New York Bay	NY-41	N 40.690563 W 74.021778	4.14	3.30	6.2 -	8.1 -	9.3 8.9-9.3	12.7 12.5-12.7

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Queens County, New York								
Oyster Bay Inlet	Q-1	N 40.594669 W 73.745862	2.82	3.21	5.4 -	7.1 6.6-7.1	8.4 8.1-8.9	12.7 12.7-12.9
Atlantic Ocean	Q-2	N 40.591015 W 73.759443	17.91	10.52	5.8 -	7.6 6.5-7.9	9.2 7.8-9.2	14.5 11.9-14.8
Atlantic Ocean	Q-3	N 40.591317 W 73.765597	17.90	10.52	5.9 5.6-5.9	7.7 6.4-7.7	9.4 7.6-9.4	14.9 11.3-14.9
Atlantic Ocean	Q-4	N 40.590428 W 73.773961	17.90	10.52	5.9 5.5-5.9	7.7 6.5-7.8	9.3 7.6-9.3	14.8 11.1-15.4
Atlantic Ocean	Q-5	N 40.588977 W 73.783052	17.89	10.44	6 5.6-6	7.8 6.2-7.8	9.4 7.4-9.7	14.8 10.8-15.4
Atlantic Ocean	Q-6	N 40.587307 W 73.792161	17.42	10.00	5.8 5.4-5.9	7.6 6.2-7.7	9.2 7.2-9.2	14.6 10.7-14.6
Atlantic Ocean	Q-7	N 40.585476 W 73.800662	17.47	9.83	5.9 5.7-5.9	7.7 6.4-7.7	9.2 7.3-9.3	14.6 10.6-14.7
Atlantic Ocean	Q-8	N 40.584194 W 73.808180	17.20	9.73	6 5.3-6	7.8 6.4-7.8	9.3 7.5-9.3	14.7 11.1-14.7
Atlantic Ocean	Q-9	N 40.582866 W 73.815873	17.60	9.77	6.1 5.6-6.1	7.9 6.7-7.9	9.4 7.9-9.4	14.8 11.4-14.8
Atlantic Ocean	Q-10	N 40.580918 W 73.822877	17.59	9.72	6.1 5.9-6.1	7.9 6.8-7.9	9.4 8-9.4	14.8 11.5-14.8
Atlantic Ocean	Q-11	N 40.578178 W 73.831836	17.40	9.68	6 -	7.8 6.8-7.8	9.4 7.9-9.4	14.5 11-14.5
Atlantic Ocean	Q-12	N 40.575263 W 73.839673	17.17	9.66	5.9 5.5-5.9	7.6 6.5-7.6	9.1 7.6-9.2	14.3 11.1-14.7
Atlantic Ocean	Q-13	N 40.572588 W 73.847907	16.98	9.56	6.1 5.7-6.1	7.8 6.9-7.8	9.3 7.8-9.3	14.5 11.3-14.8
Atlantic Ocean	Q-14	N 40.569530 W 73.856159	16.54	9.63	6.1 5.8-6.1	7.9 7.3-7.9	9.3 8-9.3	14.4 11.7-14.4
Atlantic Ocean	Q-15	N 40.566813 W 73.864874	16.64	9.41	5.9 5.6-5.9	7.7 6.8-7.7	9.1 7.9-9.1	14 11.3-14

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Atlantic Ocean	Q-16	N 40.563836 W 73.874305	16.39	9.06	6.1 -	7.8 6.9-7.8	9.2 8-9.6	14.2 11.6-14.7
Atlantic Ocean	Q-17	N 40.560930 W 73.883202	15.92	8.92	6.1 5.8-6.1	7.8 6.8-7.8	9.2 8-9.2	14 11.6-14
Atlantic Ocean	Q-18	N 40.558587 W 73.891068	15.59	8.78	6.1 -	7.8 6.9-7.8	9.1 8.1-9.1	13.8 11.7-13.8
Atlantic Ocean	Q-19	N 40.557177 W 73.897973	16.13	8.72	6.1 5.9-6.1	7.8 7.3-7.8	9.2 8.2-9.3	13.8 11.7-14.4
Atlantic Ocean	Q-20	N 40.555047 W 73.908256	16.05	8.73	6.2 5.7-6.2	8.1 7.3-8.2	9.4 8.4-9.7	13.9 11.9-14.1
Atlantic Ocean	Q-21	N 40.551618 W 73.917206	16.19	9.00	6.2 5.7-6.2	8 7.3-8.3	9.3 8.5-9.6	13.6 11.9-14
Atlantic Ocean	Q-22	N 40.548471 W 73.925678	15.96	8.97	6.2 5.7-6.5	8 7.3-8.2	9.2 8.4-9.3	13.4 12.1-13.6
Atlantic Ocean	Q-23	N 40.545638 W 73.932721	16.26	8.89	6.1 5.7-6.1	7.8 7-7.9	8.8 7.9-8.9	12.4 11.2-12.8
Atlantic Ocean	Q-24	N 40.547566 W 73.940247	6.16	6.21	6 6-6.2	7.5 7.3-7.5	8.4 8.3-8.5	11.2 11.1-11.8
Rockaway Inlet	Q-25	N 40.557202 W 73.935954	3.70	3.18	6 5.8-6	7.6 7.3-7.8	8.5 8.2-8.8	11.4 11.4-12.3
Rockaway Inlet	Q-26	N 40.560125 W 73.928427	3.53	3.29	6 5.9-6	7.6 7.4-8.1	8.5 8.5-9.2	11.3 11.3-12.9
Rockaway Inlet	Q-27	N 40.562836 W 73.918331	4.12	3.77	6 5.9-6	7.5 7.5-8	8.4 8.4-9.2	11.1 11.1-12.9
Rockaway Inlet	Q-28	N 40.562807 W 73.905540	3.59	3.32	6 -	7.5 7.3-7.5	8.2 8-8.2	10.8 10.7-11.4
Rockaway Inlet	Q-29	N 40.564806 W 73.897078	3.25	3.04	6 -	7.4 7.1-7.4	8.2 8.1-8.2	10.7 10.7-10.9
Rockaway Inlet	Q-30	N 40.568633 W 73.889579	3.77	3.71	6 -	7.4 7.2-7.4	8.1 7.9-8.1	10.3 10.1-10.4
Rockaway Inlet	Q-31	N 40.568614 W 73.879877	3.48	3.39	6 -	7.4 7.1-7.5	8.1 8.1-8.5	10.3 10.3-11.5

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Jamaica Bay	Q-32	N 40.571129 W 73.872699	3.42	3.34	6 -	7.4 7.3-7.8	8.1 8.1-9.5	10.3 10.3-13.6
Jamaica Bay	Q-33	N 40.575222 W 73.864420	2.87	2.92	6 6-6.2	7.4 7.3-7.5	8 7.9-8.8	10.2 10.2-12.1
Jamaica Bay	Q-34	N 40.579347 W 73.856668	3.11	2.93	5.9 5.8-5.9	7.3 7.2-7.4	8 7.9-8.9	10.1 10-12.7
Jamaica Bay	Q-35	N 40.581586 W 73.845151	2.49	2.46	5.9 5.9-6	7.3 7.2-7.5	7.9 7.8-8.7	10.2 10.2-12.4
Jamaica Bay	Q-36	N 40.583782 W 73.832484	2.64	2.38	5.9 -	7.2 7.1-7.2	7.8 7.6-8	10.2 10.2-11.6
Jamaica Bay	Q-37	N 40.599213 W 73.799926	2.47	2.22	5.8 5.8-5.9	7.2 6.9-7.2	7.9 7.7-8	10.6 10.4-12.8
Jamaica Bay	Q-38	N 40.601870 W 73.784291	2.22	2.23	5.8 5.7-5.8	7.2 6.7-7.3	8 7.6-8.4	10.8 10.6-12.7
Jamaica Bay	Q-39	N 40.608130 W 73.780568	2.77	2.44	5.8 -	7.2 -	8 -	10.8 -
Jamaica Bay	Q-40	N 40.604180 W 73.775460	1.97	2.12	5.8 -	7.2 -	8 -	10.9 -
Jamaica Bay	Q-41	N 40.597957 W 73.771696	1.93	2.04	5.8 5.8-5.9	7.2 7-7.3	8 7.8-9.3	11 10.9-14.3
Jamaica Bay	Q-42	N 40.608876 W 73.768933	2.41	2.30	5.8 -	7.2 7.1-7.3	8.1 7.6-8.1	11 10.6-11
Head of Bay	Q-43	N 40.636635 W 73.746686	2.27	2.23	5.7 5.6-5.7	7.3 7-7.4	8.3 7.6-8.3	11.4 10.6-11.4
Head of Bay	Q-44	N 40.632402 W 73.756471	2.82	2.41	5.7 -	7.3 7.3-7.4	8.2 7.4-8.2	11.3 9.9-11.3
Jamaica Bay	Q-45	N 40.626856 W 73.775550	2.48	2.28	5.7 -	7.2 6.5-7.4	8.1 7.3-8.1	11 9.5-11
Jamaica Bay	Q-46	N 40.630490 W 73.783438	2.83	2.54	5.8 -	7.3 7.3-7.4	8.1 7.7-8.1	11.1 7.9-11.1
Jamaica Bay	Q-47	N 40.634532 W 73.791294	3.13	2.64	5.8 -	7.3 -	8.2 8-8.2	11 9.2-11

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Jamaica Bay	Q-48	N 40.638481 W 73.799361	3.27	2.74	5.8 -	7.3 -	8.2 7.9-8.2	11 7.8-11
Jamaica Bay	Q-49	N 40.641954 W 73.807004	3.47	2.82	5.8 -	7.3 -	8.2 -	11 9.8-11.1
Jamaica Bay	Q-50	N 40.645451 W 73.815218	3.39	2.73	5.8 -	7.3 -	8.2 -	10.9 9.9-10.9
Jamaica Bay	Q-51	N 40.648086 W 73.835104	2.79	2.56	5.8 5.8-6	7.4 7-7.5	8.2 7.9-8.3	10.8 10.4-11
Jamaica Bay	Q-52	N 40.644655 W 73.843198	3.16	2.64	5.9 5.9-6	7.4 7.1-8.1	8.2 7.9-8.2	10.8 10.4-11
Jamaica Bay	Q-53	N 40.650765 W 73.854350	2.63	2.42	5.9 -	7.5 7.5-8.1	8.3 7.9-8.3	10.9 10.6-11
East River	Q-54	N 40.741010 W 73.961831	2.66	2.48	6.1 5.8-6.1	7.9 7.1-7.9	8.8 8.1-8.8	12.1 11.5-12.1
East River	Q-55	N 40.744804 W 73.958734	2.20	2.25	6.1 6.1-6.2	7.9 7-7.9	8.9 8-8.9	12.1 10.9-12.1
East River	Q-56	N 40.749444 W 73.955923	2.13	2.23	6.1 6-6.1	7.9 7.1-8	8.9 7.7-9.1	12.1 10.3-12.3
East River	Q-57	N 40.790792 W 73.909040	2.21	2.23	9 8.9-9	10.7 10.4-11.1	11.3 11-11.3	12.7 12.4-12.7
East River	Q-58	N 40.788781 W 73.900060	2.04	2.31	9.1 -	10.8 10.8-11.6	11.4 11.4-11.5	12.9 12.9-13.2
East River	Q-59	N 40.783012 W 73.895900	2.18	2.36	9.1 9-9.1	10.8 10.5-11.5	11.4 11.2-11.4	13 13-13.2
East River	Q-60	N 40.779115 W 73.891502	1.90	2.44	9.1 -	10.8 10.8-11.2	11.4 11.3-11.4	13 12.9-13
Bowery Bay	Q-61	N 40.773964 W 73.886563	1.65	2.04	9.1 9.1-9.2	10.8 10.6-11.5	11.4 11.2-11.4	12.9 12.7-12.9
East River	Q-62	N 40.780091 W 73.884032	2.13	2.57	9.1 -	10.8 10.5-11.3	11.4 11.2-11.4	12.9 12.6-12.9
East River	Q-63	N 40.785453 W 73.870015	2.35	2.57	9.4 8.7-9.4	11.1 10.3-11.5	11.7 11.1-12	13.3 12.8-14.1

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Flushing Bay	Q-64	N 40.776960 W 73.865277	1.79	2.18	9.4 9.3-9.5	11.1 11.1-11.6	11.8 11.5-12.1	13.3 13.2-13.8
Flushing Bay	Q-65	N 40.773346 W 73.857673	1.80	2.13	9.4 9.1-9.4	11.1 11.1-11.7	11.7 11.4-12	13.3 13.3-13.9
Flushing Bay	Q-66	N 40.765428 W 73.861606	1.71	2.13	9.5 9.4-9.5	11.2 11.2-11.6	11.8 11.6-11.8	13.4 13.3-13.4
Flushing Bay	Q-67	N 40.760713 W 73.855522	1.83	2.18	9.5 -	11.1 11.1-11.5	11.7 11.5-11.7	13.3 13-13.3
Flushing Bay	Q-68	N 40.762636 W 73.844918	1.78	2.10	9.4 9.1-9.4	11.1 10.6-11.7	11.7 11-11.7	13.3 11.6-13.3
Flushing Bay	Q-69	N 40.772603 W 73.849560	1.78	2.12	9.4 -	11.1 10.1-11.4	11.7 10.9-11.7	13.3 12.2-13.3
Flushing Bay	Q-70	N 40.778912 W 73.849789	1.91	2.20	9.4 -	11.1 11.1-11.5	11.7 11.6-11.7	13.3 13.1-13.3
Flushing Bay	Q-71	N 40.782781 W 73.855419	1.66	2.10	9.4 9.4-9.5	11.1 10.9-11.1	11.7 11.4-11.7	13.3 13.1-13.3
East River	Q-72	N 40.786851 W 73.858353	2.40	2.54	9.4 -	11.1 10.7-11.1	11.7 11.4-11.7	13.2 12.8-13.2
East River	Q-73	N 40.789605 W 73.854575	2.30	2.49	9.4 -	11 -	11.7 -	13.2 13.2-13.3
East River	Q-74	N 40.794228 W 73.853197	2.58	2.68	9.4 -	11.1 -	11.7 -	13.2 13.2-13.9
East River	Q-75	N 40.794223 W 73.849052	2.07	2.22	9.4 -	11 11-11.1	11.7 -	13.2 -
East River	Q-76	N 40.795995 W 73.846778	2.72	2.75	9.4 -	11.1 -	11.7 -	13.2 -
East River	Q-77	N 40.796866 W 73.840234	2.47	2.58	9.4 9.4-9.5	11.1 11.1-11.2	11.7 11.6-11.8	13.2 13.2-13.5
East River	Q-78	N 40.792646 W 73.836711	1.96	2.29	9.5 -	11.1 11.1-11.4	11.7 11.6-11.7	13.3 -
East River	Q-79	N 40.788656 W 73.832370	1.71	2.20	9.5 -	11.1 10.9-11.1	11.7 11.5-11.7	13.3 13.2-13.3

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
East River	Q-80	N 40.792125 W 73.828807	1.69	2.11	9.4 -	11.1 -	11.7 -	13.2 -
East River	Q-81	N 40.796754 W 73.827758	2.49	2.43	9.4 -	11.1 -	11.7 -	13.2 -
East River	Q-82	N 40.800467 W 73.820914	2.43	2.50	9.4 -	11 -	11.6 -	13.1 -
East River	Q-83	N 40.798011 W 73.814756	2.62	2.71	9.4 -	11.1 -	11.7 -	13.2 -
East River	Q-84	N 40.796555 W 73.807127	2.45	2.66	9.4 -	11.1 -	11.7 11.6-11.7	13.2 13.1-13.2
East River	Q-85	N 40.795622 W 73.798051	3.16	3.11	9.5 -	11.1 -	11.7 11.7-11.8	13.2 -
Little Bay	Q-86	N 40.792174 W 73.794948	3.30	3.21	9.5 9.4-9.5	11.2 11-11.2	11.8 11.7-11.8	13.4 13.2-13.4
Little Bay	Q-87	N 40.790352 W 73.788610	3.69	3.27	9.5 -	11.1 10.9-11.2	11.7 11.6-11.7	13.3 13.2-13.3
Little Bay	Q-88	N 40.792818 W 73.780787	2.92	3.10	9.5 -	11.1 -	11.7 -	13.3 -
Little Neck Bay	Q-89	N 40.796678 W 73.779399	3.83	3.14	9.5 9.5-9.6	11.1 -	11.7 11.7-11.8	13.3 -
Little Neck Bay	Q-90	N 40.793805 W 73.774072	3.16	2.94	9.5 -	11.1 -	11.7 11.7-11.8	13.3 -
Little Neck Bay	Q-91	N 40.789138 W 73.771231	2.90	2.71	9.5 -	11.1 11-11.7	11.7 11.6-11.7	13.3 13.2-13.4
Little Neck Bay	Q-92	N 40.782543 W 73.771118	2.95	2.76	9.5 -	11.1 11.1-11.8	11.7 11.7-11.9	13.3 13.3-13.5
Little Neck Bay	Q-93	N 40.777313 W 73.767301	2.70	2.65	9.5 -	11.1 -	11.7 -	13.3 -
Little Neck Bay	Q-94	N 40.771976 W 73.763192	2.14	2.38	9.5 -	11.1 10.8-11.1	11.7 11.5-11.7	13.3 13.2-13.4
Little Neck Bay	Q-95	N 40.766360 W 73.756074	1.83	2.20	9.5 9.4-9.5	11.1 10.4-11.5	11.7 11.1-11.7	13.4 12.9-13.5

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Little Neck Bay	Q-96	N 40.769218 W 73.754705	1.82	2.26	9.5 -	11.1 10.9-11.1	11.7 11.5-11.7	13.4 13.2-13.4
Little Neck Bay	Q-97	N 40.772355 W 73.753746	2.65	2.61	9.5 -	11.1 10.9-11.1	11.7 11.5-11.7	13.3 13.2-13.3
Little Neck Bay	Q-98	N 40.778121 W 73.754360	2.70	2.65	9.5 -	11.1 -	11.7 -	13.3 13.2-13.3
Little Neck Bay	Q-99	N 40.782501 W 73.751333	2.16	2.38	9.5 -	11.1 -	11.7 -	13.3 -
Little Neck Bay	Q-100	N 40.780487 W 73.748058	1.61	2.10	9.5 -	11 10.8-11	11.6 11.4-11.6	13.3 13.1-13.3
Little Neck Bay	Q-101	N 40.780321 W 73.746834	1.65	2.11	9.5 -	11 10.8-11.5	11.6 11.4-11.6	13.3 13.1-13.3

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Richmond County, New York								
Lower New York Bay	R-1	N 40.647928 W 74.078417	5.04	3.68	6.3 -	8.2 -	9.4 9.1-9.4	12.7 12.6-12.7
Lower New York Bay	R-2	N 40.643297 W 74.071423	5.31	3.91	6.3 -	8.2 -	9.3 -	12.6 12.5-12.6
Lower New York Bay	R-3	N 40.635432 W 74.073159	5.50	3.99	6.3 -	8.2 7.9-8.2	9.3 9.1-9.3	12.7 12.7-12.9
Lower New York Bay	R-4	N 40.627468 W 74.072360	5.54	4.17	6.3 -	8.2 8.1-8.2	9.3 9.2-9.4	12.6 12.6-12.8
Lower New York Bay	R-5	N 40.620604 W 74.068853	5.52	4.15	6.3 -	8.2 8.1-8.6	9.3 9.3-9.4	12.6 12.6-12.7
Lower New York Bay	R-6	N 40.615459 W 74.062568	5.66	4.20	6.3 -	8.2 -	9.2 -	12.5 -
Lower New York Bay	R-7	N 40.611680 W 74.059456	5.45	3.89	6.2 -	8.1 -	9.2 -	12.5 12.4-12.5
Lower New York Bay	R-8	N 40.605653 W 74.053732	5.81	3.99	6.2 -	8.1 8.1-8.8	9.2 -	12.4 12.3-12.4
Lower New York Bay	R-9	N 40.598287 W 74.055109	6.04	4.23	6.3 -	8.1 8-8.1	9.2 9-9.2	12.4 12.4-12.5
Lower New York Bay	R-10	N 40.593355 W 74.060615	6.34	4.40	6.3 -	8.2 8.2-8.8	9.3 9.3-9.5	12.7 12.7-13.1
Lower New York Bay	R-11	N 40.587474 W 74.066428	6.34	4.76	6.3 -	8.3 8.1-8.5	9.4 9.4-9.7	12.8 12.8-13.3
Lower New York Bay	R-12	N 40.581523 W 74.072310	6.63	4.87	6.3 -	8.3 8.1-8.4	9.4 9.2-9.6	12.8 12.8-13.5
Lower New York Bay	R-13	N 40.575897 W 74.078931	6.95	5.10	6.4 6.3-6.4	8.3 7.7-8.5	9.4 8.8-9.5	12.9 12.9-13.7
Lower New York Bay	R-14	N 40.570726 W 74.085542	7.22	5.17	6.5 6.4-6.5	8.4 7.8-8.6	9.6 9.1-9.8	13.1 13.1-13.9
Lower New York Bay	R-15	N 40.565630 W 74.092032	7.23	5.30	6.4 6.2-6.4	8.4 7.9-8.6	9.6 9.5-9.7	13.1 13.1-13.8

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		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Raritan Bay	R-16	N 40.560017 W 74.097971	6.90	5.24	6.5 -	8.5 8.4-8.5	9.7 9.7-9.9	13.2 13.2-13.8
Raritan Bay	R-17	N 40.554569 W 74.104308	6.77	5.37	6.6 5.8-6.6	8.6 8.5-8.7	9.7 9.7-9.9	13.2 13.2-13.8
Raritan Bay	R-18	N 40.550606 W 74.110940	6.44	5.44	6.6 -	8.6 8.5-8.8	9.7 9.6-9.8	13.3 13.3-13.9
Raritan Bay	R-19	N 40.547211 W 74.118255	6.06	5.61	6.6 6.5-6.8	8.6 8.5-8.7	9.8 9.6-9.9	13.3 13-14
Raritan Bay	R-20	N 40.542278 W 74.124885	6.07	5.63	6.6 -	8.6 -	9.8 -	13.4 -
Raritan Bay	R-21	N 40.536754 W 74.128999	6.05	5.51	6.7 -	8.7 -	9.9 9.7-9.9	13.4 13.3-13.4
Raritan Bay	R-22	N 40.530708 W 74.134748	6.42	5.44	6.6 6.6-6.7	8.6 -	9.8 9.6-9.8	13.4 13.4-13.7
Raritan Bay	R-23	N 40.533872 W 74.140535	4.51	4.49	6.6 -	8.7 -	9.9 9.8-9.9	13.6 -
Great Kills Harbor	R-24	N 40.537078 W 74.132095	2.13	2.23	6.6 -	8.6 -	9.9 -	13.6 -
Great Kills Harbor	R-25	N 40.544967 W 74.128942	1.84	2.10	6.6 -	8.6 -	9.9 -	13.6 13.5-13.9
Great Kills Harbor	R-26	N 40.545236 W 74.138461	1.93	2.15	6.6 6.5-6.6	8.7 8.6-8.7	9.9 9.8-9.9	13.7 -
Raritan Bay	R-27	N 40.536842 W 74.144047	4.58	4.57	6.7 6.6-6.7	8.7 -	9.9 9.9-10	13.6 13.6-13.8
Raritan Bay	R-28	N 40.532775 W 74.150388	5.50	5.24	6.7 -	8.8 -	10 10-10.1	13.6 13.6-14
Raritan Bay	R-29	N 40.528419 W 74.157873	5.63	5.00	6.8 -	8.8 -	10 -	13.7 -
Raritan Bay	R-30	N 40.525471 W 74.165748	6.32	5.27	6.8 -	8.8 -	10.1 -	13.7 -
Raritan Bay	R-31	N 40.521914 W 74.174300	6.13	5.05	6.8 -	8.9 -	10.1 -	13.8 -

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Raritan Bay	R-32	N 40.519829 W 74.183611	6.61	5.22	6.8 -	8.9 -	10.1 -	13.9 -
Raritan Bay	R-33	N 40.514262 W 74.190726	6.52	5.02	6.9 6.8-6.9	9 -	10.2 10.1-10.2	13.9 13.9-14.5
Raritan Bay	R-34	N 40.510220 W 74.194769	5.16	4.06	6.9 6.7-6.9	9 8.9-9	10.2 10.1-10.5	13.9 13.7-14.4
Raritan Bay	R-35	N 40.511679 W 74.208054	4.71	3.89	7 -	9.1 -	10.3 -	14 -
Raritan Bay	R-36	N 40.502497 W 74.222385	7.06	4.89	7.1 6-7.2	9.2 -	10.4 10.2-10.4	14.1 14-14.2
Raritan Bay	R-37	N 40.501746 W 74.231526	5.41	4.30	7.1 -	9.2 -	10.5 -	14.2 -
Raritan Bay	R-38	N 40.497605 W 74.240883	5.13	4.25	7.1 6.9-7.7	9.3 -	10.5 10.5-10.7	14.2 14.2-14.5
Raritan Bay	R-39	N 40.497433 W 74.250294	4.09	3.47	7.2 5.8-7.3	9.4 9.3-9.4	10.6 10.5-10.6	14.2 14.2-14.4
Arthur Kill	R-40	N 40.508668 W 74.254714	2.55	2.76	7.2 -	9.3 -	10.5 -	13.9 -
Arthur Kill	R-41	N 40.516106 W 74.248753	2.37	2.72	7.2 -	9.3 9.2-9.3	10.5 10.4-10.5	13.8 13.7-13.8
Arthur Kill	R-42	N 40.519839 W 74.240138	2.57	2.80	7.1 6.4-7.1	9.3 -	10.4 9.9-10.4	13.9 13.6-14.2
Arthur Kill	R-43	N 40.533052 W 74.242277	2.77	2.89	7.1 -	9.2 -	10.4 10-10.4	13.7 13.5-13.7
Arthur Kill	R-44	N 40.546489 W 74.245113	2.33	2.61	7.1 -	9.2 9.1-9.2	10.3 10.1-10.3	13.3 13.2-13.3
Arthur Kill	R-45	N 40.556223 W 74.225917	2.08	2.27	7 6.9-7.5	9 8.5-9	10.1 9.8-10.1	13.1 13.1-13.6
Arthur Kill	R-46	N 40.576712 W 74.206661	2.00	2.16	6.8 6.7-6.8	8.8 8.6-10.1	9.8 9.4-9.8	12.5 12.1-12.5
Arthur Kill	R-47	N 40.596065 W 74.198014	2.26	2.31	6.7 6.6-7.2	8.7 7.8-9	9.7 9.1-9.7	12.2 11.8-12.2

[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

TRANSECT DATA TABLE

Flood Source	Transect	Starting Wave Conditions for the 1% Annual Chance			Starting Stillwater Elevations[1] (feet NAVD88) Range of Stillwater Elevations[2] (feet NAVD88)			
		Coordinates	Significant Wave Height (feet)	Peak Wave Period (seconds)	10% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Arthur Kill/ Pralls River	R-48	N 40.611746 W 74.202226	2.41	2.31	6.6 6.5-6.8	8.6 7.6-9.1	9.5 8.7-9.5	11.9 11.2-11.9
Arthur Kill	R-49	N 40.629270 W 74.200964	1.93	2.18	6.6 6-6.6	8.5 7.3-8.9	9.4 8.4-10	11.7 10.5-11.7
Newark Bay	R-50	N 40.644615 W 74.173481	2.84	2.58	6.3 6.2-6.4	8.1 7.7-8.4	8.9 8.7-8.9	11.1 10.7-11.2
Newark Bay	R-51	N 40.641895 W 74.168219	3.21	2.62	6.3 -	8.1 7.9-8.1	8.9 8.8-8.9	11.1 -
Newark Bay	R-52	N 40.637944 W 74.157896	3.19	2.79	6.3 6.3-6.7	8 7.9-8	8.9 8.5-8.9	11 10.8-11
Newark Bay	R-53	N 40.638943 W 74.148219	3.00	2.65	6.2 6-6.2	8 7.9-8	8.8 8.6-8.8	11 10.7-11.1
Kill Van Kull	R-54	N 40.640911 W 74.138589	2.18	2.39	6.2 -	8 -	8.8 8.6-8.8	11 10.7-11
Kill Van Kull	R-55	N 40.640142 W 74.127786	2.09	2.13	6.3 6.2-6.7	8.1 -	9 8.9-9	11.5 11-11.5
Kill Van Kull	R-56	N 40.641811 W 74.117989	2.18	2.26	6.3 6.3-6.4	8.1 -	9.1 8.7-9.1	11.8 11.6-11.8
Kill Van Kull	R-57	N 40.645573 W 74.106734	3.98	3.89	6.3 6.1-6.3	8.1 7.4-8.2	9.1 -	11.8 -
Kill Van Kull	R-58	N 40.645431 W 74.095429	2.30	2.70	6.3 -	8.2 -	9.2 -	12.1 -
Kill Van Kull	R-59	N 40.648563 W 74.086878	3.11	2.90	6.3 -	8.2 -	9.3 -	12.3 -

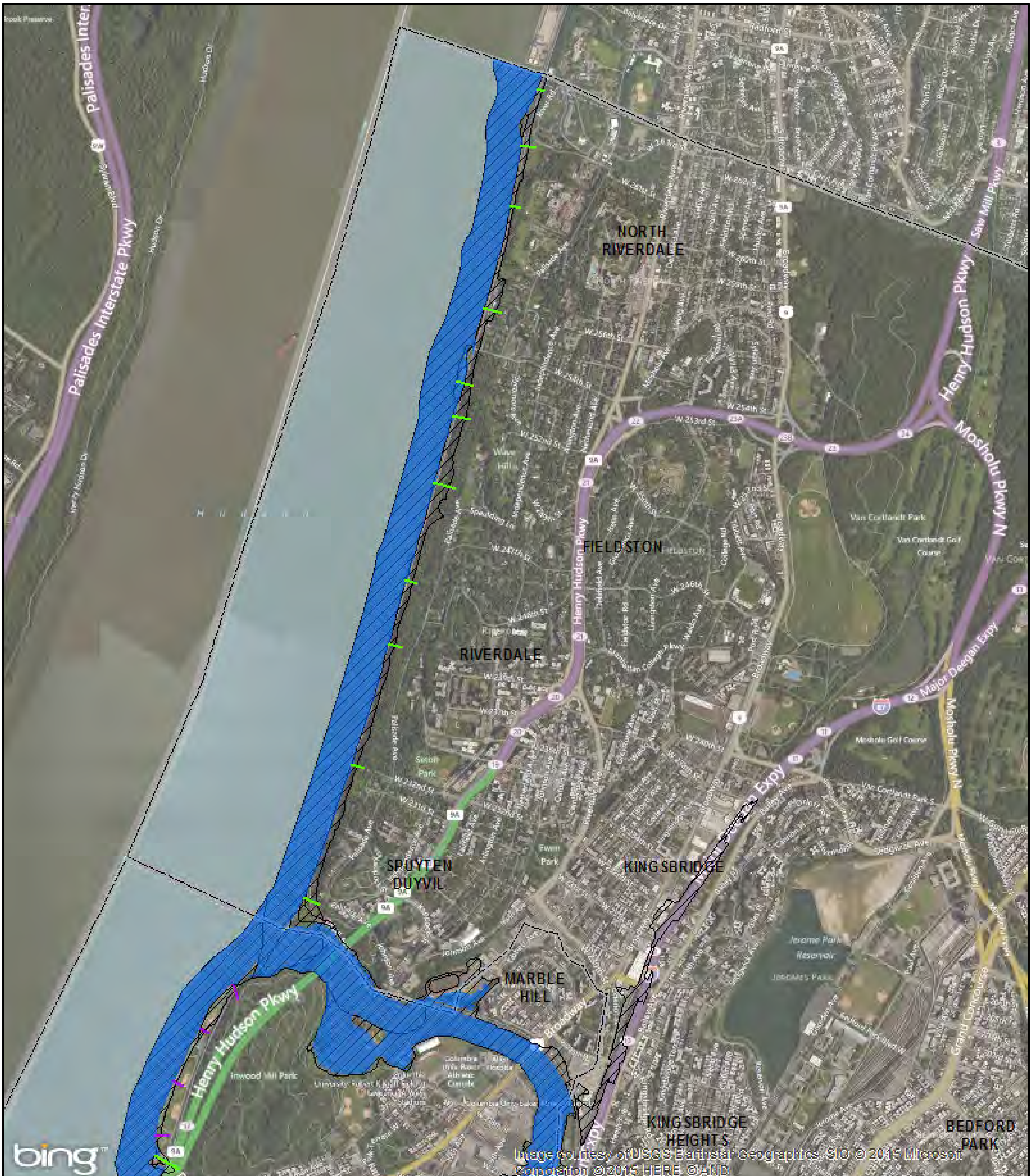
[1]Stillwater elevations include the contribution from wave setup.

[2]For transects with a constant stillwater elevation, only one number is provided to represent both the starting value and the range. Ranges from FEMA's PFIRM analysis (FEMA 2013) are applied here to define the range of the City's revised starting stillwater elevations.

APPENDIX D

REVISED SFHA BOUNDARIES

The following figures represent the approximate SFHA boundaries for New York City based on the projection of 1-percent-annual-chance stillwater elevations from the waterfront inland. Variation in stillwater elevations overland, wave runup, erosion, and primary frontal dune considerations are not included in the SFHA boundaries depicted.



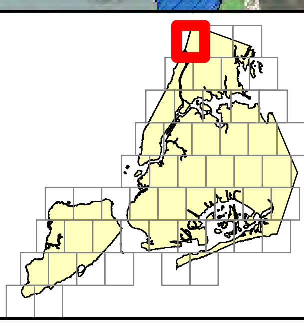
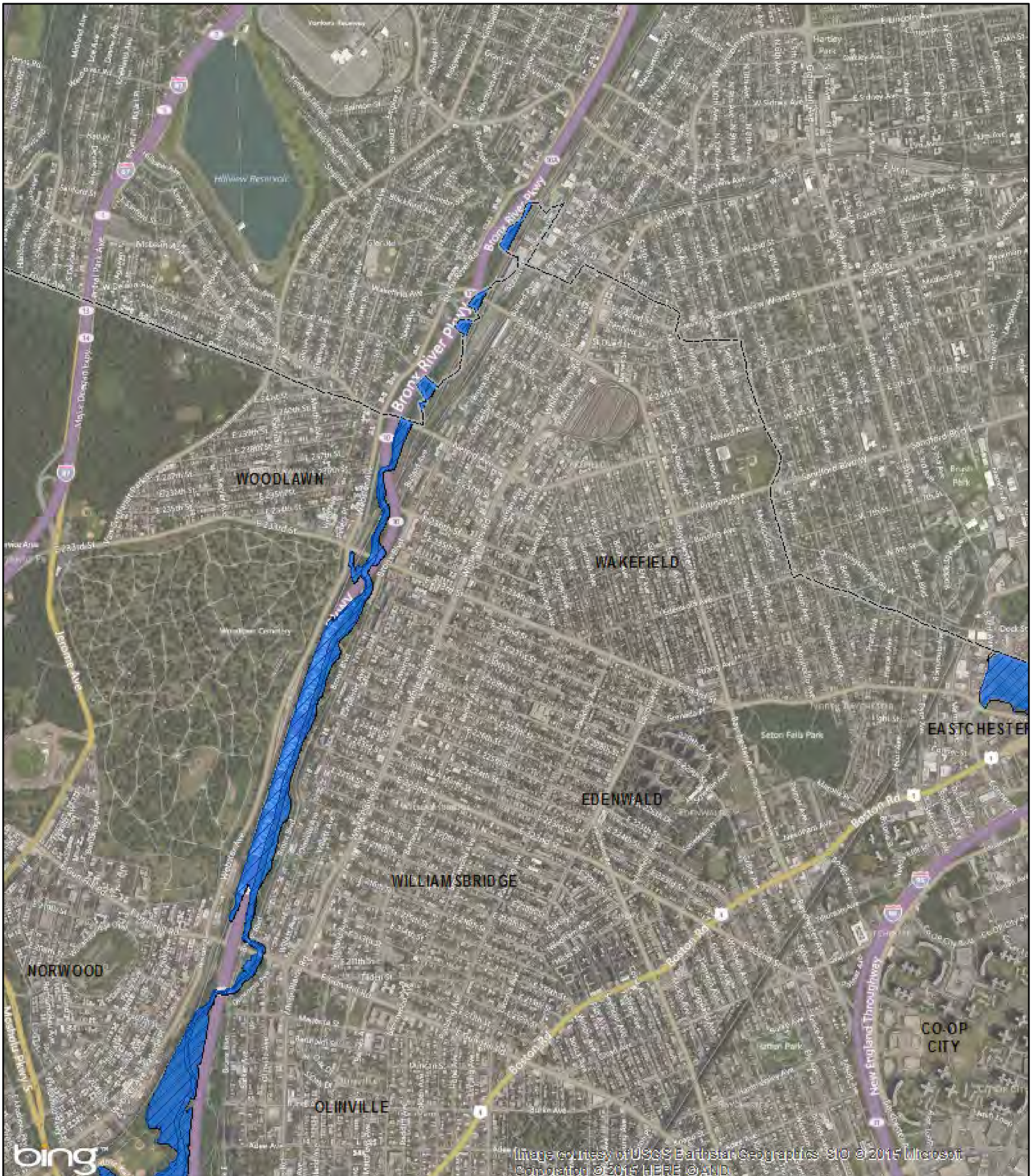
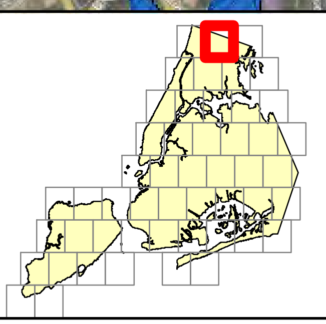


Figure D-1

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

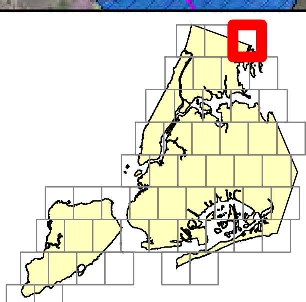
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-2

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

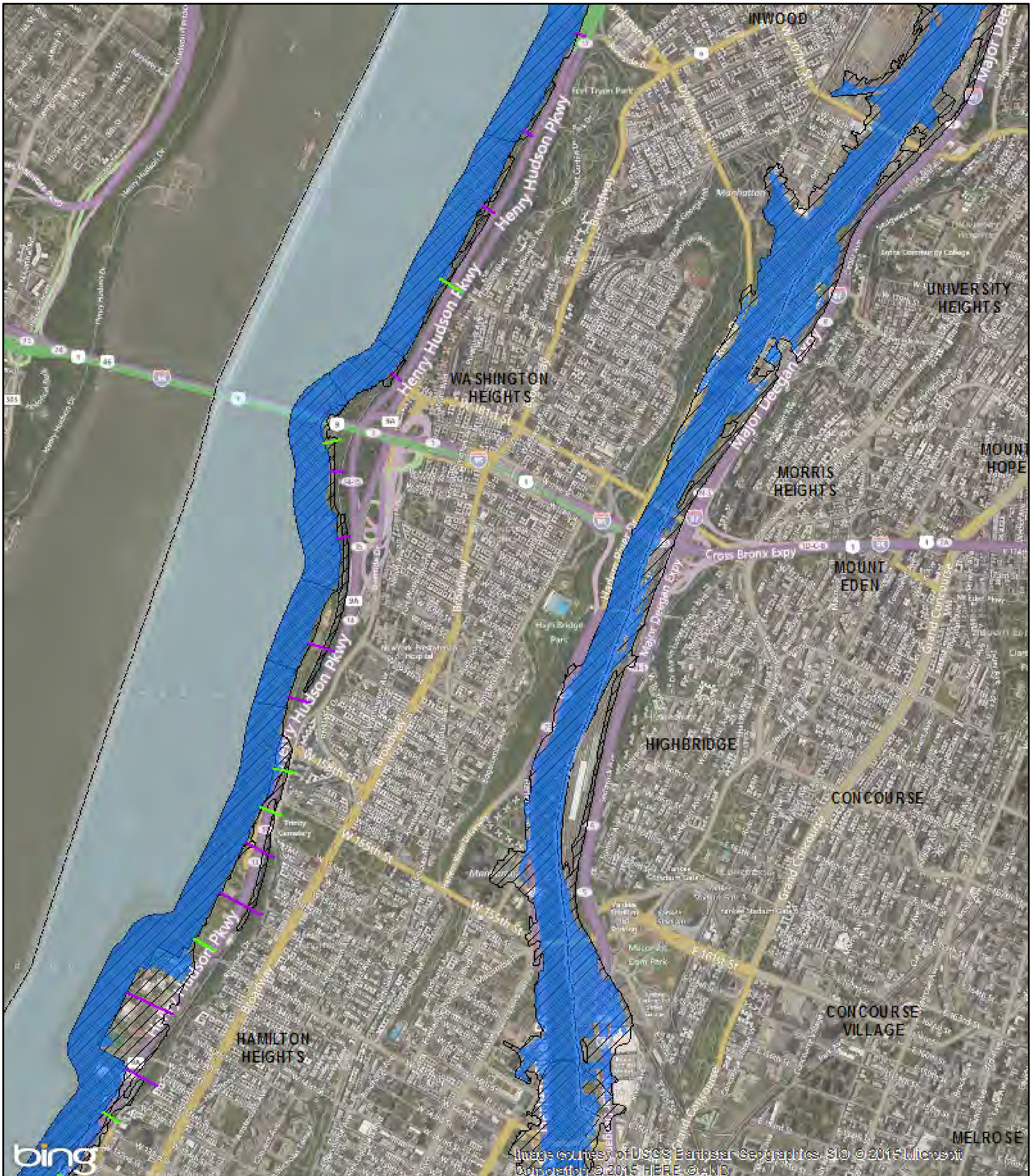
Erosion Only

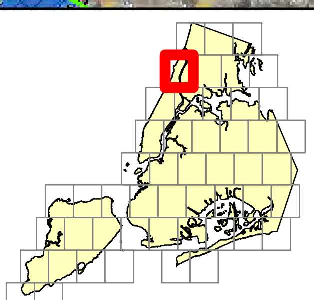
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-3

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

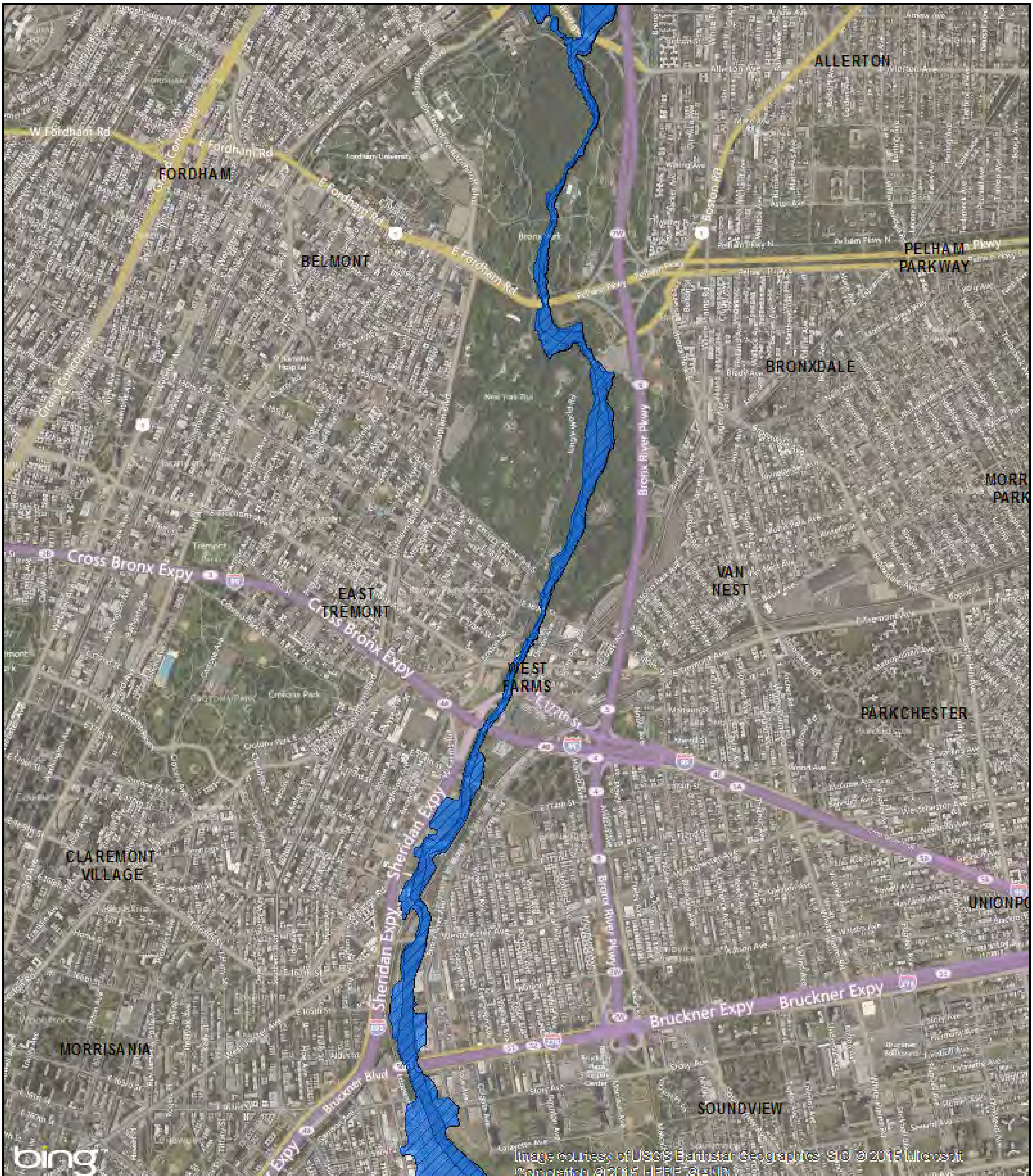
Erosion Only

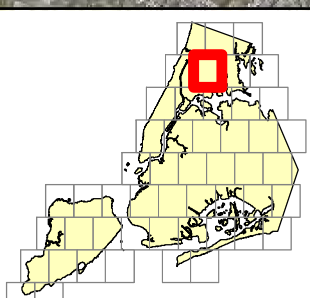
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-4

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

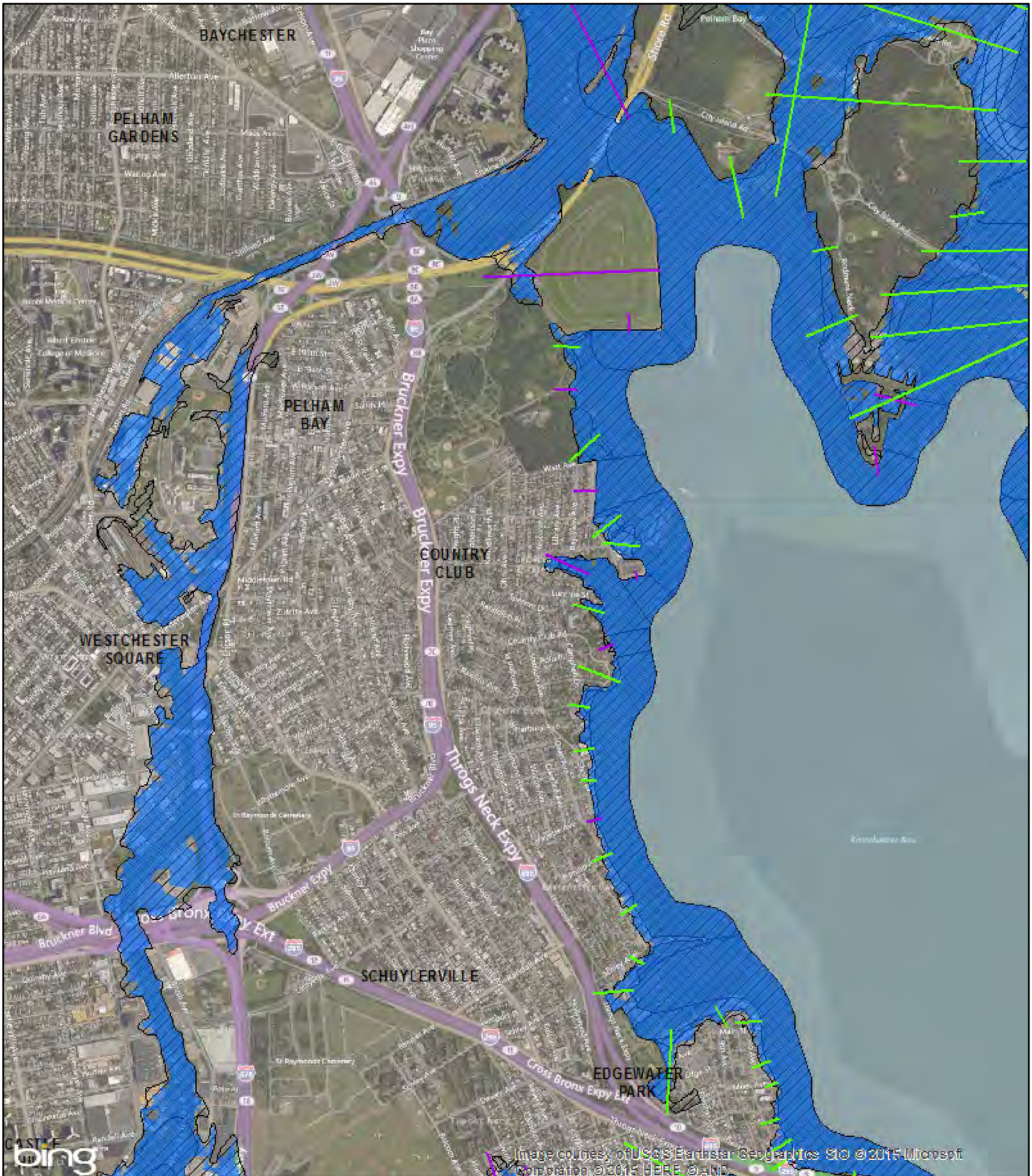
Erosion Only

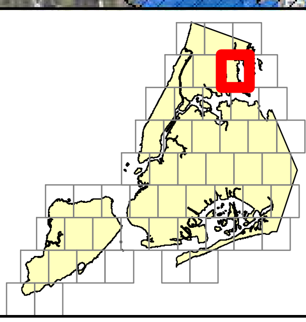
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-5

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

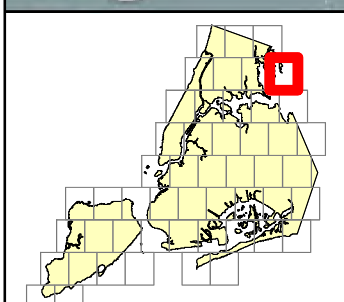
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-6

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

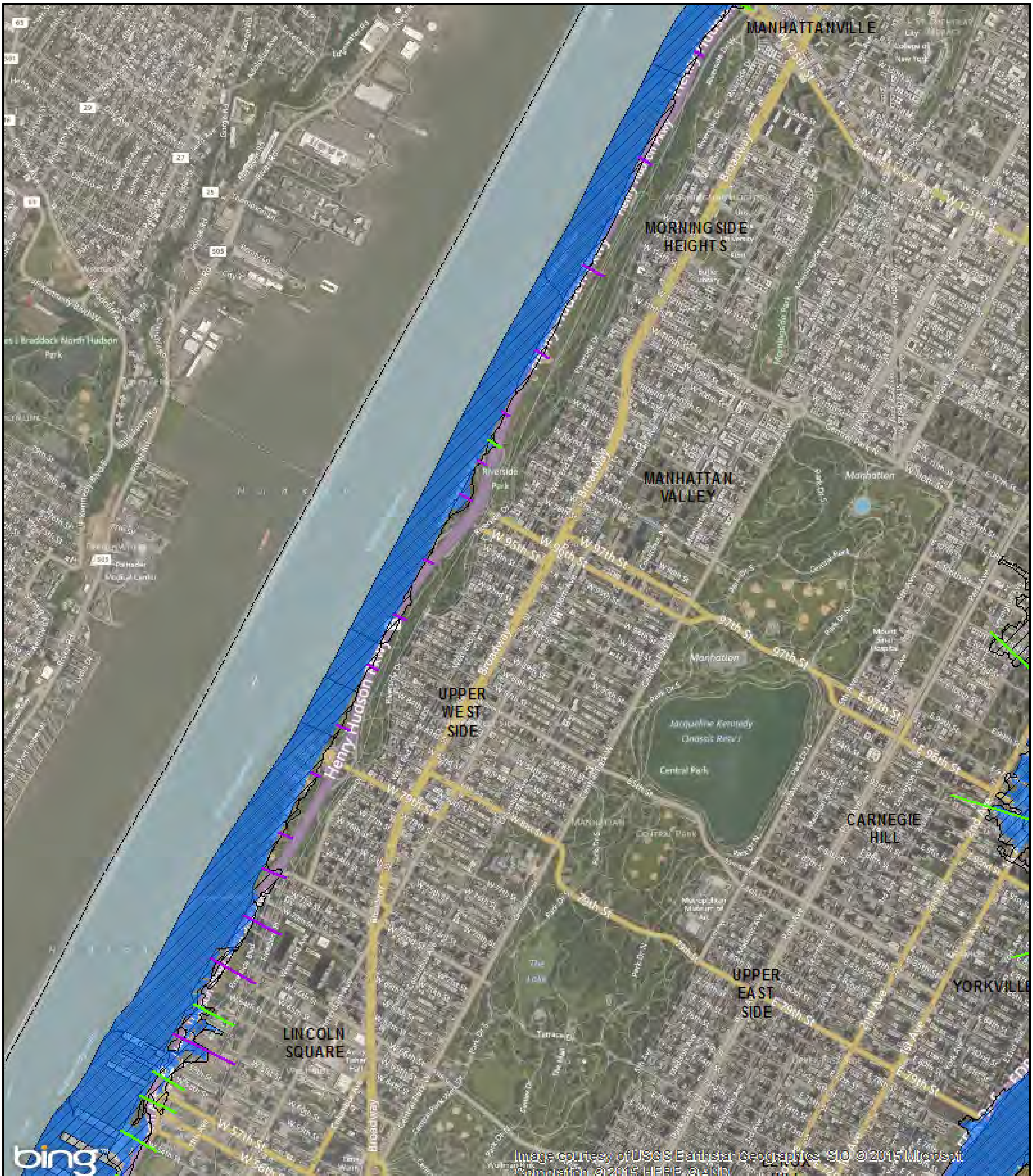
Erosion Only

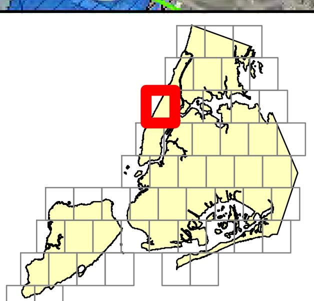
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-7

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

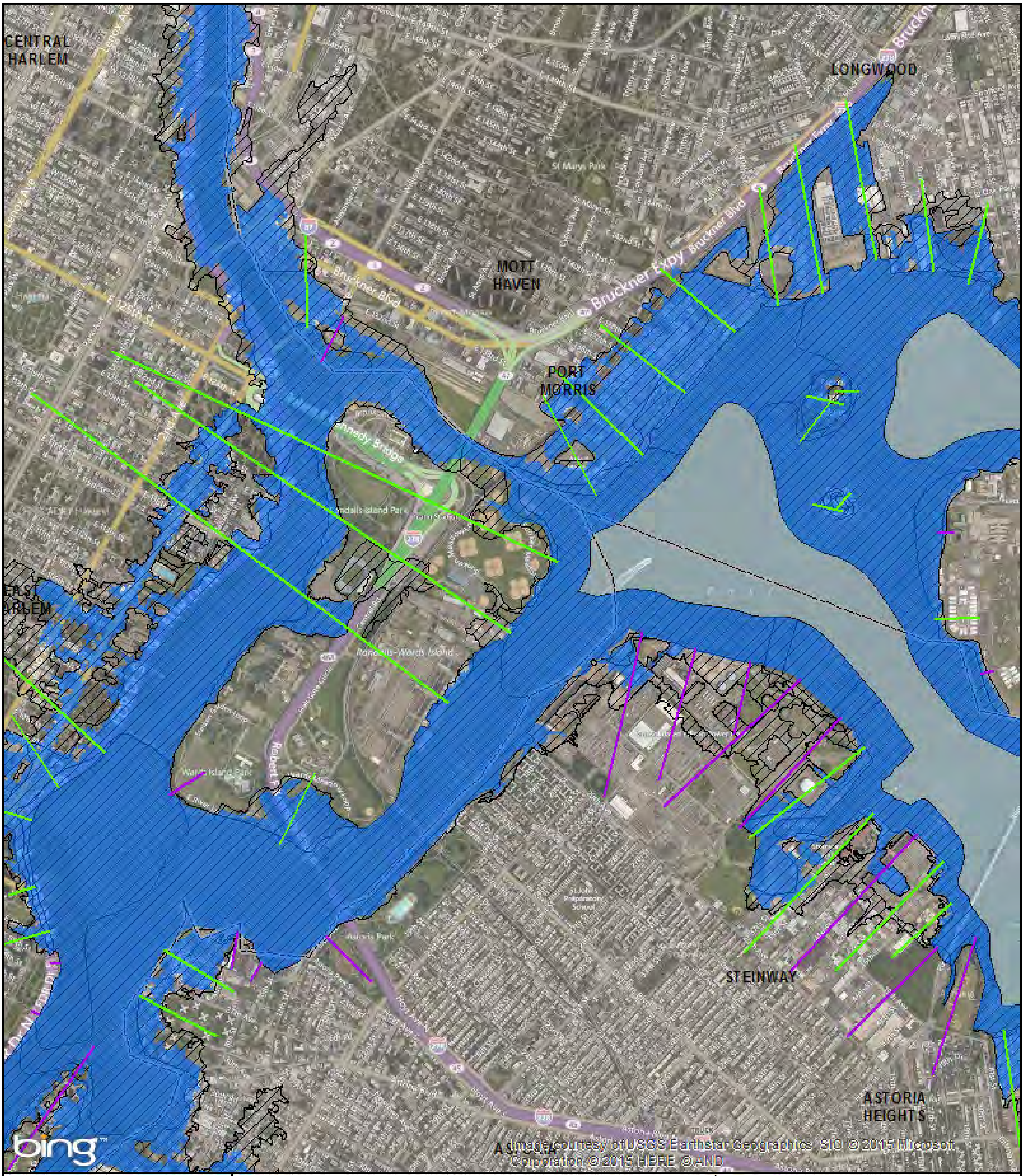
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-8

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

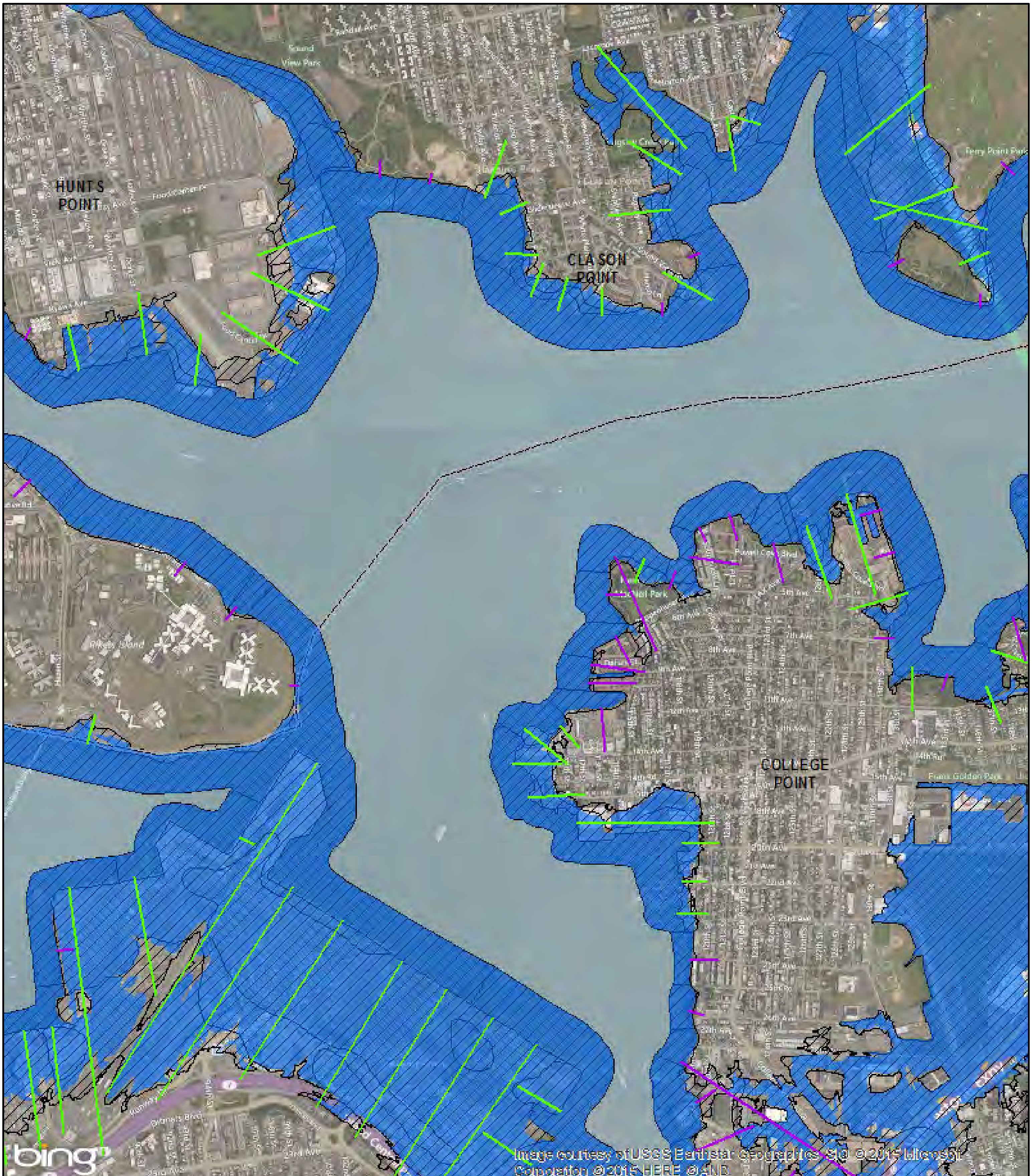
Erosion Only

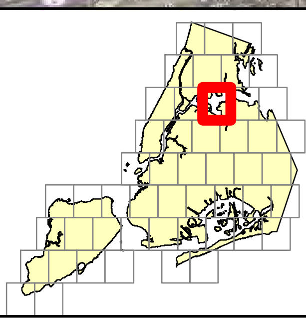
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-9

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

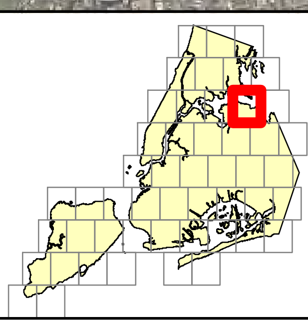
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-10

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

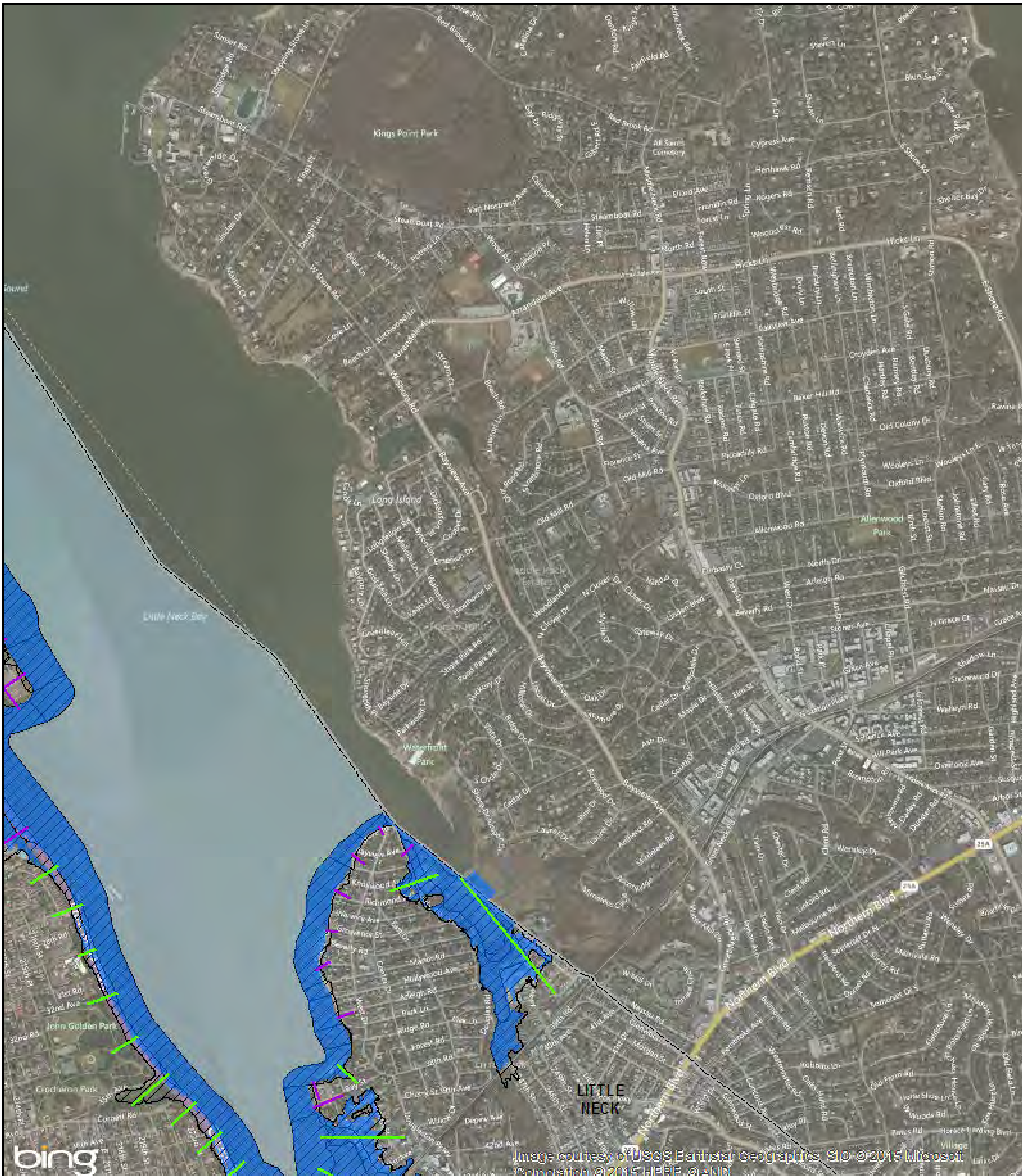
Erosion Only

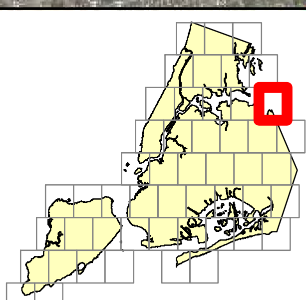
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-11

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-12

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation

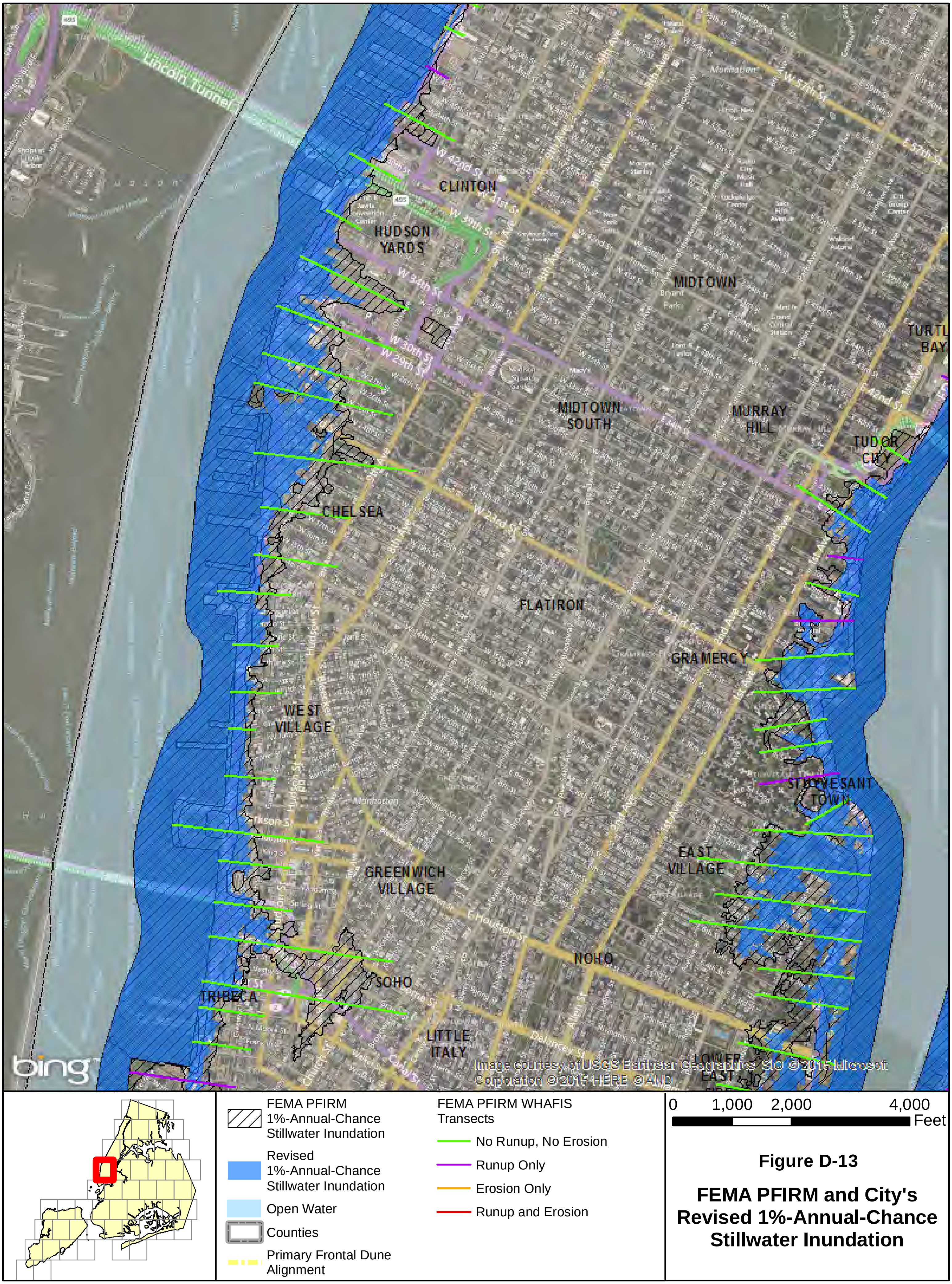
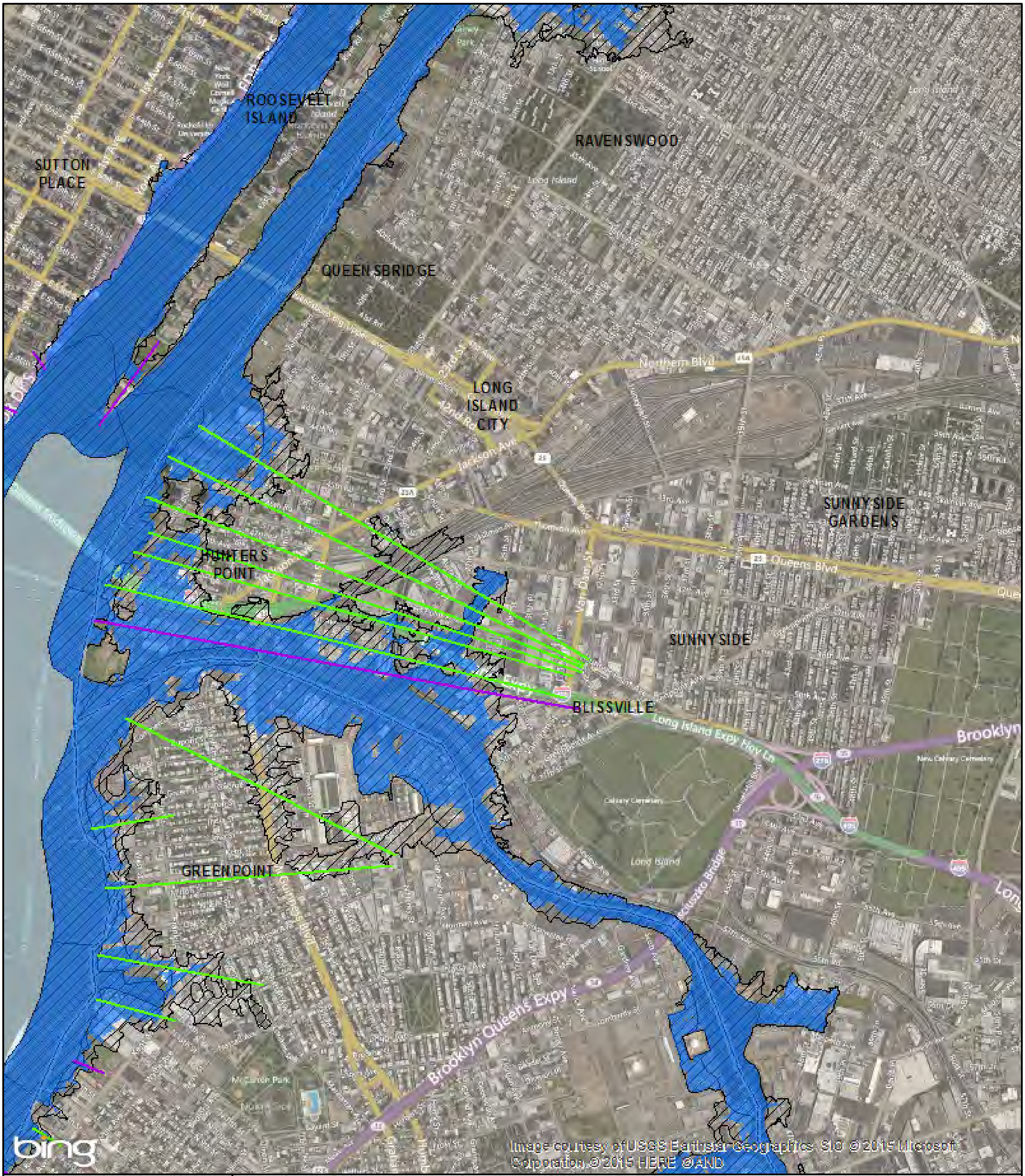
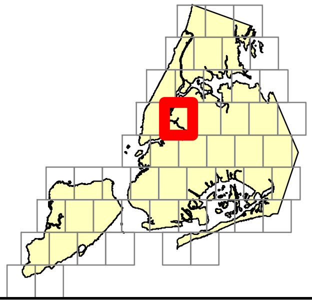


Figure D-13

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

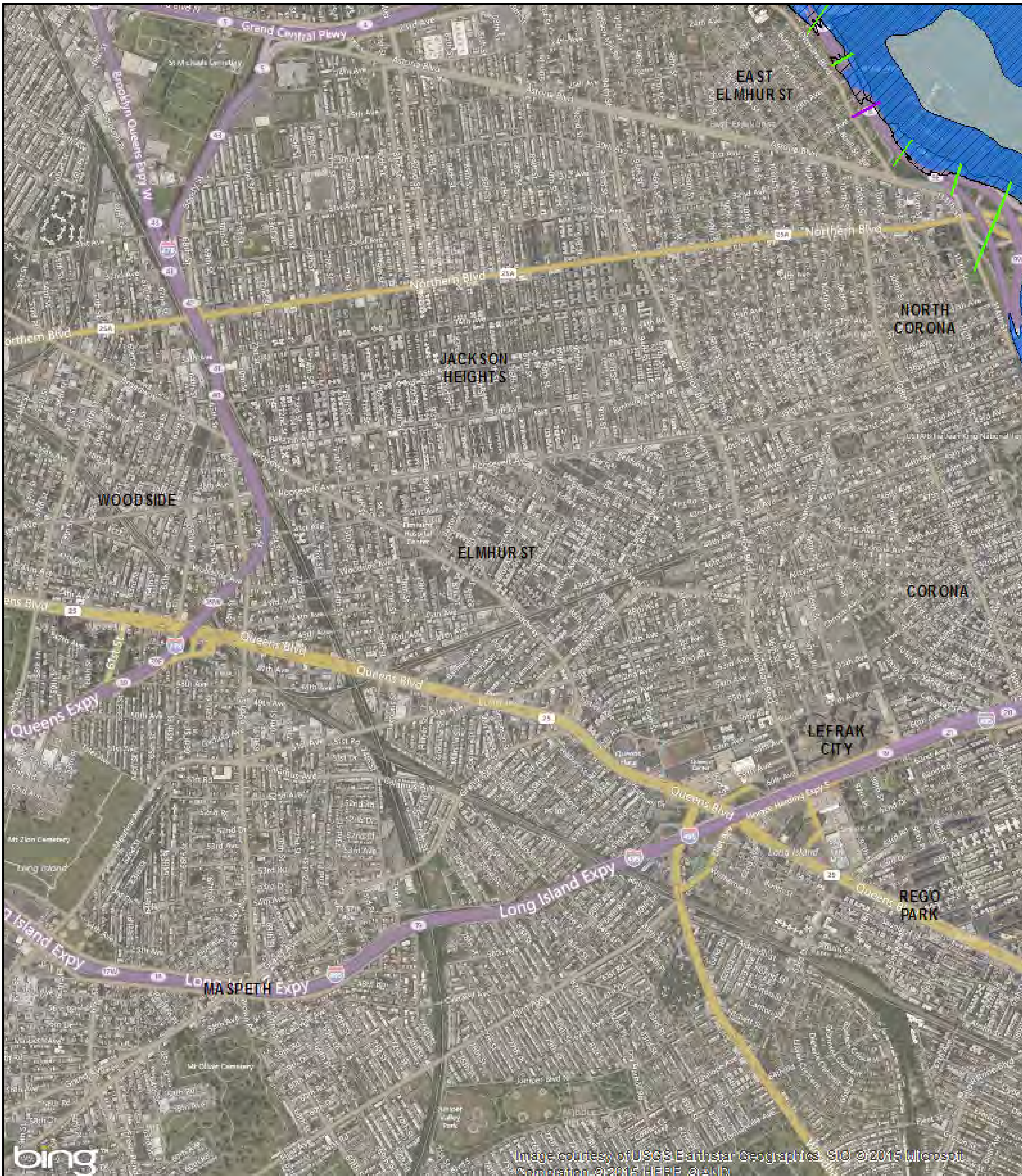
Erosion Only

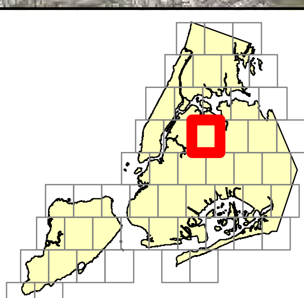
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-14

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

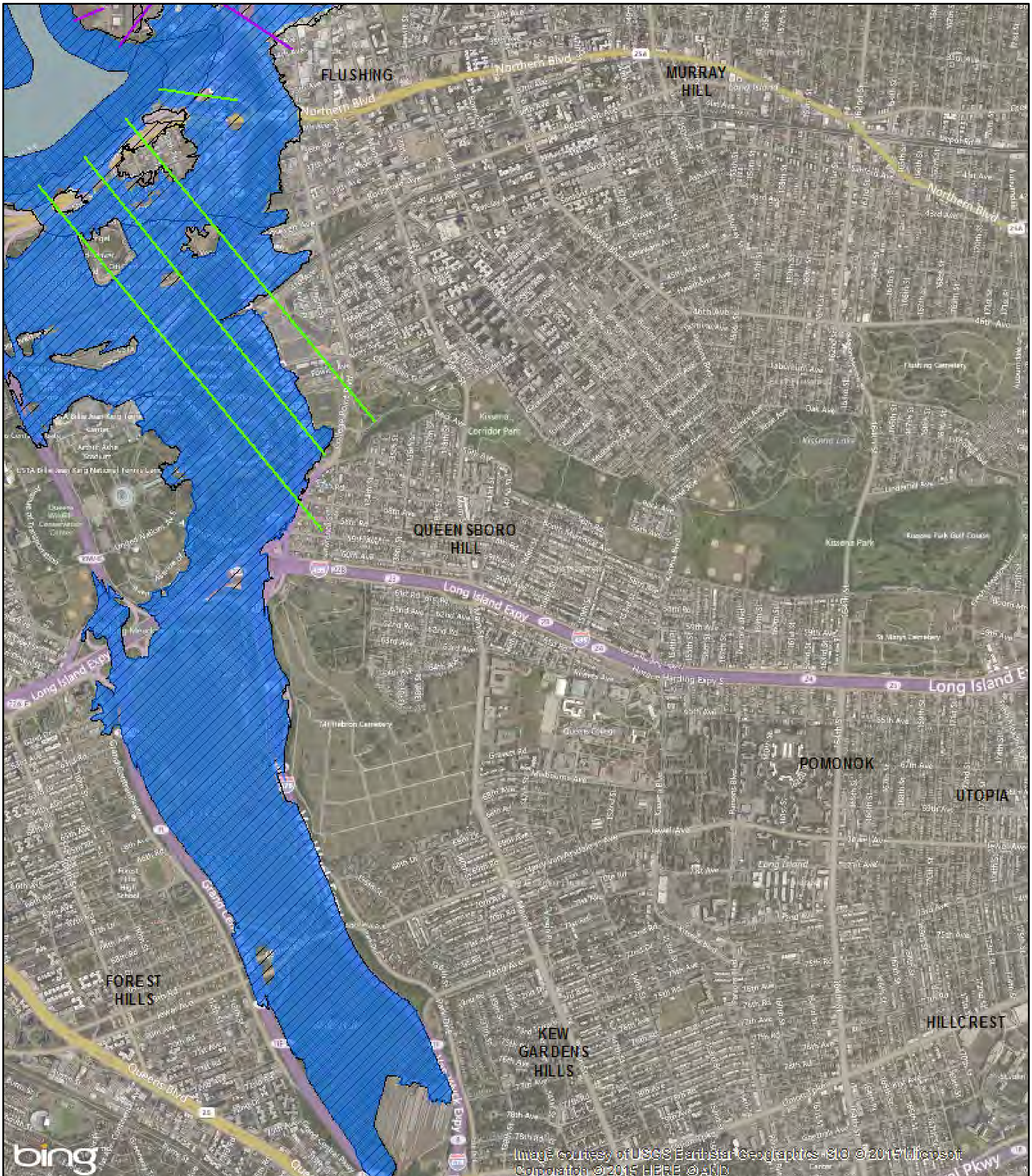
Erosion Only

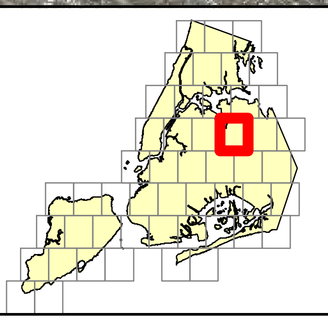
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-15

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

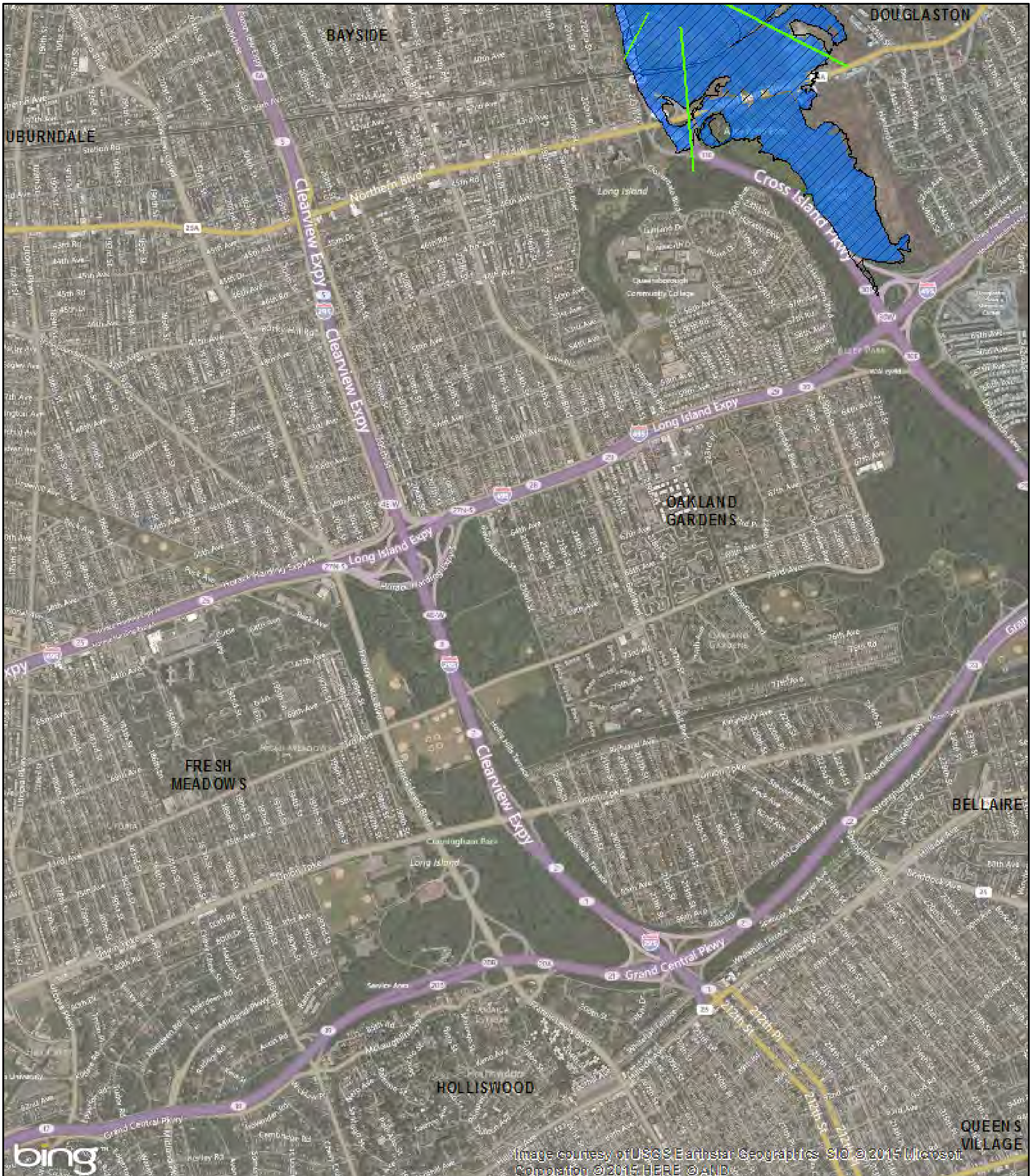
Erosion Only

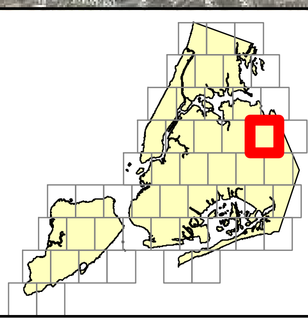
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-16

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

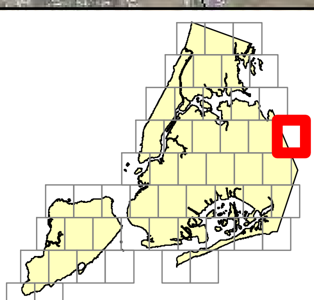
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-17

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

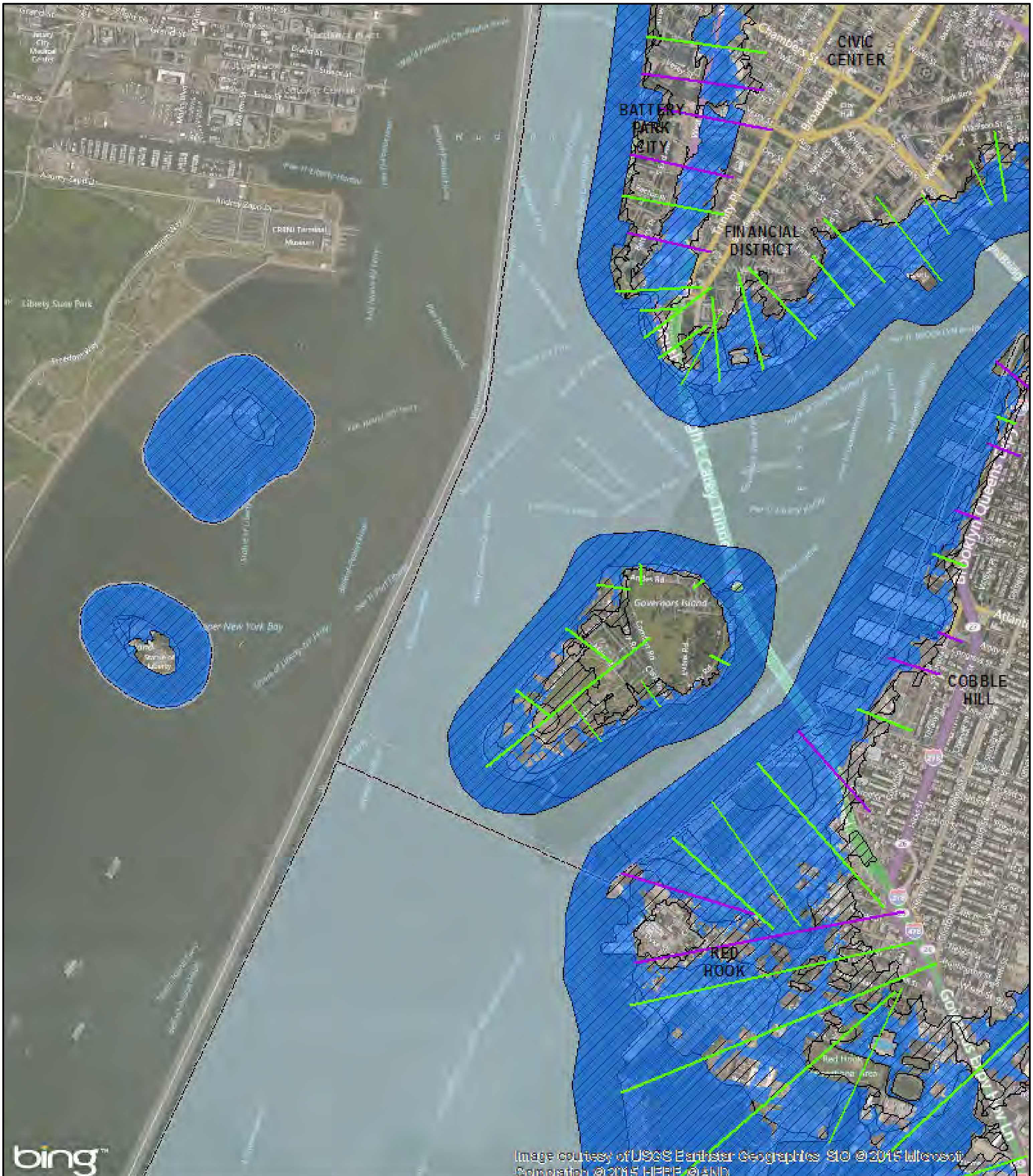
Erosion Only

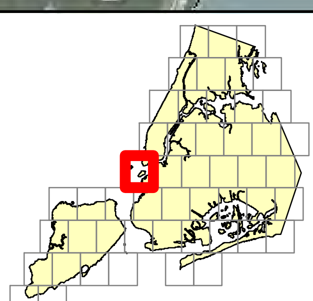
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-18

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

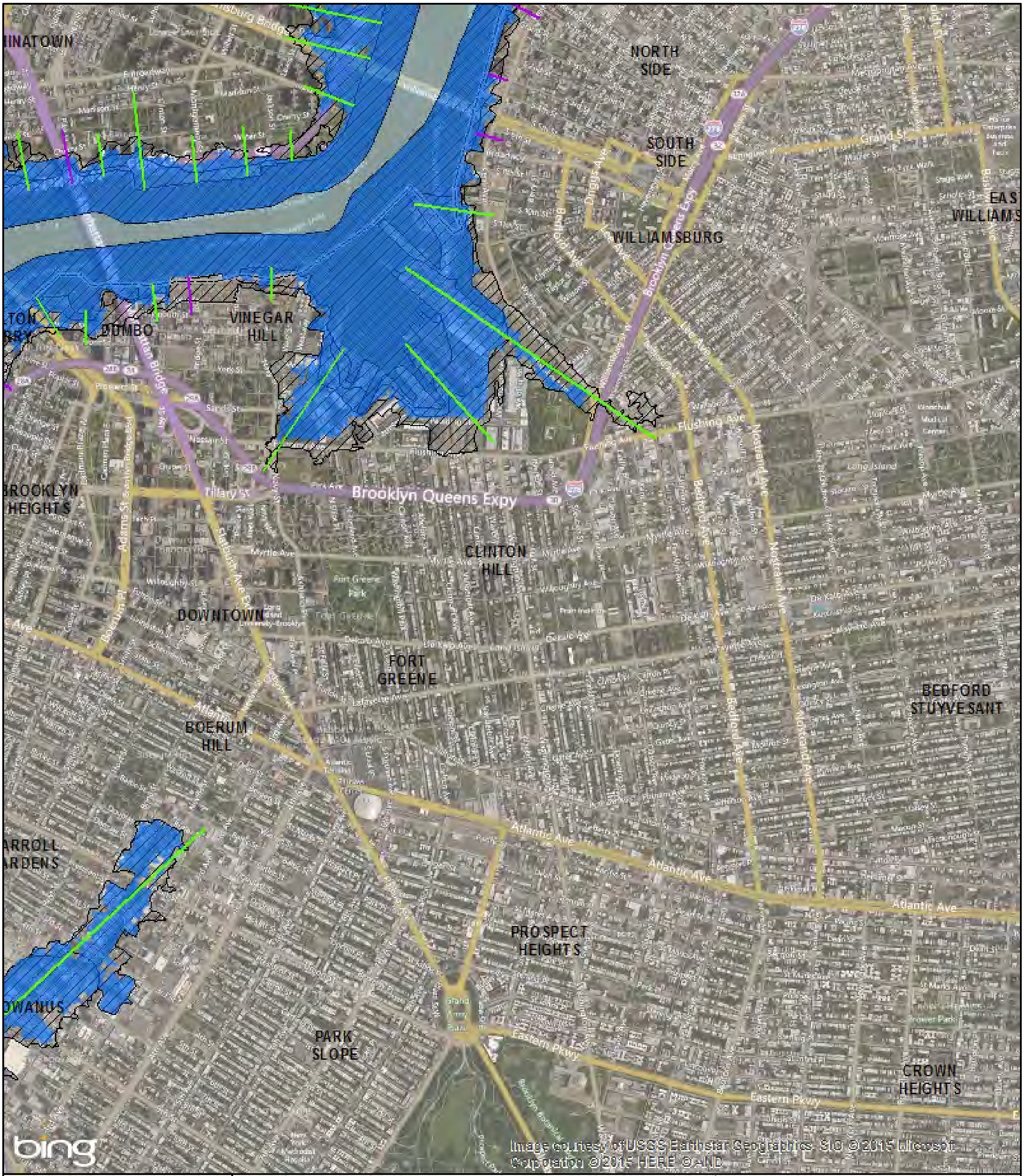
Erosion Only

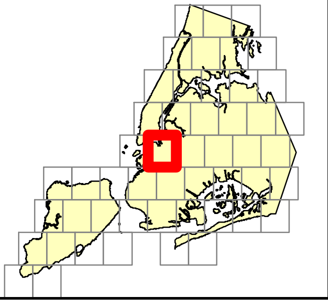
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-19

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

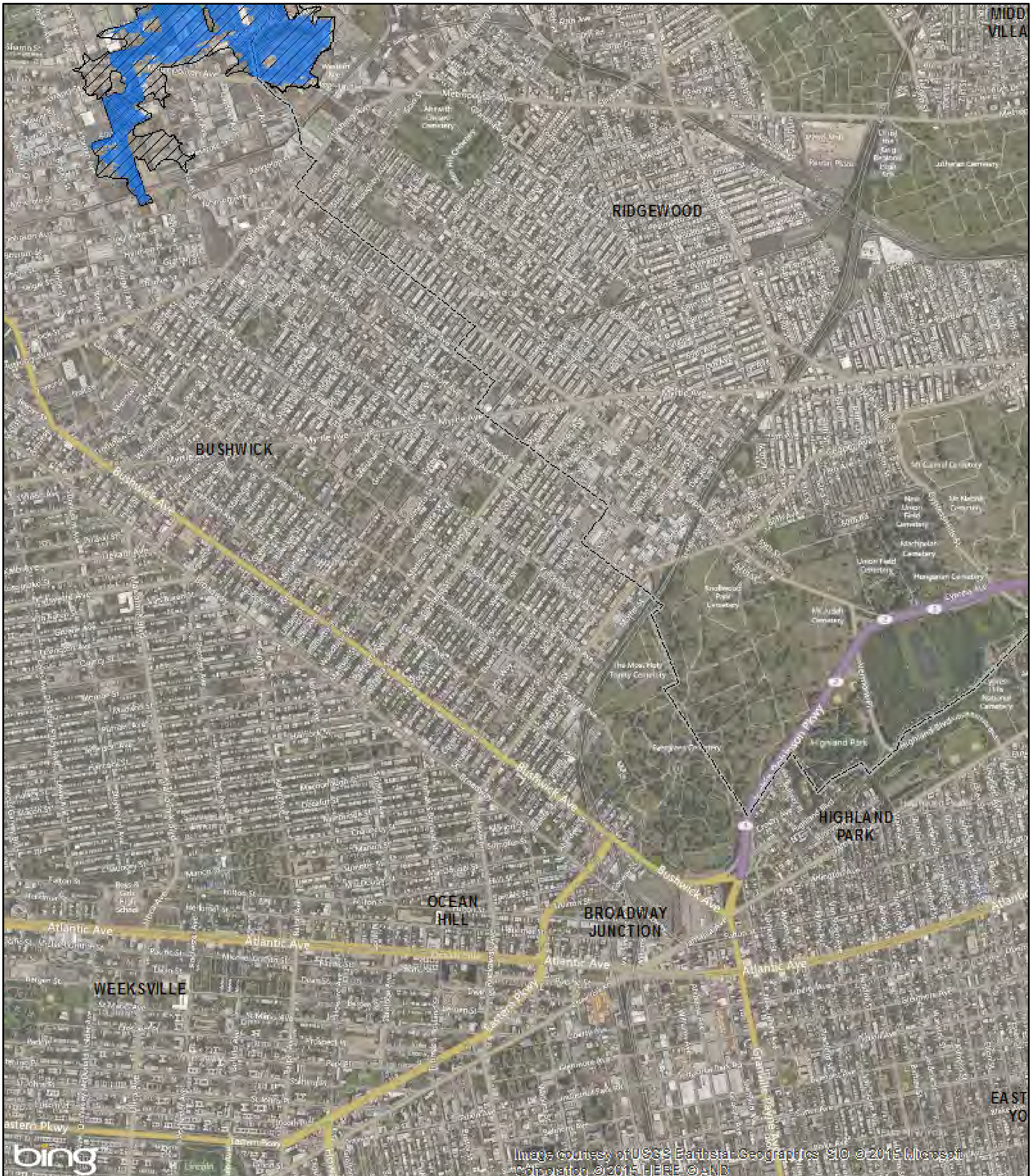
Erosion Only

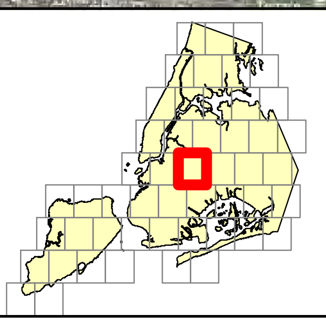
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-20

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

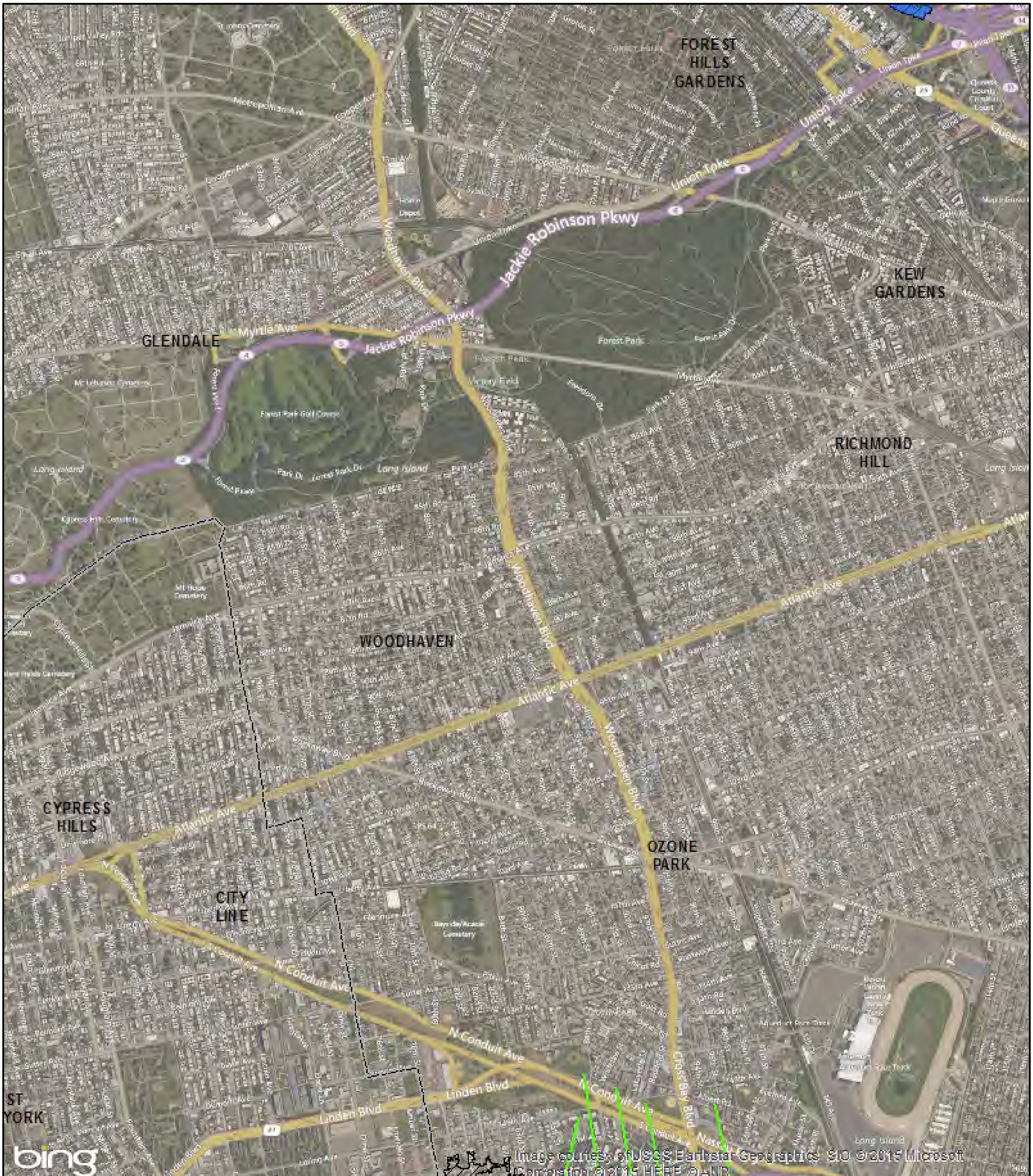
Erosion Only

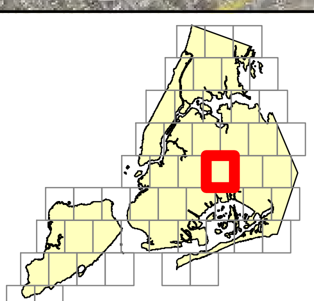
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-21

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

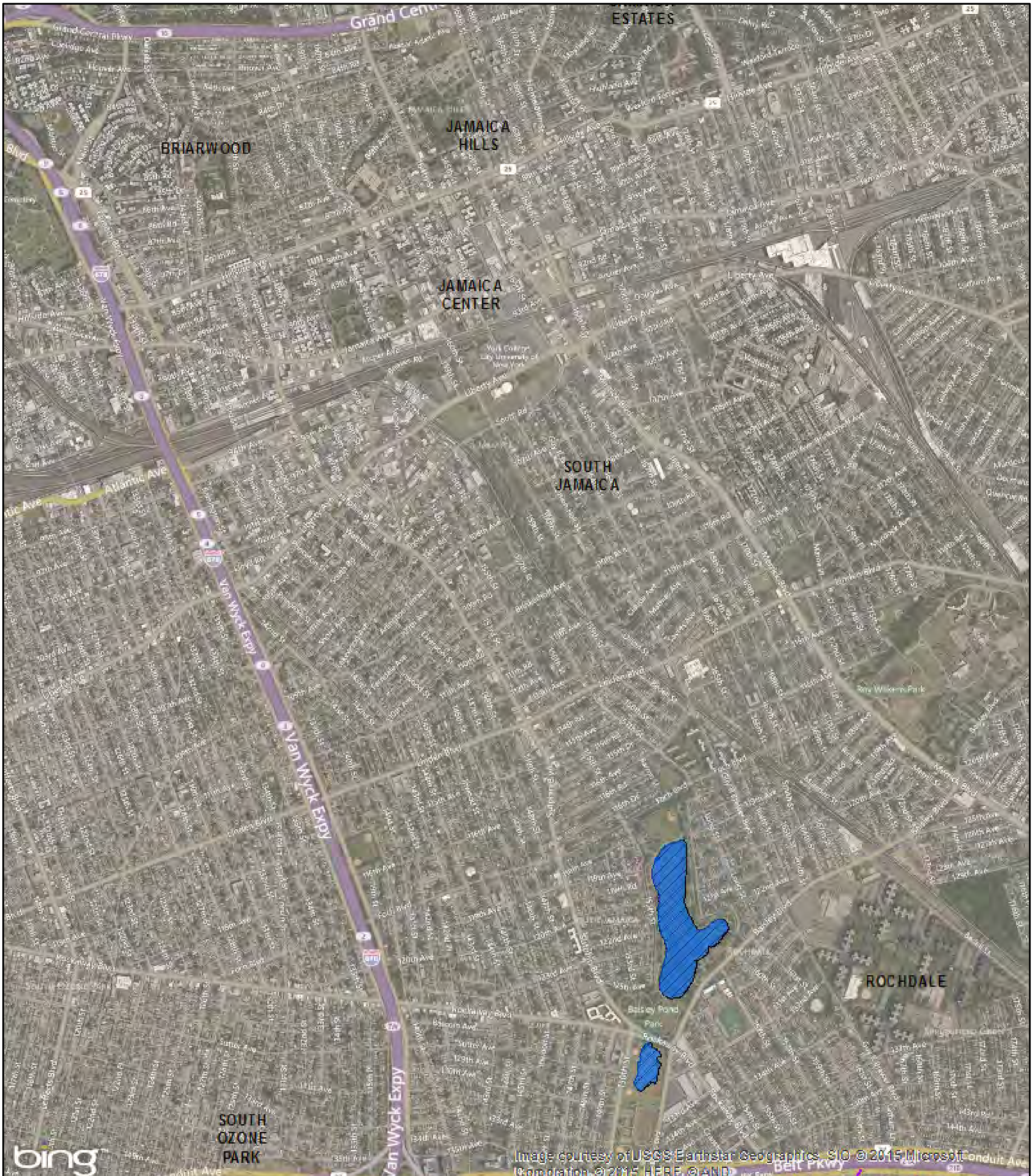
Erosion Only

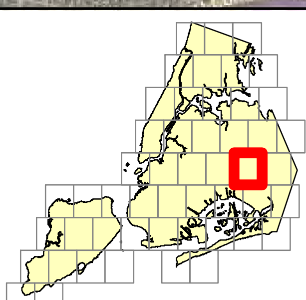
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-22

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

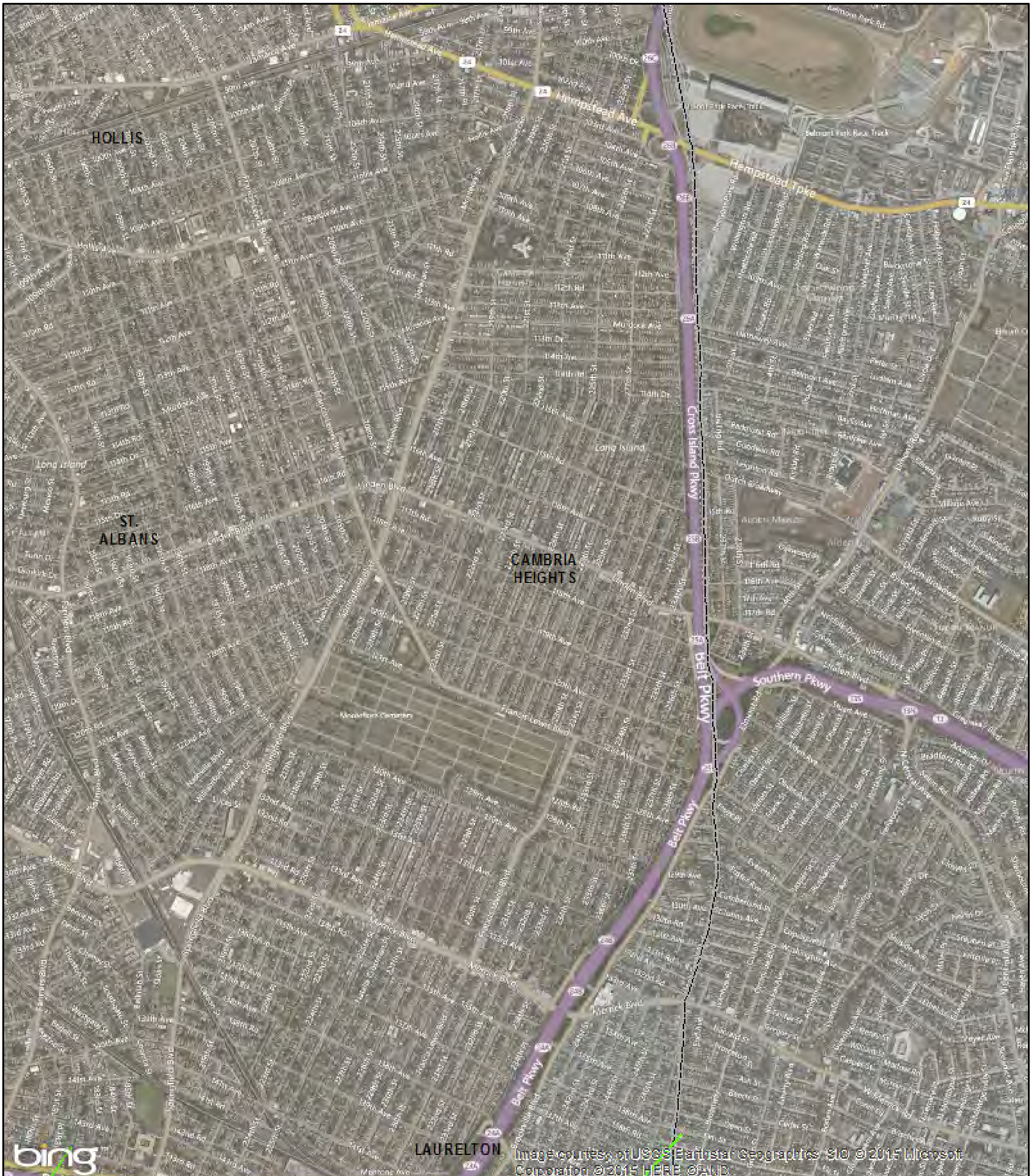
Erosion Only

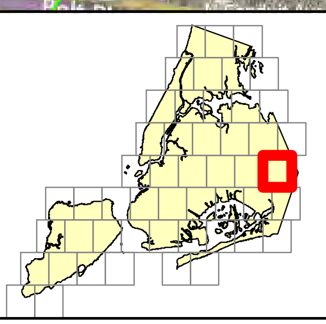
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-23

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

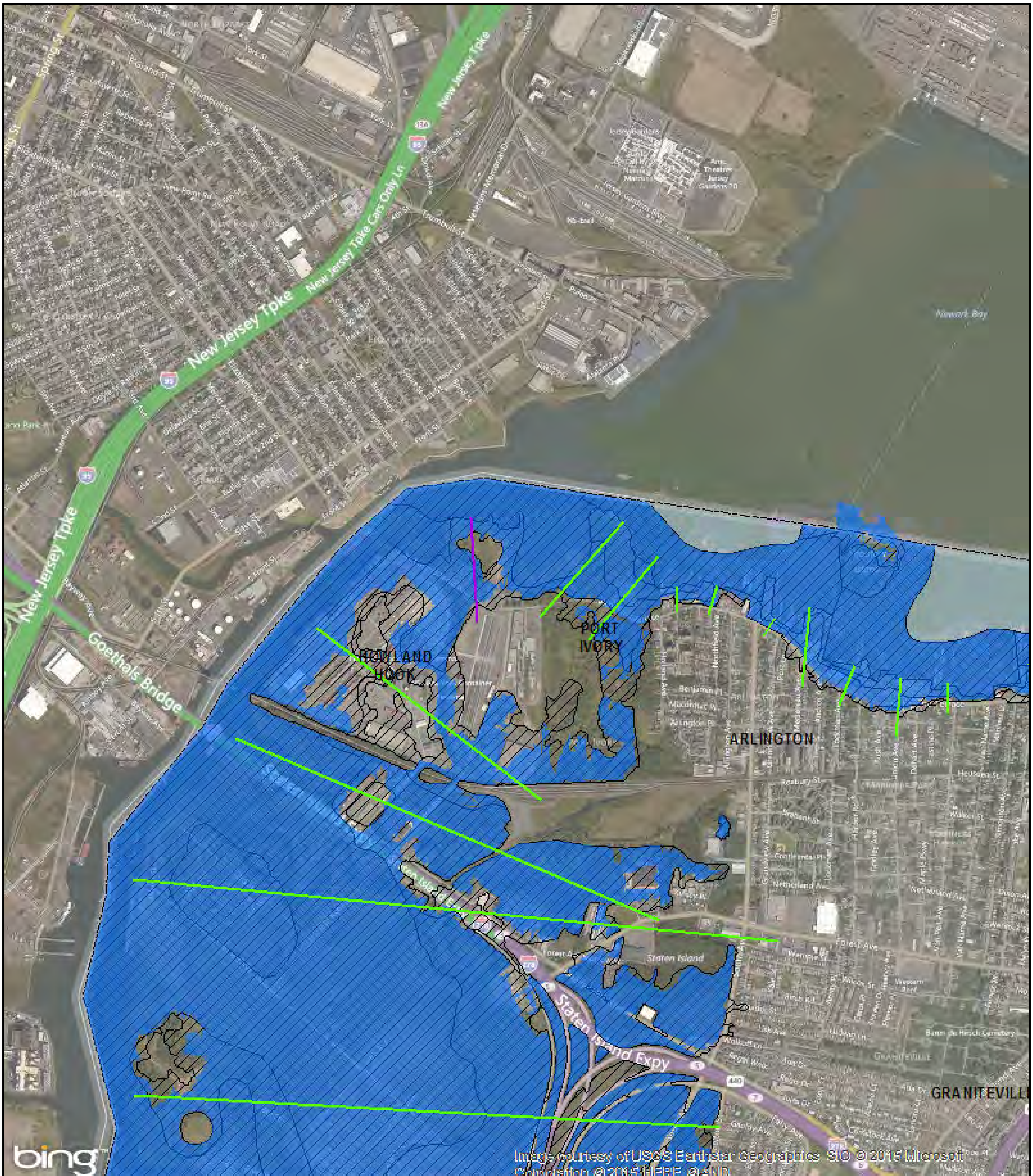
Erosion Only

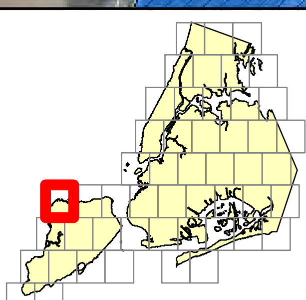
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-24

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

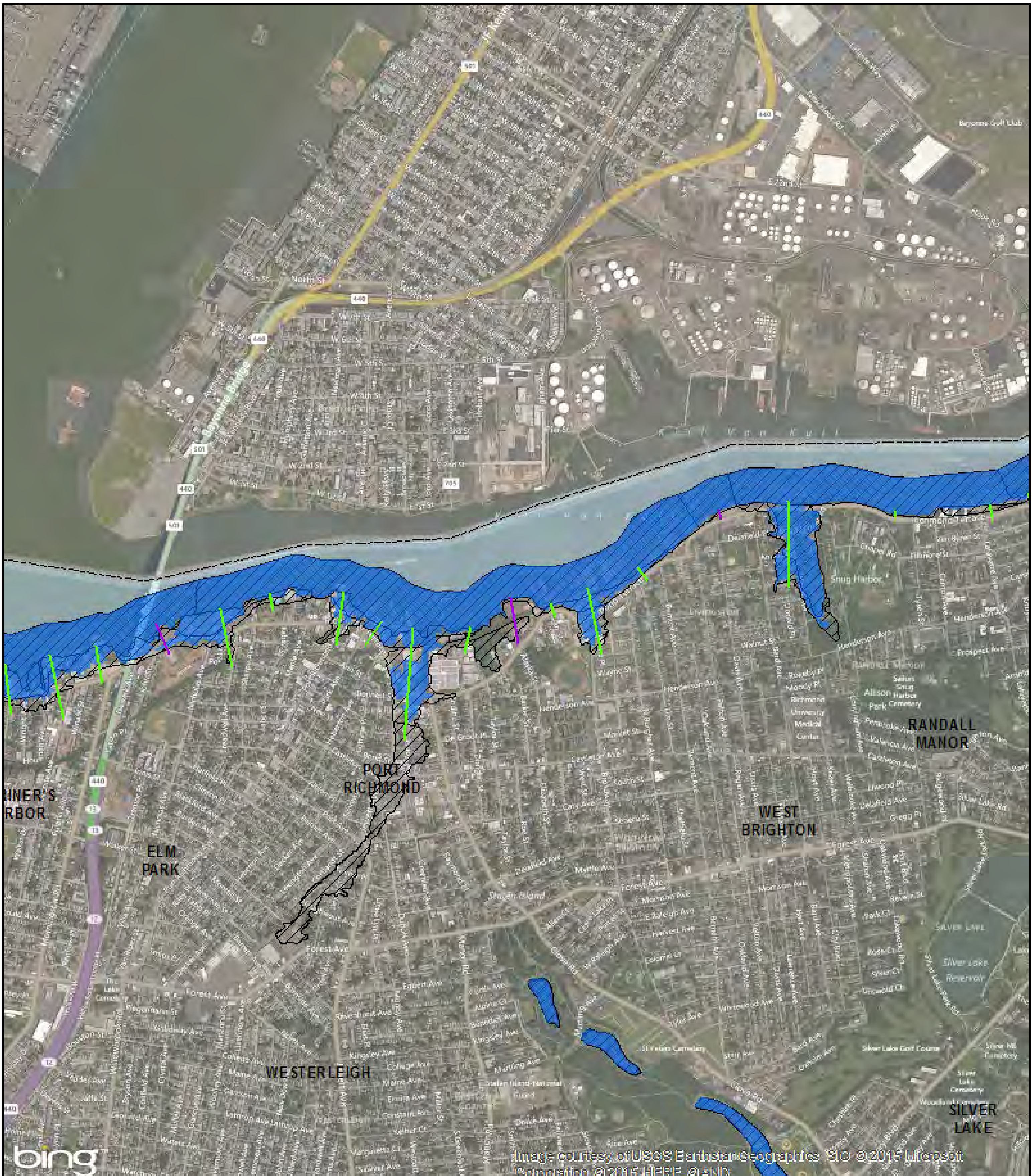
Erosion Only

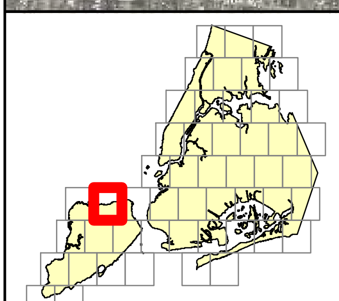
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-25

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

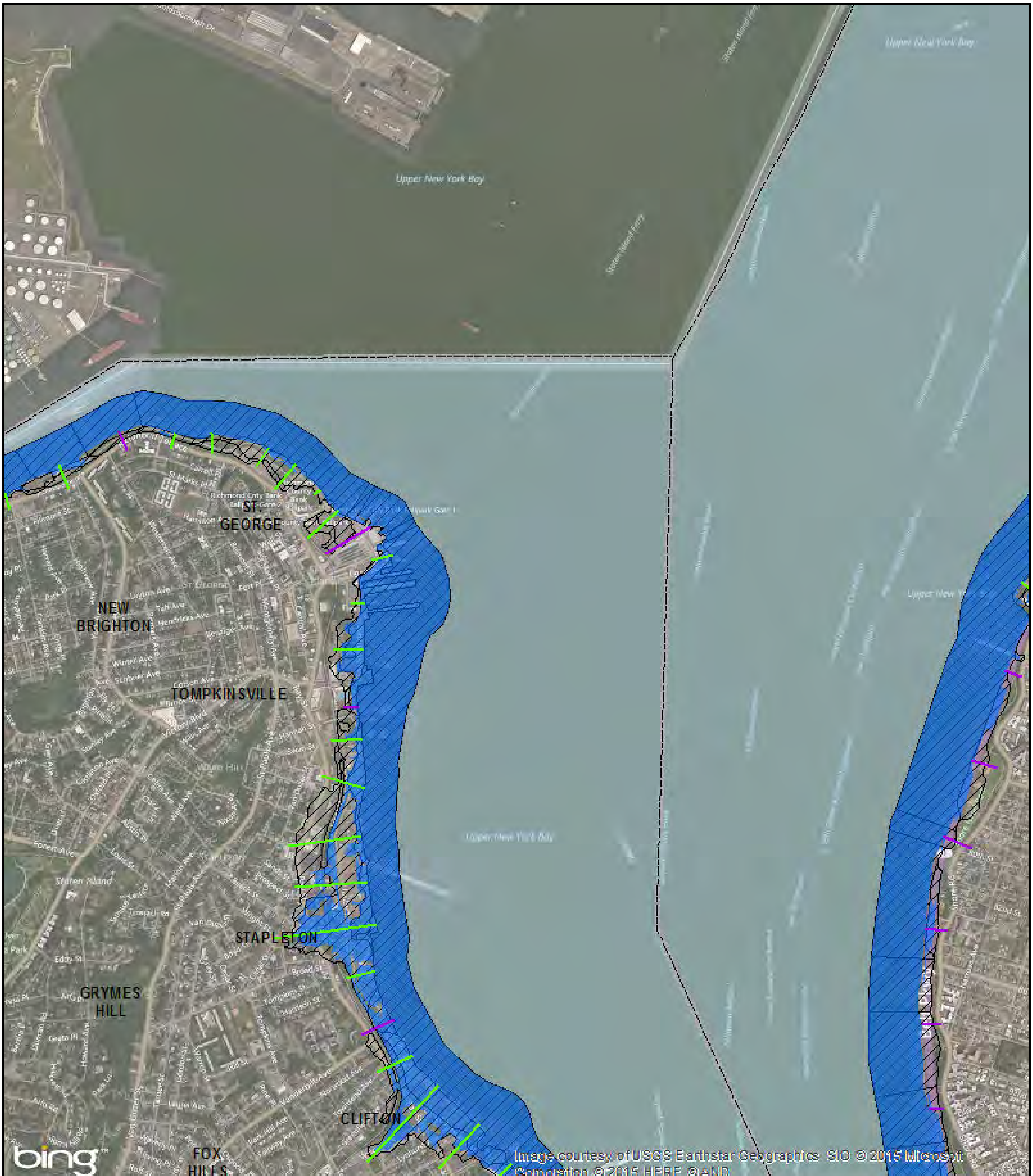
Erosion Only

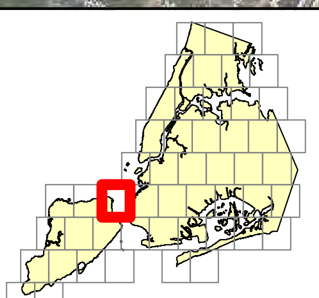
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-26

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

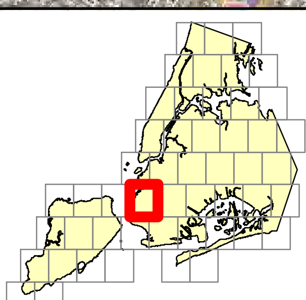
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-27

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

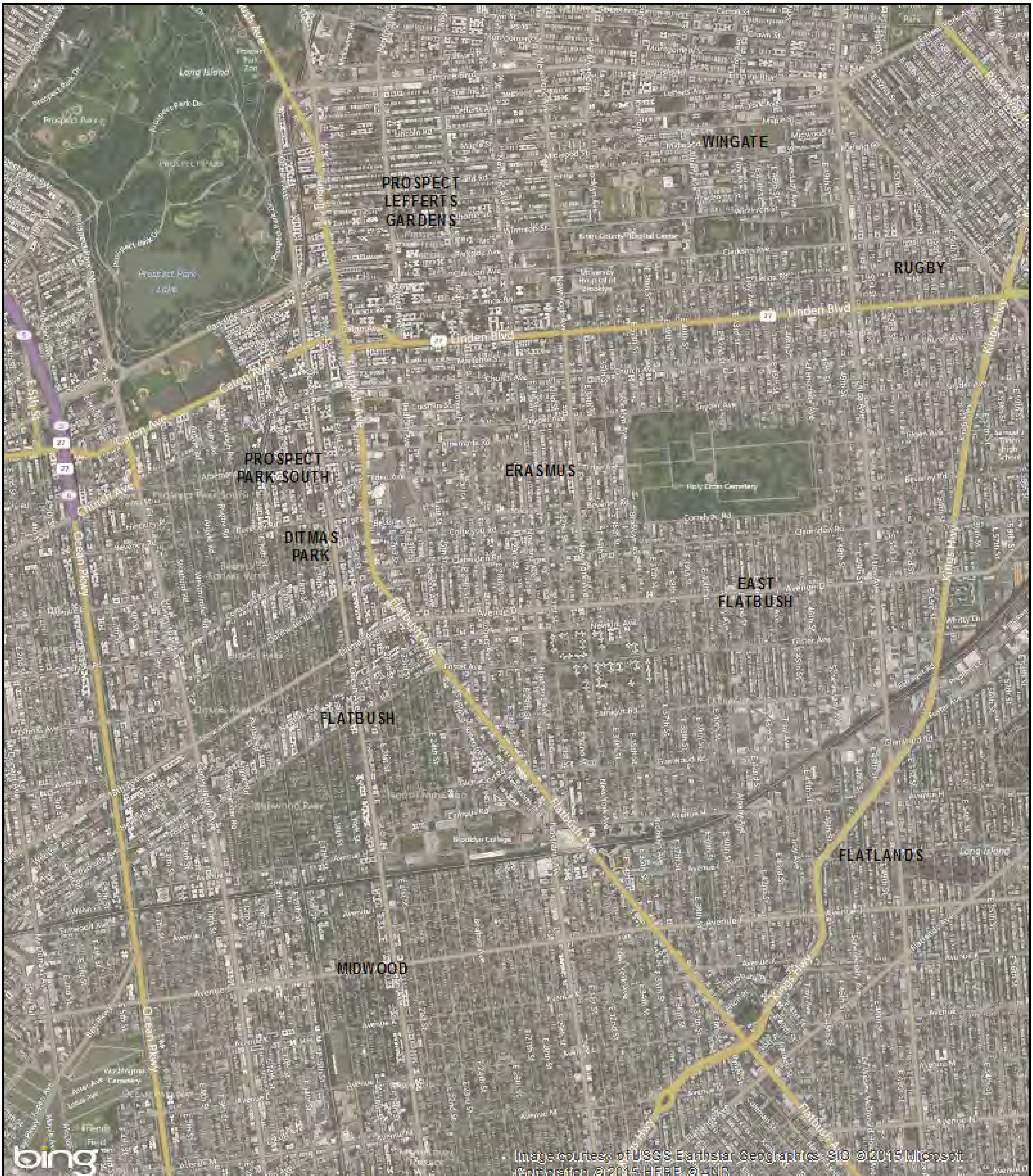
Erosion Only

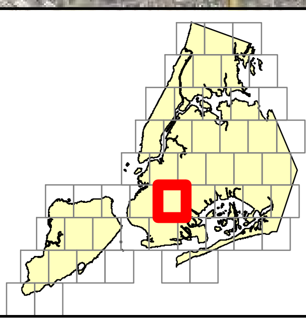
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-28

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

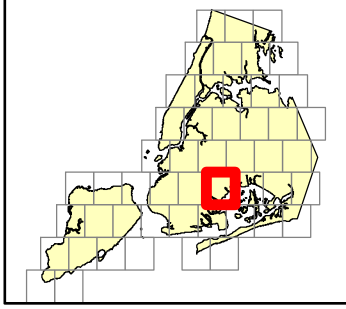
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-29

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

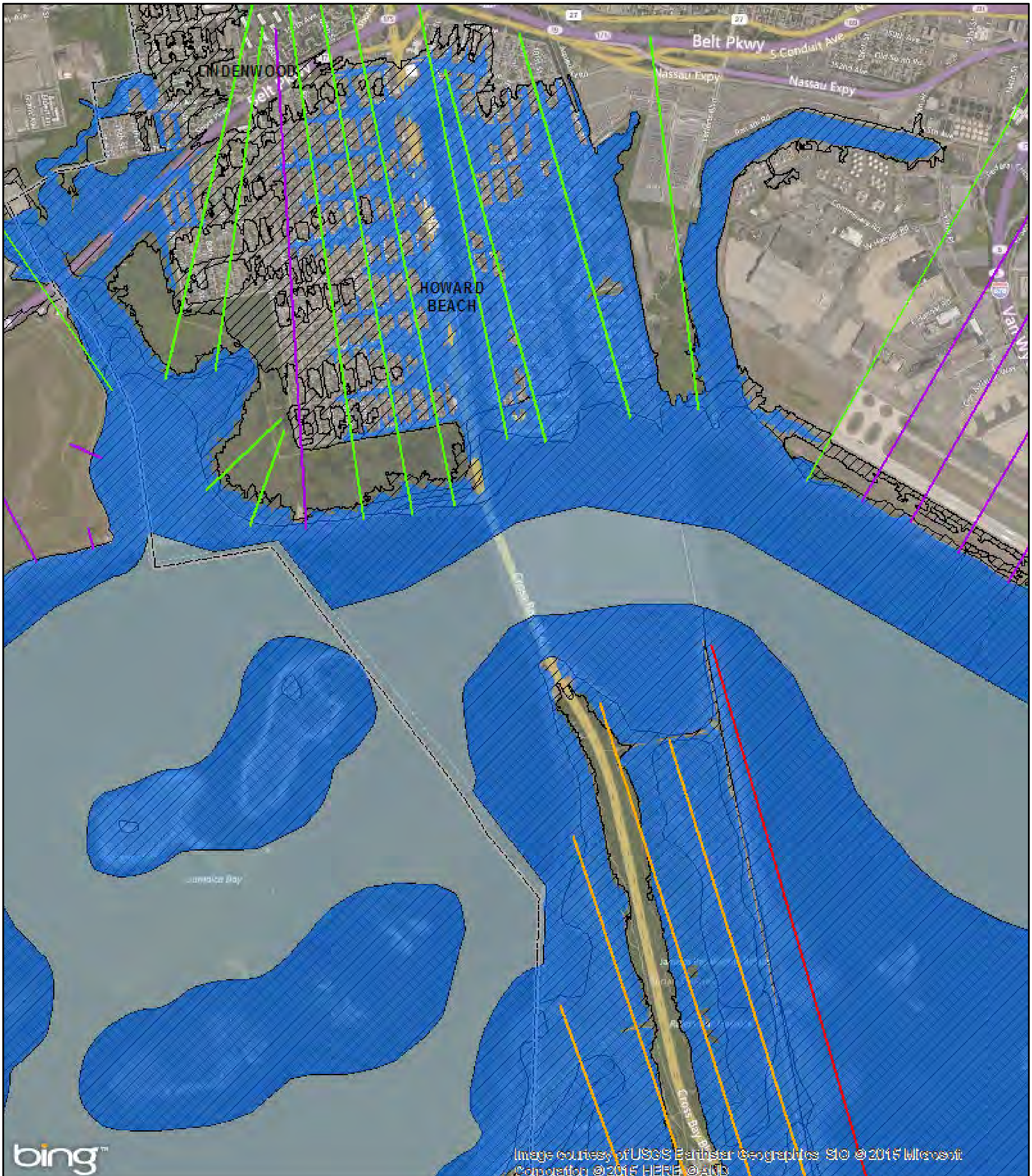
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-30

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

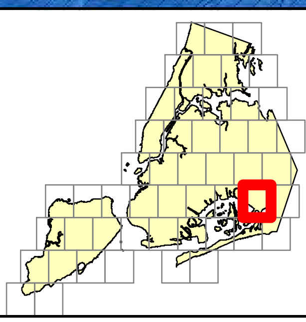
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-31

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

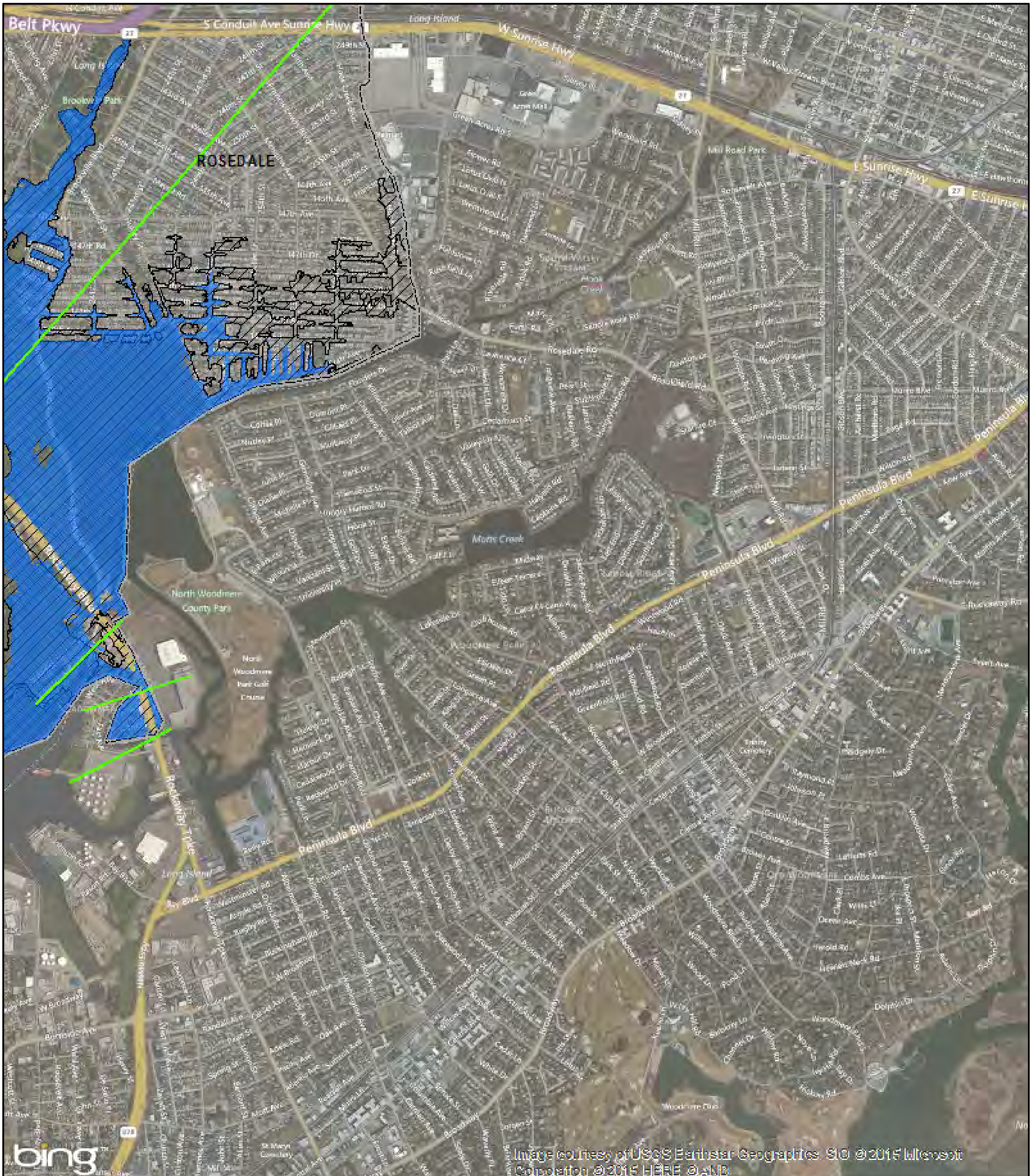
Erosion Only

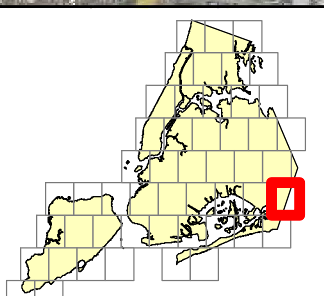
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-32

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

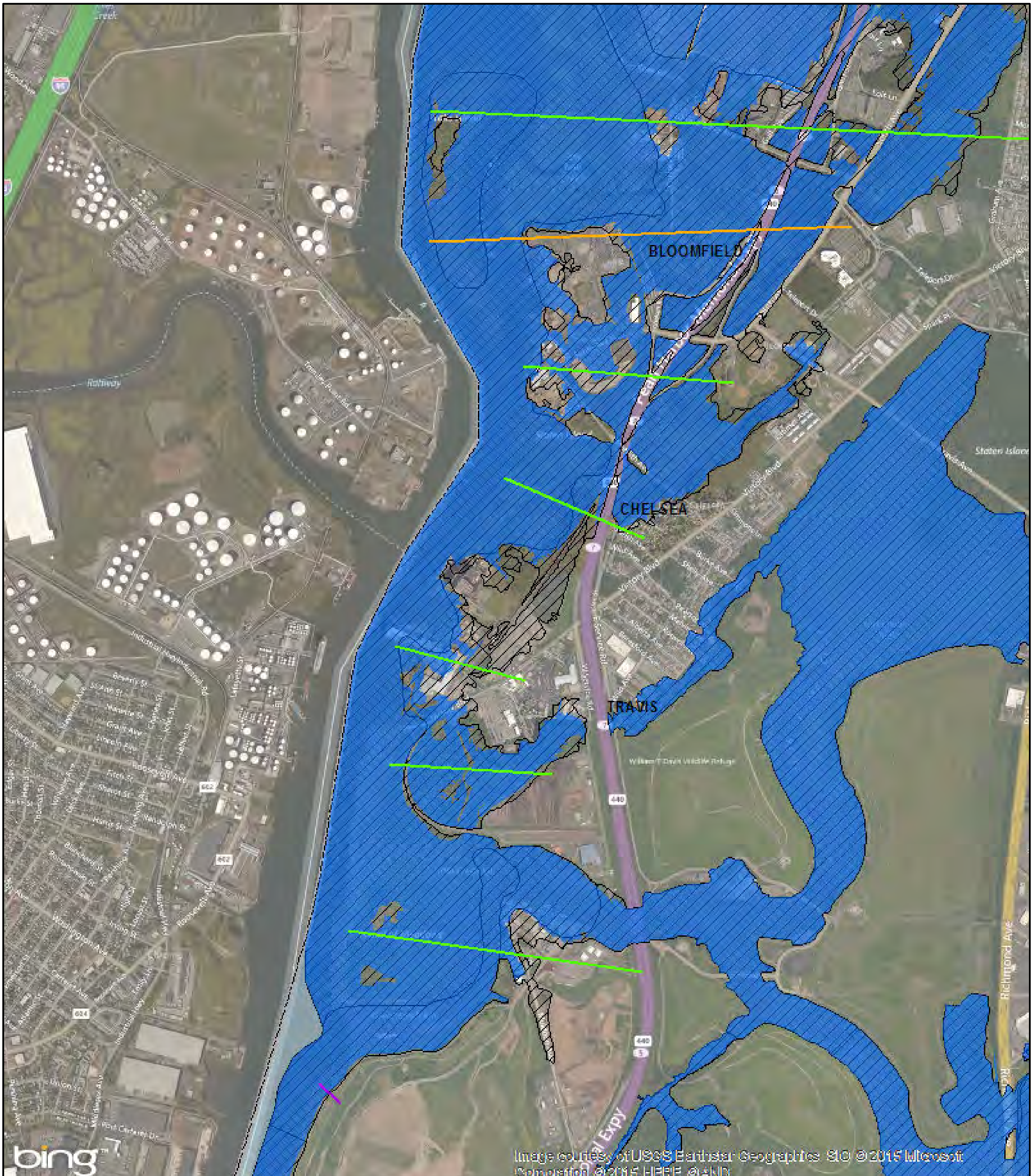
Erosion Only

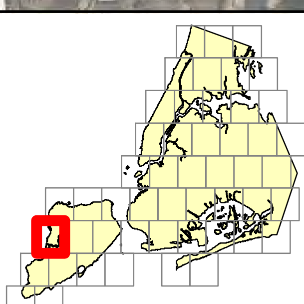
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-33

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

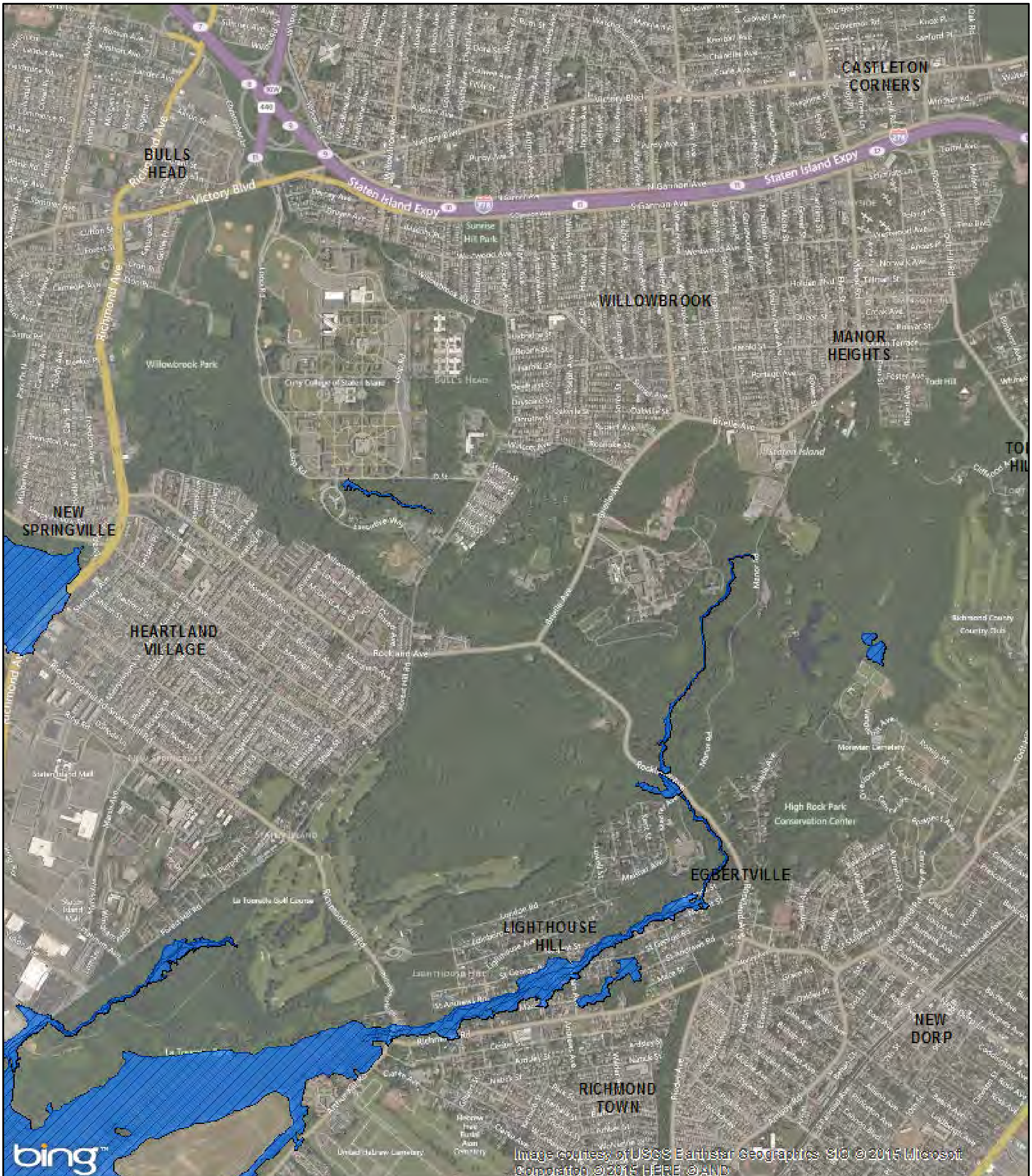
Erosion Only

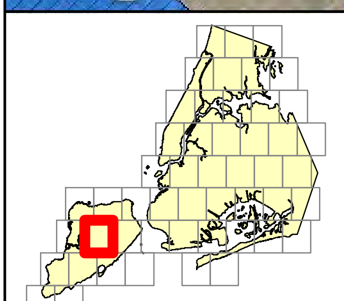
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-34

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

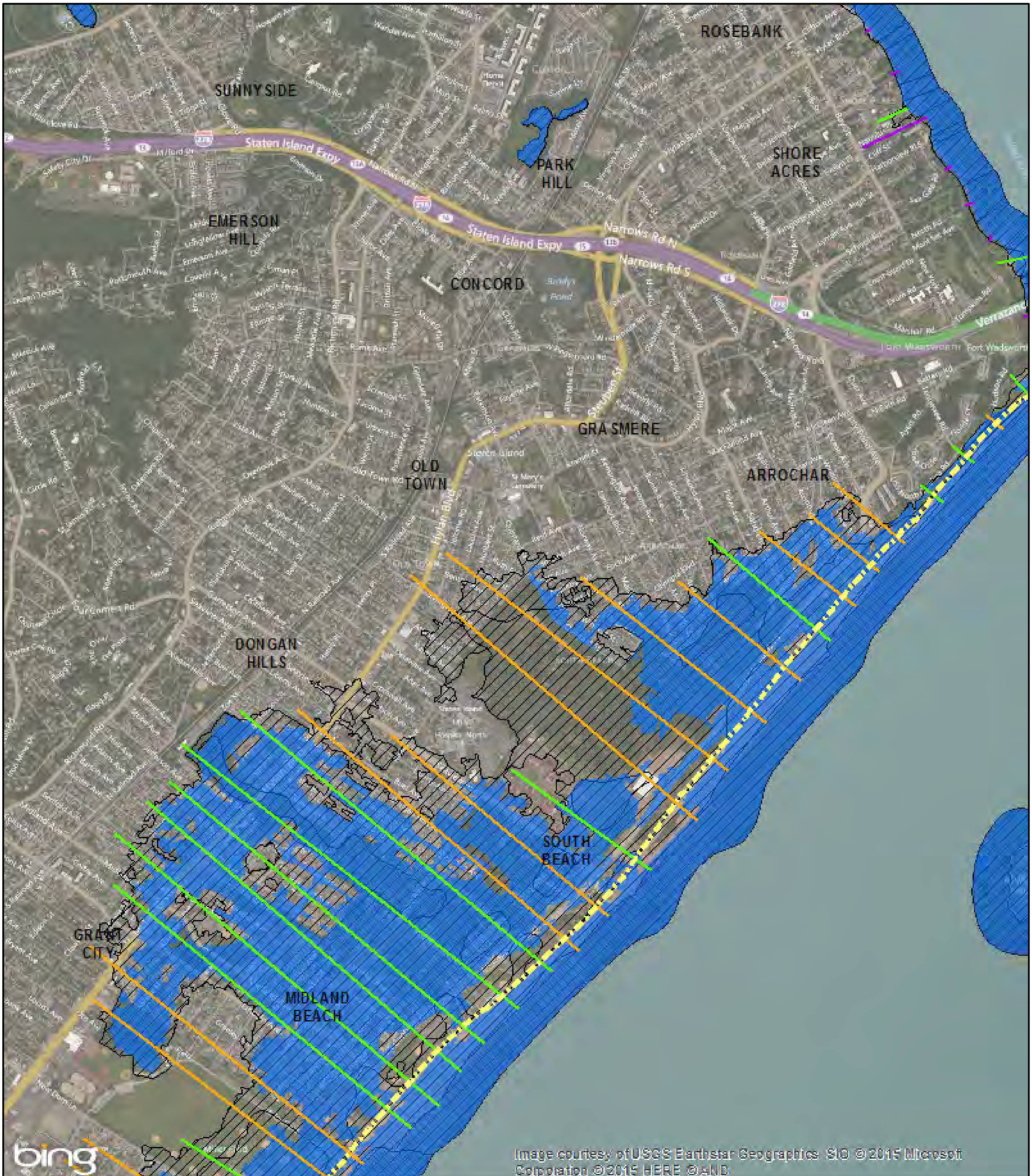
Erosion Only

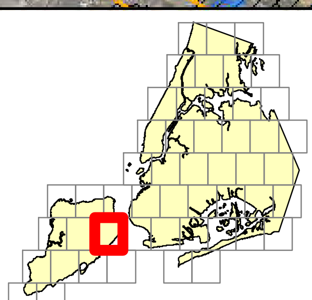
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-35

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

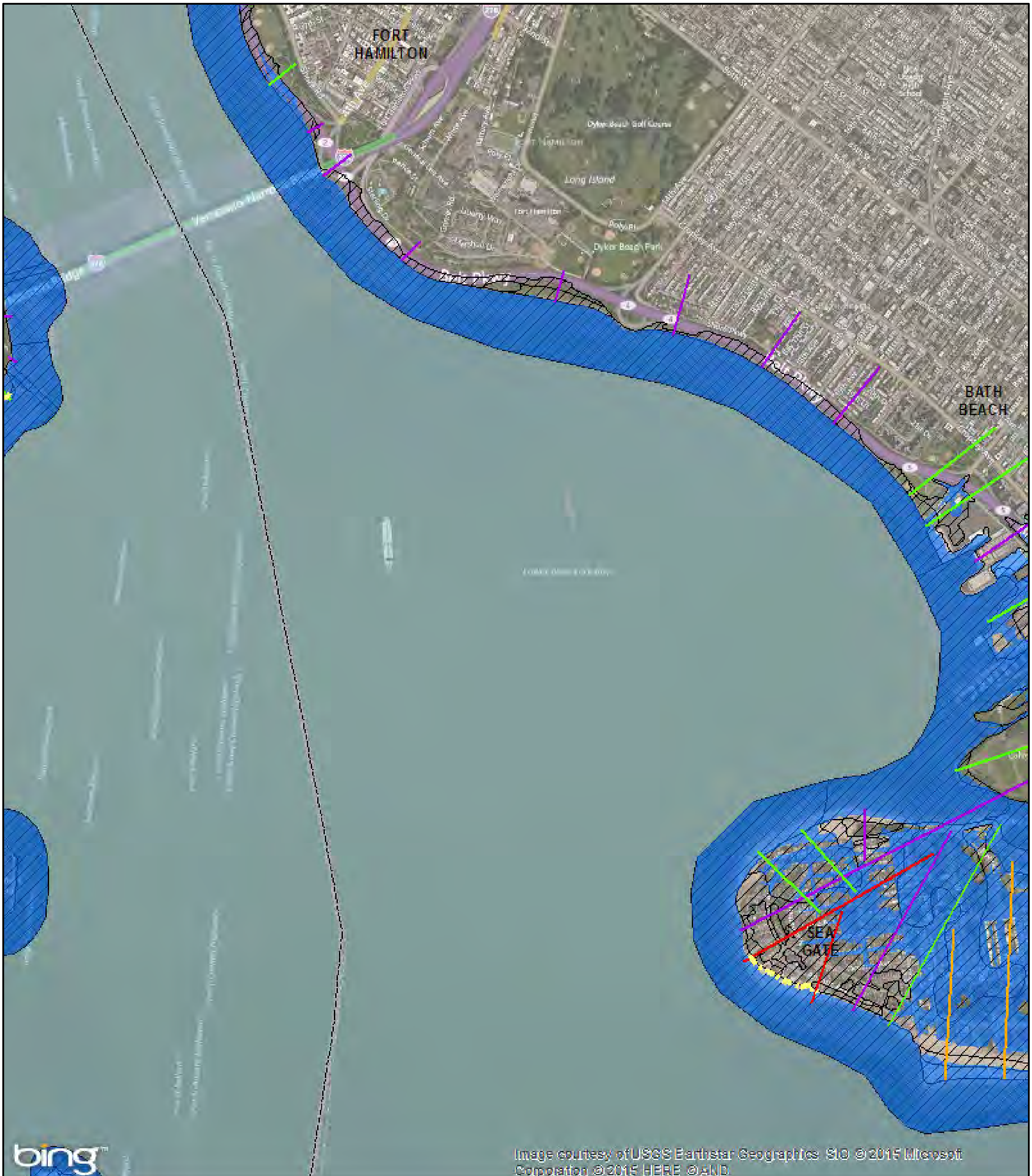
Erosion Only

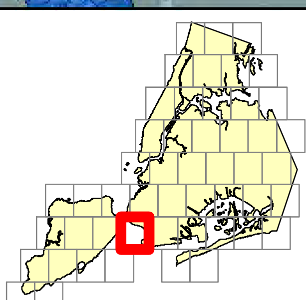
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-36

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

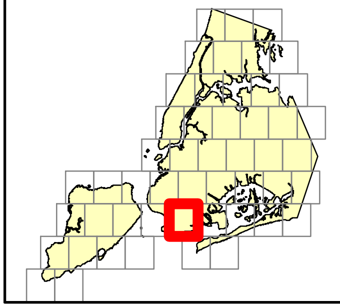
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-37

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

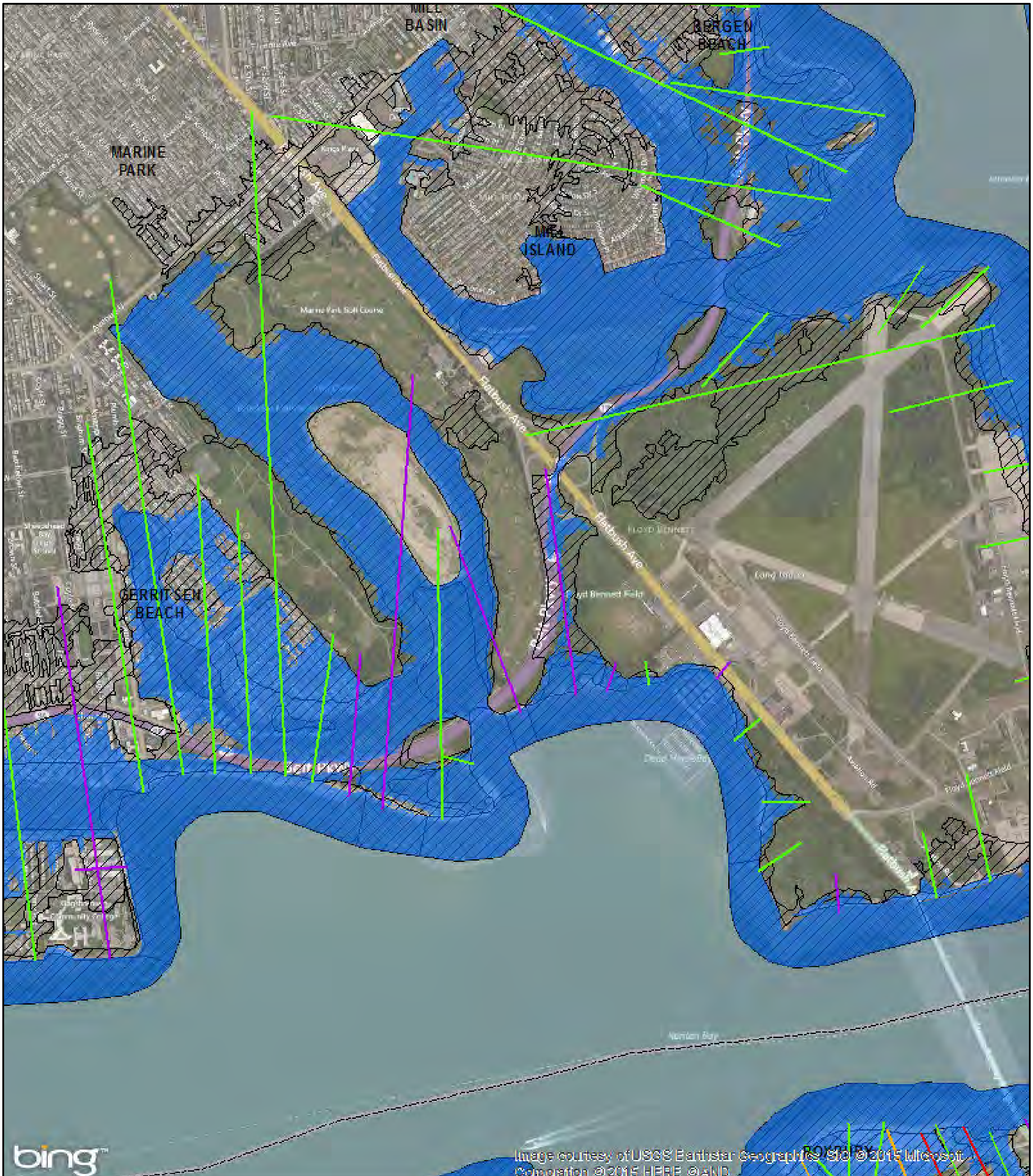
FEMA PFIRM WHAFIS Transects

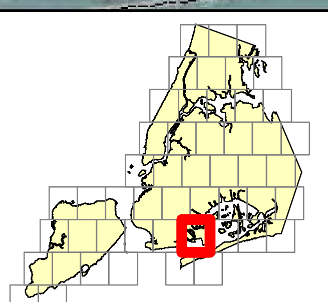
- No Runup, No Erosion
- Runup Only
- Erosion Only
- Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-38

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-39

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation

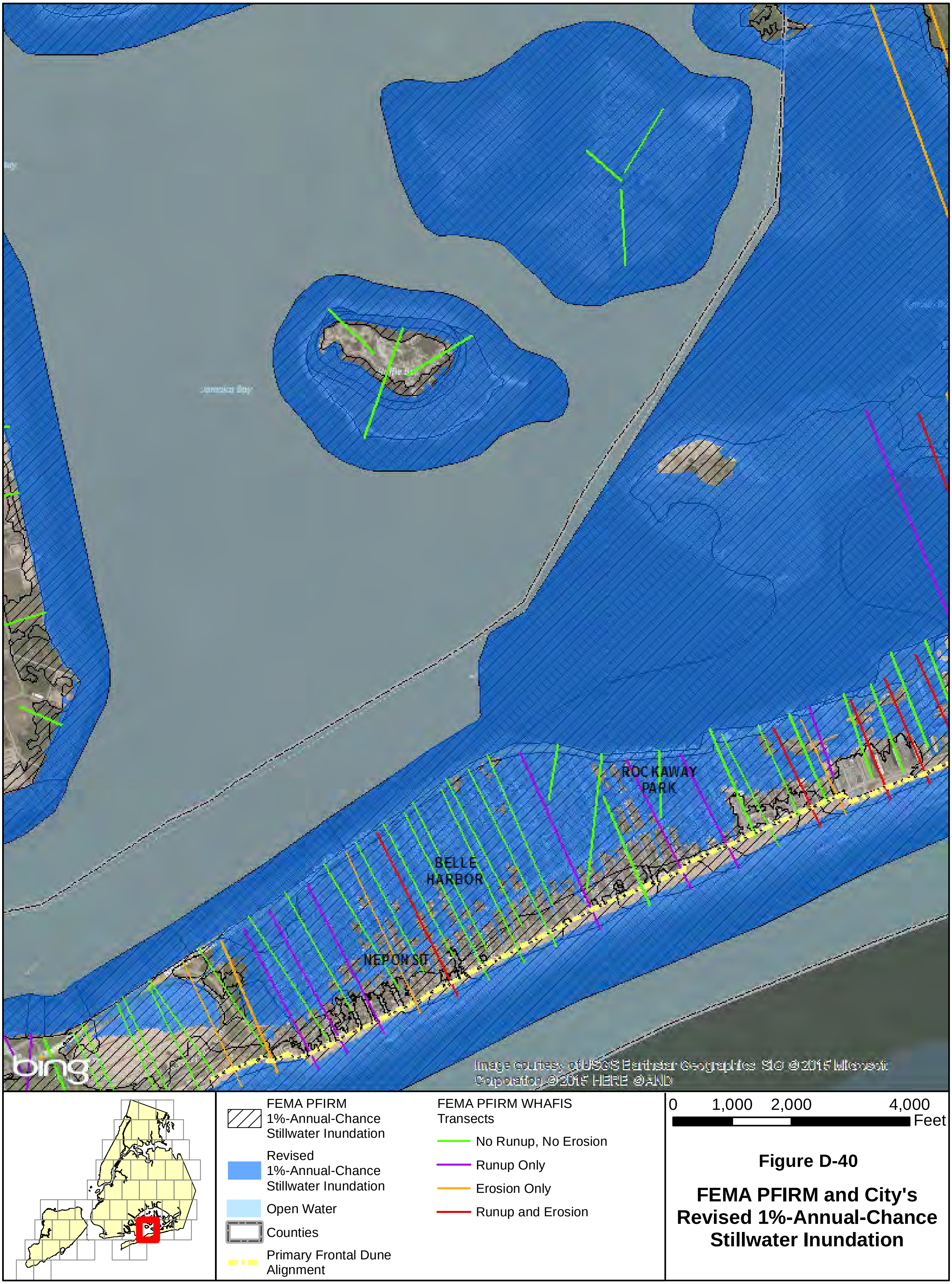
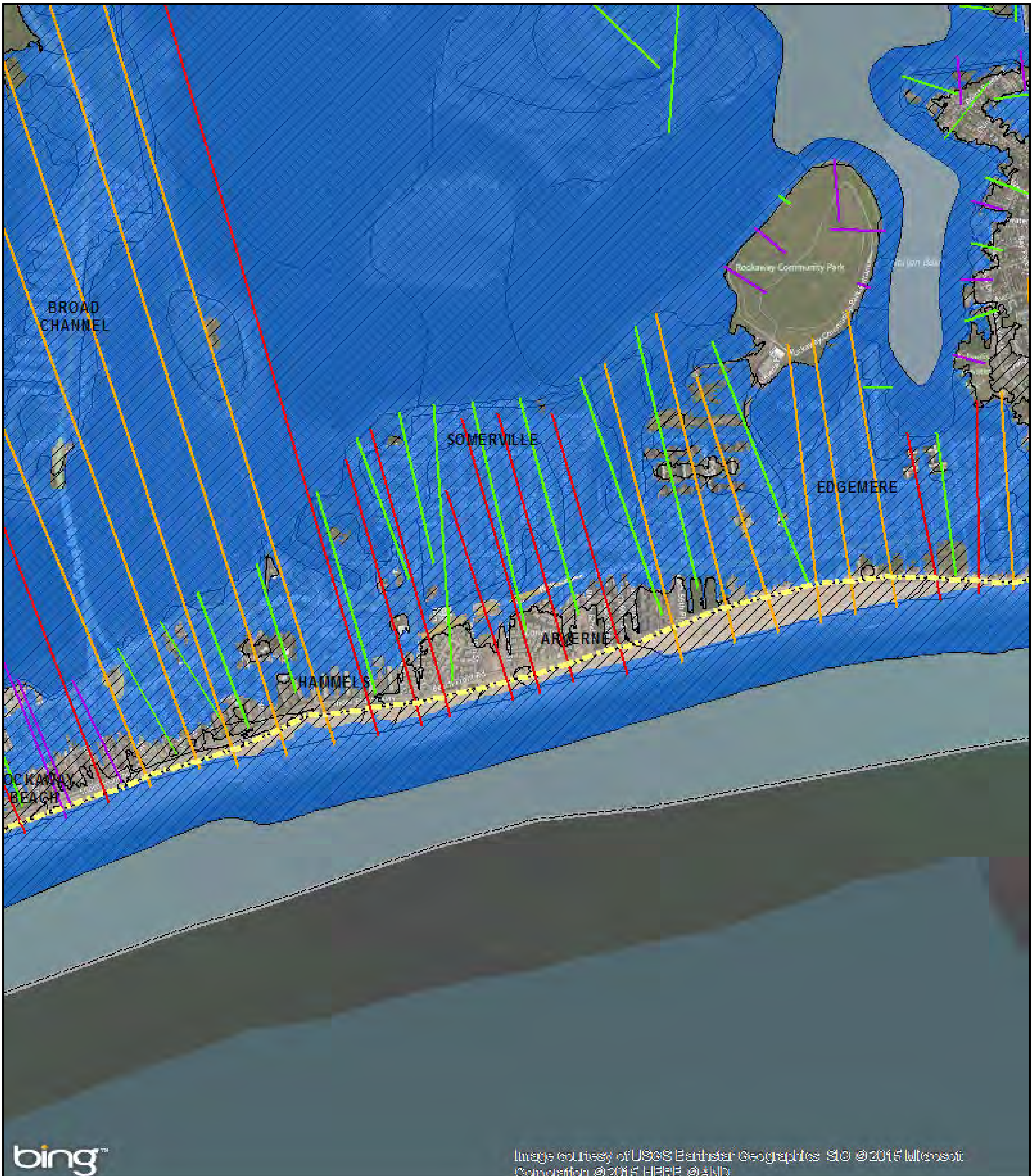
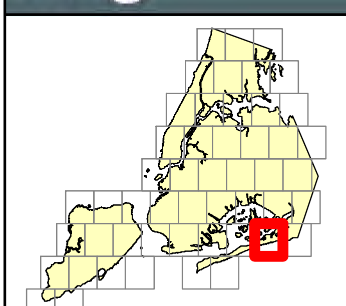


Figure D-40

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

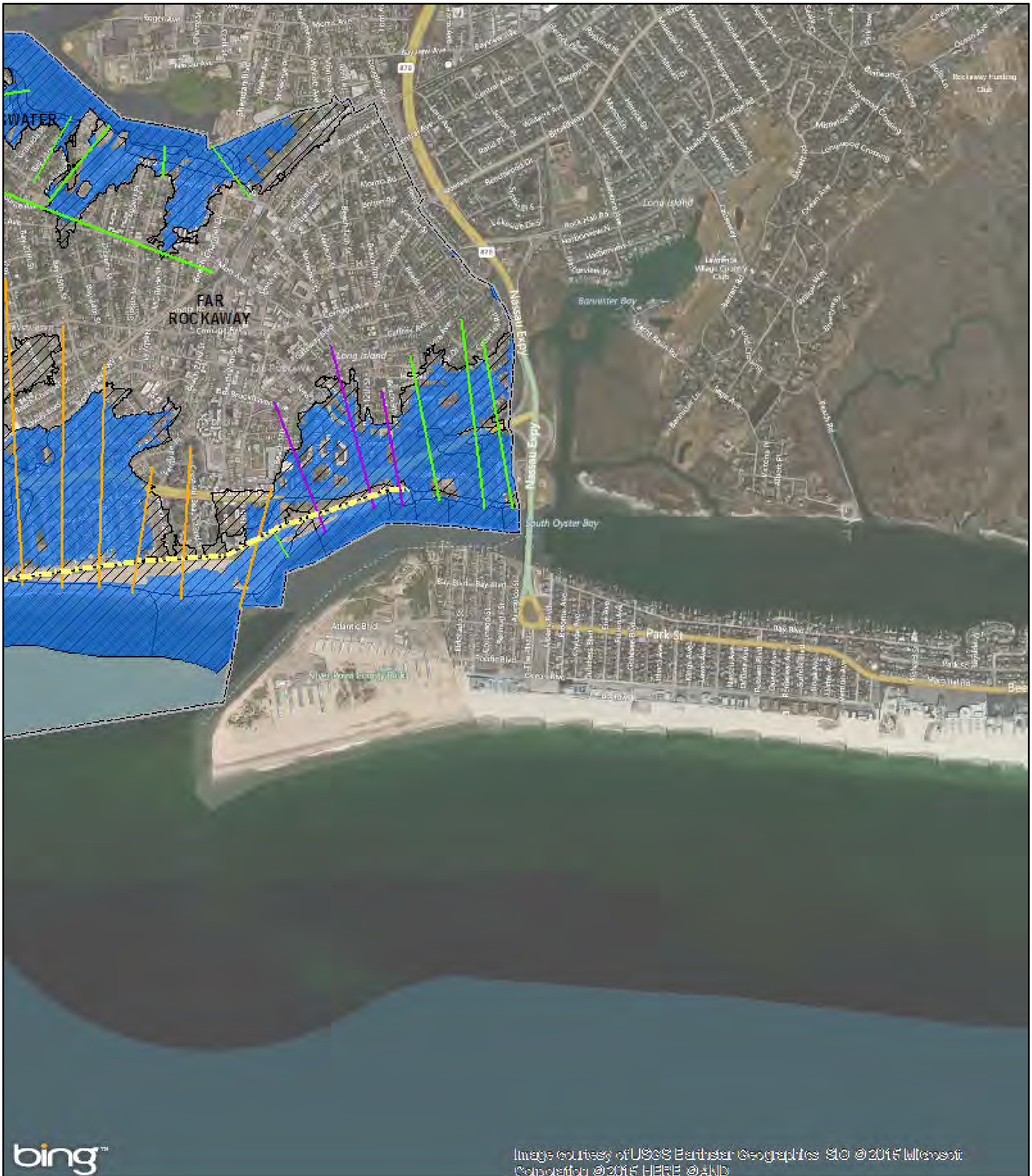
Erosion Only

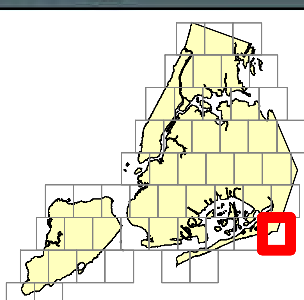
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-41

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

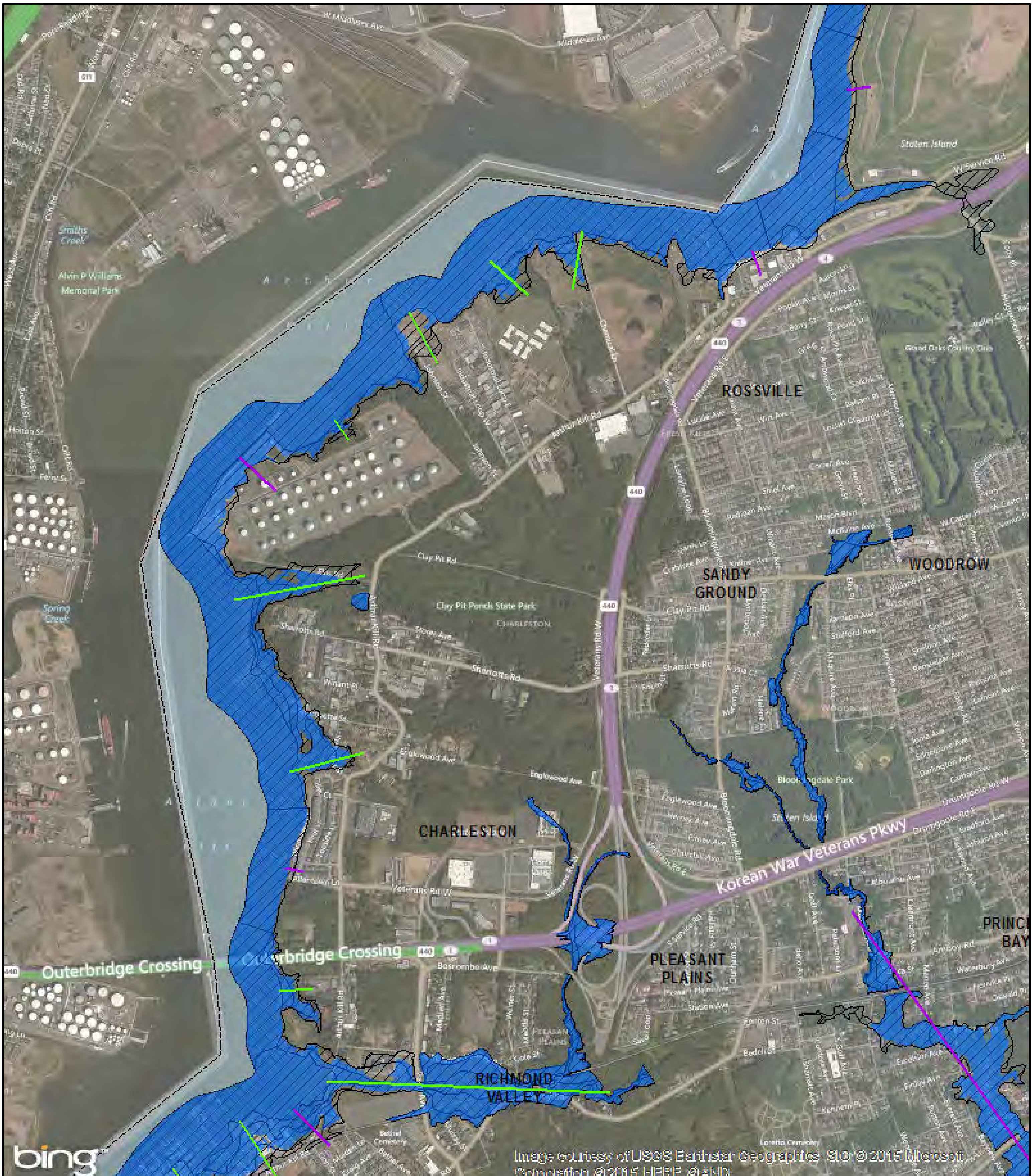
Erosion Only

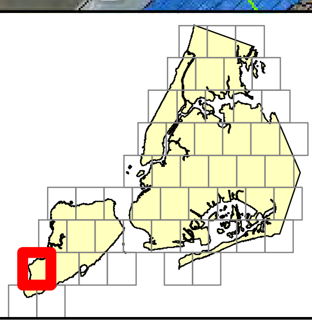
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-42

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

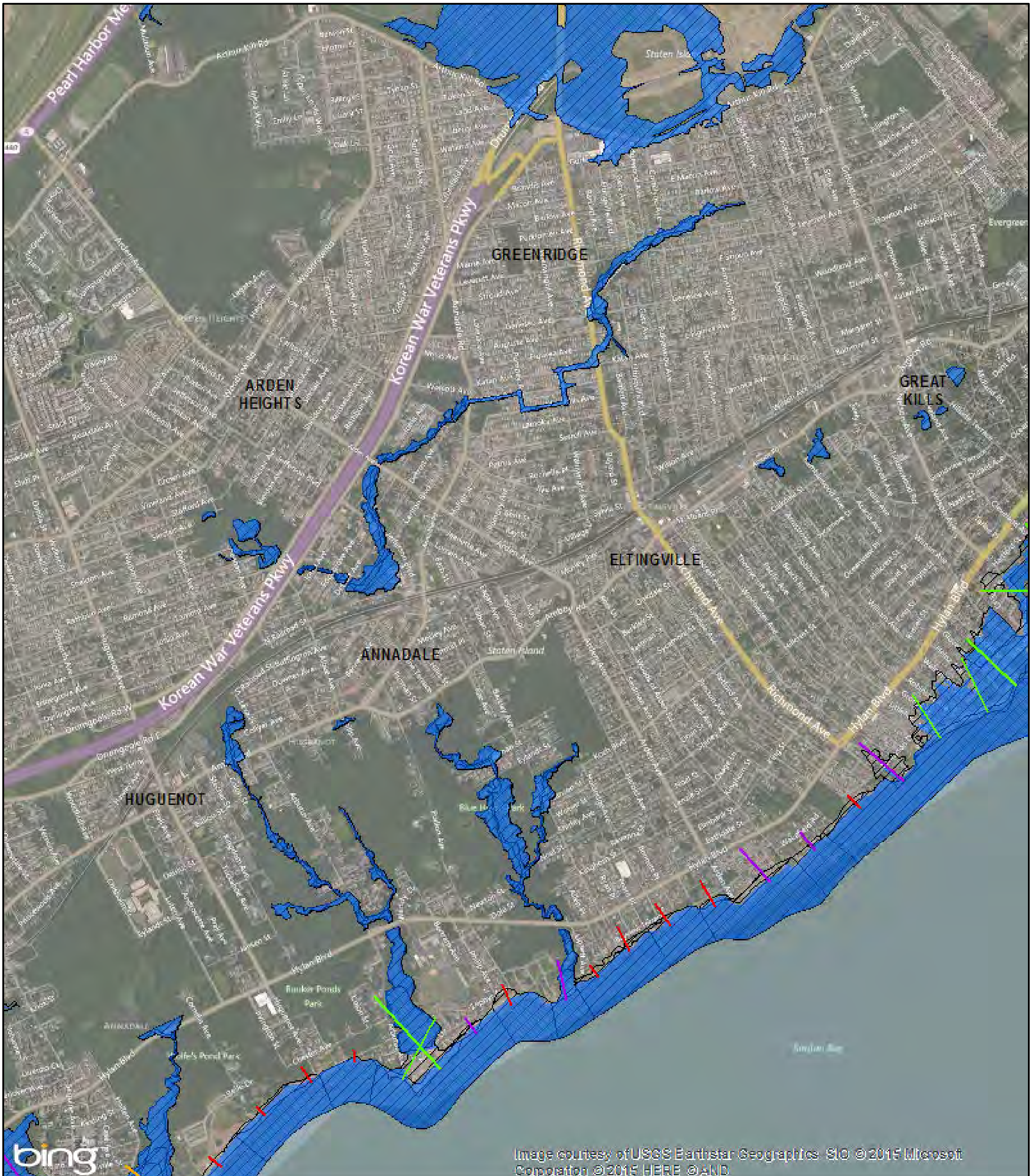
Erosion Only

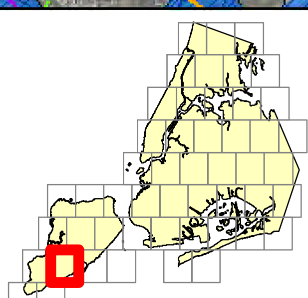
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-43

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

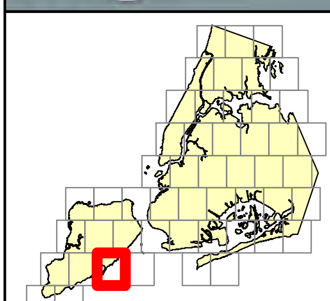
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-44

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

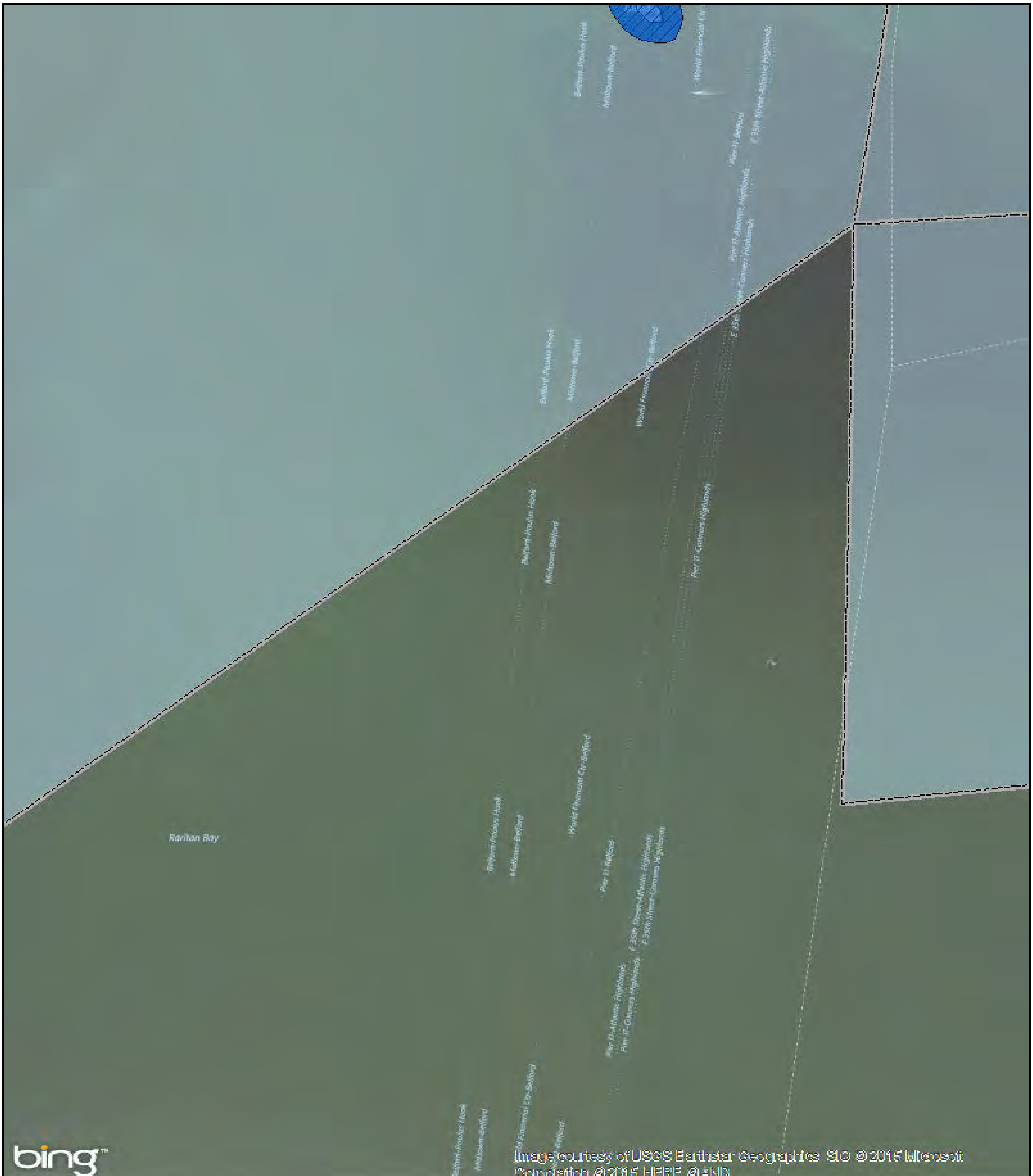
Erosion Only

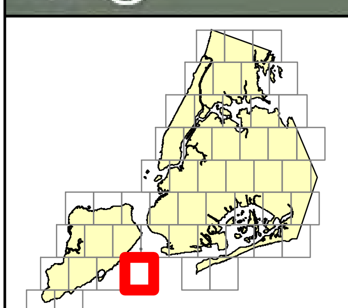
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-45

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

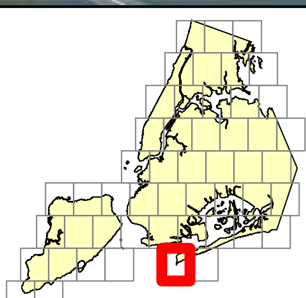
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-46

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

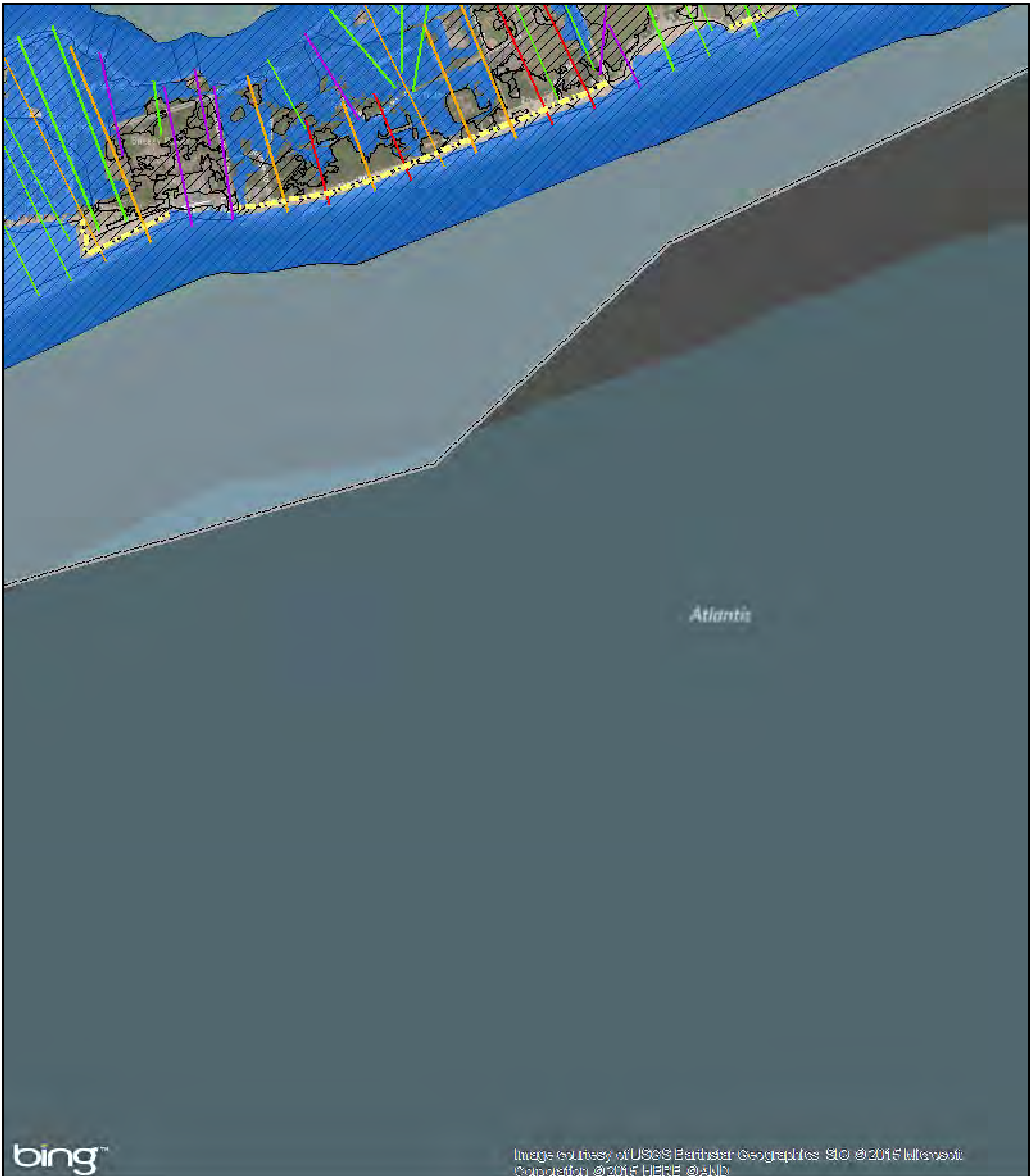
Erosion Only

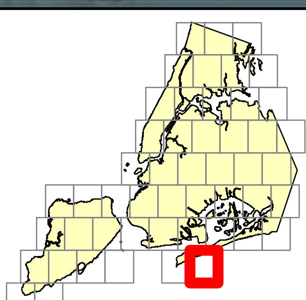
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-47

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

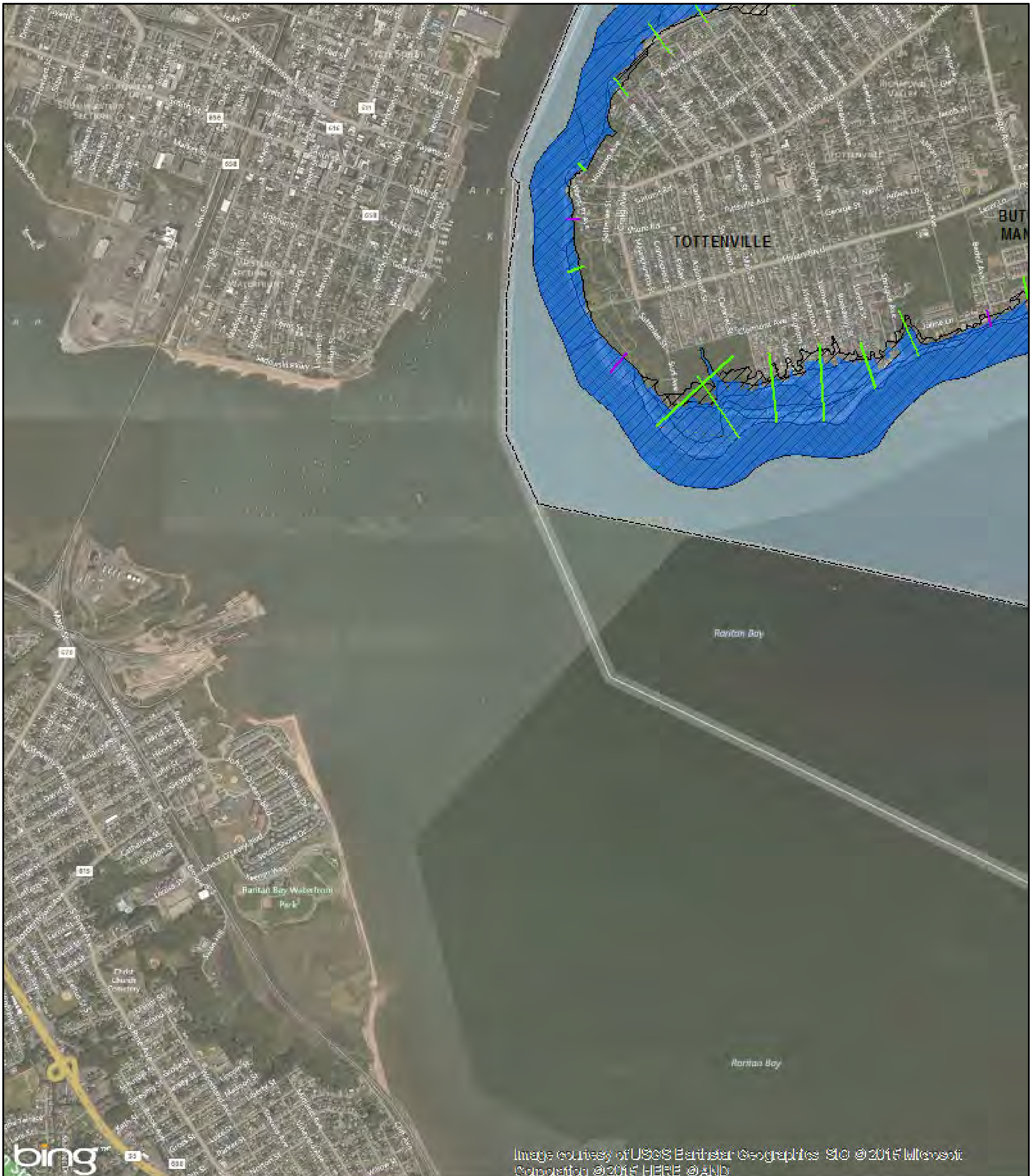
Erosion Only

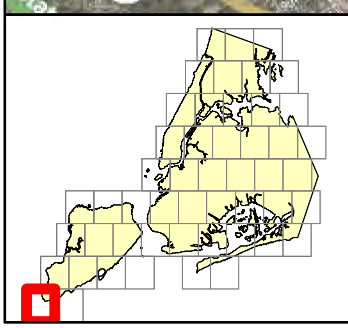
Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-48

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation





FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

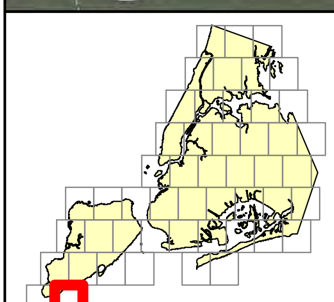
Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-49

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation



FEMA PFIRM 1%-Annual-Chance Stillwater Inundation

Revised 1%-Annual-Chance Stillwater Inundation

Open Water

Counties

Primary Frontal Dune Alignment

FEMA PFIRM WHAFIS Transects

No Runup, No Erosion

Runup Only

Erosion Only

Runup and Erosion

0 1,000 2,000 4,000 Feet

Figure D-50

FEMA PFIRM and City's Revised 1%-Annual-Chance Stillwater Inundation