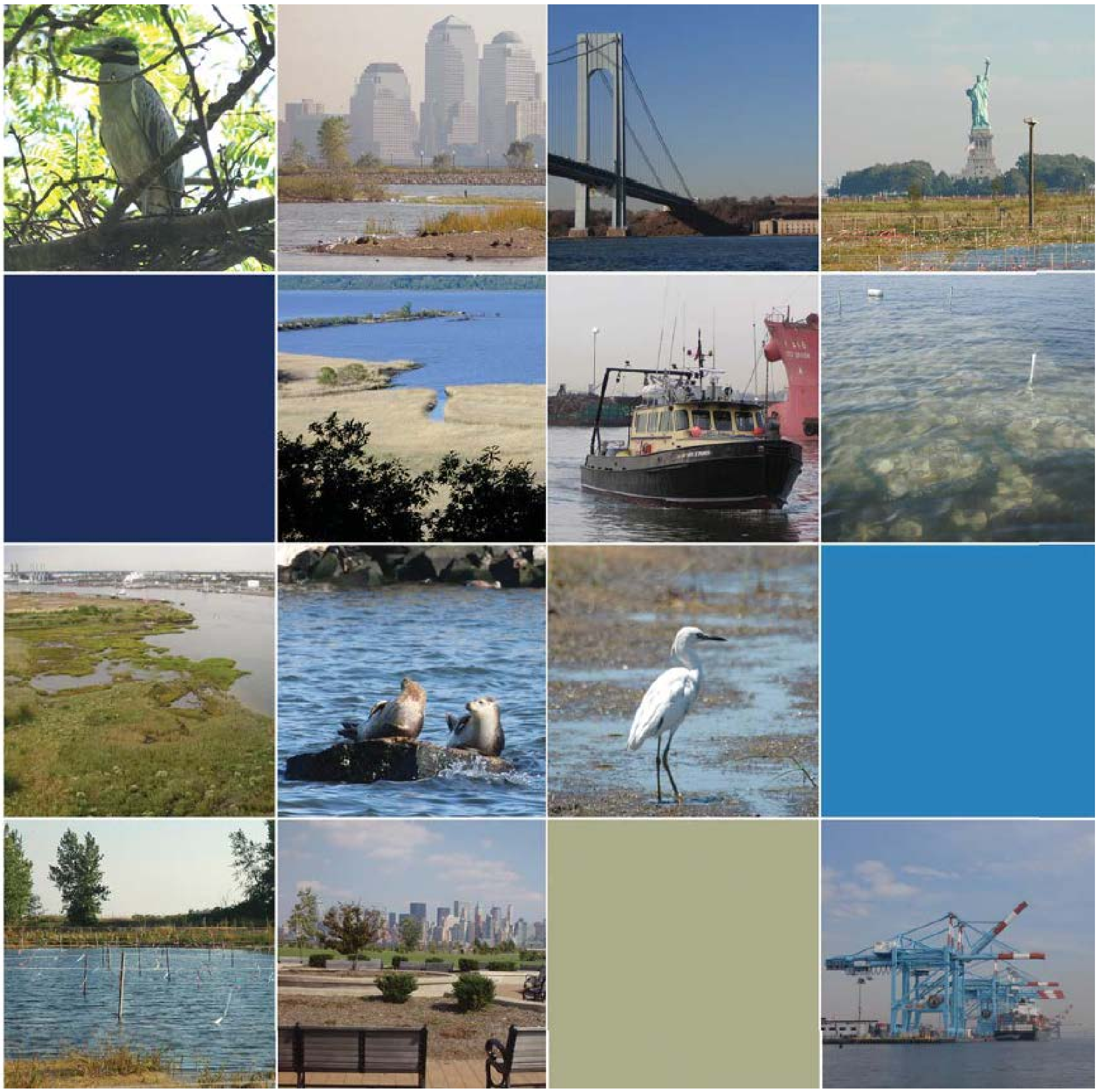
Hudson-Raritan Estuary Ecosystem Restoration Feasibility Study

Appendix D
Engineering

Draft Integrated Feasibility Report & Environmental Assessment
February 2017

Prepared by the New York District, North Atlantic Division, U.S. Army Corps of Engineers



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Appendix D: Engineering

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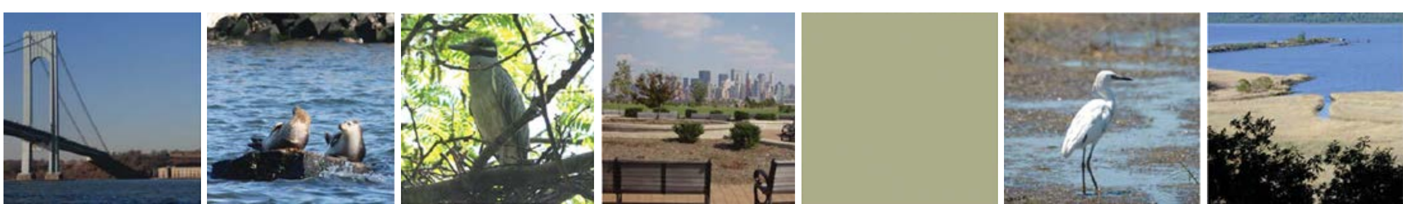

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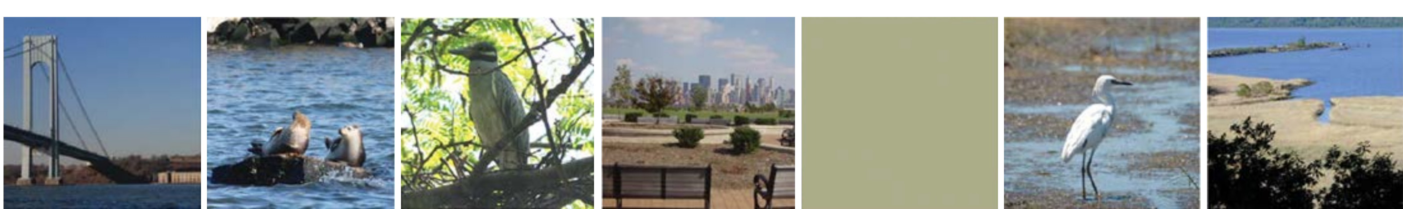


Attachments

1 Introduction

This appendix presents supporting available technical information, including topography, bathymetry, geotechnical, hydrology & hydraulics (H&H) and modeling, which was considered during formulation of the restoration alternative plans for each site (Appendix E). Hazardous Toxic and Radioactive Waste (HTRW) and additional geotechnical data are presented in the HTRW Appendix H. This appendix presents technical information available in the literature and collected within each "Source" Study including:

- Jamaica Bay, Marine Park, Plumb Beach Ecosystem Restoration Feasibility Study;
- Flushing Creek and Bay Ecosystem Restoration Feasibility Study;
- Bronx River Basin Ecosystem Restoration Feasibility Study;
- Hackensack River Ecosystem Restoration Feasibility Study; and
- Lower Passaic River Ecosystem Restoration Feasibility Study.

Specific engineering information if available is included for the following sites that are recommended in this Integrated Feasibility Report/Environmental Assessment (FR/EA) (Table 1-1).

Table 1-1: Restoration Sites Recommended for Construction

Location	Recommended Restoration	Site
Jamaica Bay Planning Region		
Jamaica Bay	Estuarine Habitat Restoration	• Dead Horse Bay • Fresh Creek • Hawtree Point • Bayswater Point State Park • Dubos Point • Brant Point
	Jamaica Bay Marsh Island Restoration	• Stony Creek • Duck Point • Elders Point Center • Pumpkin Patch West • Pumpkin Patch East
	Small-Scale Oyster Restoration	• Jamaica Bay, Head of Bay
Harlem River, East River, and Western Long Island Sound Planning Region		
Flushing Creek	Estuarine Habitat Restoration	• Flushing Creek
Bronx River	Freshwater Riverine Habitat Restoration	• River Park/West Farm Rapids Park • Bronx Zoo and Dam • Stone Mill Dam • Shoelace Park • Muskrat Cove • Bronxville Lake • Crestwood Lake • Garth Woods/Harney Road • Westchester County Center
	Small-Scale Oyster Restoration	• Soundview Park

Location	Recommended Restoration	Site
Newark Bay, Hackensack River, and Passaic River Planning Region		
Hackensack River	Estuarine Habitat Restoration	• Metromedia Tract • Meadowlark Marsh
Lower Passaic River	Tier 2 Estuarine Habitat Restoration	• Oak Island Yards • Kearny Point
	Freshwater Riverine Habitat Restoration	• Essex County Branch Brook Park • Dundee Island Park • Clifton Dundee Canal Green Acres
Upper Bay Planning Region		
Upper New York Bay	Small-Scale Oyster Restoration	• Bush Terminal • Governors Island
Lower Bay Planning Region		
Sandy Hook Bay	Small-Scale Oyster Restoration	• Naval Weapons Station Earle

2 Existing Conditions

2.1 Jamaica Bay Planning Region

2.1.1 All Sites

2.1.1.1 Topography & Bathymetry

Each of the perimeter sites within the Jamaica Bay Planning Region was surveyed in the spring of 2002. This work was accomplished by surveying multiple profile lines across the site at 100 to 200-foot intervals. The distance between surveyed points along each profile was less than 20 feet. The landward portion of the survey was completed using land-based surveying procedures, while the portions of the land that remained inundated were completed via a hydrographic survey. The landward limit of the surveys for all sites was the project limits. The seaward limit for all surveys was 300 feet from the shoreline, or the navigation channel, which ever came first. All survey data was collected with enough accuracy to produce topographic mapping with one-foot contours for use by the United States Army Corps of Engineers (USACE) in further development of the site designs.

The horizontal grid for the survey is presented in the Long Island New York State Plane North American Datum 1983 horizontal coordinate system, and the elevations are referenced to the North American Vertical Datum 1988 (NAVD88). More detailed surveys will be needed in the next phase of the study.

2.1.1.2 Navigation

A federal navigation channel is within Jamaica Bay, along both the west and south shores, with an entrance channel connecting two (2) interior channels to the Atlantic Ocean at Rockaway Inlet. North Channel is the interior channel from the Marine Parkway Bridge along the west shore of the bay and is authorized to 18 feet deep at mean low water (MLW) and 300 feet wide to Mill Basin, with a turning basin 1000 feet wide and 1000 feet long at that point. North of Mill Basin the channel continues with an authorized depth of 12 feet MLW and 200 feet wide to Fresh Creek Basin. Beach Channel, authorized to 15 feet deep MLW and 200 feet, is the interior channel from the Marine Parkway Bridge along the

south shore and continues to Head of Bay. At the entrance to Head of Bay, the channel branches, going north into the Head of Bay and south, forking again into Mott Basin and Inwood Creek. The entrance channel, Rockaway Inlet, is authorized to 18 feet deep MLW and 500 feet wide from the Marine Parkway Bridge to Rockaway Point, where it expands to an authorized 20 feet deep MLW and 1000 feet wide to the ocean. The Rockaway Inlet entrance channel is generally dredged on a two (2) to three (3) year maintenance cycle. The five-year average annual commercial tonnage at Jamaica Bay Federal Navigation Channel is 678,400 tons.

2.1.1.3 Geotechnical

The Jamaica Bay sites lie within the Southern Long Island watershed, contained within the Coastal Plain Physiographic region. Surficial deposits on Long Island are glacial in origin with morainal deposits to the north and outwash deposits to the south. The surficial deposits form the unconfined aquifer and local water-bearing deposits of lesser extent, including the Jameco aquifer. These systems are underlain by the Magothy and Lloyd aquifers, which are generally confined.

2.1.1.4 Shoreline Change

Shoreline change, mainly in the form of shoreline recession, is related to the dynamics of Jamaica Bay, such as winds, waves, tides, and current effects. Wave and current actions transports the sediment along the shoreline. Water levels, mainly due to tides and elevated water levels during storms, enhance these effects by increased destructive energy levels. Other geological and coastal developments also shape the present position of the shoreline. Soil type and grain size determines the natural angle of repose, the strength of the soil to resist erosion and its deposition/suspension characteristics. Interventions on natural dynamics due to erosion control measures (coastal structures, vegetation, and other) can decrease the recession rate locally while accelerating the rate on the adjacent shorelines. Depending on the availability of the sources in the system, a shoreline may experience both erosion and accretion due to the dynamic forces of the nature. Generally, gain of sediment in a system would translate in to shoreline accretion, whereas, loss of sediment would translate into a shoreline recession.

Dynamic shorelines exhibit both short- and long-term variations. Short-term variations can be attributed to seasonal differences in storm intensities, and localized differences in sediment type. Long-term variations (in the order of years) reflect cumulated effects. Short-term rates may be highly variable while long-term effects are averaged.

Historical shoreline change for four (4) sites, Dead Horse Bay, Brant Point, Dubos Point, and Bayswater Point State Park, was studied for the period from 1959 to 1996. The objective of this analysis was to determine a qualitative estimate of the magnitude of shoreline change occurring at the four (4) sites. The Paerdegat Basin, Fresh Creek and the northern portion of the Spring Creek site did not have visible shoreline changes, with the exception of when filling or excavation activities occurred. While the southern shorelines of Spring Creek and Hawtree Point have experienced minor erosion, the restoration goals at those sites did not involve shoreline stabilization, and most of the restoration activities concentrated on the upland habitats.

2.1.1.5 Methodology

Four (4) ortho-rectified aerial images of each of the four (4) sites were utilized for the shoreline change analysis, which were made available by the USACE. These images included 1959, 1966, 1974, and 1996 aerials spanning 37 years. The 1996 imagery was ortho-rectified by New York City Department of Environmental Protection (NYCDEP). The imagery of 1959, 1966, and 1974 were ortho-rectified based

on the imagery of 1996 using ArcView® Geographic Information Systems (GIS) software. In this process, four (4) to eight (8) ground control points were selected from each image to be rectified as well as from the imagery of 1996. The control points were selected from the visible features, both in the imagery of 1996 and the imagery to be rectified, such as streets and streams. The imagery of 1959, 1966, and 1974 were then aligned to the ortho-rectified imagery of 1996 by linking each control point on the imagery of 1959, 1966, and 1974 to the corresponding point on the imagery of 1996, thus ortho-rectifying each image. The approach used for the shoreline change analysis includes the interpretation of erosion/accretion reference features located and mapped on a series of ortho-rectified aerial images.

The first step in the historical shoreline change analysis of a site is to create an imaginary baseline common to all the digital ortho-photos from which all distances can be referenced. Therefore, a segmental baseline was created on landside roughly parallel to the shoreline for each of the four (4) sites. The length of the baseline was sized to cover the delineated areas of interest. Transects were then drawn perpendicular to the baseline across the shoreline approximately every 100 feet.

Two (2) reference features, “primary” and “secondary” lines, were initially used to assess the shoreline change for this study. These reference features and their limitations on the application to this project are defined as follows:

<u>Water Line</u>: The intersection of bay water with beach/land was selected as one of the reference feature used to measure the shoreline change process. This feature is the easiest to map as compared to other features. However, the position of the primary line is entirely dependent on the time that the aerial photograph was taken. That is, comparison of two (2) aerial photos taken at high and low tides could give the impression of erosion or accretion simply as the result of primary line position on a beach slope. This could potentially add up to significant errors in horizontal shoreline distance, as measured from the baseline. For example, an error could be as much as 40 to 60 feet in terms of shoreline location for a nearshore slope of 1V:20H and a two (2) to three (3) foot difference in tidal water elevation. Generally, aerial images do not include time stamps to determine the corresponding tide level at the time of photography. In some cases though, it is possible to assess whether the picture was taken during a high tide period or low tide period by comparing the aerial images with respect to shoreline features and field observations. This assessment was considered during the mapping of the primary line feature.

<u>Vegetation Line</u>: The secondary line was also utilized to check for changes in trends for confirmation of the primary line. The secondary line was mapped as a reference feature, which generally reflects the maximum reach of wave attack, or the vegetation line. This line was identified from the aerial photographs and digitized for analysis.

For Bayswater Point State Park, Dubos Point and Brant Point sites, the reference feature lines exhibited very similar trends for the periods considered, where shoreline recession is apparent. Since the vegetation line also corresponded to habitat maps, the vegetation line is discussed further in the shoreline change analysis, and it was used to determine erosion rates for future conditions at the site. Dead Horse Bay has only its vegetation line digitized. The remaining sites did not experience significant erosion, so the shoreline change analysis was not performed at those sites.

2.1.1.6 Shoreline Change Rate Analysis

Determination of a reliable shoreline change rate requires relatively long sampling intervals. By using long intervals, short-term variations due to episodic processes are smoothed. Since the earliest aerial dates back 37 years, this analysis period has precedence over the other periods with relatively shorter time spans.

A number of analytical methods are available to determine shoreline change rates at a specific site. In most cases, these rates will be site specific, especially when there are significant variations in the shoreline position data. For this study, an end-point analysis was used in combination with the average of rates (AOR) method where applicable. End-point analysis takes the first and last points in the selected record and calculates the rate as its name implies. Results are highly dependent on the period chosen for the analysis. Therefore, variations giving rise to certain trends might be missed. The AOR method was implemented, in addition to end-point-analysis, to account for those trends with significantly longer periods (i.e. in the order of years).

When compared to 1996 photograph year, the 1959, 1966, and 1974 photographs allow for three (3) relatively long analysis periods of 37, 30, and 22 years, respectively. These periods were used for end-point analysis, and averaged for the AOR analysis. Comparisons were made and site-specific rates were determined for all periods. The AOR methodology was employed where there are large variations in the rate data. These variations could be attributed to both natural phenomenon and/or mapping errors during the reference line process.

2.1.1.7 Slope Stability Analysis

The overall slope stability was assessed for four (4) of the sites: Fresh Creek, Brant Point, Dubos Point and Bayswater Point State Park. The goal of the analysis was to identify any areas within the sites where slopes may be unstable due to steep slopes, weak soil strata and/or exposure to high tidal velocities. For the purposes of this analysis the following data were analyzed:

- Historic and recent shoreline photographic documentation (USACE, 2002);
- Project survey topography and bathymetry data (spring 2002);
- Velocity data developed by HydroQual, Inc. (USACE, 2003); and
- Geotechnical data (grain size distribution) from the HTRW testing results (USACE, 2003).

In general, there does not appear to be any areas of significant slope instability at any of the sites. Slopes are generally 1V:4H or shallower and average velocities are generally less than one (1) foot per second (fps), the maximum permissible near bottom channel velocities for fine sand.

2.1.1.8 Wave Analysis

Wave-induced effects are one of the primary factors affecting sediment transport processes in a coastal region. Waves generated by winds, as well as waves generated by the vessels traveling along the navigational channels, were considered for the sites under investigation. Vessel generated waves are of particular interest due to the potentially high volume of ship traffic passing by each site every day.

2.1.1.9 Wind Generated Wave Analysis

Site-specific wave conditions (height, period, and direction) at Dead Horse Bay, Fresh Creek, Hawtree Point, Bayswater Point State Park, Dubos Point, and Brant Point were determined using local wind data

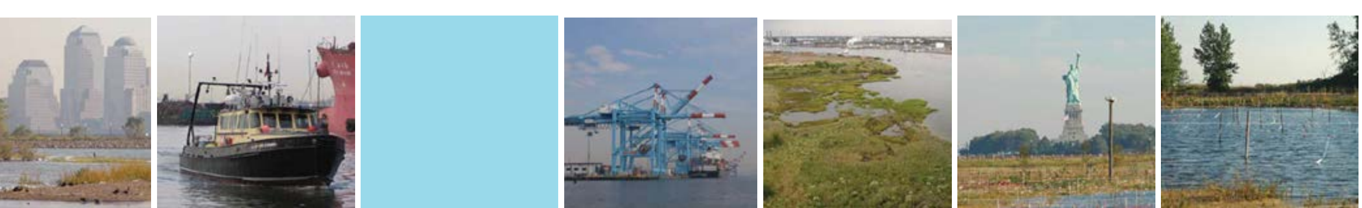
and a series of analytical models. A detailed description of the procedures used to compute wave characteristics at each of the sites is presented in this section.

Bathymetric information for the area was obtained through National Oceanographic & Atmospheric Administration (NOAA) chart (12350), and through survey transect data collected by during the Jamaica Bay "Source" Study in spring 2002.

Winds blowing across Jamaica Bay generate waves that will impact the project sites. Due to the restricted nature of the Bay, the major factors affecting the magnitude and period of the waves are the fetch length, average depth, wind speed, and wind duration. Sixteen (16) possible wind directions were considered to determine the wind-generated waves for the analysis.

Local, historic wind data collected at John F. Kennedy (JFK) International Airport (spanning from early 1980s to present) was obtained from the National Climatic Data Center. Additional information utilized during the present study included an earlier study (USACE, 1981) that utilized the JFK International Airport data as well as the some general information provided in the Coastal Engineering Manual (CEM) (USACE 2002).

Overall wind conditions during the 18-year time period for JFK International Airport are presented in Figure 2-1, which shows the distribution of wind speed (mph) data (illustrated using a wind rose plot). The color-coded sidebar indicates the magnitude of wind speed, the circular axis represents the direction of wind approach relative to North (North being 0 degrees), and the extending radial lines indicate percent occurrence within each magnitude and directional band. The most common direction of wind approach, as well as the approach direction of a significant portion of the winds, is from the southerly and northerly components of westerly directions.



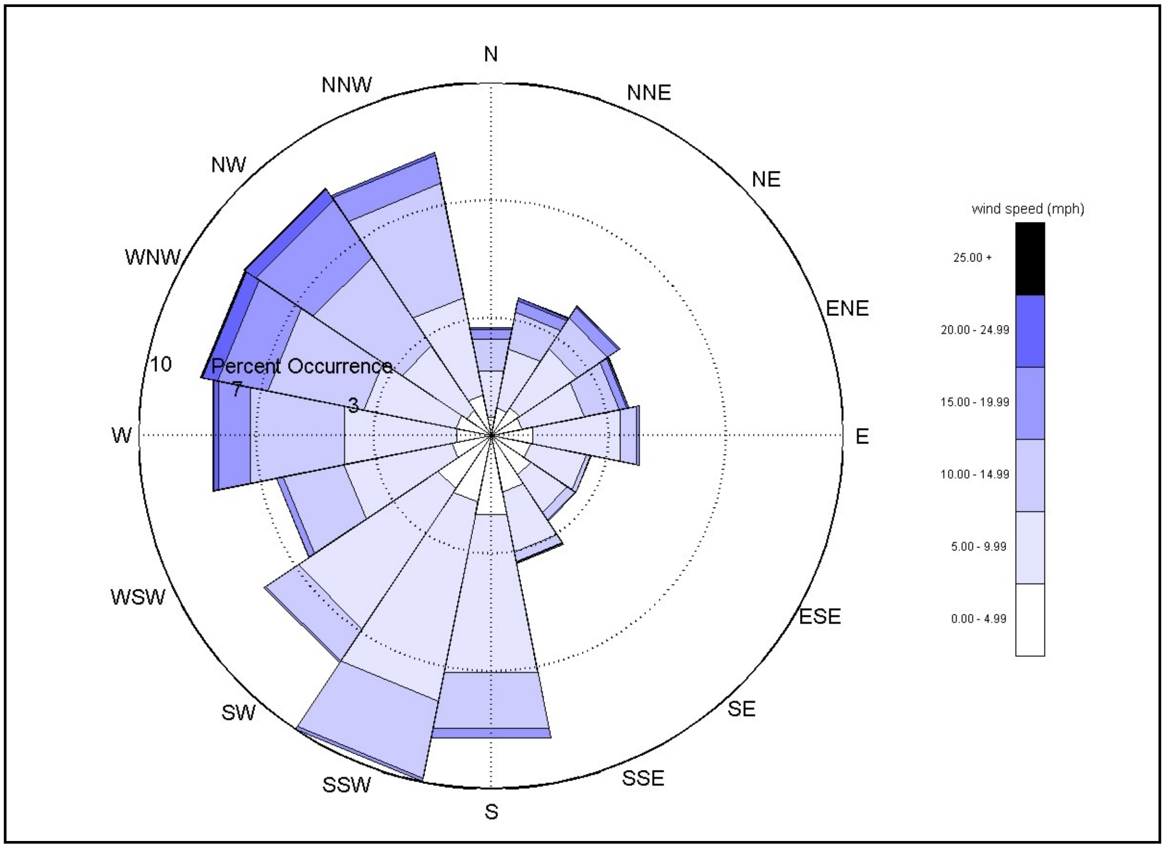


Figure 2-1: Wind Rose Plot of Resultant Wind Speed and Direction for JFK International Airport Wind Data (1984 to Present).

To determine the extreme wave conditions for design considerations, it is necessary to associate extreme wind conditions with design return period(s). Table 2-1 summarizes the extreme wind speeds determined for this study by considering the physically possible directions. The predominant wind directions match with the directions in the wind data collected.

The proper averaging time for design and planning considerations varies dramatically as a function of wind speed and fetch length (USACE, 2002). Based on the guidance provided in the CEM, 5-, 15- and 15-min averaging time intervals were utilized for 50-year, 20-year, and 10-year winds, respectively.

Table 2-1: Extreme Wind Speeds

Return Period	Wind Speed (mph)	Averaging Time
50-year	75	5-min
20-year	59	15-min
10-year	52	15-min

The waves generated by the wind data were predicted using a computer model developed by the USACE. This computer model is part of the Automated Coastal Engineering System (ACES), published by the Coastal Engineering Research Center (USACE, 1992). The program, entitled Wind Speed Adjustment and Wave Growth, provides simplified estimates for wave growth over open-water and restricted fetches, such as Jamaica Bay, in both deep and shallow water. The ACES model addresses only wind-generated waves, and does not account for the effects of refraction, diffraction, and non-linear effects.

Wind data, along with the geometry and average water depth of the fetch, is required input to the ACES program. The fetch, or distance over which wind acts on the water, is restricted in Jamaica Bay, which in turn limits the wave generation. When all other factors are kept constant, longer fetches will generate larger waves. Therefore, each wind condition input into ACES takes into account the restricted geometry and all the fetch lengths when calculating the associated wave conditions. That is, a short fetch wind direction may generate larger waves if radially close to a longer fetch direction, other conditions being equal. Additionally, an iterative approach was used to obtain maximum fetch-limited wave conditions during the modeling process, when dealing with averaging schemes as well as the storm duration. Standard ACES output includes a spectral significant (modal) wave height (H_{mo}), peak period (T_p), and a mean wave direction (MWD) for each of the fetch bands.

Fetch directions and other related information corresponding to the specific sites under investigation, as well as results of the wind-generated wave analysis for the all sites, are presented below.

2.1.2 Dead Horse Bay

2.1.2.1 Topography and Bathymetry

In the north portion of the site there is a steep sand beach with a drainage channel that meanders through the berm, emptying a standing pool of brackish water. The pool remains undrained at low tide. The beach slope varies from a 6 percent slope from the upland, towards the drainage channel inlet, and three (3) percent in the vicinity of the inlet. The beach habitat forms roughly a 25-foot strip along the shoreline at low tide. West of the inlet a scarp begins to form, which becomes as high as 10 feet. Gerritsen Creek inlet is to the west of the site. It has been stabilized by the abutments of the Belt Parkway Bridge. The standing pool extends north into the site 400 feet. The lowest elevation of the pool is 0.0 feet, while most grades are between 1.5 to 4 feet NAVD88. Proceeding inland, the next 400-foot area is relatively flat, with grades between 5 to 7 feet NAVD88. The back portion of the site, 800 to1600 feet from the shoreline, is also relatively flat with grades 10 to 12 feet NAVD88. There is a mound in the middle of this area that reaches elevations in excess of 22 feet NAVD88.

In the south portion of the site a large mudflat is present offshore of the northwest shoreline, so that the –3.5-foot contour is over 400 feet offshore. However, the beach face remains fairly steep, with 2 to 6 percent slopes present. The steeper beach slopes are present in the south section of the western facing shoreline. A 4 to 6-foot high scarp starting at 3 feet NAVD88 is a consistent feature of the topography, also steepest at the south section of the western facing shoreline. The interior section of Dead Horse Bay South is also fairly flat, with most grades ranging from 9 to 14 feet NAVD88.

2.1.2.2 Geotechnical

The soil in the area is characterized by medium, fine, well-sorted sand, with the median sand diameter of 0.226 to 0.312 millimeters (mm) for the three (3) on-shore grab samples. The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and the New York City Soil and Water Conservation District are in the process of developing an official soil survey book and maps for New York City and for Gateway National Recreation Area (GNRA). A draft soils survey of the GNRA obtained from NRCS shows that soils within the Dead Horse Bay site include Beaches, Bigapple Coarse sand, Bigapple-Blownout land complex, Fortress sand, Hooksan fine sand, Hooksan-Dune land complex, Ipswich mucky peat, Rikers gravelly coarse sand, Breeze loamy sand, Fishkill

sandy loam, and Gravesend-Oldmill coarse sand. Most of these soils series describe disturbed areas that are filled with over 40 inches of various materials that have varying drainage qualities (NRCS 2004).

2.1.2.3 Shoreline Change

Dead Horse Bay has undergone extreme changes over the last 50 years. The northern portion of the site (Dead Horse Bay North) has been influenced by the stabilization of Gerritsen Creek Inlet, and the construction of the Belt Parkway, the adjacent driving range, and the adjacent marina. The southern portion of the site lies behind a large mudflat. Dead Horse Bay South land mass was created by fill (clean and household trash) deposited there while Floyd Bennett Field was being constructed. Both portions of the site experience extremely different erosion and accretional patterns.

Overall, Dead Horse Bay North accreted between 1959 and 1996, and between 1966 and 1996. It eroded 1.93 feet/year between 1974 and 1996 (Table 2-2 and Figure 2-2). The erosion was most severe in the shoreline west of the creek outlet. This area currently has 5 to 7-foot high bluffs that have vertical faces that are most likely due to the longshore sediment transport influences of Gerritsen Creek inlet. No restoration is proposed in this section of the shoreline. The shoreline in front of the creek is highly variable, likely due to a large sediment supply coming from the bluffs, and the hydrodynamics of the creek outlet.

Table 2-2: Dead Horse Bay North Erosion Rates

	Period	Dead Horse Bay North Vegetation Line (feet/year)				
		West of Creek Outlet	East of Creek Outlet	Transition	Marina	Combined Average (All Sections)
End-point Averaging	1959-1996	1.50	1.39	4.00	1.16	1.44
	1966-1996	0.33	0.79	0.77	0.32	0.41
	1974-1996	-3.02	-1.81	-4.64	-0.52	-1.93
AVERAGE (AOR)		-0.40	0.12	0.04	0.32	**-0.03**

Dead Horse Bay South has variable erosion/deposition patterns because its shorelines face many directions (northwest, west, southwest, and south) with many different physical characteristics and influences on the shorelines. Trends that describe all of these faces are nearly non-existent. The shorelines of greatest concern to this project are those that face to the south and southwest, which are exposed to northerly and northeasterly winds and waves. Shorelines facing to the south experienced erosion in all time periods, with an average loss of 5.17 feet/year. These shorelines face toward Rockaway Inlet and are exposed to large waves. Shorelines facing to the southeast experienced erosion at a loss rate of 1.04 feet/year from 1974 to 1996, but otherwise these shorelines have been relatively stable (Table 2-3 and Figure 2-2).

Table 2-3: Dead Horse Bay South Erosion Rates

	Period	Dead Horse Bay South Vegetation Line (feet/year)					
		Section 1 Faces Southwest	Section 2 Faces West	Section 3 Faces Northwest	Section 4 Faces Southwest	Section 5 Faces South	Combined Average (All Sections)
End-point Averaging	1959-1996	-0.19	0.63	-1.99	-5.67	-0.23	-1.49
	1966-1996	0.68	0.64	-2.22	-4.54	0.80	-0.75
	1974-1996	-2.53	1.08	2.67	-5.32	-1.04	-1.48
AVERAGE (AOR)		-0.68	0.78	-0.51	-5.17	-0.16	-1.24

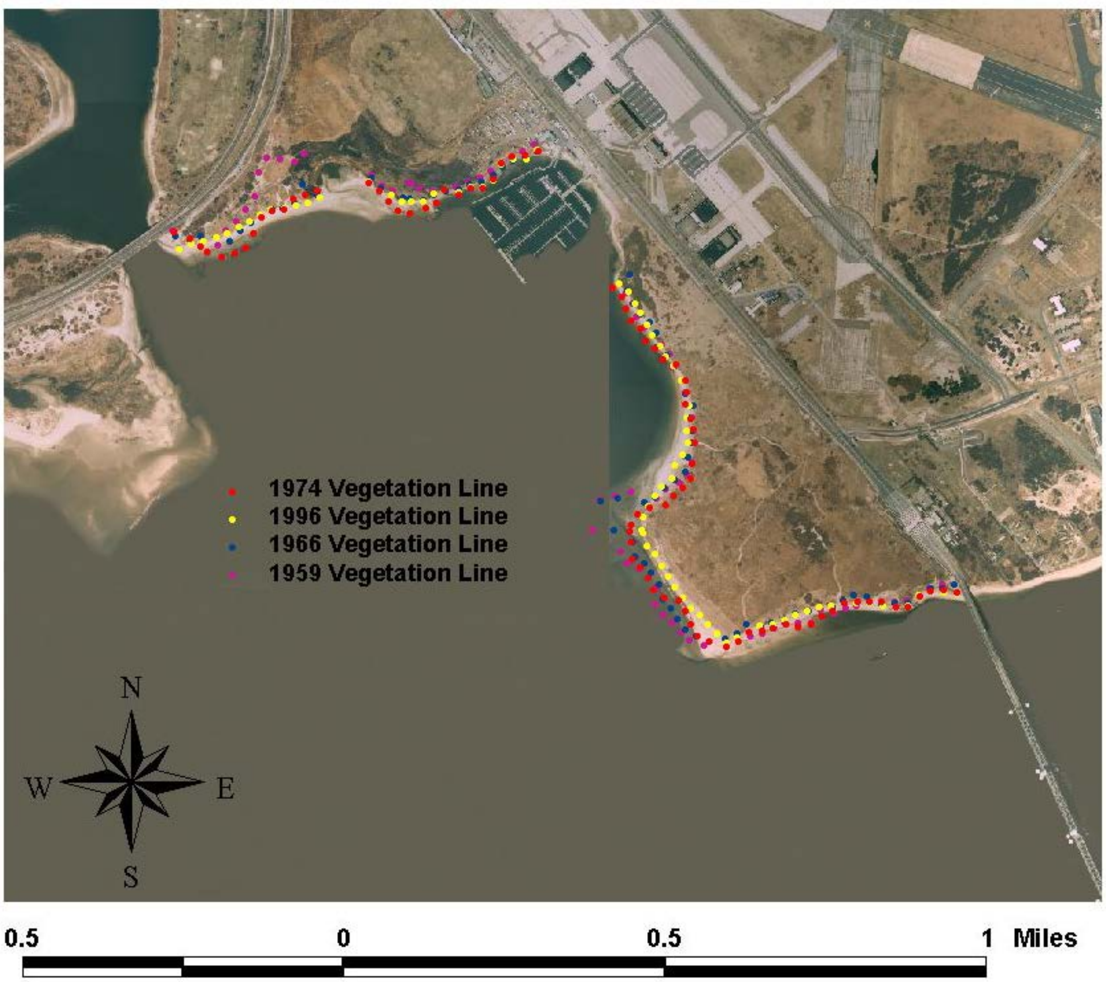


Figure 2-2: Dead Horse Bay Shoreline Change

2.1.2.4 Wind-Generated Wave Analysis

The spectral significant wave height (H_{mo}), the peak period (T_p), and mean wave direction resulting from the ACES predictions for Dead Horse Bay North and South are shown in Tables 2-4 and 2-5. These results correspond to two (2) representative (reference) locations along the North and South shorelines. Figure 2-3 shows the fetch directions for wind wave generation. Three (3) different sets of results are presented corresponding to design return periods of 50-year, 20-year, and 10-year respectively. In general, for the Dead Horse Bay North site:

- The model predicts that the maximum waves will be generated when the winds are blowing from the southwest (SW) corresponding to the longest fetch direction.
- The modal wave height was estimated to be 5.4 feet, 4.7 feet, and 4.3 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 4.4 seconds, 4.1 seconds, and 3.9 seconds for the 50-year, 20-year, and 10-year return-periods, respectively.
- Mean wave directions were estimated to be between 220 and 230 degrees (measured clockwise from true north) for northwesterly fetch directions.
- Southwesterly fetches will generate about 40 percent larger waves and longer periods than southeasterly fetches.

In general, for the Dead Horse Bay South site:

- The model predicts that the maximum waves will be generated when the winds are blowing from west-southwest (WSW) corresponding to longest fetch direction.
- The modal wave height was estimated to be 6.9 feet, 5.6 feet, and 5.0 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 5.5 sec, 4.7 sec, and 4.5 second for the 50-year, 20-year, and 10-year return-periods, respectively.
- Mean wave directions were estimated to be between 245 and 250 degrees (measured clockwise from true north) for northeasterly fetch directions.
- Southwesterly fetches will generate about 100 percent larger waves and longer periods than southeasterly fetches.

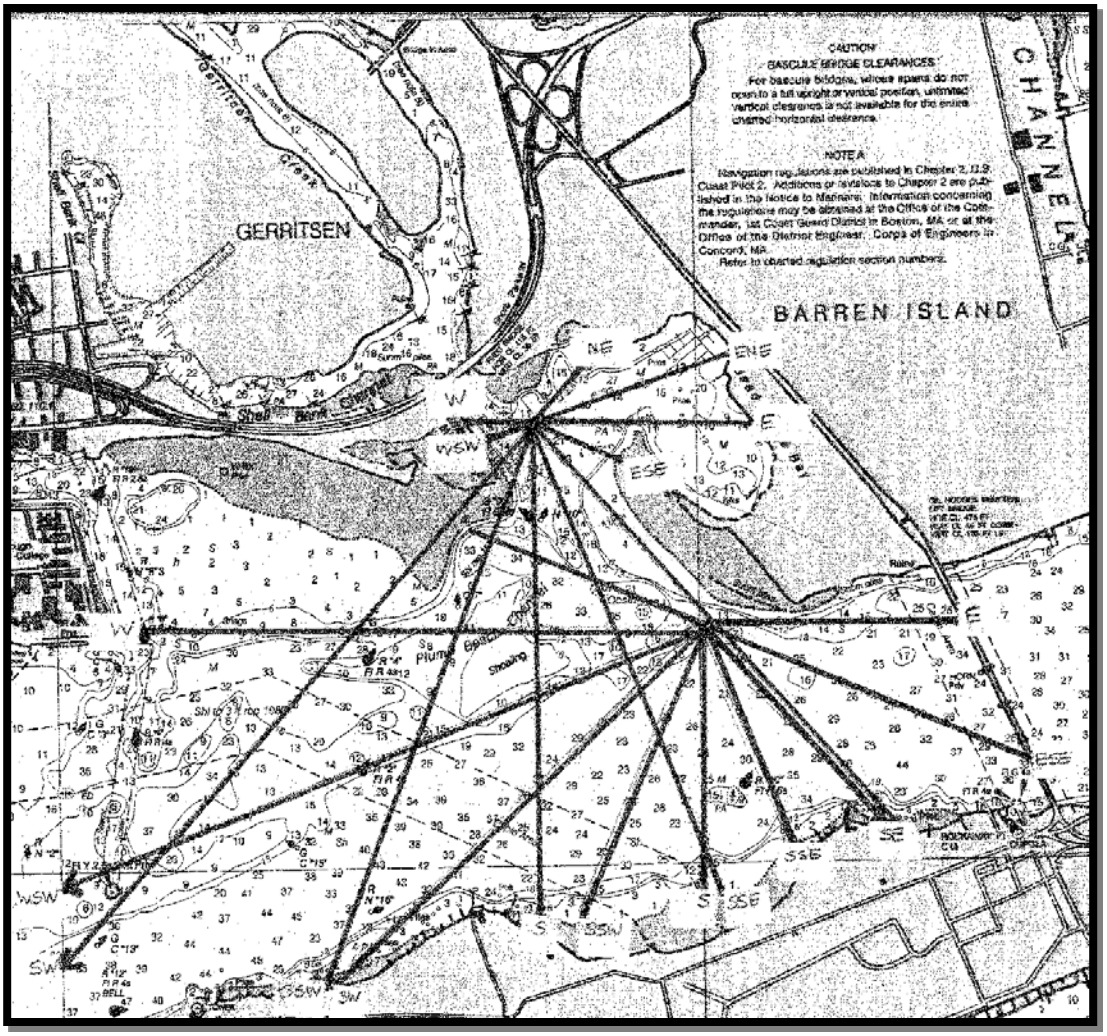


Figure 2-3: Fetch Directions for Dead Horse Bay

Table 2-4: Dead Horse Bay North Wind-Generated Wave Results Fetch

		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N											
2	NNE											
3	NE	0.20	15	2.6	2.7	70	2.2	2.5	70	1.9	2.4	70
4	ENE	0.55	20	2.7	2.8	76	2.3	2.6	76	2.0	2.4	76
5	E	0.60	15	3.6	3.3	133	3.1	3.1	133	2.7	2.9	133
6	ESE	0.25	20	3.9	3.4	137	3.3	3.2	137	2.9	3.0	137
7	SE	1.40	10	3.5	3.3	140	3.0	3.1	140	2.6	2.9	140

		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
8	SSE	1.30	15	5.2	4.2	216	4.5	3.9	216	4.0	3.7	216
9	S	1.25	15	5.4	4.4	220	4.7	4.1	220	4.2	3.8	220
10	SSW	1.50	15	5.4	4.4	222	4.7	4.1	222	4.3	3.9	222
11	SW	5.00	10	5.4	4.4	224	4.7	4.1	224	4.3	3.9	224
12	WSW	0.10	10	4.5	4.2	226	4.0	3.9	226	3.6	3.7	226
13	W	0.10	10	4.5	4.2	228	3.9	4.0	228	3.6	3.7	228
14	WNW											
15	NW											
16	NNW											

MWD = Mean Wind Direction

Table 2-5: Dead Horse Bay South Wind-Generated Wave Results

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N											
2	NNE											
3	NE											
4	ENE											
5	E	0.40	20	2.7	2.8	112	2.3	2.6	112	2.0	2.4	112
6	ESE	0.60	25	2.9	2.9	127	2.4	2.7	127	2.1	2.5	127
7	SE	0.70	30	3.0	2.9	135	2.5	2.7	135	2.2	2.6	135
8	SSE	0.60	30	3.2	3.0	178	2.6	2.8	178	2.3	2.7	178
9	S	0.80	30	4.5	4.0	241	3.5	3.6	241	3.0	3.3	241
10	SSW	0.95	25	6.4	4.8	244	5.1	4.3	244	4.4	4.0	244
11	SW	1.10	25	6.7	5.4	246	5.4	4.7	246	4.8	4.4	246
12	WSW	12.00	15	6.9	5.5	248	5.6	4.7	248	5.0	4.5	248
13	W	1.70	15	6.7	5.4	249	5.4	4.7	249	4.8	4.4	249
14	WNW	1.30	10	4.0	4.3	251	3.4	3.9	251	3.0	3.6	251
15	NW											
16	NNW											

MWD = Mean Wind Direction

2.1.3 Fresh Creek

2.1.3.1 Topography and Bathymetry

The upper 1300 feet of the creek has a maximum depth of -7 feet NAVD88, an average depth of -4 to -5 feet NAVD88, and average width of 300 feet. The banks are steep (close to 1V: 1H) and quickly rise to 15 feet NAVD88 on both sides of the creek.

The creek narrows to 130 feet width next 500 feet (downstream). The average depth is approximately -8 feet NAVD88, but the depth is very variable in this section of the creek, based on 2002 bathymetric data. There is an existing low marsh on southwest bank of the creek, with elevation ranges between 1 to 4 feet NAVD88. The northwest bank is steep, with grades rising above 20 feet NAVD88 less than 220 feet from the shoreline.

A mid-creek island exists in the next downstream section of the creek (or 2200 feet upstream from the Belt Parkway). The island is 50 to 150 feet wide, 800 feet long with most elevations between 2 to 3 feet NAVD88. The main channel of the creek becomes deeper in this section, with elevations dropping to -15 feet NAVD88. The remaining length of the creek out to the belt parkway has depths of approximately -10 to -13 feet NAVD88. On the bay side of the Belt Parkway Bridge depths rise to approximately -9 feet NAVD88 to form a “sill feature”, before eventually dropping to over -30 feet NAVD88 when the creek bottom meets the navigation channel in the bay.

2.1.3.2 Geotechnical

The soil at Fresh Creek was poorly-sorted sandy-gravel, with the median diameter of 3.01 to 4.2 mm for the gravelly areas and 0.395 to 0.458 mm for the sandy grab samples. The deposition of historic fills has been irregular at this site. All samples showed significant amounts of gravel, sand and silt for all samples. Even the clay present in each sample ranged from 2 to 7 percent. In a draft soil survey for New York City, NRCS has identified the soils of the Fresh Creek site as Bigapple-Fortress series complex, Inwood-Laguardia-Ebbetts complex, Greatkills-Freshkills complex, Pavement and Buildings-Bigapple-Verazano complex, and Ipswich-Pawcatuck-Matunuck mucky peat. Both the Bigapple and Fortress series are soils consisting of sandy dredge material over 40 inches thick, which has been placed onto an area. The Inwood, Laguardia, and Ebbetts series all consist of demolished construction material mixed with various soils to create fill material. The Verazano series consists of a thick human-transported loamy layer over sandy sediments. Greatkills soils are a mixture of household garbage, construction debris and other discarded materials layered with natural soil fill. Freshkills soils are only household landfill capped with a thin layer of loamy soils. Ipswich, Pawcatuck, and Matunuck are all tidal marsh soils, differing in the thickness of the organic layer before reaching sand (NRCS 2004).

2.1.3.3 Slope Stability Analysis

The shoreline slope stability analysis for Fresh Creek showed generally stable slopes with most slopes shallower than 1V:4H, with a few isolated areas where the slopes were in the 1V:2H range. Average velocities for incoming tides ranged from 0.6 fps to 1.1 fps and average velocities for outgoing tides ranged from 0.4 fps to 1.0 fps. Geotechnical data indicates that the upper most 5 to 26 feet of material in the area consists of fine to coarse sands and general fill/debris, which is generally underlain by an older organic silty clay meadow mat strata.

2.1.3.4 Water Quality Modeling

Jamaica Bay is a heavily impacted estuary located within the boundaries of New York City. Some areas of Jamaica Bay and the basins that are tributary to it experience hypoxic or anoxic conditions. These low dissolved oxygen levels can have a profound effect on the biota that live within the bay. Fresh Creek has a large sewage treatment plant and combined sewage overflows (CSOs) at the head of the creek. A hydrodynamic/water quality model of Fresh Creek was developed in this “source” study to assess how planned bathymetric alterations will affect habitat in these areas.

This modeling analysis consisted of developing models for Fresh Creek to evaluate up to six (6) bathymetric alteration scenarios in each tributary and their effect on habitat. The NYCDEP has facility upgrade plans to abate CSOs at the Fresh Creek sewage treatment plant. These improvements were considered in determining the scenarios. A North Channel Model (NCM) was created within the existing Jamaica Bay Eutrophication Model (NYC DEP, 2002) which included Fresh Creek, as well as Hendrix Creek and Bergen Basin. The alternatives that were analyzed are listed below. The six (6) scenarios in Fresh Creek included bathymetric changes and the incorporation of the CSO facility plans at both of the tributaries. These Fresh Creek scenarios to be evaluated included:

- Existing conditions with the natural sill in place;
- Existing conditions with CSO improvements;
- Existing conditions without the natural sill in place and with CSO improvements;
- Upstream half-filled to MLW, lower half as is, without the sill and with CSO improvements;
- Upstream half as is, lower half filled to 4 feet below MLW or as is (whichever is less), without the sill and with CSO improvements; and
- Upstream half as is, lower half hued to 8 feet below MLW or as is (whichever is less), without the sill and with CSO improvements.

All of the runs were based on 1988 meteorological, tidal, and loading conditions. Bathymetric conditions were based on the latest available data.

In general, the flood tide velocities are greater than then ebb tide velocities. Removal of the sill at the mouth of the creek does little to affect the velocities in the upper half of the creek and reduces the velocities at the mouth. Scenario 4 increases the velocities in the half of the creek except for the head. Scenarios 5 and 6 increase the maximum flood velocities to a small extent near the mouth, but the velocities are reduced in the upper half of the creek. The shear stresses generally remained below 1.0 dyne/centimeter(cm)^2 until the scenarios where portions of the creek were filled. When the creek was filled to MLW in the upper half (Scenario 4), the shear stresses increased to as high as 4.1 dyne/cm^2 during August. This shear stress would cause resuspension of material and bed loading of sandy material. Filling the lower portion of the creek in Scenario 5 resulted in occasional shear stresses greater than 1.0 dyne/cm^2. The average shear stresses remain below 0.5 dyne/cm^2 for all of the scenarios indicating, that the creek would remain a depositional area.

The dissolved oxygen (DO) in Fresh Creek is computed to be lowest at the head end and in the deeper portion near the mouth under calibration conditions. The facility plan results in improved DO along the entire creek with the largest improvements occurring in the upper portions. Removing the sill results in small changes in the average DO and the effect is slightly lower DO levels in most of the creek. Filling the upper portion of the creek results in higher DO concentrations in the upper half of the creek and slightly lower DO levels near the mouth of Fresh Creek. Filling the lower half of the creek has the opposite effect with improved DO near the mouth and slightly lower concentrations in portions of the upper end. The minimum DO concentrations are essentially anoxic in all of the scenarios. Each scenario generally results in higher minimum DO concentrations, but the DO levels do occasionally

decline to hypoxic levels. Most of the improvement to the upper half of the creek is due to the implementation of CSO controls and that filling the upper portion of the creek provides only a marginal improvement. The most effective scenario for increasing the DO concentration near the mouth is Scenario 5. Under Scenario 5 conditions Fresh Creek is computed to have a DO concentration greater than 3.0 milligrams per liter (mg/L) greater than 90 percent of the time for most of the creek during July and August. The results indicate that some bathymetric alterations would improve the DO concentrations in Fresh Creek. In general, some level of filling near the mouth of the creek would improve DO levels and as a consequence aquatic habitat. Filling portions Fresh Creek would mostly like result in bringing this tributary closer to its historical depth and bring the creek back to a more natural state.

2.1.4 Hawtree Point

2.1.4.1 Topography and Bathymetry

The topography of Hawtree Point is highly influenced by the debris and remnant structures that still exist on the site. The offshore slope between -2 to 2 feet NAVD88 varies from 4 to 40 percent, with the steeper slopes located close to the entrance to Bergen Basin. A berm feature is slightly visible, located between 1 to 2 feet NAVD88. The upland portion of the site has most grades between 5 to 7 feet NAVD88, with the maximum grade being 8.5 feet NAVD88.

2.1.4.2 Geotechnical

The soil here was poorly-sorted sand, with the median sand diameter of 0.308 to 0.376 mm for the two (2) on-shore grab samples. A significant percentage of both gravel and silt were found in the two (2) samples, suggesting that the historic placement of fill at this site was inconsistent. A draft soils survey of the GNRA obtained from NRCS shows that soils within the Hawtree Point site include Beaches, Barren sand, Bigapple Coarse sand, Bigapple sandy loam, pavement/buildings, and Sandyhook mucky fine sandy loam. The Bigapple soil series and the Barren sand series both denote areas of dredge fill placement. The pavement includes the basketball courts and buildings of the Charles Memorial Park. The Sandyhook series is a poorly drained soil with a thin organic layer, usually supporting intertidal wetlands (NRCS, 2004).

2.1.5 Bayswater Point State Park

2.1.5.1 Topography and Bathymetry

Bayswater Point State Park has 1000 feet of shoreline facing west, with a sand spit growing south. The offshore slopes are extremely flat in the southern section near the sand spit, with elevations never exceeding -7 feet NAVD88 700 feet offshore. Slopes between -4 to 0 feet NAVD88 range from 5 to 20 percent. A crumbling seawall exists parallel to the shoreline, approximately between -2 to 2 feet, although sections of the seawall top reach 5 feet NAVD88. The interior portion of this side of the site is flat, with grades ranging from 5 to 10 feet, maximum of 11 feet NAVD88.

As the shoreline bends from western facing to northern facing, the 20-foot deep navigation channel is offshore approximately 350 feet. There is an underwater bench feature at -6 feet NAVD88 for approximately 300 feet of shoreline, but for the most part there is a steady 2.5 percent slope.

2.1.5.2 Geotechnical

The soil here was medium-sorted sand, with the median sand diameter of 0.285 to 0.451 mm for the four (4) on-shore grab samples. In a draft soil survey for New York City, NRCS has identified the soils of Bayswater Point State Park as Bigapple-Fortress series complex. Both of these soil series denote sandy dredge material over 40 inches thick, which has been placed onto an area. The Bigapple series consists of very deep, well drained soils with rapid permeability (NRCS, 2004). The Fortress series consists of very deep, moderately well drained soils with rapid permeability (NRCS, 2004). An offshore geotechnical investigation off the west-facing shoreline revealed that the subsurface is primarily composed of poorly graded fine to medium sand with various amounts of silt (SP to SM) and a discontinuous layer of clay (CL and ML).

2.1.5.3 Shoreline Change

Aerial images over the years revealed the existence of spit formations along the western and northern edges of the Bayswater Point State Park site. The existing wall at the northwest corner of the Bayswater Point State Park seems to have a nodal point effect where the sediment transport patterns alter direction to each side of this point. In the 1996 image, the easterly spit has assumed a new alignment, more towards the north. Potentially, construction of the JFK International Airport runway extension and/or dredging could have affected the sediment transport patterns around Bayswater Point State Park.

The Bayswater Point State Park site was divided into two (2) sections. Section 1 includes Transects 1 through 13 on the western side of the park up to the existing wall at the northwest corner. Section 2 spans from the wall to the eastern side of the park, including Transects 14 through 38.

Table 2-6 summarizes the shoreline change rates, and Figure 2-4 shows the change in the rate along the shoreline for Bayswater Point State Park for the three (3) periods. Section 1 and 2 shows differing rates for each end-point analysis. Section 1 has an average of -1.2 feet/year recession rate for the vegetation line. Average advancement rates for Section 2 were determined 1.3 feet/year. The overall AORs were calculated as 0.0 feet/year, and 0.6 feet/year for the two (2) reference features. These averages show that the northern shoreline of Bayswater Point State Park has advanced with contribution from the spit formations. Figure 2-4 also shows that the seawall on the northwest corner of the site seems to act as a nodal point where the erosional trend on the west changes to an accretional trend. Unlike the Brant Point and Dubos Point sites, shoreline change was accretionary for the period from 1959 to 1966. This period, therefore, helped to offset some of recession rates for the remaining periods. Consequently, it is reasonable to assume that as a whole the Bayswater Point State Park site has been on average dynamically stable since 1959.

Table 2-6: Average Shoreline Change Rates for Bayswater Point State Park

	Period	Vegetation Line (feet/year)		
		Section 1 (Transect No. 1-13)	Section 2 (Transect No. 14-38)	Combined Average (Section 1-2)
End-point Averaging	1959-1996	-1.1	3.3	1.9
	1966-1996	-1.6	0.0	-0.5
	1974-1996	-0.9	0.8	0.3
AVERAGE (AOR)		-1.2	1.3	0.6

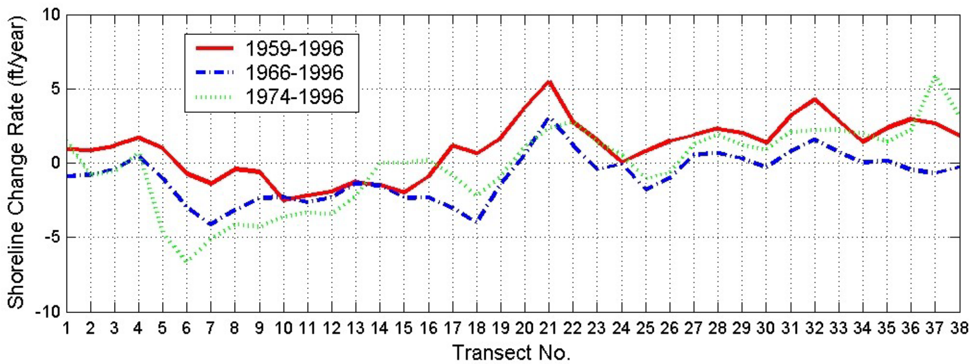


Figure 2-4: Shoreline Change Rates (End-Point Averaging) at Bayswater Point State Park

2.1.5.4 Slope Stability Analysis

The shoreline slope stability analysis for Bayswater Point State Park showed generally stable slopes with most slopes shallower than 1V:4H. Average velocities for incoming tides ranged from 0.1 fps to 0.3 fps and average velocities for outgoing tides ranged from 0.0 fps to 0.5 fps. Geotechnical data indicates that the uppermost 5 to 12 feet of material in the area consists of fine to coarse sands and general fill/debris, which is generally underlain by an older organic silty clay meadow mat strata.

The shoreline slope analysis identified a few isolated areas where the slopes were in the 1V:2H to 1V:1H range. These steeper slopes are located mostly along the northern shoreline and seem to occur along the vegetated edge of the shoreline.

2.1.5.5 Wind-Generated Wave Analysis

The spectral significant wave height (H_{mo}), the peak period (T_p), and mean wave direction resulting from the ACES predictions for Bayswater Point State Park are shown in Tables 2-7 and 2-8. These results correspond to two (2) representative (reference) locations along the Bayswater Point State Park shoreline. The first reference point was located on the west/northwest side and the second reference point was located on the north face of the Bayswater shoreline. The north reference point is naturally more protected than the west/northwest reference point. Figure 2-5 shows the fetch directions for wind wave generation. Three (3) different sets of results are presented corresponding to design return periods of 50-year, 20-year and 10-year respectively. In general, for the west/northwest reference location of Bayswater Point State Park:

- The model predicts that the maximum waves will be generated when the winds are blowing from NNW corresponding to longest fetch direction.
- The modal wave height was estimated to be 3.8 feet, 3.0 feet, and 2.6 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 3.3 second, 3.0 second and 2.8 second for the 50-year, 20-year and 10-year return-periods, respectively.

- Mean wave directions were estimated to be between 333 and 339 degrees (measured clockwise from true north) for northwesterly fetch directions.
- Northwesterly fetches will generate about 10 percent larger waves and shorter periods than northeasterly fetches.

In general, for the north reference location of Bayswater Point State Park:

- The model predicts that the maximum waves will be generated when the winds are blowing from north-northeast (NNE) corresponding to longest fetch direction.
- The modal wave height was estimated to be 3.3 feet, 2.6 feet and 2.2 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 3.1 sec, 2.7 sec, and 2.6 second for the 50-year, 20-year and 10-year return-periods, respectively.
- Mean wave directions were estimated to be between 20 and 24 degrees (measured clockwise from true north) for northeasterly fetch directions.
- Northwesterly fetches will generate about 10 percent smaller waves and shorter periods than northeasterly fetches.

Table 2-7: Bayswater Point State Park Wind Generated Wave Results for the West-Northwest Reference Point

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N	0.80	16	3.5	3.2	345	2.7	2.9	345	2.4	2.7	345
2	NNE											
3	NE											
4	ENE											
5	E											
6	ESE											
7	SE											
8	SSE											
9	S											
10	SSW	0.15	16	2.6	2.8	244	2.0	2.5	244	1.8	2.3	244
11	SW	0.22	16	3.2	3.1	246	2.5	2.7	246	2.2	2.6	246
12	WSW	0.90	42	3.6	3.3	249	2.8	2.9	249	2.5	2.7	249
13	W	0.40	34	3.4	3.2	251	2.6	2.8	251	2.3	2.7	251
14	WNW	0.30	26	3.1	3.0	321	2.4	2.7	321	2.1	2.6	321
15	NW	0.71	30	3.6	3.3	333	2.8	2.9	333	2.5	2.7	333

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
16	NNW	0.95	26	3.8	3.3	339	3.0	3.0	339	2.6	2.8	339

(MWD = Mean Wave Direction)

Table 2-8: Bayswater Point State Park Wind Generated Wave Results for the North Reference Point

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N	0.25	16	3.0	3.0	20	2.4	2.6	20	2.1	2.5	20
2	NNE	0.78	21	3.3	3.1	22	2.6	2.7	22	2.2	2.6	22
3	NE	0.16	16	3.0	2.9	24	2.3	2.6	24	2.1	2.5	24
4	ENE	0.23	16	2.4	2.7	27	1.9	2.4	27	1.6	2.2	27
5	E											
6	ESE											
7	SE											
8	SSE											
9	S											
10	SSW											
11	SW											
12	WSW											
13	W	0.39	34	2.9	2.9	287	2.3	2.6	287	2.0	2.4	287
14	WNW	0.62	26	3.0	2.9	290	2.3	2.6	290	2.0	2.5	290
15	NW	0.12	30	2.8	2.8	293	2.2	2.5	293	1.9	2.4	293
16	NNW	0.16	26	2.5	2.7	18	1.9	2.4	18	1.7	2.3	18

(MWD = Mean Wave Direction)

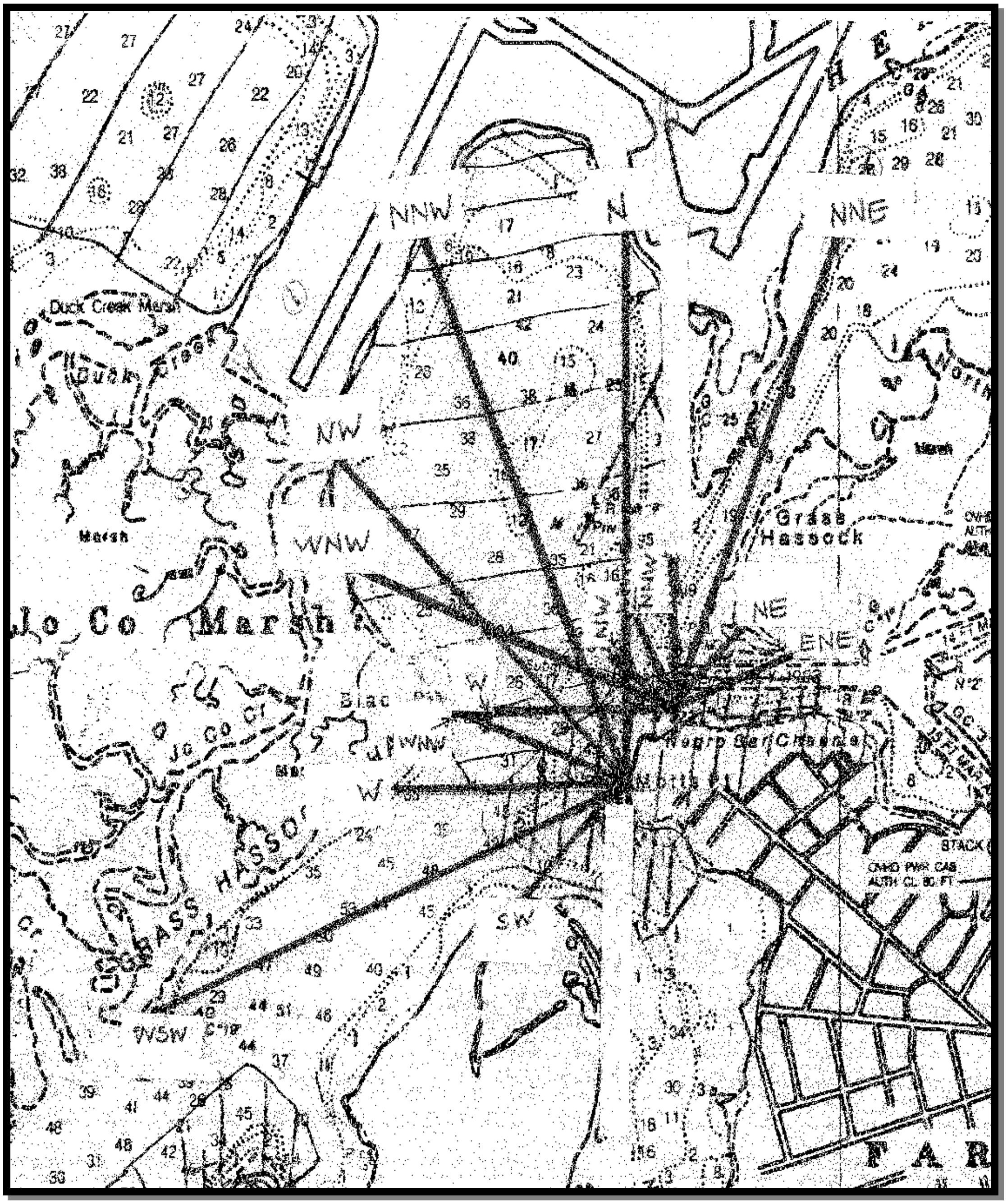


Figure 2-5: Fetch Directions for Bayswater Point State Park

2.1.6 Dubos Point

2.1.6.1 Topography and Bathymetry

The 2600-foot long Dubos Point peninsula parallels Decosta Ave, between 65th and 63rd Streets. The most eastern 1500-foot long section of the site is still connected the main barrier island mass. It has fairly flat beach slopes (between -2 to 2 feet NAVD88) (3 percent) which quickly drop to 20 percent. The offshore slope is steepest between -10 to -20 feet NAVD88, where the slope is 25 percent. A 50 to 70-

foot wide beach is present, and the topography rises to 7 feet NAVD88 80 feet inland from the waterline, with the maximum elevation at 9 feet NAVD88.

The peninsula itself protrudes into Jamaica Bay 1000 feet, and it has an average width of 50 feet. The topographic/bathymetric survey concentrated on the northwest shoreline of the peninsula, the location of the proposed restoration. The first 500 feet of the peninsula (south section) has slopes of approximately 6 percent between -2 to 2 NAVD88. Again, the offshore slope is 3 percent between 0 to -10 NAVD88, steepest (25 percent) between -10 to -20 feet NAVD88, and mildest (2.5 percent) between -20 to -30 feet NAVD88. The interior of the peninsula reaches 7.5 feet NAVD88 450 feet from the shoreline.

The northern tip of the peninsula is very flat, with interior elevations averaging 3.0 feet NAVD88, and the maximum elevation is 5 feet NAVD88. The beach slope is slightly steeper (2.6 to 6 percent) between -2 to 2 feet NAVD88. The offshore slope is 5.5 percent between 0 to -10 NAVD88, very steep (50 percent) between -10 to -20 feet NAVD88, and 25 percent between -20 to -30 feet NAVD88.

2.1.6.2 Geotechnical

The soil here was well-sorted sand, with the median sand diameter of 0.264 to 0.621 mm for the three (3) on-shore grab samples. All three (3) samples were very consistent, with less than 1 percent gravel and clay, and only 5 to 10 percent silt. A draft soils survey obtained from NRCS shows that soils within the Dubos Point site are Bigapple-Fortress complex. The Bigapple soils series includes areas covered by dredge spoils (NRCS, 2004). The Fortress series also denotes a filled area, but composing of dredged, outwash, or eolian sands (NRCS, 2004). The offshore subsurface is primarily composed of poorly graded fine to medium sand with trace amounts of silt. In summary, the offshore soils are sand (SP-SM) and fat clay (CH), with phi angles between 0 to 25 degrees.

2.1.6.3 Shoreline Change

Once a tidal marsh, Dubos Point was partially surrounded with a bulkhead and filled to allow development along the shoreline in the first quarter of the 20th century (USACE, 2002). Over the years, this bulkhead altered the sediment transport pattern around the Dubos Point. Erosion along the west bulkhead of Dubos Point was noted as a result of the deformation of the structure. Some portion of the bulkhead still remains today and has a variable effect on the shoreline process around Dubos Point. Dredging activities were also noted around the filled area where the sediment transport patterns are expected to be impacted.

Dubos Point was analyzed in two (2) sections, the natural shoreline composed of the large tidal flats and/or ditches along the beach (Section 1) and the bulkhead area (Section 2). Section 1 also covers the area to the west of the Dubos Point. Section 2 includes the remaining part of the Dubos Point shoreline.

Table 2-9 summarizes the shoreline change rates, and Figure 2-6 shows the change in the rate along the shoreline for the Dubos Point for the three (3) periods. The shoreline recession rate is significantly higher for the period of 1974-1996 while significant accretion is noted in the 1966-1974 periods, similar to what was observed at Brant Point. Section 1 has an average of -3.4 feet/year recession rate at the vegetation line. The average recession rate for Section 2 was determined to be -2.9 feet/year. Similar to Brant Point, recession rates for the periods 1959-1996, and 1966-1996 were approximately less than half the rates for the period of 1974-1996. This is mainly due to an accretionary period of 1966-1974, which reduces the long-term average recession rates. The combined average of recession rate was calculated to be -3.0 feet/year. Consequently, it is reasonable to assume that the Dubos Point shoreline retreated at a rate of about -3.0 feet/year since 1959 based on the vegetation line reference feature.

Table 2-9: Average Shoreline Change Rates for Dubos Point

	Period	Vegetation Line (feet/year)		
		Section 1	Section 2	Combined Average (Section 1-2)
End-point	1959-1996	-2.2	-2.1	-2.1
	1966-1996	-0.9	-2.1	-1.9
	1974-1996	-7.1	-4.6	-5.1
AVERAGE (AOR)		-3.4	-2.9	-3.0

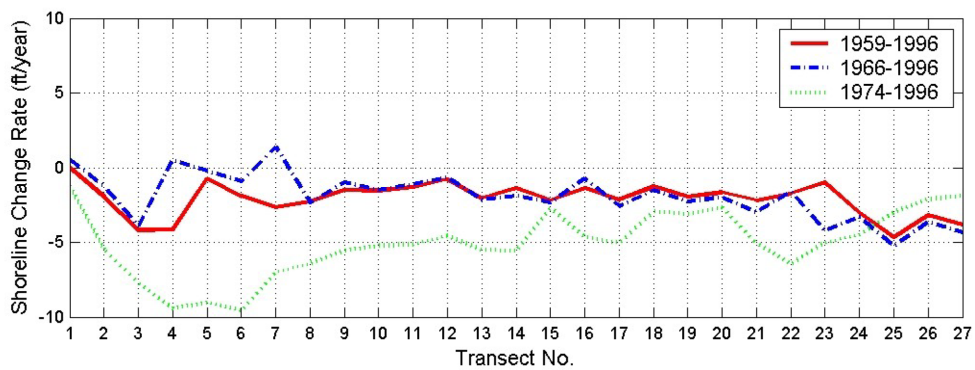


Figure 2-6: Shoreline Change Rate (End-Point Averaging) at Dubos Point

2.1.6.4 Slope Stability Analysis

The shoreline slope stability analysis for Dubos Point showed stable slopes with all slopes shallower than 1V:3H and most slopes shallower than 1V:4H. Average velocities for incoming tides ranged from 0.0 fps to 0.3 fps and average velocities for outgoing tides ranged from 0.0 fps to 0.4 fps. Geotechnical data indicates that the upper most 5 to 7 feet of material in the area consists of fine to coarse sands and general fill/debris, which is generally underlain by an older organic silty clay meadow mat strata.

No unstable slopes were identified at the Dubos Point site.

2.1.6.5 Wind-Generated Wave Analysis

The spectral significant wave height (H_{mo}), the peak period (T_p), and mean wave direction resulting from the ACES predictions for Dubos Point are shown in Table 2-10. These results correspond to a representative (reference) location along the Dubos Point shoreline. Figure 2-7 shows the fetch directions for wind wave generation. Three (3) different sets of results are presented corresponding to design return periods of 50-, 20-, and 10-year winds, respectively. In general, for the Dubos Point site:

- The model predicts that the maximum waves will be generated when the winds are blowing from northeast (NE), and north-northeast (NNE) which corresponds to longest fetch direction.
- The modal wave height was estimated to be 3.6 feet, 2.8 feet and 2.5 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 3.3 sec, 2.9 second and 2.8 second for the 50-year, 20-year and 10-year wind speeds, respectively.
- Mean wave directions were estimated to be between 40 and 45 degrees (measured clockwise from true north) for northeasterly fetch directions.
- Northwesterly fetches will generate about 20 percent smaller waves and shorter periods than northeasterly fetches.

Table 2-10: Dubos Point Wind Generated Wave Results

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N	0.39	42	3.0	3.0	33	2.3	2.7	33	2.0	2.5	33
2	NNE	0.63	42	3.6	3.3	40	2.8	2.9	40	2.5	2.8	40
3	NE	0.95	16	3.6	3.2	42	2.8	2.9	42	2.5	2.7	42
4	ENE	0.16	16	3.3	3.1	45	2.6	2.8	45	2.3	2.6	45
5	E	0.24	16	2.6	2.8	48	2.0	2.5	48	1.8	2.4	48
6	ESE											
7	SE											
8	SSE											
9	S											
10	SSW											
11	SW											
12	WSW	0.62	34	3.0	3.0	255	2.4	2.6	255	2.1	2.5	255
13	W	0.47	36	3.0	2.9	255	2.3	2.6	255	2.0	2.5	255
14	WNW	0.53	42	2.9	2.9	289	2.3	2.6	289	2.0	2.4	289
15	NW	0.30	42	2.7	2.8	294	2.1	2.5	294	1.8	2.4	294
16	NNW	0.31	42	2.4	2.7	14	1.9	2.4	14	1.6	2.3	14

(MWD = Mean Wave Direction)

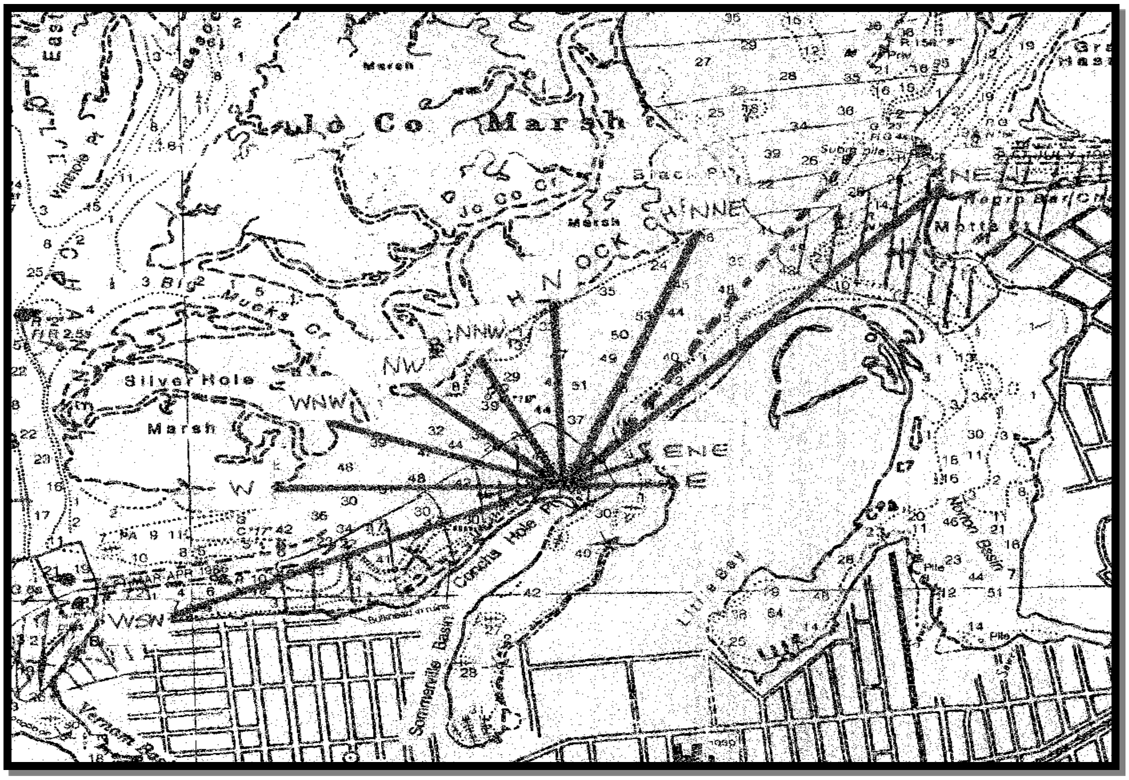


Figure 2-7: Fetch Directions for Dubos Point

2.1.7 Brant Point

2.1.7.1 Topography and Bathymetry

Brant Point has a steep beach face, with slopes ranging from 40 to 50 percent from -2 to 2 NAVD88. From 0 to -4 NAVD88 slopes range from 10 to 20 percent. The bathymetric depths at Brant Point, based on 2002 topographic surveys, ranged from -4 to -20 NAVD88 and were therefore highly variable. The western end of the site has 50 percent slopes between -10 to -20 NAVD88, while the eastern end of the site has 3 percent slopes in those depths. There was an impounded pool of water just inland of the beach, which had depths of 0.0 feet NAVD88. The average elevation of the upland portion of the site was between 5 to 7 feet NAVD88; the maximum elevation was 14 feet NAVD88.

2.1.7.2 Geotechnical

The soil here was well-sorted sand, with the median sand diameter of 0.264 to 0.621 mm for the three (3) on-shore grab samples. All three (3) samples were very consistent, with less than 1 percent gravel and clay, and only 5 to 10 percent silt. A draft soils survey obtained from NRCS shows that soils within the Dubos Point site are Bigapple-Fortress complex. The Bigapple soils series includes areas covered by dredge material (NRCS 2004). The Fortress series also denotes a filled area, but composing of dredged, outwash, or eolian sands (NRCS 2004). The offshore subsurface is primarily composed of poorly graded fine to medium sand with trace amounts of silt. In summary, the offshore soils are sand (SP-SM) and fat clay (CH), with phi angles between 0 to 25 degrees.

2.1.7.3 Shoreline Change

The Brant Point shoreline has exhibited long-term shoreline recession since the early 1900s (USACE, 2002). For the purposes of this report, Brant Point was divided into two (2) sections due to northerly and northwesterly exposures to wave attack as well as the different shoreline characteristics. Section 1 spans along the west side of the site, and Section 2 spans along the north side of the Brant Point. Section 1 shoreline consists of natural material with deposits of shells, and exposed organic clay layers. Portions of the north face of the Brant Point (Section 2) shoreline consist of a riprap edge where the shoreline is locally armored with broken concrete slabs. This armoring protects the shoreline from wave attack; therefore, historical recession rates at the north side could be expected to be less than the west side of the shoreline. A tombolo (sand bar), created by an abandoned barge founded along the west side (Section 1) of Brant Point, was not included into the rate calculations. This tombolo existed only on 1996 aerial.

Table 2-11 summarizes the shoreline change rates, and Figure 2-8 shows the change in the rate along the shoreline for the three (3) periods. Section 1 and 2 shows differing rates for each end-point analysis corresponding to different wave exposures. Section 1 has an average of -4.3 feet/year recession rate. The average recession rates for Section 2 were determined to be -2.4 feet/year. Recession rates for the periods 1959-1996, and 1966-1996 were approximately half the rates for the period of 1974-1996, especially for Section 1. This is mainly due to an accretionary period from 1966 to 1974, which reduces the long-term average recession rates. The combined average of recession rate was calculated as -2.6 feet/year. Consequently, it is reasonable to assume that the Brant Point shoreline has retreated at a rate of about -3.0 feet/year since 1959.

Table 2-11: Average Shoreline change rates for Brant Point

	Average Water line (feet/year)			Average Vegetation Line (feet/year)		
Period	**Section 1**	**Section 2**	**Combined Average**	**Section 1**	**Section 2**	**Combined Average**
1959-1996	-2.4	-1.5	-2.2	-3.4	-2.3	-2.5
1966-1996	-2.2	-1.3	-2.0	-3.5	-2.3	-2.5
1974-1996	-4.6	-2.0	-3.7	-6.0	-2.7	-3.8
AVERAGE	-3.1	-1.6	-2.6	-4.3	-2.4	-3.0
1959-1966	-3.2	-2.3	-2.7	-3.2	-2.3	-2.6
1966-1974	4.3	0.7	2.4	3.3	-1.4	1.0

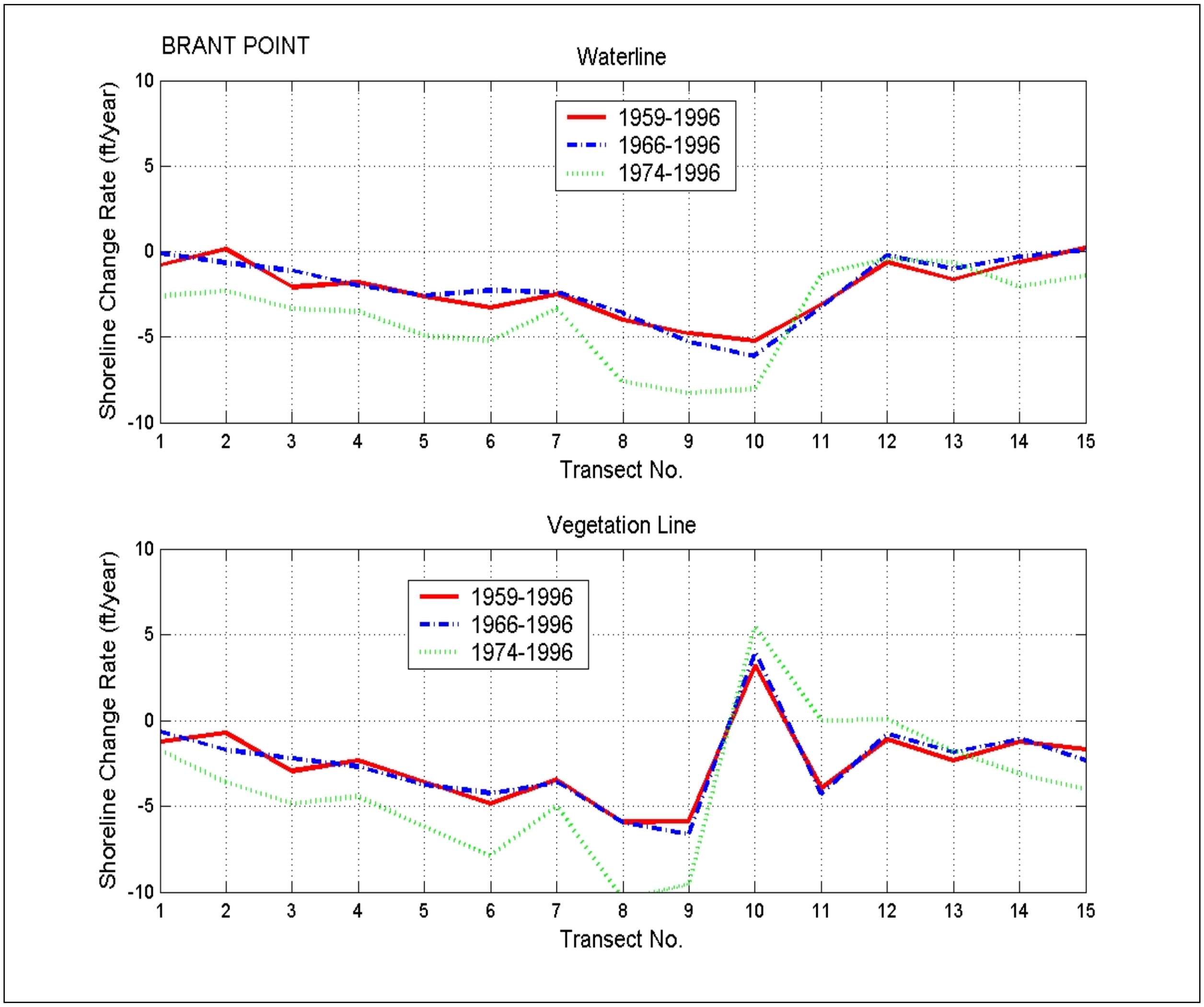


Figure 2-8: Shoreline change rates along the Brant Point site

2.1.7.4 Wind-Generated Wave Analysis

The spectral significant wave height (H_{mo}), the peak period (T_p), and mean wave direction resulting from the ACES predictions for Brant Point are shown in Table 2-12. These results correspond to a representative (reference) location along the Brant Point shoreline. Figure 2-9 shows the fetch directions for wind wave generation. Three (3) different sets of results are presented corresponding to design return periods of 50-, 20-, and 10-year winds, respectively. In general, for the Brant Point site:

- The model predicts that the maximum waves will be generated when the winds are blowing from east-northeast (ENE) corresponding to longest fetch direction.
- The modal wave height was estimated to be 3.9 feet, 3.0 feet and 2.7 feet for the 50-year, 20-year and 10-year wind speeds, respectively.
- Peak periods were 3.4 sec, 3.0 sec, and 2.8 second for the 50-year, 20-year and 10-year return-periods, respectively.
- Mean wave directions were estimated to be between 64 and 68 degrees (measured clockwise from true north) for northeasterly fetch directions.

- Northwesterly fetches will generate about 10 percent smaller waves and shorter periods than northeasterly fetches.

Table 2-12: Wind-Generated Wave Results for Brant Point

Fetch		Fetch Length	Depth	Wave Characteristics								
				50-year			20-year			10-year		
				Height	Period	MWD	Height	Period	MWD	Height	Period	MWD
No.	Direction	(mi)	(feet)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)	(feet)	(sec)	(deg N)
1	N	0.31	21	2.7	2.8	329	2.1	2.5	329	1.9	2.4	329
2	NNE	0.31	16	2.9	2.9	62	2.3	2.6	62	2.0	2.5	62
3	NE	0.39	16	3.7	3.4	65	2.9	3.0	65	2.4	2.8	65
4	ENE	1.90	26	4.1	3.6	67	3.2	3.2	67	2.7	2.9	67
5	E	0.10	16	3.6	3.4	69	2.8	3.0	69	2.4	2.8	69
6	ESE											
7	SE											
8	SSE											
9	S											
10	SSW											
11	SW	0.38	16	2.4	2.6	232	1.9	2.3	232	1.7	2.2	232
12	WSW	0.38	21	2.5	2.6	244	1.9	2.4	244	1.7	2.2	244
13	W	0.32	21	2.6	2.8	309	2.0	2.5	309	1.8	2.3	309
14	WNW	0.39	21	3.2	3.0	313	2.5	2.7	313	2.2	2.6	313
15	NW	0.79	21	3.5	3.3	333	2.7	2.9	333	2.3	2.7	333
16	NNW	1.40	21	3.7	3.4	336	2.9	3.0	336	2.4	2.8	336

(MWD = Mean Wave Direction)

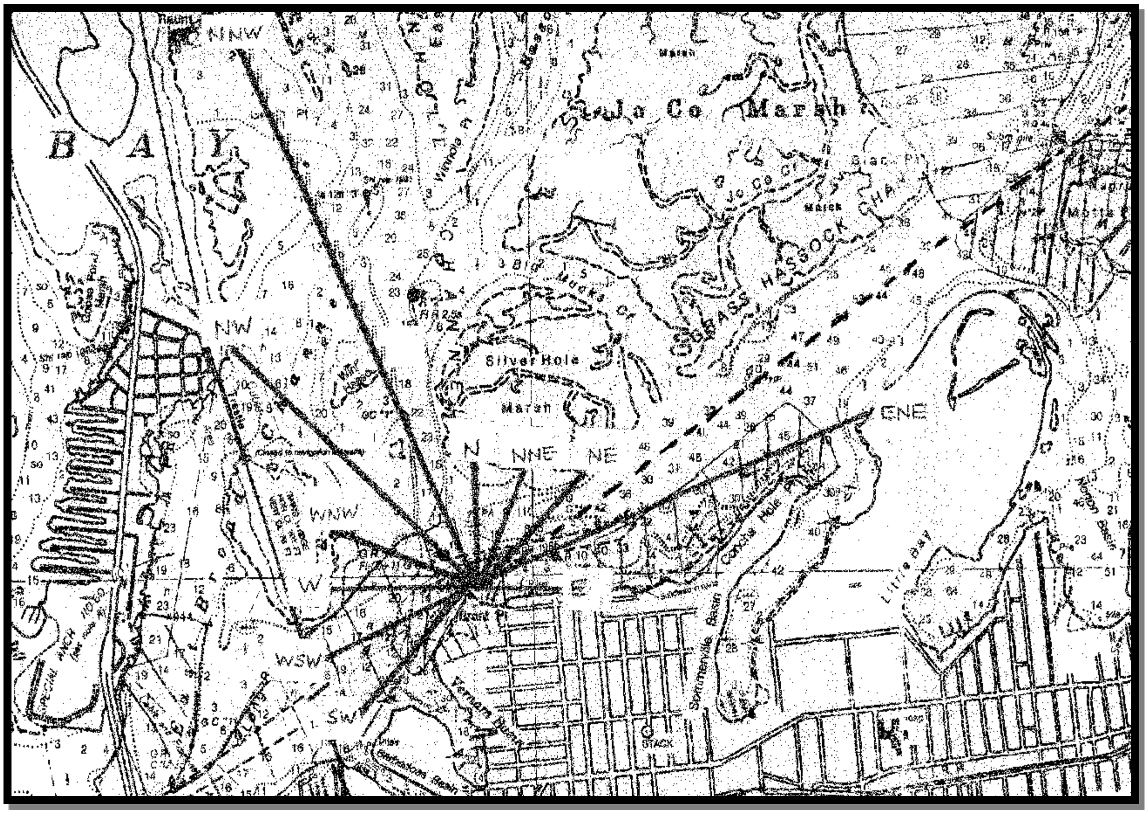


Figure 2-9: Fetch Directions for Brant Point

2.1.8 Jamaica Bay Marsh Island Sites

Site-specific field data were not collected at the proposed Jamaica Bay Marsh Islands (including Stony Creek Marsh, Duck Point Marsh, Elders Point Center, Pumpkin Patch East, and Pumpkin Patch West). Data collected for Elders Point East, Elders Point West and Yellow Bar Hassock were utilized to prepare the concept designs.

2.1.8.1 Topography and Bathymetry

Bathymetric data used in the development of the five (5) conceptual island design alternatives was a composite set that included data collected in 2008 and 2009, using single beam and multi-beam sonar. Some of the data was collected at 1-meter resolution and sampled to a 5-meter resolution. The data was projected to UTM Zone 18N with a vertical datum of NAVD88. The data can be downloaded from the National Park Service Integrated Resource Management Applications website at the following link: https://irma.nps.gov/DataStore/Reference/Profile/2204843

A composite topographic surface was created for the Elders Point Center site, which combined the final survey data from the constructed islands at Elders Point East and Elders Point West. No other topographic data were collected for the remaining four (4) islands. Instead, conceptual designs for those islands relied on publicly-available LIDAR data.

More recent topographic and bathymetric data were compiled by the Structures of Coastal Resilience team at the City College of New York (CUNY). Figure 2-10 shows the composite digital elevation model (DEM) developed at CUNY. Although this model was not used for the development of the conceptual designs, it will be compared with USACE's composite DEM to determine the level of agreement between the two (2) surfaces as we move forward into the next stages of design.

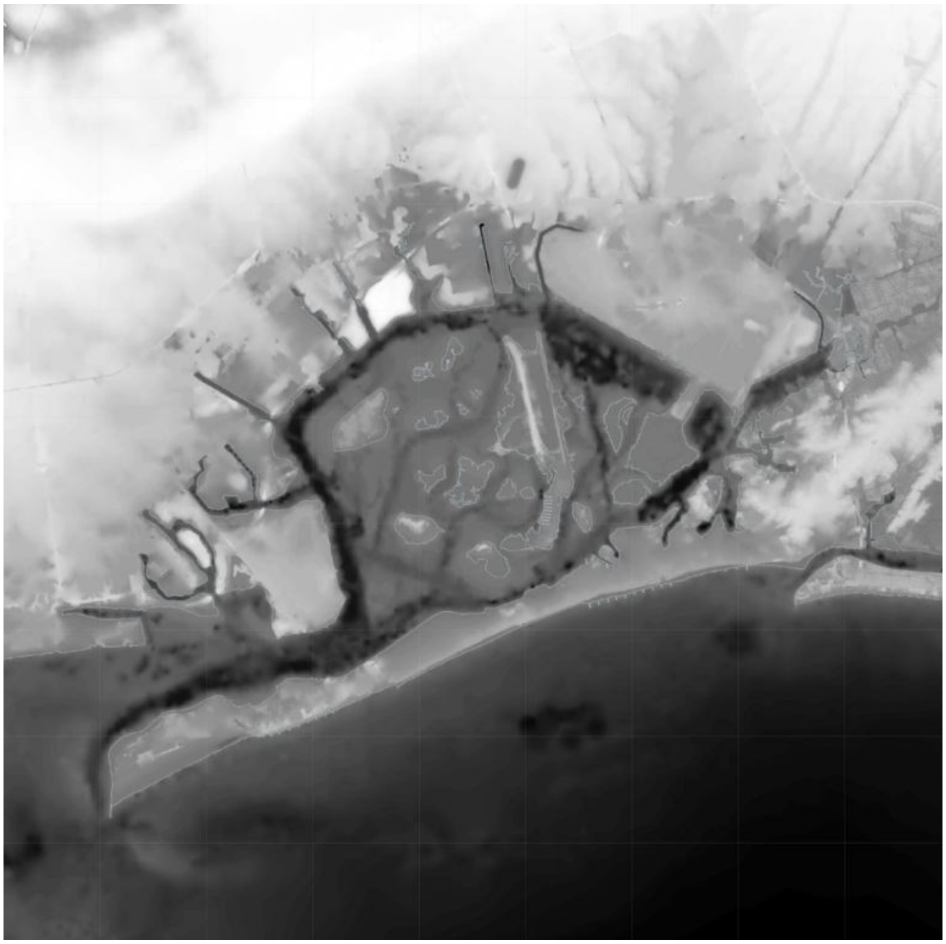


Figure 2-10: Digital Terrain Model from Structures of Coastal Resistance, CUNY (2015)
http://structuresofcoastalresilience.org/locations/jamaica-bay-ny/

2.1.8.2 Geotechnical

No geotechnical information was collected for any of the five (5) proposed marsh island sites; however, borings were collected during the design phases for the previously constructed marsh islands, including Elders Point East and Elders Point West, and Yellow Bar Hassock. The subsurface conditions for the five (5) proposed islands were assumed to be similar to those of the islands that were constructed. Geotechnical borings will be collected at each of the proposed islands during the PED phase.

Subsurface conditions at Yellow Bar Hassock, for example, consisted of a very soft silt-clay layer that ranged in depth from approximately 1 to 10 feet. The areas of thicker depth were more susceptible to natural settlement. It was anticipated that sand placement during construction would result in primary (immediate) and secondary (long-term) settlement. An initial sand loss rate of 50 percent was expected during construction; at some locations, actual losses approached 70 percent. Losses were due largely to compression of the substrate, and to a lesser extent, wind and waves.

2.2 Harlem River, East River, Western Long Island Planning Region

2.2.1 Flushing Creek Study Area

Existing conditions data was collected for the Flushing Creek "Source" Study between 2002 and 2004 and more recently conducted (2012-2014) by NYCDEP as work in kind.

2.2.1.1 Topography & Bathymetry

To establish a basis for the conceptual designs, field surveys were conducted for the shoreline properties and within the Flushing Creek. The bathymetric surveys were performed in July 2012 by Gahagan & Bryant Associates. The land survey was performed by M.J. Engineering and Land Surveying, P.C. during several site visits in 2013. All survey data was recorded relative to the NAVD88 and subsequently combined into a single 3D model.

MLW was selected as the preferred datum for the conceptual designs. Accordingly, the 3D model was adjusted from the native datum (NAVD88) to the selected project datum by applying a conversion value obtained from the NOAA application Vdatum version 2.3.3. All contours and elevations shown on the design drawings are in feet in reference to MLW, defined as 3.60 feet below NAVD88 (Table 2-13).

The bathymetric surveys reveal water depths within the study area as typically shallow, between -5 and 2 feet at MLW. A notable exception is a scour hole near outfall TI-010 at approximately 22 feet below MLW.

The horizontal coordinate system used for the geometric model and the design plans is the New York State Plane, North American Datum of 1983 (NAD83) Long Island Lambert Zone 3104, in units of feet.

Table 2-13: Tidal Elevations in Flushing Creek (in feet)

Datum	Abbreviation	Water Surface Relative to MLW (feet)
Mean Higher High Water	MHHW	7.17
Mean High Water	MHW	6.81
North American Vertical Datum-1988	NAVD 88	3.6
Mean Tide Level	MTL	3.4
Mean Low Water	MLW	0
Mean Lower Low Water	MLLW	-0.28

2.2.1.2 Geotechnical

A geotechnical study was performed for the NYCDEP by the AECOM/HydroQual Joint Venture under the Citywide Dredging Engineering Design Contract Services Contract for New York City. Shallow marine sediments were sampled and sediments were field-tested in-situ for shear strength at twelve

locations in August 2013 and were analyzed at a laboratory. Information of deeper geologic materials was gathered from prior studies by New York State Department of Transportation (various) and USACE (2004).

The subsurface investigation found that the shallow depths within the project area majorly consist of very soft, black organic silt (presumed CSO sediments) with occasional natural silt or clay material near the bottom. The thickness of the CSO and natural deposit varies from approximately 3 to 35 feet. Test data shows the CSO deposits to be highly compressible with low shear strength.

Underlying the organic materials is a silt and sand mixture layer, generally consisting of various amounts of silt, sand and clayey silt mixture. This in turn overlies a fairly dense sand layer over glacial till.

2.2.1.3 Water Quality Modeling

Flushing Bay is a moderately stratified and partially mixed estuary that is part of the HRE. Flushing Bay exchanges water with the East River which is in contact with both the Atlantic Ocean and Long Island Sound. Flushing Bay is considered a dynamic and well-mixed system. However, the mixing is significantly reduced in the inner bay. The flushing half-life varies from one tidal cycle at mid-bay to six (6) tidal cycles in Flushing Creek. The flushing effectiveness was found to be 99.9 percent. The salinity of the bay ranges from 22 to 24 parts per thousand (ppt).

Tidal range in Flushing Bay is approximately seven (7) feet. Mean tide ranges within Flushing Creek at the Northern Boulevard Bridge are reported to be 6.8 feet at mean tide and 8.0 feet at spring tide. The system receives freshwater (non-saline) flow from CSO discharges, direct rainfall runoff, and discharge through the tide gate from Meadow and Willow lakes. The bay and creek are Class I waters per the NYSDEC. The best intended usages for this classification are secondary contact recreation and fishing.

Water quality throughout Flushing Bay and Creek typically exhibit low levels of dissolved oxygen and anoxia, and high levels of bio-chemical oxygen demand. Sediments are organics-rich with a low level of benthic community diversity. Exposed intratidal mudflats generate hydrogen sulfide gas. Water and sediment quality investigations were conducted to provide the data needed to calibrate and verify an enhanced mathematical model to be used to evaluate restoration alternatives. Water and sediment quality modeling were conducted in two (2) phases.

The Phase I modeling effort focused on dissolved oxygen levels, hydrogen sulfide production, and the impacts of potential removal of the breakwater. The effect of breakwater removal on water quality was found to be minimal (see Memorandum from G. Apicella, LMS to James Mueller, NYCDEP and Pete Womack, USACE dated April 22, 2002 for a discussion of Phase I modeling results). Phase II modeling focused on sediment quality based on recent work by NYCDEP in other bays throughout the city. These bays were found to have a negative relationship between the levels of total organic carbon within the sediments and the number of benthic taxa within the sediments (see letter from James Mueller, NYCDEP to Eugene Brickman, USACE, with attachment: Flushing Bay and Creek Ecosystem Restoration Assessment dated March 31, 2003 for a discussion of Phase II modeling results). The higher the percentage of total organic carbon in the sediments, the lower the overall benthic diversity will be in the sediments.

2.2.1.3.1 Phase I Modeling and Results

Phase I modeling results indicated that no ecological benefits related to improved levels of dissolved oxygen or hydrogen sulfide would be generated by breakwater removal. Based on these results, NYCDEP proposed to extend the modeling effort (Phase II) to assess whether removal of the breakwater would provide a significant benefit to the ecosystem. The evaluation of decreasing the deposition of fine grained organic-rich sediments in inner Flushing Bay was conducted in Phase II. NYCDEP also proposed to assess the potential benefits of dredging organic-rich sediments in the inner bay. The dredged areas would be capped with clean sediments. This would reduce sediment total organic carbon concentrations.

Hydrodynamic characteristics of Flushing Bay and Creek are affected by the fast moving East River and a sill at the confluence between Flushing Bay and the East River. The tidal range throughout the system is spatially uniform, but tidal flow is attenuated the father away from the East River. Flushing Bay and Creek are depositional areas that exhibit low bottom shear stress.

Phase I water quality modeling projections were used to assess the water quality impact of breakwater removal. Breakwater removal was evaluated by comparing dissolved oxygen levels under the no-breakwater scenario, to the baseline conditions. The removal of the breakwater allows the higher salinity East River water to pass directly into and out of the inner bay. The inner bay is less diluted by Flushing Creek than under baseline conditions. The average dissolved oxygen levels in inner bay and breakwater area are higher than average dissolved oxygen levels in the East River. Under baseline conditions, removal of the breakwater causes a very slight decrease in dissolved oxygen levels in the inner bay. The effect of deeper water in the area of the former breakwater would slightly decrease re-aeration, which would also tend to lower dissolved oxygen levels.

The Phase I modeling projections indicate that hydrogen sulfide production would be reduced under the no-breakwater scenario. This result is based on the assumption that the bay bottom re-contouring associated with breakwater removal reduces the elevation of adjacent mudflats such that the sediments are no longer exposed at low tides. Although breakwater removal would have beneficial impacts to local hydrogen sulfide production, there are no ecosystem benefits to hydrogen sulfide reductions. Breakwater removal would have no impact on hydrogen sulfide production at other mud flat areas, such as in the inner bay in the vicinity of the World's Fair Marina, and upstream along Flushing Creek.

2.2.1.3.2 Phase II Modeling and Results

Phase I modeling results indicated that no ecological benefits related to improved levels of dissolved oxygen or hydrogen sulfide would be generated by breakwater removal. Based on these results, NYCDEP proposed to extend the modeling effort (Phase II) to assess whether removal of the breakwater would provide a significant benefit to the ecosystem. The evaluation of decreasing the deposition of fine grained organic-rich sediments in inner Flushing Bay was conducted in Phase II. NYCDEP also proposed to assess the potential benefits of dredging organic-rich sediments in the inner bay. The dredged areas would be capped with clean sediments. This would reduce sediment total organic carbon concentrations.

Phase II modeling included a full breakwater removal scenario. Full breakwater removal indicated minor hydrodynamic impacts to the bay and only minor impacts to sheer stress on the bay bottom that would affect sediment deposition. Deposition areas remained similar under the no-breakwater scenario as compared to baseline conditions. Overall the Phase II model results indicate that breakwater removal

would not decrease the deposition of fine grained organic-rich sediments to Flushing Bay. Also, removal of the breakwater would not reduce concentrations of total organic carbon in sediments.

The Phase II modeling effort did indicate that removal of existing sediments and replacement with clean sediments would significantly improve benthic taxa. This improvement is based on studies of sediments throughout bays in New York City. These studies have shown that a high total organic carbon level in sediments is correlated with low benthic species diversity. Operation of the Flushing Bay storage facility will greatly reduce CSO discharge volume, biological oxygen demand, and total suspended solids loading into the creek and bay. Modeling conducted in Phase II indicates that removal of existing sediments and replacement with clean sediments in the inner bay and at areas along the creek would provide improved conditions. These improvements would last for many years before total organic carbon builds back up to a new equilibrium condition.

The extent of habitat benefits based on removal of existing sediments and replacement with clean sediments will be estimated determined during this study. The goal is to guide the selection of areas that would be most beneficial to dredge. The following factors need to be evaluated to extend the life of benthic habitat improvements:

- NYCDEP's review of sediment quality data shows that settlement of CSO solids is spatially variable, with the highest settlement volume occurring at local outfall locations. The farther from an outfall, the longer the improvement would last. The impact of spatial variability is important;
- The reduction in total organic carbon loading associated with improvements to CS4 will reduce levels in Flushing Creek, reducing future levels of total organic carbon in sediments;
- The improvements in dissolved oxygen associated with improvements to CS4 are expected to continue. It is assumed that total organic carbon will reach a new equilibrium. The ambient level of dissolved oxygen will be higher than those in the observed relationship between total organic carbon and taxa diversity; and
- NYCDEP is developing a comprehensive waste water control plan for Flushing Bay that will include non-structural recommendations and best management practices alternatives that are will build on the benefits of the project.

2.2.2 Bronx River Study Area

2.2.2.1 All Bronx River Sites

2.2.2.1.1 Topography and Watershed Characteristics

The drainage area of the Bronx River is approximately 24,260 acres (55.2 square miles). Roughly 83 percent of the watershed is located in Westchester County and the remaining 17 percent is located in Bronx County. The River is approximately 23 miles long. It flows from Kensico Lake (Reservoir) in the north to Hunts Point in the East River. At the same time, it is strongly controlled by the bedrock. The present areas of investigation include a total of nine (9) sites in Westchester and Bronx Counties.

A significant portion of available land in the watershed of the Bronx River has already been developed. Generally, the degree of development increases as one proceeds downstream from Westchester County into Bronx County, particularly in the vicinity of the cities of Yonkers and Mount Vernon and Villages of Bronxville and Tuckahoe.

With urbanization comes the construction of buildings, roadways, parking lots, etc. These impervious surfaces have a dramatic impact on the Bronx River, particularly in the more urbanized lower watershed, where there is more than 25 percent impervious cover over more than half of the land area. Impervious ground surfaces deflect rainfall, rather than absorb it into the ground. Natural areas, which include parks and non-residential areas within the Bronx River watershed, typically exhibit imperviousness of 10 to 15 percent due to paved areas within parks (e.g. paths and trails) and active recreation fields (e.g. baseball fields and cricket pitches). While most of the watershed is already developed, impervious area in the Bronx River watershed is projected to increase in the future due to higher density redevelopment and implementation of existing plans to widen roadways.

The topography is dominated by several NNE-SSW trending valleys and their associated ridges (Figure 2-10). Table 2-14 list general characteristics of the Bronx River. The river flows 15 miles through Westchester County and 8 miles through the Bronx. Westchester County hosts 65 percent of the river's length and 85 percent of the river's watershed. Table 2-15 lists 19 sub-watersheds that make up the Bronx river basin. 12 of these are tributary watersheds that comprise 62 percent of the Bronx River Basin. Table 2-16 shows the drainage areas upstream of the investigation sites.

Table 2-14: Summary of Geomorphology Bronx River Valley

Bronx River Basin Ranges	
River length total	~23 miles
River length total Westchester County	~15 miles
River length total Bronx County	~8 miles
Total basin area	56.3 sq miles
Total basin area in NY	55.1 sq miles
Total basin area in Westchester County	47.1 sq miles
Bronx River valley area	21.3 sq miles
Tributary area	35.0 sq miles
Range of elevations	<0 to 270ft
Slopes	2 to 155 ft/mile
Low-flow channel width	20 to 250
Present-day width of river flood plain	50 to 620ft
Pre-railroad width of river flood plain	70 to 3,000ft
Roadway bridge crossings	66
Zoo tram bridges	2
Railroad bridges	6
Pedestrian bridges	~10
Dams	8

Table 2-15: Sub-watersheds in the Bronx River Basin

	Sub-watershed	Type	County	Drainage Area (sq miles)
1	Kensico Reservoir	Tributary	Westchester	12.42
2	Clove Brook	Tributary	Westchester	1.32
3	Davis Brook	Tributary	Westchester	2.14
4	Upper Bronx River Basin	Bronx River	Westchester	5.02
5	White Plains Reservoirs	Tributary	Westchester	0.90
6	Manhattan Park Brook	Tributary	Westchester	3.31
7	Fulton Brook	Tributary	Westchester	0.98
8	Hartsdale Brook	Tributary	Westchester	1.21
9	Fox Meadow Brook	Tributary	Westchester	1.45
10	Middle Bronx River Basin	Bronx River	Westchester	5.08
11	Troublesome brook	Tributary	Westchester	2.69
12	Sprain Brook	Tributary	Westchester	3.91
13	Grassy Sprain Brook	Tributary	Westchester	2.66
14	Grassy Sprain Brook direct	Tributary	Westchester	1.97
15	Lower Bronx River Basin	Bronx River	Westchester	3.26
16	Parkland	Bronx River	Bronx	3.58
17	Bronx Gardens/Zoo	Bronx River	Bronx	1.30
18	West Farms	Bronx River	Bronx	1.53
19	Estuary	Bronx River	Bronx	1.58

Table 2-16: Area of Bronx River Basin upstream from each site

Site	Drainage area upstream of site (sq miles)	Additional drainage area to site (sq miles)
Westchester County Center	18.18	4.44
Garth Woods/Harney Road	26.69	
Crestwood Lake	31.07	2.69
Bronxville Lake	34.63	
Muskrat Cove	48.33	
Shoelace Park	49.73	1.58
Snuff Mill (Stone Mill) Dam	52.15	
Bronx Zoo and Dam	52.57	
Bronx River Park	53.26	

The Kenisco Dam was built across the Bronx River. Kenisco Lake flows in the Bronx River. Elevation of the Bronx River below Kensico Lake is +270 feet. The Bronx River flows into the East River at sea level. At that point the river bed is below sea level. Table 2-17 shows the ranges of elevations and average slopes for all the sites. Table 2-18 shows the approximate widths of the low-flow river and flood plain for each site. The river valleys are relatively narrow.

Table 2-17: Range of elevations for the Bronx River Basin

Site	Range of river elevations		Site river length (feet)	Average slope (feet/mile)
	Upstream (feet)	Downstream (feet)		
Westchester County Center	177	174	2,620	6.0
Garth Woods/Harney Road	125	109	1,988	42.5
Crestwood Lake	98	94	2,442	4.3
Bronxville Lake	91	83	4,165	10.1
Muskrat Cove	58	56	1,350	7.8
Shoelace Park	51	48	6,757	2.3
Snuff Mill (Stone Mill) Dam	48	38	344	153.7
Bronx Zoo and Dam	29	21	1,256	33.6
Bronx River Park	16	9	905	40.8

Table 2-18: Bronx River valley characteristics for each site.
Note that the pooled area of Harney Road reach is listed separately from Garth Woods reach.

	Low-flow channel widths		Estimated present-day flood plain width		Estimated pre-railroad flood plain width		Island dimension (visible in 2014)	
	Min (feet)	Max (feet)	Min (feet)	Max (feet)	Min (feet)	Max (feet)	Length (feet)	Width (feet)
Westchester County Center	18	50	140	460	800	3,000	220[a]	135
Garth Woods	25	95	200	265	380	410	325[b]	130
Harney Road	50	95	100	260	250	620	30 [c]	8
Crestwood Lake	82	250	280	620	500	1,400	80[d]	640
Bronxville Lake	90	250	180	300	410	580	440	50
Muskrat Cove	60	85	150	210	400	575	n.a	n.a
Shoelace Park	50	90	90	400	400	850	n.a	n.a
Snuff Mill Dam	50	30	50	50	70	50	70	
Bronx Zoo and Dam	50	130	350	390	430	750+	140	65
Bronx River Park	30	50	50	60	550	650	n.a	n.a

a. Tree covered island in braided reach
b. High-flow island formed when apparent abandoned stream is full.
c. Gravel and cobble bar south of weir.
d. Largest of four (4) sediment islands as of July 2014.

The main bedrock types in the river basin consist of the Cambrian-Ordovician Inwood Marble, Hartland formation schist and gneiss, and the Proterozoic Fordham Gneiss and Yonkers Gneiss. Table 2-19 summarizes the stratigraphy of the Bronx River north of the Mosholu Parkway.

Table 2-19: General stratigraphy of the Bronx River north of Mosholu Parkway.

Age	Description
Holocene	Modern river sediments
Holocene	Fill and man-made structures
Holocene	Thin soils
Holocene	Fluvial sediments
Pleistocene	Pleistocene glacial lake clays and silts
Pleistocene	Pleistocene glacial outwash deposits
Pleistocene	Pleistocene glacial moraine tills
Cambrian-Ordovician	Inwood marble
Cambrian-Ordovician	Hartland formation
Proterozoic	Yonkers gneiss
Proterozoic	Fordham gneiss

2.2.2.1.1.1 Hydrology & Hydraulics

Precipitation in the Bronx River watershed is approximately 46 inches per year. For watersheds in their natural state, rainwater is absorbed into the soil, where it infiltrates to the groundwater or is conveyed slowly through the subsurface to stream channels. Impervious surfaces prevent rainwater infiltration and thus the degree of runoff is increased. In addition to the increase in runoff volume, urbanized watersheds such as the Bronx River convey stormwater to the main channel through sewers and drains, which is a much faster process than would naturally happen. This disturbed flow pattern of increased peak discharge rates and higher total discharge volumes results in flash floods, erosion, increased water temperatures, low base flow and increased sediment runoff from the surrounding watershed, all of which correlate to low habitat value.

The Bronx River has an average base flow (in dry weather conditions) of approximately 10 to 20 cubic feet per second. According to the FEMA Flood Insurance Study (FIS) for New York conducted in 2001, the 10-year and 100-year frequency discharge at the USGS gage at Bronxville (#01302000) are 1,875 cubic feet per second (cfs) and 3,358 cfs, respectively. Flow characteristics are generally flashy, with most events transpiring within a 24 hour period (USAERDC-CHL, 2007). Recent one-year storm hydrographs indicate that most runoff is conveyed to the channel over a short period of time.

Today much of the river has been straightened. Dams and other impoundments, many of which were originally created to serve as settling basins for sediment in the water column, alter the overall hydrology of the river by acting as detention areas and limiting connectivity between river sections and isolating different parts of the watershed that might otherwise be connected by and influence each other by a free-flowing river. Lack of proper maintenance has resulted in siltation and the formation of small islands within many of the impoundment areas. Most impoundment areas are now silted in and relatively shallow, with depths of the smaller impoundments ranging from 0.0 to

5.0 feet. Crestwood Lake and Bronxville Lake have a sediment depth greater than 4.0 feet. The locations of dams, weirs and other impoundments are shown on Figure 2-11. Table 2-20 provides a summary of these features, listing both name references and numeric designations for consistency with other reports and studies prepared on the Bronx River.

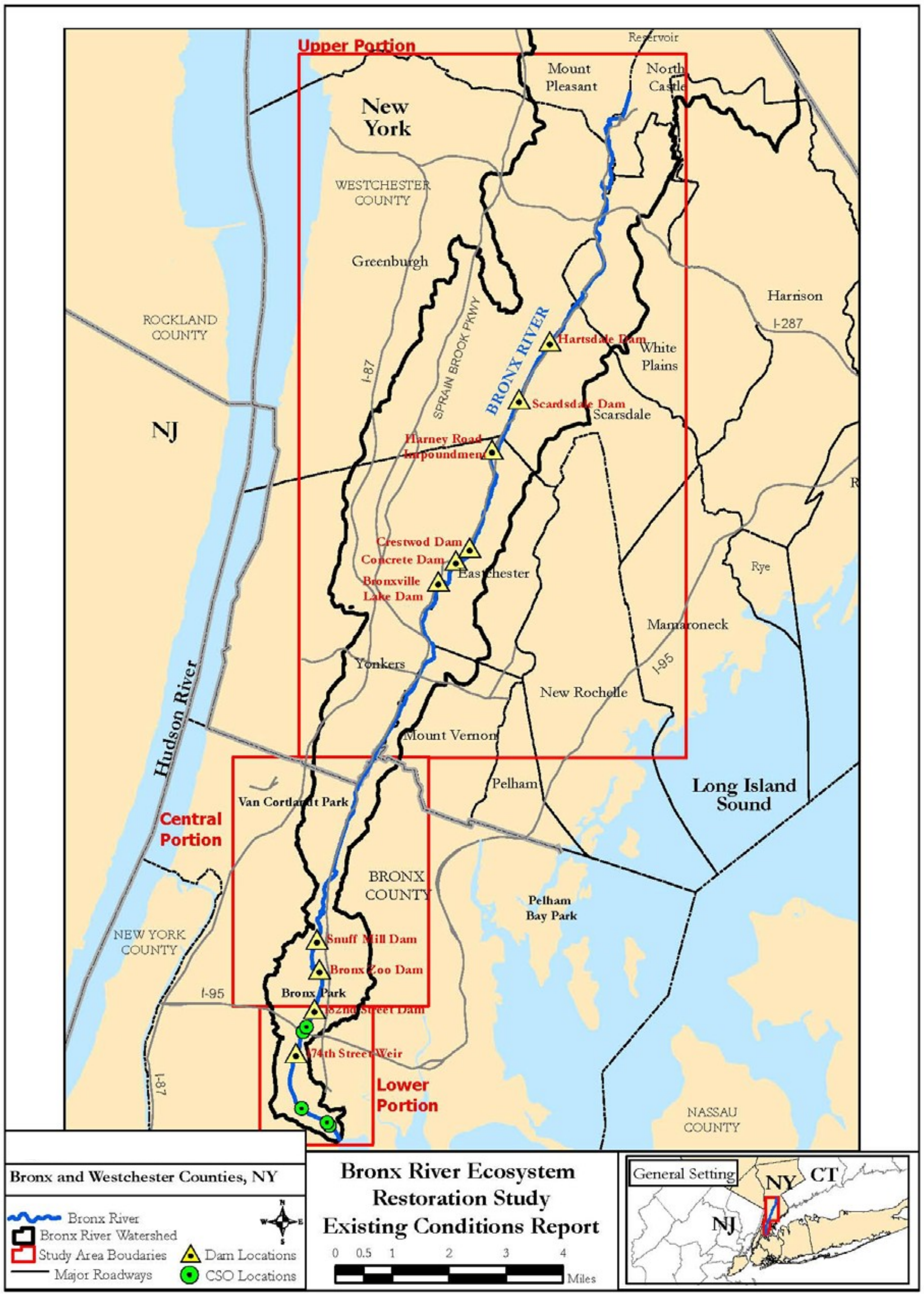


Figure 2-11: CSO and Dam Locations along the Bronx River

Table 2-20: Summary of Existing Dams and Impoundments along the Bronx River

Name/Identification	Location	Watershed
Dam 1 / 174th Street Weir	Estuary/lower portion of Bronx River, Bronx County	Estuary
Dam 2 / 182nd Street Dam	Near downstream extent of Bronx Zoo, Middle portion of Bronx River, Bronx County	West Farms / Bronx Gardens/Zoo
Dam 3 / Bronx Zoo Dam	Bronx Zoo, Middle portion of Bronx River, Bronx County	Bronx Gardens/Zoo
Dam 4 / Snuff Mill Dam	NY Botanical Garden, Middle Portion of Bronx River, Bronx County	Bronx Gardens/Zoo
Dam 5 / Bronxville Lake Dam	Westchester County	Bronx River Middle
Dam 6 / Concrete Dam	Westchester County	Bronx River Middle
Dam 7 / Crestwood Dam	Westchester County	Bronx River Middle
Dam 8 / Harney Road Impoundment	Westchester County	Bronx River Middle
Dam 9 / Scarsdale Dam	Westchester County	Bronx River Middle
Dam 10 / Hartsdale Dam	Westchester County	Hartsdale Brook
Fisher Lane Impoundment	Westchester County	Bronx River Upper
Green Acres Impoundment	Westchester County	Bronx River Upper
Ardsley Road Impoundment	Westchester County	Bronx River Upper

2.2.2.1.1.2 Hydrologic Modeling Using HEC-1

A HEC-1 Model was developed to quantify the existing conditions hydrology for the Bronx River Watershed. Refer to the full Model report, available online, for more detailed information, including key assumptions in determining impervious area, unit hydrograph parameters, Muskingum routing parameters, base flow parameters, and the adopted HEC-1 input parameters.

The USACE Generalized Stream Network Option of the HEC-1 Flood Hydrograph Package was used to hydrologically model the Bronx River watershed and its tributaries for the "source" study. The Bronx River watershed was divided into 55 sub-basins for HEC-1 modeling purposes, based on study needs, location of major and minor tributaries, USGS gaging stations, and points of interest on the Bronx River.

2.2.2.1.1.3 Urbanization

An upward trend of annual and partial peak flow data from the USGS streamflow gage at Bronxville, NY was observed when it was plotted versus time in years elapsed since data collection began in November 1943. This was assumed to be due mostly to the post World War II historic urbanization (development of suburbs) in the Bronx River watershed.

2.2.2.1.2 Base Flow Parameters

Base flow is defined as flow in the stream occurring before and after a rainfall-runoff flood, consisting of both stored water coming out of the ground between the surface and the water table, and from the water table itself, into the stream, under gravity. Base flow parameters were determined for each of six (6) major historic floods modeled.

2.2.2.1.2.1 Major Historic Flood Reproductions

The six (6) major historic floods were modeled with HEC- 1 and are listed below along with the rationale for their selection (in parentheses) and peak discharge, as recorded by the USGS gage at Bronxville, NY. Since the USGS gage was discontinued prior to the April 2007 nor'easter, no discharge data is available for that flood event at the USGS gage at Bronxville.

- June 15 1969 (former flood of record; full discharge hydrograph available from 1971 USACE COE report): 1,580 cfs.
- June 19-20, 1972 (current flood of record; about a 50 year frequency flood, full discharge hydrograph available from 1976 USACE COE report): 2,500 cfs.
- September 25, 1975 (Tropical Storm Eloise): 2,190 cfs.
- November 7-8, 1977 ("Election Day" nor'easter flood): 1,630 cfs
- April 9-10, 1980 (intense spring flood): 2,060 cfs
- April 4-5, 1984 (second-largest historic flood in adjacent Saw Mill River basin): 1,620 cfs

Note: The HEC-1 model run for the April 2007 northeaster was calibrated using the USGS gage at Bronx Botanical Garden. This calibrated model run calculated a peak discharge at the USGS gage at Bronxville of 3,120 cfs. This discharge surpasses the 2500 cfs recorded at this gage during the observed flood peak of June 1972. The Bronxville USGS gage has been discontinued since 1989, therefore the calculated model value could not be confirmed by observed gage data. It should be further noted that this model run was done after the existing conditions hydrology appendix was completed.

Three (3) Bronx River stream gages, located in Bronxville, the Bronx Botanical Gardens, and Burke Avenue in Williamsbridge, were used to calibrate the model. HEC-HMS was used to calibrate and test HEC-1 files for six (6) historic and nine (9) specific hypothetical frequency floods. Once this calibration was accomplished, the HEC-1 models of the specific-frequency hypothetical floods, along with the historic flood HEC-1 models, were considered to be an acceptable existing conditions hydrologic, or rainfall-runoff, model of the Bronx River watershed, suitable for use in the study of water quality, sedimentation, and other parameters to be considered in future studies of proposed ecosystem restoration plans of improvement. Flows from the HEC-1 model were used in the HEC-RAS model for sediment analysis, but not to calibrate water surfaces along the Bronx River. It was determined that calibration of the HEC-RAS model and updating the historical flood events within the HEC-1 model was not necessary because typical streambank restoration projects do not significantly change channel morphology or significantly alter water surface elevations. The flows from the HEC- 1 model were therefore, determine to be acceptable. Table 2-21 summarizes existing conditions peak discharges at key points of interest along the Bronx River. Locations of sub-watersheds for the tributaries mentioned in Table 2-15 are shown on Figure 2-12.

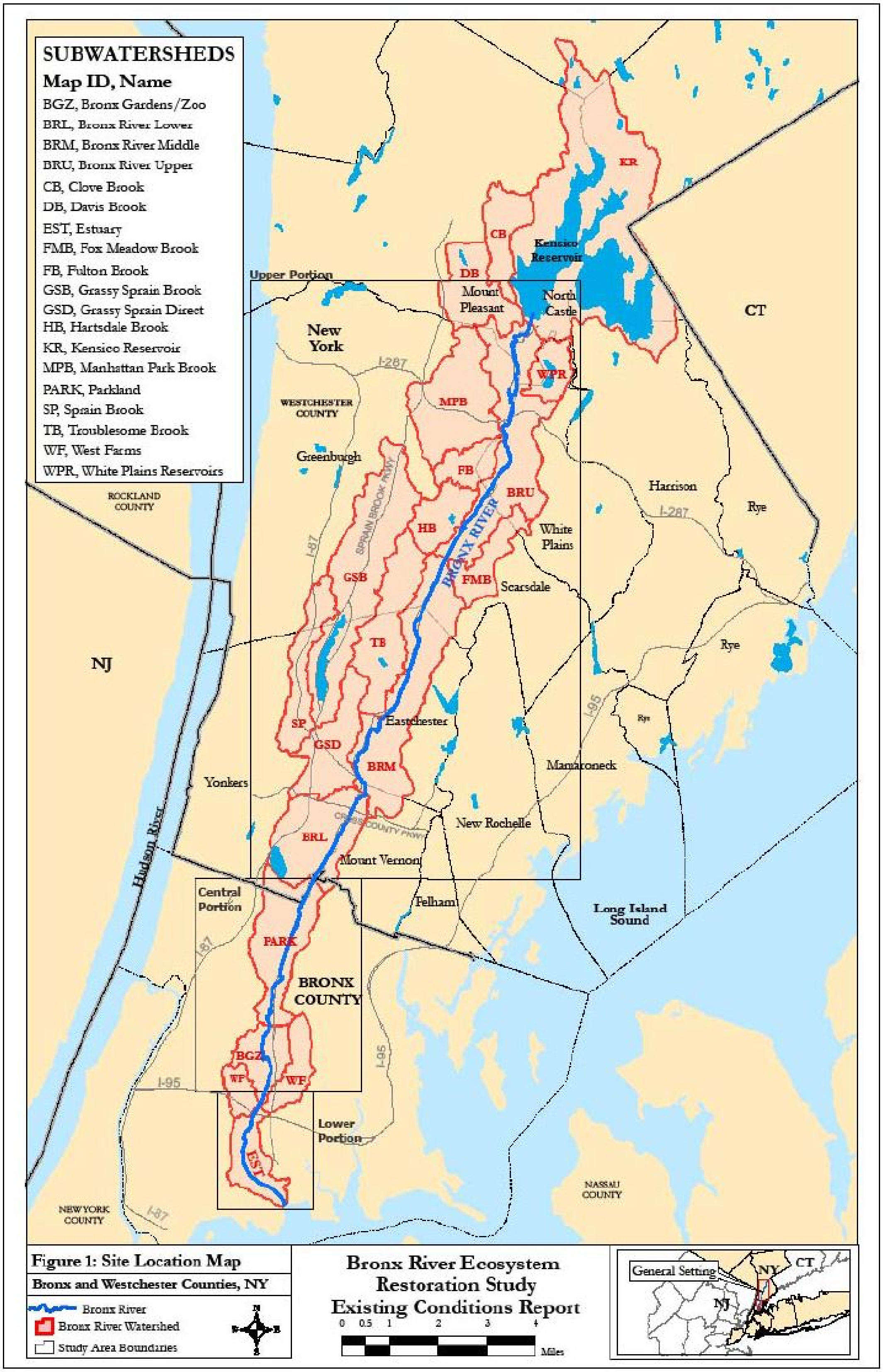
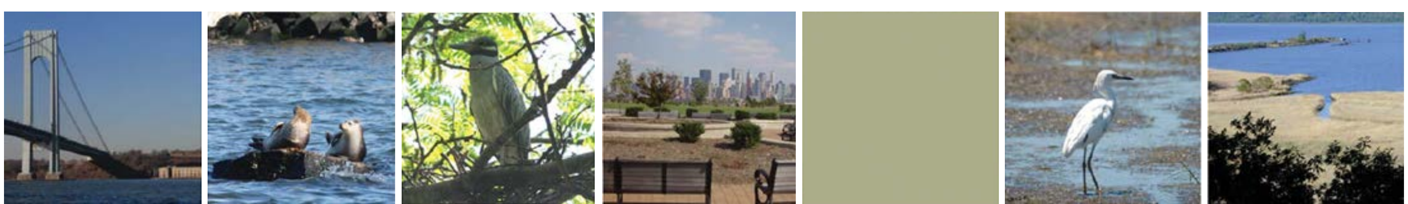


Figure 2-12: Locations of Sub-Watersheds within the Bronx River Basin

Table 2-21: Existing Conditions Peak Discharges in cfs at Key Points of Interest

Description of Location	HEC-1 ISTAQ	Contributing Drainage Area (sq. mi.)	Flood Frequency in Years									
			1	2	5	10	25	50	100	250	500	Jun-72
Bronx River : at Kensico Dam Plaza and Bronx River Parkway Traffic Circle.	C1	0.275	230	250	300	330	380	420	460	510	550	100
Downstream of first right bank tributary	C5	3.8	760	840	1040	1190	1400	1560	1720	1930	2110	910
Downstream of Fulton Brook	C12	9.56	1190	1420	1820	2120	2480	2780	3090	3490	3760	1820
Downstream of Davis Brook	C16	10.47	1140	1370	1740	2040	2380	2670	2970	3370	3660	1900
Upstream of Troublesome Brook	C26	17.17	750	900	1130	1320	1550	1750	1940	2220	2440	1880
Upstream of grassy Sprain Brook	C28	20.4	830	990	1250	1450	1690	1910	2110	2420	2660	1960
Sprain Brook at mouth	S32	3.95	270	330	420	490	580	650	730	830	910	630
Grassy Sprain Brook at mouth	C34	6.04	420	500	630	740	860	960	1060	1200	1310	970
Bronx River: USGS gage at Bronxville	302000	26.5	1070	1290	1620	1880	2200	2490	2750	3150	3460	2500
At Westchester County-Bronx NYC Border	R20	31.42	950	1140	1430	1660	1930	2180	2400	2760	3030	2190
USGS gage # 01302015 Bronx River at Williams Bridge (Burke Avenue Bridge)	BURKE	33.24	890	1060	1330	1550	1800	2030	2230	2570	2820	2010
USGS gage # 01302020 Bronx River at NY Botanical Garden at Bronx,NY	BTANIC	34.47	890	1070	1340	1550	1810	2040	2230	2570	2820	2010
At East 180th St. bridge (head of tide)	R23	35.97	880	1050	1310	1520	1770	2000	2190	2520	2760	1950
At East 174th St. Bridge	C46	38.55	890	1060	1320	1540	1790	2020	2200	2540	2790	1970
Bronx River at mouth (East River)	BRNXMO	39.94	860	1020	1280	1480	1720	1940	2110	2540	2680	1860



2.2.2.1.2.2 Conclusions

Model calibrations show reasonable agreement with actual observed storm events. Numerous impoundments have affected the overall hydrology of the river by acting as detention areas and limiting connectivity between river sections. The disturbed flow pattern of increased peak discharge rates and higher total discharge volumes generally results in flash floods, erosion, increased water temperatures, low base flow and increased sedimentation, all of which correlate to low habitat value. Hydraulic models can be utilized to assess improved conditions alternatives that involve possible changes to the hydrologic regime.

2.2.2.1.3 Geotechnical

2.2.2.1.3.1 Regional Geology

The course of the Bronx River, like most rivers in the Manhattan Prong, follows a narrow band of weak Inwood marble. The river follows the southwesterly trend of the marble and then turns southward to empty into the East River at the apex of the Long Island Sound. Many believe that prior to the Pleistocene Period, the Bronx River was a pre- glacial stream that wound its way from its source in present-day upstate New York to the present Long Island Sound. When a glacier came through the Bronx, approximately 240,000 years ago, it blocked part of the original path of the Bronx River and subsequently reshaped and modified the path of the River. (Van Driver, Roadside Geology of New York, 1985)

2.2.2.1.3.2 Regional Soils

The natural surficial material in Bronx County is predominantly glacial till that consists of a mixture of clay, silt, sand, gravel, and boulders. Freshwater and tidal marsh deposits, consisting predominantly of organic silt and clay, commonly overlie the glacial deposits. The glacial deposits are commonly underlain by bedrock. Miscellaneous (artificial) fill deposits in the Bronx contain mixtures of glacial soil, riprap (i.e., large blocks of rubble rock), building-demolition rubble (e.g., glass, wood, brick and concrete), and cinders. (*Reconnaissance Soil Survey of the Boroughs of New York* to be published by the United States Department of Agriculture, Natural Resources Conservation Service)

Soils in the area of the study area belong to the LaGuardia and Ebbets Series soil classification and consist of very deep, well-drained soils with moderate permeability. These soils occur in and near major urbanized areas of New York City and are formed from construction debris intermingled with fill soil materials. Fill materials ranges in thickness from approximately 3.3 to 6.7 feet. The transported construction debris may include pieces of plastic, glass, rubber, bricks, lumber, asphalt, coal ash, unburned coal, gypsum board, concrete, and steel. LaGuardia Soils contained greater than 35 percent of transported construction debris. Ebbets Soils contain between 10 percent and 35 percent of transported construction debris. The transported natural soil material may originate from any geological deposit ranging from till, outwash, alluvium, coastal plains sediments or residuum, usually from a local source.

2.2.2.1.3.3 Sediment Impact Assessment Model (SIAM)

The Sediment Impact Assessment Model (SIAM) provides a framework to combine hydrology, hydraulics, and sediment supply into a geomorphic assessment and rehabilitation design for the reaches along the Bronx River. It is an important tool in the evaluation of the physical support structure for habitats, ecosystems and ecosystem services.

A key component of the SIAM is its ability to assess short-term changes in sediment delivery and the potential morphological response to sediment management features such as bank stabilization, grade control structures, flow control, land treatments, or any other measure that alters the flow and/or sediment regime. Sediment is a significant pollutant in streams and a contributing agent in many others. SIAM is an important tool in assessing impacts, stability and sustainability by showing areas of accretion, degradation and equilibrium along defined reaches to evaluate restoration scenarios.

The erosion of channel banks is exacerbated during periods of elevated flows. As stream energy works to erode particles from channel banks, the particles are carried downstream. In locations where flows have decreased sufficiently, these particles are later re-deposited. This process of erosion and deposition is occurring in the Bronx River study area. Sedimentation and associated channel aggradation fosters a state of continued instability in the channel.

Problem areas with regard to sedimentation in limited segments of the Bronx River Basin have been reported by several local planning entities in recent years (USACE 1999, WCDOP 2000, Bronx River Alliance 2006). Watershed problems associated with sedimentation and channel instability (Figure 2-13) often require a system-wide analysis to adequately identify the causes and effects of the problems and to formulate potential solutions.

Figure 2-13: Channel Sedimentation in the Garth Woods section. The new channel runs along the Bronx River Parkway.

2.2.2.1.3.4 SIAM Study Objectives

Recognizing the importance of conducting such a comprehensive and system-wide analysis in the Bronx River Study Area, in 2006, the US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory (ERDC-CHL) in Vicksburg, Mississippi studied both the Westchester and Bronx County portions of the Bronx River in detail. The study was conducted in two

(2) phases: a geomorphic assessment (to identify sediment sources), and a sediment assessment (to estimate sediment loads) using the SIAM model. The portion of the Bronx River downstream of Dam 1 is in the tidal zone of the East River and was not included in the assessments. The remainder of this section presents an overview of the analysis of sedimentation trends based on two (2) study phases. See full report --"Geomorphic Assessment and Sediment Impact Assessment for the Bronx River, New York – Final Report" (USACE-CHL, March 2007) for more details.

2.2.2.1.3.5 Geomorphic Assessment – Sediment Sources and Geomorphic Reaches

The baseline geomorphic assessment consisted of data gathering, field investigations, and data analysis. This was conducted primarily to determine the existing sources and characteristics of sediment within the project area and to assess the overall stability of the stream/watershed in the project area. The baseline geomorphic assessment also provides the foundation for the more quantitative SIAM analysis.

Bed material samples were also collected during the field investigation and the samples were sieved in the laboratory to develop bed material gradations along the Bronx River (See Technical Appendices). In general, the bed material is very coarse in the steeper reaches of the river, consisting of gravels and cobbles. No analyses were conducted to determine the mineralogical characteristics of the sediments to determine the sources of origin.

2.2.2.1.3.6 Sediment Sources

An attempt was made to identify sediment sources and estimate sediment loads within the watershed. These estimates serve as the basis for the SIAM sediment load input data. Based on the data collection effort, there is limited published quantitative data on bank and watershed sediment supply for this basin. Five (5) potential sediment sources were evaluated: stream banks, tributaries, watershed (upland), railroad grades, and re-suspension of sediment from the channel.

The results from the geomorphic assessment indicate that the Bronx River is stable in plan form and profile. No significant indicators of channel incision were observed on a broad reach-based macroscopic level, and no active channel migration was observed. Bank erosion observed during the field investigation was significant in localized stretches primarily in tight curvature bends with little existing vegetation.

However, based on defined reach lengths, the average bank incision rates were not significant when evaluated over greater distances. Reaches where bank stabilization measures, both hard and soft, currently exist appear to be performing satisfactory. Although difficult to quantify, recession rates at bank erosion sites were estimated to be on the order of 2 inches annually on average. Results from the SIAM computations indicate that control of bank erosion sediment sources has little overall impact on the average annual bed material sediment balance of the system. In consideration of all observations and data, there is evidence to suggest that while localized bank caving exists or once existed, on a reach-based average the banks are not considered a significant contributor to the larger sediment deposits in the Bronx River.

Given that bank erosion is not considered a reach-based average significant contributor of sediment, it appears that the primary source of sediment deposited in the pools is mainly from the watershed. It is unclear, however, whether the watershed contribution was greater in years past when urban development was more active than at the present. Sediment generation within the watershed was observed at localized gullies formed by concentrated run-off from parking lots, roadways and walking

paths adjacent to the river, as well as railroad embankments immediately adjacent to the river. Observations of sediment delivered from tributaries also suggest that the watershed contributes sediment. In particular, the Westchester County Center tributary was noted as a substantial contributor of sediment to the system, but the sediment load could not be quantified since sediment sampling gages or other flow gages do not exist in the basin. Estimating the annual sediment yield from the watershed areas was difficult due to the unavailability of published data, and development of watershed yield models was beyond the scope of this study. Estimates of watershed sediment loads for the SIAM computations were estimated from study results of a similar urbanized area. SIAM computation scenarios assuming 25 percent and 50 percent control of watershed sediment sources show modest reductions in bed material supply for the reaches ranging from 100 to 200 tons/year.

Dredging records were provided for two (2) locations within the Bronx River Basin, Crestwood Lake and Bronxville Lake. Dredge volumes excavated during these maintenance events are shown in Table 2-22.

Table 2-22: Dredge records provided by Westchester County, New York

Dredge Year	Dredge Volumes in cubic yards (CY)	
	Crestwood Lake	Bronxville Lake
1980/1981	13,000 (approx)	---
1993	13,000	---
2001/2002	46,000	25,000
2006	17,000	---

The pool areas located throughout the system serve as sediment traps, and apparently have done so for many years. The dredge records for Crestwood Lake provide temporal information as well as sediment volume data. The dredge records for Bronxville Lake provide volume for only a single dredging event. A calculation of deposition rates can therefore only be done for Crestwood Lake. The dredge volumes for Crestwood Lake were converted to average annual deposition by dividing the volumes by the number of years between dredging events. This assumes that the dredged volume represents the total deposition that occurred over the entire time span. Using this method the average annual deposition between 1981 and 1993 (12 years) is 1,083 CY/year, between 1993 and 2002 (9 years) is 5,111 CY/year, and between 2002 and 2006 (4 years) is 4,250 CY/year.

The computed average annual deposition volumes were converted to average annual tons/year by using an assumed sediment deposit unit weight of 90 pounds/cubic foot. The computed average annual sediment deposition in tons/year for the three (3) time periods is 1,316 tons/year, 6,210 tons/year, and 5,164 tons/year, respectively. The average of the three (3) time periods is 4,230 tons/year.

Field observations show that sands and fine gravels deposit in the upper reaches of the pooled areas, while the fine sands and silts deposit in the lower reaches. Sediment depths were in excess of 4 feet, but it was difficult to determine actual depths from the available dredging records and the lack of historic channel surveys. Sediment deposition immediately upstream of most of the major impoundment dams and weirs was level or near level with the crest of the dam/weir. In some of the larger impoundments, sizable middle bars or low islands have developed and been vegetated. SIAM computations also verify these deposition areas. The primary areas of deposition that were identified are Fisher Lane (Reach 2), Ardsley Road (Reach 8), Harney Road (Reach 10), Crestwood Lake

(Reach 12), Bronxville Lake (Reach 14), and Dams 2 (Reaches 21) in the Bronx Park. Depths of annual deposition estimated from SIAM results for these areas range from approximately 0.1 to 0.2 feet to 1.8 feet per year; however, the depth of 1.8 feet is probably excessive based on observations of existing pools, and an average annual depth of deposition of 0.1 to 0.2 feet is considered more reasonable. An important but unknown aspect of the pool areas is the possibility for deposited sediments to re-suspend during major flood events. The degree to which this may occur should be investigated with a more detailed numerical sediment transport model such as HEC-RAS Sediment Transport or Adaptive Hydraulic Model (ADH).

2.2.2.1.3.7 Geomorphic Reaches

The Bronx River study area was divided into 26 geomorphic reaches, primarily based on information from the field investigation and the data search. Factors considered in the identification of the geomorphic reaches included plan form determined from aerial photography, channel slope determined from the HEC-RAS geometry data, sediment transport characteristics, tributary locations, and channel structures (dams). The geomorphic reaches provide the basis for organizing the SIAM model reach structure and input data. The limits of each reach are presented in Table 2-23.

By definition, a through-put reach simply “flushes” all sediments that enter to the next reach downstream, effectively transporting the material as wash load. Of the 26 geomorphic reaches used in the assessment, ten were identified as through-put reaches (Reaches 3, 4, 5b, 7a, 7b, 9, 11, 13b, 15, and 19).

The geomorphic assessment did not reveal any significant indicators of active channel incision along the study reach. The primary reason for this vertical stability is the coarse gravel and cobble bed material found through most of the area, as well as the periodic grade control provided by the dams. This lack of vertical incision also contributes to the overall stability of the stream banks in the study area. Overall, bank erosion in the study area is limited to a few isolated areas, and estimated erosion rates are very low (2 inches per year). No active bank line meanders or other indicators of recent changes in channel location were observed, indicating that the position of the river has changed little over the recent years, at least by natural processes. In consideration of the significant amount of sediment deposits observed in the pool areas and the observed stability of the channel banks, the assessment is that the channel banks are a minor to insignificant contributor of sediment to the deposits in the pools.

Table 2-23: Geomorphic Reaches

Reach	Description
1	From Kensico Dam to the upper end of Fisher Lane Pool
2	From the upper portion of Fisher Lane pool to Fisher Lane.
3	From Fisher Lane to Cemetery Road
4	From Cemetery Road to the Bronx River Parkway (BRP) bridge downstream of I-287
5a	From the BRP bridge below I-287 to the third BRP crossing above Hartsdale Station
5b	From the third BRP crossing above Hartsdale Station to the second BRP crossing above Hartsdale Station

Reach	Description
6	From the second BRP bridge above Hartsdale Station to the dam near Green Acres
7a	From the Green Acres dam to approximately 2,200 feet above the first Metro North crossing above Crane Road
7b	From approximately 2,200 feet above the first Metro North crossing above Crane Road to the Metro North crossing
8	From the Metro North crossing above Crane Road to the Ardsley Road dam
9	From the Ardsley Road dam to approximately 1,250 feet above Harney Road dam.
10	From approximately 1,250 above Harney Road dam to Harney Road dam
11	From Harney Road dam to approximately 5,000 feet above Crestwood dam
12	From approximately 5,000 feet above Crestwood dam to Crestwood dam
13a	From Crestwood dam to the concrete weir upstream of Scarsdale Road
13b	From the concrete weir upstream of Scarsdale Road to the BRP exit ramp downstream of Scarsdale Road
14	From the BRP exit ramp downstream of Scarsdale Road to Bronxville dam
15	From Bronxville dam to Sprain Brook confluence
16a	From Sprain Brook confluence to Cross County Parkway
16b	From Cross County Parkway to Nereid Avenue
17	From Nereid Avenue to Gun Hill Road
18	From Gun Hill Road to Dam 4
19	From Dam 4 in the Bronx Park to just upstream of Fordham Road
20	From just upstream of Fordham Road to Dam 3 in the Bronx Park
21	From Dam 3 in the Bronx Park to Dam 2 in the Bronx Park
22	From Dam 2 in the Bronx Park to Dam 1 near 174^{th} Street
Note	Area downstream of Dam 1 is tidal and was not included in the assessment

Numerous small dams or weirs are located throughout the study reach. These dams form pools which act as sediment traps, and sediment deposits of 4 feet or more were observed in most of the pools. It was not possible to determine how long these deposits have existed or how quickly the pools originally filled due to (1) the lack of historical channel surveys, and (2) the limited data presented in the dredging records. The assessment that the channel banks are not a significant source of sediment to the pools suggests that the material came from the watershed and/or the tributaries. It is not known if the material has been delivered consistently over the years, or if yields were greater during years of the heaviest development of the watershed. The data collection effort located no reliable published estimates of the loading from any of these sources. Therefore, it is difficult to quantify the relative magnitudes of these sources with any certainty. Re-suspension of in-channel sediment deposited in the pools may also be a significant source, but the relative contribution of this potential source is uncertain without conducting more advanced computer models to determine the flow conditions that result in re-entrainment of the sediment.

2.2.2.1.3.8 Sediment Impact Assessment

The sediment impact assessment for the Bronx River was conducted using the SIAM model. Using sediment data and other information garnered in the geomorphic assessment phase, the SIAM model was used to determine the sediment continuity for each geomorphic reach. The SIAM model was constructed from the 1970s HEC-2 model and the 2005 HEC-RAS model provided by NAN, and covered the study area from Dam 2 in Bronx Park to Kensico Dam.

SIAM is a reach-based sediment accounting model that has been embedded in the Hydraulic Design module of HEC-RAS, and provides an expedient means of determining average annual sediment impacts for stream networks. It provides a framework to combine sediment sources and computed sediment transport capacities in order to evaluate sediment balances and downstream sediment yields for different alternatives. The model uses the 1-dimensional hydraulic computations from HEC-RAS to compute average annual sediment transport capacity for each reach, and sediment continuity is determined by comparing the capacity to the sediment supply for each reach. Computations are made by grain size, allowing the fate of a particular size particle to be traced. The SIAM model is currently available in HEC-RAS Version 4.0.

SIAM input data for each sediment reach consists of five (5) key input parameters for each reach: bed material composition, hydrology/flow duration, sediment properties, sediment loading from local sources and reach average hydraulic parameters. Detailed, reach-specific results of the SIAM computations for bed material local balance, wash load, and bed material supply for each scenario are shown in the Tables of the Technical Appendices. Sedimentation affects critical life stages of aquatic species such as fish, mollusks, and crustaceans.

2.2.2.1.3.9 SIAM Results

In general, the results of the SIAM computations were considered reasonable and representative of conditions documented not only by the geomorphic assessment, but also by NAN observations noted in the restoration project scoping document. In this section, results of the SIAM model are presented in question and answer format.

2.2.2.2 Bronx Zoo and Dam

2.2.2.2.1 Geotechnical

Sediment analysis at the Bronx Zoo and Dam site showed that over half of the sediment collected was medium size sand, 31.44 percent was coarse sand and 16.33 percent was fine gravel. Fine sand as well as silt clay were also present in lower quantities. No coarse gravel was present.

2.2.2.3 Shoelace Park

2.2.2.4 Muskrat Cove

2.2.2.4.1 Geotechnical

Sediment analysis showed the bottom substrate at Muskrat Cove Riffle habitat was dominated by medium and fine sands, accounting for approximately 43 percent each of the total bottom habitat substrate. Fine gravel accounted for 7.38 percent of the total bottom substrate and 6.49 percent of the total bottom habitat was coarse sand. Only trace amounts of silt clay was present and no coarse gravel was found.

2.2.2.5 Bronxville Lake

The Bronxville Lake site is located along the Bronx River, in the Village of Bronxville and the City of Yonkers, Westchester County, NY. The site is bounded by the Bronx River Parkway to the west, Tuckahoe Road to the north, Metro North Railroad to the east and private properties to the south. At this location, the Bronx River flows through a broad valley (~400 feet wide), the sides of which are twenty to forty (20-40) feet high. The weir across the River at the southern end of the site creates a broad and shallow lake in the southern two-thirds (2/3) of the proposed Bronxville Lake site. The stone weir is 48 feet wide and approximately 5.5 feet high at the highest elevation and the Bronxville Lake as approximate surface area of 7 acres. Figure 2-14 shows the stone weir controlling the lake. The lake is surrounded by a park, which is part of the Bronx River Parkway Reservation and is maintained by the Westchester County Department of Parks, Recreation, and Conservation. The park consists largely of maintained lawns with trees, with several pockets of emergent wetlands that are landscaped and mowed.

Figure 2-14: Existing Stone Weir at Bronxville Lake

2.2.2.5.1 Topography and Bathymetry

A field survey performed for Bronxville Lake on October 23, 2015. Data collection included five (5) east/west cross-sections (bathymetric & topographic) across the Bronxville Lake, and a weir survey consisting of an upstream cross-section, a downstream cross-section and the top of the weir section. The coordinate system used for data acquisition is the New York State Plane (NAD1983) NY EAST horizontal and NAVD88 vertical datum.

The field data collected during this effort included:

- Lake/channel bathymetry;
- Riparian/floodplain topography (over bank grades along the cross-sections);

- Sediment thickness in lakes;
- Location/presence of thalweg;
- Weir dimensions and materials;
- Topography/bathymetry immediately upstream and downstream of existing weir;
- Field photographs;
- Changes in slope, top of bank, toe of bank, thalweg, water's edge, and limits of existing path; and
- Sediment depth across the section within lake/channel boundaries using appropriate sediment probe.

A number of data sources were reviewed to provide an understanding of the existing and pre-existing site characteristics. These included:

- Federal Emergency Management Agency's (FEMA) 2007 Flood Insurance Study (FIS) HEC-RAS hydraulic models;
- FEMA Hydraulic model back up GIS data including Topographic (TIN), Survey and Cross-section geometry;
- NYD – Provided 1M DEM for project area;
- USGS 1:24,000 Quadrangles;
- NYSOGS 2013 Orthoimagery; and
- FEMA Flood Insurance Study (Westchester County).

2.2.2.5.1.1 Existing Hydrologic Models

Existing hydrologic analyses available from FEMA Flood Insurance Study (FIS) and USACE-NYD Bronx River SIAM model were used for the Bronx River H&H analyses. The Bronx River has a contributing area of approximately 34 square miles at Bronxville Lake that includes developed and undeveloped area in central Westchester County.

The effective FEMA 2007 hydrologic analysis was based on an updated Log-Pearson type – III analysis on Bronxville gage located just downstream of the Bronxville Lake site. Peak flows for the 10 year, 50 year, 100 year and 500 year flood events established by FEMA and used in the effective FEMA HEC-RAS model, were directly incorporated into the current project model without any changes.

USACE-NYD had developed a detailed HEC-1 model for the Bronx River watershed as a part of the Bronx River" Source" Study in July 2010. The HEC-1 model was calibrated for the rainfall events and used to predict hypothetical peak discharges for 1 year, 2 year, 5 year, 10 year, 25 year, 50 year, 100 year, 250 year and 500 year events. From these models, this analysis utilized the hypothetical peak flood volumes and the nodes where the rate of flow changes to determine the flood volumes at the cross section locations.

2.2.2.5.1.2 Hydraulic Model

The existing FEMA model was used as a basis for this analysis. The FEMA model was developed on the latest GIS-based hydraulic analysis platform, using the USACE's HECGeoRAS and HEC-RAS model interfaces. In order to set up the base analysis for this project, the effective FEMA model was imported in the USACE HEC-RAS version 4.1 and ran using the steady state hydraulic analysis. The backup FEMA GIS data along with FEMA's Topographic data (TIN) were used to develop project specific data at Bronxville Lake.

The general steps followed in the development of the project specific analyses at Bronxville Lake are summarized below.

- The field survey was imported in ARCGIS map and the survey shapefiles for the project area were extracted.
- Initial project setup was performed using effective FEMA data, field survey and other recent basemap data. The project specific cross-section location plan along with field survey data is provided in Attachment A.
- After initial set up of the hydraulic analysis, the channel cross-sections from Bronxville site were removed manually from the HEC-RAS model and Bronx River GIS dataset.
- New cross-sections based on the field survey were added in GIS for the data processing.
- The cross-section geometry for the HEC-RAS hydraulic model was developed from two (2) data sources, surveyed cross-sections and FEMA Bronx River TIN elevation data.
- No changes were made to the existing cross-sections and structure on the Bronx River outside the project area within the Bronx River Model and database.
- The weir profile was then modified in HEC-RAS to match the recently surveyed data and field observations.
- Upon completion of the geometric data input of the model the Channel Manning's n values and in-effective flow areas were updated on each affected cross-sections following the guidance provided in the HEC-RAS user's manual.
- Two (2) different models scenario with FEMA and USACE-NYD hydrology were simulated to evaluate different flow conditions through the lake and establishment of the base flood elevations for the selected frequencies.
- The result of the hydraulic analysis using USACE-NYD hydrology is provided in Attachment A .

2.2.2.5.1.3 Model Results

As part of Bronxville Lake investigation, the following items were reviewed and evaluated using the field survey data and the H&H model results. The HEC-RAS summary output table, cross-sections and flood profiles for 1 year through 500 year simulation run are provided in Attachment A.

- **Stream Thalweg:** The stream thalweg represents the existing channel invert along the stream through the site. A GIS feature line representing the location of existing stream invert was developed using the field survey and ArcGIS application. At Bronxville Lake, the existing thalweg line is mostly in the center of the stream/lake in the north and central portion of the Bronxville Lake. However, in the southern portion of the lake, the thalweg shifts close to the left overbank in the weir vicinity. The maximum depth surveyed is approximately 6.5 feet +/- closer to the weir (XS#19575.24), whereas a minimum depth of 3.5 feet +/- was observed at the upper portions of the lake (XS#20678.07).
- **Channel Banks:** The average bottom of the bank elevations along the Bronxville Lake is 85.0 feet +/- whereas the average top of the bank elevation ranges from 87.3 to 87.8 feet. A GIS feature line representing the edge of banks is plotted on the map in Attachment A.
- **Sediment Depths:** The maximum sediment depth (refusal depth) observed ranged from 3 to 7 feet.
- **Bank Full Flows:** Based on hydraulic model simulations, the average bank full flood event is a 1 year flood with an average maximum depth of 6 feet along the cross-section.
- **Extreme Floods:** Bronxville Lake and the adjacent park land would be submerged in flood event greater than the 5-year recurrence interval level. During extreme flood events such as the

500-year interval, the predicted flood depth varies spatially from approximately 8 to 12 feet above the normal lake surface.

- **Channel Velocities:** The channel velocity along the Bronxville Lake varies from below 1 feet/sec at the widest portion of the lake to approximately 3.5 feet./sec at the weir.

2.2.2.6 Crestwood Lake

The Crestwood Lake site is located on the Bronx River in the City of Yonkers and Village of Tuckahoe, Westchester County, NY. The site is bounded by the Bronx River Parkway and Read Avenue to the west, Thompson Street to the north, Metro North Railroad and private properties to the east, and a ballfield (owned by the Town of Eastchester) to the south. The river at Crestwood Lake site flows through a broad valley (~400 to 600 feet wide), the sides of which are approximately 20 feet in elevation. At the southern end, the river is dammed, forming a broad, shallow lake approximately three (3) times the width of the river upstream. On the west side, a small tributary of moderate flow named Troublesome Creek is confluent with the lake. A walking trail and lawns with trees border the eastern side of the lake; woodlots and lawns bordering the northwest side of the lake are part of the Bronx River Parkway Reservation maintained by the Westchester County Department of Parks, Recreation, and Conservation. Crestwood Lake has an approximate surface area of 10.5 acres. A stone weir, located at the south end of the lake, is 66 feet wide and approximately 4.0 feet high at the highest elevation (Figure 2-15).

Figure 2-15: Existing Stone Weir at Crestwood Lake

The Westchester County Department of Planning prepared a detailed restoration report for Crestwood Lake (Westchester, 2008).

2.2.2.6.1 Topography and Bathymetry

A field survey was performed for the Bronx River for Crestwood Lake on October 22, 2015. Data collection included five (5) east/west cross-sections (bathymetric & topographic) across the Crestwood Lake, and a weir survey consisting of an upstream cross-section, a downstream cross-section and the top of the weir section. The coordinate system used for data acquisition is the New York State Plane (NAD1983) NY East horizontal and NAVD88 vertical datum.

The field data collected during this effort included:

- Lake/channel bathymetry;
- Riparian/floodplain topography (over bank grades along the cross-sections);
- Sediment thickness in lakes;
- Location/presence of thalweg;
- Weir dimensions and materials;
- Topography/bathymetry immediately upstream and downstream of existing weir;
- Field photographs;
- Changes in slope, top of bank, toe of bank, thalweg, water's edge, & limits of existing path; and
- Sediment depth across the section within lake/channel boundaries using appropriate sediment probe (n/a for Garth Woods).

A number of data sources were reviewed to provide an understanding of the existing and pre-existing site characteristics. These included:

- Federal Emergency Management Agency's (FEMA) 2007 Flood Insurance Study (FIS) HEC-RAS hydraulic models;
- FEMA Hydraulic model back up GIS data including Topographic (TIN), Survey and Cross-section geometry;
- NYD – Provided 1M DEM for project area;
- USGS 1:24,000 Quadrangles;
- NYSOGS 2013 Orthoimagery; and
- FEMA Flood Insurance Study (Westchester County).

2.2.2.6.1.1 Hydrologic Models

Existing hydrologic analyses available from FEMA FIS and USACE-NYD Bronx River SIAM model were used for the Bronx River H&H analyses. The Bronx River has a contributing area of approximately 30 square miles at Crestwood Lake that includes developed and undeveloped area in central Westchester County.

The effective FEMA 2007 hydrologic analysis was based on an updated Log-Pearson type – III analysis on Bronxville gage located just downstream of the Bronxville Lake site. Peak flows for the 10 year, 50 year, 100 year and 500 year flood events established by FEMA, and used in the effective FEMA HEC-RAS model, were directly incorporated into the current project model without any changes.

USACE-NYD had developed a detailed HEC-1 model for the Bronx River watershed as a part of Bronx River "Source" Study in July 2010. The HEC-1 model was calibrated for the rainfall events and used to predict hypothetical peak discharges for 1 year, 2 year, 5 year, 10 year, 25 year, 50 year, 100 year, 250 year and 500 year events. USACE-NYD provided the A/E with the HEC-1 model and the SIAM HEC-

RAS model for possible use and guidance. From these models, this analysis utilized the hypothetical peak flood volumes and the nodes where the rate of flow changes to determine the flood volumes at the cross section locations.

2.2.2.6.1.2 Hydraulic Model

The existing FEMA model was used as basis for this analysis. The FEMA model was developed on the latest GIS-based hydraulic analysis platform, using the USACE's HECGeoRAS and HECRAS model interfaces. In order to set up the base analysis for this project, the effective FEMA model was imported in the USACE HEC-RAS version 4.1 and ran using the steady state hydraulic analysis. The backup FEMA GIS data along with FEMA's Topographic data (TIN) were used to develop project specific data at Crestwood Lake.

The general steps followed in the development of the project specific analyses at Crestwood Lake are summarized below.

- The field survey was imported in ARCGIS map and the survey shapefiles for the project area were extracted.
- Initial project setup was performed using effective FEMA data, field survey and other recent basemap data acquired. The project specific cross-section location plan along with field survey data is provided in Attachment A.
- After initial set up of the hydraulic analyses the channel cross-section from Crestwood Lake site were removed manually from the HEC-RAS model and Bronx River GIS dataset.
- New cross-sections based on the field surveyed were added in GIS for the data processing.
- The cross-section geometry for the HEC-RAS hydraulic model was developed from two (2) data sources, surveyed cross-sections and FEMA Bronx River TIN elevation data.
- No changes were made to the existing cross-sections and structure on the Bronx River outside the project area within the Bronx River model and database.
- The weir profile was then modified in HEC-RAS to match the recently surveyed data and field observations.
- Upon completion of the geometric data input to the model, the Channel Manning's n values and in-effective flow areas were updated on each affected cross-sections following the guidance provided in the HEC-RAS user's manual.
- Two (2) different model scenarios with FEMA and USACE-NYD hydrology were simulated to evaluate different flow conditions through the lake and establishment of the base flood elevations for the selected frequencies.
- The result of the hydraulic analyses using USACE-NYD Hydrology is provided in Attachment A.

2.2.2.6.1.3 Model Results

As part of H&H evaluation for Crestwood Lake, the following items were reviewed and evaluated using the field survey data & H&H model results. The HEC-RAS summary output table cross-sections and flood profiles for 1 year through 500 year simulation run are provided in Attachment A.

- **Stream Thalweg:** The stream thalweg represent the existing channel invert along the stream through the site. A GIS feature line representing the location of existing stream invert was developed using the field survey and ArcGIS application. At Crestwood Lake the existing thalweg line is mostly in the center of the stream/lake for the north and central portions. However, in the southern portion of the Crestwood Lake it shifts close to the left overbank as it moves closer to the weir. The maximum depth on the lake observed from the survey data is approximately 10.5 feet closer to the weir (XS#24961.15) whereas minimum depth of approximately 4.5 feet was observed at the upper portions of the lake (XS#26356.25).

- **Channel Banks:** The average bottom of the banks elevations along the Crestwood Lake wais approximately 95.0 feet whereas average top of the banks elevations are in the range of 97.5. to 98.8 feet. A GIS feature line representing the edge of banks is plotted on Attachment "A".
- **Sediment Depths:** The average sediment depth (refusal depth) observed ranges from 3 to 8 feet at the maximum.
- **Bankfull Flows:** Based on the simulation run from the hydraulic model the average bankfull flood event at the Crestwood Lake site is 1 year flood with an average maximum depth along the cross-section of 7 feet, with the maximum depth at cross section 24961.15 of 13 feet.
- **Extreme Floods:** The Crestwood Lake and adjacent park land would bbe submerged during flood events greater than 5 year recurrence interval level. During extreme flood events such as the 500-year interval, the predicted flood depth varies spatially from approximately 10 to 12 feet, with the maximum depth of approximately 18+ feet at cross-section 24961.15.
- **Channel Velocities:** The channel velocities along the Crestwood Lake are mostly below 1 fps at the all cross-sections with exception of 2.5 fps at the weir.

2.2.2.6.2 Geotechnical

Results of the sediment analysis for the Crestwood Lake site showed fine and medium sand, accounting for 94.85 percent, dominated that bottom. Fine gravel, coarse sand, and silt clay combined accounted for 5.15 percent. There was no coarse gravel found at the Crestwood Lake site in summer.

2.2.2.7 Garth Woods/Harney Road

The Harney Road site (downstream portion of combined Garth Woods/Harney Road site) located along the Bronx River in the City of Yonkers and Town of Eastchester, Westchester County, NY. The site is bounded by the Bronx River Parkway to the east and west, Garth Woods to the north, and Harney Road at the south side of the lake. At the Harney Pond site, the river flows through a broad valley (~400 to 600 feet wide), the sides of which are approximately 20 feet in elevation. The channel in this site is over-widened and shallow, with a ponded area upstream of the weir located immediately south of Harney Road bridge. A paved path and park on the east side of the river are part of the Bronx River Parkway Reservation maintained by the Westchester County Department of Parks, Recreation, and Conservation. The concrete weir is 50 feet wide and approximately 5.0 feet high at the highest elevation and the ponded area at Harney Road has an approximate surface area of 2.0 acres. Figure 2-16 shows the masonry weir controlling the ponded area.

Figure 2-16: Existing Masonry Weir at Harney Road Site

2.2.2.7.1 Topography and Bathymetry

A field survey was performed for the Bronx River Garth Woods/Harney Road site on October 22, 2015 (focusing on Harney Road only). Data collection included five (5) east/west cross-sections (bathymetric & topographic) across the Harney Pond, and a weir survey consisting of an upstream cross-section, a downstream cross-section and the top of the weir section. The coordinate system used for data acquisition is the New York State Plane (NAD1983) NY East horizontal and NAVD88 vertical datum.

The field data collected during this effort included:

- Lake/channel bathymetry;
- Riparian/floodplain topography (over bank grades along the cross-sections);
- Sediment thickness in lakes;
- Location/presence of thalweg;
- Weir dimensions and materials;
- Topography/bathymetry immediately upstream and downstream of existing weir;
- Field photographs;
- Changes in slope, top of bank, toe of bank, thalweg, water's edge, & limits of existing path; and
- Sediment depth across the section within lake/channel boundaries using appropriate sediment probe (n/a for Garth Woods).

A number of other topographic data sources were reviewed to provide an understanding of the existing and pre-existing site characteristics. These included:

- Federal Emergency Management Agency's (FEMA) 2007 Flood Insurance Study (FIS) HEC-RAS hydraulic models;
- FEMA Hydraulic model back up GIS data including Topographic (TIN), Survey and Cross-section geometry;
- NYD – Provided 1M DEM for project area;
- USGS 1:24,000 Quadrangles;
- NYSOGS 2013 Orthoimagery; and
- FEMA Flood Insurance Study (Westchester County).

2.2.2.7.1.1 Hydrologic Models

Existing hydrologic analyses available from FEMA FIS and USACE-NYD Bronx River SIAM model were used for the Bronx River H&H analysis. The Bronx River has a contributing area of approximately 29 square miles at Harney Road site that includes developed and undeveloped area in central Westchester County.

The effective FEMA 2007 hydrologic analysis was based on an updated Log-Pearson type – III analysis on Bronxville gage located just downstream of the Bronxville Lake site. Peak flows for the 10 year, 50 year, 100 year and 500 year flood events established by FEMA and used in the effective FEMA HEC-RAS model were directly incorporated into the current project model without any changes.

USACE-NYD had developed a detailed HEC-1 model for the Bronx River watershed as a part of the Bronx River "Source" Study in July 2010. The HEC-1 model was calibrated for the rainfall events and used to predict hypothetical peak discharges for 1 year, 2 year, 5 year, 10 year, 25 year, 50 year, 100 year, 250 year and 500 year. USACE-NYD provided the A/E with the HEC-1 model and the SIAM HEC-RAS model for possible use and guidance. From these models, this analysis utilized the hypothetical peak flood volumes and the nodes where the rate of flow changes to determine the flood volumes at the cross section locations.

2.2.2.7.1.2 Hydraulic Model

The existing FEMA model was used as basis for this analysis. The FEMA model was developed on the latest GIS-based hydraulic analysis platform, using the USACE's HECGeoRAS and HEC-RAS model interfaces. In order to set up the base analysis for this project, the effective FEMA model was imported in the USACE HEC-RAS version 4.1 and ran using the steady state hydraulic analysis. The backup FEMA GIS data along with FEMA's Topographic data (TIN) were used to develop project specific data at Crestwood Lake. The general steps followed in the development of the project specific analyses at Harney Road are summarized below.

- The field survey was imported in ARCGIS map and the survey shapefiles for the project area were extracted.
- Initial project setup was performed using effective FEMA data, field survey and other recent basemap data acquired. The project specific cross-section location plan along with field survey data is provided in Attachment A.
- After initial set up of the hydraulic analyses the channel cross-section were removed manually from the HEC-RAS model and Bronx River GIS dataset.
- New cross-sections based on the field survey were in GIS for the data processing.

- The cross-section geometry for the HEC-RAS hydraulic model was developed from two (2) data sources, surveyed cross-sections and FEMA Bronx River TIN elevation data.
- No changes were made to the existing cross-sections and structure on the Bronx River outside the project area within the Bronx River Model and database.
- The weir profile was then modified in HEC-RAS to match the recently surveyed data and field observations.
- Upon completion of the geometric data input of the model the Channel Manning's n values and in-effective flow areas were updated on each affected cross-sections following the guidance provided in the HEC-RAS user's manual.
- Two (2) different models scenario with FEMA and USACE-NYD hydrology were simulated to evaluate different flow conditions through the lake and establishment of the base flood elevations for the selected frequencies.
- The result of the hydraulic analyses using USACE-NYD Hydrology is provided in Attachment A.

As part of the H&H evaluation for the Harney Road site, the following items were reviewed and evaluated using the field survey data and the H&H model results. The HEC-RAS summary output table, cross-sections and flood profiles for 1 year through 500 year simulation run is provided in Attachment A.

- **Stream Thalweg:** The stream thalweg represent the existing channel invert along the stream through the site. A GIS feature line representing the location of existing stream invert was developed using the field survey and ArcGIS application. At Harney Road the existing thalweg line is in the center of the stream/pond for the north portion and moves closer to the left overbank in central portion of Harney Road. However in the southern portion of the pond it shifts to the center as passes beneath Harney Road. The maximum depth on the pond observed from the survey data is approximately 10.5 feet closer to the weir (XS#35451.72), whereas a minimum depth of approximately 2.5 feet was observed at the middle portions of the pond (XS#35892.15).
- **Channel Banks:** The average bottom of the bank elevations along the Harney Pond is approximately 112.0 feet, whereas average top of the bank elevations are in the range of 113.9. to 117.5 feet. A GIS feature line representing the edge of banks is plotted on the Cross-Section Location Map.
- **Sediment Depths:** The maximum sediment depth (refusal depth) observed is in the range of 1 to 3 feet.
- **Bank Full Flows:** Based on the hydraulic model simulations, the average bank full flood event is 1 year flood with an average maximum depth along the cross-section of 5 feet, with the maximum depth at cross section 35432.17 of 8.6 feet.
- **Extreme Floods:** Harney Road and the adjacent park land would be submerged during the flood event greater than the 5 year recurrence interval level. During extreme flood events such as the 500-year interval, the predicted flood depth varies spatially from approximately 8 to 11.5 feet, with the maximum depth of 13.5 feet at cross-section 35432.17.
- **Channel Velocities:** The channel velocities along the Harney Road are mostly between 2 feet/ sec and 3 feet /sec at all of the cross-sections with exception of 4.5 feet. /sec at the weir.

2.2.2.8 Westchester County Center

2.2.2.8.1 Geotechnical

The bottom substrate results for the fall at Westchester County Center Pond habitat were found to be a mixture of fine gravel, coarse, medium and fine sand. Coarse and medium sand were the principal sediment size classes, accounting for approximately 30 percent of total bottom sediment sizes each. Fine gravel accounted for 26.35 percent of the total bottom sediment sizes and fine sand accounted for 12.77 percent. Only trace amounts of silt clay was found and no coarse gravel was present.

2.3 Newark Bay, Hackensack River, Passaic River Planning Region

2.3.1 All Sites

2.3.1.1 Geotechnical

The Passaic and Hackensack Rivers flow into the northern end of Newark Bay at the Kearny Point site in Newark Bay, the lower 14 miles of the Hackensack River, and the lower Passaic River are tidal. The upper Hackensack River is dammed north at the Oradell Dam. The Passaic River has multiple dams, the most downstream of which is Dundee Dam.

The underlying bedrock of all three (3) water bodies consists of the Newark Series Triassic-Jurassic sedimentary rocks deposited in the Newark Basin and intrusive and volcanic Jurassic igneous basalts and diabases. The igneous rocks and the surrounding contact metamorphic rocks are the most resistant, and form ridges. The least resistant are the fine-grained sedimentary rocks of the Passaic Formation. These shales and siltstones underlie valleys. The eastern edge of the Newark Bay watershed is underlain by the Lockatong Formation, whereas the rest is underlain either by the Passaic Formation or the igneous dikes and sills that cross-cut the Passaic Formation.

Newark Bay, the lower 14 miles of the Hackensack River, the lower 1 mile of the Passaic River, northern Arthur Kill, and associated wetlands lie in a subtle valley between north-east trending ridges. The eastern ridge is the Palisades diabase. The western limit of the valley is formed by small ridges underlain by the Passaic Formation shales and sandstones. The eastern edge of the valley is underlain by the Lockatong Formation. The remaining majority is underlain by the shale-dominated Passaic subunits. This valley is tidally influenced and includes the Meadowlands between the Passaic and Hackensack Rivers.

The main strike of the strata is 36° east of north and beds dip 15° to the northwest. The area consists of buried northeast trending ridges and valleys of bedrock. The top of rock is mantled by Pleistocene Glacial till. The valleys are filled with Pleistocene glacial lake deposits, the majority of which are varved clays and silts. Locally, these are interbedded with glacial lake delta deposits of sands and tills. The clay unit may be as thick as 200feet. These lake deposits are interbedded with tills and are overlain by outwash silts and sands.

The Pleistocene outwash sands transition to Holocene fluvial and estuarine sands that grade vertically into finer estuarine silts and clays and marsh deposits. In the last few hundred years, much of the low-lying marsh and shallow waters areas have been filled to build up the land for roads, railroads, industrial sites, airports, and port facilities. Bridges are generally built where bedrock is shallow.

Locally, either bedrock or Pleistocene sediments are exposed in Newark Bay and in the Hackensack River. In Newark Bay, these units were uncovered by dredging, whereas in the Hackensack River, the units were uncovered both by dredging and by river currents eroding overlying sediments. Such scouring is deep at bridges.

The movement and storage of groundwater in this area occurs primarily in the interconnected network of openings that form along joints, fractures, and other channels in the Passaic Formation.

The shallower upper Pleistocene and Holocene silts and sands in addition to the historic fill form shallow groundwater aquifers that are generally laterally discontinuous. Where bedrock is deep, the relatively impermeable, Pleistocene varved clays and silts are thick and create barriers atop the bedrock aquifers. Where rock is shallow, the Pleistocene clay and silt may be thin or completely eroded and bedrock aquifers are more vulnerable to infiltration and contamination from the surface.

Much of the contaminated sediment and groundwater is in the shallower aquifers. The historic fill was usually placed for industrial use and is commonly found at the surface of contaminated sites.

2.3.1.2 Hydrodynamic Modeling (*www.ourpassaic.org* 2008-1-25-LPR-NB_Hydrodynamic Report)

The Passaic River, along with the Hackensack River and Newark Bay, is one of the most complex estuarine systems in the United States. The system is connected to two (2) tidal straits, named the Kill van Kull and the Arthur Kill. These straits connect Newark Bay and the Passaic and Hackensack Rivers with the Upper New York Bay and Raritan Bay, through which tides, originating in the Atlantic Ocean, enter the system. The bathymetry of the Passaic-Hackensack-Newark Bay system is characterized by deep shipping channels along the center of both the Arthur Kill and the Kill van Kull, as well as the west side of Newark Bay through the center of both the Lower Passaic and Hackensack Rivers, with shallower side banks. The USACE maintains the navigability of the channels in order to support New York-New Jersey Port operations. The shipping channels, maintained by the USACE to facilitate the movement of container ships in and out of Newark Bay, added additional complexity to the dynamics of the system. The shipping channels in Newark Bay and the Kills are relatively deep (11 -15 m) with respect to the near-shore depths, significant variability in depths across the channels. The average depth of the shipping channel in the Arthur Kill is about 11 meters MSL, while the average shipping channel depth in the Kill van Kull and Newark Bay are 15 m MSL. These channels play an important role in transporting saline water from the ocean into the system.

The hydrodynamics of the Passaic-Hackensack-Newark Bay system is predominantly controlled by three (3) forcing mechanisms, freshwater flows (buoyancy sources), tides, and winds. Two (2) major sources of freshwater inflows, the Passaic and Hackensack Rivers, contribute to the salinity gradients in the system. By far, the largest freshwater contribution is from the Passaic River. The long-term daily average flow measured at Little Falls is about 29 m^3/sec (1,000 cfs) and the maximum flow during this 21-year period was approximately 500 m3/sec (18,000cfs) in April 1984. In contrast the average flow in the Hackensack River is only 1.6 m^3/sec (56 cfs) and a maximum flow of approximately 158 m3/s (5,500 cfs) was measured in September 1999 during Hurricane Floyd. The salinity dynamics in the system are mostly controlled by the freshwater flows from the Passaic and Hackensack Rivers and the saltier ocean waters that enter the system through the Kill van Kull and the Arthur Kill. During most low to moderate flow periods, the salinity front stays within upper Newark Bay and the Lower Passaic and Hackensack Rivers. However, during extreme high flow periods the front is pushed further downstream to the Arthur Kill and the Kill van Kull. Salinity is, in general, higher during the time of low freshwater flow and is also more uniform both vertically and horizontally throughout the system than during the time of high freshwater flow. Freshwater flows emanating from the Passaic River stay along the western edge of Newark Bay, creating cross channel salinity gradients (Pence, 2004). The deep shipping channels in the system act as conveyances of denser and saltier ocean water to upper Newark Bay and to the Lower Passaic and Hackensack Rivers.

Tidal currents in Newark Bay and in the Passaic and Hackensack Rivers are found to be moderate, with maximum amplitudes of 0.5 m/sec. Most of the time, the surface and bottom tidal currents are of

equal magnitude and are in phase in Newark Bay. However, during high-flow periods the surface currents, directed towards the ocean (ebb currents), become much stronger than the bottom currents, indicating the presence of strong vertical shear (Pence, 2004). During high freshwater flow, classical two-layer estuarine circulation is observed during flood tides, with surface currents flowing seaward and bottom currents flowing upstream. The net flow along the side banks is downstream, with an increased magnitude under higher freshwater flow conditions.

Strong and persistent wind events in Newark Bay can have a strong effect on the circulation in the estuary, and in some extreme cases can disrupt the normal pattern of estuarine circulation. Modeling analysis (Pence, 2004, Pecchioli et al., 2006) suggests that strong winds from the west will flush water and water borne constituents from Newark Bay out through the Kill van Kull, with weaker flow in through the Arthur Kill. Model computations indicate that this flow pattern changes direction when strong winds blow from the east, i.e., flow enters the Kill van Kull from the upper portion of New York/New Jersey Harbor and then enters Newark Bay (Pecchioli et al., 2006). The full hydrodynamic modeling report can be found at www.ourpassaic.org (USEPA, 2008).

2.3.2 Hackensack River Study Area

2.3.2.1 All Hackensack River Sites

2.3.2.1.1 Hydrology and Hydraulics

An H&H Analysis was conducted to inform the restoration design, including establishing target vegetation community limits and planting elevations, to improve design accuracy and reduce risk; intensive modeling was not conducted. Available tidal data was utilized to establish tidal datums and planting elevations for each site. Additional more in-depth H&H analyses will be completed for each site during PED for the Selected Plan.

2.3.2.1.2 Surface Water

The Hackensack River, running 11.5 miles within the Meadowlands, is the central feature of the Hackensack Meadowlands. The quantity and quality of surface water in the Meadowlands is influenced by such factors as tidal flow, precipitation, permitted discharges, and the release or detainment of freshwater from the Oradell Reservoir. Surface water features of the Meadowlands District are characterized by the many streams, creeks, and smaller channels and ditches that drain the area. Salinity in the Hackensack River ranges from 0 to 16 parts per thousand; the reach of the river from the mouth upriver to Cromakill Creek is a moderate salinity (mesohaline) zone supporting both marine and estuarine invertebrates, fish, and turtles, while the reach of the river above Cromakill Creek to just upriver of Hackensack is a low salinity (oligohaline) zone supporting both estuarine and freshwater invertebrates, fish, and turtles.

Approximately 90 percent of the 30.4 square-mile Hackensack River watershed within the Meadowlands drains through the Newark Bay at Kearny Point. There are 17 major tributaries to the Hackensack River that form several sub-watersheds. The major tributaries include Penhorn Creek, Losen Slote, Anderson Creek, Sawmill Creek, Kingsland Creek, Berry's Creek Canal, Bashes Creek, Moonachie Creek, Mill Creek, Cromakill Creek, Bellman's Creek, Overpeck Creek, Berry's Creek, Peach Island Creek, West Riser Ditch, and East Riser Ditch.

In the past, the Hackensack River and its tributaries have been altered to meet specific needs. The river has been dredged to handle barge traffic and ditches and canals have been dug to control the flow of water into the tidal marshes. Currently, the USACE is tasked at maintaining a shipping channel at an average depth of 12 feet.

2.3.2.2 Metromedia Tract

The Metromedia Tract is an approximately 67-acre site located within the Hackensack Meadowlands in Carlstadt, NJ. The site is undeveloped and surrounds the Metromedia broadcast radio towers, and is largely dominated by common reed. The Metromedia Tract is a poorly drained, frequently flooded marsh that is located above peat, muck, and some fill material (gravel and debris). The marsh deposits are approximately 10feet thick. The closest known contamination site is 1,400 feet southeast of the border of the Metromedia Tract site.

2.3.2.2.1 Topography and Bathymetry

Topographic and bathymetric surveys were conducted in 2008 by Rogers Surveying, PLLC, of Staten Island, NY (Figure 2-17.) The Metromedia Tract site is generally flat.

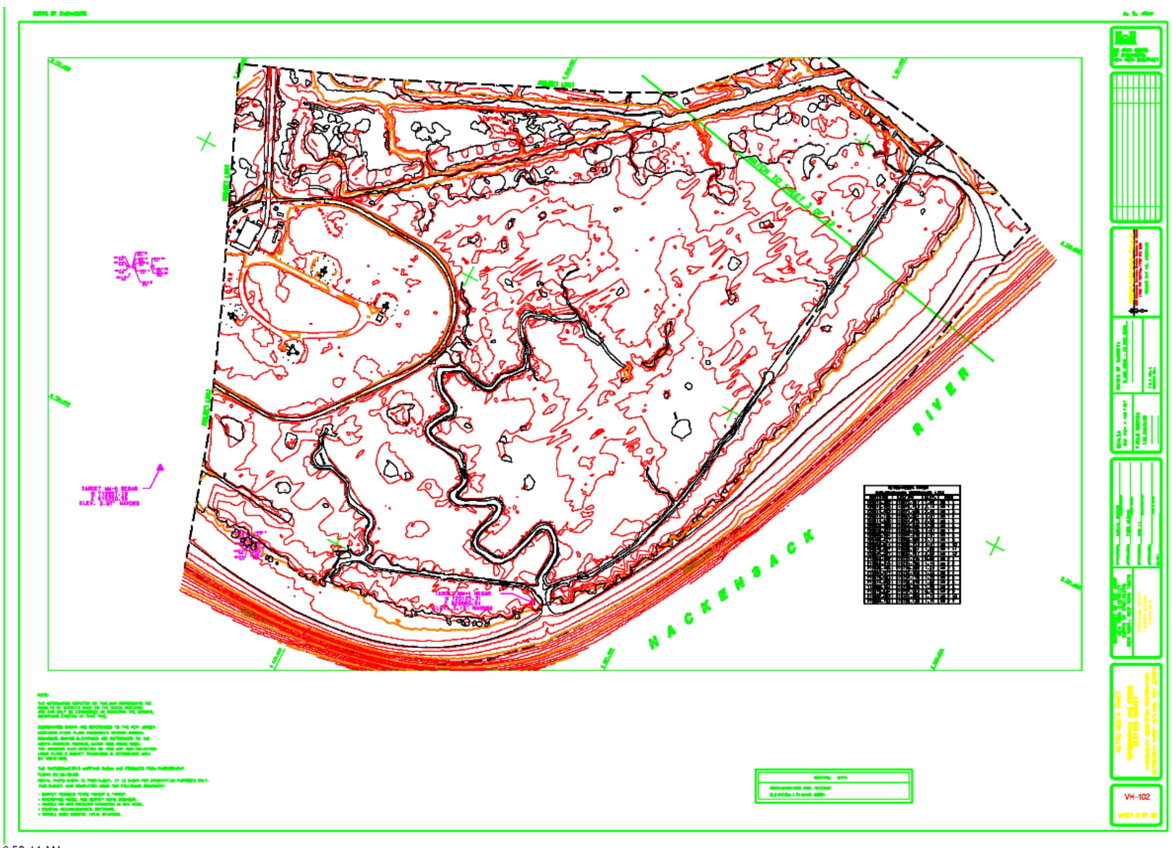


Figure 2-17: Topographic and bathymetric surveys at Metromedia Tract site

2.3.2.2.2 Geotechnical

The surface expression of the Holocene estuarine salt-marsh deposits at the Metromedia Tract site consists of mucky peat underlain by muck, silt, or sand. The distribution of the sand is likely defined by tidal tributaries. Areas farther away from the historic channels are characterized by less sand and silt. This is documented by the USDA NRCS Soil Survey Geographic (SSURGO) database, which identifies that the soil unit at the site is composed of three (3) soil types: Westbrook, Ipswich, and Sandyhook.

Each type is 64 percent organic matter and the remainder is composed of clay, silt and sand. Each type makes up 30 percent of the overall composition. The Westbrook and Ipswich types originated from partly decomposed herbaceous organic material (marsh plants), whereas the Sandyhook type came from sandy estuarine deposits.

2.3.2.2.3 Tide Analysis and Datums

Tide data were collected at the Metromedia Tract site during a 4-month period from August 2008 to November 2008. Gauges were placed both in the channel and on the marsh surface. The tide datums at the Metromedia Tract site were computed using the Modified-Range Ration Method, correcting the short-term locally-collected data to that of the long-term 19-year National Tidal Datum Epoch (NTDE) of The Battery, NY gauge.

2.3.2.3 Meadowlark Marsh

The approximately 85-acre Meadowlark Marsh is located within the Hackensack Meadowlands in Ridgefield, Bergen County, New Jersey. It is fed by the Hackensack River through Bellman's Creek and the Vince Lombardi channel (tributaries to the Hackensack River) and is confined on the west and east by the New Jersey Turnpike – Eastern Spur and Westside Avenue/New Jersey Transit Rail Line, respectively. The site is a poorly drained, frequently flooded marsh that is located above mucky peat and some sand. While there are groundwater contamination sites nearby, the extent of the effects of contamination on the health of Meadowlark Marsh is unknown.

2.3.2.3.1 Geotechnical

The surface expression of the Holocene estuarine salt-marsh deposits at the Meadowlark Marsh site consists of soils of mucky peat underlain by muck, silt, or sand. The distribution of the sand is likely defined by tidal tributaries. The further away from the historic channels, the less sand and silt. This is documented by the USDA NRCS soil survey database, SSURGO, which identifies that the soil unit at the site is composed of three (3) soil types: Westbrook, Ipswich, and Sandyhook. Each type is 64 percent organic matter, and the remainder consists of clay, silt, and/or sand. Each type makes up 30 percent of the overall composition.

The Westbrook and Ipswich soil types originated from partly decomposed herbaceous organic material (marsh plants), whereas the Sandyhook type came from sandy estuarine deposits

2.3.2.3.2 Hydrology & Hydraulics

Additional details on the H&H evaluation for the Meadowlark Marsh site can be found in Appendix E-2.

2.3.2.3.2.1 Methodology

Using the baseline studies performed for the Evaluation of Planned Wetlands (EPW) in 2015 and the H&H water surface elevation data collected by USACE in 2008, a two-dimensional hydraulic/hydrodynamic model using Surface-water Modeling Systems (SMS) Coastal Modeling System (CMS) was established to assess the existing site conditions and three (3) conceptual designs to restore H&H ecological function to the Meadowlark Marsh site. The CMS model was used in place of the RMA2 platform as CMS uses a finite element size and pattern within the two-dimensional grid, which results in a more stable simulation. RMA2 does not use a finite element size, which can

significantly decrease the stability of the two-dimensional model and cause it to fail. In addition, compared to RMA2, CMS provides a better platform for the modeling of culvert structures, several of which are present at Meadowlark Marsh. The platform switch was presented to the USACE after review of their RMA2 model of the Hackensack Meadowlands. In the provided USACE RMA2 model, only one element represented the entire Meadowlark Marsh site. The significant alterations required to modify this would most likely cause the model to fail due to the large size of the model. Therefore, the need for a new Meadowlark Marsh model was identified instead of using the RMA2 model provided.

2.3.2.3.2.2 Simulation Period

The simulation period for all three (3) models was for a 30-day period (one month) between the months of September and October 2008. Start dates varied based on peak tides (existing conditions and Alternative C began on September 13, 2008 with a peak tide at 2.964 Feet NAVD88, Alternatives A and B began on September 19, 2008 with a peak tide of 3.388 Feet NAVD88), but ran for a duration of 30 days to verify a full tidal lunar period under normal conditions. The modeling of Alternatives A and B began after the completion of modeling the existing conditions and Alternative C, and were modeled at a point in time with a higher tide to insure the start of the more detailed Alternative simulations. The first 12 hours of this simulation were omitted in the evaluation of the results as the model takes a designated amount of time to ramp up into a simulation. This “ramping period” is specified in the model parameters and can be adjusted based on the results, if needed, to allow for more or less time to calibrate the simulation process.

These months were selected for the simulation time frame as they contained some of the highest water surface elevation data at the beginning of the cycle period for the data collected. By using this time period, the model has a greater success rate in running as it considers m2ost of the site as wet or underwater during its ramping period.

2.3.2.3.2.3 Model Analysis

The H&H analysis indicates that the proposed conceptual restoration alternatives will provide sufficient tidal inundation, drainage, and the hydraulic/hydrodynamic capacity to the interior marsh to support a native tidal salt marsh, including low marsh, high marsh and scrub-shrub marsh.

2.3.3 Lower Passaic River Study Area

2.3.3.1 All Lower Passaic River Sites

2.3.3.1.1 Geotechnical

Till, glacial deltaic deposits, and glacial outwash terrace deposits are located upland from the Lower Passaic River. The surface soils near the river are often disturbed by human activities, such as placement of fill material. The Riverhead-Dunellen soil series (which consists of a sandy loam) dominates the riverbanks of the Lower Passaic River above River Mile 5 (RM5). The Wetherfield Urban land-Boonton soil series (which consists of deep, moderately-well and well drained soils that form in till on uplands) dominates the riverbanks below RM5.

2.3.3.1.2 Hydrodynamic Modeling

The hydrodynamics of the Passaic-Hackensack-Newark Bay system is predominantly controlled by three (3) forcing mechanisms, freshwater flows (buoyancy sources), tides, and winds. Two (2) major sources of freshwater inflows, the Passaic and Hackensack Rivers, contribute to the salinity gradients in the system. By far, the largest freshwater contribution is from the Passaic River. The long-term daily average flow measured at Little Falls is about 29 m^3/sec (1,000 cfs) and the maximum flow during this 21-year period was approximately 500 m^3/sec (18,000cfs) in April 1984. In contrast the average flow in the Hackensack River is only 1.6 m^3/sec (56 cfs) and a maximum flow of approximately 158 m^3/s (5,500 cfs) was measured in September 1999 during Hurricane Floyd. The salinity dynamics in the system are mostly controlled by the freshwater flows from the Passaic and Hackensack Rivers and the saltier ocean waters that enter the system through the Kill van Kull and the Arthur Kill. During most low to moderate flow periods, the salinity front stays within upper Newark Bay and the Lower Passaic and Hackensack Rivers. However, during extreme high flow periods the front is pushed further downstream to the Arthur Kill and the Kill van Kull. Salinity is, in general, higher during the time of low freshwater flow and is also more uniform both vertically and horizontally throughout the system than during the time of high freshwater flow. Freshwater flows emanating from the Passaic River stay along the western edge of Newark Bay, creating cross channel salinity gradients (Pence, 2004). The deep shipping channels in the system act as conveyances of denser and saltier ocean water to upper Newark Bay and to the Lower Passaic and Hackensack Rivers.

Tidal currents in Newark Bay and in the Passaic and Hackensack Rivers are found to be moderate, with maximum amplitudes of 0.5 m/sec. Most of the time, the surface and bottom tidal currents are of equal magnitude and are in phase in Newark Bay. However, during high-flow periods the surface currents, directed towards the ocean (ebb currents), become much stronger than the bottom currents, indicating the presence of strong vertical shear (Pence, 2004). During high freshwater flow, classical two-layer estuarine circulation is observed during flood tides, with surface currents flowing seaward and bottom currents flowing upstream. The net flow along the side banks is downstream, with an increased magnitude under higher freshwater flow conditions.

Strong and persistent wind events in Newark Bay can have a strong effect on the circulation in the estuary, and in some extreme cases can disrupt the normal pattern of estuarine circulation. Modeling analysis (Pence, 2004, Pecchioli et al., 2006) suggests that strong winds from the west will flush water and water borne constituents from Newark Bay out through the Kill van Kull, with weaker flow in through the Arthur Kill. Model computations indicate that this flow pattern changes direction when strong winds blow from the east, i.e., flow enters the Kill van Kull from the upper portion of New York/New Jersey Harbor and then enters Newark Bay (Pecchioli et al., 2006).

The full hydrodynamic modeling report can be found at www.ourpassaic.org (2008-1-25-LPR-NB_Hydronamic Report) (Table 2-24).

Table 2-24: Available Hydrodynamics Data

Nov 2004 to Sep 2005	November 2004 to September 2005 Malcolm Pirnie, Inc. Survey	USEPA	Malcolm Pirnie, Inc.	Upper 11 miles of Passaic
Aug 2004 to Oct 2004	August to October 2004 Rutgers University Survey First Deployment	USACE & NJDOT	Rutgers University	RM0 to RM6

Nov 2004 to Jan 2005	November 2004 to January 2005	USACE & NJDOT	Rutgers University	RM 0 to RM6
Jul 2005 to Sep 2005	July to September 2005 Rutgers University Survey Third Deployment	USACE & NJDOT	Rutgers University	RM 0 to RM6
2005	NJDOT Environmental	USACE &	TAMS/EarthTech & Malcolm Pirnie	Between RM2.6 and RM3
2008 to 2009	Rutgers University and University of Delaware ADCP Study	Rutgers University	Rutgers University and University of Delaware	Arthur Kill, Kill van Kull, Newark Bay, Passaic River and Hudson River near Newark Bay
2009	TSI ADCP Moorings Study	USEPA	TSI	RMs 2.1, 3.2 and 4.1
2010	CPG Physical Water Column Monitoring Program	USEPA	CPG	RMs 1.4, 4.2, 6.7, 10.2 and 13.5

2.3.3.2 Essex County Branch Brook Park

Branch Brook Park's 30-acre freshwater system is 5 miles from the Newark Bay and is located within the northeast flyway for migratory birds. This site contains of approximately 4,200 linear feet of Branch Brook and adjacent parkland. The surrounding environment consists primarily of commercial and residential developments and roadways. The site includes a day-lighted section of Branch Brook as well as three (3) larger pond features (Branch Brook Lake, Clarks Pond, and an unnamed pond) that were created with weirs. Branch Brook Park was established by Essex County as the first county park in the nation. The park is notable as having the largest collection of cherry blossom trees in the United States. The park is four (4) miles long and a quarter mile wide and includes open grassland with patches of forest stands that line Branch Brook. A narrow band of forested wetlands is found along the stream of this site. Two (2) emergent wetland areas are found in the northern section of this site. Uplands within the site are primarily mowed areas indicative of a park setting. The stream and adjacent forest areas experience considerable amounts of anthropogenic trash. The ponds suffer from algal blooms and eutrophication indicative of excess nutrient inputs. The park acts as a habitat island in highly developed and densely populated urban setting. However, the understory of the upland and wetland forested habitats of the site are dominated by nonnative, invasive vegetation, limiting ecological value.

2.3.3.2.1 Geotechnical

The Essex County Branch Brook Park site's Holocene swamp deposits consist of organic silts and organic silty clays. This is corroborated by the USDA NRCS SSURGO database which identifies five (5) soil types present at the site: Boonton Red Sandstone Lowland with 0-8 percent slope, Boonton Red Sandstone Lowland with 8-15 percent slope, Udorthents Boonton red sandstone lowland substratum, Udorthents loamy fill substratum, and Urban land Boonton red sandstone lowland substratum. Both Boonton red sandstone lowland types come from coarse loamy till derived from sandstone and shale, both Udorthents types come from loamy material transported by human activity, and the Urban land soil

type originates from surfaces covered by man-made structures such as pavement, concrete, and buildings that are underlain by disturbed and natural soil material.

2.3.3.2.2 Hydrology & Hydraulics

H&H analysis was conducted following field investigations and initial development of three (3) conceptual restoration alternatives for each site (as outlined in Alternatives Development Appendix E-5). The H&H Analysis was conducted to inform the restoration design, including establishing target vegetation community limits and planting elevations, to improve design accuracy and reduce risk. Intensive modeling was not conducted for any of the Lower Passaic River sites. Rather available tidal data was utilized to establish tidal datums and planting elevations for each site.

2.3.3.2.2.1 Analysis

Branch Brook Park is primarily located within the Passaic River Lower (Newark Bay to Saddle) sub-watershed, and the Passaic River Lower (4th St. Bridge to Second River) subsubwatershed. The headwaters for the First River are located within Branch Brook Park and thus are a significant contributor to the water quality and quantity of the Passaic River. Second River, connecting to the Passaic River) flows to and through the Extension of the park in the north, and was channelized during the development of the Extension (Rhodeside & Harwell, Inc. et. al. Volume 3, year?). The hydrology of Branch Brook Park is highly manipulated, with a networking of stormwater systems conveying surface water to the lakes, ponds and streams within the Park and a recirculation system that moves water from the downstream areas back up to North Brook. The recirculation system was designed to offset challenges posed by an inadequate water supply to the Park's water features, which persists today.

While several studies of Branch Brook Park have been conducted, most hydrologic studies have focused on characterizing the water quality and quantity issues that persist within the Park's waterways. Data regarding the fluctuation of shallow groundwater during the growing period and bio-benchmark studies, which would be necessary to inform the design of freshwater wetland restoration, have not been conducted within the Park. Additional in-depth H&H analyses will be completed for each site during the Preliminary Engineering Design phase (PED) of the Tentatively Selected Plan (TSP).

2.3.3.2.2.2 Results

Conceptual designs were created to maximize restoration possibilities based off of recommendations and existing conditions established in the Branch Brook Park Alliance reports Volumes 1-5, by Rhodeside & Harwell, Inc. et. al. (2002 and 2005). Channel deepening within the open water ponds of the site will provide better habitat for fish, as well as stream naturalization of the culvert sections channels. Designs would require a detailed water budget analyses and bio-benchmark assessments during PED to support design boundaries and develop aquatic habitat levels.

Advancement of the conceptual designs in the PED phase will require a site water budget analysis for the freshwater wetlands, as well as bio-benchmark studies within local stream banks and wetlands to provide supporting data needed for habitat design. Topographic surveys will also be needed to refine elevations. Hydraulic modeling by HEC-RAS will be required to design stream naturalization sections of the channel to remove existing culverts.

2.3.3.3 Dundee Island Park/Pulaski Park

This site consists of approximately 2,370 linear feet of the western shoreline of the Lower Passaic River, approximately 1.3 miles downstream of the Dundee Dam in Passaic, NJ. An inactive set of railroad tracks and right-of-way border the site to the west and north; a church and commercial properties border the site to the south. The City of Passaic has established Dundee Island Park within the site, which includes a soccer field, benches, a playground, trash and recycling bins, a boat launch and fish consumption advisory signage. Flood-driven woody debris and floatable trash has been deposited along the shore of the site. A very narrow band of forested wetlands occurs along the shore of this site. Large ash trees have been removed from the shoreline and bank is now dominated by Japanese knotweed (*Polygonum cuspidatum*). Within the boundary of the site, the bank of the Passaic River is very steep and stabilized with riprap and concrete.

2.3.3.3.1 Geotechnical

The Dundee Island Park/Pulaski Park site's Holocene artificial fill consists of silty sands. This is corroborated by the SSURGO soil database, which identifies two (2) soil types present at the site: Urban land (60 percent) and Riverhead (40 percent). The parent material of the Urban land type is a surface covered by man-made structures such as pavement, concrete, and buildings underlain by disturbed and natural soil material. There was no soil property information available for the Urban land type. The Riverhead soil type comes from glaciofluvial deposits derived from granite and gneiss.

2.3.3.3.2 Hydrology & Hydraulics

H&H analysis was conducted following field investigations and initial development of three (3) conceptual restoration alternatives for each site (as outlined in Alternatives Development Appendix E-5). The H&H Analysis was conducted to inform the restoration design, including establishing target vegetation community limits and planting elevations, to improve design accuracy and reduce risk. Intensive modeling was not conducted for any of the Lower Passaic River sites. Rather available tidal data was utilized to establish tidal datums and planting elevations for each site.

2.3.3.3.2.1 Analysis

No existing or available published hydrologic, hydraulic, tidal or groundwater data in the vicinity of Dundee Island Park that would inform conceptual design development for this site. Additional in-depth H&H analyses will be completed for each site during the Preliminary Engineering Design phase (PED) of the Tentatively Selected Plan (TSP)

2.3.3.3.2.2 Results

Conceptual designs were created to maximize restoration possibilities and to support conceptual designs and develop aquatic habitat level. Conceptual designs are based off of recommendations established in the *Restoration Opportunities Report Lower Passaic River Restoration Project, 2006,* existing Baseline EPW evaluation completed in 2015 (Appendix E-5), and design charrette meeting with NJDEP in June 2015.

Dundee Island Park/Pulaski Park is predominately an active recreation park with sports fields. Trail enhancements through the park were identified within the EPW, as well as portions of the site in the north that are unused and open for re-vegetation of the riparian buffer. The banks along the Passaic

River will allow for debris removal and shoreline softening and stabilization techniques identified within the Restoration Opportunities Report Lower Passaic River Restoration Project, 2006.

2.3.3.3.2.3 Next Steps

Advancement of the conceptual designs in the PED phase will require a site water budget analysis for the freshwater wetlands, as well as bio-benchmark studies within local stream banks and wetlands to provide supporting data needed for habitat design. Topographic surveys will also be needed to refine elevations.

2.3.3.4 Clifton Dundee Canal Green Acres and Dundee Island Park

This site consists of approximately 1,800 linear feet of the western shoreline of the Lower Passaic River downstream of the Dundee Dam in Clifton, NJ. Route 21 and a commercial property border the landward side of the site. The City of Clifton has established Dundee Island Park within the site, which includes a trail network, benches, interpretive signage, trash and recycling bins, and fish consumption advisory signage. This site is located adjacent to the Safas property, which is subject to an NJDEP environmental investigation/cleanup (NJDEP case # E20050092). Large volumes of flood-driven woody debris and floatable trash have been deposited along the shore of the central portion of the site, immediately below a low, flat peninsula projecting out into the river. An active vagrant campsite strewn with trash was observed during the site visit within the southern portion of the site near Ackerman Ave.

Forested and scrub-shrub wetlands occur along portions of the shore of this site. Riparian uplands within the site are primarily forested by native plant species, though some areas are dominated by Japanese knotweed. Large amounts of cement, stone, brick, asphalt and steel debris fill have been historically placed at the site and are now heavily overgrown with vegetation.

2.3.3.4.1 Geotechnical

The Clifton Dundee Canal Green Acres and Dundee Island Park sites' Holocene deltaic/alluvial fan deposits consist of silty sands. This is corroborated by the USDA NRCS. The USDA NRCS SSURGO database, which identifies two (2) soil types present at the site: Urban land (60 percent) and Riverhead (40 percent). The parent material of the Urban Land soil type is a surface covered by man-made structures such as pavement, concrete, and buildings underlain by disturbed and natural soil material. There was no soil property information available for urban land soil. The Riverhead complex comes from glaciofluvial deposits derived from granite and gneiss.

2.3.3.4.2 Hydrology & Hydraulics

H&H analysis was conducted following field investigations and initial development of three (3) conceptual restoration alternatives for each site (as outlined in Alternatives Development Appendix E-5). The H&H Analysis was conducted to inform the restoration design, including establishing target vegetation community limits and planting elevations, to improve design accuracy and reduce risk. Intensive modeling was not conducted for any of the Lower Passaic River sites. Rather available tidal data was utilized to establish tidal datums and planting elevations for each site.

2.3.3.4.2.1 Analysis

No existing or available published hydrologic, hydraulic, tidal or groundwater data in the vicinity of the Clifton Dundee Canal Green Acres site that would inform conceptual design development for these sites. Additional in-depth H&H analyses will be completed for each site during the Preliminary Engineering Design phase (PED) of the Tentatively Selected Plan (TSP).

2.3.3.4.2.2 Results

Conceptual designs were created to maximize restoration possibilities and to support conceptual designs and develop aquatic habitat level. Conceptual designs are based off of recommendations established in the *Restoration Opportunities Report Lower Passaic River Restoration Project, 2006,* existing Baseline EPW evaluation completed in 2015 (Appendix E-5), and design charrette meeting with NJDEP in June 2015.

Clifton Dundee Canal Green Acres is identified as predominantly invasive uplands. Conceptual designs for this site incorporate the regrading of the upland shoreline along the Passaic River to establish a forested and scrub shrub freshwater wetland habitat. A water budget analyses and bio-benchmark assessments would be utilized during PED to further design this wetland function to adequate grade elevations.

2.3.3.4.2.3 Next Steps

Advancement of the conceptual designs in the PED phase will require a site water budget analysis for the freshwater wetlands, as well as bio-benchmark studies within local stream banks and wetlands to provide supporting data needed for habitat design. Topographic surveys will also be needed to refine elevations.

2.3.3.5 Oak Island Yards

This site is located along approximately 900 feet of Newark Bay and is bordered by a shipping container yard, railroad tracks, and a HESS petroleum tank farm. A semi-tidal ditch with a tide gate is located adjacent to the site, below the railroad track embankment on the southeast border of the site. Since the date of the project mapping aerial photo, the shipping container storage yard has been extended southeast to within approximately 100 feet of the pond and runs the full width of the northwestern boundary of the site. Also, a considerable amount of rock and gravel fill has been placed onsite since the aerial photo was taken. Rock fill extends from the shipping containers all the way to the river along the southeast portion of the site and has also been placed in the river. The majority of the site contains riprap fill material preventing vegetation growth. Where vegetation does grow within the upland and wetlands areas, it is dominated by nonnative invasive vegetation.

2.3.3.5.1 Geotechnical

The Oak Island Yards site's Holocene estuarine salt-marsh deposits consist of clay and silty sands. This is corroborated by the U.S. Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS) Soil Survey Geographic (SSURGO) database, which identifies the Udorthents soil unit, a loamy fill substratum, as being the dominant soil unit at the site. The Udorthents series is the product of past dredge-and-fill activities, and so the parent material of this complex is loamy-skeletal human-transported material.

2.3.3.5.2 Hydrology & Hydraulics

2.3.3.5.2.1 Analysis

The conceptual-level planting elevations for the Kearny Point and Oak Island Yards sites were established utilizing tidal and bio-benchmark data collected by Louis Berger in 2002. Louis Berger was contracted by USACE to perform the preliminary studies and design for the salt marsh restoration of Minish Waterfront Park, which is approximately 4.1 miles upstream along the lower Passaic River from the Kearny Point to Oak Island Yards. Due to the proximity of the Minish Park project site to the Kearny Point and Oak Island Yards sites, tidal conditions and elevations at which target vegetative communities exist are comparable and appropriate to use to inform the restoration designs. A considerable gap does exist between when the data was collected and today, which could affect the tidal datum. The degree of uncertainty posed by this factor was evaluated by comparing the historic

National Oceanic and Atmospheric Administration – National Ocean Service (NOAA-NOS) Epoch datum to the current NOAA-NOS Epoch datum, as described below.

2.3.3.5.2.2 Tidal Datums

As part of the prior study, tidal data was collected for approximately seven (7) weeks, from October 4, 2002 to November 22, 2002, in 10-minute intervals within the Passaic River near the Minish Park site (Table 2-25). Utilizing this data, the site tidal datum was established and compared to the Kearny Point and Belleville NOAA-NOS Epoch datum's for the observed inundation period, which verified the data integrity. A summary of the data collected in 2002 and a comparison to the NOAA-NOS Epoch datum used in 2002, as well as the current NOAA-NOS Epoch datum, is provided in the table below. Data collected in 2002 was collected in the National Geodetic Vertical Datum of 1929 (NGVD29). This was converted to North American Vertical Datum of 1988 (NAVD88) using the USACEs' Coprscon 6.0.1 datum conversion computer program, and was determined as NAVD88 = NGVD29 - 1.122 FEET. The information in the table below is provided in NAVD88 for consistency of the project design.

Table 2-25: Tidal Datums within the Passaic River near the Minish Park Site

	Minish Park Passaic River	Kearny Point Passaic River	Belleville Passaic River	Belleville Passaic River	Kearny Point Hackensack River
	Berger	NJDEP/NOAA-NOS	NJDEP/NOAA-NOS	NJDEP/NOAA-NOS	NJDEP/NOAA-NOS
	Observed	Epoch	Epoch	Epoch	Epoch
Datum	Oct 2002 – Nov 2002	1960-1978	1960-1978	1983-2001	1983-2001
MHWS	3.33				
MHHW	2.92	2.62	2.85	3.06	2.7
MHW	2.63	2.29	2.48	2.72	2.38
MTL	-0.02	-0.33	-0.33	-0.08	-0.23
MLW	-2.67	-2.95	-3.15	-2.88	-2.84
MLLW	-2.94	-3.19	-3.41	-3.13	-3.08
MLWS	-3.34				

Although it has been nearly 14 years since the tidal data was collected, the current epoch resembles the historic epoch datums as well as the tidal data collected for Minish Park in 2002. The Belleville NOAA gauge shows a slight increase (0.3 feet) with the current epoch datum, however this is still within reason to validate the collective data available to utilize the analysis performed in 2002 into the conceptual designs along the Passaic River.

2.3.3.5.2.3 Bio-benchmarks

Bio-benchmark data was collected within the Minish Park site and within wetlands located across the Passaic River from Minish Park as part of the 2002 study. Twelve biobenchmarks were surveyed, capturing the lowest and highest elevations of both *Spartina alterniflora* and *Phragmites australis* communities. The results indicated that *Spartina alterniflora* was present on-site from elevation -0.22 to 1.28 feet NAVD88 and off-site from elevation 0.18 to 2.48 feet NAVD88. The lowest elevation of Phragmites dominance was observed at elevation 1.88 feet NAVD88.

2.3.3.5.2.4 Results

Preliminary salt marsh habitat ranges were developed for the Minish Waterfront Park project using the observed inundation periods, bio-benchmark studies, and the calculated tidal datum (Table 2-26). Due to the proximity of the sites, this habitat datum was utilized as the conceptual marsh restoration datum for the Kearny Point and Oak Island Yards sites.

Table 2-26: Minish Waterfront Park Project Preliminary Aquatic Habitats

Habitat	Elevation Range (feet NGVD29)	Elevation Range (feet NAVD88)*
Open water	<0.5	<(-0.72)
Low marsh	0.5 – 3.0	(-0.72) – 1.88
High marsh	3.0 – 4.0	1.88 – 2.88
Total wetland	**0.5 – 4.0**	**(-0.72) – 2.88**

The conversion from NGVD29 to NAVD88, using the USACEs' Coprscon 6.0.1 datum conversion computer program, was determined as NAVD88 = NGVD29 - 1.122 FEET.

The EPW site assessment for Oak Island indicated predominately invasive vegetation and upland areas. A small section of functioning emergent wetland (open water and low marsh) was identified along the Passaic River in the north east quadrant of the site, as well as an open water area within the central portion of the site. The conceptual design for Oak Island was developed to maximize the restoration benefits through re-establishment of a predominately low marsh wetland. Channel alignments were established to provide water supply to various portions of the site, and have re-established an inlet connection to the Passaic River at the existing emergent wetland area. This was chosen to reduce construction costs for the channel development by excavating in lower areas of the site and within open water portions. Islands of high marsh and scrub shrub habitats were incorporated in the larger areas of low marsh to provide different habitat diversity within the site. Additionally, a perimeter berm of high marsh, scrub shrub and coastal maritime forest was incorporated to provide protection to the neighboring properties from the reintroduction of the tidal period to the site, as well as incorporating diversity within the site to accommodate for possible sea level rise within the Passaic River. Stabilization areas along the channel inlets have been incorporated to protect susceptible areas along the shore from significant wave action in the area.

Kearny Point was identified as predominantly upland invasive vegetation and gravels, with a small boarder of wetland along the southeast perimeter of the Hackensack River. Along the Passaic River, on the west, is an existing bulkhead to provide stabilization of the upland gravels and protect the site from wave action caused by boating along the navigable channel. In the central area of the site, an eagle nest was identified that will prevent construction within a 300 feet perimeter. The conceptual design for Kearny Point, like Oak Island, was developed to maximize wetland restoration, maximizing low marsh establishment within the site. Channel alignments were established to provide inundation to all areas of the site. Large areas of high marsh and scrub shrub habitats along the northern perimeter of the site were incorporated, as well as a small band of maritime forest to provide diversity, account for sea level rise, and protect neighboring properties from the introduction of a tidal period. A 300 foot buffer placed around the eagles' nest was incorporated to avoid disturbance during construction, and small bands of scrub shrub and high marsh were offset from this buffer to provide a slope down to the restoration of low marsh. Bank stabilization along the Passaic River is included, as the bank will still be susceptible to wave action from boating.

2.3.3.5.2.5 Next Steps

Advancement of the designs in the PED phase will require site topographic surveys to refine the planting elevations identified in the design phase.

2.3.3.6 Kearny Point

This site consists of a 300- to 1,000-foot wide area located along approximately 3,000 linear feet of the northern shore of Newark Bay in Kearny, NJ. The surrounding land use consists entirely of commercial developments and roadways. Within the site boundary, half of the site is an active soil sorting site and half of the site is an undeveloped forested area. This eastern half of the site provides fairly high ecological value, despite the heavy development of the area. An active bald eagle nest is located within one of the eastern cottonwood trees located on site. Table 2-27 provides key information and references for the Kearny Point site and its surrounding area.

Table 2-27: Key Information and References for the Kearny Point Restoration Site and its Surrounding Area.

Feature/reference type	Name/reference
City	Kearny
County	Hudson
State	New Jersey
Coordinates of site	40.7192532N 74.114763W
Size of site	110 acres
USGS Quad (ID)	Jersey City (o40074f1)
USGS maps	N4037.5–W7400/7.5
Geological maps	OFM 20, I-2540-A, HFM-53
USACE reports	Earthworks 2006, Earthworks 2007, Earthworks 2008
Watersheds	Hackensack River, Passaic River Lower and Newark Bay
Sub-watersheds	Hackensack R. (below Amtrak Bridge),Passaic R. Lower (Newark Bay to 4th
Tidal range[a]	5.10feet

[a] MHW-MLW feet based on tides recorded Oct 2005 – Sept 2013 at USGS tidal station 01392650 Passaic Valley Sewerage Commission.

Kearny Point used to be marshland/meadowland, but was then filled in and constructed on between 1899 and 1955. Today the area is very industrial, and includes many warehouses, manufacturing plants and shipbuilding yards, as well as the Pulaski Skyway running north of the area.

2.3.3.6.1 Geotechnical

The presence of surficial Holocene artificial fill in the general stratigraphy of the Kearny Point site is consistent with the soil type that USDA NRCS SSURGO database identifies as being present at the site; Secaucus artifactual fine sandy loam soil, 0-3 percent slope and 3-8 percent slope. The Secaucus artifactual fine sandy loam soil with a slope of 0-3 percent is located in the western half of the site, and the 3-8 percent slope is located in the eastern half. This soil type most likely originated from human activity.

2.3.3.6.2 Hydrology and Hydraulics

(See Hydrology & Hydraulics section for Oak Island Yards, above)

2.4 Hudson-Raritan Estuary (HRE) Oyster Restoration Sites

2.4.1 All Sites

Historically, Upper and Lower New York Bay were known for its oysters, which covered an extensive area along the shoreline (Figure 2-18. Around the 1770s, 765 million oysters per year were harvested from the waters of New York Bay (Sanderson 2016). Since then, oysters have nearly disappeared due to overharvesting, water quality deterioration, sedimentation, and other factors. Restoring the oyster population in New York Bay is considered to be advantageous for both ecosystem health and protecting New York City's shoreline.

Five (5) sites have been recommended for small-scale oyster restoration within multiple planning regions (Table 2-28 and Figure 2-19). All sites are in tidal waters of the Hudson Raritan Estuary, and border man-made structures and altered shorelines. Nearby soils on land are described, as they are potential sediment sources.

Table 2-28: Proposed Oyster Restoration Sites

Oyster habitat restoration	Planning Region	Sub-watershed/water body
Site 864. Governors Island	Upper Bay	Upper New York Bay/ Buttermilk Channel
Site 154. Bush Terminal	Upper Bay	Upper New York Bay/ Bay Ridge Channel
Unnumbered site: Soundview Park	Harlem River/East River/Western Long Island Sound	Bronx River: Confluence of Bronx and East Rivers
Unnumbered site: Head of Bay	Jamaica Bay	Hook Creek-Head of Bay
Unnumbered site: Naval Weapons Station Earle	Lower Bay	Compton Creek-Sandy Hook Bay

Figure 2-18: Historic Map of the New York Bay area Depicting Major Oyster Habitats in 1911. Shaded Areas Indicate the Principal Sources of Oysters (Metropolitan Sewerage Commission 1911).

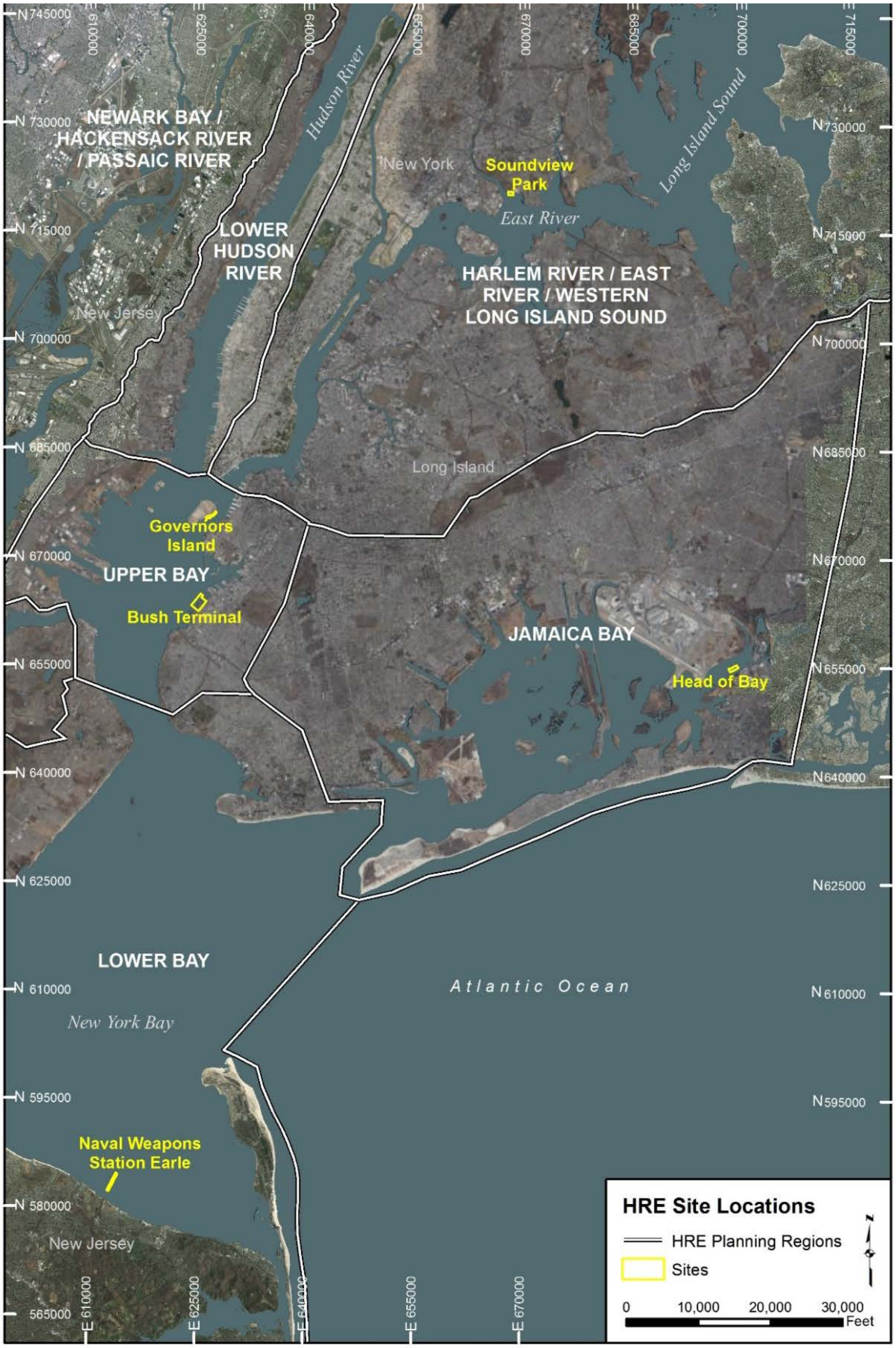


Figure 2-19: HRE restorations sites and associated watersheds in New York Harbor and Jamaica Bay area.
Watershed boundaries are from USDA Watershed Boundary Dataset (February 2016).

2.4.1.1 Geological

Figure 2-20 is a topographic map showing the oyster habitat restoration sites and their corresponding watersheds.

Figure 2-21 shows the map of bedrock underlying the oyster restoration sites. e4sciences compiled and modified this map based on numerous sources including the bedrock geology maps of the NJDEP Geological Survey and the New York State Geological Survey. The NYS bedrock geological map and compilations incorporating it are either out of date or have not accepted revisions in the New York City area based on mapping and numerous publications by Baskerville (e.g., Baskerville, 1994, USGS map), Merguerian (e.g. Merguerian and Baskerville, 1987), Sanders (e.g. Merguerian and Sanders, 1991) and Moss (e.g. Moss and Merguerian, 2010). e4 modified the map in Figure 2-21 with the above mentioned revisions based on e4sciences' local knowledge, much of which is related to USACE-NAN contracts. Key USACE reports are included in the references.

Figure 2-22 shows the map of surficial geology encompassing the oyster habitat restoration sites. The southern termination of the last Pleistocene glacier (Wisconsin) is marked by the glacial terminal moraine (Qwtm) extending along Staten Island and Long Island. North of this, Pleistocene glaciers have scraped down to bedrock or to the semi-consolidated Tertiary and Cretaceous Coastal Plain Group sediments. North of the terminal moraine, Pleistocene glacial tills drape the bedrock and glacial lake sediments filled valleys. As the glacier receded, it also deposited a blanket of outwash sands and silts that "washed out" from the glaciers. These Pleistocene sediments overlie Coastal Plain Group strata.

On land, north of the terminal moraine, Holocene sediments are predominantly fluvial, estuarine, and marine deposits. The Holocene sediments are thin and true soils are relatively thin. Underwater, north of the Terminal moraine, the Holocene coarser sediments are marine reworked Pleistocene sands and gravels. The fine-grained sediments are estuarine deposits. In the Hudson River channel, these Holocene deposits are up to 300feet thick. At the oyster habitat restoration sites, Holocene deposits are relatively thin (0 to 20feet). Black silt deposited during is deposited in lows and current shadows.

On land, south of the terminal moraine, there are minor Holocene sediments and true soils may be thick. Underwater Holocene deposits are predominately sands and marsh deposits. Sands are reworked out wash sands and Coastal Plain Group strata. At Jamaica Bay Holocene sediments are estimated to be 20-feet thick.

The New Jersey coast south of New York Bay is predominantly erosive. On land, the soils have variable thicknesses and lie on the Coastal Plain Group deposits. Holocene stream deposits are relatively minor. Underwater along the New Jersey Coast the Holocene is dominated by reworked sands of the Coastal Plain Group.All of the oyster habitat restoration sites are adjacent to built-up shorelines and are in channels with varying degrees of marine vessel traffic. Naval Weapons Station Earle and Governors Island sites are adjacent to active piers. The Bush Terminal site is in an underwater field of pier "ruins" adjacent to piers that have been re-purposed as a park.

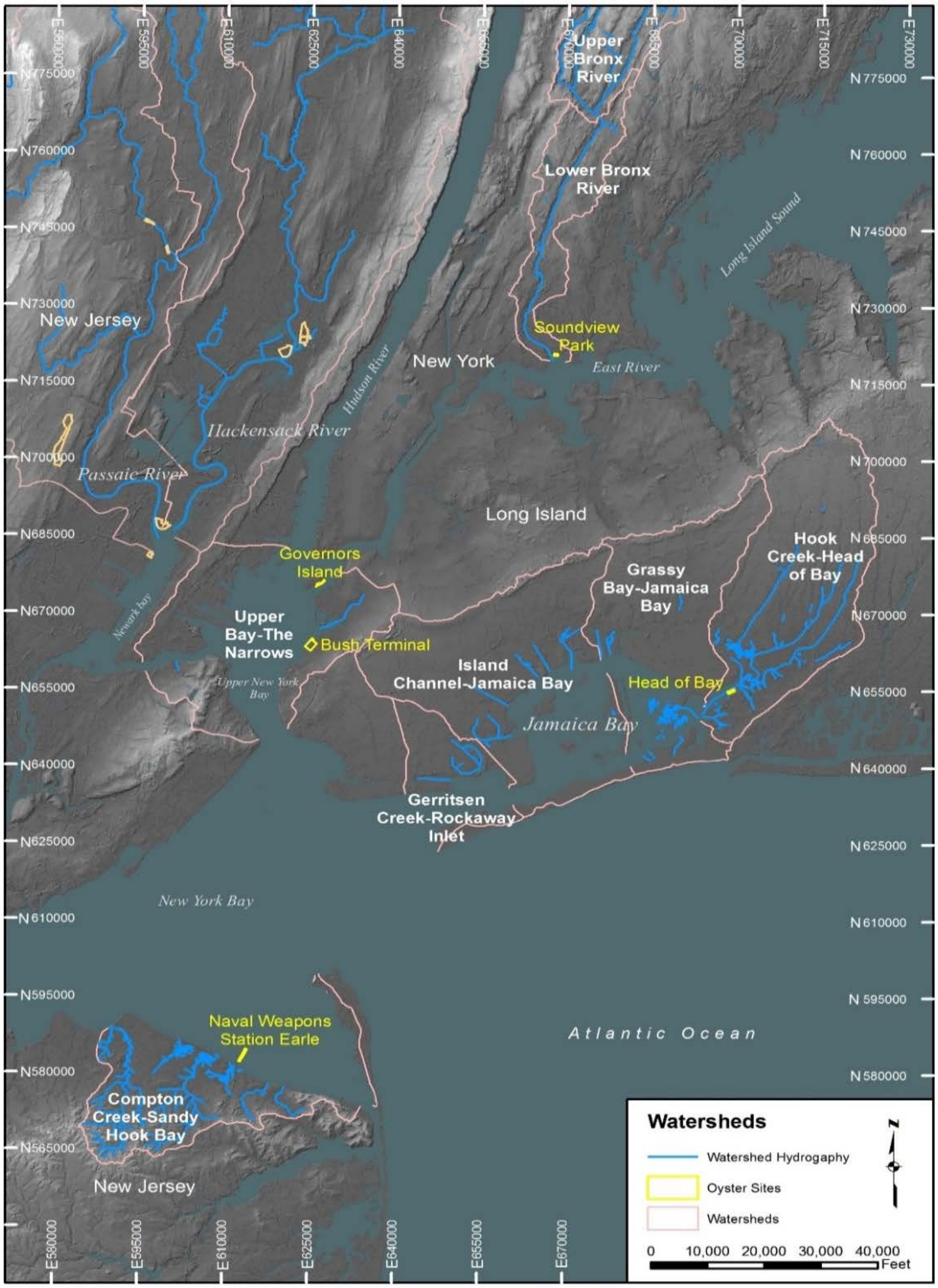
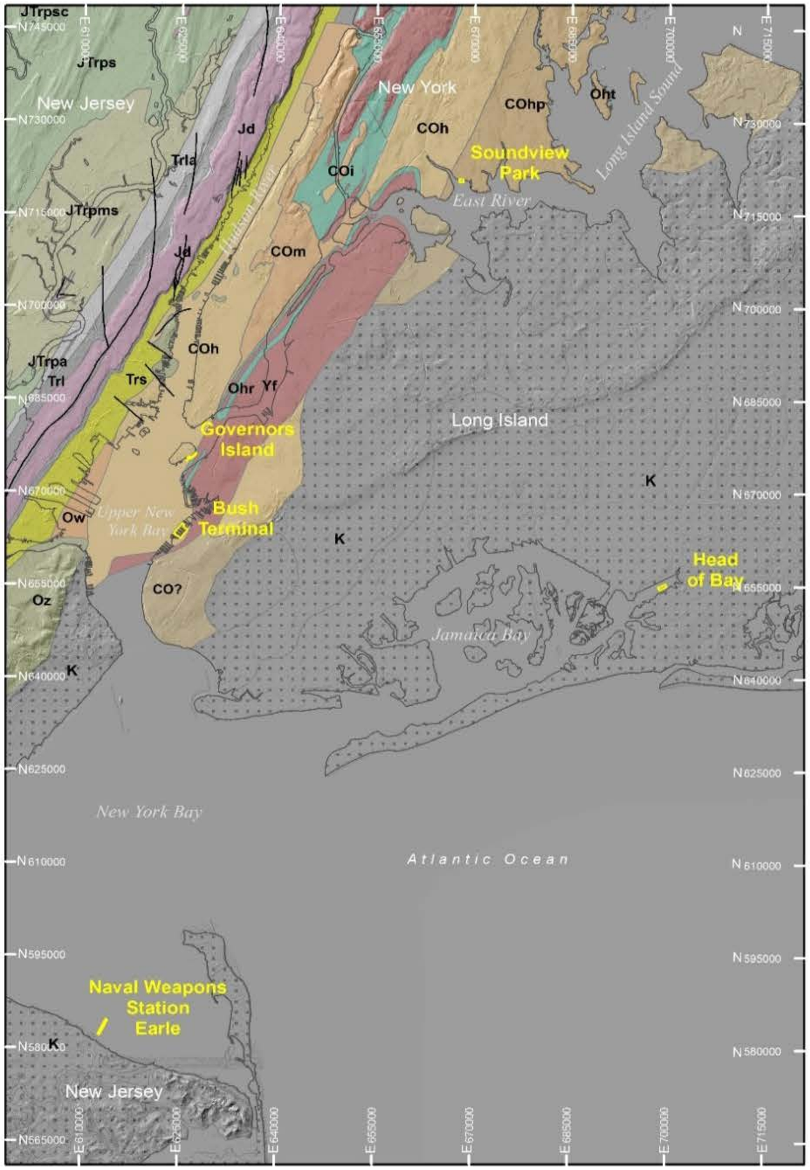


Figure 2-20: Location Map the proposed oyster habitat restoration sites and the HRE planning regions.
Base map images are 2014 ortho-rectified aerial images for NY (NYSDOP, 2014) and March-May 2015 ortho-rectified images for NJ (NJGIN, 2015), as well as images from USGS EROS (2014).



Bedrock Geology

Geologic Age	Label	Unit	Rock or Sediment Type
Cretaceous	K	Coastal Plain Group	clay, silt and sand
Jurassic	Jd	Palisade Diabase	diabase
Lower Jurassic Upper Triassic	JTrp: JTrpsc	Passaic Formation	shale and conglomerate
	JTrp: JTrpms		shale and silstone
	JTrp: JTrps		shale and sandstone
	JTrp: JTrpa		shale with silstone and sandstone
Upper Triassic	Trl: Trl	Lockatong Formation	argillite
	Trl: Trla		sand stone
Triassic	Trs	Stockton Formation	sandstones and shales
Ordovician	Oz	Serpintinite	serpintinite
	Ow	Walloomsac Formation	graphite schist
Cambrian-Ordovician	COh: COh, COhp	Hartland Formation	gneiss and schist
	COm	Manhattan	schist
	COi	Inwood Marble	marble
	CO?		undifferentiated metamorphics
PreCambrian	Yf	Fordham Gneiss	gneiss

Fault Lines
Oyster Sites

0 7,500 15,000 30,000 45,000 60,000 Feet

Figure 2-21: Bedrock Underlying the Oyster Restoration Sites

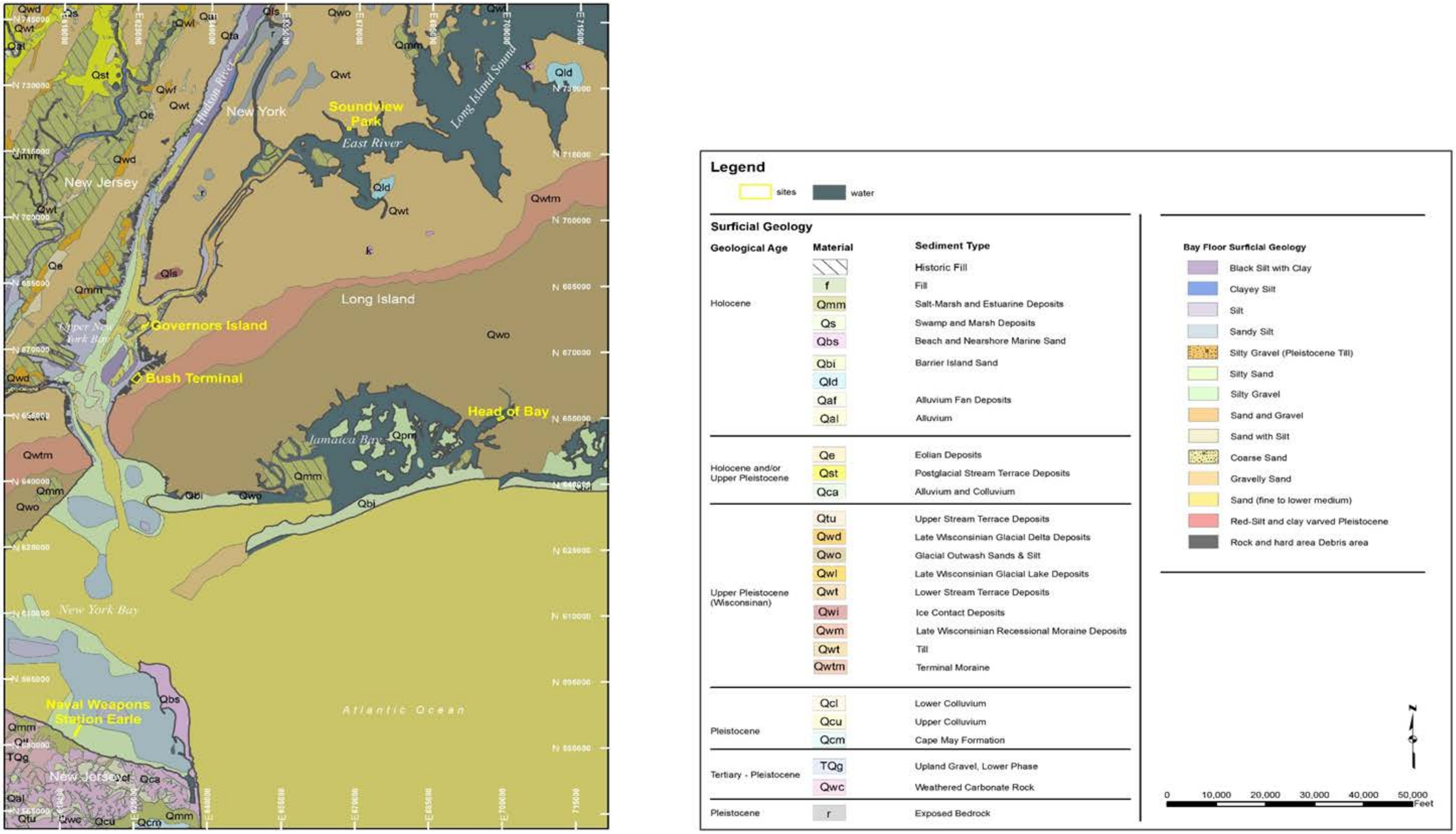
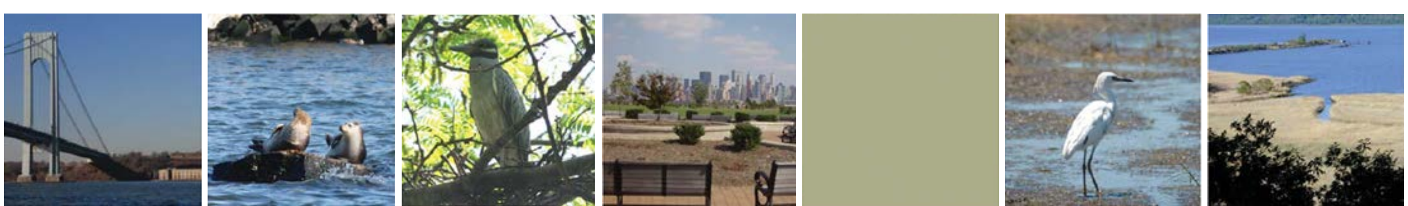


Figure 2-22: Surficial geology map and the New York oyster ecosystem restoration sites.

The NY land-based surficial geology is modified from NYSGS surficial geology map (Caldwell 1989), the NJ land-based surficial geology is from NJDEP Gelogical Survey surficial geology map of New Jersey (DGS07-2). The water-based NYNJ Harbor bay and river floor geology map was compiled for an ongoing USACE-NAN project (e4sciences, 2016). NYSGS geology boundaries were modified to align with orthoimagery (NYSDOP 2014, NJGIN 2015, USGS EROS 2014).



2.4.2 Governors Island Oyster Restoration Site

2.4.2.1 Bathymetry

Figures 2-23 and 2-24 show nautical charts from 1845, 1906, 1912, and 2014 outlining the Governors Island oyster restoration site in New York Harbor. As seen in the 1845 chart, the original island covered just the northeastern quarter of modern-day Governors Island. The rest of the island was built up above sea level with fill between 1906 and 1912. The proposed oyster restoration site lies just offshore of both the area of the original island, and the filled-in island. Much of the area is in waters shallower than 15 feet deep, although on the south side, the bottom slopes down to a 40-foot-deep channel. The water depth of present-day Buttermilk Channel appears to be no more than 5feet deeper than in 1845. Another 1.59 feet should be added to that change to account for relative sea level change between 1845 and 2016 (based on NOAA's average sea level rise of 2.84mm per year determined from continuous measurements just north of Governors Island at The Battery tidal station (8518750) from 1856 to the present). The USACE maintains the Buttermilk channel with periodic dredging.

2.4.2.2 Geotechnical

The Governors Island oyster restoration site lies between the rip-rap lined seawall of the island and Buttermilk Channel. The site is underlain by schist (Hartland formation) that is 0 to 40feet below the bay floor. At the northern end of the site, rock is exposed on the channel floor. Overlying the rock is variable thicknesses of interlayered Pleistocene glacial deposits that include glacial lake clay and silt, glacial outwash sand and silt, and glacial till. Overlying Holocene sediments are generally less than 10 feet thick. Coarse Holocene sediments appear to be reworked Pleistocene sediments. Locally, a thin layer of black silt overlies the Holocene sands.

The general stratigraphy of the Governors Island oyster habitat restoration site is outlined in Table 2-29. Figure 2-25 shows a map of the surficial geology of the area. Governors Island is underlain by bedrock of schist and gneiss of the Hartland Formation and is overlain by varying thicknesses of glacial lake clay and silts and interlayered glacial outwash sands and two (2) glacial till layers. The Hartland Formation is considered to be dominantly gray-weathering, fine-to-coarse grained, well-layered muscovite-biotite-quartz-plagioclase-garnet schist, gneiss and granofels that contains layers of greenish amphibolite and/or garnet (Merguerian and Baskerville, 1987). Note that the Baskerville, 1994, map I-2306 shows incorrectly that the uppermost bedrock beneath Governors Island is the Manhattan Schist instead of the Hartland Formation.

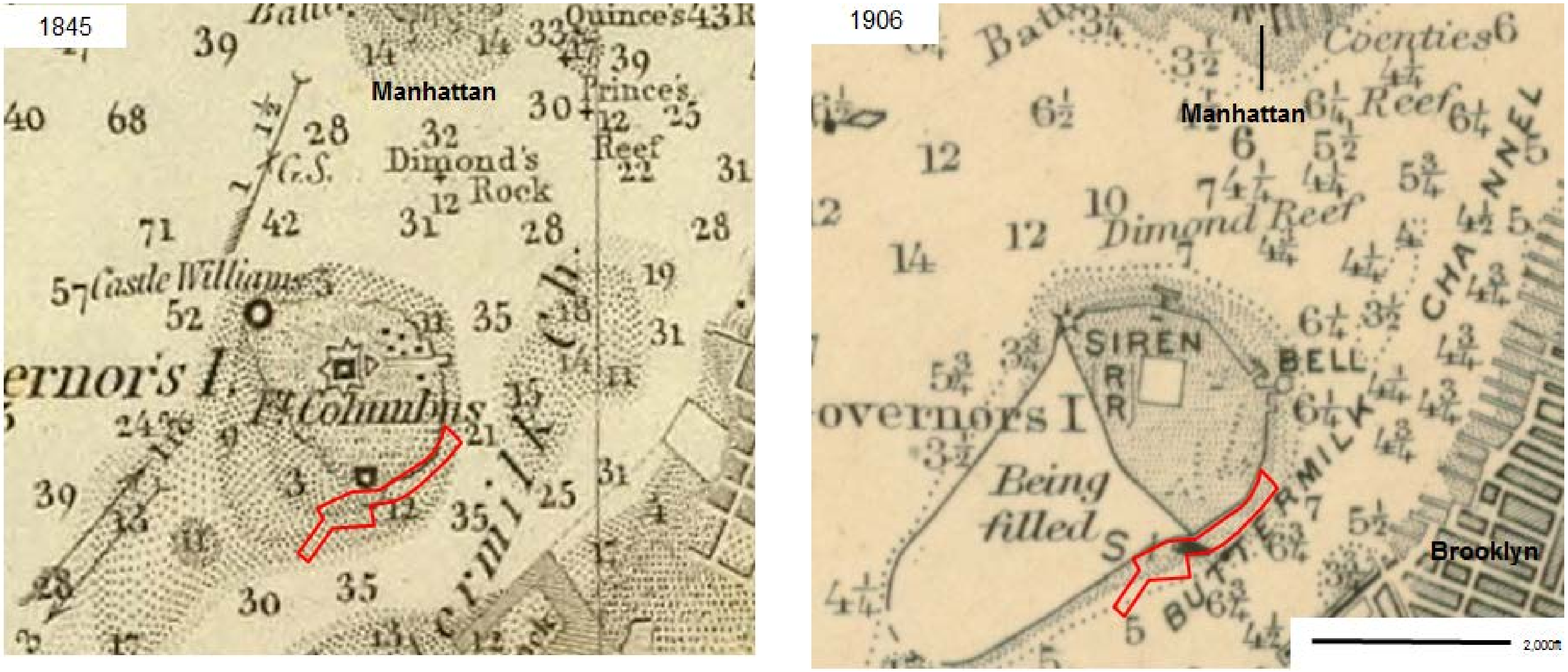


Figure 2-23: NOAA nautical charts from 1845 and 1906 (No. 120) showing Governors Island and its surrounding bathymetry in New York Harbor.

Red lines delineate the area of oyster restoration opportunity.

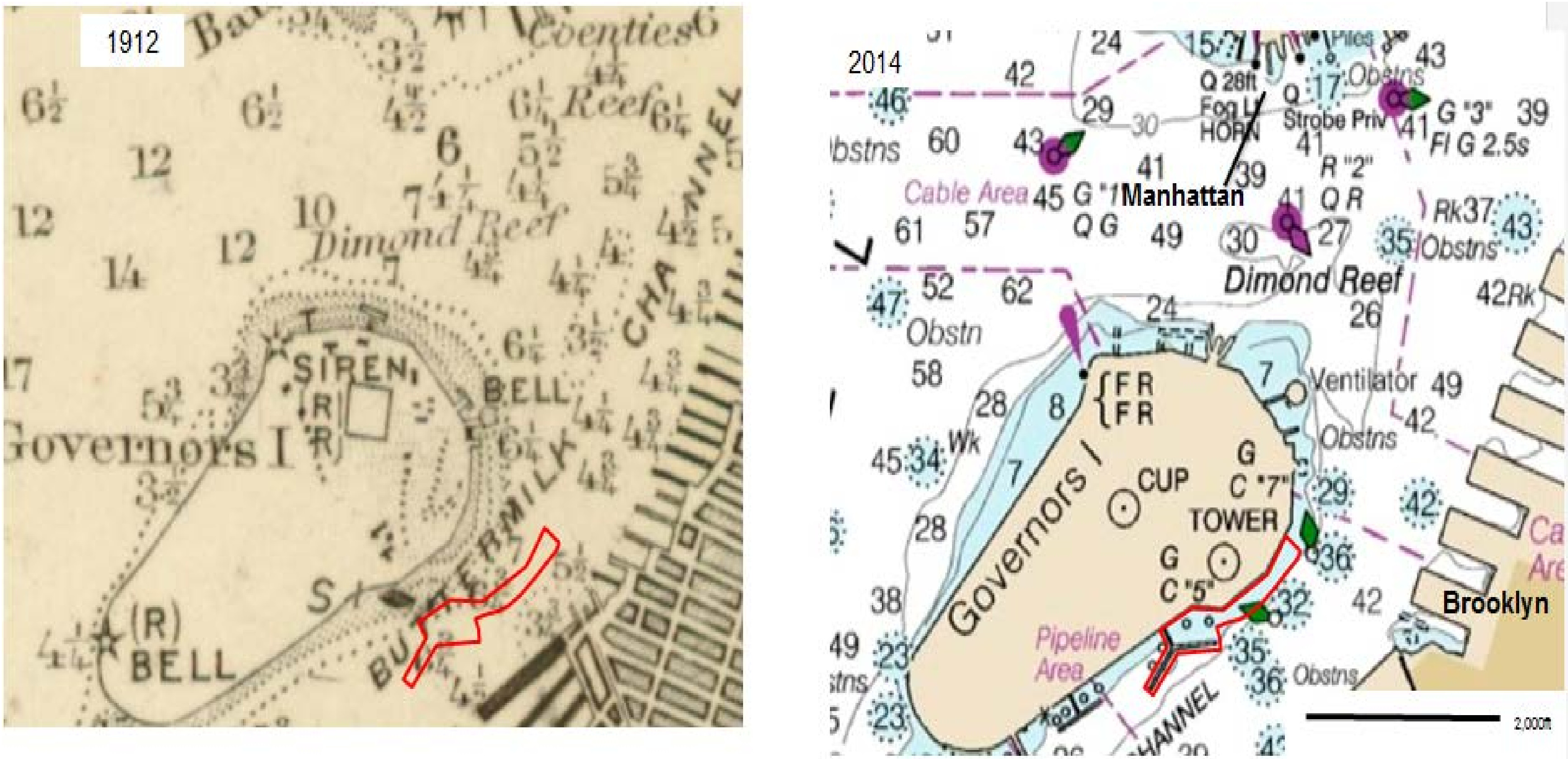


Figure 2-24: NOAA nautical charts from 1912 (No. 120) and 2014 (No. 12327) showing Governors Island and its surrounding bathymetry in New York Harbor.

Red lines delineate the area of oyster restoration opportunity. In the 1912 chart, depth soundings are in fathoms below MLW and in the 2014 chart, depth soundings are in feet below MLLW.

Table 2-29: General stratigraphy of the Governors Island oyster site based on borings along the battery tunnel.

Age	Thickness (feet)	Geologic Unit	Description
Holocene-historic	0 to 10ft?	Rip rap	Protected barrier along sea wall.
Holocene	0 to 4.1ft	Black silt	Organic silt
Holocene	0 to 1.7ft	Black silt and gravel	Organic silt and gravel
Holocene	0 to 3ft	Marine sands	Silty sands
Holocene	0 to 6ft	Marine gravel	Sandy gravel with shells
Pleistocene	0 to 20ft	Glacial outwash sand	Stratified sand and silty sands
Pleistocene	0 to 10ft	Glacial till	Silty sand and gravel to clayey gravel with cobbles & boulders
Pleistocene	0 to >22ft	Glacial lake deposits	Silt and fine sand
Cambrian-Ordovician	n.a.	Hartland Formation	Bedrock: gneiss, schist and pegmatites

USACE 1998 borings in Buttermilk Channel and e4sciences 2015 NYCDEP report.

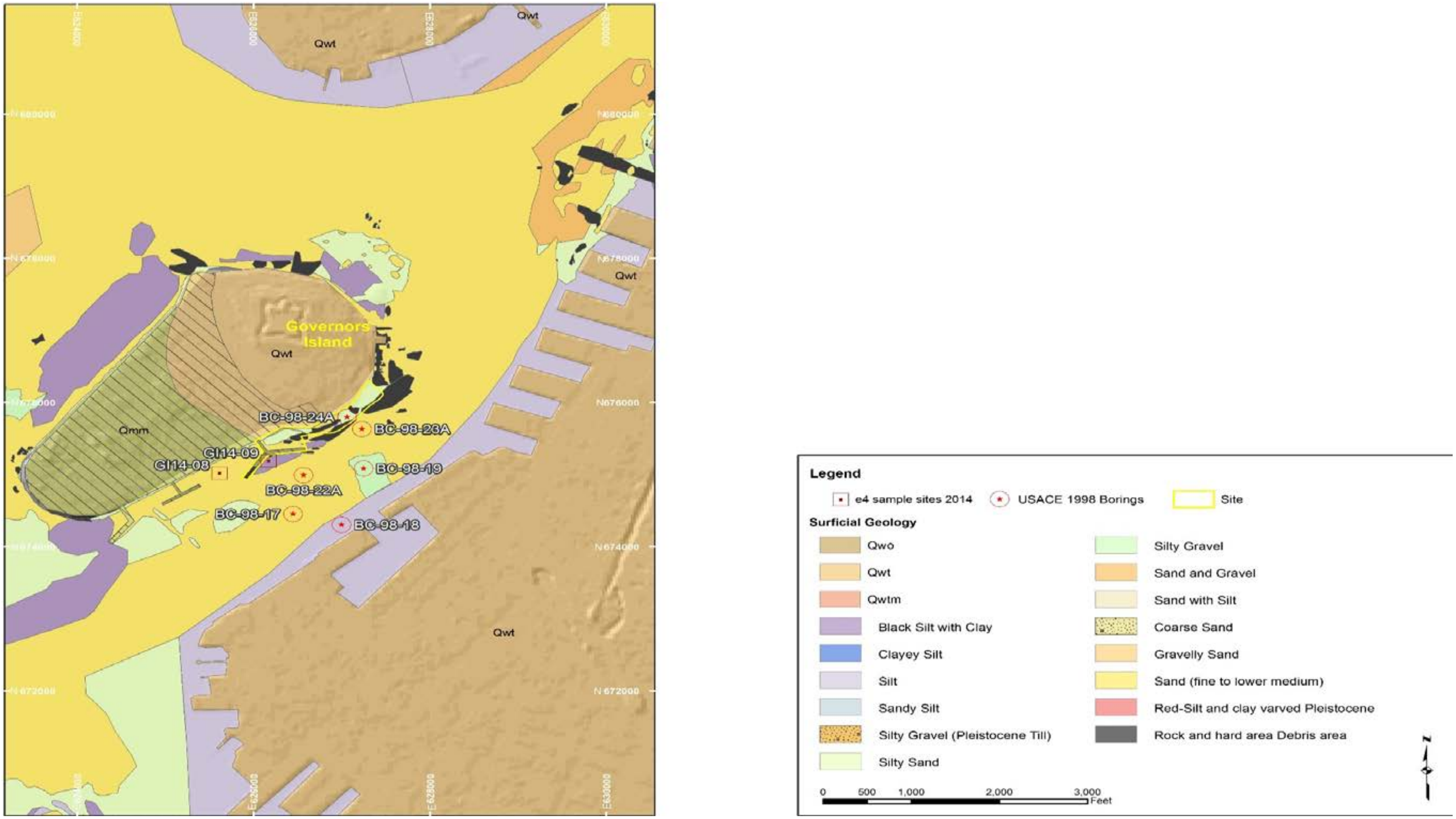


Figure 2-25: Surficial geology and boring locations of the Governors Island site.
Land surficial geology is from a NYSGS surficial geology map (Caldwell 1989). Bay floor sediment map is from an ongoing USACE-NAN project (e4sciences, 2016), Boundaries were modified to align with orthoimagery (NYSDOP 2014, USGS EROS 2014).

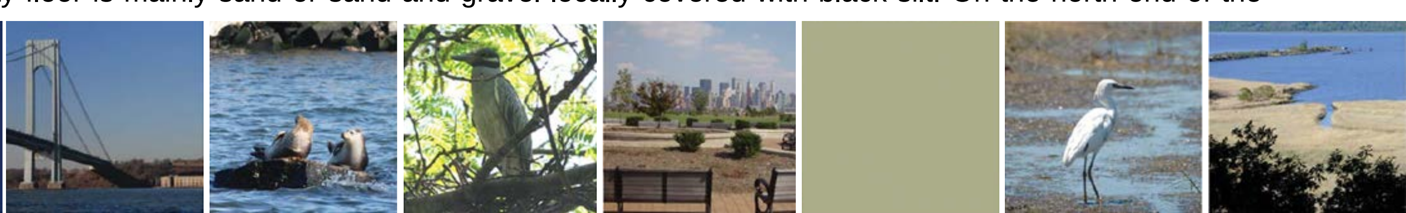
The general stratigraphy of Governors Island is recorded in borings drilled for the construction of the Brooklyn-Battery tunnel that runs east of the northeastern edge of Governors Island (Sanborn, 1950; Berkey, 1948; and reinterpreted by Merguerian, 2003). The tunnel is less than 1,000feet from the oyster habitat restoration site. The sediment making up the original core of Governors Island is known from trenching for archeological studies (Thieme, 2008).

The shallow subsurface in the vicinity of the oyster site is also recorded in USACE 1998 geotechnical borings in the Buttermilk Channel that were drilled for the feasibility study of the harbor deepening project (USACE, 1999). The USACE borings are listed in Table 2-30.

Table 2-30: Borings and sampling sites in or near the Governors Island site.

Boring ID	Source	Distance from site (feet)
BC-98-24A	USACE 1999	0
GI-14-09 sediment core	e4sciences 2015 for NYCDEP/NYSDEC	0ft, At center of “Y” in pier
GI-14-09 benthic sample	e4sciences 2015 for NYCDEP/NYSDEC	0ft, At center of “Y” in pier
GI-14-09 SPI sample	e4sciences 2015 for NYCDEP/NYSDEC	0ft, At center of “Y” in pier
BC-98-23A	USACE 1999	150
BC-98-22A	USACE 1999	540
BC-98-19	USACE 1999	600
GI-14-08 sediment core	e4sciences 2015 for NYCDEP/NYSDEC	800
GI-14-08 benthic sample	e4sciences 2015 for NYCDEP/NYSDEC	800
GI-14-08 SPI sample	e4sciences 2015 for NYCDEP/NYSDEC	800
BC-98-18	USACE 1999	1300
BC-98-17	USACE 1999	1050

For the last 16 years NYSDEC benthic habitat studies have sampled the sediments and biota just offshore Governors Island (Bell et al. 2000, 2003, 2004a, 2004b; e4sciences, 2015). The latter study was conducted by e4sciences in 2014 and 2015 for NYSDEC and NYCDEP. e4 produced bathymetrical maps and sonar images of the bay floor surrounding Governors Island, and e4 seismically imaged and interpreted the shallow subsurface. Interpretation of the stratigraphy was based on the borings in Table 2.1.1-3. The sonar image map shows that outside the riprap along the shore, the bay floor is mainly sand or sand and gravel locally covered with black silt. On the north end of the



oyster site, rock is exposed in and at the edge of Buttermilk Channel. Overall, the sediment type of the area of the oyster site includes black silt, sand, silty sand, rip rap, and “hard bottom” of man-made debris and exposed bedrock.

At sample site GI-14-09, on the out-board side of the Y-shaped pier at the southwest end of the oyster site, e4 collected a) a sediment core, b) a grab sample for grain size and benthic invertebrate analysis, and c) made sediment profile images (SPI). The analysis of GI-14-09 shows that the grain size of the top 10cm of surface sediment is 1.4 percent gravel, 27.7 percent sand, 50.8 percent silt, and 20.0 percent clay. The GI-14-09 sample site has an intermediate Organism-Sediment Index (OSI) stress level classification, whereas the nearby GI-14-08 sample site, which is southwest of GI-14-09, is considered a stressed site.

According to the U.S. Department of Agriculture’s Natural Resources Conservation Service (USDA-NRCS) SSURGO database[1], the closest land to the proposed oyster site is made up of Urban Land and Laguardia soil types. The Urban land soil type originates from asphalt over human-transported material, the Laguardia type comes from loamy human-transported material (fill). Soil profiles and properties of the two (2) soil types can be found in Tables 2-31 to 2-34. The distribution of the two (2) soil types within the Governors Island oyster site is unmapped.

Table 2-31: Soil profile of Governors Island’s Urban Land soil type, which is located on the coast closest to the offshore proposed oyster restoration site.

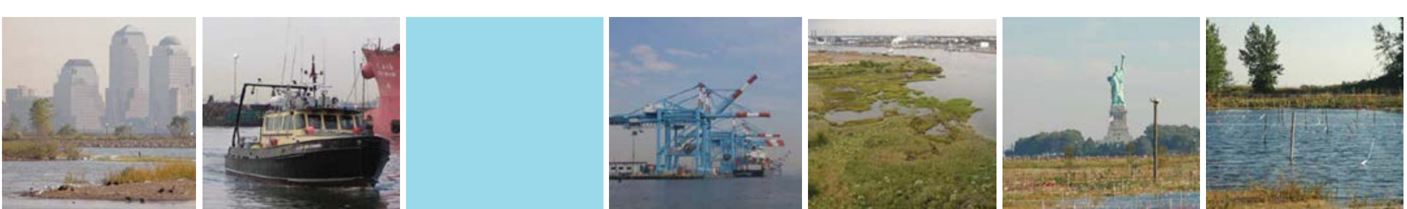
Soil Layer	Depth (inches)	Description
Surface	0-15	Cemented material
Subsurface	15-79	Gravelly sandy loam

Table 2-32: Summary of properties of the urban land soil type located on closest shore of Governors Island to the offshore proposed oyster restoration site.

Property	Description
Slope	0-3%
Available water capacity	Very low (about 0.0 inches)

[1]Information about the types of soil found at the Governors Island oyster site was obtained through the USDA NRCS. The USDA NRCS operates the SSURGO database, which contains soil data covering more than 95 percent of U.S. counties and is produced by the National Cooperative Soil Survey.

The soil information in the SSURGO database was collected by walking over the land and observing the soil, at scales ranging from 1:12,000 to 1:63,360. Soil properties were determined by sample analysis in laboratories, in conjunction with use of the Java Newhall Simulation Model (jNSM) to better understand soil climate. jNSM is a mesoscale model whose output reports consist of soil moisture, temperature regime classification and precipitation/potential evapo-transpiration climographs.



Property	Description
Surface Runoff	Very high
Organic matter content	0.10%
Percent clay	5.00% of clay, silt and sand fraction
Percent sand	70.00% of clay, silt and sand fraction
Percent silt	25.00% of clay, silt and sand fraction

Table 2-33: Soil profile of the Laguardia soil type located on closest shore of Governors Island to the offshore proposed oyster restoration site.

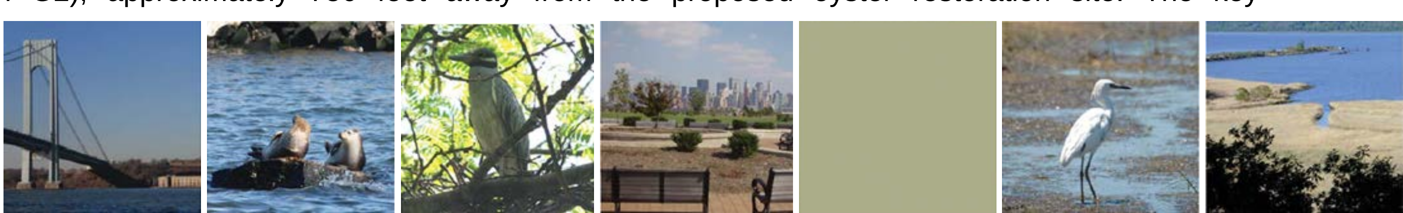
Soil Layer	Depth (inches)	Description
Surface	0-8	Cobbly-artifactual coarse sandy loam
Subsurface	8-79	Very cobbly-artifactual coarse sandy loam

Table 2-34: Summary of properties of the Laguardia soil type located on closest shore of Governors Island to the offshore proposed oyster restoration site.

Property	Description
Natural drainage class	Well drained
Flooding	None
Slope	0-3%
Depth to water table	> 80 inches
Available water capacity	Low (about 3.1 inches)
Surface Runoff	Low
Organic matter content	09.15%
Percent clay	07.60% of clay, silt and sand fraction
Percent sand	75.50% of clay, silt and sand fraction
Percent silt	16.90% of clay, silt and sand fraction

2.4.2.3 Surface water quality data

The Governors Island oyster site is part of the estuarine Upper New York Bay. The New York Harbor Sea, Estuary, Air, and Land (SEALs) Voluntary Environmental Monitoring Program has been measuring water, air, and sediment quality parameters as part of the Upper Hudson River Estuary Water/Air Quality Monitoring Program. One of their monitoring sites is on the eastern shore of Governors Island (station G2), approximately 750 feet away from the proposed oyster restoration site. The key



measurements are listed in Table 2-35. These parameters were measured every few minutes on certain sampling days from February, 2013, to April 2014; the measured values are averaged by month.

Table 2-35: Summary of water quality parameters in February 2013 – April 2014

Date	02/26/13	03/21/13	4/18/13	09/26/13	10/22/13	11/19/13	12/05/13	3/12/14	4/29/14
Acidity (pH)	7.60	6.80	7.0	6.20	6.80	6.20	6.50	7.00	7.03
DO Conc. (ppm)	16.00	14.00	-	8.40	6.90	6.00	8.33	-	-
Temperature (°F)	39.20	44.60	45.50	45.50	66.20	21.80	47.61	-	48.65

Measured on the eastern shore of Governors Island at station G2 by the NY Harbor SEALs Voluntary Environmental Monitoring Program.

2.4.2.4 Groundwater quality data

Governors Island (more specifically Fort Jay) is listed as a state superfund site. Governors Island was used as an active military base for over 200 years, which included a variety of activities of environmental concern (fuel storage, maintenance, etc.). A subsurface investigation conducted in 2011 identified heavy metals, semi-volatile organic compounds (SVOC's), pesticides, polychlorinated biphenyls (PCBs) and residual petroleum. In addition, there remains the possibility of unexploded ordnance (UXO) both on land and in the waters surrounding Governors Island, which is described in the "Proposed Phased Redevelopment of Governors Island" (2011). However, this study does not mention specific environmental testing performed on the study area.

2.4.3 Bush Terminal Oyster Restoration Site

2.4.3.1 Geotechnical

The Bush Terminal oyster restoration site includes pier ruins between the Bay Ridge Channel and the re-purposed Bush Terminal Pier Park. Bedrock (Hartland Formation) is greater than 120feet deep. Overlying the rock is a thick sequence of Pleistocene sediments dominated by glacial lake clay and silt. This is overlain by Holocene sands and Holocene black silt. The surface of Bush Terminal Piers Park is made up of the Laguardia soil unit, which is an artifactual coarse sandy loam (fill).

2.4.4 Soundview Park Oyster Restoration Site

2.4.4.1 Geotechnical

The Soundview Park oyster restoration site is part of the Bronx sub-watershed within the larger Atlantic Ocean/Long Island Sound watershed system. The site is underlain by shallow bedrock composed of schist (Hartland formation). This is overlain by Holocene estuarine sands and silts. The land surface of Soundview Park is made up of the Laguardia soil unit.

2.4.5 Head of Bay Oyster Restoration Site

2.4.5.1 Geotechnical

The Head of Bay oyster restoration site is part of the Hook Creek-Head of Bay sub-watershed within the larger Jamaica Bay watershed system. The site is adjacent to JFK International Airport where construction started in the 1940s. The site is underlain by estuarine sands and over 100-foot-thick glacial-outwash deposits, which are on top of older Pleistocene sediments and Cretaceous Coastal Plain Sediments. The top of crystalline rock is over 600feet deep. The surface of the Queens County north shore of Jamaica Bay in the Head of Bay area is made up of the Jamaica sand soil unit.

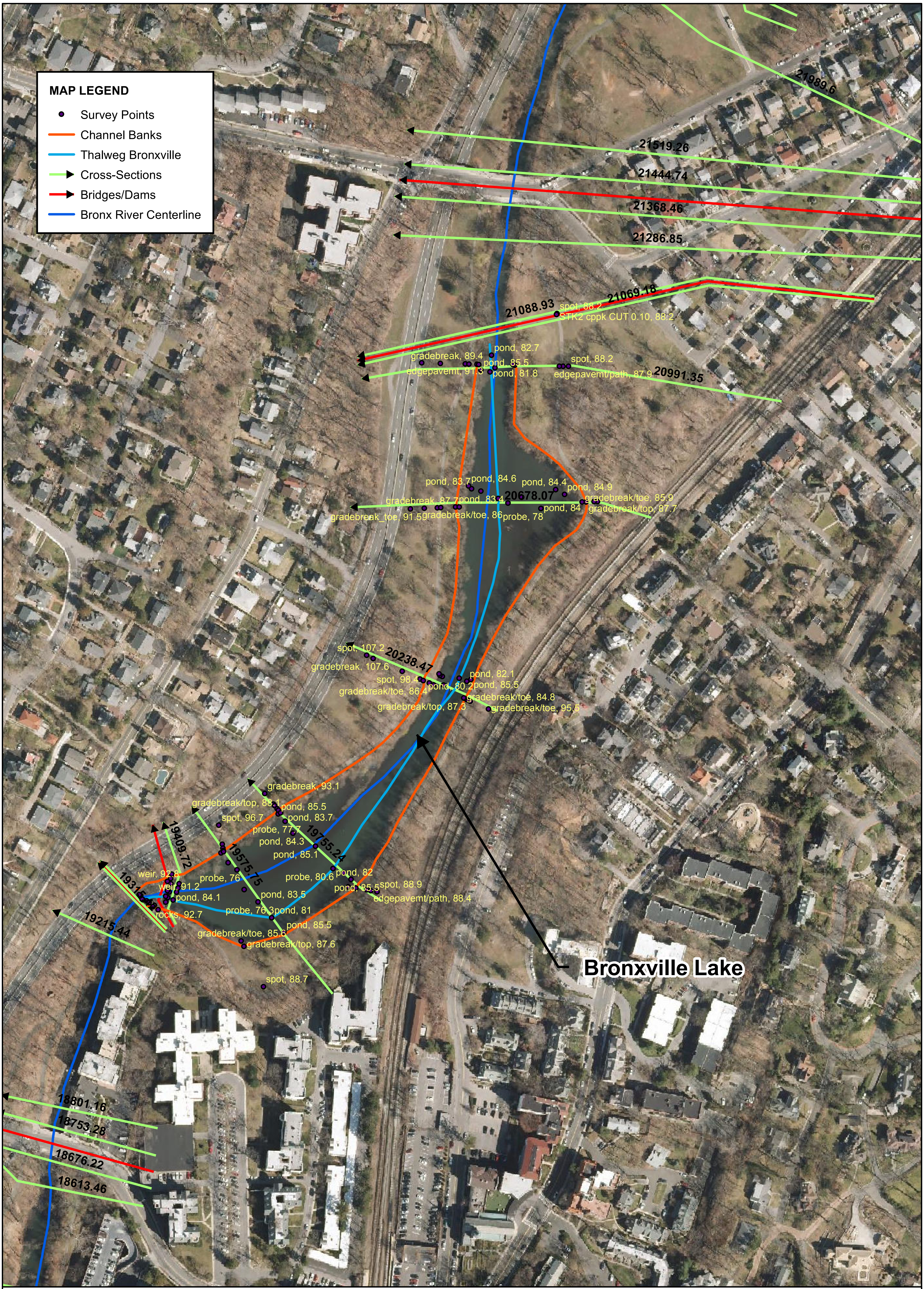
2.4.6 Naval Weapons Station Earle Oyster Restoration Site

2.4.6.1 Geotechnical

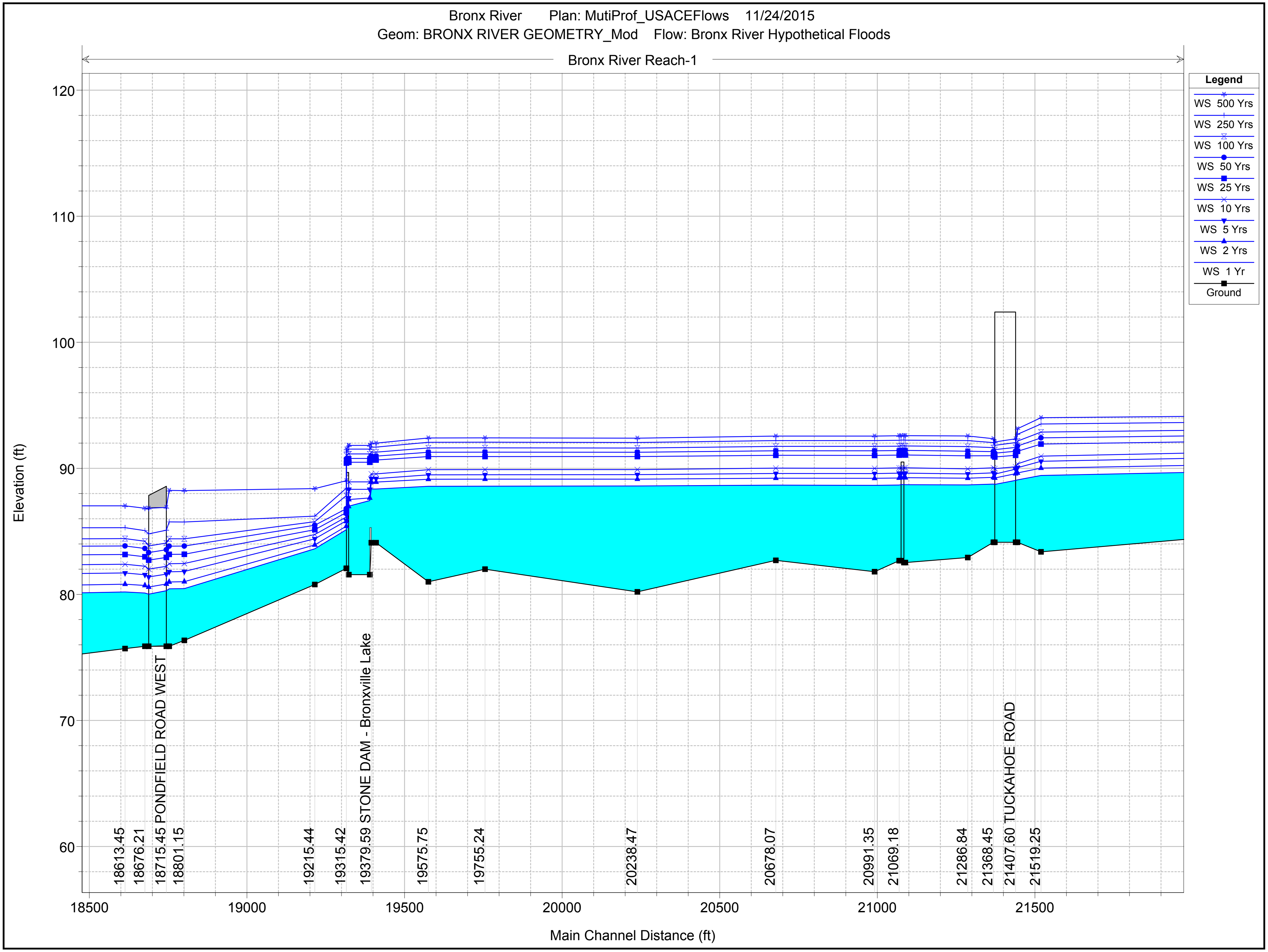
The Naval Weapons Station Earle oyster habitat restoration site is part of the Sandy Hook-Staten Island sub-watershed within the larger Monmouth watershed system. The site is underlain by the Cretaceous Coastal Group sand, silt and clay.

Attachment A
Bronx River Hydrologic and Hydraulic Analysis

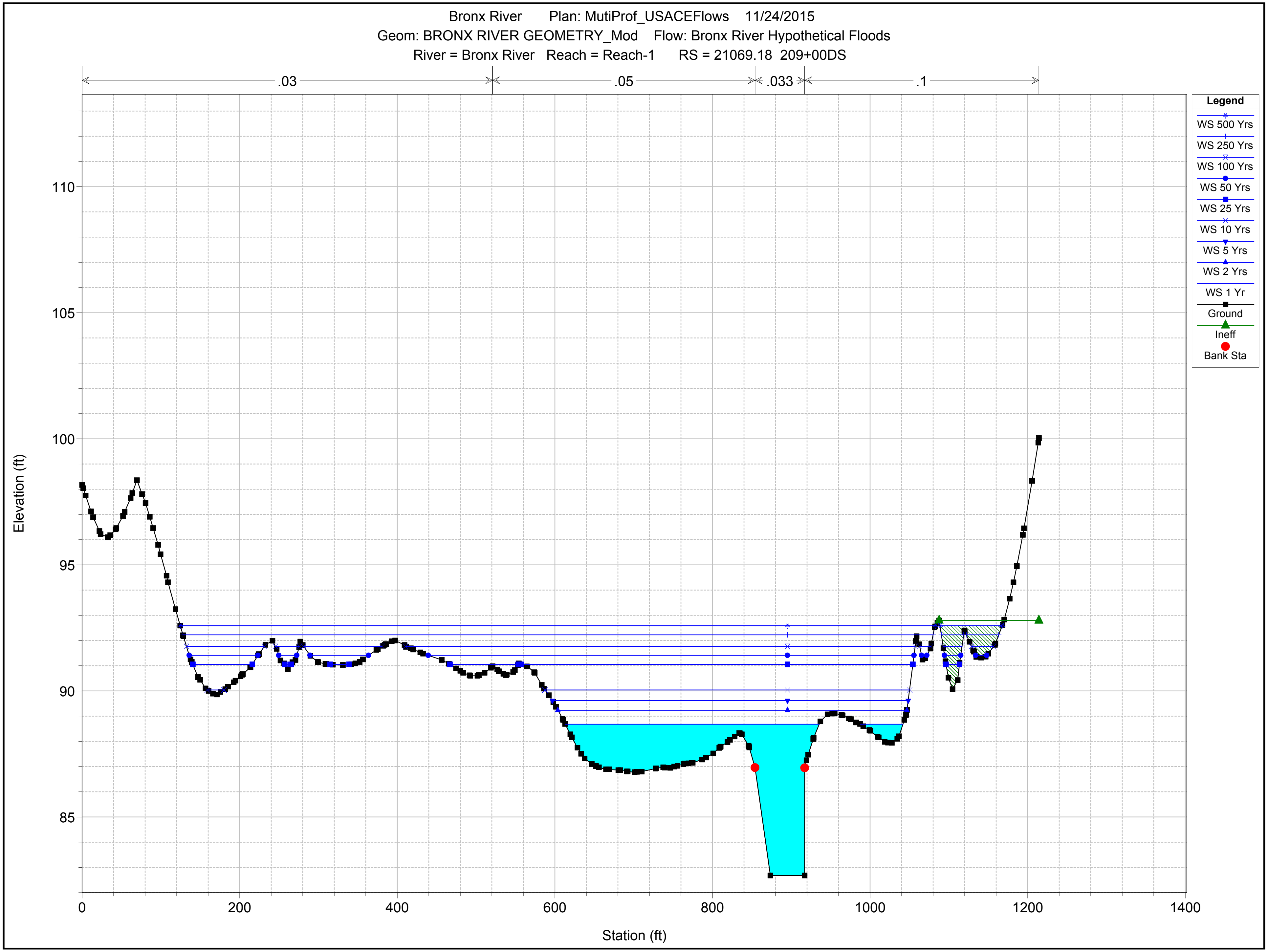
Bronxville Lake



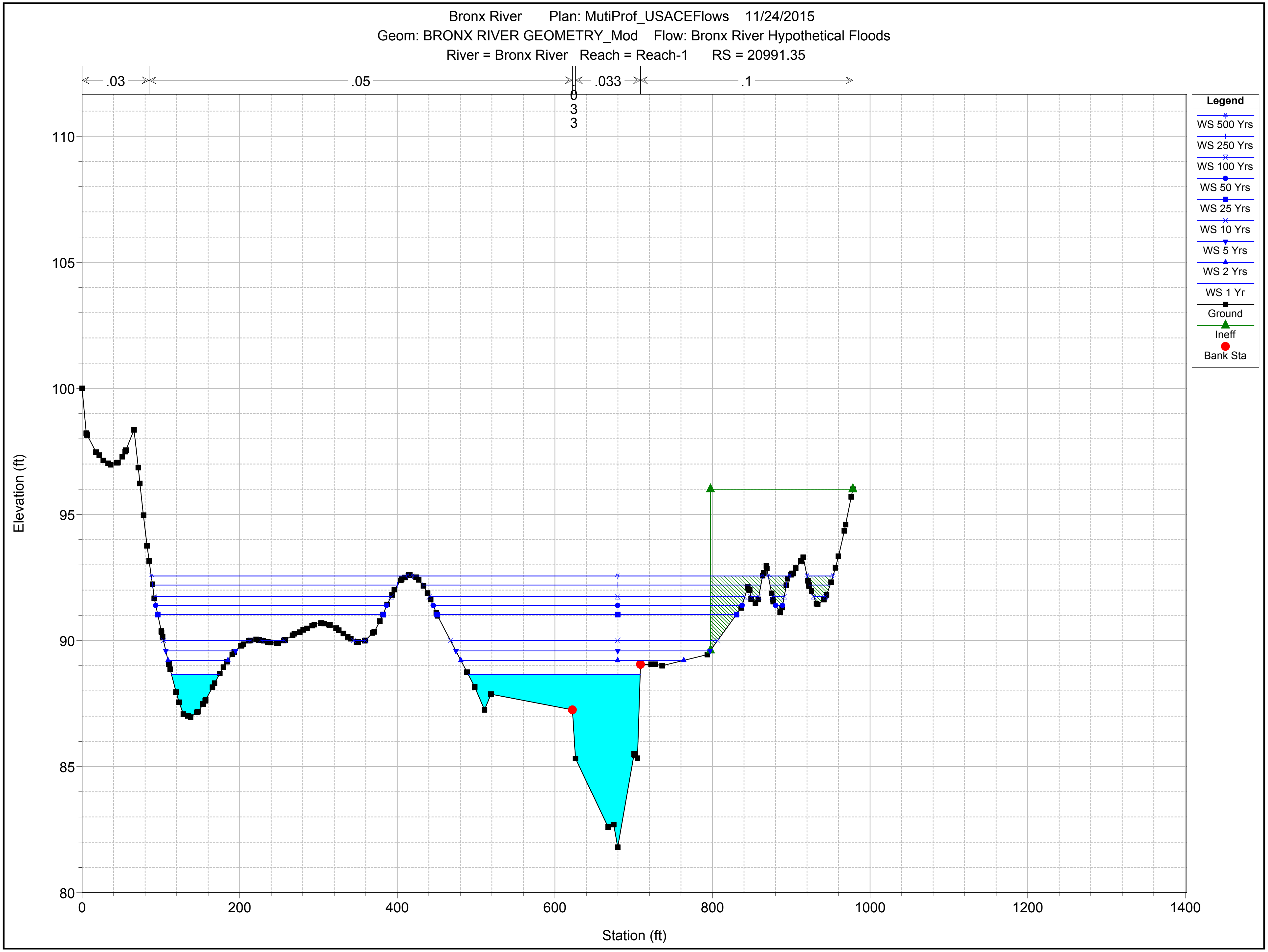
CROSS-SECTION LOCATION MAP - BRONXVILLE LAKE



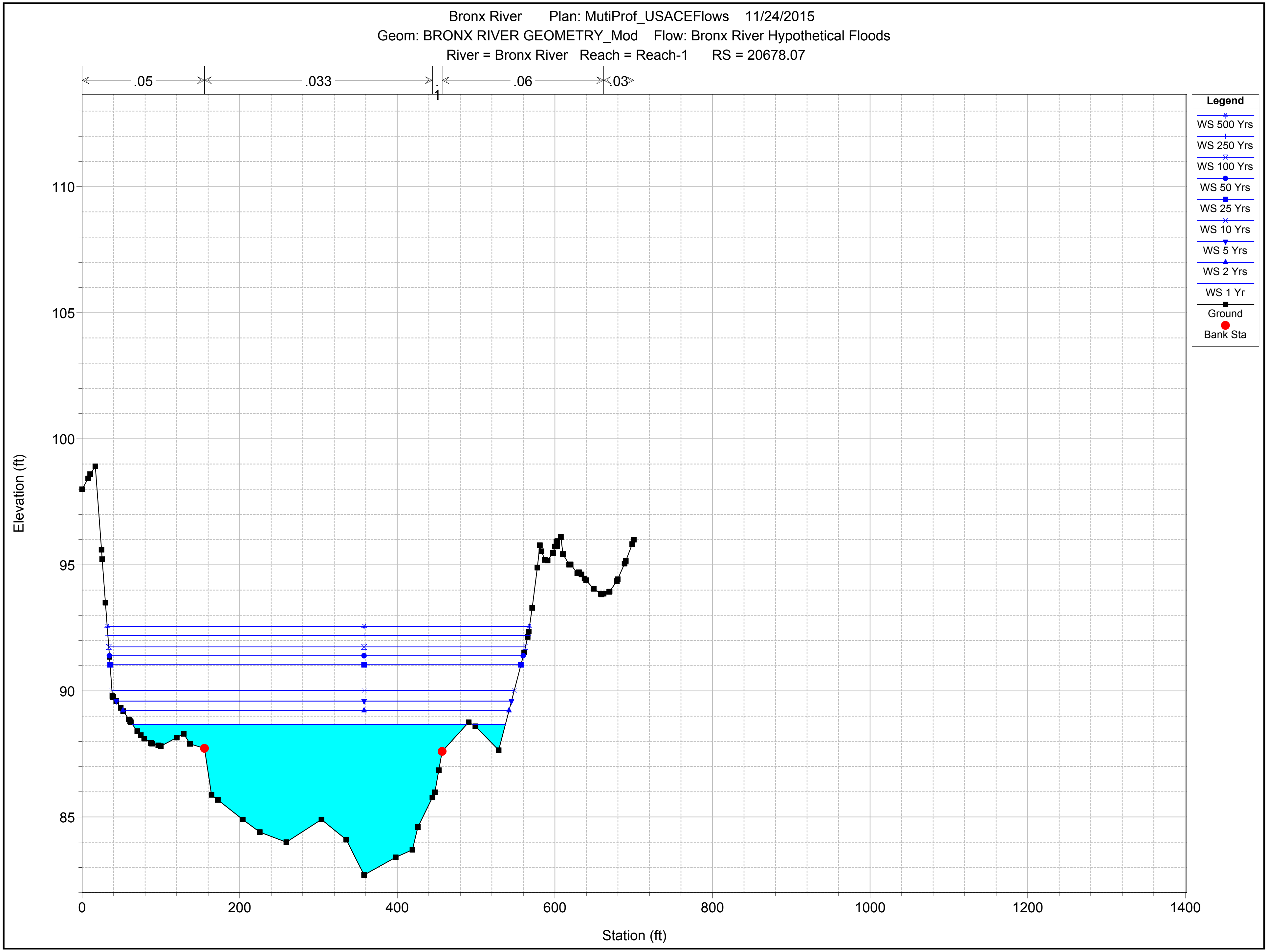
1 in Horiz. = 400 ft 1 in Vert. = 10 ft



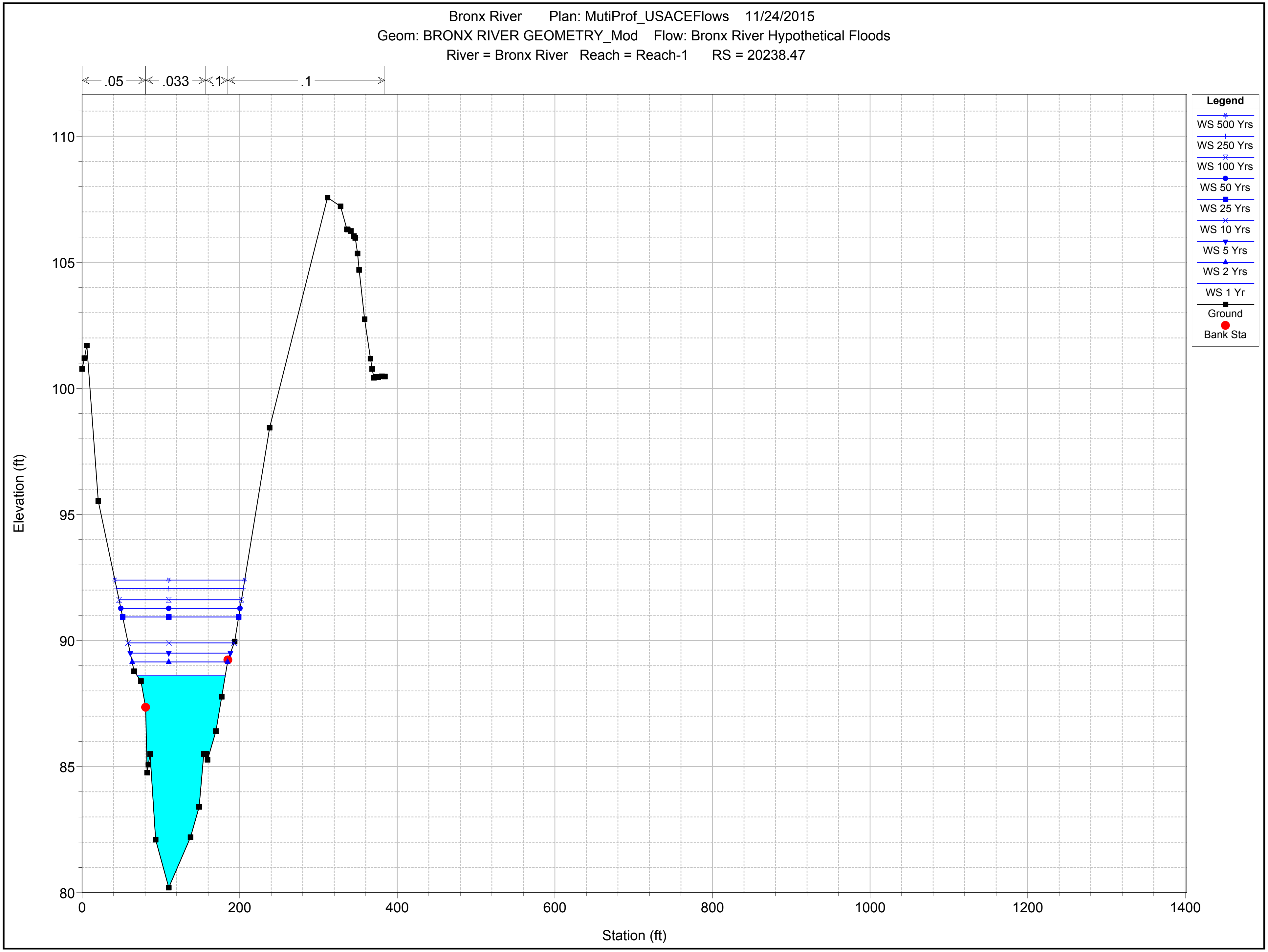
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



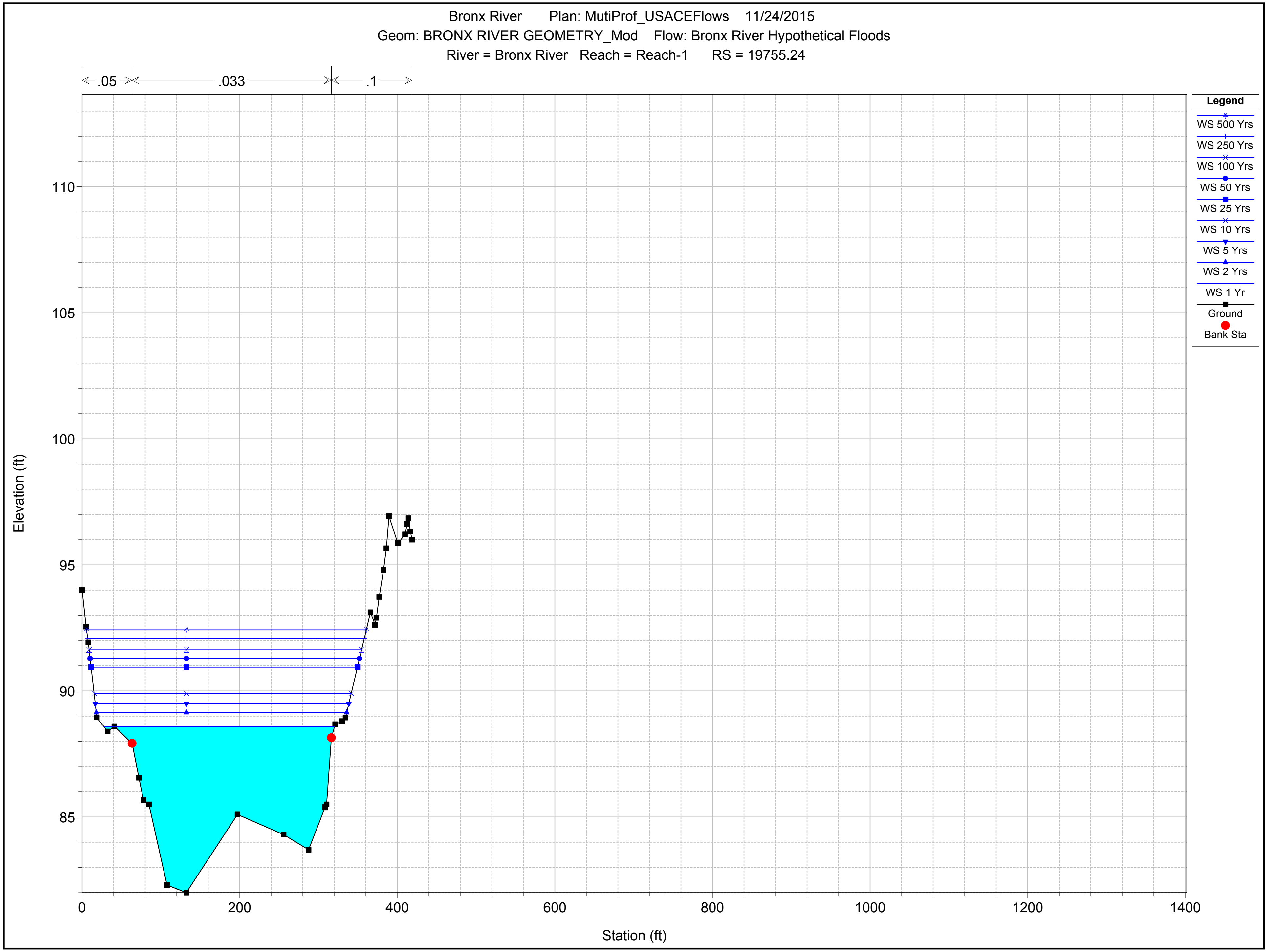
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



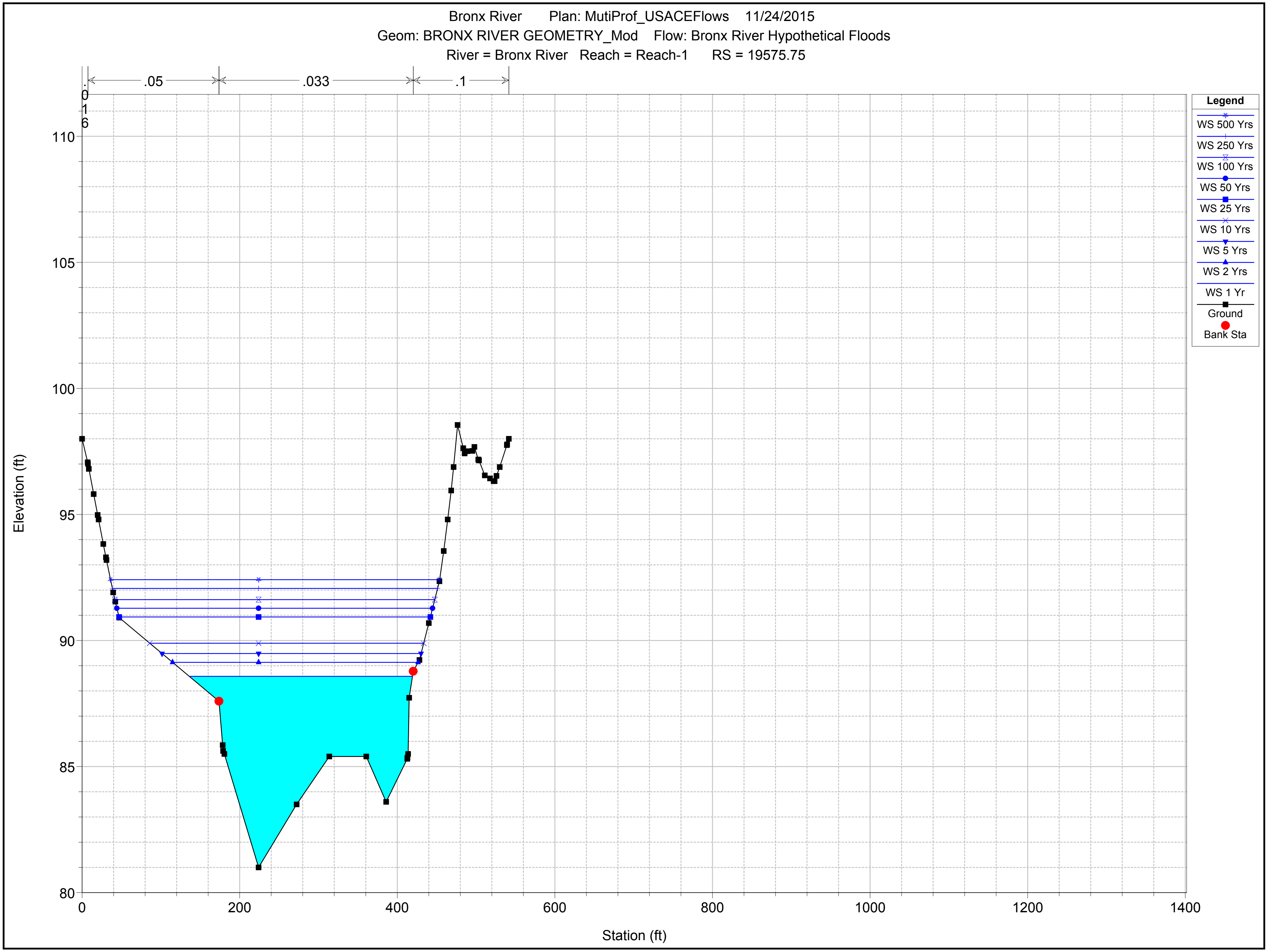
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



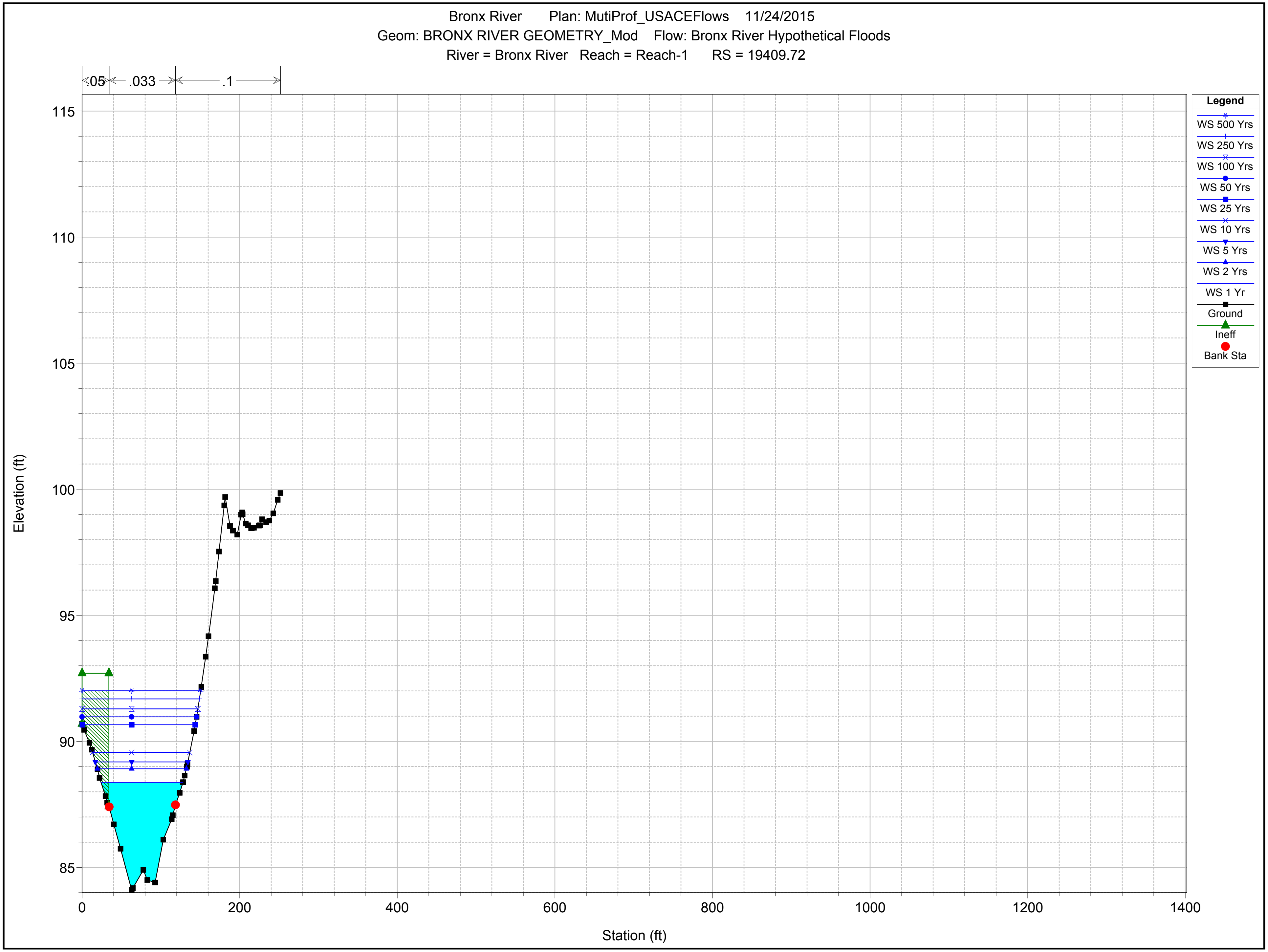
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



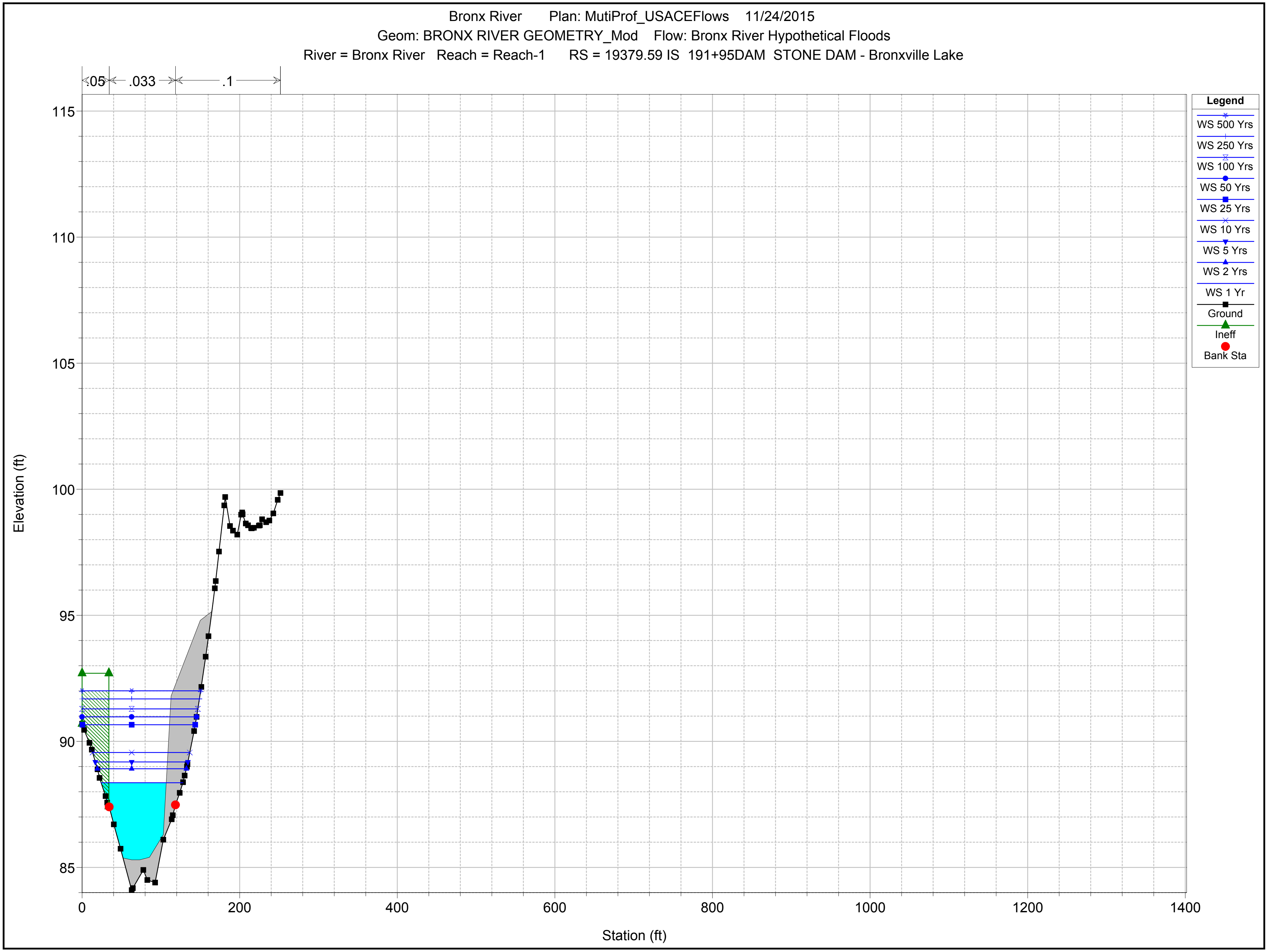
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



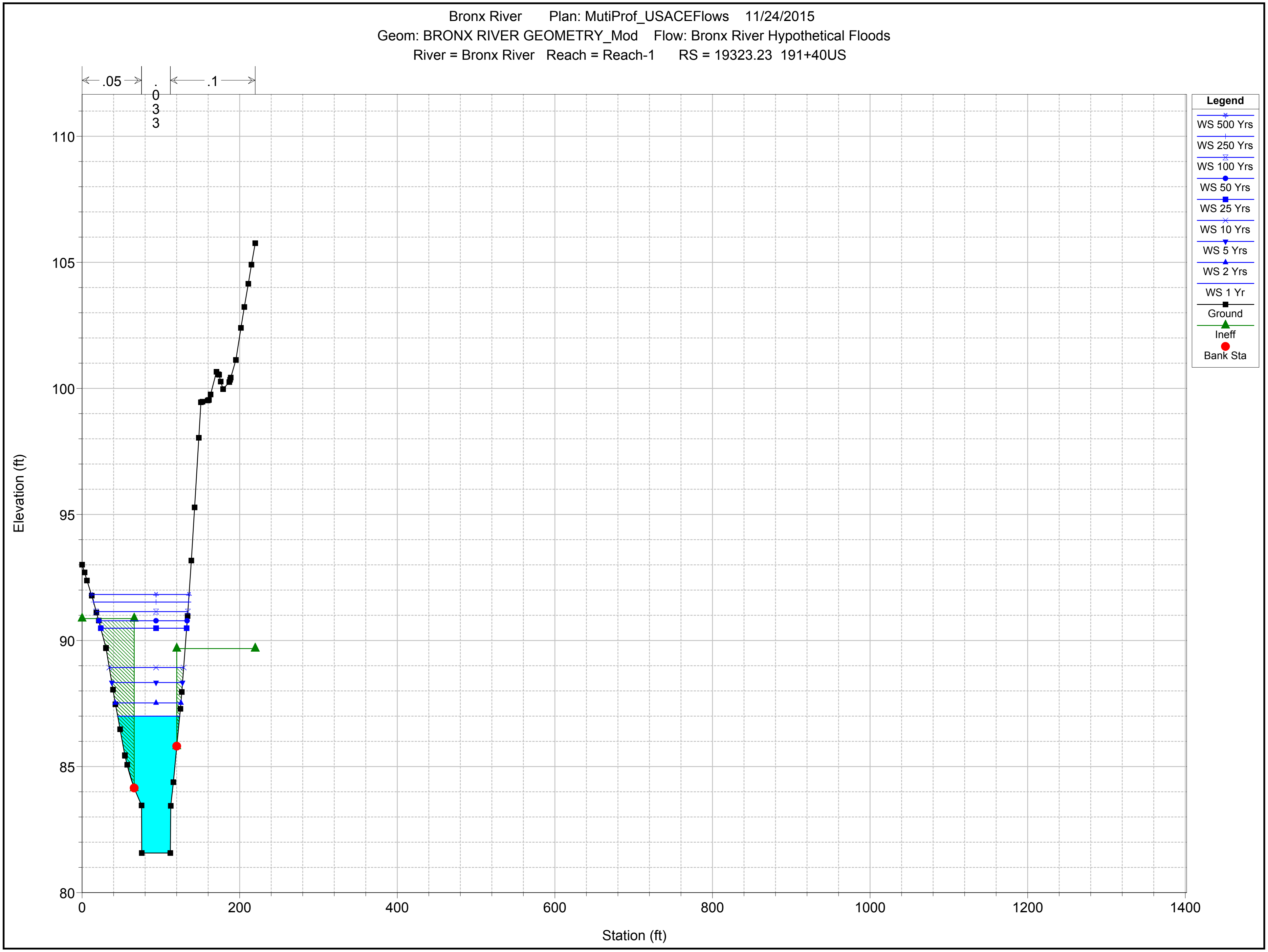
1 in Horiz. = 160 ft 1 in Vert. = 5 ft



1 in Horiz. = 160 ft 1 in Vert. = 5 ft



1 in Horiz. = 160 ft 1 in Vert. = 5 ft



1 in Horiz. = 160 ft 1 in Vert. = 5 ft

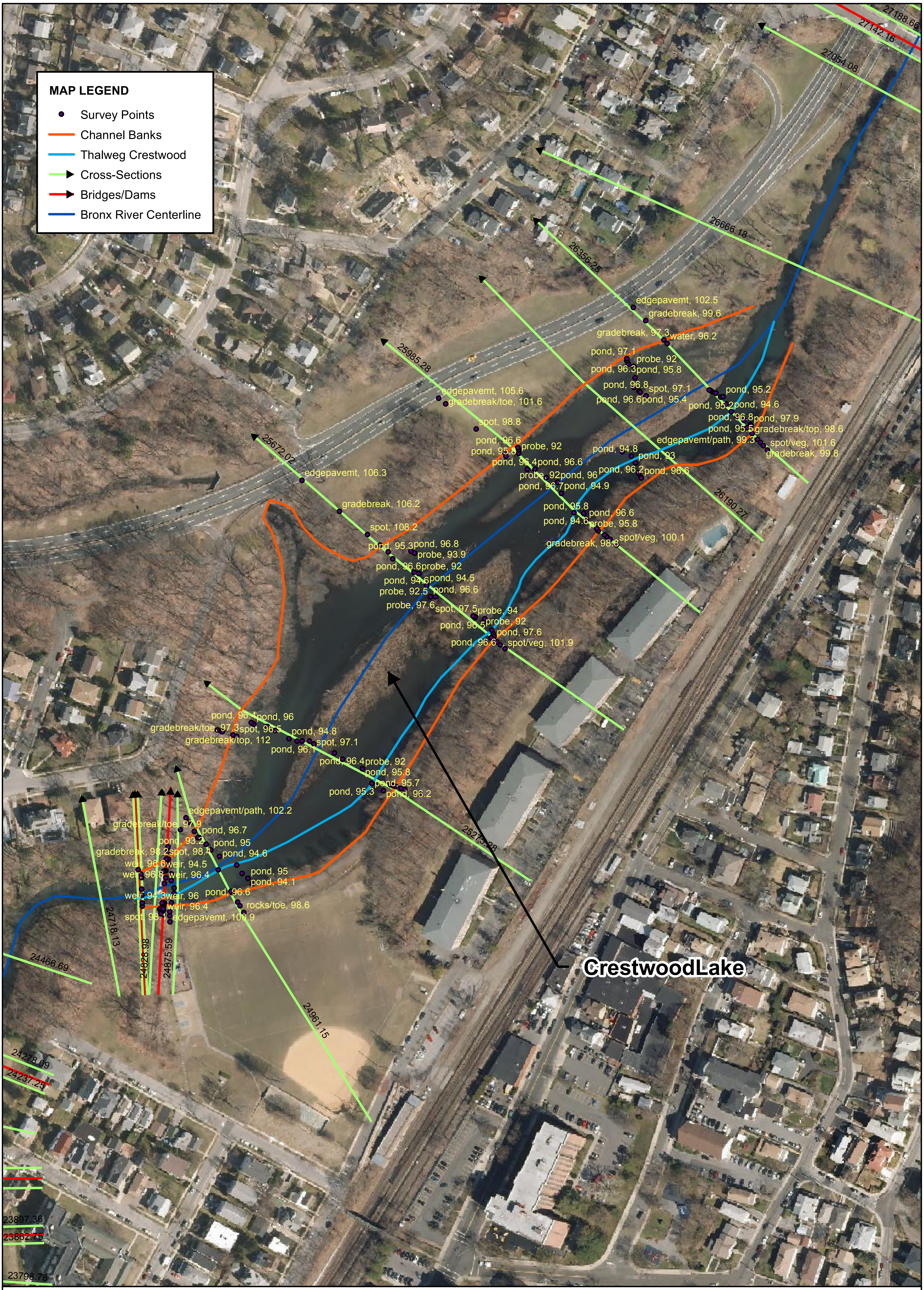
HEC-RAS Plan: Multi_USACE River: Bronx River Reach: Reach-1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	21069.18 209+00DS	1 Yr	870.00	82.68	88.68	6.00	1.23	2.01	376.11	706.72	336.37
Reach-1	21069.18 209+00DS	2 Yrs	1040.00	82.68	89.23	6.55	1.11	1.96	442.97	935.30	371.46
Reach-1	21069.18 209+00DS	5 Yrs	1320.00	82.68	89.62	6.94	1.19	2.18	451.58	1106.27	395.56
Reach-1	21069.18 209+00DS	10 Yrs	1540.00	82.68	90.04	7.36	1.18	2.22	483.75	1301.12	422.13
Reach-1	21069.18 209+00DS	25 Yrs	1800.00	82.68	91.03	8.35	2.85	3.33	110.69	632.06	484.48
Reach-1	21069.18 209+00DS	50 Yrs	2040.00	82.68	91.41	8.73	0.96	2.00	842.08	2133.16	508.62
Reach-1	21069.18 209+00DS	100 Yrs	2260.00	82.68	91.76	9.08	0.93	1.97	941.15	2432.75	530.87
Reach-1	21069.18 209+00DS	250 Yrs	2590.00	82.68	92.22	9.54	0.91	1.95	1021.48	2861.36	559.86
Reach-1	21069.18 209+00DS	500 Yrs	2840.00	82.68	92.58	9.90	0.89	1.89	1037.50	3205.07	582.54
Reach-1	20991.35	1 Yr	870.00	81.80	88.66	6.86	1.44	1.93	278.86	602.61	402.93
Reach-1	20991.35	2 Yrs	1040.00	81.80	89.21	7.41	1.35	1.92	359.04	771.72	450.79
Reach-1	20991.35	5 Yrs	1320.00	81.80	89.59	7.79	1.44	2.18	410.99	917.67	483.16
Reach-1	20991.35	10 Yrs	1540.00	81.80	90.01	8.21	1.40	2.25	495.26	1098.52	519.42
Reach-1	20991.35	25 Yrs	1800.00	81.80	91.07	9.27	1.05	1.94	668.16	1714.04	611.15
Reach-1	20991.35	50 Yrs	2040.00	81.80	91.39	9.59	1.06	2.00	693.56	1920.66	639.05
Reach-1	20991.35	100 Yrs	2260.00	81.80	91.74	9.94	1.05	2.01	741.93	2149.86	669.45
Reach-1	20991.35	250 Yrs	2590.00	81.80	92.20	10.40	1.05	2.04	787.84	2455.02	709.00
Reach-1	20991.35	500 Yrs	2840.00	81.80	92.56	10.76	1.05	2.06	829.04	2700.36	739.87
Reach-1	20678.07	1 Yr	870.00	82.70	88.67	5.97	0.63	0.67	465.48	1371.93	1277.03
Reach-1	20678.07	2 Yrs	1040.00	82.70	89.22	6.52	0.63	0.70	490.08	1638.78	1444.29
Reach-1	20678.07	5 Yrs	1320.00	82.70	89.60	6.90	0.72	0.81	501.57	1825.67	1557.92
Reach-1	20678.07	10 Yrs	1540.00	82.70	90.02	7.32	0.76	0.86	510.49	2038.56	1684.47
Reach-1	20678.07	25 Yrs	1800.00	82.70	91.07	8.37	0.70	0.82	521.78	2583.61	2002.86
Reach-1	20678.07	50 Yrs	2040.00	82.70	91.39	8.69	0.74	0.88	525.22	2752.02	2099.85
Reach-1	20678.07	100 Yrs	2260.00	82.70	91.74	9.04	0.77	0.92	528.77	2936.69	2205.50
Reach-1	20678.07	250 Yrs	2590.00	82.70	92.20	9.50	0.81	0.98	533.11	3178.94	2343.05
Reach-1	20678.07	500 Yrs	2840.00	82.70	92.56	9.86	0.84	1.01	535.80	3369.45	2450.51
Reach-1	20238.47	1 Yr	870.00	80.20	88.60	8.40	1.64	1.65	111.68	530.18	525.36
Reach-1	20238.47	2 Yrs	1040.00	80.20	89.15	8.95	1.75	1.78	121.14	594.59	581.65
Reach-1	20238.47	5 Yrs	1320.00	80.20	89.50	9.30	2.07	2.12	127.05	638.01	618.25
Reach-1	20238.47	10 Yrs	1540.00	80.20	89.90	9.70	2.23	2.31	134.46	691.05	660.63
Reach-1	20238.47	25 Yrs	1800.00	80.20	90.97	10.77	2.14	2.28	147.59	841.53	772.00
Reach-1	20238.47	50 Yrs	2040.00	80.20	91.28	11.08	2.30	2.47	151.25	887.23	803.96
Reach-1	20238.47	100 Yrs	2260.00	80.20	91.62	11.42	2.41	2.61	155.31	939.19	839.38
Reach-1	20238.47	250 Yrs	2590.00	80.20	92.05	11.85	2.57	2.82	160.56	1008.32	885.12
Reach-1	20238.47	500 Yrs	2840.00	80.20	92.40	12.20	2.67	2.96	164.68	1064.29	921.08
Reach-1	19755.24	1 Yr	870.00	82.00	88.59	6.59	0.77	0.78	291.98	1123.50	1113.89
Reach-1	19755.24	2 Yrs	1040.00	82.00	89.14	7.14	0.80	0.83	317.87	1294.08	1253.78

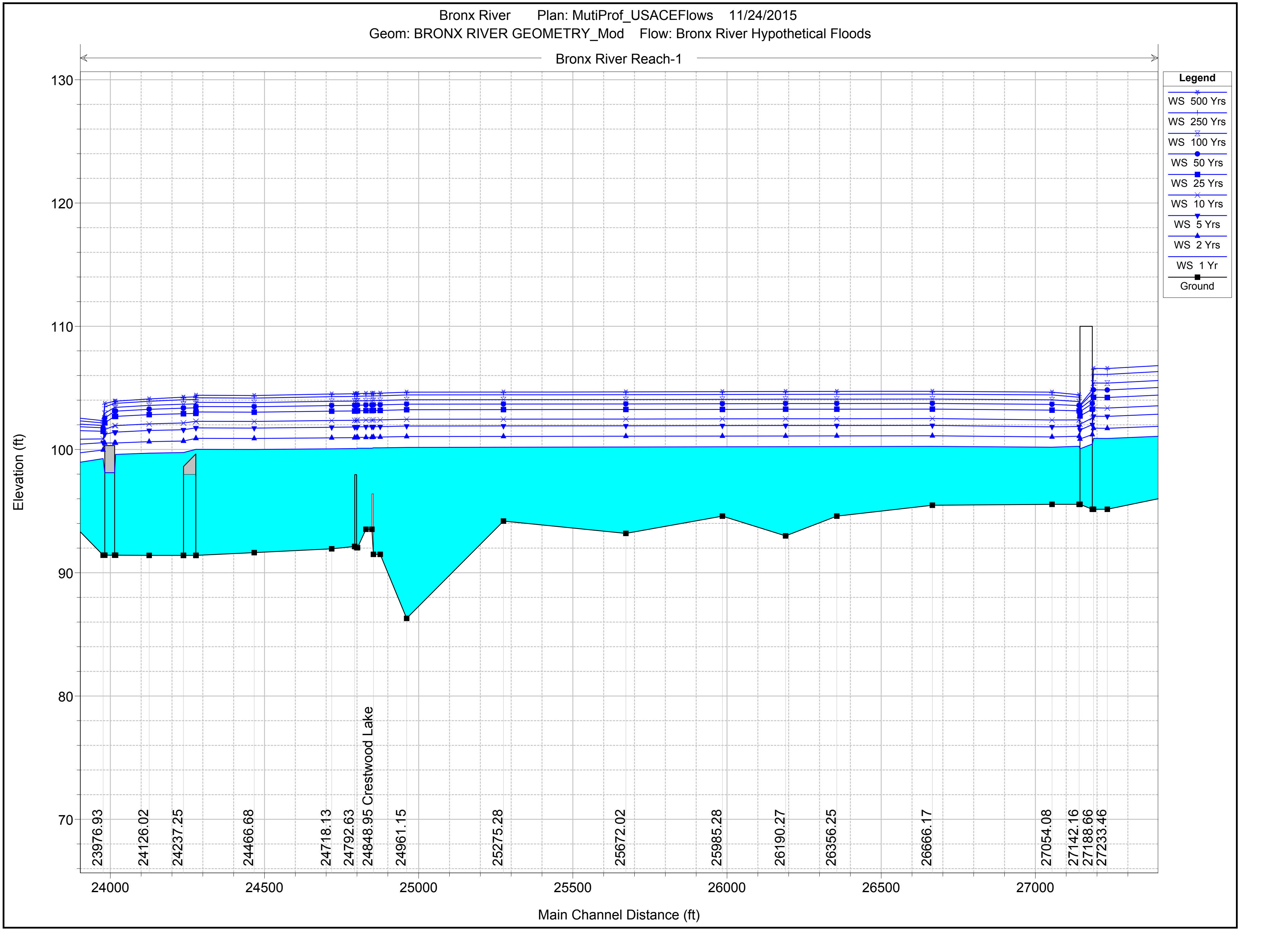
HEC-RAS Plan: Multi_USACE   River: Bronx River   Reach: Reach-1 (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	19755.24	5 Yrs	1320.00	82.00	89.49	7.49	0.94	0.97	321.82	1406.59	1342.76
Reach-1	19755.24	10 Yrs	1540.00	82.00	89.90	7.90	1.00	1.05	326.41	1539.33	1446.36
Reach-1	19755.24	25 Yrs	1800.00	82.00	90.98	8.98	0.95	1.02	338.47	1896.77	1718.34
Reach-1	19755.24	50 Yrs	2040.00	82.00	91.29	9.29	1.02	1.10	341.94	2002.12	1796.67
Reach-1	19755.24	100 Yrs	2260.00	82.00	91.63	9.63	1.07	1.16	345.79	2120.02	1883.41
Reach-1	19755.24	250 Yrs	2590.00	82.00	92.07	10.07	1.14	1.25	350.87	2274.53	1995.62
Reach-1	19755.24	500 Yrs	2840.00	82.00	92.42	10.42	1.18	1.31	355.01	2397.61	2083.84
Reach-1	19575.75	1 Yr	870.00	81.00	88.58	7.58	0.78	0.79	283.35	1112.88	1094.16
Reach-1	19575.75	2 Yrs	1040.00	81.00	89.13	8.13	0.81	0.84	311.61	1277.04	1230.47
Reach-1	19575.75	5 Yrs	1320.00	81.00	89.48	8.48	0.95	0.99	328.69	1389.07	1316.66
Reach-1	19575.75	10 Yrs	1540.00	81.00	89.89	8.89	1.01	1.07	347.63	1527.37	1417.49
Reach-1	19575.75	25 Yrs	1800.00	81.00	90.97	9.97	0.93	1.03	395.71	1928.97	1683.26
Reach-1	19575.75	50 Yrs	2040.00	81.00	91.28	10.28	0.99	1.11	400.64	2052.06	1759.47
Reach-1	19575.75	100 Yrs	2260.00	81.00	91.62	10.62	1.03	1.16	406.05	2190.32	1843.98
Reach-1	19575.75	250 Yrs	2590.00	81.00	92.07	11.07	1.09	1.25	412.70	2371.81	1953.27
Reach-1	19575.75	500 Yrs	2840.00	81.00	92.41	11.41	1.13	1.30	417.64	2516.61	2039.24
Reach-1	19409.72	1 Yr	870.00	84.10	88.36	4.26	3.47	3.52	103.81	251.00	246.36
Reach-1	19409.72	2 Yrs	1040.00	84.10	88.91	4.81	3.42	3.53	113.07	304.45	293.09
Reach-1	19409.72	5 Yrs	1320.00	84.10	89.18	5.08	3.99	4.15	117.45	331.09	315.63
Reach-1	19409.72	10 Yrs	1540.00	84.10	89.56	5.46	4.17	4.39	123.36	369.34	347.31
Reach-1	19409.72	25 Yrs	1800.00	84.10	90.70	6.60	3.67	3.99	143.81	490.93	443.44
Reach-1	19409.72	50 Yrs	2040.00	84.10	90.97	6.87	3.92	4.29	145.32	520.61	466.01
Reach-1	19409.72	100 Yrs	2260.00	84.10	91.29	7.19	4.06	4.49	146.91	556.05	492.59
Reach-1	19409.72	250 Yrs	2590.00	84.10	91.68	7.58	4.31	4.80	148.91	601.32	526.01
Reach-1	19409.72	500 Yrs	2840.00	84.10	92.00	7.90	4.45	4.99	150.51	638.24	552.84
Reach-1	19379.59 191+95DAM		Inl Struct								
Reach-1	19323.23 191+40US	1 Yr	870.00	81.57	87.00	5.43	3.50	3.50	78.81	248.87	248.87
Reach-1	19323.23 191+40US	2 Yrs	1040.00	81.57	87.53	5.96	3.75	3.75	83.48	277.37	277.37
Reach-1	19323.23 191+40US	5 Yrs	1320.00	81.57	88.33	6.76	4.11	4.11	89.74	320.98	320.98
Reach-1	19323.23 191+40US	10 Yrs	1540.00	81.57	88.93	7.36	4.36	4.36	94.42	353.30	353.30
Reach-1	19323.23 191+40US	25 Yrs	1800.00	81.57	90.53	8.96	4.09	4.09	54.11	439.88	439.88
Reach-1	19323.23 191+40US	50 Yrs	2040.00	81.57	90.78	9.21	4.18	4.42	112.07	488.27	453.55
Reach-1	19323.23 191+40US	100 Yrs	2260.00	81.57	91.14	9.57	3.31	3.90	116.35	683.37	473.13
Reach-1	19323.23 191+40US	250 Yrs	2590.00	81.57	91.53	9.96	3.55	4.23	120.56	728.58	493.78
Reach-1	19323.23 191+40US	500 Yrs	2840.00	81.57	91.82	10.25	3.71	4.45	123.90	764.95	509.88

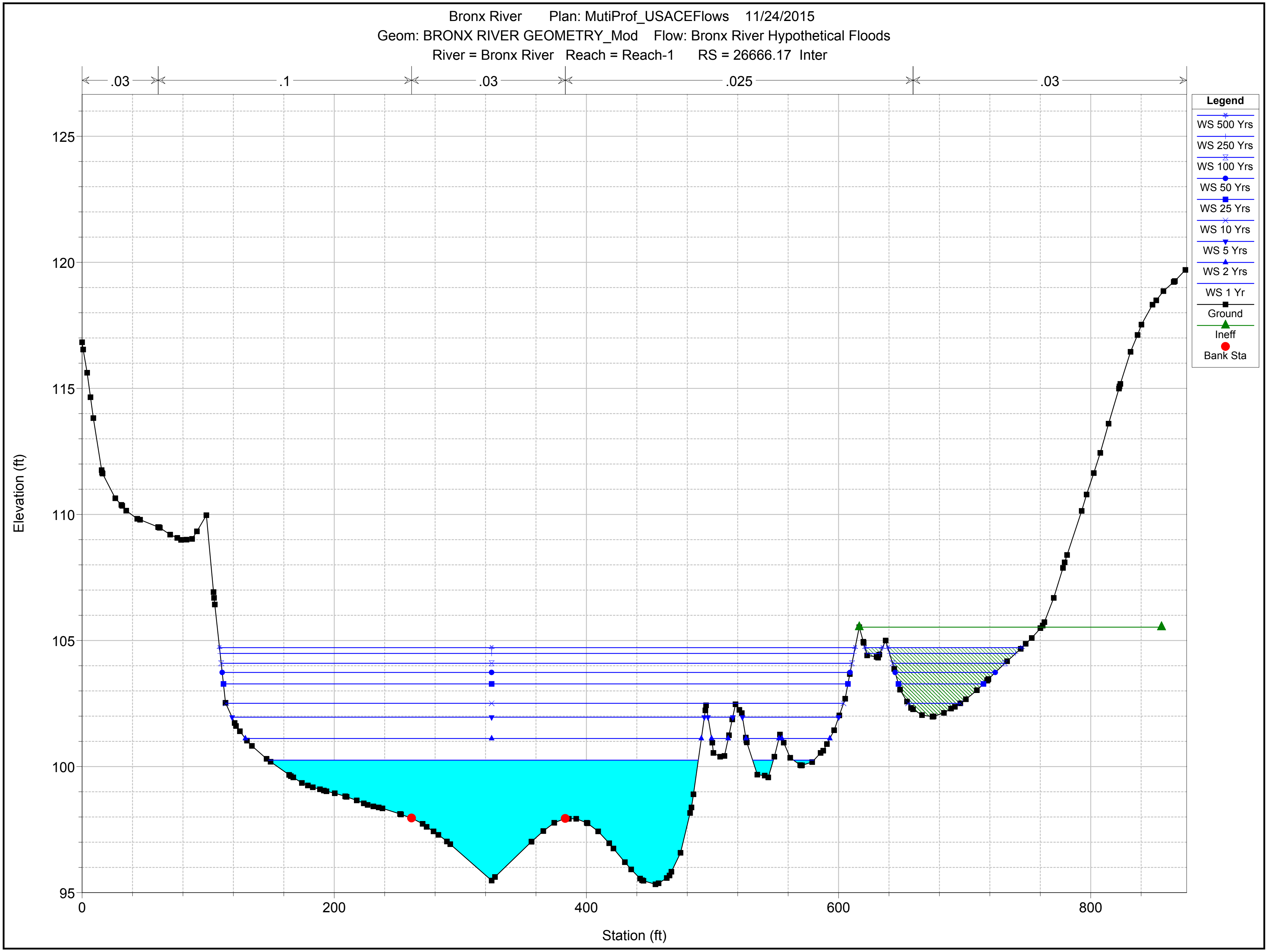
Crestwood Lake



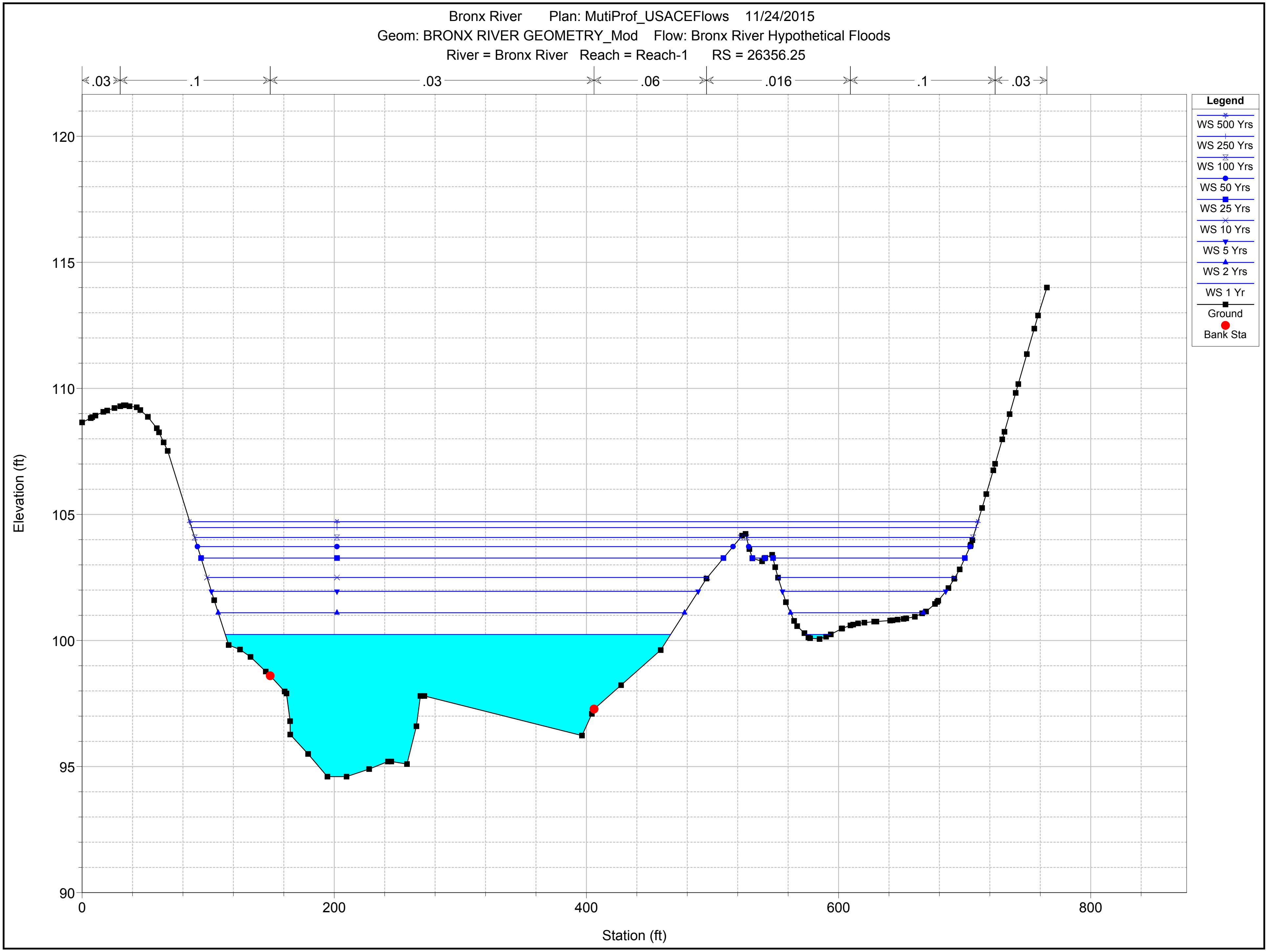
CROSS-SECTION LOCATION MAP - CRESTWOOD LAKE



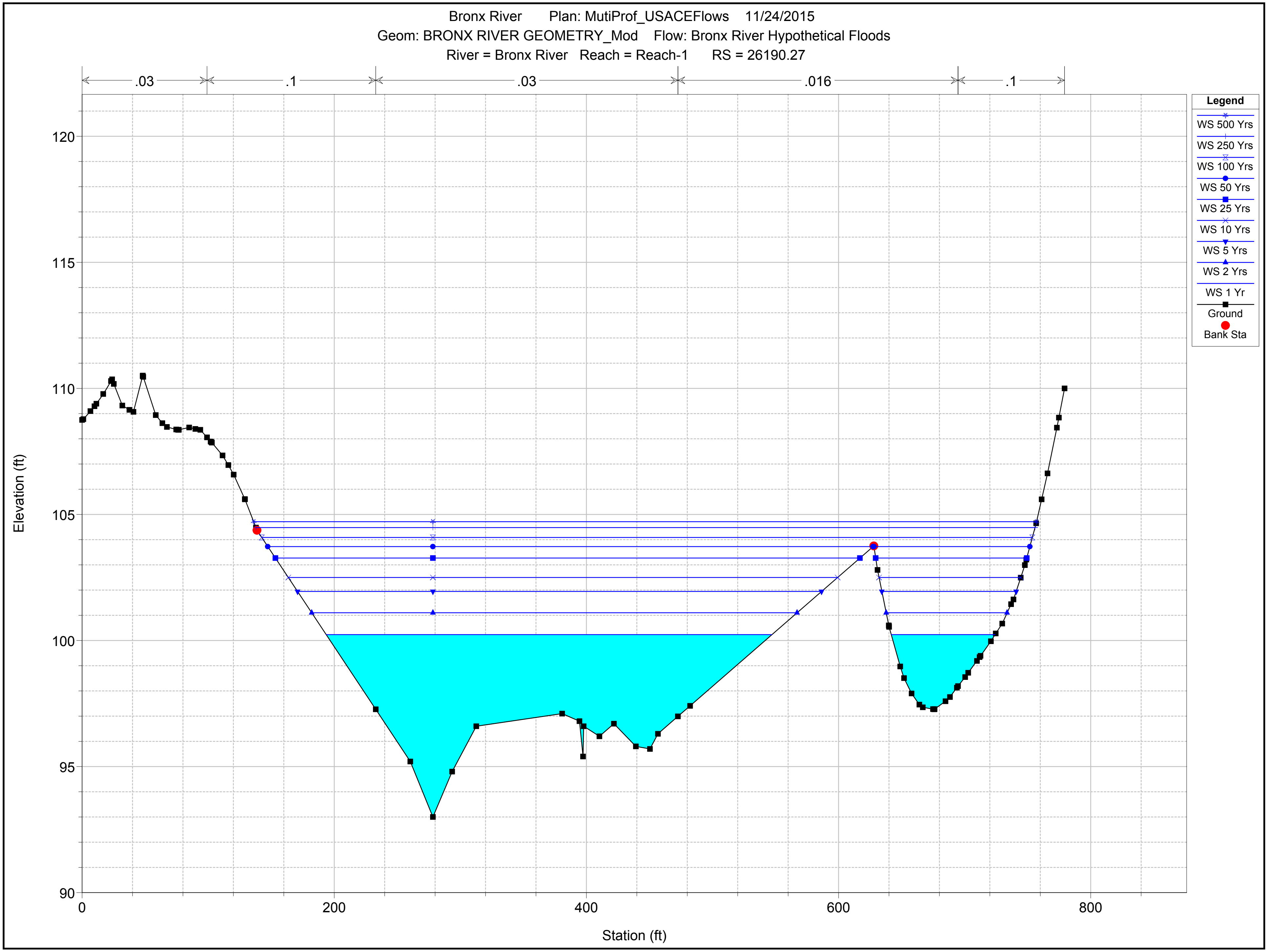
1 in Horiz. = 400 ft 1 in Vert. = 10 ft



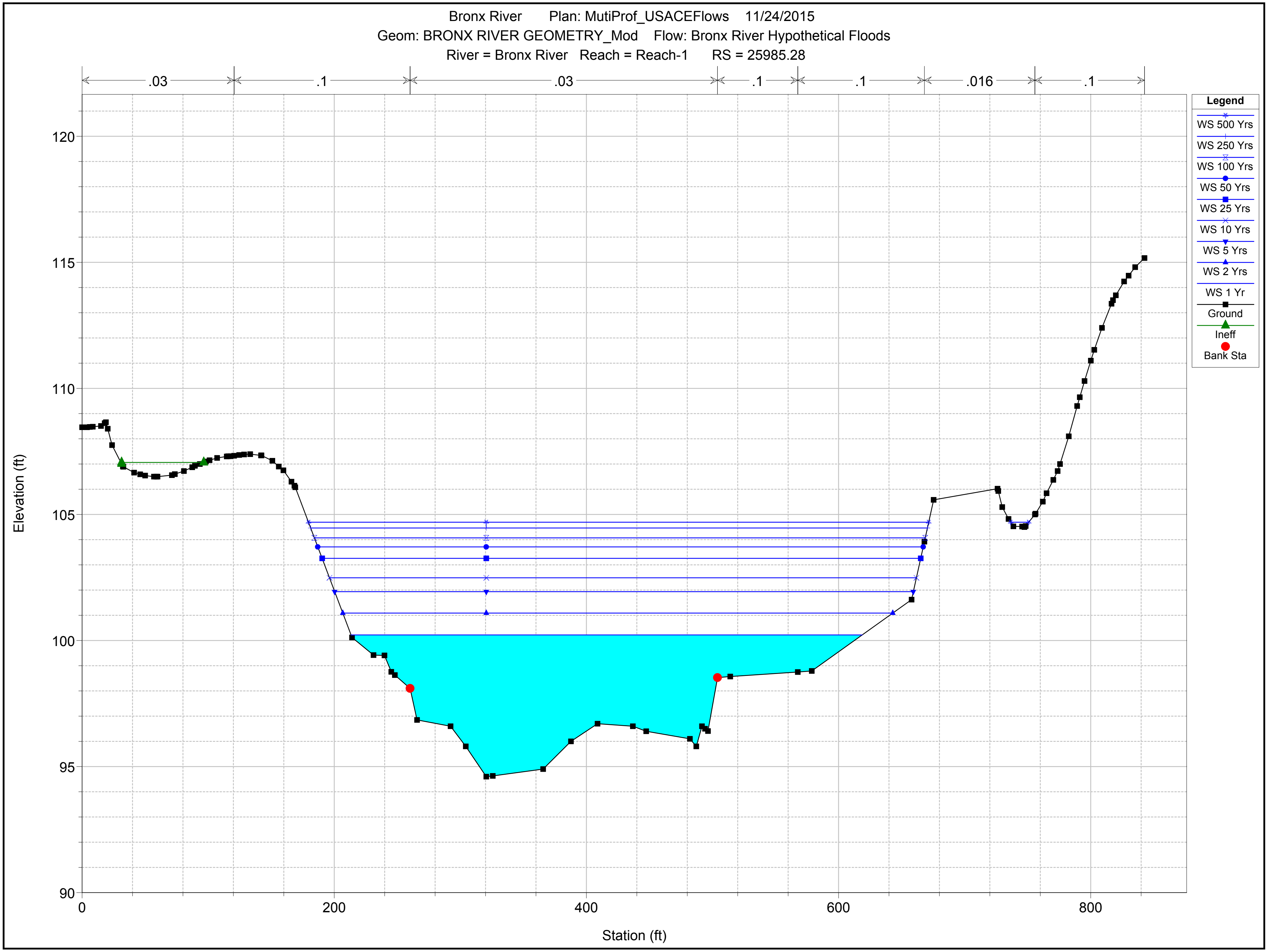
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



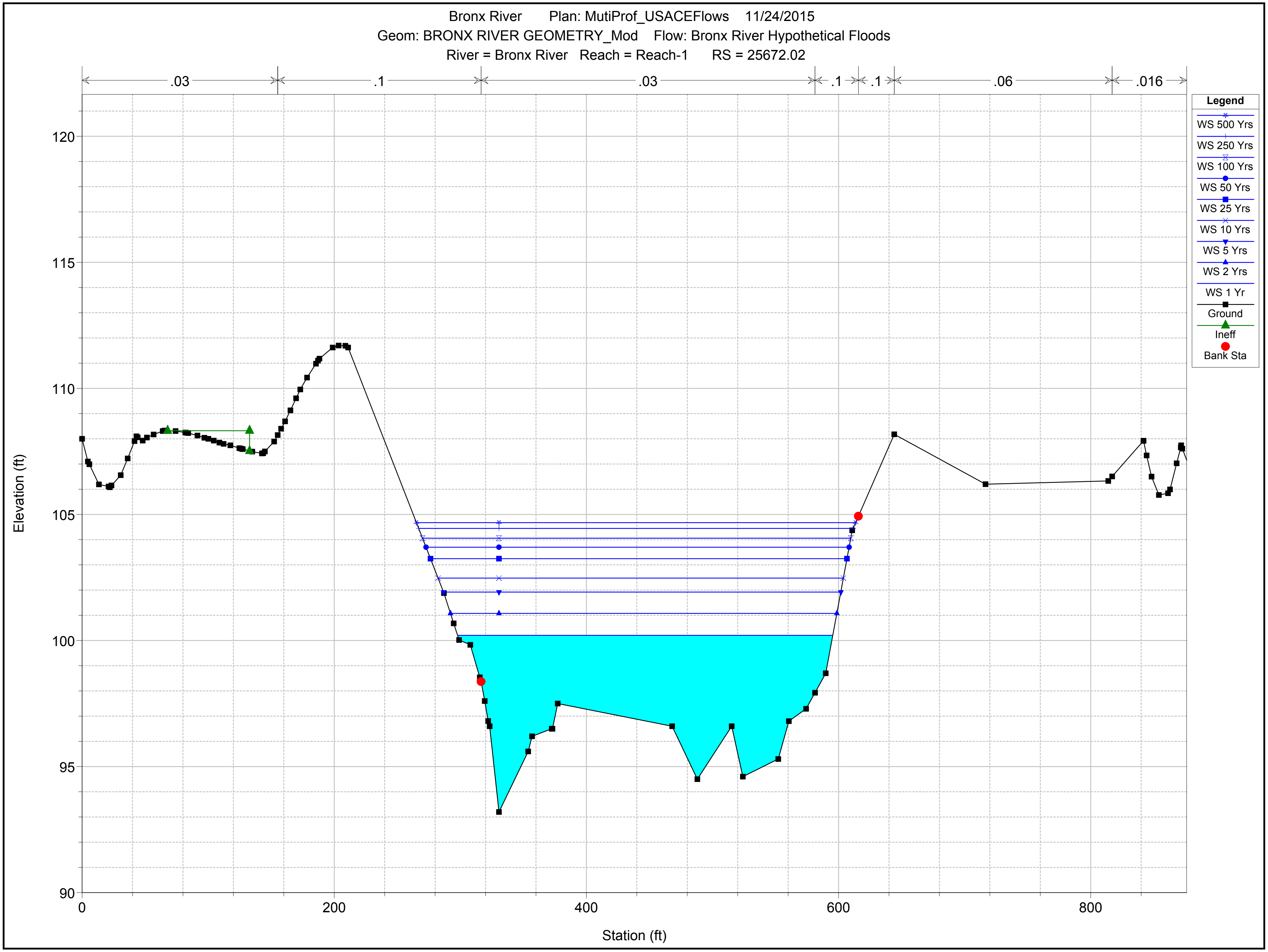
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



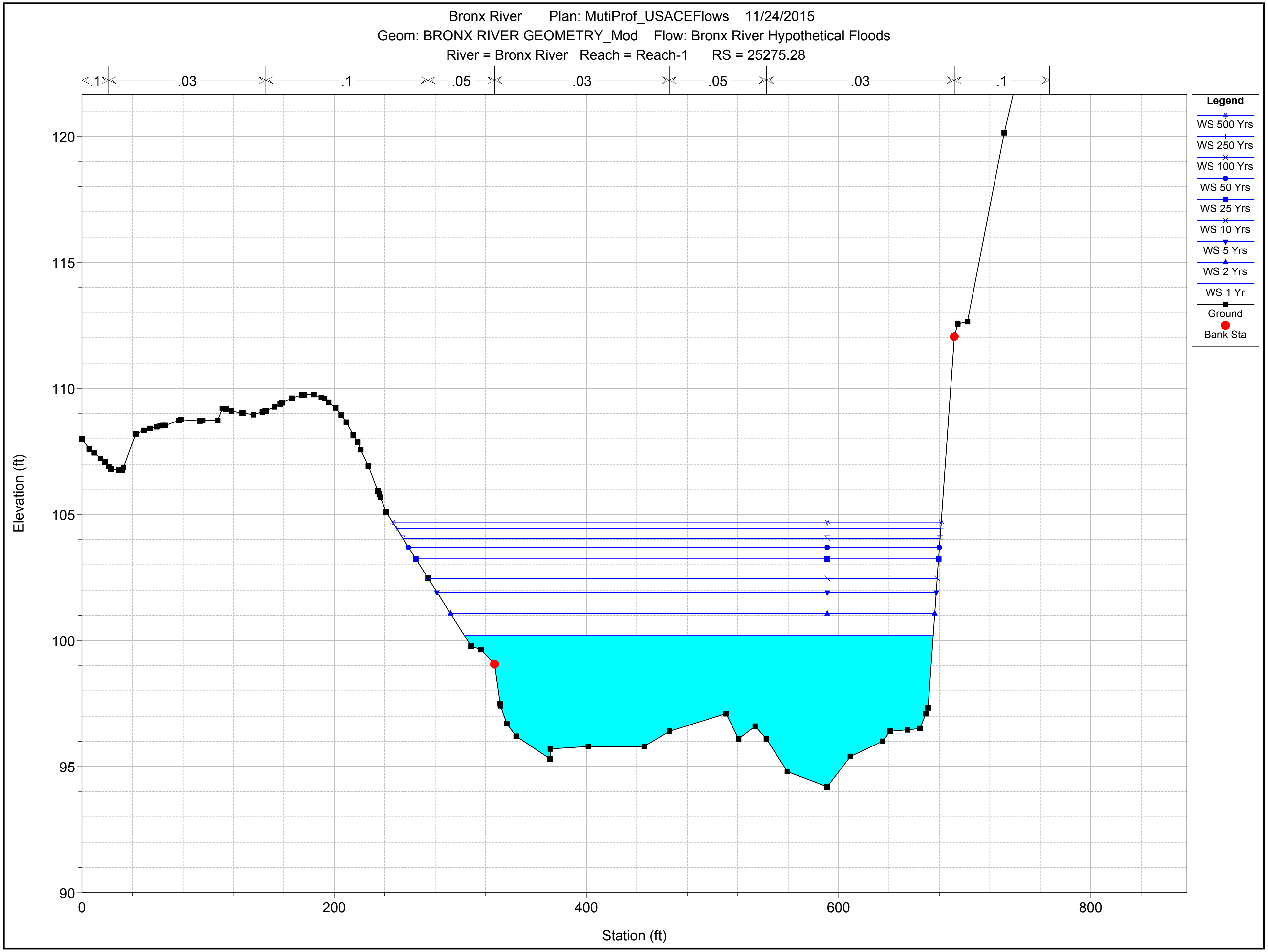
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



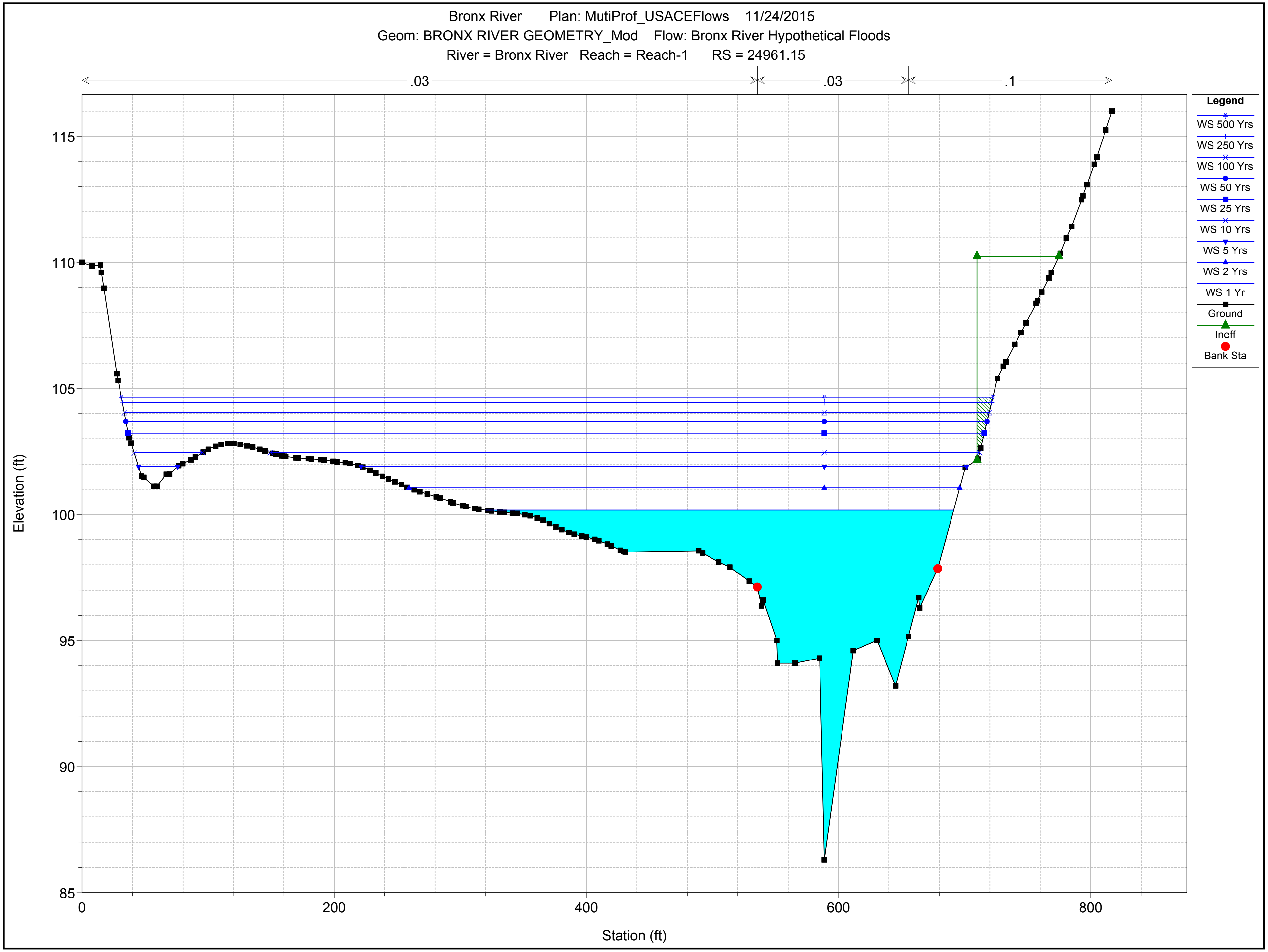
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



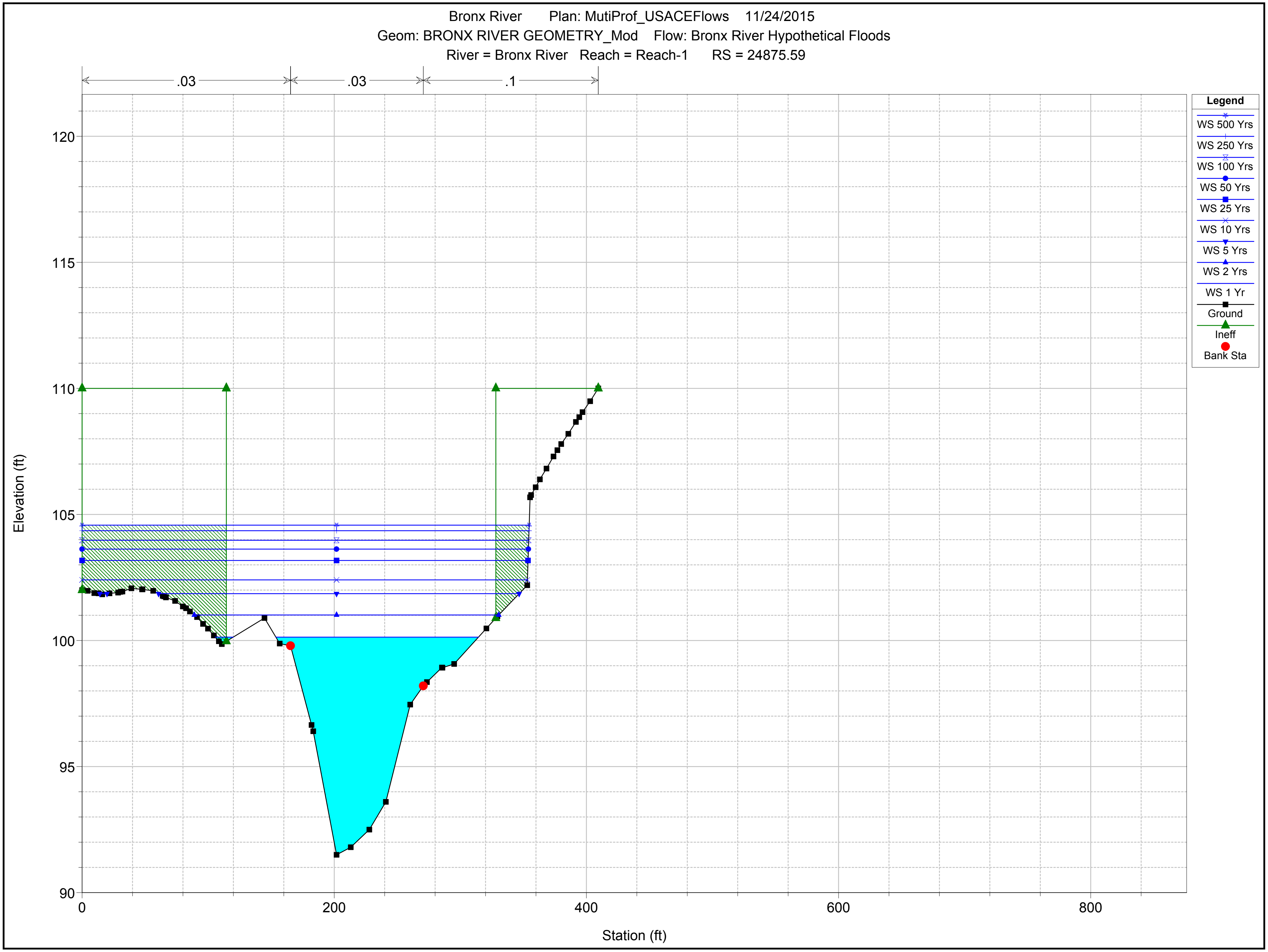
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



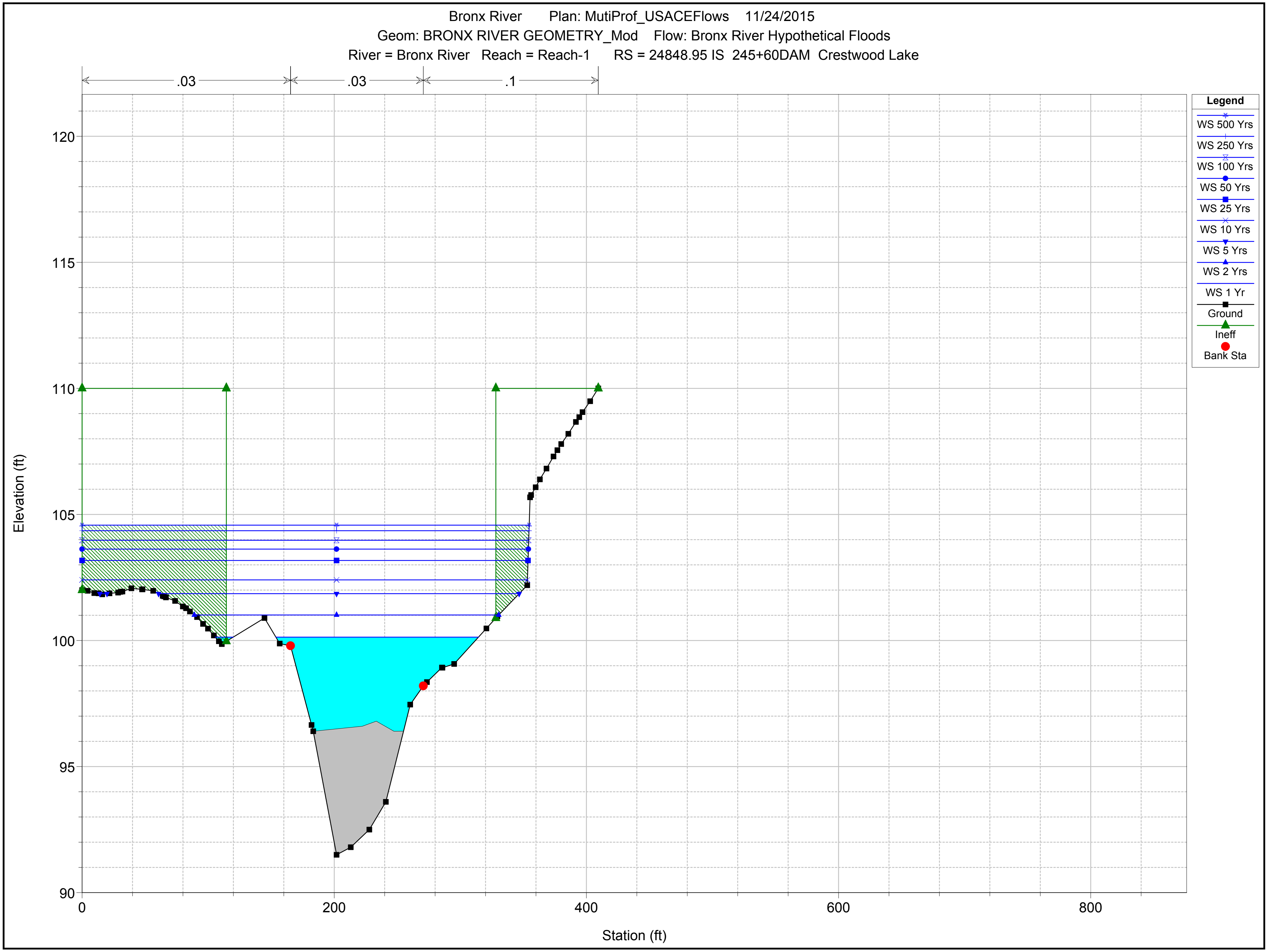
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



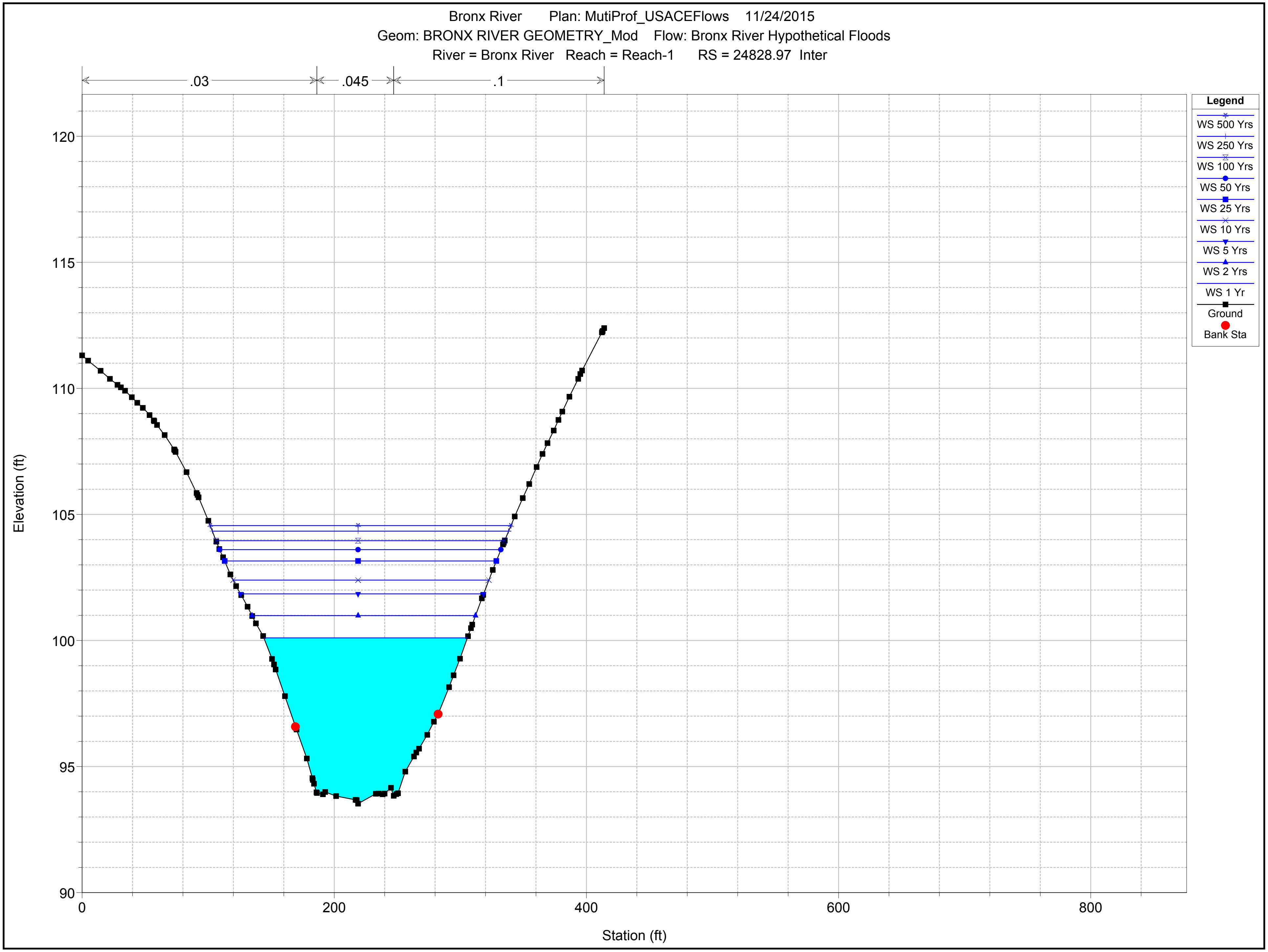
1 in Horiz. = 100 ft 1 in Vert. = 5 ft



1 in Horiz. = 100 ft 1 in Vert. = 5 ft



1 in Horiz. = 100 ft 1 in Vert. = 5 ft



1 in Horiz. = 100 ft 1 in Vert. = 5 ft

HEC-RAS Plan: Multi_USACE River: Bronx River Reach: Reach-1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	26666.17 Inter	1 Yr	940.00	95.48	100.25	4.92	0.99	1.06	373.41	944.75	416.60
Reach-1	26666.17 Inter	2 Yrs	1130.00	95.48	101.11	5.78	0.87	0.99	439.12	1297.93	521.45
Reach-1	26666.17 Inter	5 Yrs	1450.00	95.48	101.96	6.63	0.86	1.03	470.46	1684.06	624.51
Reach-1	26666.17 Inter	10 Yrs	1690.00	95.48	102.51	7.18	0.87	1.13	531.34	1948.67	691.68
Reach-1	26666.17 Inter	25 Yrs	1980.00	95.48	105.13	9.80	1.23	1.16	194.03	1614.63	1011.32
Reach-1	26666.17 Inter	50 Yrs	2230.00	95.48	103.73	8.40	0.87	1.13	577.47	2553.94	840.93
Reach-1	26666.17 Inter	100 Yrs	2480.00	95.48	104.09	8.76	0.91	1.17	589.35	2734.10	884.92
Reach-1	26666.17 Inter	250 Yrs	2810.00	95.48	104.49	9.16	0.96	1.23	613.25	2930.59	932.68
Reach-1	26666.17 Inter	500 Yrs	3030.00	95.48	104.72	9.39	0.99	1.27	624.40	3046.95	960.85
Reach-1	26356.25	1 Yr	940.00	94.60	100.24	5.64	0.83	0.91	373.08	1129.56	999.27
Reach-1	26356.25	2 Yrs	1130.00	94.60	101.10	6.50	0.76	0.87	475.30	1493.49	1221.48
Reach-1	26356.25	5 Yrs	1450.00	94.60	101.95	7.35	0.76	0.91	515.65	1914.41	1438.99
Reach-1	26356.25	10 Yrs	1690.00	94.60	102.50	7.90	0.77	0.94	537.13	2204.56	1580.51
Reach-1	26356.25	25 Yrs	1980.00	94.60	105.14	10.54	0.52	0.68	630.37	3774.63	2258.19
Reach-1	26356.25	50 Yrs	2230.00	94.60	103.73	9.13	0.77	0.98	600.40	2900.15	1895.52
Reach-1	26356.25	100 Yrs	2480.00	94.60	104.09	9.49	0.80	1.02	612.79	3119.27	1988.28
Reach-1	26356.25	250 Yrs	2810.00	94.60	104.48	9.88	0.84	1.09	622.27	3361.70	2088.88
Reach-1	26356.25	500 Yrs	3030.00	94.60	104.71	10.11	0.86	1.12	625.12	3505.93	2148.27
Reach-1	26190.27	1 Yr	940.00	93.00	100.23	7.23	0.71	0.71	435.73	1316.15	1165.65
Reach-1	26190.27	2 Yrs	1130.00	93.00	101.10	8.10	0.66	0.65	480.84	1714.15	1485.88
Reach-1	26190.27	5 Yrs	1450.00	93.00	101.95	8.95	0.68	0.67	522.21	2139.54	1825.24
Reach-1	26190.27	10 Yrs	1690.00	93.00	102.50	9.50	0.69	0.69	548.11	2434.66	2059.97
Reach-1	26190.27	25 Yrs	1980.00	93.00	105.14	12.14	0.49	0.49	626.19	4012.53	3310.22
Reach-1	26190.27	50 Yrs	2230.00	93.00	103.73	10.73	0.71	0.71	603.84	3141.95	2622.01
Reach-1	26190.27	100 Yrs	2480.00	93.00	104.09	11.09	0.74	0.73	611.22	3361.57	2796.57
Reach-1	26190.27	250 Yrs	2810.00	93.00	104.48	11.48	0.78	0.78	617.91	3602.57	2987.82
Reach-1	26190.27	500 Yrs	3030.00	93.00	104.71	11.71	0.81	0.81	620.92	3745.85	3100.98
Reach-1	25985.28	1 Yr	940.00	94.60	100.22	5.62	0.77	0.89	405.39	1219.67	1027.11
Reach-1	25985.28	2 Yrs	1130.00	94.60	101.09	6.49	0.71	0.87	436.26	1585.47	1239.09
Reach-1	25985.28	5 Yrs	1450.00	94.60	101.94	7.34	0.74	0.94	458.91	1966.49	1445.62
Reach-1	25985.28	10 Yrs	1690.00	94.60	102.49	7.89	0.76	1.00	465.50	2220.97	1579.89
Reach-1	25985.28	25 Yrs	1980.00	94.60	105.13	10.53	0.56	0.80	523.11	3505.17	2224.94
Reach-1	25985.28	50 Yrs	2230.00	94.60	103.71	9.11	0.80	1.08	480.19	2800.61	1878.83
Reach-1	25985.28	100 Yrs	2480.00	94.60	104.07	9.47	0.83	1.15	484.51	2974.20	1966.60
Reach-1	25985.28	250 Yrs	2810.00	94.60	104.46	9.86	0.89	1.23	489.18	3163.98	2061.66
Reach-1	25985.28	500 Yrs	3030.00	94.60	104.69	10.09	0.92	1.29	506.26	3278.71	2117.69
Reach-1	25672.02	1 Yr	940.00	93.20	100.20	7.00	0.85	0.86	297.61	1104.21	1092.17
Reach-1	25672.02	2 Yrs	1130.00	93.20	101.08	7.88	0.83	0.84	306.46	1367.95	1337.19

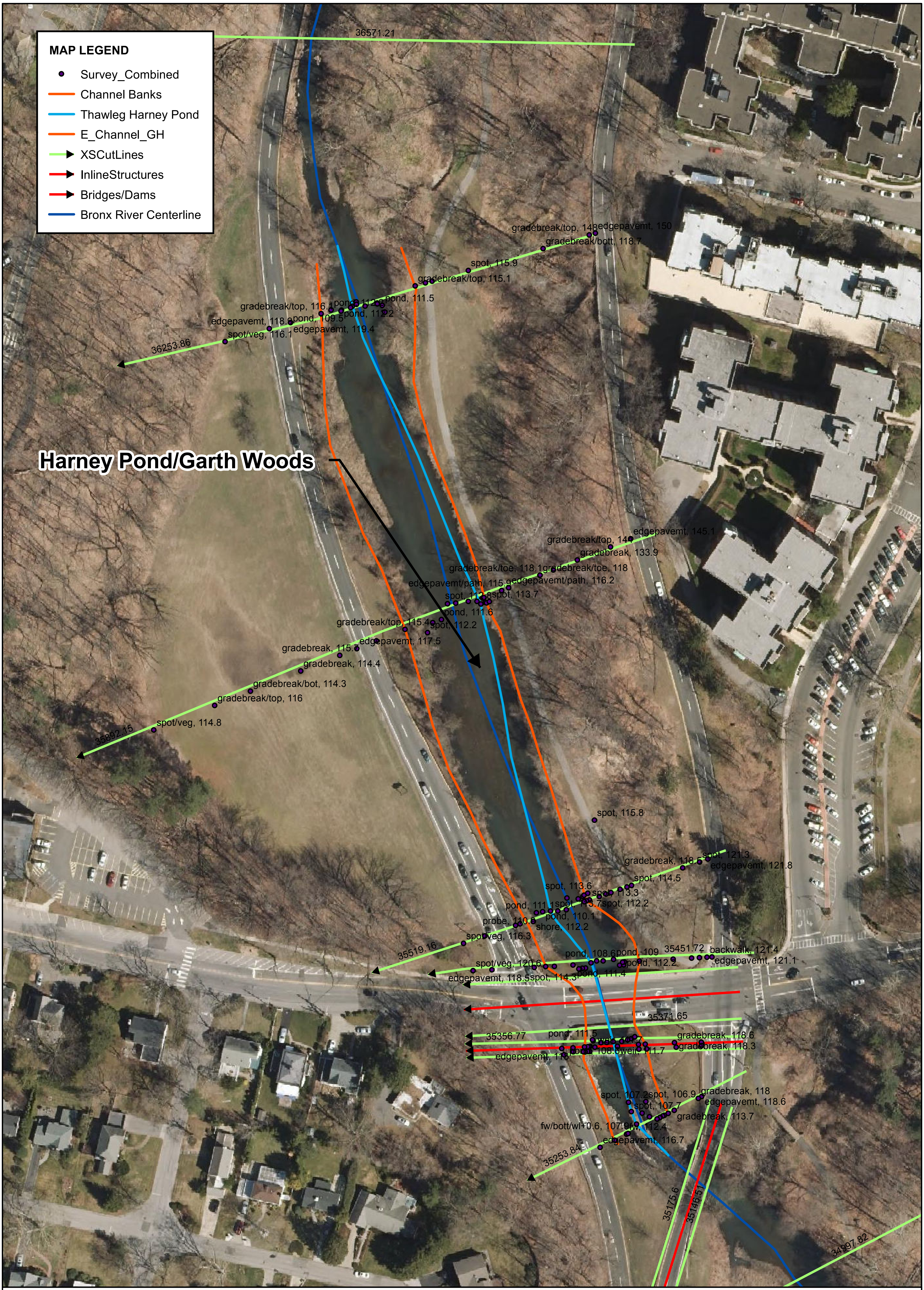
HEC-RAS Plan: Multi_USACE   River: Bronx River   Reach: Reach-1 (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	25672.02	5 Yrs	1450.00	93.20	101.92	8.72	0.89	0.91	315.12	1631.18	1577.56
Reach-1	25672.02	10 Yrs	1690.00	93.20	102.47	9.27	0.94	0.97	321.45	1806.35	1735.16
Reach-1	25672.02	25 Yrs	1980.00	93.20	105.13	11.93	0.73	0.78	355.80	2700.81	2511.64
Reach-1	25672.02	50 Yrs	2230.00	93.20	103.70	10.50	1.01	1.05	335.56	2209.04	2090.22
Reach-1	25672.02	100 Yrs	2480.00	93.20	104.06	10.86	1.06	1.12	339.69	2330.23	2195.24
Reach-1	25672.02	250 Yrs	2810.00	93.20	104.45	11.25	1.14	1.20	344.55	2462.99	2309.39
Reach-1	25672.02	500 Yrs	3030.00	93.20	104.67	11.47	1.19	1.26	348.34	2542.16	2377.05
Reach-1	25275.28	1 Yr	940.00	94.20	100.19	5.99	0.63	0.64	371.79	1483.55	1469.62
Reach-1	25275.28	2 Yrs	1130.00	94.20	101.07	6.87	0.62	0.63	384.14	1814.85	1775.09
Reach-1	25275.28	5 Yrs	1450.00	94.20	101.91	7.71	0.68	0.69	396.08	2145.50	2071.50
Reach-1	25275.28	10 Yrs	1690.00	94.20	102.46	8.26	0.71	0.74	403.84	2365.70	2264.58
Reach-1	25275.28	25 Yrs	1980.00	94.20	105.12	10.92	0.57	0.60	441.05	3488.60	3202.64
Reach-1	25275.28	50 Yrs	2230.00	94.20	103.69	9.49	0.78	0.81	421.09	2871.67	2696.33
Reach-1	25275.28	100 Yrs	2480.00	94.20	104.05	9.85	0.82	0.86	426.13	3023.60	2822.96
Reach-1	25275.28	250 Yrs	2810.00	94.20	104.44	10.24	0.88	0.92	431.58	3189.85	2960.05
Reach-1	25275.28	500 Yrs	3030.00	94.20	104.67	10.47	0.92	0.97	434.78	3288.63	3040.77
Reach-1	24961.15	1 Yr	940.00	86.30	100.17	13.87	0.82	0.97	371.28	1152.06	860.24
Reach-1	24961.15	2 Yrs	1130.00	86.30	101.05	14.75	0.75	0.93	436.61	1510.83	986.19
Reach-1	24961.15	5 Yrs	1450.00	86.30	101.90	15.60	0.76	0.97	511.40	1913.38	1107.60
Reach-1	24961.15	10 Yrs	1690.00	86.30	102.45	16.15	0.76	1.02	616.95	2224.60	1186.38
Reach-1	24961.15	25 Yrs	1980.00	86.30	105.12	18.82	0.49	0.65	695.26	4014.02	1568.05
Reach-1	24961.15	50 Yrs	2230.00	86.30	103.68	17.38	0.73	1.01	682.93	3039.66	1362.41
Reach-1	24961.15	100 Yrs	2480.00	86.30	104.04	17.74	0.76	1.03	686.01	3282.47	1413.81
Reach-1	24961.15	250 Yrs	2810.00	86.30	104.43	18.13	0.79	1.07	689.34	3545.23	1469.32
Reach-1	24961.15	500 Yrs	3030.00	86.30	104.66	18.36	0.82	1.10	691.29	3699.91	1501.94
Reach-1	24875.59	1 Yr	940.00	91.50	100.14	8.64	1.52	1.63	175.02	618.13	570.22
Reach-1	24875.59	2 Yrs	1130.00	91.50	101.01	9.51	1.43	1.66	241.52	788.09	662.82
Reach-1	24875.59	5 Yrs	1450.00	91.50	101.86	10.36	1.50	1.81	291.65	968.00	751.48
Reach-1	24875.59	10 Yrs	1690.00	91.50	102.40	10.90	1.56	1.92	353.19	1084.70	808.99
Reach-1	24875.59	25 Yrs	1980.00	91.50	105.09	13.59	1.19	1.52	354.93	1658.79	1091.92
Reach-1	24875.59	50 Yrs	2230.00	91.50	103.62	12.12	1.66	2.09	353.98	1345.69	937.62
Reach-1	24875.59	100 Yrs	2480.00	91.50	103.98	12.48	1.75	2.21	354.21	1420.98	974.72
Reach-1	24875.59	250 Yrs	2810.00	91.50	104.35	12.85	1.87	2.37	354.45	1501.68	1014.49
Reach-1	24875.59	500 Yrs	3030.00	91.50	104.57	13.07	1.96	2.48	354.59	1548.83	1037.73
Reach-1	24848.95 245+60DAM		Inl Struct								
Reach-1	24828.97 Inter	1 Yr	940.00	93.53	100.11	6.58	1.33	1.41	161.47	705.81	626.64
Reach-1	24828.97 Inter	2 Yrs	1130.00	93.53	100.99	7.46	1.32	1.43	177.35	855.31	726.53

HEC-RAS Plan: Multi_USACE River: Bronx River Reach: Reach-1 (Continued)

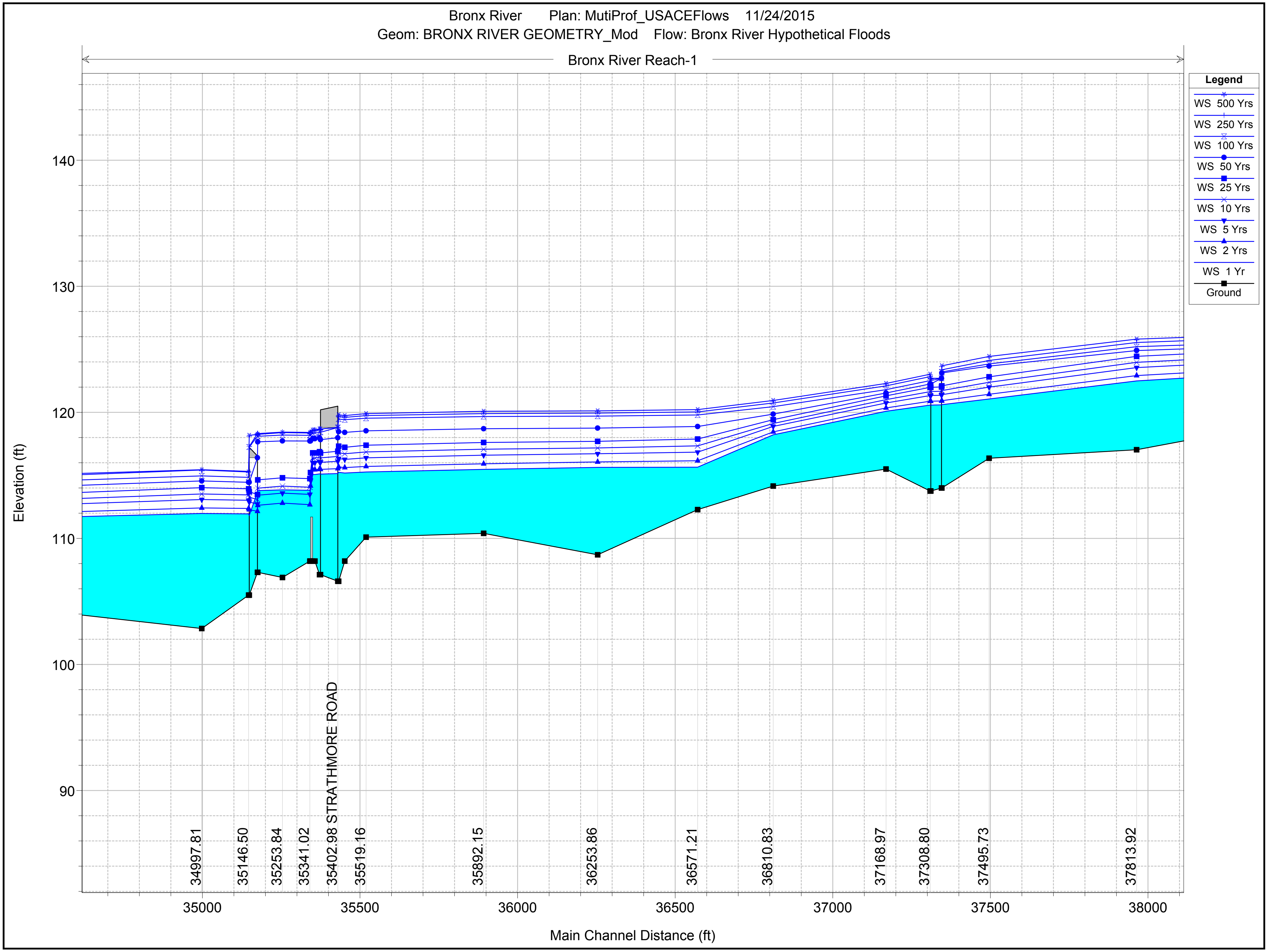
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	24828.97 Inter	5 Yrs	1450.00	93.53	101.85	8.32	1.43	1.57	192.77	1014.38	823.90
Reach-1	24828.97 Inter	10 Yrs	1690.00	93.53	102.39	8.86	1.51	1.67	202.86	1122.54	885.76
Reach-1	24828.97 Inter	25 Yrs	1980.00	93.53	105.06	11.53	1.59	1.60	120.65	1246.51	1187.32
Reach-1	24828.97 Inter	50 Yrs	2230.00	93.53	103.60	10.07	1.62	1.83	223.11	1380.27	1022.70
Reach-1	24828.97 Inter	100 Yrs	2480.00	93.53	103.96	10.43	1.70	1.93	228.91	1460.12	1062.69
Reach-1	24828.97 Inter	250 Yrs	2810.00	93.53	104.34	10.81	1.82	2.07	234.95	1547.95	1105.55
Reach-1	24828.97 Inter	500 Yrs	3030.00	93.53	104.56	11.03	1.89	2.16	238.47	1600.33	1130.60

Garth Woods/Harney Road

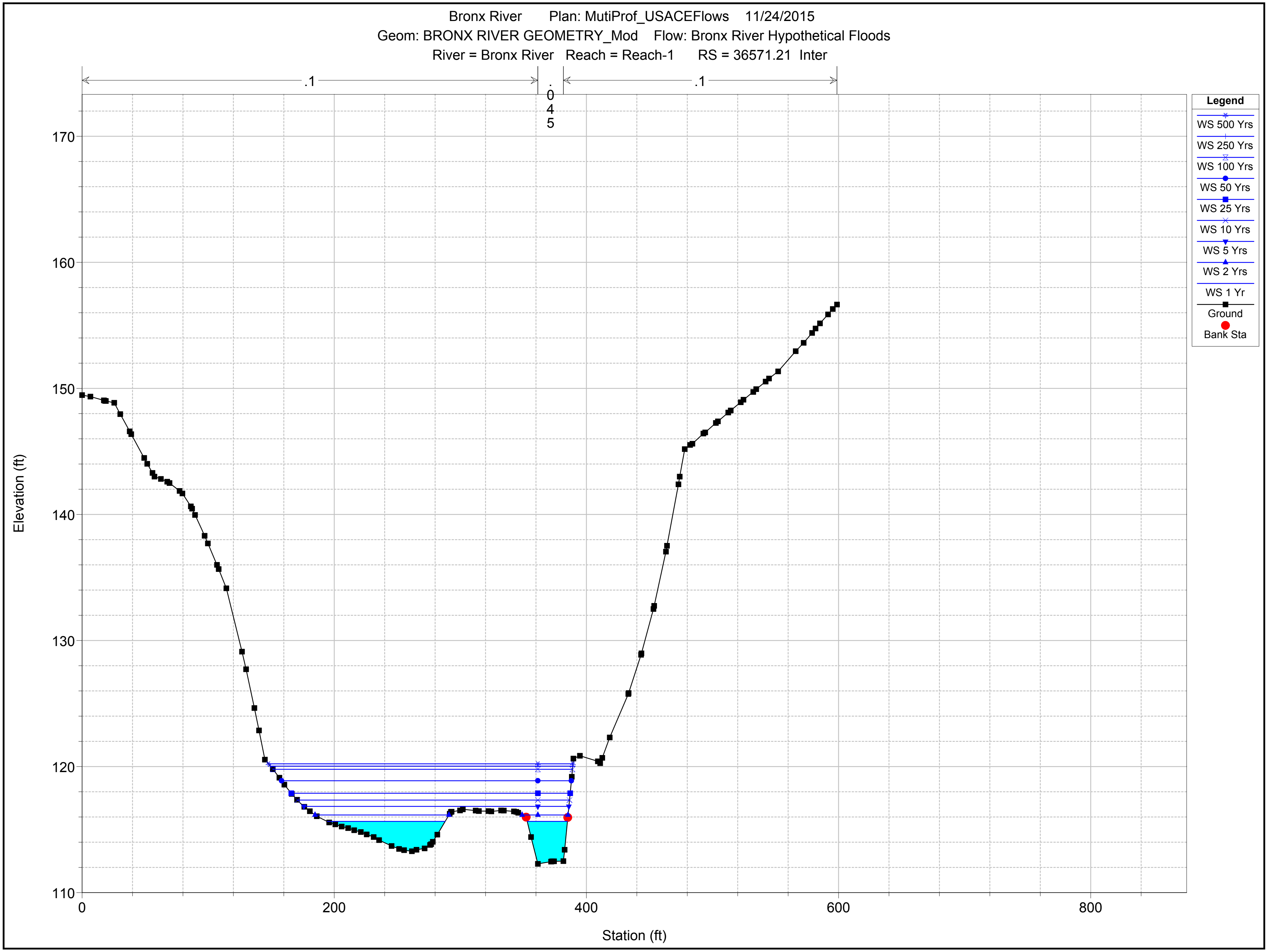


CROSS-SECTION LOCATION MAP - HARNEY POND/GARTH WOODS

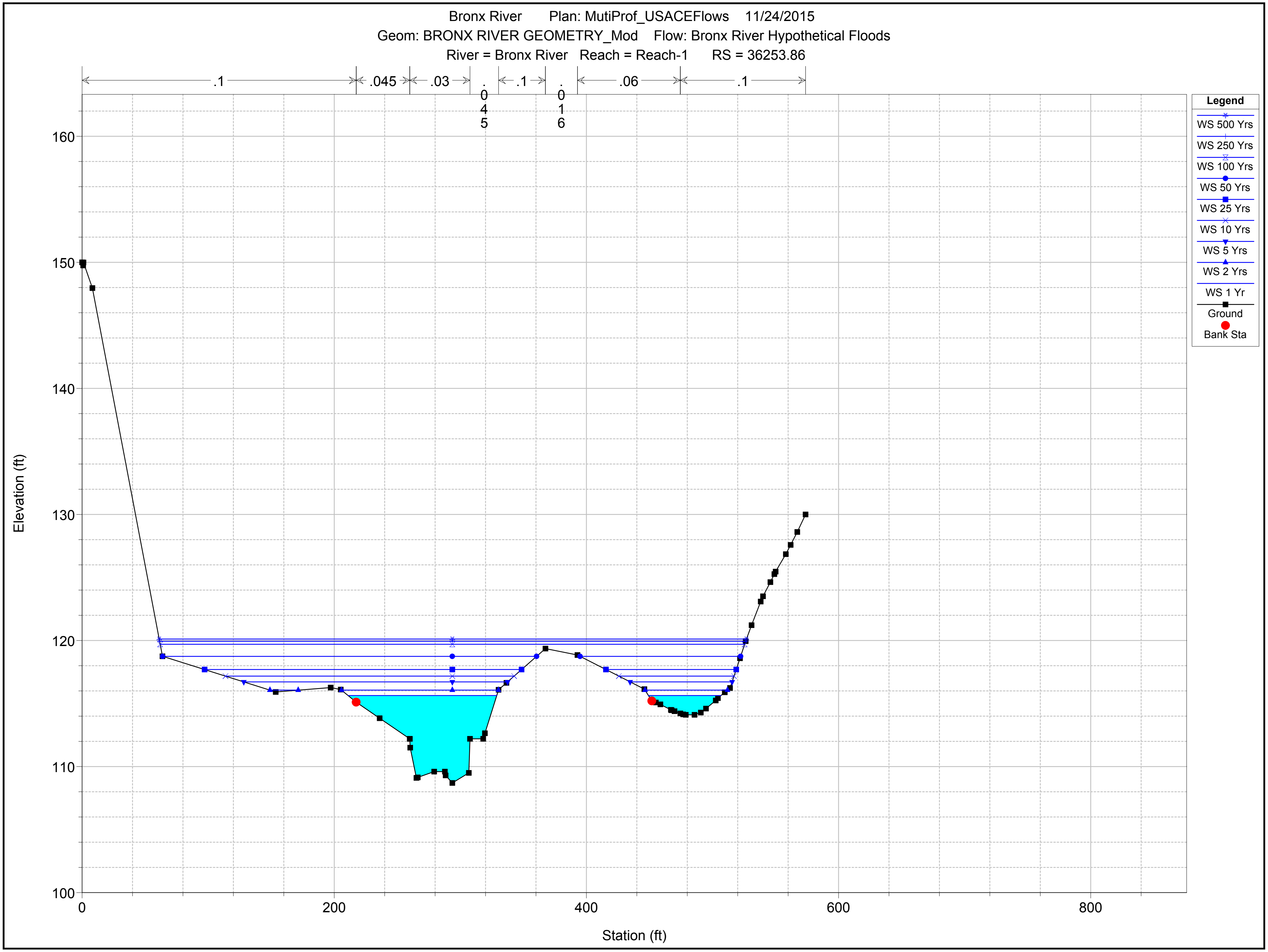
0 100 200 Feet



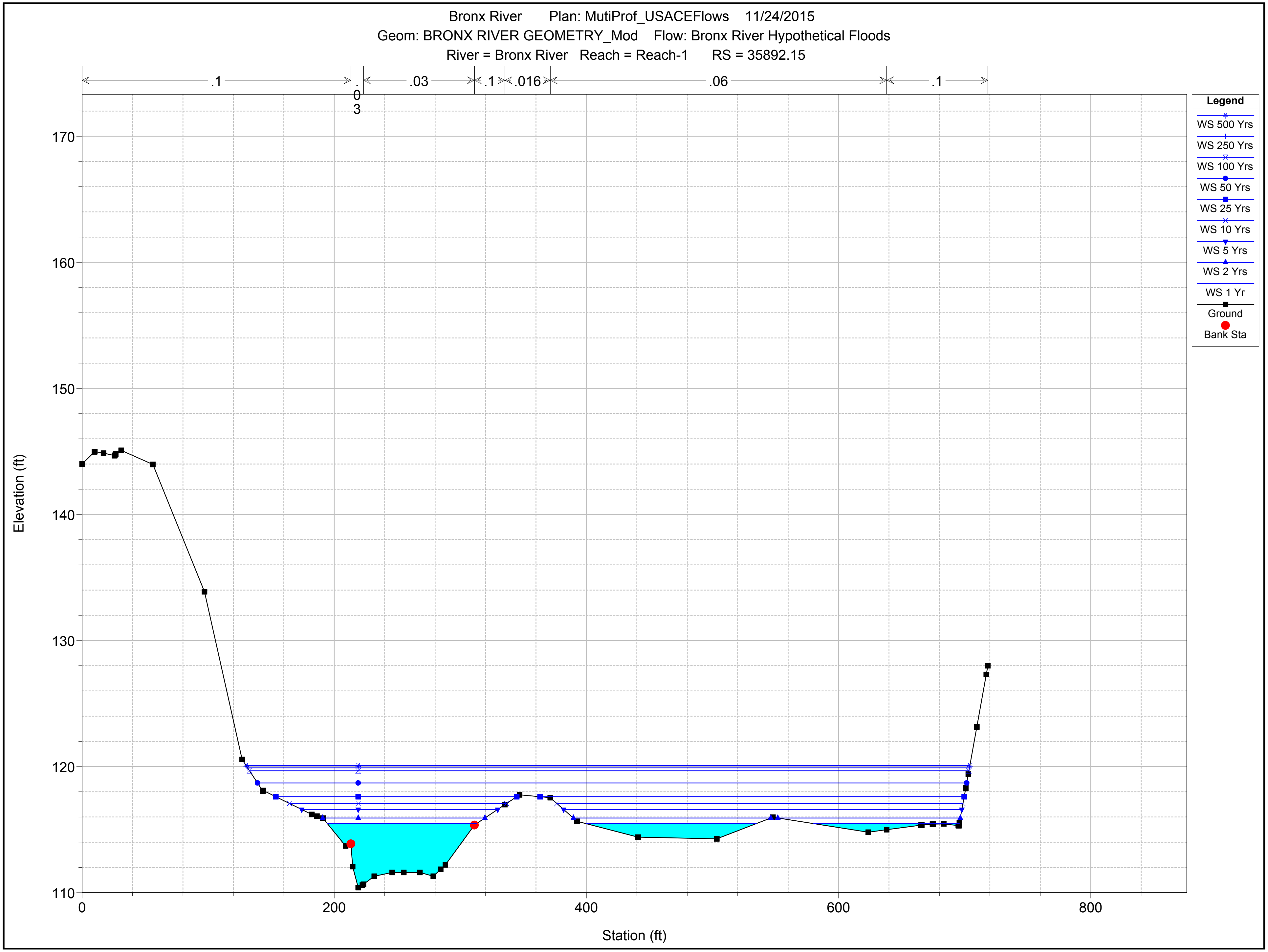
1 in Horiz. = 400 ft 1 in Vert. = 10 ft



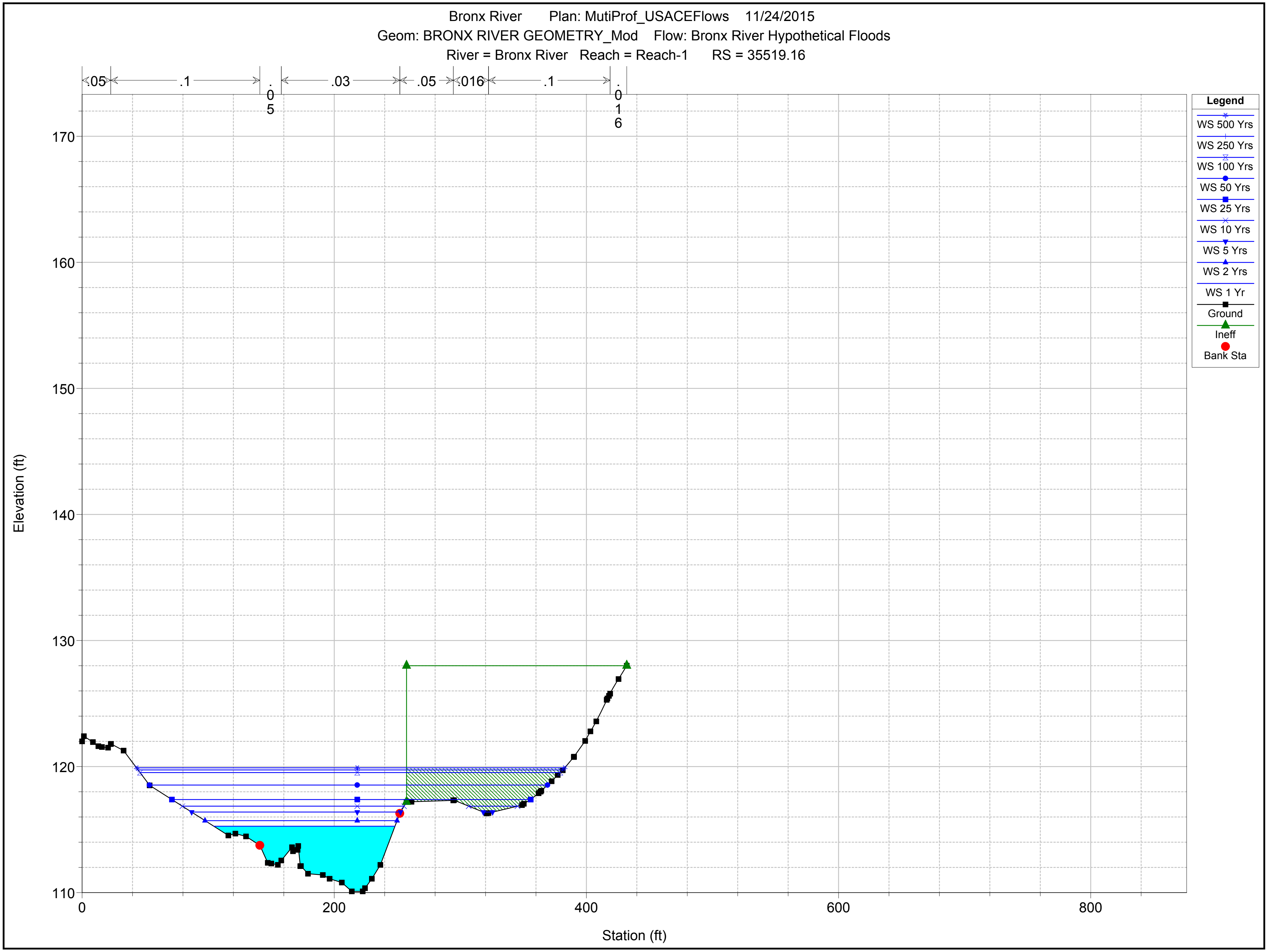
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



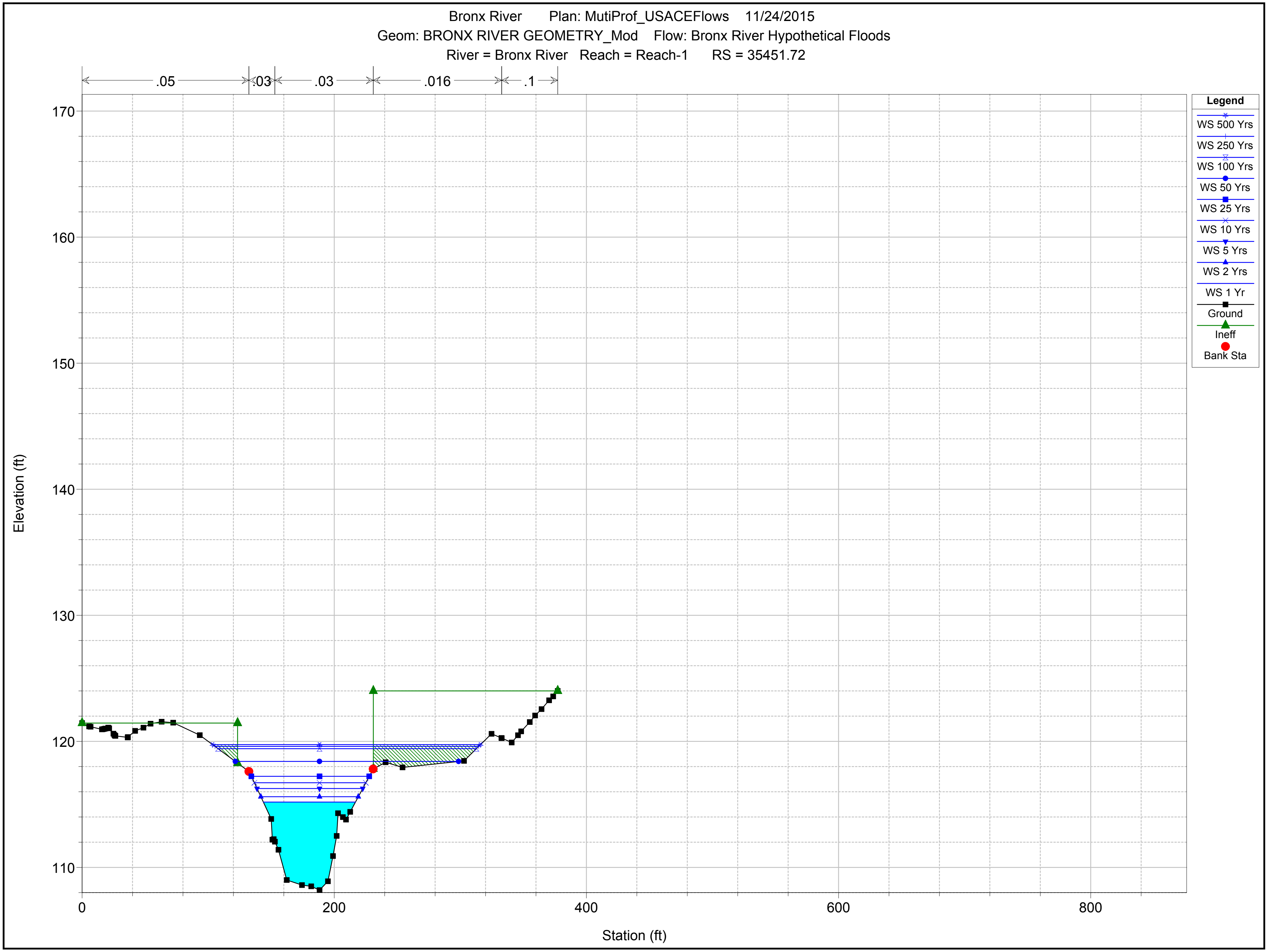
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



1 in Horiz. = 100 ft 1 in Vert. = 10 ft

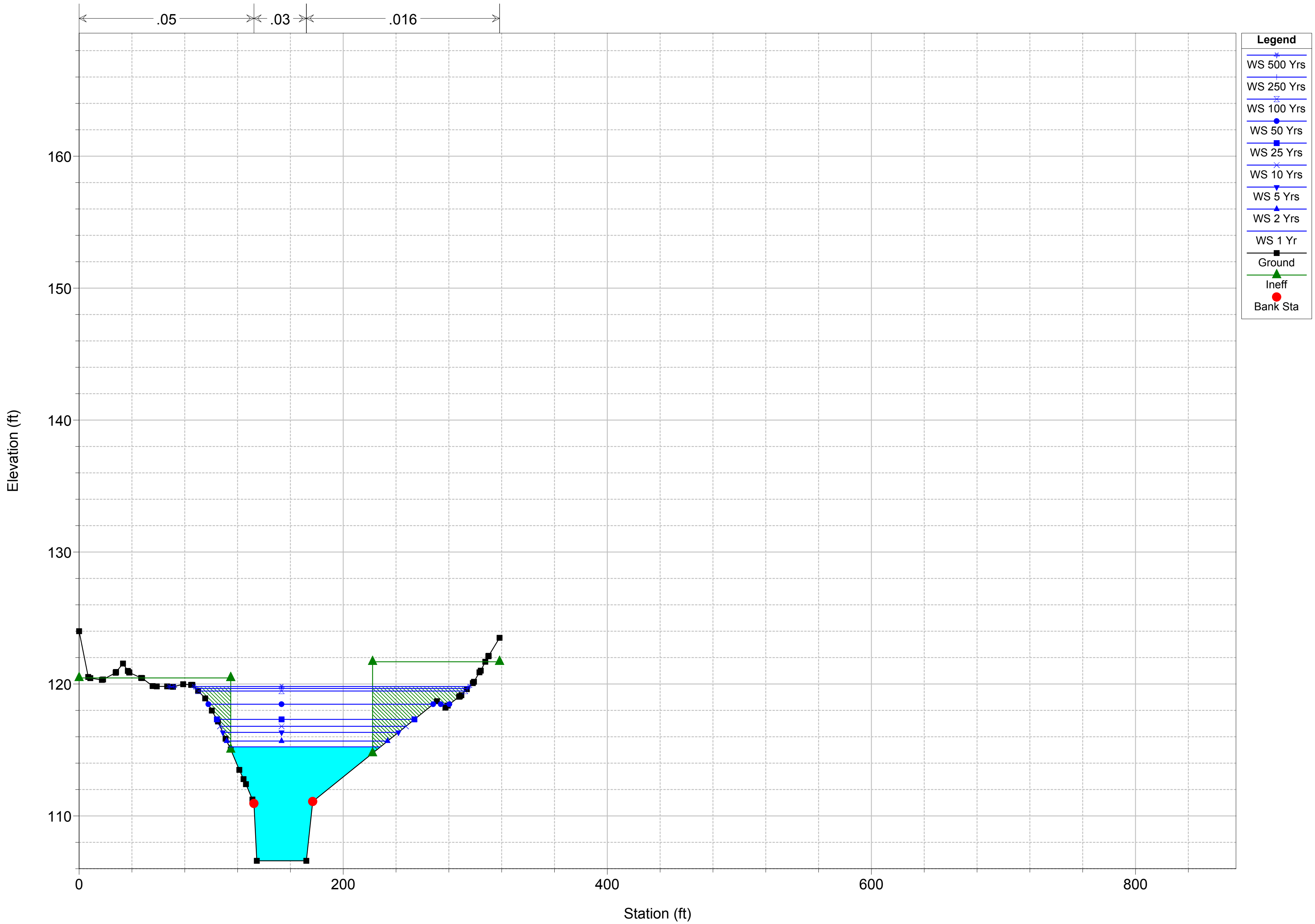


1 in Horiz. = 100 ft 1 in Vert. = 10 ft

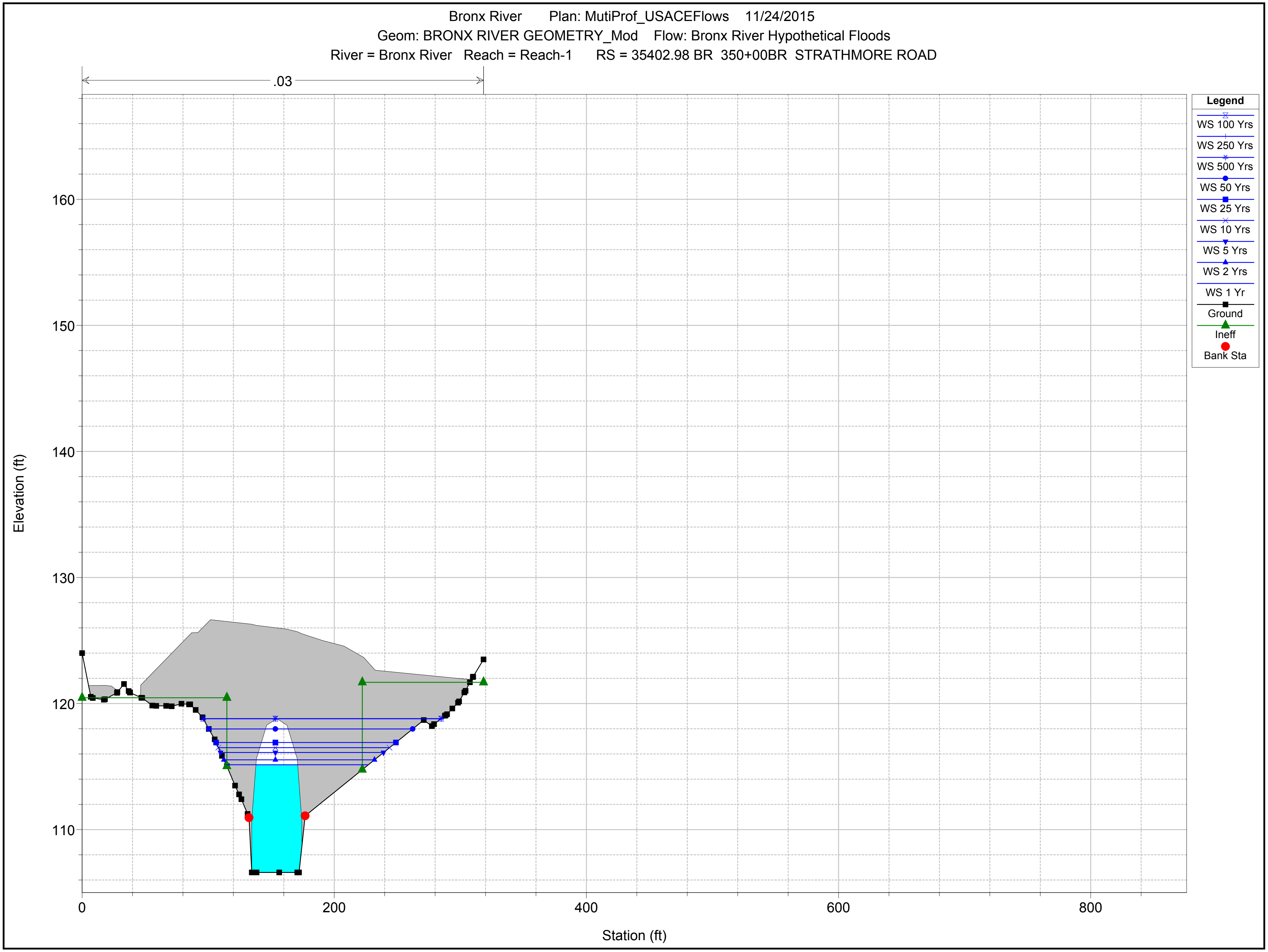


1 in Horiz. = 100 ft 1 in Vert. = 10 ft

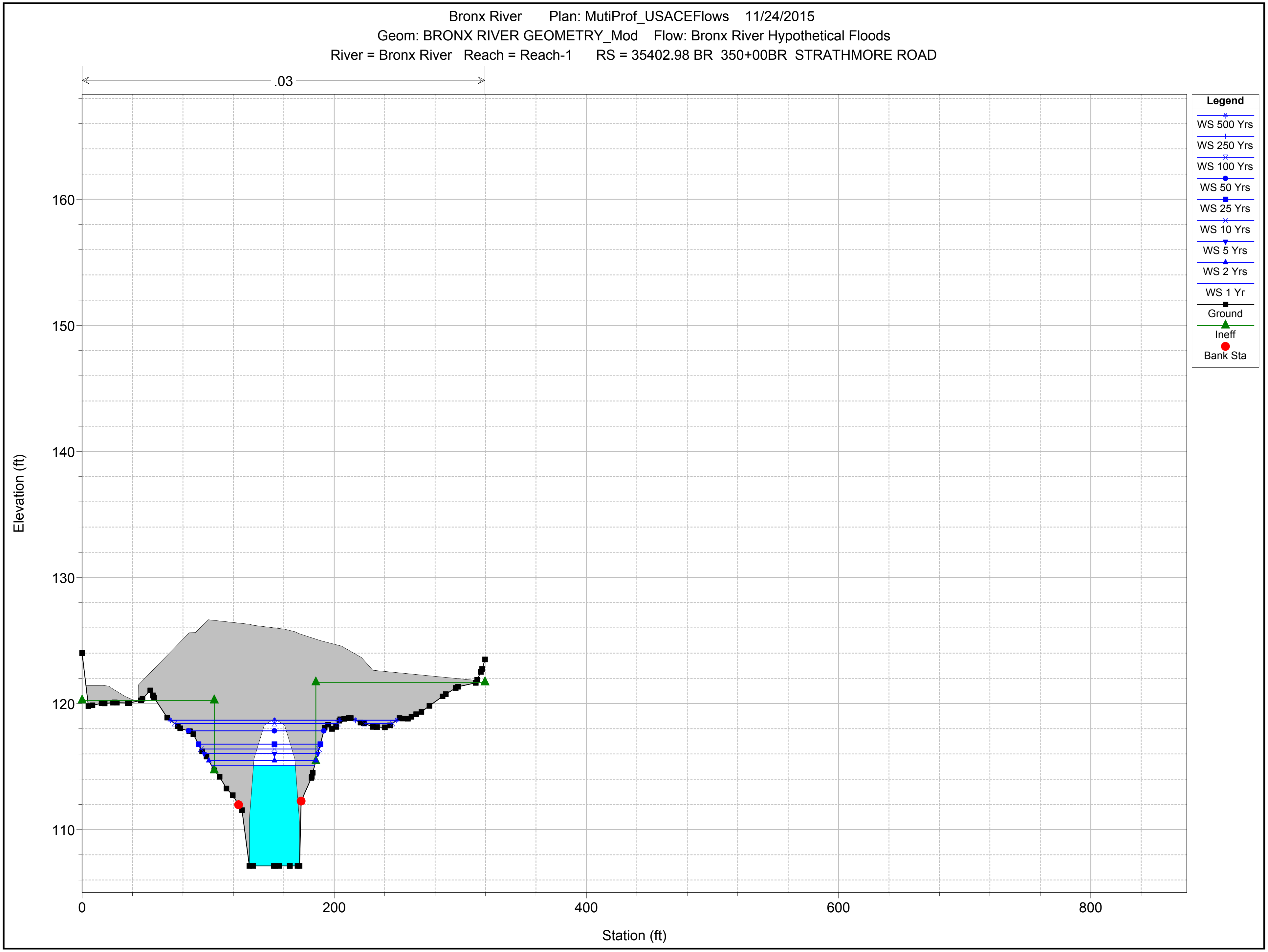
Bronx River Plan: MutiProf_USACEFlows 11/24/2015
Geom: BRONX RIVER GEOMETRY_Mod Flow: Bronx River Hypothetical Floods
River = Bronx River Reach = Reach-1 RS = 35432.17 350+00US



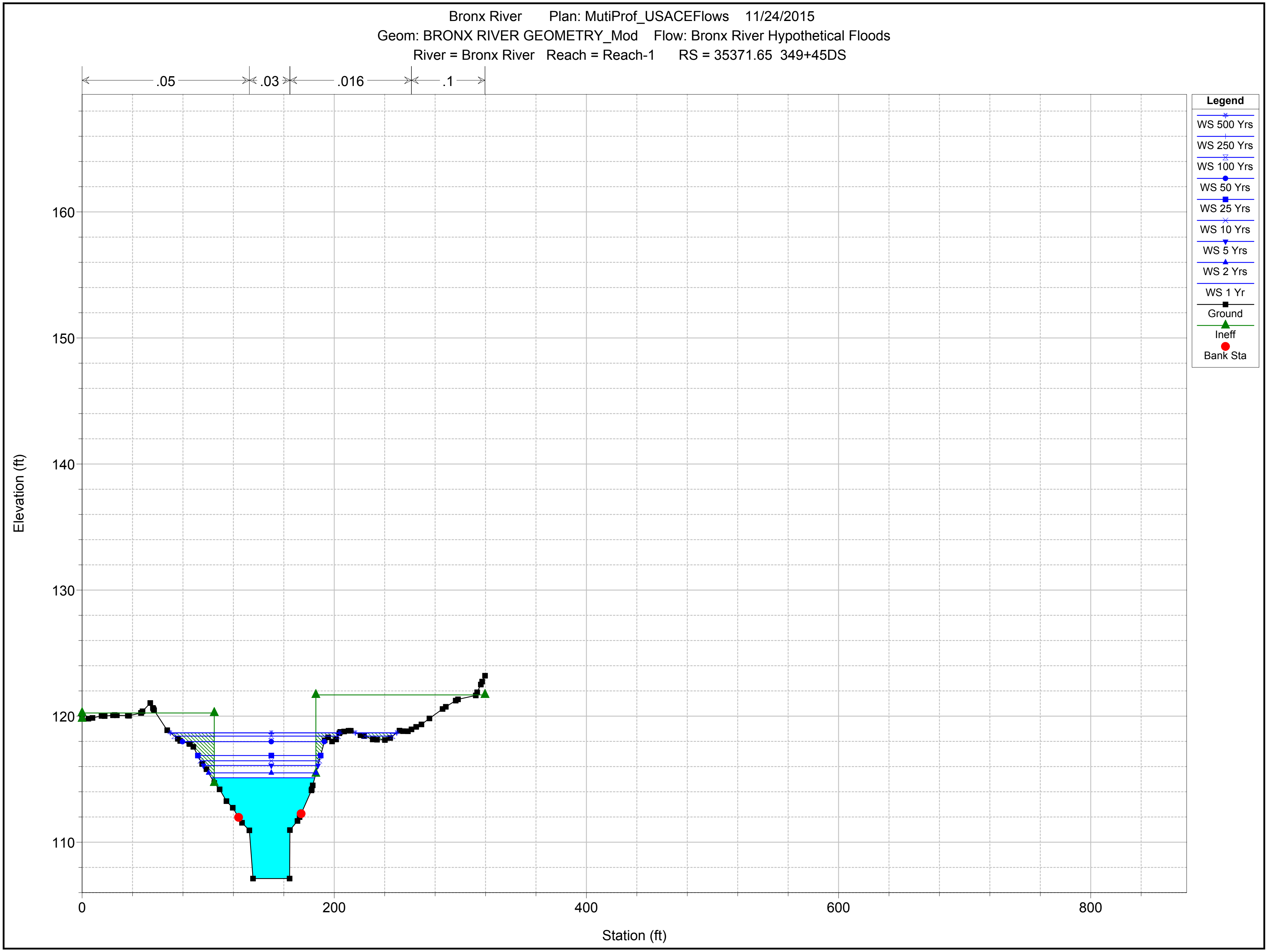
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



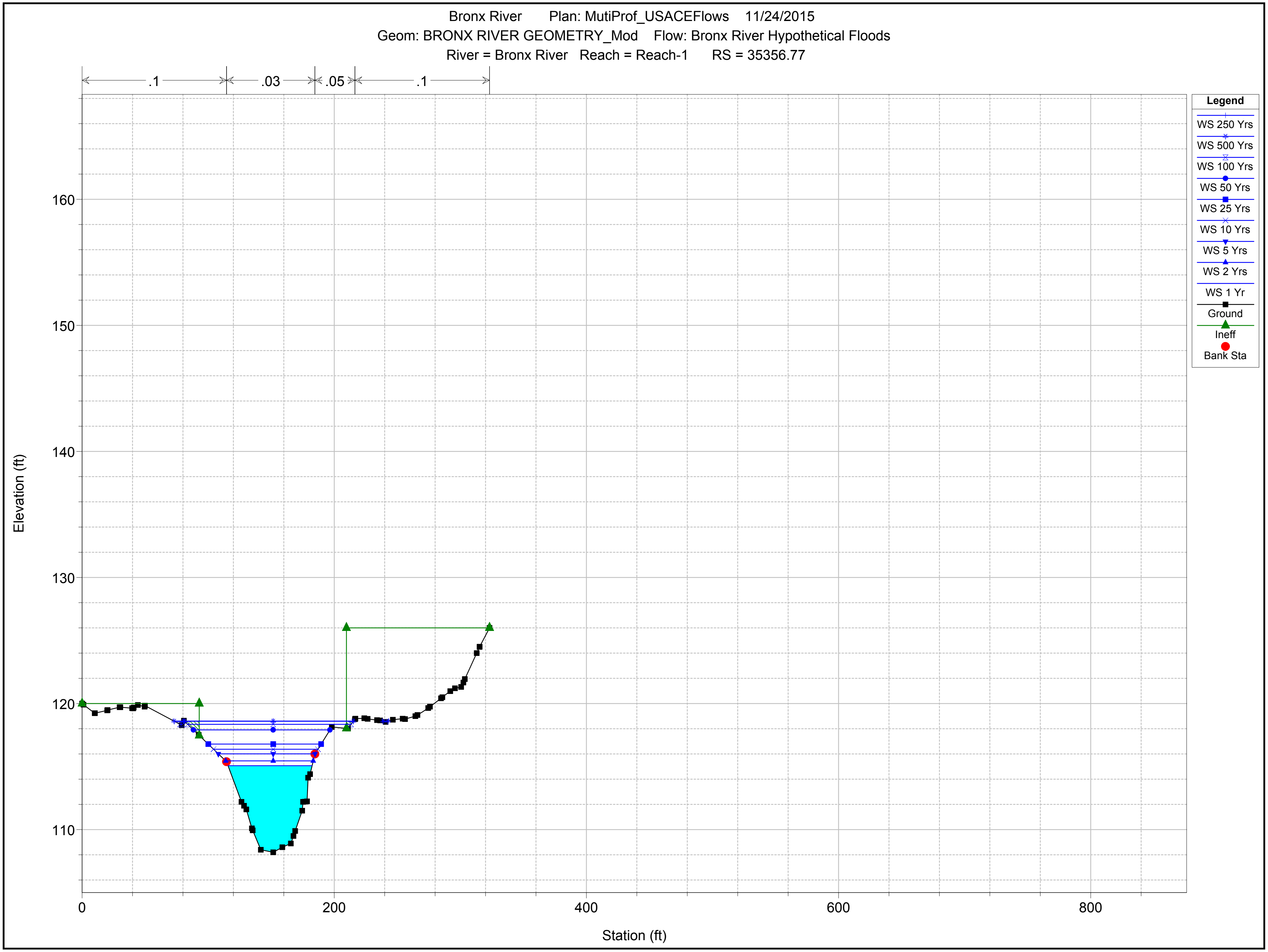
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



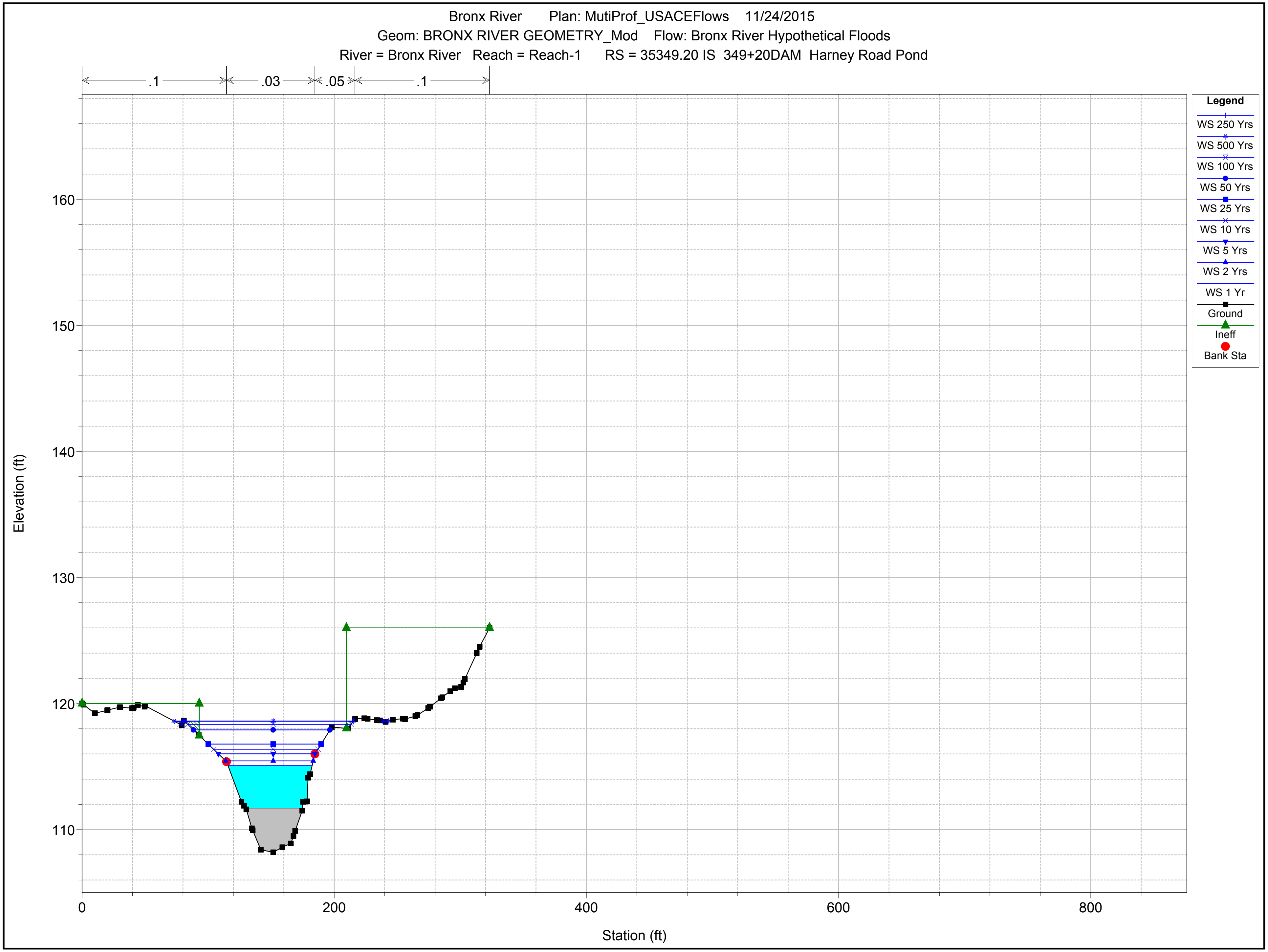
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



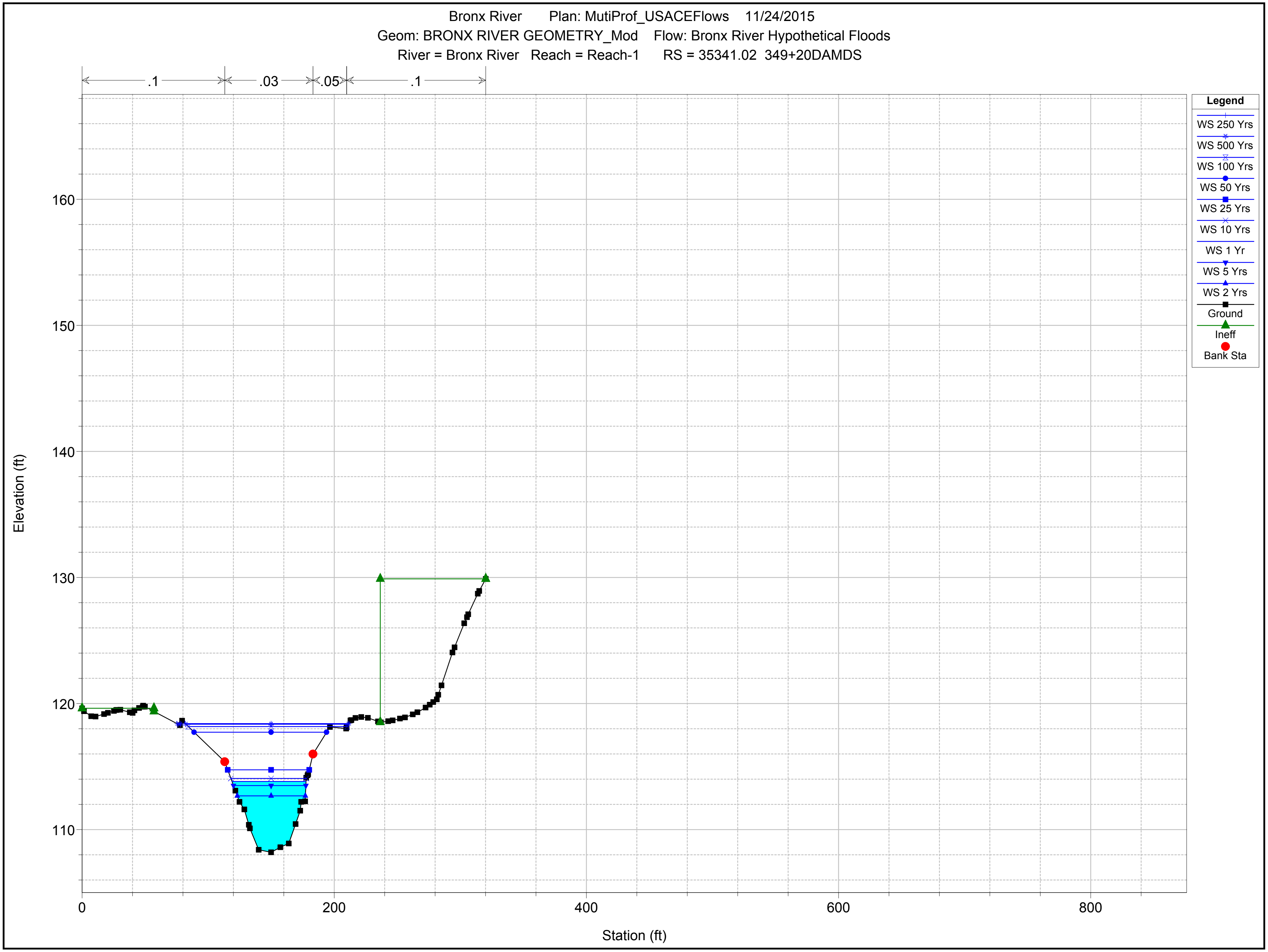
1 in Horiz. = 100 ft 1 in Vert. = 10 ft



1 in Horiz. = 100 ft 1 in Vert. = 10 ft



1 in Horiz. = 100 ft 1 in Vert. = 10 ft



1 in Horiz. = 100 ft 1 in Vert. = 10 ft

HEC-RAS Plan: Multi_USACE   River: Bronx River   Reach: Reach-1

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	36571.21 Inter	1 Yr	940.00	112.28	115.65	3.37	4.51	6.67	125.38	208.39	84.69
Reach-1	36571.21 Inter	2 Yrs	1130.00	112.28	116.16	3.88	4.08	6.05	142.69	276.73	101.41
Reach-1	36571.21 Inter	5 Yrs	1450.00	112.28	116.84	4.56	3.64	6.13	210.16	398.45	123.87
Reach-1	36571.21 Inter	10 Yrs	1690.00	112.28	117.34	5.06	3.34	5.56	215.81	505.69	140.49
Reach-1	36571.21 Inter	25 Yrs	1980.00	112.28	117.63	5.35	6.83	9.69	115.75	289.70	150.09
Reach-1	36571.21 Inter	50 Yrs	2230.00	112.28	118.87	6.59	2.63	4.23	229.86	847.16	191.01
Reach-1	36571.21 Inter	100 Yrs	2480.00	112.28	119.79	7.51	2.34	3.70	237.54	1060.74	221.18
Reach-1	36571.21 Inter	250 Yrs	2810.00	112.28	120.04	7.76	2.51	3.97	239.84	1120.12	229.39
Reach-1	36571.21 Inter	500 Yrs	3030.00	112.28	120.22	7.94	2.60	4.11	241.54	1164.12	235.43
Reach-1	36253.86	1 Yr	940.00	108.70	115.64	6.94	1.90	2.12	175.54	493.77	435.62
Reach-1	36253.86	2 Yrs	1130.00	108.70	116.06	7.36	1.97	2.26	212.34	573.52	485.34
Reach-1	36253.86	5 Yrs	1450.00	108.70	116.72	8.02	1.95	2.42	290.06	745.24	568.50
Reach-1	36253.86	10 Yrs	1690.00	108.70	117.17	8.47	1.91	2.48	320.27	884.93	634.58
Reach-1	36253.86	25 Yrs	1980.00	108.70	117.59	8.89	1.94	2.59	347.47	1022.51	699.60
Reach-1	36253.86	50 Yrs	2230.00	108.70	118.75	10.05	1.52	2.15	423.97	1469.59	910.67
Reach-1	36253.86	100 Yrs	2480.00	108.70	119.70	11.00	1.31	1.87	463.58	1898.11	1123.00
Reach-1	36253.86	250 Yrs	2810.00	108.70	119.94	11.24	1.40	2.00	464.83	2008.99	1179.01
Reach-1	36253.86	500 Yrs	3030.00	108.70	120.12	11.42	1.45	2.07	465.82	2091.98	1220.83
Reach-1	35892.15	1 Yr	940.00	110.40	115.47	5.07	1.85	2.55	368.90	506.97	340.89
Reach-1	35892.15	2 Yrs	1130.00	110.40	115.92	5.52	1.65	2.57	429.95	684.81	384.31
Reach-1	35892.15	5 Yrs	1450.00	110.40	116.60	6.20	1.46	2.55	471.34	994.22	451.01
Reach-1	35892.15	10 Yrs	1690.00	110.40	117.07	6.67	1.38	2.53	494.20	1221.82	497.15
Reach-1	35892.15	25 Yrs	1980.00	110.40	117.49	7.09	1.38	2.61	514.33	1431.25	537.79
Reach-1	35892.15	50 Yrs	2230.00	110.40	118.70	8.30	1.06	2.08	562.50	2098.26	656.18
Reach-1	35892.15	100 Yrs	2480.00	110.40	119.67	9.27	0.94	1.83	570.55	2648.29	751.19
Reach-1	35892.15	250 Yrs	2810.00	110.40	119.90	9.50	1.01	1.97	572.51	2782.59	774.19
Reach-1	35892.15	500 Yrs	3030.00	110.40	120.08	9.68	1.05	2.05	573.97	2883.77	791.46
Reach-1	35519.16	1 Yr	940.00	110.10	115.27	5.17	2.40	2.55	143.65	392.01	365.51
Reach-1	35519.16	2 Yrs	1130.00	110.10	115.71	5.61	2.47	2.69	152.31	457.81	413.54
Reach-1	35519.16	5 Yrs	1450.00	110.10	116.39	6.29	2.56	2.90	173.10	565.51	488.17
Reach-1	35519.16	10 Yrs	1690.00	110.10	116.86	6.76	2.62	3.04	214.49	645.45	540.14
Reach-1	35519.16	25 Yrs	1980.00	110.10	117.25	7.15	2.76	3.27	256.40	716.34	583.86
Reach-1	35519.16	50 Yrs	2230.00	110.10	118.53	8.43	2.31	2.90	315.74	965.03	726.14
Reach-1	35519.16	100 Yrs	2480.00	110.10	119.53	9.43	2.12	2.75	333.37	1172.20	836.89
Reach-1	35519.16	250 Yrs	2810.00	110.10	119.74	9.64	2.31	3.02	337.09	1216.45	860.05
Reach-1	35519.16	500 Yrs	3030.00	110.10	119.90	9.80	2.42	3.18	339.62	1250.63	877.82
Reach-1	35451.72	1 Yr	940.00	108.20	115.19	6.99	2.98	2.98	73.06	315.43	315.43
Reach-1	35451.72	2 Yrs	1130.00	108.20	115.61	7.41	3.25	3.25	77.32	347.46	347.46

HEC-RAS Plan: Multi_USACE   River: Bronx River   Reach: Reach-1 (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	35451.72	5 Yrs	1450.00	108.20	116.26	8.06	3.63	3.63	83.83	399.84	399.84
Reach-1	35451.72	10 Yrs	1690.00	108.20	116.71	8.51	3.85	3.85	88.34	438.63	438.63
Reach-1	35451.72	25 Yrs	1980.00	108.20	117.08	8.88	4.20	4.20	92.01	471.71	471.71
Reach-1	35451.72	50 Yrs	2230.00	108.20	118.40	10.20	3.69	3.71	177.05	604.33	600.10
Reach-1	35451.72	100 Yrs	2480.00	108.20	119.42	11.22	3.48	3.53	204.86	713.37	699.89
Reach-1	35451.72	250 Yrs	2810.00	108.20	119.60	11.40	3.83	3.89	209.20	733.12	717.97
Reach-1	35451.72	500 Yrs	3030.00	108.20	119.74	11.54	4.05	4.12	212.60	748.59	732.12
Reach-1	35432.17 350+00US	1 Yr	940.00	106.60	115.24	8.64	1.83	2.03	114.36	512.93	368.54
Reach-1	35432.17 350+00US	2 Yrs	1130.00	106.60	115.67	9.07	2.02	2.22	121.84	559.70	387.90
Reach-1	35432.17 350+00US	5 Yrs	1450.00	106.60	116.34	9.74	2.30	2.49	133.02	630.92	417.38
Reach-1	35432.17 350+00US	10 Yrs	1690.00	106.60	116.79	10.19	2.48	2.66	140.69	680.08	437.74
Reach-1	35432.17 350+00US	25 Yrs	1980.00	106.60	117.06	10.46	4.13	4.29	49.52	479.08	449.67
Reach-1	35432.17 350+00US	50 Yrs	2230.00	106.60	118.47	11.87	2.59	2.66	176.72	859.82	512.15
Reach-1	35432.17 350+00US	100 Yrs	2480.00	106.60	119.47	12.86	2.56	2.58	202.01	967.17	556.59
Reach-1	35432.17 350+00US	250 Yrs	2810.00	106.60	119.66	13.06	2.84	2.85	205.69	987.85	565.15
Reach-1	35432.17 350+00US	500 Yrs	3030.00	106.60	119.81	13.21	3.02	3.01	212.59	1003.87	571.78
Reach-1	35402.98 350+00BR		Bridge								
Reach-1	35371.65 349+45DS	1 Yr	940.00	107.12	115.11	7.99	2.57	2.80	82.01	365.14	314.16
Reach-1	35371.65 349+45DS	2 Yrs	1130.00	107.12	115.50	8.38	2.85	3.12	85.27	396.45	333.50
Reach-1	35371.65 349+45DS	5 Yrs	1450.00	107.12	116.08	8.96	3.27	3.60	90.82	442.86	362.04
Reach-1	35371.65 349+45DS	10 Yrs	1690.00	107.12	116.46	9.34	3.57	3.92	94.21	473.62	380.95
Reach-1	35371.65 349+45DS	25 Yrs	1980.00	107.12	116.76	9.64	5.00	5.00	49.52	395.94	395.94
Reach-1	35371.65 349+45DS	50 Yrs	2230.00	107.12	117.97	10.85	3.75	4.09	112.48	595.44	455.87
Reach-1	35371.65 349+45DS	100 Yrs	2480.00	107.12	118.41	11.29	3.93	4.28	151.70	630.81	477.62
Reach-1	35371.65 349+45DS	250 Yrs	2810.00	107.12	118.68	11.56	4.31	4.68	167.15	651.97	490.63
Reach-1	35371.65 349+45DS	500 Yrs	3030.00	107.12	118.68	11.56	4.65	5.05	167.16	651.99	490.64
Reach-1	35356.77	1 Yr	940.00	108.20	115.06	6.86	3.10	3.10	66.69	303.00	303.00
Reach-1	35356.77	2 Yrs	1130.00	108.20	115.45	7.25	3.44	3.44	69.48	328.93	328.90
Reach-1	35356.77	5 Yrs	1450.00	108.20	116.01	7.81	3.92	3.94	76.70	369.81	367.77
Reach-1	35356.77	10 Yrs	1690.00	108.20	116.38	8.18	4.23	4.29	82.85	399.38	393.76
Reach-1	35356.77	25 Yrs	1980.00	108.20	116.78	8.58	4.56	4.68	89.47	433.78	421.76
Reach-1	35356.77	50 Yrs	2230.00	108.20	117.91	9.71	4.09	4.40	108.23	544.61	501.06
Reach-1	35356.77	100 Yrs	2480.00	108.20	118.35	10.15	4.18	4.59	131.22	593.93	532.02
Reach-1	35356.77	250 Yrs	2810.00	108.20	118.61	10.41	4.50	5.01	146.47	624.02	550.08
Reach-1	35356.77	500 Yrs	3030.00	108.20	118.59	10.39	4.87	5.42	144.98	622.44	549.14
Reach-1	35349.20 349+20DAM		Inl Struct								

HEC-RAS Plan: Multi_USACE River: Bronx River Reach: Reach-1 (Continued)

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Max Chl Dpth	Vel Total	Vel Chnl	Top Width	Flow Area	Area Channel
			(cfs)	(ft)	(ft)	(ft)	(ft/s)	(ft/s)	(ft)	(sq ft)	(sq ft)
Reach-1	35341.02 349+20DAMDS	1 Yr	940.00	108.20	113.82	5.62	4.18	4.18	58.73	224.92	224.92
Reach-1	35341.02 349+20DAMDS	2 Yrs	1130.00	108.20	112.67	4.47	7.04	7.04	53.99	160.51	160.51
Reach-1	35341.02 349+20DAMDS	5 Yrs	1450.00	108.20	113.49	5.29	7.04	7.04	57.37	205.88	205.88
Reach-1	35341.02 349+20DAMDS	10 Yrs	1690.00	108.20	114.06	5.86	7.06	7.06	59.73	239.30	239.30
Reach-1	35341.02 349+20DAMDS	25 Yrs	1980.00	108.20	115.66	7.46	5.75	5.76	72.18	344.17	343.76
Reach-1	35341.02 349+20DAMDS	50 Yrs	2230.00	108.20	117.72	9.52	4.24	4.53	105.10	525.56	487.80
Reach-1	35341.02 349+20DAMDS	100 Yrs	2480.00	108.20	118.18	9.98	4.30	4.72	126.08	576.27	519.61
Reach-1	35341.02 349+20DAMDS	250 Yrs	2810.00	108.20	118.41	10.21	4.64	5.17	132.69	606.00	535.78
Reach-1	35341.02 349+20DAMDS	500 Yrs	3030.00	108.20	118.36	10.16	5.05	5.61	130.90	600.00	532.60
Reach-1	35253.84	1 Yr	940.00	106.90	113.85	6.95	2.96	3.06	70.92	317.16	305.05
Reach-1	35253.84	2 Yrs	1130.00	106.90	112.80	5.90	4.51	4.54	59.28	250.54	248.89
Reach-1	35253.84	5 Yrs	1450.00	106.90	113.59	6.69	4.83	4.96	67.77	300.26	291.34
Reach-1	35253.84	10 Yrs	1690.00	106.90	114.15	7.25	5.01	5.22	74.78	337.53	321.18
Reach-1	35253.84	25 Yrs	1980.00	106.90	115.69	8.79	4.39	4.80	98.04	450.69	403.58
Reach-1	35253.84	50 Yrs	2230.00	106.90	117.73	10.83	3.37	4.08	189.24	661.61	513.06
Reach-1	35253.84	100 Yrs	2480.00	106.90	118.20	11.30	2.97	4.19	209.13	834.58	538.16
Reach-1	35253.84	250 Yrs	2810.00	106.90	118.43	11.53	3.17	4.59	216.72	885.17	550.88
Reach-1	35253.84	500 Yrs	3030.00	106.90	118.39	11.49	3.46	4.98	215.36	876.48	548.72
Reach-1	35175.60 347+60US	1 Yr	940.00	107.31	113.79	6.48	3.04	3.07	59.99	308.95	305.77
Reach-1	35175.60 347+60US	2 Yrs	1130.00	107.31	112.63	5.32	4.66	4.66	54.38	242.28	242.27
Reach-1	35175.60 347+60US	5 Yrs	1450.00	107.31	113.42	6.11	5.05	5.07	58.15	287.03	285.58
Reach-1	35175.60 347+60US	10 Yrs	1690.00	107.31	113.98	6.67	5.28	5.34	60.92	320.31	315.99
Reach-1	35175.60 347+60US	25 Yrs	1980.00	107.31	115.57	8.26	4.92	4.92	54.54	402.66	402.23
Reach-1	35175.60 347+60US	50 Yrs	2230.00	107.31	117.66	10.35	3.83	4.18	215.81	582.99	516.04
Reach-1	35175.60 347+60US	100 Yrs	2480.00	107.31	118.10	10.79	3.97	4.42	248.31	624.55	540.08
Reach-1	35175.60 347+60US	250 Yrs	2810.00	107.31	118.31	11.00	4.35	4.88	264.57	645.65	551.56
Reach-1	35175.60 347+60US	500 Yrs	3030.00	107.31	118.25	10.94	4.74	5.31	261.73	639.20	548.10