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Interior Drainage Sub-Appendix

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New York – New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study

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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
CFS	Cubic Feet Per Second
CSO	Combined Sewer Outflow
CSS	Combined Sewer System
CY	Cubic Yards
E&D	Engineering & Design
EL.	Elevation
EM	Engineer Manual
ER	Engineer Regulation
HFFPF	High Frequency Flood Protection Feature
IFF	Induced Flooding-Mitigation Feature
GIS	Geographic Information Systems
LOP	Line of Protection
NAVD88	North American Vertical Datum of 1988
NJ	New Jersey
NY	New York
NYNJHAT	New York-New Jersey Harbor and Tributaries Coastal Storm Risk Management Feasibility Study
NYC	New York City
RRF	Risk Reduction Feature
SBMs	Shore-Based Measures
SSBs	Storm Surge Barriers
TSP	Tentatively Selected Plan
USACE	United States Army Corps of Engineers
USACE-NAN	USACE New York District
USGS	United States Geologic Survey
WSEL	Water Surface Elevation

1 INTRODUCTION

1.1 Description of Study

This document describes the Interior Drainage Analysis to support the Tentatively Selected Plan (TSP) of the New York/New Jersey Harbor & Tributaries Coastal Storm Risk Management Feasibility Study (NYNJHAT). The project includes storm surge barriers and shore-based methods to reduce flood risk in parts of New York and New Jersey, as shown in **Figure 1**.

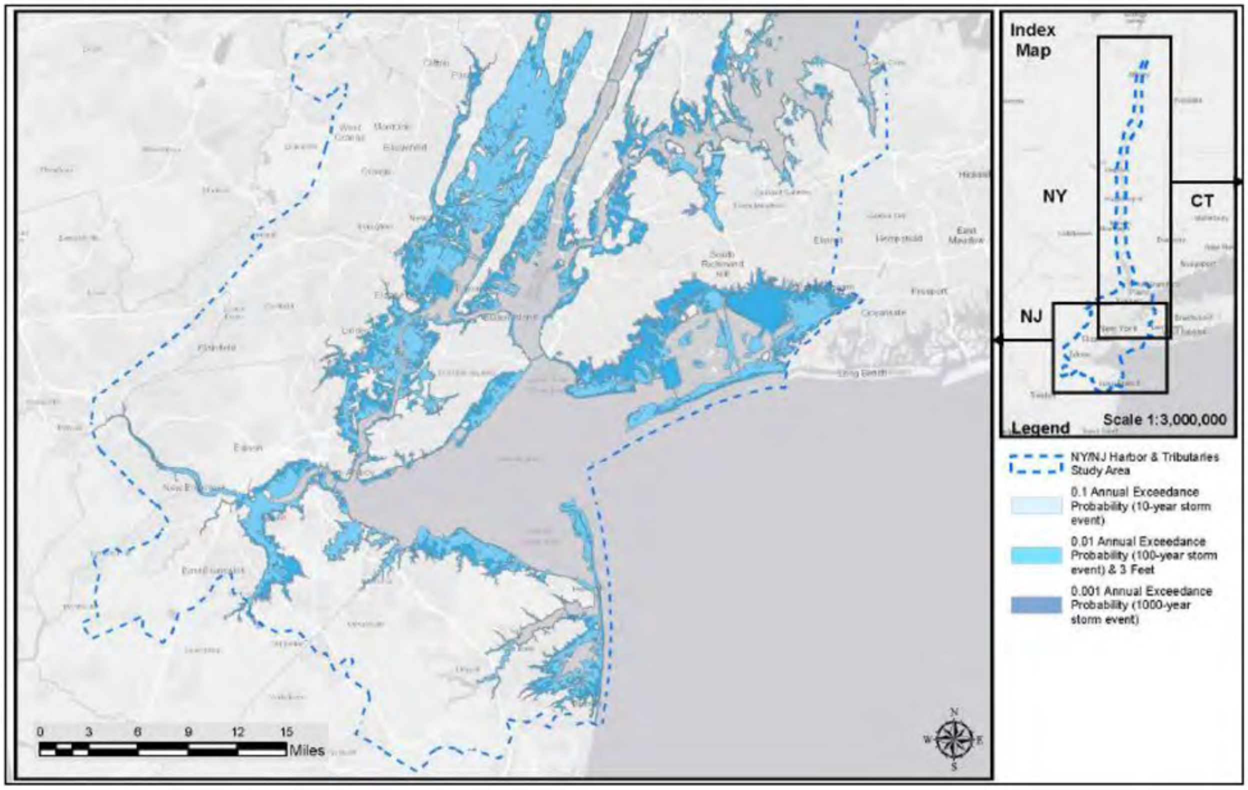


Figure 1 - NYNJHAT Study Area

The goal of the study was to refine the design of both the in-water (i.e., storm surge barriers) and land-based features (i.e., levees, floodwalls, etc.), in order to identify the TSP. The plans evaluated were grouped into two main engineering components: Storm Surge Barriers (SSBs) and Shore-Based Measures (SBMs).

The feasibility study phase advanced the design of the following three (3) selected Storm Surge Barriers from the conceptual level to the feasibility level:

- Verrazano Narrows (a feature of Alternative 3A),
- Jamaica Bay (a feature of Alternatives 3A and 3B), and
- Hackensack River (a feature of Alternative 4)

1.2 Purpose of Report

This Interior Drainage Sub-Appendix describes the basis of the interior drainage analysis associated with the study, specifically, the interior drainage features associated with the Storm Surge Barriers (SSBs) and Shore-Based Measures (SBMs). The SSBs include large pump stations as well as Risk Reduction Feature (RRF) which are land-based or in-water feature that can reduce residual coastal storm flooding prior to closure of a storm surge barrier, and to address risk behind a storm surge barrier due to interior drainage or other hydrodynamics, and Induced Flooding-Mitigation Feature (IFF), which are low level structures to limit potential induced flooding from the closure of the SSBs.

Typical SBM interior drainage features include gravity outfalls along the lines of protection and outfall chambers for the existing Combined Sewer System (CSS), which will allow diversion of combined flow to new pump stations.

2 INTERIOR DRAINAGE OVERVIEW

The purpose of this analysis is to provide estimates of interior drainage costs to support the economic analysis for both SSBs and SBMs. This involved two primary efforts:

- Identify preliminary pump station requirements associated with proposed SSB based on typical projects constructed in the region.
- Estimate interior drainage costs for SBMs based on typical projects in the projects in the region.

Any project that incorporates a barrier to storm surge flooding will also form a barrier to drainage of runoff in some conditions. The SSB limit the discharge from the river or estuary to the ocean while the barrier is closed, and the SBMs typically cut off interior stormwater drainage or overland flow. The SSBs will have pump stations, RRF and IFF to limit interior flooding. The SBMs typically include flap gates on new and existing drainage pipes to prevent storm surge from backing up through the drainage system and CSS pump stations.

USACE policy for interior drainage planning and design as documented in Engineer Manual (EM) 1110-2-1413 *Hydrologic Analysis of Interior Areas* (1987) is to include “Minimum Facility” interior drainage features integral to the line of protection (LOP) plus any additional facilities that are incrementally cost justified. Such assessments are highly complex, time consuming, and are frequently considered part of the optimization phase of study and are not necessary to meet the objectives of the current study. The current assessment incorporated a review of the interior drainage features for prior projects in the area that have similar rainfall and runoff characteristics in order to scale the various interior drainage features. The types of features in these prior projects, such as pump sizes at storm surge barriers, are considered representative of what would be expected as part of plans recommended as part of this study.

3 STORM SURGE BARRIER INTERIOR DRAINAGE

3.1 General Approach

The implementation of barriers and gates to reduce the risk of flooding from storm surges requires the addition of pump stations to prevent excessive flooding behind the line of protection when the barriers and gates are closed. The amount of pumping required is driven by many factors including the peak runoff rate, total runoff volume, the timing of runoff relative to the storm surge, as well as the amount of flood storage available upstream of the SSB. The assessment of pump capacity evaluated prior projects' relationship between the project's pump capacity and the storage area upstream of the gate, the peak flow in the river, and the tributary drainage area (as a representation of both the volume and timing of runoff). The results of this analysis are described below.

3.2 Data Collection

Data for similar pump stations associated with existing barriers in the northeast United States was collated and reviewed. The structures reviewed were:

- Fox Point Barrier, Providence, RI
- New Bedford Hurricane Barrier, New Bedford, MA
- Stamford Hurricane Protection Barrier, Stamford, CT
- Charles River Dam, Charlestown, MA
- Pews Creek Barrier, Port Monmouth, NJ
- South River Barrier, Sayreville, NJ (subsequently excluded since the barrier was not approved for construction).

The drainage area for each location was calculated using StreamStats®, the online spatial analysis tool developed by the USGS which enables users to delineate drainage areas and estimate peak flow characteristics. For each location, storage areas were calculated using standard GIS tools at elevation zero (0) feet or 1-foot NAVD88 (i.e., at the waterline), since pump size as a percentage of the peak inflow will vary based on the available storage. Inflows for each location were estimated using project reports, StreamStats® or existing gage data, depending on availability, and pump costs were derived from cost curves used for previous studies of a similar nature.

3.3 Development of Regression Curves

The regression equation used to estimate pump capacity as a percentage of inflow was developed by calculating two ratios: drainage area versus storage area, and pump capacity versus inflow. The areas and ratios calculated for this analysis are presented in **Table 1**.

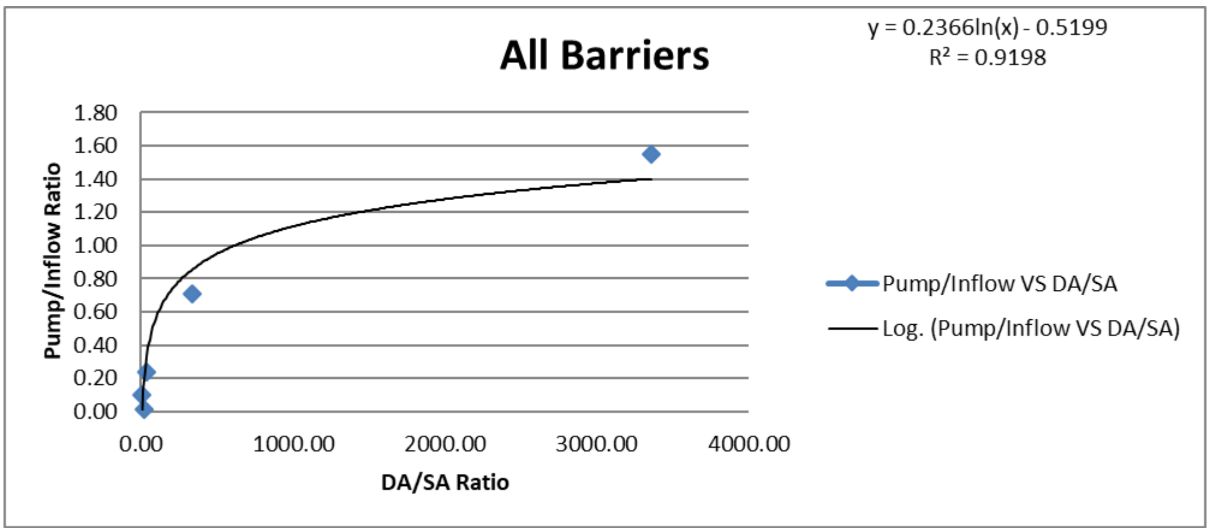
The drainage area versus storage area ratio was plotted against the pump capacity versus inflow ratio, as shown in **Figure 2**, and a regression equation was derived from the resulting curve.

Table 1 - Pump Analysis –Calculated Areas and Ratios

Name	Pump Capacity (cfs)	Drainage Area (DA) (square miles)	Peak Inflow (cfs)	Storage Area (SA) @1 ft NAVD88 (acres)	@5 ft NAVD88 (Acres)[1]	DA/SA ratio	Pump/Inflow Ratio
Fox Point Barrier	7,000	77	4,520	15	49	3,357	154%
New Bedford Barrier	240	29	16,000	986	2,689	19	2%
Stamford Barrier	100	2	422	37	47	33	24%
Charles River Dam	8,400	313	11,900	601	5,663	333	71%
Pews Creek	120	2	1,200	213	7,055	5	10%

[1]The 5ft NAVD88 elevation storage dimension is provided to give a sense of the spatial extent of the storage basin behind the barrier.

Figure 2 – SSB Pump and Drainage Area Ratio



3.4 SSB Pump Station Costs

The pumping requirements for various surge barriers proposed for the NYNJHAT project have been estimated using the curve-fitting formula shown in Figure 3. The storm surge barriers considered for the current assessment are presented in **Table 2**. The larger barriers under consideration, such as the Arthur Kill, Verrazano Narrows, Jamaica Bay, and the Rockaway to Sandy Hook Barriers are expected to be operated in a manner that limits closures to larger, low frequency storm events. Deployment of large SSBs solely during low frequency storm events will leave properties in the study area vulnerable to residual, high frequency flooding. Therefore, these barriers are expected to be supplemented with high frequency local protection features such as levees or floodwalls, or with non-structural measures, for which separate costs are provided in the Cost Appendix. High frequency local protection features will also provide protection against interior flooding, so additional interior drainage pump stations have not been included for the SSBs.

Table 2 – Summary of Interior Pumping at SSBs

SSB	Drainage Area (ac)	Storage Area (ac)	DA/SA	Pump/ Inflow Ratio	Inflow (100yr)	Pump Required (cfs)	Pump Station Cost (2022 PL)
Gowanus	1,714	17.04	100.6	57%	771	439	$12,700,000
Newtown	7,833	152.14	51.5	41%	3025	1,240	$21,020,000
Hackensack	122,577	5,787.7	21.2	20%	8320	1,664	$17,680,000
Pelham Bay	8,187	204.3	40.1	35%	2052	718	$17,770,000
Howard Beach	1801	53.4	33.7	31%	771	239	$7,630,000
Bay Gate	24813	654	37.9	34%	5795	1,970	$11,920,000
Raritan	704,000	2,643.65	266.3	80%	56100	22,440*	$204,220,000

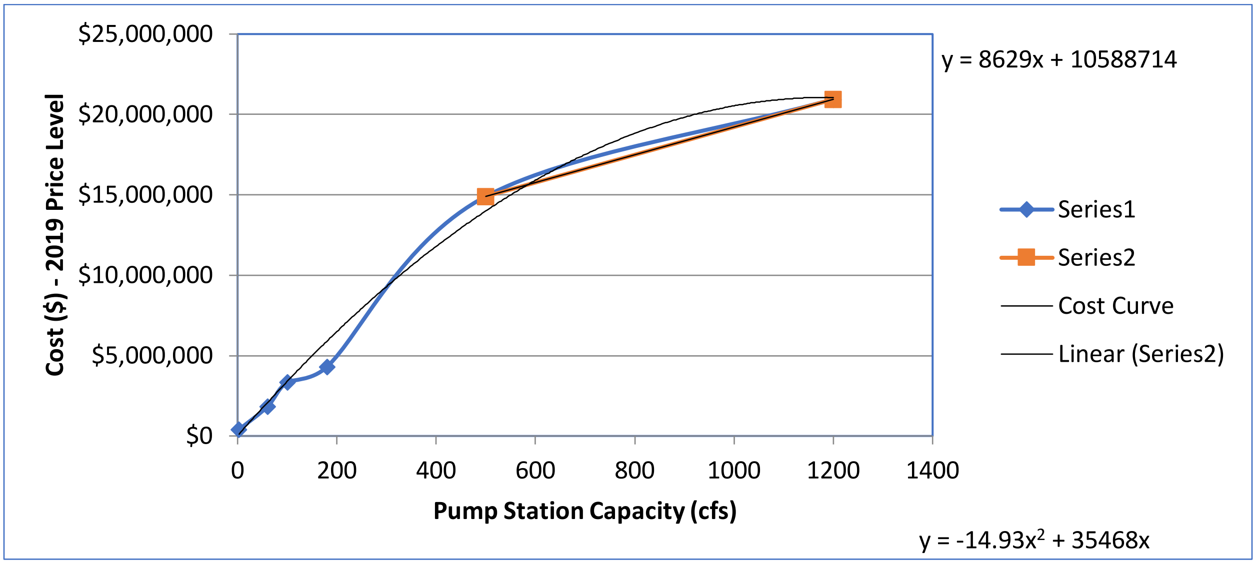
*Assume 50% of flow required (44,880 cfs / 2 = 22,440 cfs)

The pumping capacities of the four gates listed inThe **pumping** requirements for various surge barriers proposed for the NYNJHAT project have been estimated using the curve-fitting formula shown in Figure 3. The storm surge barriers considered for the current assessment are presented in **Table 2.** The larger barriers under consideration, such as the Arthur Kill, Verrazano Narrows, Jamaica Bay, and the Rockaway to Sandy Hook Barriers are expected to be operated in a manner that limits closures to larger, low frequency storm events. Deployment of large SSBs solely during low frequency storm events will leave properties in the study area vulnerable to residual, high frequency flooding. Therefore, these barriers are expected to be supplemented with high frequency local protection features such as levees or floodwalls, or with non-structural measures, for which separate costs are provided in the Cost Appendix. High frequency local protection features will also provide protection against interior flooding, so additional interior drainage pump stations have not been included for the SSBs.

Table 2 range from a high of 57% of the peak 1% Annual Exceedance Probability (AEP) at the Gowanus Canal barrier, to a low of 20% of the peak 1% AEP flow at the Hackensack River barrier. The 80% ratio for the Raritan River barrier is an outlier and a more practical value of 50% was used for the pump sizing and cost calculation. The need for a comparatively low pump capacity at the Hackensack Barrier is reasonable given the presence of extensive storage available in the Hackensack Meadowlands. In contrast, the Gowanus Canal is an industrial canal in an urban area and has relatively little storage available, resulting in the need to pump a larger proportion of the peak inflow.

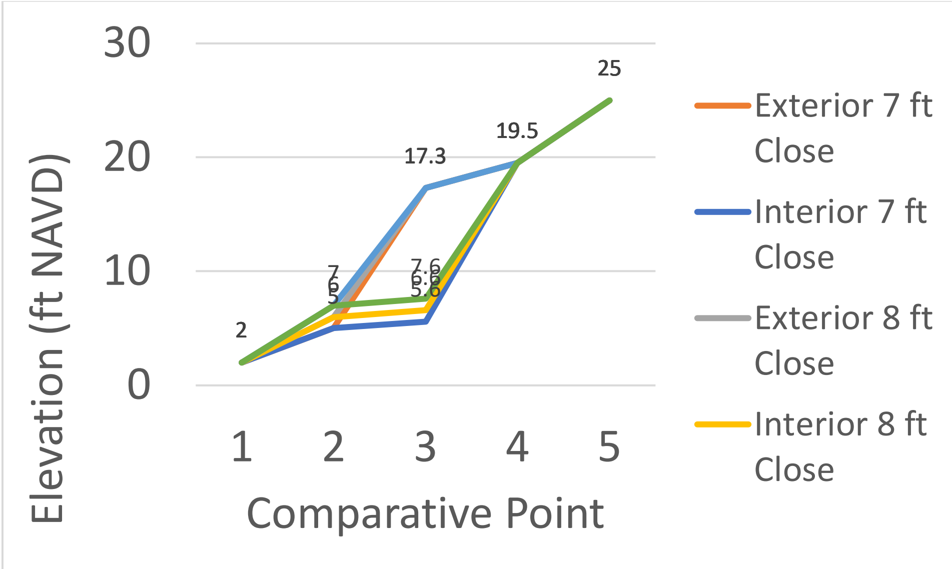
Pump station costs have been estimated using a cost curve developed from prior USACE projects. This curve reflects relatively simple pump stations where the pumps are located directly at the line of protection and there is no need for a force main or check valves, resulting in very low dynamic head loss. The pump station cost curves are shown in **Figure 3**. The need for a second linear cost curve is driven by the excessive flow of the Raritan River. As several smaller/mid-sized rivers drain into the Raritan River, the drainage area covers approximately 704,000 ac (1,100 sq mi). Due to this large basin size, to account for the timing of the various tributaries, 50% of the "pump required" flow was used in the pump station cost curve. To delineate a reasonable cost, a second linear curve was derived to extrapolate the large flow. The trendline for both the exponential and linear interpolation can be seen in the table.

Figure 3 – Pump Station Cost Curve



To limit frequent deployment of the SSBs, the proposed operating scenarios included not closing the storm gates until the water surface elevation (WSEL) reached a specific, trigger elevation. Closure of the gates at elevations 7 feet, 8 feet and 9 feet NAVD88 were evaluated with the calculated pump capacity to assess the potential economic impact. **Figure 4** shows the typical trends of exterior and interior WSELs preceding and following storm gate closure. The x-axis points represent a point of comparison between the interior and exterior water surface elevations before and during gate closure.

Figure 4 – Hackensack SSB Exterior/Interior WSEL Relationship



4 SHORE-BASED MEASURES INTERIOR DRAINAGE

4.1 General Approach

Areas protected from exterior flood elevations are subject to interior residual flooding from stormwater runoff. Thus, interior drainage facilities may be required to safely store and discharge the runoff to limit interior residual flooding. Typically, interior drainage is managed with a series of gravity outlets/outfalls, natural storage, excavated ponding, and pumping. On rare occasions, runoff can be diverted through or around the line of protection using pressure interceptors. Where space is available, the interior drainage can often be managed with gravity outlets, natural storage, and ponding. The cost of interior drainage facilities can vary with the size of the drainage area relative to the length of the line of protection, the cost of real estate, and the complexity of the existing drainage system.

As space becomes more limited, static interior drainage features can be supplemented with pump stations to reduce the water volume to be stored. The addition of the pumping capacity typically results in higher initial costs and a substantial increase in operating costs over the life of the project. One advantage of including pumping capacity is that the overall drainage facilities are easier to adapt to rising sea levels.

Where space is very limited, there may be no area for ponds or natural storage, and the drainage must be handled almost entirely by gravity pipes and pumps. In some cases, particularly in New York City, the stormwater outfalls are combined with wastewater to form Combined Sewer Overflows (CSOs). While several older projects, such as the New Bedford Hurricane Barrier, allowed open ponding of the CSO, it is anticipated that future projects will require special handling of CSO discharge. The majority of CSO areas are in NYC and they were defined and evaluated to provide a pump capacity equal to the collection system design criteria (5-year rainfall in NYC).

4.2 SBM Drainage Areas

Figure 5 shows all the major drainage areas considered in the SBM interior drainage analysis. Drainage areas were separated into two main types:

1) Combined sewer system drainage areas, which had CSO outfalls, and
2) Municipal Separate Storm Sewer System (MS4) drainage areas, which were stormwater-only and may or may not have had stormwater outfalls.

The distinction is critical because while MS4 outfalls may back up as a result of storm surge blockage, the result is residual stormwater surcharge of the drainage system or ponding in collection areas. Backup of the combined system results in combined stormwater-sanitary waste backing up into the system, the street, or homes and businesses. Thus, while MS4 systems can be equipped with only backflow devices, the combined system needs a means – pump stations – to maintain discharge to prevent significant health and safety issues with blocked sanitary lines.

Figures 6 through 12 depict the large-scale drainage areas for the following areas:

- Figure 6 - Gowanus Canal
- Figure 7 - Harlem
- Figure 8 - Long Island Sound (West)
- Figure 9 - Lower Bay-Coney Island
- Figure 10 - Outfalls OH-015 and OH-021
- Figure 11 - Staten Island
- Figure 12 - West Side Manhattan

Figure 5 – SBM Drainage Areas

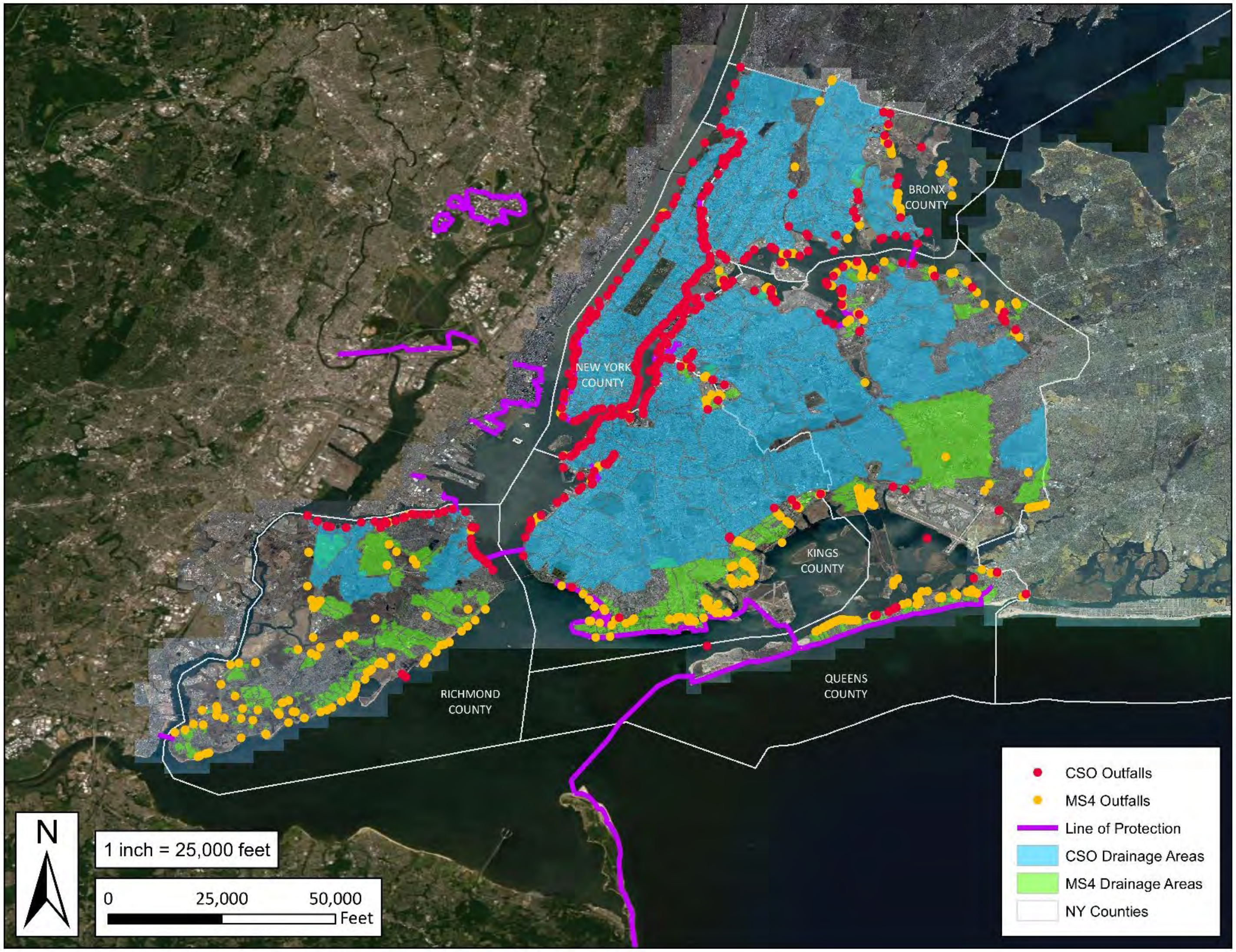


Figure 6 – Gowanus Canal Drainage Areas

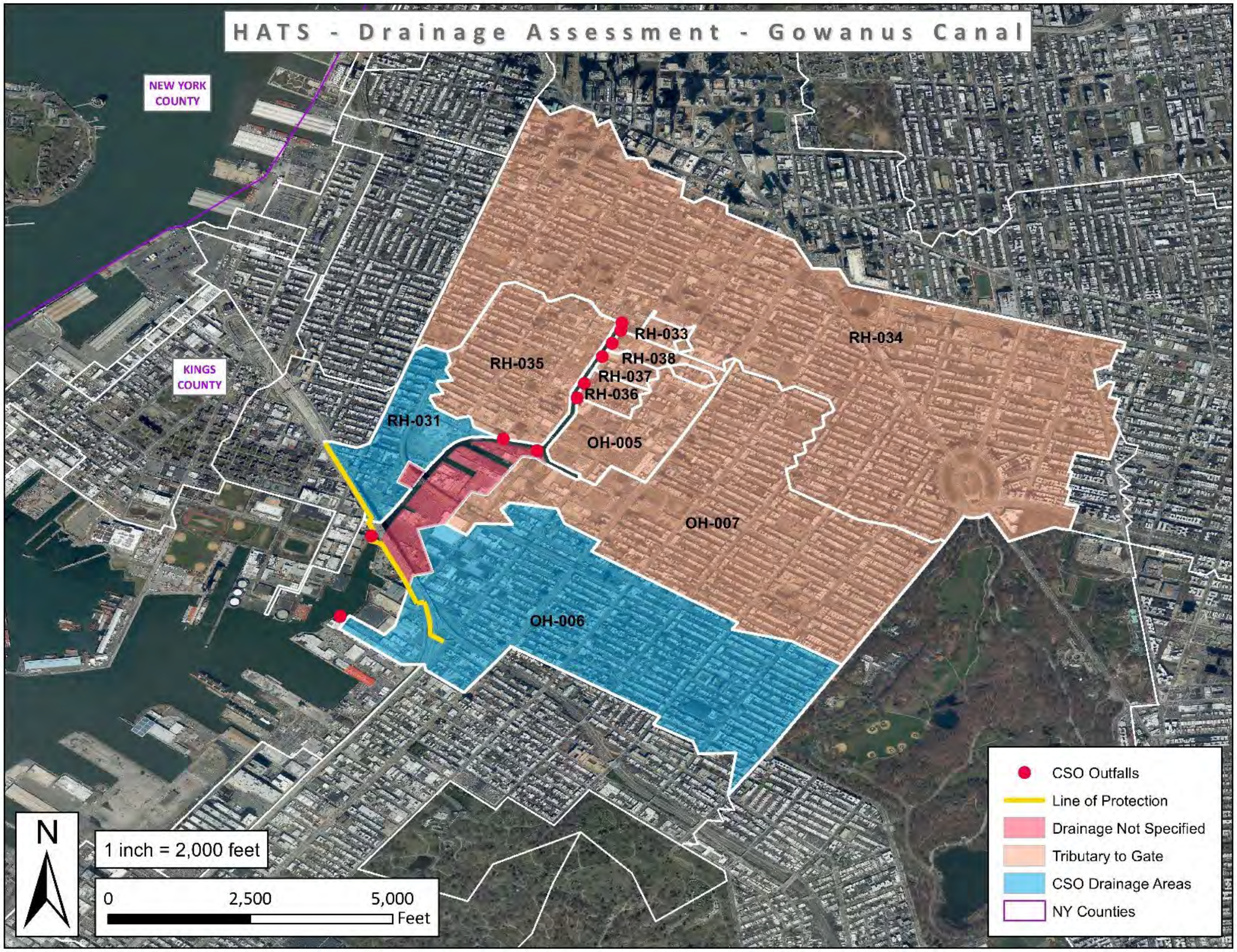


Figure 7 – Harlem Drainage Areas

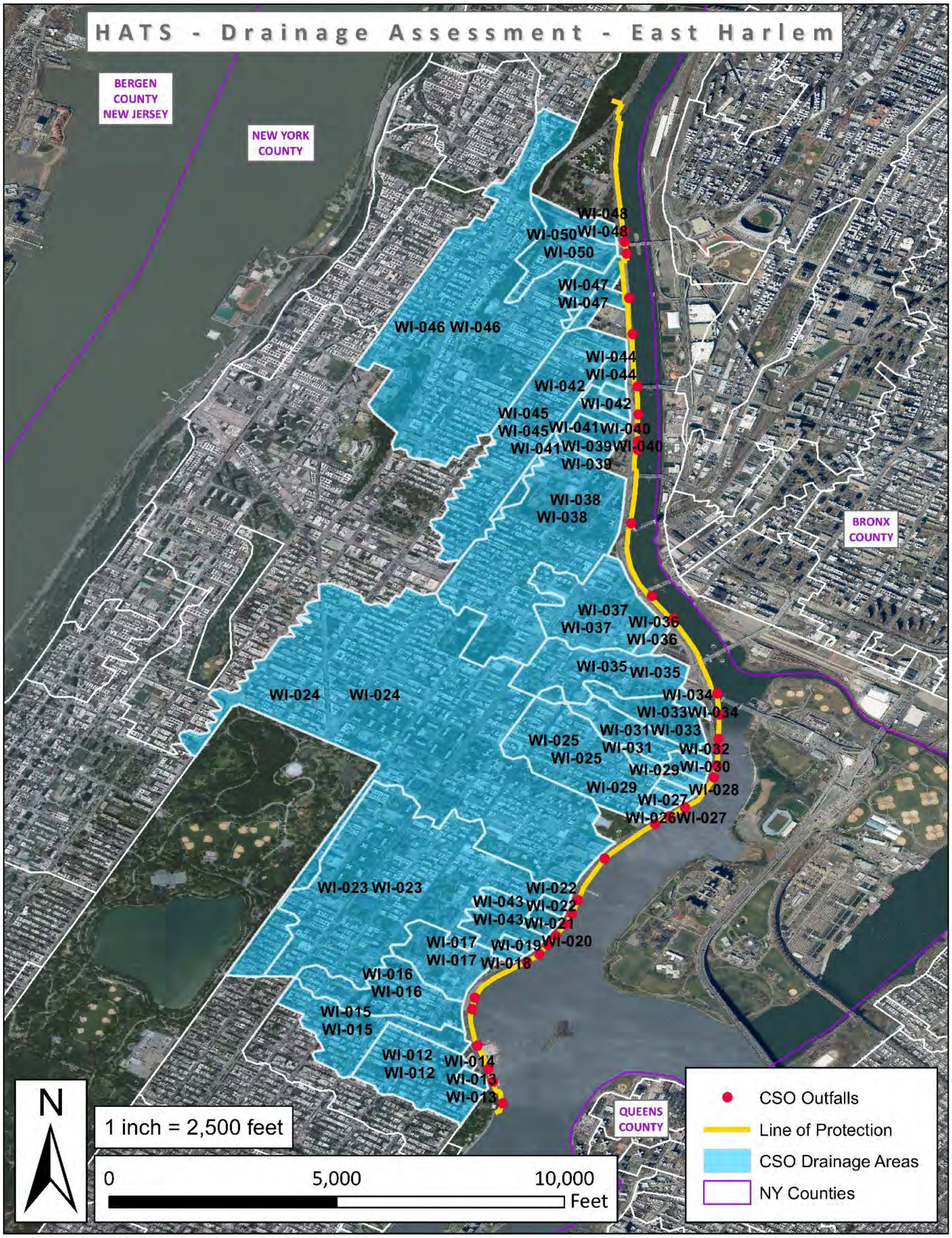


Figure 8 – Long Island Sound (West) Drainage Areas

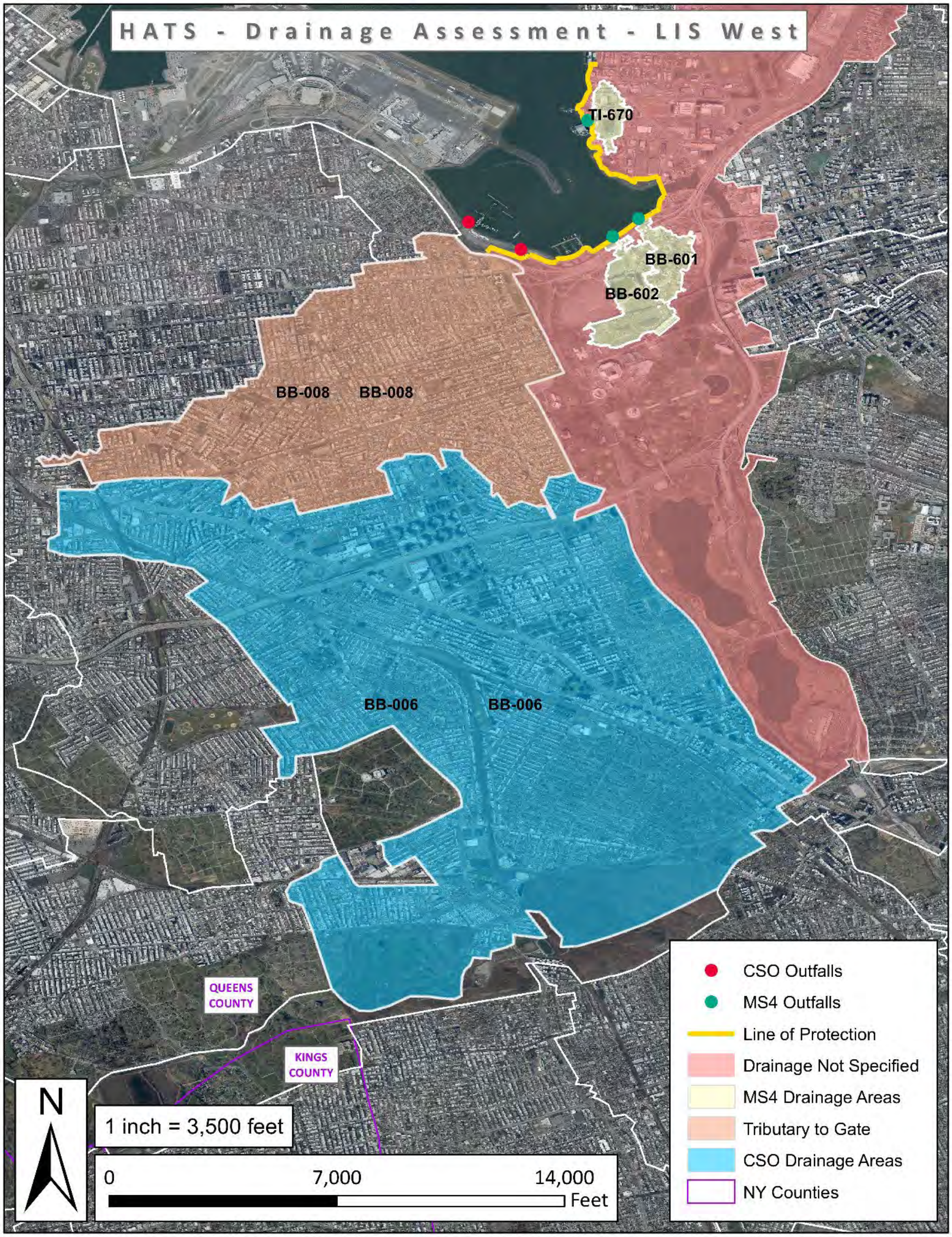


Figure 9 – Lower Bay-Coney Island Drainage Areas

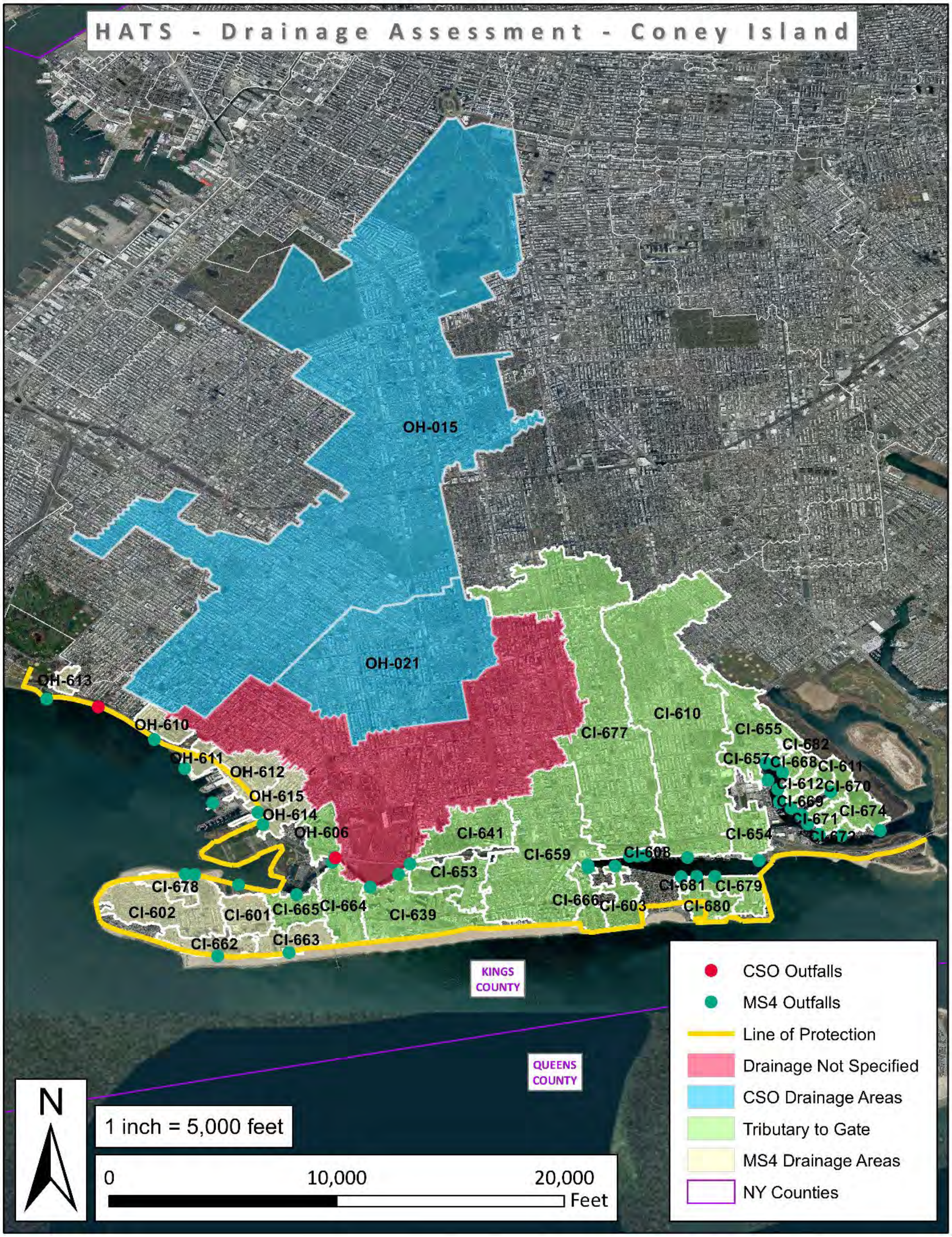


Figure 10 - Outfalls OH-015 and OH-021

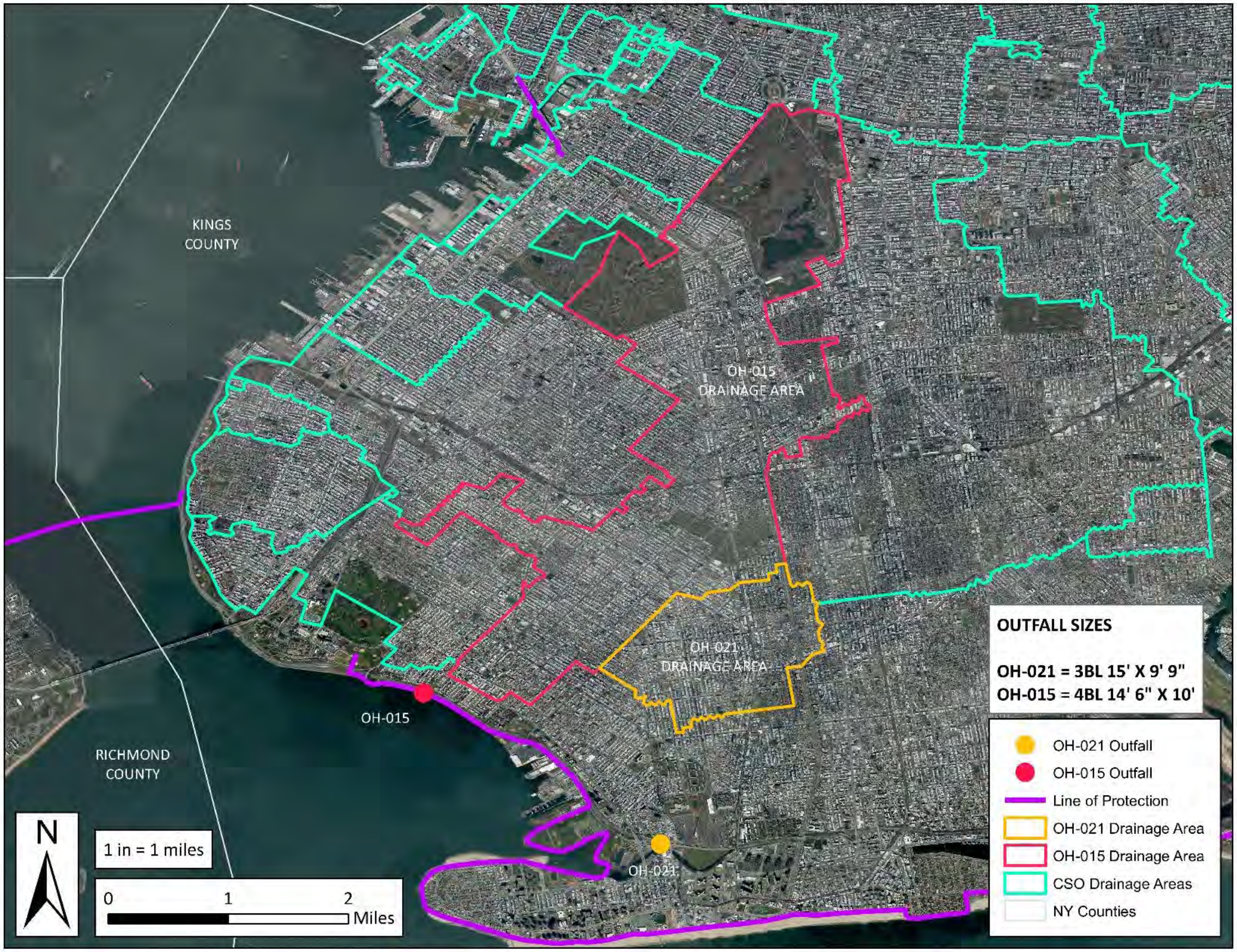


Figure 11 – Staten Island Drainage Areas

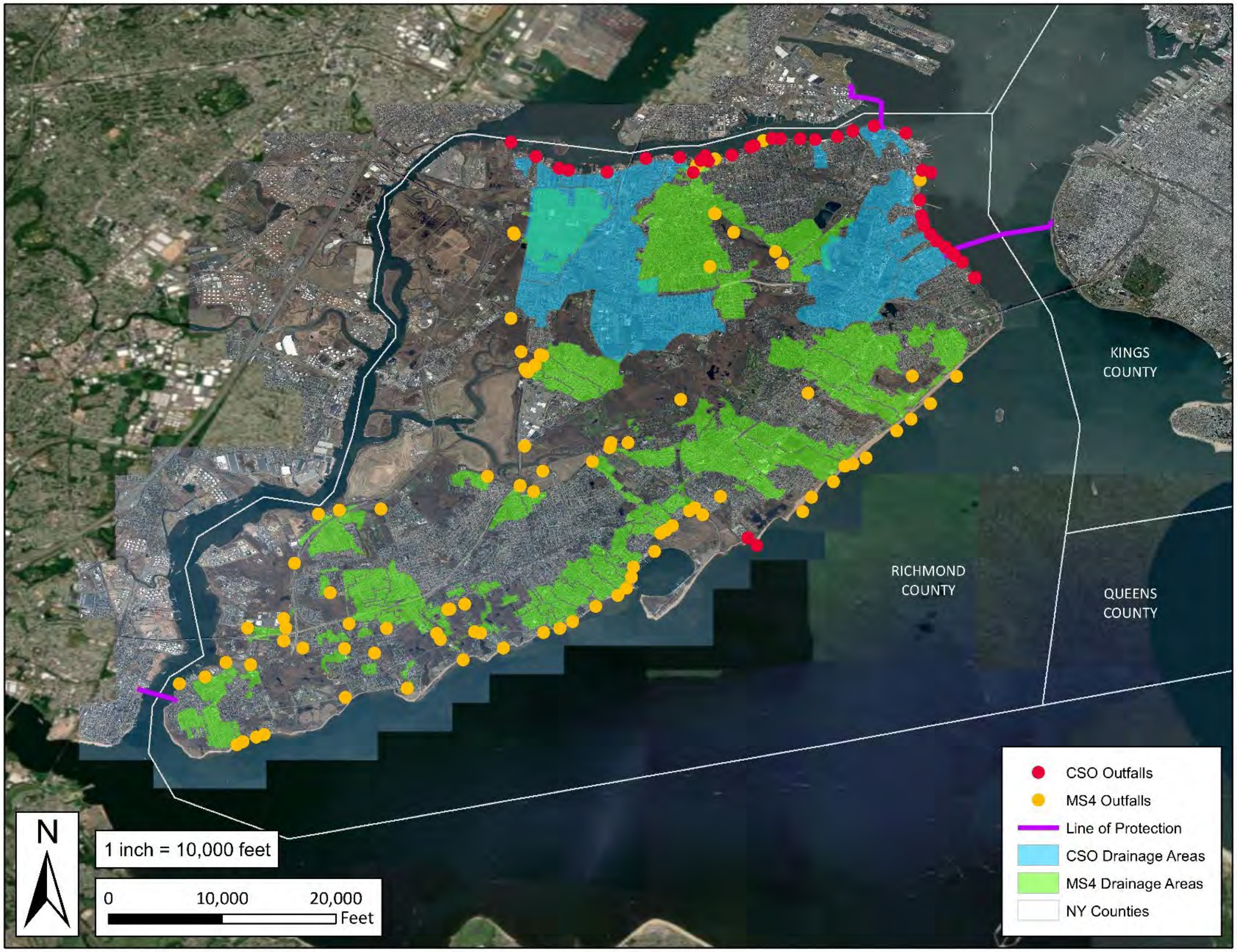
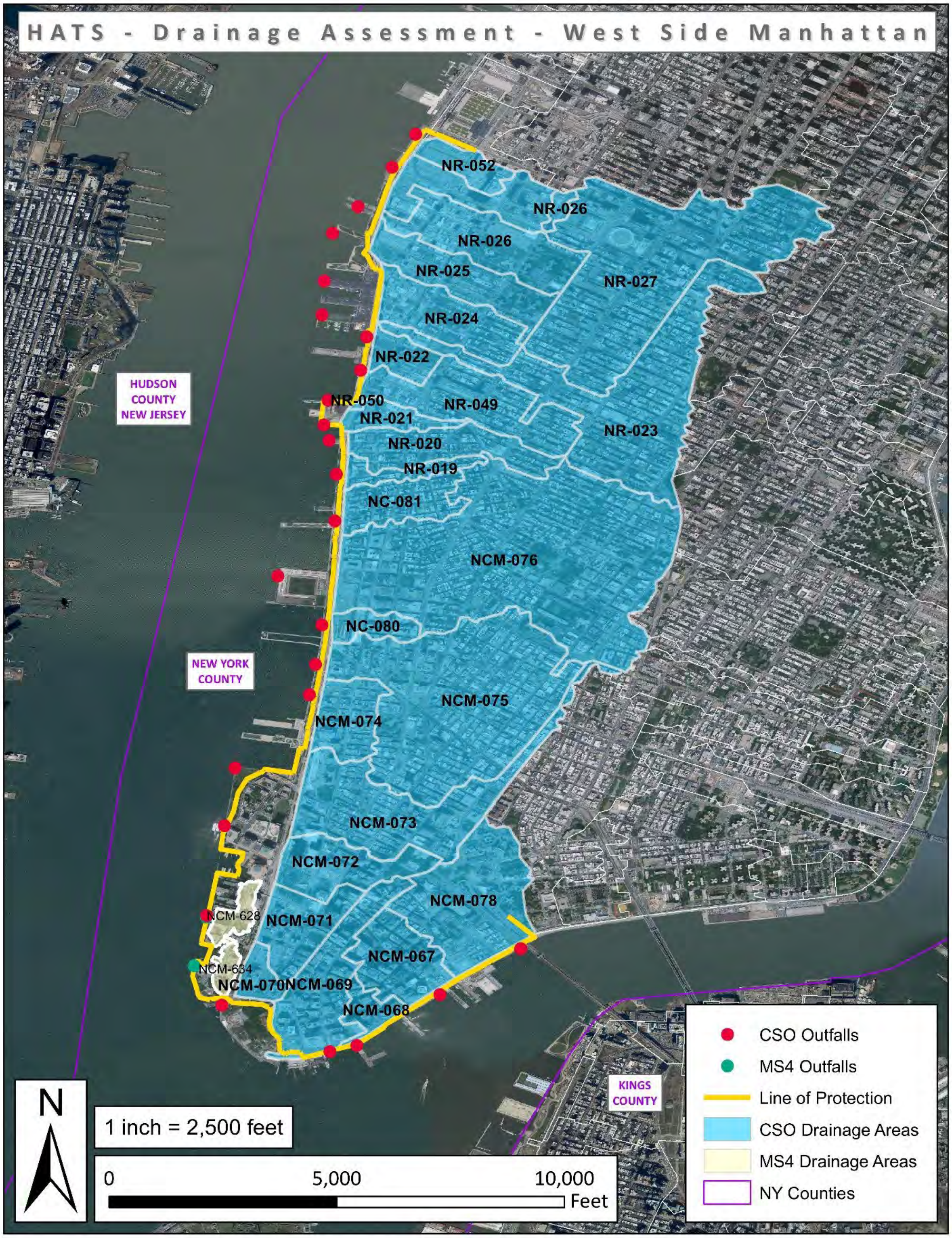


Figure 12 – West Side Manhattan Drainage Areas



4.3 Cost Estimate Development

For the purposes of estimating preliminary costs of interior drainage facilities behind fixed lines of protection, three conditions were identified, based on the storage/access constraints. These conditions are:

Unlimited/Limited Access:	This represents locations with enough volume to store floodwaters, typically without pumping, and areas where some limitations in space or high real estate costs make if more cost effective to pump a portion of the inflow.
Very Limited Access:	Fully developed locations where there are no areas available for natural or constructed storage. The drainage, therefore, requires pumping a high proportion of the inflows.
Combined Sewer Overflow:	Areas where local drainage is predominantly based on CSO facilities require a unique approach. This may include construction of underground storage or construction of pump stations with backup capacity. Interior drainage requirements for areas with CSOs have not been evaluated at this stage of the study.

4.3.1 General Interior Drainage Costs / Linear Foot Costs

Preliminary, interior drainage linear foot costs for a fixed line of protection were estimated based on the historical costs of such facilities for previously constructed or currently proposed USACE projects of a similar nature in the New York/New Jersey area. The coastal and/or flood risk management projects reviewed were:

- South Shore of Staten Island, NY
- Port Monmouth, NJ
- South River, Sayreville, NJ
- Green Brook Segment C, Bound Brook, NJ
- Rockaway/Jamaica Bay Backbay, NY

The calculation of preliminary interior drainage costs for the "Unlimited/Limited Access" and "Very Limited Access" conditions is summarized in **Table 3**.

Table 3 – Interior Drainage Historical Costs

Project Name	Location	Price Level	Interior Drainage Project Features	Interior Drainage Costs	I.D. Cost / LF	Total LOP Length	Update Factor Original Price Level (Acct 15)	Current Year Update Factor (Acct 15)	Interior Drainage Cost (2022)	I.D. Cost / LF (2022)
Unlimited and limited Access										
Staten Island FR Contract 1 (Area A& B M2 15 account)	Staten Island, NY	2016	Minimum Facility/ Ponds	**$47,058,507.00**	$3,790.15	12,416	799.5	1018.1	**$59,923,949**	**$4,826**
Staten Island FR Contract (Area C, D & E TPCS)	Staten Island, NY	2016	Min Fac/ Ponds	**$62,541,000.00**	$3,998.79	15,640	799.5	1018.1	**$79,639,239**	**$5,092**
SSSI Total						28,056			**$139,563,188**	**$4,974**
Port Monmouth	Port Monmouth, NJ	2011	Ponds/ Pumps	**$2,052,105.73**	$192.23	10,675	733.1	1018.1	**$2,849,708**	**$267**
South River	Sayerville, NJ	2015	Pump/ Ponds	**$5,718,893.00**	$419.09	13,646	790.6	1018.1	**$7,364,424**	**$540**
Green Brook (Seg C) - Int. Analysis	Bound Brook, NJ	2016	Ponds/ Pumps	**$2,234,150.93**	$136.73	16,340	799.5	1018.1	**$2,844,951**	**$174**
						Unlimited & Limited Access Average cost / lf				**$1,489**
Very Limited Access										
Rockaway/ Jamaica Bay - Mid Rockaway	Queens, NY	2019	Drainage Outlets/ Pumps	$ 44,307,000	$1,951.85	22700	877.4	1018.1	$44,307,000	**$1,952**
Rockaway/ Jamaica Bay - Cedarhurst	Nassau, NY	2019	Drainage Outlets/ Pumps	$ 3,606,000	$3,606.00	1000	877.4	1018.1	$3,606,000	**$3,606**
	Very Limited Access Average cost / lf									**$3,511**

4.3.2 SSBs Tie-Offs

The length for each project segment was multiplied by the linear foot cost to estimate the interior drainage costs per segment, including the landward tie-offs of the SSBs. This assessment does not include interior drainage costs for those SSBs tie-offs. It is assumed that the drainage for those tie-offs is directed to the interior of the barrier and that additional interior drainage features are not needed.

4.3.3 CSO Considerations

The historical costs assessment described in Section 4.3 utilized data from locations that do not have special requirements to address CSOs. In areas with combined drainage systems (sanitary and stormwater) additional design constraints are expected to avoid open ponding of stormwater that is contaminated with wastewater. The majority of the CSO areas to be considered lie within New York City. Initial assessments of CSO drainage requirements for coastal resilience projects developed by NYC have assumed that the CSO will need to be pumped through the SBMs to limit backup and ponding. The preliminary cumulative costs for CSO pumping developed by others for some areas, such as the NYC financial district, exceed $1 billion. This level of drainage costs could significantly alter the comparison of alternatives and the selection of the TSP. Thus, a detailed assessment of the CSOs was warranted.

Seventy-eight (78) CSO sub-basins (mapped drainage areas to outfalls) as shown in **Figures 6 through 12.** The interior drainage cost estimate for these areas was based on a conceptual level flow estimate to size the requisite pump stations and a conceptual chamber design to provide sluice gate and flap gate chambers for direct gravity discharges as well as a chamber to facilitate effluent by-pass to a pump station during storm surges that block the gravity flow. The NYC drainage design standard is to accommodate a 5-year AEP flow with full buildout; that is, the flow that will be used to estimate pump station capacity. This approach is generally consistent with the concept of Minimum Facilities, which are intended to maintain the function of the existing drainage system.

4.3.4 CSO Flow Calculations / Pump Costs

Flow estimates for each CSO outfall were developed using drainage areas and capacity/design information available from the NYC Department of Environmental Protection (NYCDEP). No hydrologic routing or hydraulic models were developed, only peak inflows. Pump station costs have been estimated using the NYC wastewater pump station cost curve. An additional 25% flow was added to incorporate redundancy in the pump station sizing. The costs were increased 20% and 60% (80%) to account for bypassing and automated trash racks, respectively. CSO pump station flows and costs (less chamber) are shown in **Table 4**.

Table 4 – CSO Pump Station Flow and Cost

Name / DA	Location	5-yr Flow + 25% (cfs)	Pump Station Cost*
OH-015	Coney Island	6,051	$177,669,000
OH-021	Coney Island	1,640	$48,601,800
WI-012	East Harlem	79	$2,935,800
WI-013	East Harlem	2	$669,600
WI-014	East Harlem	0.3	$624,600
WI-015	East Harlem	68	$2,606,400
WI-016	East Harlem	67	$2,590,200
WI-017	East Harlem	35	$1,643,400
WI-018	East Harlem	2	$664,200
WI-019	East Harlem	2	$671,400
WI-020	East Harlem	1	$651,600
WI-021	East Harlem	2	$666,000
WI-022	East Harlem	2	$673,200
WI-023	East Harlem	398	$12,265,200
WI-024	East Harlem	785	$23,590,800
WI-025	East Harlem	105	$3,693,600
WI-026	East Harlem	1	$658,800
WI-027	East Harlem	2	$687,600
WI-028	East Harlem	3	$705,600
WI-029	East Harlem	9	$865,800
WI-030	East Harlem	5	$752,400
WI-031	East Harlem	38	$1,738,800
WI-032	East Harlem	0.5	$630,000
WI-033	East Harlem	26	$1,389,600
WI-034	East Harlem	4	$718,200
WI-035	East Harlem	80	$2,955,600
WI-036	East Harlem	4	$738,000
WI-037	East Harlem	60	$2,376,000
WI-038	East Harlem	278	$8,760,600
WI-039	East Harlem	8	$855,000
WI-040	East Harlem	7	$810,000
WI-041	East Harlem	21	$1,225,800
WI-042	East Harlem	4	$727,200
WI-043	East Harlem	16	$1,074,600
WI-043A	East Harlem	0.4	$628,200
WI-044	East Harlem	5	$765,000
WI-045	East Harlem	183	$5,963,400
WI-046	East Harlem	499	$15,215,400
WI-047	East Harlem	12	$970,200
WI-048	East Harlem	2	$662,400
WI-050	East Harlem	45	$1,929,600
OH-005	Gowanus	80	$2,946,600
OH-006	Gowanus	522	$15,899,400
OH-007	Gowanus	551	$16,725,600
RH-031	Gowanus	77	$2,860,200
RH-033	Gowanus	4	$745,200
RH-034	Gowanus	1,115	$33,255,000
RH-035	Gowanus	134	$4,539,600

Name / DA	Location	5-yr Flow + 25% (cfs)	Pump Station Cost*
RH-036	Gowanus	8	$855,000
RH-037	Gowanus	4	$743,400
RH-038	Gowanus	8	$851,400
BB-006	LIS West	10,594	$310,608,000
BB-008	LIS West	3,622	$106,606,800
NC-080	West Side Manhattan	26	$1,373,400
NC-081	West Side Manhattan	72	$2,709,000
NCM-067	West Side Manhattan	92	$3,294,000
NCM-068	West Side Manhattan	29	$1,456,200
NCM-069	West Side Manhattan	162	$5,369,400
NCM-070	West Side Manhattan	21	$1,224,000
NCM-071	West Side Manhattan	80	$2,957,400
NCM-072	West Side Manhattan	78	$2,910,600
NCM-073	West Side Manhattan	310	$9,682,200
NCM-074	West Side Manhattan	68	$2,597,400
NCM-075	West Side Manhattan	547	$16,630,200
NCM-076	West Side Manhattan	943	$28,204,200
NCM-078	West Side Manhattan	185	$6,042,600
NR-019	West Side Manhattan	28	$1,443,600
NR-020	West Side Manhattan	94	$3,362,400
NR-021	West Side Manhattan	32	$1,557,000
NR-022	West Side Manhattan	27	$1,418,400
NR-023	West Side Manhattan	457	$13,986,000
NR-024	West Side Manhattan	103	$3,618,000
NR-025	West Side Manhattan	104	$3,657,600
NR-026	West Side Manhattan	174	$5,698,800
NR-027	West Side Manhattan	780	$23,428,800
NR-049	West Side Manhattan	182	$5,932,800
NR-050	West Side Manhattan	0.4	$628,200
NR-052	West Side Manhattan	29	$1,456,200
*2020 Price Level			

4.3.5 CSO Outfall By-pass Chambers

Conceptual chamber quantities for the sluice and flap gates were developed using the designs currently under development for the USACE South Shore Staten Island Coastal Flood Risk Management Project. The outfalls and associated dimensions were identified using the NYCDEP drainage maps. Quantities and costs for each outfall were estimated using a typical chamber dimensions calculator. The NYCDEP Drainage Maps contained three drainage areas with missing dimensions. The missing dimensions for outfalls WI-028, WI-029 and WI-043A were assumed to be identical as drainage areas with the closest equivalent acreage. A conservative approach has been taken when determining sluice and flap gate dimensions to accommodate various design uncertainties.

The following assumptions were made when calculating the quantities and cost per drainage area:

Combined sluice and flap gate chambers:

1. Single structure with a common interior separating the two gates.
2. Chamber height for sluice and flap gate section controlled by the proposed Line of Protection.
3. Set sluice gate section 10 feet long (2 feet for mounted frame plus 8 feet working area) and Flap section to 2 feet (for mounted frame) plus required length for gate to open and 3.5' for working area.
4. Set chamber width one foot beyond outside width of existing culvert (both sides). Assume no space between multiple culverts.
5. Exterior/interior walls, roof and base slab assumed to be 2 feet thick.
6. Access hatches included for maintenance, testing and gate removal.
7. Access hatch for flap gate chambers shall have grated opening for ventilation.

Chamber Layout:

1. Set interior width 2 feet wider than the existing culvert.
2. Assume exterior walls to be two foot thick.
3. Assume inside length of sluice gate chamber to be 10' long.
4. Set top of sluice gate roof slab to match line of protection.
5. Set Interior length of flap gate chamber to allow gate fully open plus 2 feet for mounting and min 3 feet working area.
6. Combined sluice/flap gate chamber with common wall between.
7. Set top of flap gate chamber two feet above existing grade.
8. Set chamber slab one foot below the existing pipe invert. Utilize concrete fill to create channel.

Pipe Data & Chamber Dimensions:

1. Set chamber width (sluice, flap gate & combined) minimum 2 feet wider than the existing culvert.
2. Set chamber roof elevation to match the line of protection for sluice gates and 2 feet above existing grade for flap gates.
3. Set interior chamber length to 10 feet for sluice gate & mounted flap gate length in the open position plus.
4. Set chamber invert to -3.0

Gate dimensions are shown in **Table 5**.

Table 5 – CSO Outfall Chamber Dimensions

Name / DA	Location	Pipe Width (feet)	Pipe Height (feet)
OH-015	Coney Island	14.50	10.00
OH-021	Coney Island	15.00	9.75
WI-012	East Harlem	5.00	
WI-013	East Harlem	4.00	2.33
WI-014	East Harlem	1.25	
WI-015	East Harlem	4.00	
WI-016	East Harlem	4.00	
WI-017	East Harlem	3.50	
WI-018	East Harlem	3.50	2.33
WI-019	East Harlem	4.00	2.33
WI-020	East Harlem	4.00	2.33
WI-021	East Harlem	3.50	2.33
WI-022	East Harlem	4.00	2.33
WI-023	East Harlem	6.00	7.50
WI-024	East Harlem	8.50	7.50
WI-025	East Harlem	5.25	8.00
WI-026	East Harlem	1.25	
WI-027	East Harlem	1.25	
WI-028	East Harlem	1.25	
WI-029	East Harlem	4.00	2.67
WI-030	East Harlem	4.50	2.33
WI-031	East Harlem	5.00	4.50
WI-032	East Harlem	4.00	2.33
WI-033	East Harlem	4.75	4.00
WI-034	East Harlem	3.50	2.33
WI-035	East Harlem	4.00	2.67
WI-036	East Harlem	3.50	
WI-037	East Harlem	4.00	2.67
WI-038	East Harlem	6.00	8.50
WI-039	East Harlem	4.00	2.67
WI-040	East Harlem	5.00	2.33
WI-041	East Harlem	6.00	4.00
WI-042	East Harlem	3.50	2.00
WI-043	East Harlem	3.50	
WI-043A	East Harlem	3.50	2.33
WI-044	East Harlem	6.00	2.67
WI-045	East Harlem	6.00	5.50
WI-046	East Harlem	8.50	8.00
WI-047	East Harlem	6.00	4.00
WI-048	East Harlem	4.00	2.33
WI-050	East Harlem	1.25	
OH-005	Gowanus	3.50	
OH-006	Gowanus	3.00	
OH-007	Gowanus	6.50	
RH-031	Gowanus	6.00	
RH-033	Gowanus	3.50	

Name / DA	Location	Pipe Width (feet)	Pipe Height (feet)
RH-034	Gowanus	10.00	10.00
RH-035	Gowanus	2.00	
RH-036	Gowanus	1.50	
RH-037	Gowanus	1.50	
RH-038	Gowanus	12.00	5.25
BB-006	LIS West	10.50	9.17
BB-008	LIS West	13.75	8.00
NC-080	West Side Manhattan	4.00	
NC-081	West Side Manhattan	5.00	4.00
NCM-067	West Side Manhattan	6.00	6.00
NCM-068	West Side Manhattan	4.50	3.67
NCM-069	West Side Manhattan	5.00	4.00
NCM-070	West Side Manhattan	7.00	
NCM-071	West Side Manhattan	8.00	
NCM-072	West Side Manhattan	8.00	
NCM-073	West Side Manhattan	4.50	
NCM-074	West Side Manhattan	5.00	3.67
NCM-075	West Side Manhattan	5.50	
NCM-076	West Side Manhattan	12.00	6.25
NCM-078	West Side Manhattan	12.00	6.00
NR-019	West Side Manhattan	4.00	
NR-020	West Side Manhattan	4.00	
NR-021	West Side Manhattan	4.00	
NR-022	West Side Manhattan	4.50	
NR-023	West Side Manhattan	5.00	4.50
NR-024	West Side Manhattan	4.00	
NR-025	West Side Manhattan	3.50	
NR-026	West Side Manhattan	4.00	3.00
NR-027	West Side Manhattan	11.00	6.00
NR-049	West Side Manhattan	6.00	4.00
NR-050	West Side Manhattan	3.50	2.33
NR-052	West Side Manhattan	4.75	4.50

4.3.6 CSO Pump Station Costs

The total cost estimate per CSO drainage area includes the sluice and flap gate chamber cost as well as the pump station cost with bypassing and trash rack, as shown in **Table 6**.

Table 6 – CSO Pump Station Costs

Name / DA	Location	Outfall Chamber	Pump Station	Total Pump Station and Outfall
OH-015	Coney Island	$7,385,800	$177,669,000	$185,054,800
OH-021	Coney Island	$6,223,800	$48,601,800	$54,825,600
WI-012	Harlem	$1,777,900	$2,935,800	$4,713,700
WI-013	Harlem	$1,572,000	$669,600	$2,241,600
WI-014	Harlem	$1,407,800	$624,600	$2,032,400
WI-015	Harlem	$1,641,800	$2,606,400	$4,248,200
WI-016	Harlem	$1,641,800	$2,590,200	$4,232,000
WI-017	Harlem	$1,585,000	$1,643,400	$3,228,400
WI-018	Harlem	$1,539,900	$664,200	$2,204,100
WI-019	Harlem	$1,572,000	$671,400	$2,243,400
WI-020	Harlem	$1,572,000	$651,600	$2,223,600
WI-021	Harlem	$1,539,900	$666,000	$2,205,900
WI-022	Harlem	$1,572,000	$673,200	$2,245,200
WI-023	Harlem	$2,221,300	$12,265,200	$14,486,500
WI-024	Harlem	$2,447,400	$23,590,800	$26,038,200
WI-025	Harlem	$2,163,400	$3,693,600	$5,857,000
WI-026	Harlem	$1,407,800	$658,800	$2,066,600
WI-027	Harlem	$1,407,800	$687,600	$2,095,400
WI-028	Harlem	$1,407,800	$705,600	$2,113,400
WI-029	Harlem	$1,595,400	$865,800	$2,461,200
WI-030	Harlem	$1,620,800	$752,400	$2,373,200
WI-031	Harlem	$1,813,100	$1,738,800	$3,551,900
WI-032	Harlem	$1,580,500	$630,000	$2,210,500
WI-033	Harlem	$1,777,700	$1,389,600	$3,167,300
WI-034	Harlem	$1,589,000	$718,200	$2,307,200
WI-035	Harlem	$1,595,400	$2,955,600	$4,551,000
WI-036	Harlem	$1,585,000	$738,000	$2,323,000
WI-037	Harlem	$1,616,600	$2,376,000	$3,992,600
WI-038	Harlem	$2,275,500	$8,760,600	$11,036,100
WI-039	Harlem	$1,595,400	$855,000	$2,450,400
WI-040	Harlem	$1,649,100	$810,000	$2,459,100
WI-041	Harlem	$1,896,400	$1,225,800	$3,122,200
WI-042	Harlem	$1,528,300	$727,200	$2,255,500
WI-043	Harlem	$1,585,000	$1,074,600	$2,659,600
WI-043A	Harlem	$1,520,700	$628,200	$2,148,900
WI-044	Harlem	$1,721,300	$765,000	$2,486,300
WI-045	Harlem	$2,019,300	$5,963,400	$7,982,700
WI-046	Harlem	$2,483,700	$15,215,400	$17,699,100
WI-047	Harlem	$1,896,400	$970,200	$2,866,600
WI-048	Harlem	$1,603,900	$662,400	$2,266,300
WI-050	Harlem	$1,407,800	$1,929,600	$3,337,400
OH-005	Gowanus	$1,585,000	$2,946,600	$4,531,600
OH-006	Gowanus	$1,533,600	$15,899,400	$17,433,000
OH-007	Gowanus	$2,035,100	$16,725,600	$18,760,700
RH-031	Gowanus	$1,942,400	$2,860,200	$4,802,600
RH-033	Gowanus	$1,585,000	$745,200	$2,330,200
RH-034	Gowanus	$5,522,000	$33,255,000	$38,777,000
RH-035	Gowanus	$1,496,900	$4,539,600	$6,036,500
RH-036	Gowanus	$1,420,000	$855,000	$2,275,000

Name / DA	Location	Outfall Chamber	Pump Station	Total Pump Station and Outfall
RH-037	Gowanus	$1,420,000	$743,400	$2,163,400
RH-038	Gowanus	$2,495,400	$851,400	$3,346,800
BB-006	LIS West	$2,989,300	$310,608,000	$313,597,300
BB-008	LIS West	$3,252,500	$106,606,800	$109,859,300
NC-080	West Side Manhattan	$1,732,000	$1,373,400	$3,105,400
NC-081	West Side Manhattan	$1,834,000	$2,709,000	$4,543,000
NCM-067	West Side Manhattan	$2,031,800	$3,294,000	$5,325,800
NCM-068	West Side Manhattan	$1,708,400	$1,456,200	$3,164,600
NCM-069	West Side Manhattan	$1,793,500	$5,369,400	$7,162,900
NCM-070	West Side Manhattan	$2,183,000	$1,224,000	$3,407,000
NCM-071	West Side Manhattan	$2,400,000	$2,957,400	$5,357,400
NCM-072	West Side Manhattan	$2,415,600	$2,910,600	$5,326,200
NCM-073	West Side Manhattan	$1,768,300	$9,682,200	$11,450,500
NCM-074	West Side Manhattan	$1,791,400	$2,597,400	$4,388,800
NCM-075	West Side Manhattan	$1,622,800	$16,630,200	$18,253,000
NCM-076	West Side Manhattan	$2,627,900	$28,204,200	$30,832,100
NCM-078	West Side Manhattan	$2,611,800	$6,042,600	$8,654,400
NR-019	West Side Manhattan	$1,678,200	$1,443,600	$3,121,800
NR-020	West Side Manhattan	$1,678,200	$3,362,400	$5,040,600
NR-021	West Side Manhattan	$1,678,200	$1,557,000	$3,235,200
NR-022	West Side Manhattan	$1,744,300	$1,418,400	$3,162,700
NR-023	West Side Manhattan	$1,813,100	$13,986,000	$15,799,100
NR-024	West Side Manhattan	$1,641,800	$3,618,000	$5,259,800
NR-025	West Side Manhattan	$1,585,000	$3,657,600	$5,242,600
NR-026	West Side Manhattan	$1,642,800	$5,698,800	$7,341,600
NR-027	West Side Manhattan	$2,504,200	$23,428,800	$25,933,000
NR-049	West Side Manhattan	$1,896,400	$5,932,800	$7,829,200
NR-050	West Side Manhattan	$1,578,400	$628,200	$2,206,600
NR-052	West Side Manhattan	$1,803,100	$1,456,200	$3,259,300
*2020 Price Level				

4.4 SBM Interior Drainage Costs

Total interior drainage costs per SBM are shown in **Table 7**.

Table 7 – SBM Total Interior Drainage Costs

SBM Location	Length	Base Cost (LF cost)	New Outfall Chambers	Pump Stations	Total
Astoria SBM	21,205	$69,976,500	$0	$0	$69,976,500
Coney Island	61,700	$80,210,000	$13,609,600	$226,270,800	$320,090,400
Gowanus Canal	3,000	$9,900,000	$21,035,400	$79,421,400	$110,356,800
Long Island Sound West	8,000	$26,400,000	$6,241,800	$417,214,800	$449,856,600
East Harlem SBM	24,916	$38,370,800	$60,306,100	$104,887,800	$203,564,700
Hackensack Perimeter SBM	57,422	$74,648,600	$0	$0	$74,648,600
Haverstraw SBM	9,514	$12,368,200	$0	$0	$12,368,200
Long Island City Astoria SBM	17,153	$56,604,900	$0	$0	$56,604,900
New Jersey along Hudson River SBM	43,055	$141,889,500	$0	$0	$141,889,500
New York City West Side SBM	32,283	$71,791,900	$43,580,300	$138,045,600	$253,417,800
Ossining SBM	3,789	$4,925,700	$0	$0	$4,925,700
Tarrytown SBM	7,324	$14,111,200	$0	$0	$14,111,200
Yonkers	13,093	$17,020,900	$0	$0	$17,020,900
TOTALS =	**302,454**	**$618,218,200**	**$144,773,200**	**$965,840,400**	**$1,728,831,800**
*2020 Price Level					

5 RISK REDUCTION FEATURES

As described in Section 3, the SSBs gates' operational parameters will likely require maintaining the gates in the open position during high frequency storm events and/or as a surge approaches. That operational scenario will result in moderate surge inside the SSBs. The TSP assessment determined the needs and extents of the SBMs to manage both induced flooding associated with the storm surge barriers and RRFs incorporated to manage flood risk from storm events where the SSBs may be open to maintain navigation access to the harbor. The interior drainage costs for these additional RRFs were estimated in the same manner as described above for linear foot costs. The costs for the RRFs, shown in **Table 8**, will be incorporated into each alternative as appropriate.

Table 8 – RRF Interior Drainage Cost Estimates

RRF Name	Length (ft)	Type	Int. Drng Cost*
Arthur Kill	189	VERY LIMITED	$622,000
Atlantic Basin	2,900	UNLIMITED	$3,770,000
Bayonne Bridge	390	UNLIMITED	$507,000
Bergen Pt SI	1,433	UNLIMITED	$1,863,000
Bridge Street Bridge	989	UNLIMITED	$1,286,000
Caseys Creek	761	VERY LIMITED	$2,510,000
Chelsea	5,525	UNLIMITED	$7,182,000
Clay Street Bridge	1,040	UNLIMITED	$1,352,000
Coney Is Creek	4,599	UNLIMITED	$5,979,000
Dock Bridge	897	UNLIMITED	$1,166,000
Elizabeth River	1,150	UNLIMITED	$1,494,000
Elizabethport	3,948	UNLIMITED	$5,133,000
EssexCntyCorrFac	6,340	UNLIMITED	$8,242,000

RRF Name	Length (ft)	Type	Int. Drng Cost*
Flushing Creek	1,009	UNLIMITED	$1,312,000
Fort Hancock	3,129	UNLIMITED	$4,068,000
Gowanus Canal	1,342	VERY LIMITED	$4,429,000
Green Pt LI	2,002	UNLIMITED	$2,603,000
Hackensack River	5,816	UNLIMITED	$7,561,000
Harrison Reach	623	UNLIMITED	$810,000
Highlands	9,247	VERY LIMITED	$30,516,000
HudsonCntyCorrFac	1,660	UNLIMITED	$2,157,000
Jersey City	2,322	UNLIMITED	$3,018,000
KearnyPoint	5,158	UNLIMITED	$6,705,000
Kips Bay	1,597	UNLIMITED	$2,077,000
Lenox Yard	329	UNLIMITED	$427,000
Leonardo	1,431	UNLIMITED	$1,860,000
Long Island City	3,903	UNLIMITED	$5,073,000
Many Mind Creek	103	VERY LIMITED	$340,000
Mariners Harbor SI E	4,106	UNLIMITED	$5,338,000
Mariners Harbor SI W	2,786	UNLIMITED	$3,622,000
meadowlandsgate	23,180	VERY LIMITED	$76,494,000
Morses Creek	1,060	UNLIMITED	$1,378,000
Newton Creek	370	VERY LIMITED	$1,222,000
Norfolk Southern	3,160	UNLIMITED	$4,108,000
North Arlington	1,221	UNLIMITED	$1,588,000
Passaic River	1,258	UNLIMITED	$1,635,000
Passaic Upriver	2,797	UNLIMITED	$3,636,000
Red Hook	3,982	UNLIMITED	$5,177,000
RockawayPt	7,065	UNLIMITED	$9,184,000
Route 1 Bridge	1,324	UNLIMITED	$1,722,000
Roxbury	3,617	UNLIMITED	$4,702,000
S. Kearny-Passaic	2,340	UNLIMITED	$3,042,000
Sheepshead Bay	10,568	UNLIMITED	$13,738,000
Shell - Passaic	879	LIMITED	$1,143,000
South River	5,458	UNLIMITED	$7,095,000
South Slope	2,300	UNLIMITED	$2,990,000
Tottenville	2,585	UNLIMITED	$3,361,000
Tremley	559	LIMITED	$727,000
UpperHudson	5,575	UNLIMITED	$7,247,000
Wall Street	5,009	UNLIMITED	$6,512,000
Whitehead	2,734	LIMITED	$3,554,000
Yankee Stadium	2,896	UNLIMITED	$3,764,000
Arthur Kill	189	VERY LIMITED	$622,000
*2020 Price Level			