Bronx River Corridor Study and Management Plan for Westchester County, NY – Volume II

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EXECUTIVE SUMMARY

Improving the health, ecology, and aesthetic of the Bronx River Parkway Reservation has been championed by Westchester County and its residents for nearly a century. Recent advancements in river science and engineering provide a new opportunity to assess the Bronx River's condition and identify approaches to reduce flooding and erosion while further enhancing the aesthetic and habitat within the Reservation. Towards this end, a two volume Bronx River Corridor Study and Management Plan was developed for the Westchester County Soil and Water Conservation District and Westchester County Department of Planning to improve channel stability, aquatic and riparian habitat, and recreational opportunities along the Bronx River while simultaneously reducing flood and erosion hazards. Volume I completed in May 2019 identified how centuries of human alterations along the river and in the surrounding watershed are responsible for degraded aquatic habitat, persistent flooding and erosion, and ongoing channel adjustments. Short segments of the river and adjoining corridor were rated in terms of their presence of certain conditions that are associated with stable equilibrium channels, high-quality habitat, limited flooding and erosion, and existing or potential recreational opportunities. Those segments ranking poorly for these various attributes are considered to be in greater need of human intervention to improve the conditions through stream restoration, flood control or bank stabilization, and other actions.

Volume II of the Management Plan is presented here and identifies specific restoration approaches, hazard mitigation efforts, and other channel management strategies that can be used to address eight identified objectives that when achieved would result in: 1) improved water quality; 2) less extensive and less frequent hazardous flooding and erosion; 3) enhanced aquatic habitat; 4) greater connectivity between the river and floodplain; 5) the restoration of natural channel processes including a meandering river planform; 6) controlling the spread of invasive species; 7) enhanced natural riparian vegetation; and 8) improved recreational opportunities along the river. To work towards achieving those objectives, 10 restoration alternatives were identified (some embodying multiple techniques) for use on the Bronx River and rated in terms of their effectiveness in addressing the project's eight objectives and the cost of implementation: 1) increase floodplain connectivity (generally an expensive approach such as removing artificial fill or elevating the Parkway on a viaduct); 2) remove channel obstructions (generally very expensive such as removing check dams); 3) resize bridges and culverts (generally very expensive to reduce flooding and improve habitat); 4) reestablish meandering planform (ranging from relatively inexpensive to expensive approaches such as removing bank armor to excavating new meanders using natural channel design principles); 5) biostabilization (typically a moderately expensive approach including the construction of marginal log jams or rock vanes with log supports); 6) in-stream habitat enhancement (generally moderately expensive using techniques such as boulder clusters and partially buried logs); 7) invasive species control and riparian plantings (ranging from inexpensive to moderately expensive options); 8) improve recreational opportunities (ranging from inexpensive to very expensive where supporting infrastructure modifications are required); 9) stormwater upgrades (ranging from inexpensive to expensive); and 10) channel management strategies (inexpensive passive approaches such as leaving fallen wood in place when safe to do so or creating a "watch" list to take advantage of other projects as they arise such as bridge replacements to reduce the cost of resizing the structure).

To identify where on the river these restoration options would be best applied, the river was partitioned into 97 discrete segments of uneven length (including two assessed tributaries – Laurel Brook and Grassy Sprain Brook) with similar conditions along their length but distinct from adjacent segments. The Volume I assessment data was used to determine how well each segment's conditions met the eight project objectives. Segments were considered a high priority for restoration if the current conditions do not reflect the ideal conditions embodied by the objectives. By rating each objective separately within any given segment, the best restoration alternative could be selected for implementation. In this way, the highest priority sites for restoration and the most impactful restoration alternatives to use at those sites were identified throughout the full length of the Bronx River in Westchester County.

The restoration prioritization process, however, could not address all of the local issues that might preclude restoration in a particular area such as landowner resistance or proximity to critical infrastructure nor could the specific techniques to be used and their precise location be identified. Additionally, the status of the Bronx River Parkway Reservation as a National Register-Listed property was not taken into consideration when identifying restoration needs (Volume I) and prioritizing potential projects (Volume II), but preserving the historic character of the Reservation, as has been successfully accomplished with several other recently completed capital improvement projects, must be considered among other local issues when undertaking detailed restoration planning at a specific site.

To illustrate the more detailed restoration planning process, conceptual restoration designs were developed for five restoration reaches in the following areas: 1) Dewitt Avenue and confluence of Grassy Sprain Brook; 2) Crestwood Station; 3) Scarsdale Village south past Harney Road; 4) County Center; and 5) Fisher Lane and North White Plains Station. All five sites include one or more bridges that require resizing with the recommended dimensions of the new structures often more than twice the current span. Each site includes several potential projects ranging from inexpensive options that can be implemented readily such as invasive species control to very expensive options such as building elevated garages to replace existing parking lots built on artificial fill that constrains the floodplain (as at the Fisher Lane site). Implementation of simpler and less expensive projects in the short term could build the public support necessary for planning and ultimate construction of larger more complex multi-year endeavors.

The comprehensive restoration of the Bronx River, ultimately over several decades, has the potential to create a corridor with both lateral connectivity (between the channel and floodplain) and longitudinal connectivity (no blockages by bridges or check dams down the length of the river). As the connectivity improves, the impacts to natural river processes and the ecosystem, resulting from urbanization and a long history of channel alterations, will be minimized and the hazards associated with flooding and erosion greatly mitigated. As progress is made over several years, restoration in one area may lead to improvements elsewhere such that priority areas for restoration may change over time. The assessment approach presented in Volume I and the restoration prioritization process detailed in Volume II were designed to be replicable, so the same methods can be repeated in the future and restoration priorities updated to reflect ongoing changes on the river (that can be charted through a recommended monitoring protocol). In this way the BRCSMP represents a "living document" that will still be valuable even as the river and priorities change. While the eight project objectives may never be fully achieved, all future activities in the corridor for years to come should progress towards the aspirations the objectives embody such that all future bridge work should increase hydraulic, geomorphic, and ecological connectivity rather than continue to constrain it, future bank stabilization projects should simultaneously improve aquatic habitat rather than harm it by using biostabilization rather than hard armoring, and future road work or other construction on the floodplain should improve flow conveyance on the floodplain rather than block it. By taking limited steps little by little, future generations will experience a healthier river offering more enriching experiences without the same unstable conditions facing residents today.

1.0 INTRODUCTION

The Westchester County Soil and Water Conservation District and Department of Planning contracted with Field Geology Services, LLC and Tau Engineering PC to develop a two-volume Bronx River Corridor Study and Management Plan (BRCSMP) with the goal of identifying and prioritizing opportunities for reducing flooding and erosion along the Bronx River while simultaneously improving channel stability, aquatic habitat, and recreational use within the river corridor. The term river “corridor” is defined here as the valley bottom area across which the river flows (or once flowed) and includes the floodplain as well as areas of artificial fill on the valley bottom that have raised the valley bottom above the level of the largest floods. The area covered by the BRCSMP covers the 14.1 mile length of the Bronx River and adjacent floodplain corridor in Westchester County from Kensico Dam in Valhalla, NY to the Bronx border in Yonkers, NY (Figure 1). Two tributaries, Grassy Sprain Brook and Laurel Brook, were also investigated as part of the Volume I assessments given their close association with known areas of concern on the Bronx River itself.

Volume I of the two-volume BRCSMP was previously completed and presents the results of a geomorphic and hazard assessment that were used to identify the locations where human modifications of the corridor and watershed at large have exacerbated flooding and erosion, degraded aquatic habitat, destabilized the channel, and limited recreational opportunities. The Bronx River mainstem was initially subdivided into 20 reaches (Figure 2) (numbered sequentially from the downstream end as BR_01 to BR_20) with the assessment findings used to further divide the river into 97 segments (including the two tributaries) of uneven length with similar conditions along their length but distinct from adjacent segments. (The segments are labeled with the reach number within which they are located and letters added sequentially from the downstream end such that BR_10B represents the second segment from the downstream end in Reach 10.) Volume I prioritized the “need” for restoration (or other forms of action) in each segment to accomplish hazard reductions, habitat improvements, and increases in recreational use.

Volume II of the BRCSMP is designed to answer the dual questions of “*Where should restoration (or other activities) occur?*” and “*What should be done?*” to improve river conditions. The answer to the first question is addressed by determining how well the existing conditions already achieve the eight BRCSMP objectives (Table 1) with restoration prioritized in those segments that depart the furthest from the ideal conditions reflected by the objectives (see Section 3.2 below). The second question is answered by aligning 10 general restoration alternatives (see Section 3.1 below) with their perceived effectiveness of achieving the eight objectives in each segment.

Once general strategies for addressing the “needs” of the 97 segments have been identified and prioritized, more detailed design concepts are presented for five sites to illustrate how a range of restoration alternatives varying in cost and complexity can be planned for a single or several contiguous segments to fulfill the eight objectives with consideration given to the specific techniques to be used, their location and dimensions, their phasing through time, and the cost of implementation (see Section 4.0 below). After providing a brief summary of Volume I (Section 2.0), Volume II, presented below, details the prioritization process (Section 3.0) and design concepts (Section 4.0) before providing recommendations for moving forward (Section 5.0).

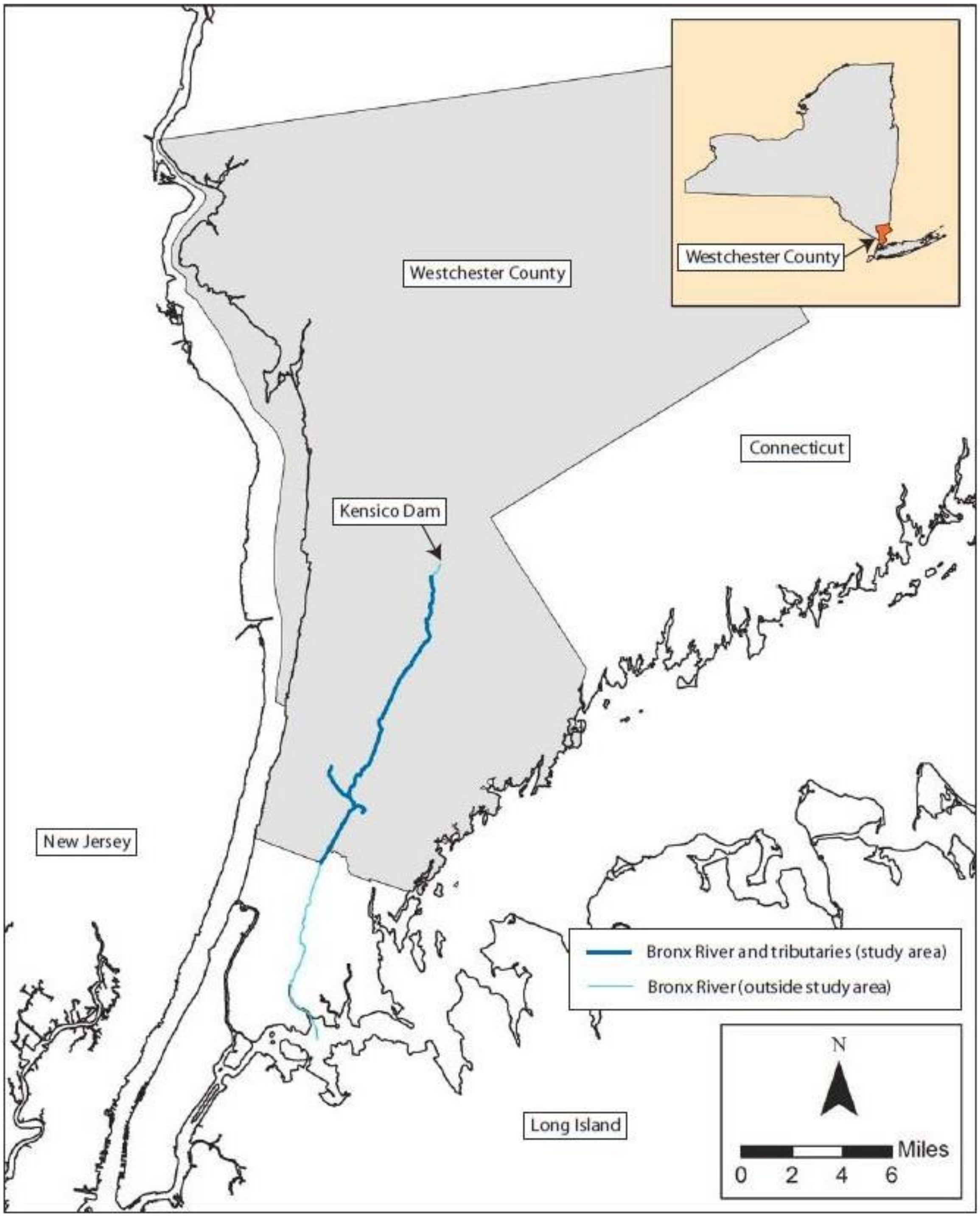

Figure 1. Location of Bronx River corridor in Westchester County, N.Y.

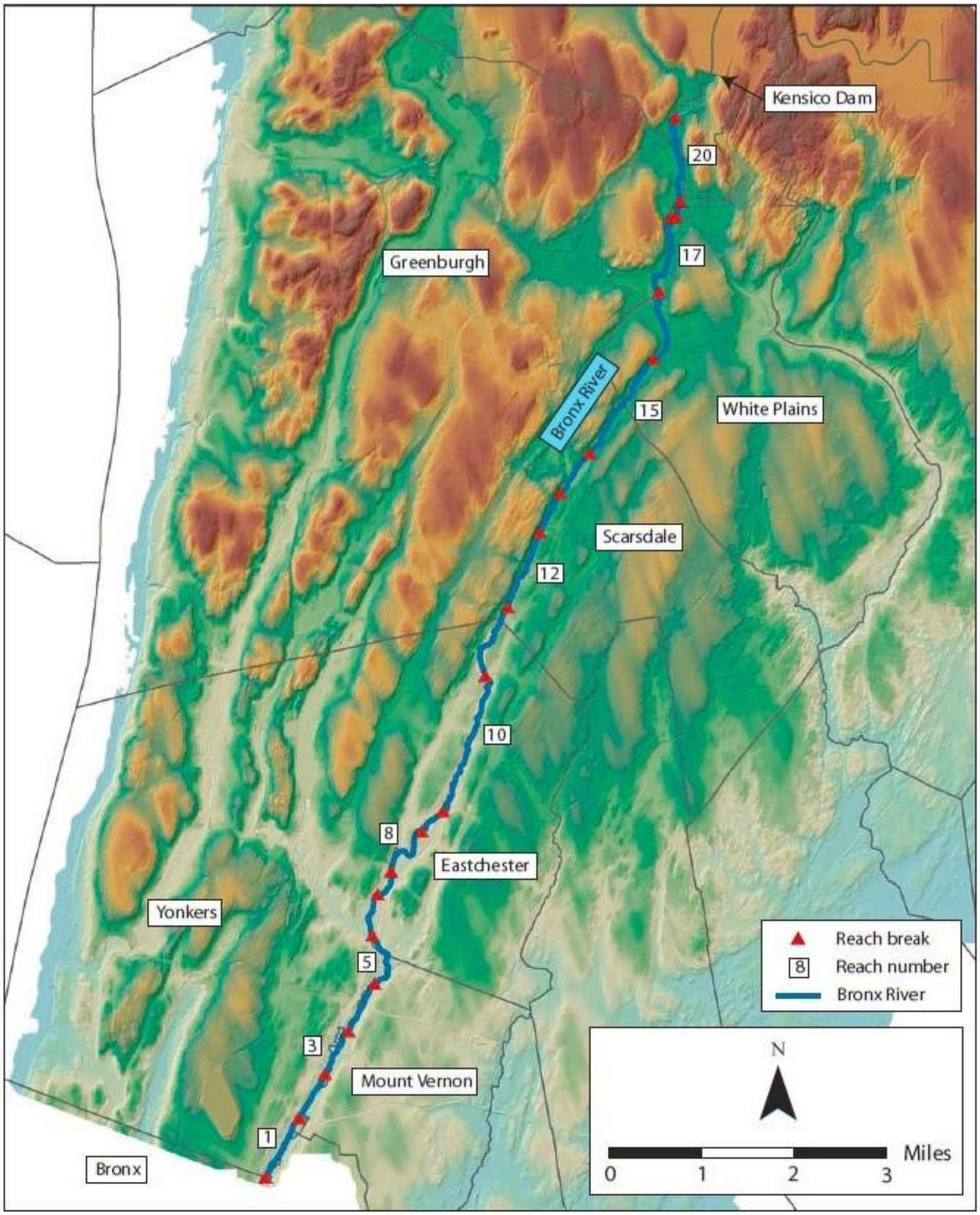

Figure 2. Geomorphic reaches on the Bronx River and the two assessed tributaries.

BRCSMP Objective	Weighting factor*
Improve water quality	4
Mitigate flood and erosion hazards	5
Enhance aquatic habitat	4
Increase floodplain connectivity	5
Restore natural river processes	4
Control the spread of invasive species	3
Enhance natural riparian vegetation	3
Develop recreational opportunities	2

*Weighting factor reflects the relative importance stakeholders assigned to each objective with higher numbers reflecting a greater importance

Table 1. List of BRCSMP objectives and weighting factor assigned to each. The hazard mitigation objective is a condensation of three hazard related objectives presented in Volume I (Section 5.1). The riparian vegetation and recreational opportunities objective were not included in Volume I but are added here for the first time to better reflect the overall goals of the BRCSMP.

2.0 VOLUME I SUMMARY

The Bronx River Corridor Study and Management Plan (BRCSMP) consists of two volumes. Volume I with its baseline assessment of the river's physical and biological conditions established the framework for Volume II presented here. Volume I's snapshot-in-time observations of river conditions located problems within the river corridor such as flood hazards and degraded aquatic habitat, linked those problems causally to past human activities such as undersized bridge crossings and artificial channel straightening, and developed a replicable methodology for future measurements and assessments. Volume I included a detailed review of documents spanning hundreds of years to provide a historical context for understanding the river's current condition that will, in turn, serve as the baseline for assessing improvements resulting from future BRCSMP restoration initiatives.

A foundational component of Volume I was input from a stakeholder group consisting of staff from multiple Westchester County government departments (including the Department of Planning and the Soil and Water Conservation District) who make day-to-day and major capital improvement project decisions within the Bronx River corridor. The stakeholder group also included staff of elected officials who represent constituents who live in the river corridor and experience the positive attributes of the river, (i.e. recreation, flora, and fauna) as well as the problems such as flooding. Non-profit organizations whose mission is to invite the public to enjoy the Bronx River also served as stakeholders (e.g., Bronx River Alliance). From this diverse group of people, eight key problems were articulated and addressing these problems was later reframed as the BRCSMP's objectives (Table 1). The identified problems, not necessarily all present everywhere on the river or at any single point, are:

- Poor water quality in the river
- River caused flooding and erosion hazards
- Degraded aquatic habitat
- Nominal or non-existent floodplain connection with the river channel
- River conditions inconsistent with natural processes
- Spread of invasive plant species
- Limited to no riparian vegetation along the river
- Limited opportunity to recreate on the river

Identifying the cause and location of these problems were the focus of the Volume I assessments of hazards and geomorphic conditions. These investigations collected remote sensing data (e.g., aerial photographs and Geographic Information System [GIS] data), conducted field observations by walking the entire 14.1 mile length of the Bronx River within Westchester County, and completed one-dimensional hydraulic modeling at select locations. The results of these investigations were the basis for subdividing the river and two assessed tributaries into 97 segments with relatively uniform character within a given segment but distinct from adjacent segments. The severity of the eight problems listed above within each segment was also determined. Overall, the important findings of Volume I were:

- Over 70 buildings are within flood prone areas;
- Eight locations where the Bronx River Parkway is predicted to be frequently inundated by floodwaters;
- Over five miles of eroding river bank that contribute to poor water quality with 10 erosion sites having a high to moderate severity of impacting nearby infrastructure;
- An additional 8.5 miles of river bank are armored and protected from erosion (although some of that armor is failing), meaning roughly half of the 28.2 miles of river bank either have been, currently are, or were perceived to be susceptible to erosion;
- More than 90 percent of the river channel was artificially straightened multiple times in the past with meanders having naturally reformed in multiple locations in the past century;
- Numerous undersized bridge crossings and check dams that partially or fully obstruct the channel's cross section and exacerbate upstream flooding;
- The placement of artificial fill on the floodplain severely constrains the river channel in many locations with overbank flow blocked from spreading over the floodplain throughout much of the river's length; and
- Invasive species are found along most of the river's length and represent the dominant bank vegetation in many segments.

The 97 delineated segments partition the river into manageable lengths for the restoration planning process described in Volume II. The Volume I analysis determined the "need" for restoration in each segment based on how closely the documented observations and measurements reflect natural river conditions with good water quality, minimal infrastructure threatened by flooding, good connectivity between the channel and floodplain, no channel obstructions restricting the flow of water or movement of aquatic organisms, and healthy riparian vegetation free of invasive species. With an understanding of what is required to achieve the eight BRCSMP objectives (Table 1), site specific restoration strategies can be developed to improve the health of the Bronx River even if the ideal natural condition is ultimately unattainable.

(The location of the segments and all other GIS data generated during both the Volume I and Volume II phases of the project, such as the location of eroding banks, are included as a digital supplement to this report and available at www.westchestergov.com/bronxriver or www.westchestergov.com/soilwater. The GIS files are also available upon request from the Westchester County Department of Planning. All Volume I and Volume II tables are also included in the digital supplement as Excel or Word files for better readability and to make changes as restoration efforts progress and priorities change.)

3.0 RESTORATION PRIORITIZATION

To achieve the BRCSMP goals of reducing flooding and erosion hazards while enhancing aquatic habitat and recreational opportunities, implementation of hazard mitigation and river restoration projects must address the segment "needs" identified as part of Volume I. Dozens of techniques have been utilized worldwide to reduce flooding, control bank erosion, enhance aquatic habitat, and restore natural channel processes (Yochum, 2018; Wohl et al., 2015; Cramer, 2012; Reich et al., 2003; Roni et al., 2002; Rosgen, 1996). Of the panoply of restoration techniques available, ten general restoration alternatives (and specific associated techniques) have been identified that best address the BRCSMP objectives (Table 2 and Appendix 1). (All of the Volume I and Volume II tables are also provided in the digital supplement to this report in Excel or Word format, so they can be more easily read and manipulated if desired.) Most of the 10 restoration alternatives embody multiple restoration techniques that achieve similar improvements related to the eight objectives. A description of each alternative is provided below (Section 3.1) before detailing the process for prioritizing the best restoration alternatives to use within each of the 97 segments delineated on the Bronx River in Westchester County (Section 3.2).

	Specific techniques (organized by cost and complexity)		
Restoration alternatives	**High**	**Moderate**	**Low**
Increase floodplain connectivity	- Remove fill - Viaducts & raised structures	- Lateral relief culverts - Longitudinal relief culverts - Remove berms/constraints	
Remove channel obstructions	- Dismantle check dams - Move sewer line - Bury sewer pipes/utilities		
Resize culverts and bridges	- Increase crossing span		
Reestablish meandering planform	- Excavate meanders	- Divert into old meanders - Construct marginal log jams	- Remove bank armor
Biostabilization		- Construct marginal log jams - Crib walls - Boulder deflectors/vanes	- Brush mattresses
In-stream habitat enhancement		- Construct marginal log jams - Boulder supported log jams	- Partially buried logs - Boulder clusters
Invasive species control/riparian plantings		- Plant larger mature trees - Deep excavation of invasives - Chemically treat invasives	- Plant young saplings - Cover invasives w/ dark fabric
Improve recreational opportunities	- Develop boating areas - Outdoor amphitheater	- Add recreational paths - Native plant gardens	- Install play/exercise areas - Install picnic tables - Develop interpretive signs
Stormwater upgrades	- Bury/move obstructing pipes	- Flap gates on outfalls	
Channel management strategies		- Annual monitoring - Public outreach/pamphlets	- Leave wood in place - Reduce road sanding/salting - Create a "watch" list - Avoid bank armoring

Table 2. Ten restoration alternatives useful for the Bronx River and the various techniques within those alternatives that can be used (organized by their perceived relative cost and complexity).

3.1 Restoration alternatives

The 10 restoration alternatives identified for realizing the BRCSMP objectives are summarized in Table 2, illustrated with typical drawings in Appendix 1, and each described more thoroughly below. (In Appendix 1, no typical drawings were developed for the "stormwater upgrades" or "channel management strategies" alternatives.)

3.1a Increase floodplain connectivity

Human activities within the Bronx River corridor have largely disconnected the river channel from its adjacent floodplain. This has largely resulted from: 1) artificial filling of the floodplain surface such that no floods are able to spread out over areas elevated by fill (e.g., the area across the river from Scout Field) and 2) the development of a transportation network (railways and roadways) that in many instances has blocked flow from either laterally (when a slightly elevated road runs parallel to the river channel) or longitudinally (elevated approaches to bridges crossing the river) flowing on the floodplain. This loss of floodplain connectivity is widespread within the Bronx River corridor and results in higher flow velocities and depths during floods, which, in turn, causes greater channel instability (i.e., bank erosion), degraded aquatic and wetland habitat (i.e., logs and other cover structures washed out of the channel), and deeper and more frequent inundation of remaining portions of floodplain. Restoring floodplain connectivity, therefore, would not only help achieve the eponymous objective but also the objectives of hazard mitigation and enhancing aquatic habitat, while perhaps also creating additional space for recreational opportunities.

Increasing floodplain connectivity can be achieved through multiple restoration techniques including, but not limited to: 1) removing berms and other floodplain encroachments (Figure 3), b) floodplain reclamation through the removal of fill, 3) installation of lateral floodplain relief culverts to allow floodwaters to pass under roads and railways, 4) installation of longitudinal relief culverts under bridge approaches, and 5) construction of viaducts to elevate (portions of) roadways and railways in the corridor above the floodplain surface (Appendix 1). Most of these techniques would be of high cost given the amount of earth moving and disturbance to transportation networks required with some (e.g., elevated viaduct) far more expensive and difficult to implement than others (e.g., lateral relief culverts under smaller access roads). The actual costs and complexities of such projects will be highly variable and depend on site specific conditions and constraints. Small select projects targeted to high priority segments (see Section 3.2 below) may still be practical such as, for example, installing longitudinal relief culverts where bridge approaches are blocking the floodplain and contributing to flooding of a high hazard area (e.g., Dewitt Avenue). Furthermore, potential projects that are currently deemed infeasible to proceed could be placed on a "watch" list, so they can be reconsidered when a section of road, for example, is slated for resurfacing and installation of lateral relief culverts would be far less expensive and complex if included as part of the larger road repair project. Twenty segments share the highest priority score for increasing floodplain connectivity (see Section 3.2 below), emphasizing the great need for floodplain reclamation on the Bronx River. Therefore, the two or three segments with the greatest potential increase in floodplain width should be given serious consideration for further site-specific project design and implementation despite the likely high cost and complexity.

Figure 3. Berm removal (left) on Long Creek floodplain in October 2019 in South Portland, ME resulted in flow on the floodplain for the first time in more than 40 years (right) less than two months later during December 2019 rainstorm.

3.1b Remove channel obstructions

Artificial channel obstructions are human-made structures that block all or a portion of the river channel, which, for the Bronx River, includes check dams (n=6), low weirs protecting utility line crossings (n=6), a sewer line (on Laurel Brook), trash booms (n=2), and undersized road and rail crossings (although these are addressed separately in Section 3.1c below). [Natural channel obstructions, such as log jams, are also present on the river but are discussed separately as part of Section 3.1j below.] The artificial obstructions on the river are generally narrow and oriented perpendicular to the river's flow direction with the notable exception of the sewer line that runs parallel to Laurel Brook and obstructs a portion of the channel. Nationally, check dams and small run-of-the-river dams (where water spills over the top) were typically installed in the 18th and 19th centuries to raise water elevations to power mill dams. In the 20th century, check dams, like those on the Bronx River, were installed to protect infrastructure from erosion. Recently, check dams are being increasingly replaced with armored rock riffles or step pools to enable easier passage of aquatic organisms.

Channel obstructions can greatly alter a river's geomorphic and ecological function (Brandt, 2000). Unaltered natural rivers tend towards the development of a smooth graded concave up longitudinal profile where the change in slope from point to point from the river's headwaters to the mouth is minimized (Leopold and Maddock, 1953). This grading leads to effective sediment transport along the rivers length with the sediment that is deposited distributed evenly along its length rather than focused in small areas. The check dams on the Bronx River, and dams in general, create a sharp nearly vertical drop in the river profile, disrupting the ideal natural graded condition where no rapid changes in slope occur. As a result, dams are associated with erosion downstream in order to replenish the sediment load deposited in the upstream impoundment where the river's slope has been reduced (Kondolf, 1997). Ecologically, dams not only impede the upstream (and downstream) movement of aquatic species, but important habitat features (e.g., spawning gravels, pools) are buried in fine sediments upstream and washed away by erosion downstream.

While the trash booms and low weirs on the Bronx River are only minor obstructions and do not appear to have resulted in any significant loss of river function or adverse channel responses, the check dams on the Bronx River fully block the channel (Figure 4). The resulting check dams' impacts to river function extend both upstream and downstream, sometimes for several hundred feet. The impounded areas upstream of the check dams have largely lost their riverine character with emergent wetlands developed along the margins where sediment has accumulated over time. The sediment-free water flowing over the dams has led to bank erosion downstream, often treated with bank armor (Figure 4).

The check dams were likely originally built for aesthetic and recreational purposes. Large dams are sometimes used for downstream flood control by holding water in their upstream impoundments but the check dams on the Bronx River are too small to store sufficient volumes of flow to significantly attenuate flood peaks, especially when accounting for the loss in potential storage resulting from the sedimentation in the impoundments. Removing the check dams would address the objectives to restore natural channel processes and enhance aquatic habitat without exacerbating downstream flooding. While their removal could potentially reduce the existing recreational benefits associated with the upstream impoundments (e.g., walking trails, birdwatching), other new and unique recreational opportunities within the Bronx River corridor could emerge, such as canoeing and kayaking, if long uninterrupted sections of free-flowing river are restored.

Figure 4. Check dam downstream of Harney Road fully blocks the channel. Note bank armor extending downstream.

The removal of channel obstructions, particularly the check dams, will restore the river's function and character to those areas impacted by the structures. The cost and complexity of removing channel obstructions will be highly variable depending on the nature of the obstruction and its location. Check dam removal is likely to be expensive and complex. Their removal will require bank and bed restoration to protect the newly exposed banks and to manage the release of impounded sediments upstream. All of the check dams are run-of-the-river structures (i.e., water runs over the top of them) and do not impede floodwaters, so their removal will have little to no impact on flood levels downstream. Removing the trash booms and utility lines would be far simpler to implement, but given the limited impact these structures are having on river function they are not a high priority restoration target unless the utility lines themselves may be threatened by bank erosion or bed scour. Partial removal of obstructions is an alternative that could be pursued on a case-by-case basis to reduce the cost and complexity of implementation, but would necessarily result in only partial achievement of BRCSMP objectives. All of the check dams should be placed on a "watch" list as these structures will eventually need costly maintenance and repairs at which time their removal or partial removal may be viewed as more desirable and feasible.

3.1c Resize culverts and bridges

The Bronx River passes under (or through) over 75 road, rail, or pedestrian bridges and culverts. Several of these fully span the river and its floodplain such that these structures have no observable impact on the river's geomorphic or ecosystem function (Figure 5a). However, a majority of the structures obstruct a portion of the channel's bankfull width (Figure 5b) with the approaches often blocking all or part of the floodplain as well. Undersized crossing structures represent partial channel obstructions with impacts to river and ecological function similar to other significant obstructions as described in Section 3.1b above.

A typical channel response to undersized bridges and culverts is for deposition to occur upstream as floods backwater upstream of the constricting structure with channel incision and bank erosion taking place downstream as the sediment-free high-velocity constricted flows exit the structure (Cenderelli et al., 2011). These channel adjustments generally become more pronounced as the degree of constriction by the structure increases. Flood hazard areas on the Bronx River are typically located in areas inundated due to backwatering upstream of undersized bridges and culverts (Figure 6). Undersized structures also alter the natural passage of sediment and nutrients downstream as well as the passage of recreational bikers who need to dismount to pass under bridges with particularly low clearances (Figure 5b). Resizing bridge crossings, therefore, helps fulfill the objectives of restoring natural processes, improving water quality, enhancing aquatic habitat, and improving recreational opportunities.

Figure 5. Some bridges a) fully span the bankfull channel of the Bronx River (Grassy Sprain Parkway) while b) others have spans narrower than the channel's bankfull width (Northbound lanes of Parkway in Garth Woods).

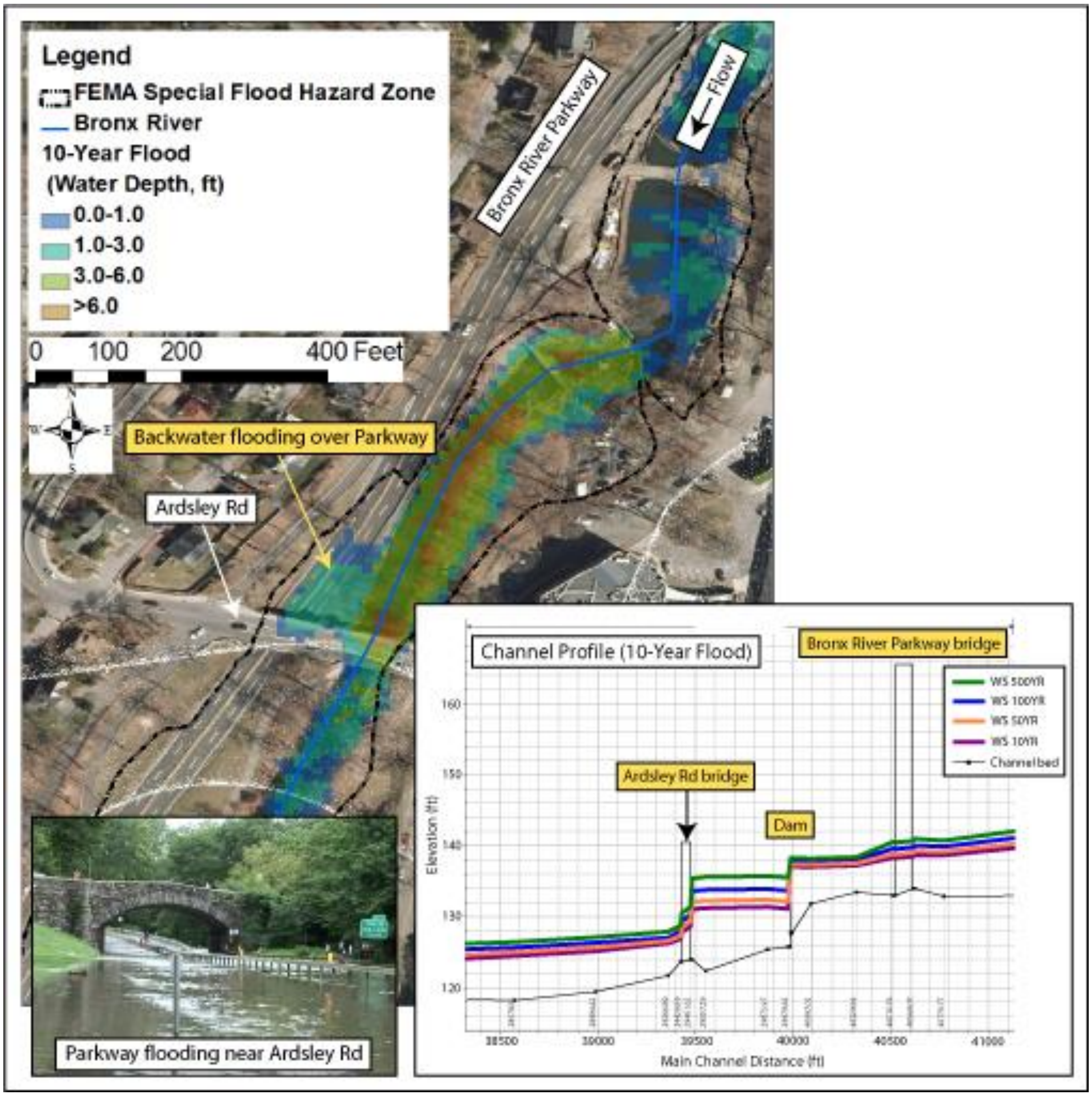

Figure 6. Planview map and longitudinal profile of hydraulic modeling near Ardsley Road reveals how undersized bridges cause backwater flooding upstream. Note the step up in the water surface profile upstream of Ardsley Road.

Increasing the width (and sometimes height) of undersized bridges and culverts reduce upstream flooding and downstream erosion while restoring geomorphic, hydraulic, and ecological continuity through the crossings (Figure 7). Since the morphology of river channels are largely controlled by bankfull flows that occur nearly once every year, river crossings should ideally have a span that at least matches the bankfull width. Spans of 1.25 times the bankfull width are typically the minimum recommended when resizing undersized crossings to ensure ecosystem continuity through the structure and to accommodate some channel adjustment over time (Web citation 1). An even greater width should be considered on the Bronx River at those crossings that must accommodate the bike path under the structure (Figure 5b). Where the floodplain is blocked by the road approaches, longitudinal relief culverts may also be advisable as presented in Section 3.1a above and Appendix 1.

Resizing bridges to span the entire channel may in some instances transfer the backwatering problem to undersized bridges further downstream. Undersized bridges impede the flow of water downstream and often cause higher water surface elevations upstream of the structure. Floodwaters will backwater upstream of an undersized bridge until the flow overtops a low spot on the road approaches or the structure itself. In these situations, little to no increase in downstream flooding should result from bridge widening. Careful consideration should be made for bridge crossings that completely contain floodwaters without overtopping as, in these instances, the bridge is essentially acting like a flood control dam and widening of the bridge could potentially increase flood conditions downstream. In these cases, detailed hydraulic modeling, such as the HEC-RAS software program, will need to be completed for bridges being considered for resizing to determine changes in downstream flood stages by comparing the existing and proposed conditions (see Section 5.0 below). Bridges particularly prone to backwatering should be considered a high priority for resizing as bridges are not designed or constructed as flood control dams and, therefore, may be at risk of failure during floods.

Figure 7. Paired photographs of a stream crossing on Long Mountain Brook in Coös County, NH a) before and b) after resizing the span in September 2008 to accommodate the channel's bankfull dimensions.

Many of the Bronx River crossing structures are among the contributing components of the Bronx River Parkway Reservation's historic character and its placement on the National Register of Historic Places. The resizing of any such crossings must preserve their historic character and be reviewed by the County's Historic Preservation Advisory Committee, Planning department, and Parks, Recreation and Conservation department as well as receive approval from the New York State Historic Preservation Office. The State's review is included in the state environmental quality review (SEQR) process that would be mandatory for any bridge resizing project. In the last 30 years at least three large capital improvement bridge and viaduct projects have been completed in the Reservation by the County's Department of Public Works and Transportation after passing through this historic review and approval process (e.g., Woodlands Viaduct, Harney Road Bridge, and Crane Road Bridge). The Harney Road Bridge, one of the original parkway structures and therefore of historic importance, was replaced in the 1990s with a concrete structure and faced with granite blocks to remain compatible with the historic character of the Reservation. This example demonstrates that the resizing of bridges and other structural crossings can be completed in a manner sensitive to historic preservation.

The cost and complexity of resizing undersized bridges and culverts should be considered high given the need to entirely rebuild the structure and the associated road, railway, or walking path. Three bridges with a high need for resizing are the railroad bridge downstream of Parkway Road, Harney Road Bridge, and Fisher Lane Bridge given the degree to which they constrict the river channel and, in some cases, result in upstream flooding. All of the undersized structures, even those not in priority segments, should be added to a "watch" list to take advantage of scheduled repair or replacement work when the cost and complexity of achieving an enhanced hydraulic section would be less prohibitive.

3.1d Reestablish meandering planform

Volume I documents multiple periods of artificial channel straightening along nearly the full length of the Bronx River since European settlement of the region (Figure 8). Channel straightening is often associated with other channelization processes such as the desnagging of wood, removal of gravel bars, and armoring of the banks as also occurred on the Bronx River. All of these activities lead to a loss of aquatic cover habitat, flow complexity, and other habitat features while increasing bank erosion as flood flows are accelerated through the shortened channel (Brookes, 1985). Artificially straightened channels are inherently unstable with a risk of rapid channel migration as the natural reformation of meanders following straightening is a common process on rivers throughout the northeastern United States (Field, 2007). While many meanders have already naturally reformed along the artificially straightened portions of the Bronx River (Figure 8b), restoring meanders on the remaining straightened sections of the river would address several BRCSMP objectives including mitigating flood and erosion hazards, enhancing aquatic habitat, and restoring natural river processes (as natural rivers with an adjacent floodplain tend to meander).

Figure 8. Example of a) artificially straightened channel near Scarsdale Village and b) naturally reformed meander downstream of Harney Road.

Reestablishing a meandering planform can be achieved through multiple restoration techniques including, but not limited to: 1) excavating meanders utilizing natural channel design principles (Rosgen, 1996); 2) diverting flow into existing previously abandoned meanders; 3) removing bank armor along straightened reaches to permit natural meander growth; and 4) constructing marginal log jams built along one bank in order to divert flows into the opposite bank to encourage meander growth (Figure 9; Appendix 1). Two or more of these techniques could be used together such as the use of marginal log jams to divert flow into the opposite bank where bank armor has been removed. These techniques include options that are of low (e.g., remove armor), moderate (e.g., marginal log jams), and high (e.g., excavate meanders) cost and complexity. The exact location and rate of meander formation would be more difficult to control unless high cost options such as excavating new meanders or diverting flow into former ones were utilized, so the lower cost options need to be thoroughly analyzed prior to implementation to ensure no infrastructure would be put at risk as new meanders develop. Encouraging meander development by removing armor or constructing marginal log jams will be largely restricted to those few areas where considerable space is available between the river and the Parkway or other infrastructure, although such space could be created as part of larger floodplain restoration projects such as elevating the Parkway on a viaduct (see Section 3.1a above). While removing riprap and encouraging meander formation may seem counterintuitive in terms of reducing hazards, meander development encouraged to occur along one section of a straightened channel may actually reduce the likelihood of rapid unplanned hazardous meander formation elsewhere with nearby infrastructure.

Figure 9. Flow diversion around a marginal log jam is enhancing meander formation on the opposite bank along Nash Stream in Coös County, NH.

3.1e Biostabilization

As detailed in Volume I, bank erosion was mapped along 17 percent of the banks with 28 erosion sites considered hazardous given their proximity to existing infrastructure. Rock revetments (i.e., riprap) are the traditional approach for stabilizing banks as has also been the case on the Bronx River where 34 percent of the total bank length is currently armored (see Volume I). Due to concerns that rock revetments may destabilize adjacent unarmored banks and degrade aquatic habitat (e.g., limits bank cover), biostabilization (i.e., use of vegetation and other natural materials in bank stabilization) is becoming an increasingly popular approach around the country (Web citation 2). Unchecked erosion does not only pose a risk to nearby infrastructure but degrades water quality and aquatic habitat through fine sediment deposition, particularly in impounded reaches of the Bronx River. Biostabilization would address several BRCSMP objectives including mitigating erosion hazards, enhancing aquatic habitat, and improving water quality.

Biostabilization can be completed using multiple restoration techniques including, but not limited to: 1) log crib walls; 2) marginal log jams; 3) brush mattresses; and 4) boulder deflectors with log supports (Figure 10; Appendix 1). Two or more of these techniques could be used together such as the use of marginal log jams at the base of the slope with brush mattresses on the upper slope. Marginal log jams and boulder deflectors are redirective techniques that divert the strongest erosive forces away from the bank. While log crib walls and brush mattresses leave the erosive forces acting on the bank, they may be more appropriate where the erosive forces are not as strong and along narrower sections of the Bronx River or tributaries where flow diversion techniques may negatively impact the opposite bank. Treating the base of an eroding river bank with brush mattresses alone is not advisable given the strong erosive forces in certain locations on the Bronx River, but this technique, given its lower cost than other treatments, may be well suited for the back edge of floodplains that would be bare after artificial fill removal projects designed to reconnect the floodplain with the channel (see Section 3.1a).

Figure 10. A series of marginal log jams protecting an eroding bank on the Connecticut River in Columbia, NH one year after construction.

While largely used in more rural and agricultural settings (Figure 10), the wood-based biostabilization techniques have also been used in urban and suburban environments as illustrated by some of the photographs in Appendix 1. Given the usually limited space available, wood might be better suited for bank stabilization projects in urban settings, because log jams and crib walls can be constructed vertically with stacked logs. This allows wood-based projects to be built without grading back the bank to a 3:1 or 4:1 slope as required for rock revetments that tend to be unstable if built on a steeply sloping bank. While wood used in log jams and crib walls decompose over time, their life span can be increased dramatically when using rot-resistant species and if the wood remains covered by sediment and brush, providing enough time for natural vegetation on the bank to mature sufficiently with soil-binding root systems that will sustain the bank stability. Furthermore, biostabilization projects may be more durable than rock revetments as projects using interlocking logs tend to work as a single unit withstanding the river's forces while an entire rock revetments can unravel with the displacement of a single rock that exposes the erodible bank material to the river's flow (see Section 4.3a in Volume I).

The cost and complexity of the biostabilization techniques are considered low to moderate (Table 2). Treating eroding banks with biostabilization techniques can simultaneously mitigate erosion hazards while improving aquatic habitat, two high priority objectives of the BRCSMP. Biostabilization techniques should be considered in any segment where bank stabilization is slated to occur. Consequently, all areas identified as erosion hazards in Volume I should be placed on a "watch" list to ensure biostabilization is included in any alternatives analysis during the early stages of bank stabilization design at any of these critical locations.

3.1f In-stream habitat enhancement

The mapping of channel features as part of the Volume I assessment documented the absence of high quality aquatic habitat features along long lengths of the Bronx River. Wood is a critical feature of high quality aquatic habitat on rivers in temperate climates such as New York. Streams with wood generally have higher fish populations (Flebbe, 1999), a greater abundance and richness of macroinvertebrates (Bond et al., 2006), deeper and more frequent pools (Montgomery et al., 1995), and more complex physical habitat (Benke and Wallace, 2003). The low levels of wood on the Bronx River (see Section 4.3e in Volume I) indicate poor cover and flow complexity. While some excellent habitat elements are present (e.g., good canopy, isolated log jams, numerous pools) (Figure 11a), the often long gaps between such features hinders the movement of species through the river system and jeopardizes ecosystem diversity. Therefore, restoring aquatic habitat to fill in the gaps will be essential for fulfilling the BRCSMP objective to enhance aquatic habitat.

In-stream habitat enhancement can be completed using multiple restoration techniques including, but not limited to: 1) partial burial of isolated logs with root wad exposed on the channel bed; 2) boulder clusters; 3) small boulder-supported log jams; 4) mid-channel log jams; and 5) wood and/or boulder cover structures (Figure 11b; Appendix 1). The biostabilization techniques mentioned in Section 3.1e above also can be modified to enhance habitat along the margins of the channel even where bank erosion is not an issue. Many of the techniques utilize wood that will blend in with the existing forested Bronx River landscape. Boulder clusters could be used to enhance habitat but may appear more "out of place" than wood structures as boulders are not naturally widespread along the Bronx River. The cost and complexity of all of the in-stream habitat enhancement techniques are considered low to moderate. In-stream habitat enhancement directly targets the BRCSMP objective to improve aquatic habitat, but also addresses the objectives to restore natural river processes reconnect floodplain access, and hazard mitigation (when biostabilization is used). High priority segments for in-stream habitat enhancement are concentrated along the downstream half of the river, but should be considered wherever long gaps between habitat features exist.

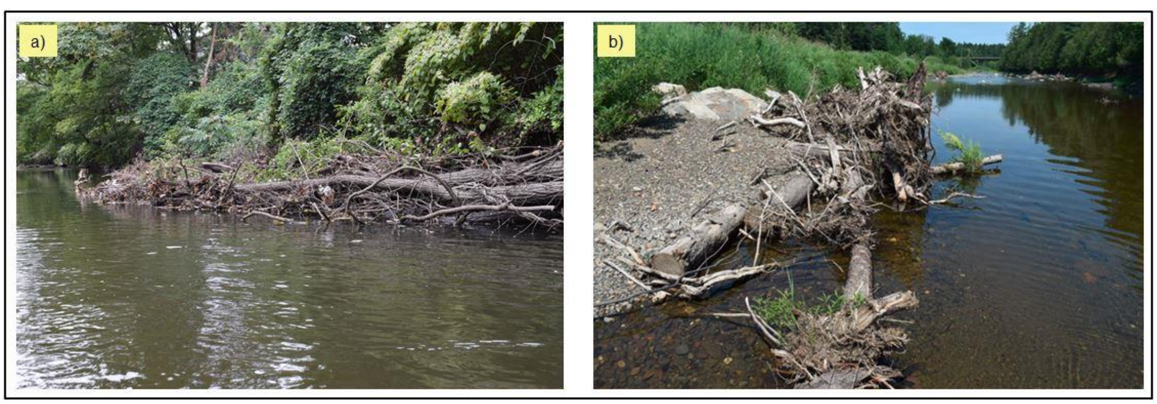

Figure 11. Wood occurs naturally on the Bronx River including in a) marginal log jams but is widely spaced, so habitat continuity along the length of the river can be enhanced by constructing similar structures such as b) boulder-supported log jams that trap sediment and other wood (from Meduxnekeag River, ME one year after construction).

3.1g Invasive species control and riparian plantings

Invasive species are found nearly everywhere in the Bronx River corridor but are often the dominant vegetation (Figure 12) where no mature riparian forest is present or unless landscaped vegetation is maintained (i.e., mown grass in parks). Establishing a mature riparian forest where invasive species predominate is difficult as young trees are often crowded out by invasives unless significant shade is present from taller trees. In addition to inhibiting forest vegetation from becoming established in the corridor, invasive species also compromise aquatic habitat since 1) a shaded canopy to keep water temperatures low in the summer is unlikely to develop if no trees are growing on the bank; 2) wood cannot be recruited into the channel if no trees are present to fall into the river; and 3) the poor root systems of most invasive species will compromise the bank stability otherwise provided by the roots of mature trees. Therefore, invasive species control and riparian plantings would not only fulfill the BRCSMP objectives of invasives species control and enhance natural riparian vegetation but also enhance aquatic habitat.

Figure 12. Invasive species are the dominant vegetation on the banks of the Bronx River in some areas, particularly in the lower reaches such as Reach 2 in Yonkers/Mount Vernon shown here.

Establishing mature trees where none currently exist in the riparian zone of the Bronx River will in most instances also require invasive species control. A number of approaches are available for removing and controlling the spread of invasive species including physical removal and chemical treatment (Web citation 3). Removing invasive species where they are already well established is extremely difficult and requires long-term diligence to succeed, so the cost and complexity of invasive species control is generally considered moderate to high where invasives represent the dominant vegetation in the corridor. The focus of invasive species control is typically on preventing their spread by removing small new patches before they take over an area. The academic, technical, and financial resources available in the New York City metropolitan area may, in contrast, provide an opportunity to develop and test novel approaches for removing well established invasive species and replacing them with native plant communities. The cost and complexity of native riparian planting efforts when considered by themselves is considered low to moderate and provides an excellent opportunity to directly engage students, civic groups, and other members of the public in improving the health of the river. The cost of riparian plantings will be higher where larger trees need to be planted to ensure shade will be immediately available to control the return of invasive species. Invasive species control and riparian plantings directly target the BRCSMP objectives of invasive species control and enhance natural riparian vegetation, but also addresses the objectives to restore natural river processes, enhance aquatic habitat, and increase recreational opportunities (e.g., civic and school groups assisting with riparian plantings).

The segments with the highest priority for invasives species control and riparian plantings tend to be in the downstream sections of the river. However, until the plans and resources are available to remove well established invasive plant communities, other lower priority segments should be considered targets for removing small patches of invasive species. Riparian plantings should accompany such efforts to help prevent the return of the invasive species.

3.1h Improve recreational opportunities

The long continuous path along much of the Bronx River in Westchester County provides an opportunity for biking, jogging, and walking. User experience along the river is further enriched by interpretive signs (Figure 13), benches, parks, and perhaps occasional ice skating in impoundment areas. Swimming may have occurred in the past but deposition and encroachment of emergent wetlands within the impoundments has presumably greatly reduced this activity. The landscape today is vastly different than what met the earliest European settlers and is a tremendous improvement over the polluted river of the late 19th and early 20th centuries. As restoration efforts of the BRCSMP continue the river's reclamation towards a more natural condition, additional recreational opportunities not available along the river for centuries may reemerge. Developing recreational opportunities will not only directly achieve that eponymous BRCSMP objective, but increased interaction with the river should also increase public support to achieve other BRCSMP objectives.

Figure 13. Interpretive signs enrich the user experience along the recreational path along the Bronx River, but new ones could better reflect BRCSMP priorities and activities.

A number of additional recreational opportunities could potentially be developed within the Bronx River corridor including, but not limited to: 1) fishing; 2) boating; 3) extending the recreational path where none currently exists; and 4) updating interpretive signs to discuss the BRCSMP objectives and restoration activities (Appendix 1). The cost and complexity of developing these new opportunities ranges from low (e.g., updating interpretive signs) to high (e.g., boating). While low-cost options could likely be implemented immediately, more complex options will take much longer to develop and will need to be integrated with other restoration activities. For example, establishing boating on a long uninterrupted section of river would likely entail removal of check dams and the resizing of bridges. A continuous 1.7 mile length of river from Segments BR_12A to BR_14B (Scarsdale Village north to Greenacres Avenue) is rated as a high priority for improving recreational opportunities (see Section 3.2 below) that will, in part, be addressed by current work to extend the recreational path in this area. However, if other restoration projects related to other objectives gives rise to new recreational opportunities (e.g., boating) in lower priority segments, these should also be pursued to further diversify activities available along the river.

3.1i Stormwater upgrades

Stormwater (and water supply) infrastructure impacts the river in at least three different ways. As discussed in Section 3.1b above, pipes cross the river to form low weirs and a sewer line parallels Laurel Brook. The third impact occurs where stormwater of unknown water quality from tributaries drains directly into the channel with the same outlets holding the potential for the Bronx River at high flow to backwater into the tributaries. Those same outfalls can also destabilize the river banks over which they sometimes drain or are protected with armor. Addressing stormwater concerns would address the BRCSMP objectives to improve water quality and, to the extent channel obstructions are removed, may also fulfill the objectives to restore natural river processes and mitigate flood and erosion hazards (i.e., backwatering up tributaries).

Stormwater upgrades could involve the removal of channel obstructions, placement of flap gates on stormwater drains to prevent high flow from the Bronx River backwatering up the tributaries, and preventing erosion of the banks over which the outfalls drain with brush mattresses or marginal log jams. The cost and complexity of stormwater upgrades is considered moderate (e.g., flap gates) to high (e.g., removing obstructions). The single largest issue related to upgrading stormwater infrastructure is the sewer line that parallels Laurel Brook for a long distance and obstructs portions of the channel. Stormwater issues on the Bronx River have largely only local impacts. Since the cost to address these localized problems would be relatively high if dealt with in isolation, they could be included as part of larger restoration efforts in segments where they are present in order to reduce the planning and mobilization costs.

3.1j Channel management strategies

The restoration alternatives described above are what are referred to as "active" approaches requiring physical or vegetative changes in the river channel, on the floodplain, or both. A number of other "passive" approaches, referred to here as channel management strategies, could also be used to achieve BRCSMP objectives without making direct or immediate alterations to the channel or floodplain. These channel management strategies include, but are not limited to: 1) leaving in place trees that fall into the channel if they are within identified "no cut" zones where unanchored wood would not pose a hazard; 2) reducing road sanding and salting to the extent practicable and safe in order to reduce fines and chlorides in the river, perhaps on small secondary roads; 3) avoiding future bank stabilization in areas where the reformation of meanders is desired and will not threaten infrastructure; 4) initiating annual monitoring of sensitive areas (e.g., erosion hazard sites) with topographic cross sections and repeated ground photographs to identify rapid changes that might necessitate more immediate bank stabilization or other action; 5) producing pamphlets and holding informational sessions to inform the public of possible future restoration activities and to develop support for such projects early in the design and development process; and 6) establishing a "watch list" for projects too costly and complex to immediately undertake in isolation but that may be more practicable at a later date when other scheduled projects (e.g., road maintenance) could greatly reduce the cost, complexity, and construction impacts compared to undertaking the efforts separately.

Little upfront cost is associated with implementing these channel management strategies, although some human resources will need to be invested in identifying the segments within which to undertake the "no cut", "no armoring", "monitoring", and "watch list" efforts. Costs, of course, will be incurred later if projects on the "watch list" move to a design and implementation phase. Channel management strategies should be applied to all applicable segments as benefits can then accrue over a wide area with limited investment of financial and human resources. Adoption of these channel management strategies should advance nearly all of the BRCSMP objectives, particularly improve water quality, enhance aquatic habitat, and restore natural channel processes.

3.2 Prioritizing restoration alternatives by segment

The 10 restoration alternatives described in Section 3.1 above represent a general outline of measures appropriate for use on the Bronx River. The prioritization process described below identifies and ranks the best restoration alternative(s) to implement that will best achieve the 8 BRCSMP objectives in each of the 97 delineated segments (see digital supplement). Volume I consisted of two distinct assessments: 1) geomorphic and habitat conditions assessment and 2) flood and erosion hazard assessment. The geomorphic and habitat assessment quantified the "needs" within each segment (for certain physical and biological attributes such as floodplain access, meandering planform, and riparian vegetation) that would need to be fulfilled before a geomorphically stable, biologically diverse, and recreationally enriching condition could be achieved (see Section 5.2b in Volume I). Separately, the severity of erosion and flood hazards present in each segment were also quantified (see Sections 5.3 and 5.4 in Volume I). The results of both the geomorphic/habitat and hazard assessments must be considered together to identify the restoration alternatives that will provide the greatest benefit. The Volume I values for hazard severity and geomorphic and habitat "needs" were modified to establish a base score (from 1 to 4) that establishes the degree to which restoration or hazard mitigation efforts are required to achieve each of the 8 BRCSMP objectives in each segment. Table 3 summarizes the data utilized to establish the base scores for each objective with Appendix 2 providing a detailed explanation of how the base scores were calculated from the data.

After establishing the base scores, a final prioritization score was calculated by multiplying the base score with a weighting factor (ranging from 2 to 5) agreed upon during a meeting with stakeholders in May 2019. The weighting factor is used to reflect the relative importance stakeholders assign to each objective (Table 1) such that objectives of greater concern are scored higher or, in other words, given a greater priority even if the base score for all of the objectives is the same. For example, if the base score calculated for hazard mitigation and recreational improvements are both "2" in a particular segment then the final prioritization score for hazard mitigation (with a weighting factor of 5) would be "10" and for recreational improvements (with a weighting factor of 2) would be only "4". Therefore, when reviewing the final prioritization scores for that segment to determine what types of restoration projects might have the greatest positive impact, more consideration will be given to identifying hazard mitigation projects than recreational improvement projects despite the initial base score being the same.

The final prioritization scores for the eight objectives and the cumulative total in each segment is provided below in Table 4. The maximum possible final prioritization score is 20 (maximum base score of 4 multiplied by maximum weighting factor of 5), but only hazard mitigation and floodplain reconnection scores can reach that value, since those are the only two objectives assigned a weighting factor of 5. Twenty segments have at least one of these two objectives reaching the maximum score of 20.

Higher prioritization scores reflect those objectives that should garner more attention when planning restoration projects in a given segment. The cumulative scores of all 8 objectives can reach a maximum value of 120 (cumulative sum of each objective's maximum score) with higher scores highlighting those segments with the greatest overall need for restoration. The highest recorded prioritization score on the Bronx River is "104" in Segment BR_08C, reflecting the highly constrained river channel flowing through Tuckahoe Village with poor aquatic habitat and nearby infrastructure potentially at risk of flooding and erosion.

Volume I Assessment Data Used	BRCSMP Objectives							
	Water Quality	Hazard Mitigation	Aquatic Habitat	Floodplain Connection	Restore Process	Control Invasives	Riparian Enhancement	Improve Recreation
Hazard assessment data								
Stream bank composition	x							
Erosion susceptibility (BEHI)	x							
Near bank shear stress	x							
Surface area of erosion	x							
Percentage of segment's banks eroding	x							
Proximity of erosion to infrastructure		x						
Frequency of infrastructure inundation		x						
Types of infrastructure inundated		x						
Types of infrastructure near erosion		x						
Geomorphic & habitat assessment data								
Particle size segregation			x					
Degree of flow complexity			x					
Frequency and quality of pools			x					
Presence & geomorphic effect of wood			x					
Presence and extent of floodplain				x				
Natural physiographic setting					x			
Stage of meander development					x			
Presence of artificial grade controls					x			
Height of artificial grade controls					x			
Percentage of armor in segment					x			
Native/invasive species in riparian zone						x	x	
Percentage of canopy cover over river						x	x	
Width of riparian vegetation						x	x	
Presence of recreational path								x
Presence of other recreational assets								x

Table 3. Volume I assessment data utilized to calculate the base scores for each objective that established the priorities for restoration and hazard mitigation on the Bronx River. See Appendix 2 for details on scoring.

Segment	Town(s)	Length (ft)	Water Quality (4)	Hazard Mitigation (5)	Aquatic Habitat (4)	Floodplain Connect (5)	Restore Process (4)	Control Invasives (3)	Riparian Enhance (3)	Recreation (2)	Total
BR_01A	Yonkers/New York	2,294	12	10	12	15	8	9	9	6	81
BR_01B	Yonkers/New York	1,626	12	15	16	20	8	6	12	8	97
BR_02A	Yonkers/Mount Vernon	1,638	4	20	15	20	12	6	12	8	97
BR_02B	Yonkers/Mount Vernon	1,320	4	20	14	20	12	6	12	6	94
BR_03A	Yonkers/Mount Vernon	1,974	16	20	12	10	8	12	9	4	91
BR_03B	Yonkers/Mount Vernon	929	4	10	8	15	8	3	6	4	58
BR_04A	Yonkers/Mount Vernon	663	4	10	12	15	9	9	6	8	73
BR_04B	Yonkers/Mount Vernon	860	4	10	11	15	11	12	6	8	77
BR_04C	Yonkers/Mount Vernon	1,671	8	15	10	20	12	9	12	8	94
BR_05A	Yonkers/Mount Vernon	997	12	15	9	10	7	6	9	8	76
BR_05B	Yonkers/Mount Vernon	1,064	16	15	6	15	7	12	3	2	76
BR_05C	Yonkers/Eastchester	456	4	20	11	15	13	3	9	8	83
BR_05D	Yonkers/Eastchester	1,107	8	20	14	15	11	6	9	8	91
BR_06A	Yonkers/Eastchester	1,061	16	20	16	5	11	9	6	6	89
BR_06B	Yonkers/Eastchester	1,014	16	20	12	10	8	12	6	4	88
BR_06C	Yonkers/Eastchester	502	4	15	6	20	12	3	3	4	67
BR_07	Yonkers/Eastchester	1,729	4	10	14	5	9	6	12	2	62
BR_08A	Yonkers/Eastchester	1,391	16	10	14	10	12	9	9	2	82
BR_08B	Yonkers/Eastchester	1,018	4	20	15	20	13	9	12	6	99
BR_08C	Yonkers/Eastchester	845	4	20	15	20	16	9	12	8	104
BR_08D	Yonkers/Eastchester	522	4	15	11	15	13	3	3	6	70
BR_09	Yonkers/Eastchester	1,795	4	10	14	5	9	6	12	2	62
BR_10A	Yonkers/Eastchester	675	4	10	15	5	12	6	12	2	66
BR_10B	Yonkers/Eastchester	636	12	10	14	10	12	9	12	4	83
BR_10C	Yonkers/Eastchester	497	16	20	15	15	8	6	9	4	93
BR_10D	Yonkers/Eastchester	1,042	16	20	12	5	8	9	9	4	83
BR_10E	Yonkers/Eastchester	365	16	10	15	5	4	9	12	4	75
BR_10F	Yonkers/Eastchester	769	16	10	8	5	11	6	12	4	72
BR_10G	Yonkers/Eastchester	842	8	10	14	20	9	9	12	6	88
BR_10H	Yonkers/Eastchester	649	16	10	14	5	8	9	12	2	76
BR_10I	Yonkers/Eastchester	726	12	10	8	5	5	6	6	2	54
BR_10J	Yonkers/Eastchester	1,760	16	10	14	10	7	9	6	2	74
BR_10K	Yonkers/Eastchester	835	4	10	9	5	12	6	12	2	60

Table 4. Final prioritization scores by objective and cumulative total for each segment. Highlighted scores in gray represent some, but not necessarily all, of the highest scoring values. Numbers in parentheses by the objectives in the column headings represent the weighting factor used for that objective. See text for further detail.

Segment	Town(s)	Length (ft)	Water Quality (4)	Hazard Mitigation (5)	Aquatic Habitat (4)	Floodplain Connect (5)	Restore Process (4)	Control Invasives (3)	Riparian Enhance (3)	Recreation (2)	Total
BR_11A	Yonkers/Eastchester	1,069	4	15	16	15	12	12	12	2	88
BR_11B	Yonkers/Eastchester	1,044	4	15	7	15	9	12	9	2	73
BR_11C	Yonkers/Eastchester	519	8	20	4	15	8	9	6	2	72
BR_11D	Yonkers/Eastchester	346	12	20	5	15	5	6	6	2	71
BR_11E	Yonkers/Eastchester	897	12	20	12	10	12	9	9	2	86
BR_11F	Greenburgh/Scarsdale	788	4	15	13	15	15	12	12	2	88
BR_12A	Greenburgh/Scarsdale	1,388	4	10	10	15	15	3	9	2	68
BR_12B	Greenburgh/Scarsdale	640	8	10	9	15	8	9	6	8	73
BR_12C	Greenburgh/Scarsdale	739	8	10	8	15	8	12	6	8	75
BR_12D	Greenburgh/Scarsdale	809	4	10	7	20	12	3	6	8	70
BR_12E	Greenburgh/Scarsdale	720	4	10	5	20	12	3	9	8	71
BR_12F	Greenburgh/Scarsdale	529	4	10	9	20	12	3	9	8	75
BR_13A	Greenburgh/Scarsdale	1,424	12	10	13	20	12	6	12	8	93
BR_13B	Greenburgh/Scarsdale	1,112	16	10	12	20	9	9	12	8	96
BR_14A	Greenburgh/Scarsdale	851	8	10	8	20	11	9	9	8	83
BR_14B	Greenburgh/Scarsdale	742	4	10	10	15	11	6	12	8	76
BR_14C	Greenburgh/Scarsdale	1,396	4	10	10	10	15	6	12	2	69
BR_15A	Greenburgh/Scarsdale	1,655	8	10	12	10	11	12	12	4	79
BR_15B	Greenburgh/Scarsdale	569	8	10	5	20	11	12	9	4	79
BR_15C	Greenburgh/Scarsdale	859	4	10	6	20	5	3	9	4	61
BR_15D	White Plains	1,414	12	10	8	15	5	12	6	4	72
BR_15E	White Plains	467	8	5	9	20	9	6	12	4	73
BR_15F	White Plains	1,768	16	15	13	15	7	12	12	4	94
BR_16A	White Plains	809	8	15	13	15	7	12	9	4	83
BR_16B	White Plains	629	4	20	13	15	12	9	12	4	89
BR_16C	White Plains	647	4	20	12	10	12	6	12	4	80
BR_16D	White Plains	1,264	4	20	15	5	12	6	12	4	78
BR_16E	White Plains	357	12	20	10	10	5	9	12	4	82
BR_16F	Greenburgh/White Plains	788	8	20	7	5	4	12	9	4	69
BR_17A	Greenburgh/White Plains	650	8	15	11	5	9	12	12	8	80
BR_17B	Greenburgh/White Plains	880	12	10	10	5	7	12	9	8	73
BR_17C	Greenburgh/White Plains	927	12	10	13	5	11	9	12	4	76

Table 4 (continued). Final prioritization scores by objective and cumulative total for each segment. Highlighted scores in gray represent some, but not necessarily all, of the highest scoring values. Numbers in parentheses by the objectives in the column headings represent the weighting factor used for that objective. See text for further detail.

Segment	Town(s)	Length (ft)	Water Quality (4)	Hazard Mitigation (5)	Aquatic Habitat (4)	Floodplain Connect (5)	Restore Process (4)	Control Invasives (3)	Riparian Enhance (3)	Recreation (2)	Total
BR_17D	Greenburgh/White Plains	618	4	20	5	5	4	3	6	4	51
BR_17E	Greenburgh/White Plains	1,192	16	10	8	5	8	9	6	4	66
BR_17F	Greenburgh/White Plains	512	12	10	5	15	7	12	9	8	78
BR_17G	Greenburgh/White Plains	816	16	10	4	10	7	12	12	8	79
BR_18	Greenburgh/White Plains	343	4	10	6	15	7	3	3	6	54
BR_19	Greenburgh/White Plains	936	4	20	14	15	13	6	12	8	92
BR_20A	Greenburgh	668	4	20	15	5	9	6	12	2	73
BR_20B	Greenburgh	771	8	15	12	5	5	9	12	4	70
BR_20C	Greenburgh/North Castle	696	12	15	8	5	4	12	6	4	66
BR_20D	Greenburgh/North Castle	787	4	15	8	5	4	12	9	4	61
BR_20E	Greenburgh/North Castle	644	8	10	12	5	8	6	12	4	65
BR_20F	Mount Pleasant/North Castle	1,106	12	10	5	5	5	12	9	4	62
BR_20G	Mount Pleasant/North Castle	1,289	16	10	4	5	5	6	9	4	59
GS_01A	Yonkers	528	4	15	16	15	15	6	12	8	91
GS_01B	Yonkers	1,145	8	15	16	20	16	9	12	8	104
GS_01C	Yonkers	422	4	15	13	15	16	3	12	8	86
GS_02A	Yonkers	761	16	15	11	10	5	12	12	8	89
GS_02B	Yonkers	626	4	15	13	15	9	6	12	8	82
GS_02C	Yonkers	822	12	5	12	20	13	9	12	8	91
GS_03A	Yonkers	448	4	5	10	15	13	6	12	8	73
GS_03B	Yonkers	937	12	5	7	15	12	12	6	8	77
GS_03C	Yonkers	583	4	5	15	15	16	6	12	8	81
GS_04A	Yonkers	522	8	5	8	15	12	12	12	8	80
GS_04B	Yonkers	352	4	5	8	15	13	12	6	8	71
GS_05A	Yonkers	574	4	5	7	20	15	9	6	8	74
GS_05B	Yonkers	1,163	4	5	14	20	13	6	12	8	82
LAU_01A	Mount Vernon	689	16	15	5	10	5	9	9	4	73
LAU_01B	Mount Vernon	634	12	15	10	10	7	6	3	4	67
LAU_02A	Mount Vernon	687	16	15	7	5	5	6	3	4	61
LAU_02B	Mount Vernon	541	4	15	5	10	4	6	3	4	51
LAU_03A	Mount Vernon	676	8	5	11	15	7	3	3	4	56
LAU_03B	Mount Vernon	428	4	5	13	20	12	6	3	4	67

Table 4 (continued). Final prioritization scores by objective and cumulative total for each segment. Highlighted scores in gray represent some, but not necessarily all, of the highest scoring values. Numbers in parentheses by the objectives in the column headings represent the weighting factor used for that objective. See text for further detail.

The final prioritization table (Table 4) can be of value in restoration planning in at least three ways. First, focus can center on an individual objective column when a particular source of funding is available that aligns with a specific objective. For example, funds allocated for the resizing of bridges or culverts would perhaps accrue the greatest benefit in segments that rank the highest for hazard mitigation, an objective assigned the highest weighting factor of 5 and a primary benefit of increasing the span of river crossings (see below). Since several segments have the highest possible score for hazard mitigation, the potential list of sites could be shortened by looking at other objectives that would benefit from bridge resizing such as enhancing aquatic habitat. Scanning Table 4, Segment BR_06A starting at the confluence with Grassy Sprain Brook has the maximum possible score for both hazard mitigation and aquatic habitat enhancement, indicating the highly constrictive railroad bridge just downstream might be an excellent candidate for resizing (Figure 14). This process would not necessarily lead to the selection of one best candidate site as many local factors not embodied in the prioritization process will be important as well (such as fitting the new larger bridge around other nearby infrastructure), but the prioritization process can certainly focus attention quickly on a few excellent candidate sites. Additionally, the prioritization table, and the BRCSMP assessments and restoration planning more generally, can strengthen grant applications by providing strong justification for the funding requests.

Figure 14. The railroad bridge just downstream of Parkway Avenue is an excellent candidate for resizing based on the hazard mitigation and aquatic habitat enhancement benefits that could potentially accrue.

A second valuable use of the prioritization table (Table 4) is when opportunities for restoration arise in particular segments due to proposed work along the river, even if that other work is unrelated to the BRCSMP objectives. For example, partial removal of artificial fill on the floodplain across from Scout Field in Segment BR_05B is being planned, but as currently envisioned is insufficient to reconnect the floodplain, a high scoring objective in this segment. Lowering the high bank of fill (Figure 15a) down to the floodplain level would potentially reduce the persistent flooding on the ball field directly across the river channel (Figure 15b), thereby addressing another high scoring objective – flood and erosion hazard mitigation. By focusing attention on the potential benefits of additional fill removal, two high priority BRCSMP objectives could be addressed at minimal additional expense since planning for the partial fill removal of the fill is already underway.

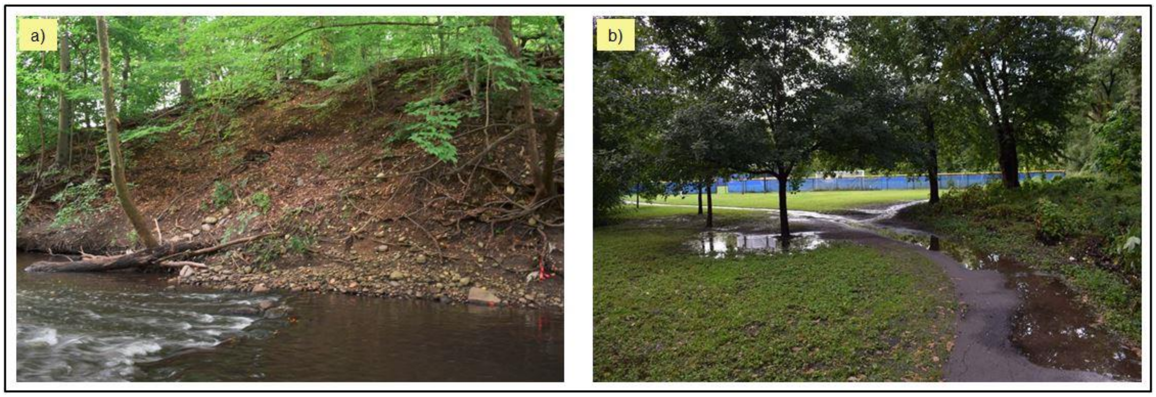

Figure 15. At Scout Field (Segment BR_05B), a) a high bank of artificial fill blocks the floodplain across from b) a ball field that experiences persistent flooding as a result.

Finally, the cumulative total scores in Table 4 can be useful in long-term restoration planning by focusing attention on those segments with the greatest overall need of restoration. Within this context, Segments BR_08C (Figure 16) and BR_02A (Figure 12) (along with the other adjacent contiguous high scoring segments adjacent to these but not highlighted) are the best initial targets for restoration activities. The highest scoring objectives within Segment BR_08C are hazard mitigation, floodplain reconnection, and restoring river processes, so restoration alternatives addressing these objectives would likely provide the greatest improvements and should be the first considered in the restoration planning of this segment.

Local factors not embodied in the prioritization table, however, may preclude restoration in these two high scoring segments given that Segment BR_08C flows through Tuckahoe Village (and its nearby infrastructure) and Segment BR_02A in Mount Vernon is severely constrained by the railroad and Parkway running parallel to the river on opposite banks. Despite the limited opportunities for near-term restoration in these highest scoring segments on the Bronx River, focusing on segments with the highest cumulative scores and continuing to the next highest scoring segments illustrates how the prioritization table can be useful in the restoration planning process and guide outreach to other parties such as the Tuckahoe municipal government. In addition, high priority restoration segments (where near-term restoration is not possible) should be placed on a “watch” list, so restoration can be undertaken at a future date when other projects make restoration more practicable (such as overhauls of the Parkway or railroad in Segment BR_02A).

Figure 16. The segment with the highest cumulative prioritization score (BR_08C) flows through Tuckahoe Village, so may limit restoration opportunities given the nearby infrastructure.

The prioritization table (Table 4) identifies the BRCSMP objectives to address within each of the 97 segments, but does not identify the restoration alternatives best suited to fulfill those objectives. To achieve that next step in the prioritization process, the 10 restoration alternatives (see Section 3.1 above) are linked to one or more objectives that would benefit from restoration applying that alternative (Table 5). Some links are immediately obvious with the alternative "create floodplain access" addressing the objective to reconnect floodplains, although secondary benefits of creating floodplain access would also accrue to other objectives such as "hazard mitigation" and "restore natural river processes". Other restoration alternatives like "resize culverts and bridges" are less clearly linked to the objectives, but are discussed in Section 3.1 above and Appendix 1 to justify the assignment of primary and secondary benefits detailed in Table 5.

Where multiple objectives are addressed by a single restoration alternative, one or two primary, or target, objectives are highlighted (bolder colors) with the others considered secondary (lighter colors) beneficiaries. Each objective has at least one restoration alternative for which a "primary" designation is assigned (Table 5). As discussed in Section 3.1 above, some restoration alternatives are relatively inexpensive and more easily implemented (e.g., riparian plantings) while others are far more costly and complex (e.g., creating floodplain access). Table 5 reflects these differences in cost and complexity through color coding to assist in readily: 1) identifying the most easily implemented restoration projects and 2) recognizing those projects that will require long-term planning to martial the financial, technical, and human resources required for completion. The suggested relative costs, however, are meant as a very general guideline only since the cost of the treatments will vary greatly with the length or size of the restoration project (e.g., span of new bridge, depth of fill to be removed) under consideration, ancillary construction costs, such as associated with traffic control, that will vary by site, and the specific restoration technique(s) that will be used for a particular alternative. More detail on the relative costs of various techniques within a particular alternative is provided in Table 2 with the higher end of that cost spectrum used in Table 5.

Restoration Alternatives	Water Quality	Hazard Mitigation	Aquatic Habitat	Floodplain Connect	Restore Process	Control Invasives	Riparian Enhance	Recreational opportunities
Increase floodplain connectivity	○	○	○	●	○		○	○
Remove channel obstructions	○	●	○		●			○
Resize culverts and bridges	○	●	○		○			
Reestablish meandering planform		○	○	○	●			
Biostabilization	●	●	○		○	○	○	
In-stream habitat enhancement			●	○	○			○
Invasive species control and riparian plantings	○				○	●	●	○
Improve recreational opportunities								●
Stormwater upgrades	○	●	○		○			
Channel management strategies	○		○			○	○	

● / ○ Higher cost and complexity ● / ○ Moderate cost and complexity ● / ○ Lower cost and complexity

Note: Solid color represents primary benefit, faded color represents secondary benefit

Table 5. The primary and secondary objectives addressed by the 10 restoration alternatives. The relative costs of each alternative are also shown.

The two-part prioritization process described above consists of first identifying the segments within which restoration is of the highest priority for particular objectives (Table 4) and then selecting the restoration alternative(s) best suited to fulfill those objectives in selected priority segments (Table 5). The prioritization process is intended to guide restoration, but is not in and of itself a replacement for detailed restoration planning. The first consideration should be to address the highest priority objectives in a particular segment with the suggested restoration alternative aligned with those objectives. However, a myriad of financial, technical, and cultural factors may make implementation of the priority project unfeasible at least in the short term. In these cases, the value in the prioritization process is that additional less costly or more feasible restoration alternatives may be available to address the priority or other objectives more immediately. A more detailed restoration planning process (see Section 4.0 below) is required to identify the constraints to implementing the recommended restoration alternatives for particular segments and to select the specific techniques to use within those alternatives that are feasible and selected for implementation.

4.0 RESTORATION PLANNING AND CONCEPT DEVELOPMENT

Restoration in each segment, or set of contiguous segments, will have its own unique financial, technical, or human constraints that preclude using the prioritization process to identify the specific techniques to be used in the restoration and their placement at the site. To illustrate the restoration planning process at the segment level, six sites were selected for topographic surveying (Appendix 3) that aided the development of five conceptual restoration projects designed to fulfill unmet BRCSMP objectives (Figure 17 and Appendix 4). The project concepts described below include a layout plan of all the project elements envisioned, reference to typical drawings in Appendix 1, and rough cost estimates (ordered from downstream to upstream). All five sites are in the Bronx River Parkway Reservation, but the concepts also provide a template for developing projects outside the Reservation and on other river systems in the County. Built resources that contribute to the National Register character of the Reservation are located within the concept sites (Appendix 5), so changes to these structures will need approval by the County's Historic Preservation Advisory Committee, Planning and Parks, Recreation and Conservation departments, and New York State Historic Preservation Office.

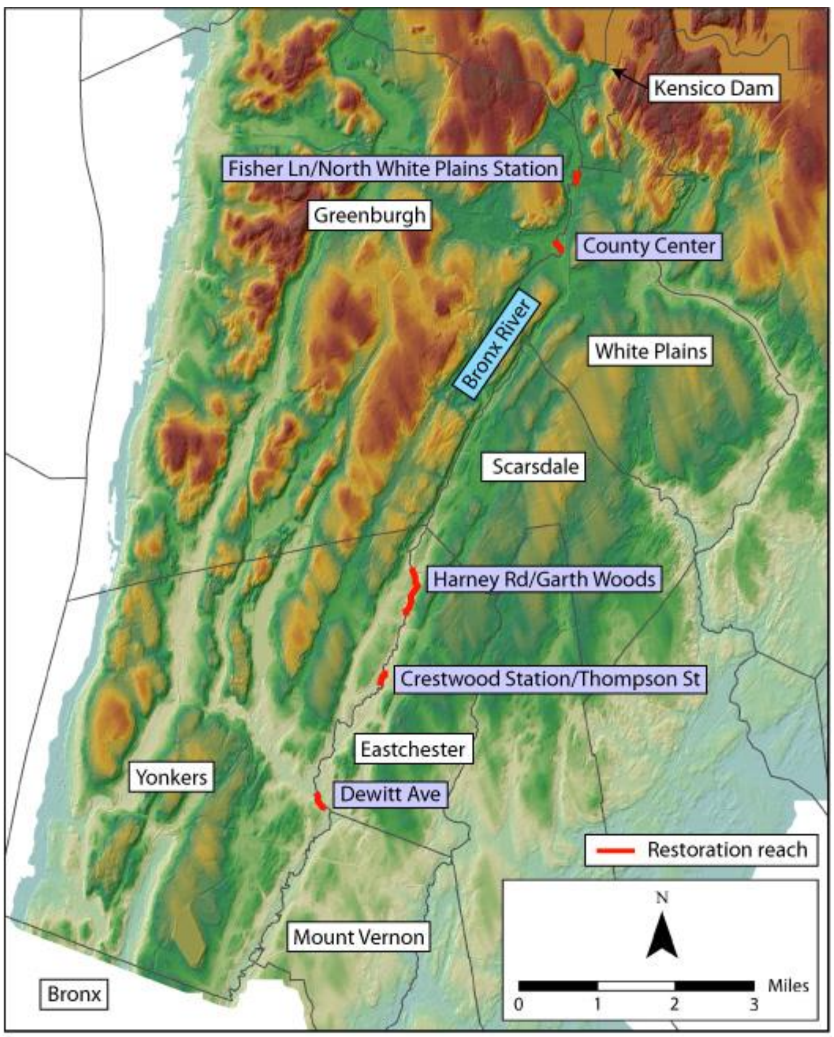

Figure 17. Location of conceptual restoration sites.

4.1 Dewitt Avenue (Segment BR_5D)

The Dewitt Avenue restoration reach (Figure 18) has three bridges including the railroad bridge at the downstream end of Segment BR_5D, Parkway Road Bridge just upstream, and Dewitt Avenue Bridge near the confluence of Grassy Sprain Brook at the upstream end of the segment. The railroad bridge has the greatest hydraulic impact of any crossing along the river in Westchester County given its highly constrictive nature (Figure 14). The length of this restoration reach, comprised of only a single segment, is over 1,100 ft. Reducing the backwatering resulting from the undersized crossings could mitigate hazards not only in Segment BR_5D but other segments further upstream and up Grassy Sprain Brook. Hazard mitigation is a high priority objective in this segment with three other priority objectives (i.e., weighting of 4 or 5) scoring high enough (i.e., > 10) to be worthy of addressing (Table 4). A need for recreational improvements has a maximum score of 8 for this reach but limited space other than across from the Grassy Sprain confluence severely constrains the development of new opportunities. The topographic survey of the restoration reach documents a bankfull width of 96 ft, an intact floodplain across from the Grassy Sprain Brook confluence, and a significant channel constriction at the railroad bridge (Appendix 3).

Figure 18. The Dewitt Avenue restoration reach looking upstream from Parkway Road Bridge.

The primary goal of restoration in the Dewitt Avenue restoration reach is to mitigate flood hazards that impact areas upstream of the bridges. With this objective and existing site conditions in mind, two restoration techniques are envisioned to address unsatisfied BRCSMP objectives: bridge resizing and use of longitudinal relief culverts. The various elements of the conceptual restoration plan illustrated and laid out in Appendix 4 include:

- Resizing of the railroad bridge that represents the biggest constraint to the natural passage of flood flows in the reach. The current opening at the railroad bridge is 40 ft wide whereas the recommended span would be 120 ft (i.e., 1.25 times the bankfull width) or nearly three times the existing span. Hydraulic modeling during a detailed design phase would be able to refine this estimate and quantify the reduction in upstream flood stage that would result from a larger opening. The opening at the Dewitt Avenue Bridge is greater than the bankfull width of the channel so is not a priority for resizing. The Parkway Road Bridge is slightly narrower than the natural channel but was rated during the Volume I assessment as only a minor constriction, so its resizing is also not critical; and

- Longitudinal relief culverts under the approach roads on the left bank of the Dewitt Avenue Bridge will aid in reestablishing floodplain conveyance and further assist in hazard mitigation. Significant development adjacent to the two downstream bridges constrains the river channel between higher banks of artificial fill and hinders implementing other floodplain-reconnection techniques.

Rough cost estimates to implement each of these elements are also provided and help establish the proposed order for implementing the restoration elements (Appendix 4). Recreational improvements would be relatively inexpensive but given the confinement of the river between high banks through much of the reach, no readily implemented opportunities were identified beyond the existing recreational path. Flood inundation is a significant concern in this segment and on the lower sections of Grassy Sprain Brook, so in-stream structures are not recommended, despite the need for aquatic habitat enhancement, because such structures, even if hydraulic modeling could demonstrate no significant increase in flood stage, would likely be perceived by local residents as having the potential to exacerbate flooding. Only after flood levels are demonstrably reduced by resizing the railroad bridge (and public anxiety similarly reduced) should in-stream structures be considered for installation as a complement to the recent bank stabilization project completed at the Grassy Sprain Brook confluence. Initial hydraulic modeling indicates the railroad bridge is the controlling constraint on upstream flooding (see Section 6.2d in Volume I). Further modeling is warranted to establish the value in installing longitudinal relief culverts on the left bank under Dewitt Avenue prior to resizing the railroad bridge as this is likely a more feasible project in the short term, but the resulting benefits may not be realized until after the constraint at the railroad bridge is rectified.

4.2 Crestwood Station/Thompson Street (Segments BR_10A through 10B)

Segments BR_10A through 10B upstream and downstream of the Thompson Street Bridge that leads to Crestwood Station have a combined length of over 1,300 ft (Figure 19). Together these two segments have 3 objectives that are highlighted as priorities with “improve water quality” receiving a high score in BR_10B and “control invasive species” and “enhance aquatic habitat” receiving the highest or nearly the highest scores possible in BR_10A (Table 4). Other priority objectives (i.e., weighting of 4 or 5) that require addressing in the two segments include “hazard mitigation” and “restore natural processes”. The topographic survey of these segments documents: 1) a bankfull width of 69 ft downstream of the bridge where there is less confinement by roads; 2) a channel constricted by the Thompson Street Bridge; 3) the road approaches to the bridge blocking longitudinal flow on the floodplain; and 4) the access road to the County maintenance facility blocking lateral flow from the channel onto the floodplain (Appendix 3).

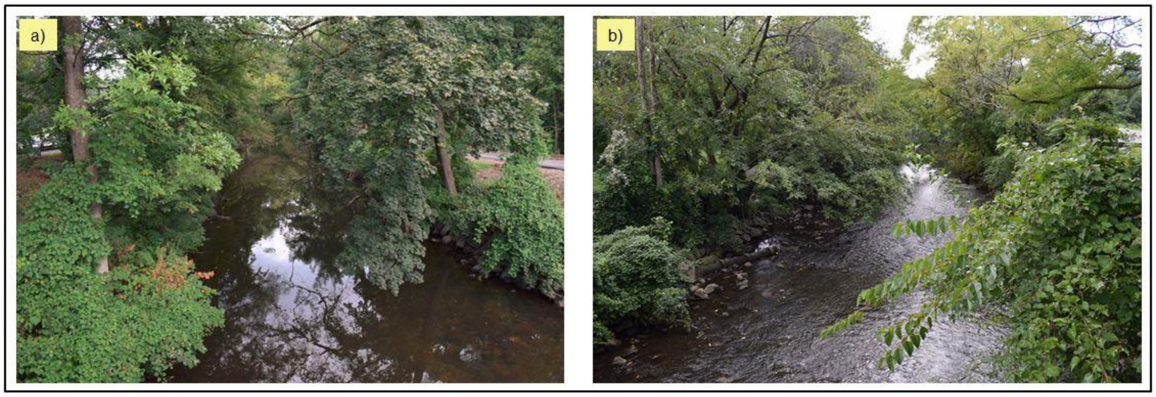

Figure 19. The Crestwood Station/Thompson Street restoration reach a) looking upstream (access road to County maintenance facility visible on right side of photo) and b) looking downstream from Thompson Street Bridge.

The primary goals of restoration at the Crestwood Station/Thompson Street site are to increase floodplain connectivity and reduce inputs of fine sediment into the stream in order to improve water quality and aquatic habitat. With these goals and the existing conditions in mind, a number of restoration techniques are envisioned to improve conditions that will fulfill several BRCSMP objectives. The various elements of the conceptual restoration plan illustrated and laid out in Appendix 4 include:

- Installation of lateral relief culverts under the access road leading to the County maintenance facility will improve floodplain connectivity. The road is slightly elevated and blocks a small portion of floodplain, although the road is likely overtopped during larger flows;
- Installation of longitudinal relief culverts under the Thompson Street approaches to the bridge that will allow floodplain flow from upstream to be conveyed on the floodplain rather than having to pass under the bridge. This should reduce upstream flooding;
- Resizing the Thompson Road Bridge that constricts the channel would remove a channel obstruction that currently exacerbates upstream flooding. The current opening at the bridge is 36 ft wide whereas the recommended span would be 86 ft (i.e., 1.25 times the bankfull width), although hydraulic modeling during a detailed design phase would refine this estimate and quantify the reduction in upstream flood stage that would result from a larger opening;
- Removal of the trash boom in Segment BR_10B will eliminate a minor channel obstruction if the structure is considered ineffective, but could remain as no significant instabilities are resulting from its presence;
- Biostabilization of unstable banks in Segment BR_10B would reduce erosion and improve water quality. Log crib walls would be the best technique to use given that flow deflection techniques in the narrow channel could destabilize the opposite bank where the Parkway on-ramp on the right bank or maintenance facility and access road on left bank could be put at risk. The crib walls would also serve as aquatic habitat enhancement as in-stream structures are similarly not recommended due to the narrow channel and nearby infrastructure;
- Invasive species removal and riparian plantings should first be done with simple physical means such as covering treatment areas with dark fabric for extended

periods and planting with trees to shade the area as a means of preventing the return of the invasives. If this less expensive approach fails, then mechanical (e.g., deep excavation to remove roots and rhizomes) or safe chemical (e.g., using an eye dropper to treat each stem individually) approaches should be considered later; and

- Reforming meanders through the parkland on the left bank downstream of the Thompson Street Bridge would serve to restore natural processes. Although water quality improvement is not a high priority objective in this segment downstream of the bridge, water quality is a high priority objective in the adjacent upstream segment, so the reformation of meanders should be completed using natural channel design principles to minimize the amount of bank erosion that would ensue if meanders were encouraged to form naturally through the use of marginal log jams on the opposite bank (see Appendix 1 typical).

Rough cost estimates to implement each of these elements are also provided and help establish the proposed order for implementing the restoration elements (Appendix 4). Improving recreational opportunities is not a highly ranked objective in these segments, so no readily implemented recreational opportunities are proposed beyond the existing recreational path. Invasive species control by covering the area with dark fabric followed by the planting of trees for shading can be executed as an early phase project, but if this proves to be ineffective then mechanical or chemical options could be considered later.

In general, the more complex and costly options (e.g., resizing of the bridge) are listed as later stage options as typically considerable time is needed to secure the necessary funding, environmental permits, and public support. As these options also hold the promise of providing the greatest benefit to high priority objectives (e.g., enhance aquatic habitat, floodplain reconnection, hazard mitigation), planning should be undertaken early, so potential funding sources can be capitalized on quickly as they arise. In some instances, lower cost options are listed in later stages than more costly options as the benefits of the work will only be accrued after completion of more costly options. For example, the installation of lateral relief culverts under the access road to the County maintenance facility will only provide minimal flood storage unless the more costly longitudinal relief culverts under Thompson Street are installed at which point flood conveyance across the floodplain will be restored and the potential hazard mitigation benefits of the lateral relief culverts can be fully realized. For the most part, however, the benefits accrued from individual elements of the restoration plan are not dependent on completion of others and, as such, later stage elements can be completed prior to the completion of projects envisioned for earlier stages if funding opportunities arise.

4.3 Harney Road/Garth Woods (Segments BR_10I through 11F)

Segments BR_10I through 11F extends from downstream of Harney Road upstream to Scarsdale Village (Figure 20). The combined length of this restoration reach is nearly 8,000 ft and includes Garth Woods. Envisioning restoration over an extended length of river will give rise to additional benefits that cannot be achieved through separated and disjointed efforts; these benefits include ecological, geomorphic, and hydraulic continuity as well as the potential to develop currently unavailable recreational activities (e.g., kayaking and canoeing). Together the nine segments within the reach have several objectives that are highlighted as priorities: water quality improvement, aquatic habitat enhancement, restore natural processes, control invasives, and enhance natural riparian vegetation (Table 4). Other priority objectives (i.e., weighting of 4 or 5) in the reach include hazard mitigation and floodplain reconnection. The topographic survey of these segments documents a bankfull width of 59 ft just downstream of the check dam where the river is confined, a channel constricted by the Harney Road Bridge, and flow impoundment and related deposition upstream of the check dam just downstream of Harney Road (Appendix 3). For the section through Garth Woods, an earlier study was useful in the development of the conceptual restoration plan of this restoration reach and surveyed in the field a bankfull width of 77 ft in an abandoned channel formed under more natural and less confined conditions (Field and Fowler, 2015).

Figure 20. The Harney Road/Garth Woods restoration reach a) near Scarsdale Village at the upstream end and b) downstream of Harney Road near the downstream end.

The long-term vision for the Harney Road/Garth Woods restoration reach is to create a long free-flowing section of river without obstructions where natural geomorphic and ecological conditions can develop and be sustained, potentially leading to opportunities for canoeing or kayaking. With this vision and existing conditions in mind, a number of restoration techniques are proposed to address unsatisfied BRCSMP objectives. The various elements of the conceptual restoration plan illustrated and outlined in Appendix 4 include:

- Resizing the Harney Road Bridge and the two other bridges over the northbound lanes of the Parkway upstream and downstream of Harney Road would remove channel obstructions that currently exacerbate upstream flooding. The upstream bridge is a particularly severe constriction with the recreational path barely able to pass through the opening (Figure 5b), so its resizing could have secondary benefits towards recreational improvements. The current opening at the Harney Road Bridge and the Parkway bridge just downstream is 34 ft wide whereas the recommended span would be 96 ft (i.e., 1.25 times the unconstrained bankfull width of 77 ft). No survey data was collected at the upstream Parkway bridge, but the recommended span would likely match the 96 feet given the proximity to the two bridges downstream. Achieving this recommended width at this upstream crossing may be particularly difficult where the north and south lanes of the Parkway converge together (traveling north), thus reducing the available space. Any increase in the width or height of the crossing would be helpful in reducing the impacts of the undersized crossing including the low clearance bikers face passing under the bridge on the recreational path. Reducing the bridge's skew relative to the river channel and the bridge's central pier could also help reduce the backwatering effects resulting in deposition upstream and the deep scour pool downstream of the bridge (Field and Fowler, 2015). Hydraulic modeling during a detailed design phase would determine the reduction in upstream flood stage that might result from larger openings and changes in alignment;

- Elevating the northbound lanes of the Bronx River Parkway to increase floodplain connectivity in BR_11C through 11E will reconnect a significant portion of the floodplain. Although very expensive, the proposed Parkway viaduct would not need to be very high, perhaps only elevated to the 100-yr flood level or to the height required to walk or bike under the viaduct for recreational purposes. Lateral relief culverts could also be considered as a cheaper option to achieve similar benefits. In addition to the high cost, elevating the Parkway as a more general strategy along the Bronx River might have only minimal applicability given the narrowness of the floodplain, alteration to the historic character of the Reservation, and potential grading issues with adjacent infrastructure (e.g., on/off ramps, side roads). Raising the Parkway in BR_11C through 11E where the floodplain is wider than elsewhere might dovetail well with resizing the upstream bridge (Figure 5b) as the larger bridge might require regrading a portion of the Parkway to a slightly higher level anyway. The historic character of the Reservation could potentially be retained by cladding low support piers with stone similar to that used on bridges elsewhere along the river. Beyond this restoration reach, areas of the Parkway that are regularly flooded might be the best candidate locations for constructing elevated viaducts despite the high cost;
- Installing lateral relief culverts under the southbound lanes of the Parkway immediately upstream of Harney Road to reconnect a small portion of unused floodplain. The small area is constrained by higher ground at the downstream end, so the relief culverts would provide only minor flood storage and would do little to improve flood conveyance as all of the flow across this small floodplain area would still need to pass under the Harney Road bridge;
- Removing the check dam in the reach will remove a significant channel obstruction, reduce upstream flooding, and improve natural channel processes. The impoundment upstream is largely filled in with sediment, so its removal may not meet public resistance like others along the river such as at Crestwood Lake;
- Reforming meanders can occur in multiple locations in the restoration reach to improve natural channel processes and aquatic habitat. Upstream of Harney Road, meander reformation could occur by diverting flow into an old abandoned channel as described in Field and Fowler (2015). Downstream, meander reformation can be achieved by excavating a new channel using natural channel design principles with the dimensions of the naturally reformed meander downstream of Harney Road serving as a guide (where rock spurs were recently

constructed). While natural meanders are currently forming in this area where the bank armor has failed (Figure 8b), excavating new stabilized meanders would eliminate the ongoing erosion that is degrading water quality.

- The use of partially buried logs, boulder clusters, and boulder-supported log jams (see Appendix 1 typical for habitat enhancement) could all be utilized to improve aquatic habitat in the straight sections of channel from BR_10I through 10J and BR_11D through 11F. If the Parkway were to be elevated as described above, marginal log jams along the high slope on the left bank at this upstream section could further improve aquatic habitat while encouraging meander reformation across the reconnected floodplain on the right bank. In-stream structures would need to be located in such a way as not to preclude the possibility of boating access in the future such as placing them along the margins of the channel;
- Biostabilization could be used for multiple purposes. First, areas of current erosion downstream of Harney Road could be stabilized with log crib walls as the channel is too narrow for marginal log jams that might destabilize the opposite bank. If meander reformation is being considered through natural channel design, then a second use of biostabilization could be for stabilizing the outer bends of the newly excavated channels. Marginal log jams or boulder deflectors with log supports might be more appropriate in these cases (see Appendix 1 typical for biostabilization). Finally, biostabilization using log crib walls will be required on both exposed banks that would result from check dam removal;
- Invasive species removal and riparian plantings should first be done with simple physical means such as covering treatment areas with dark fabric for extended periods and then planted with trees to shade the area as a means of preventing the return of the invasives. If this less expensive approach fails then mechanical (e.g., deep excavation to remove roots and rhizomes) or safe chemical (e.g., using an eye dropper to treat each stem individually) approaches should be considered later. Independently, riparian planting could be used to shade the channel downstream of Harney Road along the right bank where few trees are currently present, although such work would need to be coordinated with potential meander reformation also recommended in this area; and
- Removal of the check dam and resizing of the bridges offers the potential for a 1.5 mi length of river for canoeing and kayaking, because no channel obstructions would remain in the restoration reach.

Rough cost estimates to implement each of these elements are also provided and help establish the proposed order for implementing the restoration elements (Appendix 4). Initial efforts at invasive species control consisting of physical removal and the planting of trees would be a relatively easy and low cost project along the river that could be implemented quickly. Doing such visible work with immediate benefits to the public could increase engagement with the river and build support for more complex costly late-phase restoration options such as the resizing of the bridges. If initial invasives removal efforts prove to be ineffective then chemical options could be considered without necessarily disturbing previously planted trees. The biostabilization and aquatic habitat improvement elements of restoration could also likely move forward relatively quickly at greater cost, although education regarding the benefits and history of using wood in rivers will likely be needed to allay public concerns.

For later stage projects, resizing of the Harney Road Bridge should precede removal of the check dam. Check dam removal will create a steep drop in the river bed that would lead to channel bed incision through an upstream migrating headcut that could potentially undermine the bridge structure, although details of the current bridge's design are unknown. If the resized bridge is completed first, then the bridge can be designed to accommodate a lower bed level in anticipation of removing the check dam. The headcutting could still release fine impounded sediment downstream if left unaddressed. A series of rock weirs could create a series of steps to accommodate this elevation drop with intervening pools improving aquatic habitat. An alternative approach would be to coordinate check dam removal with meander reformation upstream to ensure an evenly graded profile, perhaps requiring some excavation of the impounded sediments to achieve this. A graded profile would be more consistent with natural processes, create geomorphic and ecological continuity along a 1.5 mi reach of river (assuming the three bridges are also resized), and allow for a unique recreational opportunity along the river in Westchester County – canoeing and kayaking.

4.4 County Center (Segments BR_16E through 17B)

Segments BR_16E through 17B is in the vicinity of the Westchester County Center (Figure 21). The combined length of this restoration reach is nearly 2,675 ft. Restoration adjacent to the County Center provides an opportunity to reach thousands of residents that may otherwise be unaware of the BRCSMP. Four objectives are highlighted as priorities in this reach, one in BR_16F and three in Segment BR_17A: hazard mitigation, control invasives, enhance natural riparian vegetation, and improve recreational opportunities (Table 4). Restoring aquatic habitat and improving water quality are other priority objectives (i.e., weighting of 4 or 5) that require addressing (score >10) as adequate floodplain connectivity and natural river processes (e.g., meanders) are already present. The topographic survey of the restoration reach documents a bankfull width of 43 ft, a floodplain unblocked from the river channel except at the bridges, and a channel constriction at the bridge carrying the Parkway's northbound lanes (Appendix 3).

Figure 21. The County Center restoration reach a) upstream of the Parkway bridge (looking downstream) and b) showing bank erosion downstream of the Parkway bridge that contribute fine sediment to the reach.

The long-term vision for the County Center restoration reach is to showcase BRCSMP activities to the thousands of people visiting Westchester County Center each year through an interpretive trail passing by some of the implemented restoration projects envisioned for the reach. With this vision and existing conditions in mind, several restoration techniques are proposed to address unsatisfied BRCSMP objectives. The various elements of the conceptual restoration plan illustrated and outlined in Appendix 4 include:

- Resizing of both bridges (i.e., bridge to the Westchester County Center East Lot and upstream where the northbound lanes of the Parkway cross the river) would remove channel obstructions that currently exacerbate upstream flooding. The current opening at both bridges is 30 ft wide whereas the recommended span would be 54 ft (i.e., 1.25 times the bankfull width). Hydraulic modeling during a detailed design phase would refine these estimates and quantify the reduction in upstream flood stage that would result from larger openings;
- Installation of longitudinal relief culverts under the floodplain-blocking approaches to the Parkway bridge will allow overbank flow from upstream to be conveyed on the floodplain rather than having to pass under the bridge. This will further reduce upstream flooding and improve natural channel processes. The downstream bridge approaches are built at the level of the presumed fill on which the County Center and parking lot are built, so longitudinal relief culverts would be difficult to install;
- Biostabilization of eroding banks that could threaten the recreational path and Westchester County Center East Lot will eliminate a hazard contributing to the high hazard mitigation scores in Table 4. Marginal log jams are an appropriate treatment in this reach, despite its narrowness, given the intact floodplain with no nearby infrastructure on the opposite bank. This erosion and elsewhere in the reach may be associated with the constrictive bridges, so resizing of the bridges may also help address the erosion problems and improve water quality;
- Installation of in-stream structures upstream of the bridge leading to the Westchester County Center East Lot will address the need for aquatic habitat enhancement in this section of river. Partially buried logs may be the best technique to utilize given the narrowness of channel and would blend better with the local setting where no natural boulders are present (as opposed to the reach near Scarsdale – see above – where the adjacent high slope would at least give the impression the boulders are natural even if such boulders are not present); and
- The proximity to County Center provides an opportunity to engage thousands of visitors with the river. A native-vegetation garden replacing invasive species could be part of an interpretive trail with informational signs illustrating many of the findings, recommendations, and, ultimately, outcomes of the BRCSMP. A pedestrian walkway from County Center over the Parkway may entice more use of this area compared to the existing ground-level crossing. Given County Center users come from a broad geographic area, investing in educational outreach at this location will have a greater impact for building broad public support for BRCSMP restoration efforts compared to other potential sites along the river.

Biostabilization would probably have the greatest impact related to a high priority objective at the lowest cost and least public resistance (i.e., most people would appreciate the importance of reducing erosion hazards). While construction of in-stream structures would also be relatively inexpensive, the public and permitting agencies may initially resist installation of wood in the channel (as compared to the margin of the channel for biostabilization) for enhancing aquatic habitat. Resizing the bridges and installation of relief culverts are later stage projects due to the much higher cost, required review of changes to historic structures (Appendix 5), and long-term planning needed for implementation. However, the cost to resize the bridge to the Westchester County Center East Lot, given the limited traffic and size, may be less expensive, while providing the greatest public exposure (given its proximity to County Center) for a technique of great importance for mitigating hazards, restoring natural processes, and enhancing aquatic habitat along the entire length of the river.

An early stage project to develop recreational opportunities would be to create interpretive signs that present the BRCSMP findings and recommendations in an engaging way for pedestrians crossing the river from the Westchester County Center East Lot on their way to the County Center. These signs could have headings such as: 1) “Wood, wood everywhere but none in the river” discussing reasons why wood was historically removed from the river and how it could be reintroduced in responsible ways to improve habitat while mitigating erosion hazards; 2) “The Bronx River is a shell of its old self” discussing flow diversion and the Kensico Dam; 3) “The Bronx River is in a straightjacket and its breaking out” discussing the river’s history of straightening and subsequent meander reformation; 4) “Fighting back the invasion of the green monsters” describing invasive species and the need for their control and eradication, 5) “Creating elbow room for the river” describing the techniques and value of removing channel obstructions and restoring floodplain access; 6) “Bronx River: envisioning a safer and brighter future” spelling out the BRCSMP’s vision for future restoration projects, hazard mitigation efforts, and recreational improvements; and 7) “Dip your toe in the river” detailing ways schools, civic groups and individuals can become involved in riparian planting efforts, invasives control, and citizen science monitoring projects. With little investment, outreach to thousands of individuals can begin the critical process of building public support for larger projects requiring significant investments. The interpretive signs could later be relocated to a loop trail on the floodplain as part of a larger showcasing of state-of-the-art efforts at controlling invasives (with related sign placed near a native plant garden), bank stabilization (with sign placed at the location of a biostabilization project), and resizing crossings (with related sign placed at a new crossing). The showcased techniques could serve as templates for work elsewhere on the Bronx River and on other rivers in the County.

4.5 Fisher Lane/North White Plains Station (Segments BR_19 through 20A)

The North White Plains Station and associated parking area (between the station and river) are situated on artificial fill along the left bank of Segments BR_19 through 17A. The Bronx River channel used to flow, before filling, where the parking lot is now located. Now, the Bronx River is confined between a natural elevated bedrock knob on the right bank and bank armor protecting the parking area from erosion (Figure 22). The combined length of this restoration reach is over 1,600 ft. The bedrock knob provides an opportunity for recreational improvements near the heavily used rail station. Five objectives are highlighted as priorities in this restoration reach: hazard mitigation, enhance aquatic habitat, restore natural processes, enhance natural riparian vegetation, and improve recreational opportunities (Table 4). Segment BR_19 is highlighted as a segment with one of the highest cumulative prioritization scores, indicating the importance of restoration in this area. Floodplain reconnection is another high priority objective (i.e., weighting of 4 or 5) that requires addressing in Segment BR_19. The topographic survey of the restoration reach documents a bankfull width of 33 ft (under severely constrained conditions, so naturally would be higher), an intact floodplain upstream of Fisher Lane, and a channel constriction at the Fisher Lane Bridge (Appendix 3).

Figure 22. The Fisher Lane/North White Plains Station restoration reach showing a) the armor protecting the bank of artificial fill downstream of Fisher Lane (upstream view) and b) the parking lot built on that fill where the Bronx River used to flow prior to filling.

The long-term vision for the Fisher Lane/North White Plains Station restoration reach is to reclaim the floodplain filled to build the parking lot by constructing an elevated garage under which flood flows could pass after removing fill and allowing for a high pedestrian bridge to cross from the garage to the bedrock knob where recreational improvements could be made. With this vision and existing conditions in mind, a number of restoration techniques are envisioned to address unsatisfied BRCSMP objectives. The various elements of the conceptual restoration plan illustrated and outlined in Appendix 4 include:

- Resizing the Fisher Lane Bridge would remove a channel obstruction that currently exacerbates upstream flooding where six homes are at risk of inundation during the 100-yr flood. The bridge constriction is so severe that a ponded area persists upstream even at low flow, but resizing the bridge should alleviate the ponding and restore natural channel processes in this low area that may naturally have been a wetland. The current opening at the bridge is 21 ft wide whereas the recommended span would be at least 41 ft (i.e., 1.25 times the constrained bankfull width). Hydraulic modeling during a detailed design phase would refine these estimates and quantify the reduction in upstream flood stage that would result from a larger opening;

- Reestablishing floodplain connectivity could be achieved by rebuilding the parking area on the west side of the railroad tracks at the natural floodplain level after removing the artificial fill. This would leave the parking area prone to periodic flooding but would restore natural channel processes and lateral connectivity between the channel and floodplain. Alternatively, the parking area could be replaced by a parking garage with an elevated base level under which flood flows up to the 100-yr flood level could pass unimpeded and without threatening parked vehicles;
- Removing bank armor currently protecting the parking lot would be a viable restoration option only if an elevated garage replaces the parking lot at which point the river would be free to migrate under the parking garage where historically the channel once flowed;
- Installation of in-stream structures would be restricted to a limited number of partially buried logs in the constricted channel between the armored bank along the parking lot and the forested bedrock knob. In the event an elevated garage replaces the parking lot and the bank armor removed, marginal log jams along the right bank could enhance aquatic habitat while encouraging channel migration towards its former historical position; and
- Recreational opportunities could be developed in the forested natural area of high ground on the river's right bank downstream of Fisher Lane with the potential for improving the appeal of the existing recreational trails by including, for example, steep spur trails to take advantage of the topographic relief. Ultimately, if a parking garage is built, pedestrian bridges could connect the garage to both the North White Plains Metro station and across the river to the bedrock knob, allowing hundreds of commuters to quickly and easily access improved recreational opportunities.

Rough cost estimates to implement each of these elements are also provided and help establish the order for implementing the restoration elements (Appendix 4). The improvement of recreational opportunities could be completed relatively easily and inexpensively, but access to this area would be greatly improved only with installation of a more costly pedestrian bridge over the river. Removing bank armor and installation of in-stream structures both represent relatively inexpensive means of addressing high priority objectives, but their implementation is largely dependent on construction of an expensive parking garage to improve floodplain connectivity. Partially buried logs to enhance aquatic habitat could be completed sooner, although public outreach would be required to explain and justify this approach in an area with a long history of removing wood from the channel. Although resizing of the Fisher Lane Bridge and restoring floodplain access at the parking lot will be expensive complicated endeavors, they will provide the greatest benefit towards hazard mitigation and other high priority objectives, so long-term planning of those efforts will need to begin long before their ultimate implementation.

5.0 RECOMMENDATIONS AND NEXT STEPS

The following next steps are recommended (in no particular order) to move forward with restoration efforts and other activities aimed at fulfilling the BRCSMP objectives:

1) Identify the restoration concept in Appendix 4 and described in Section 4.0 above where multiple elements covering multiple stages are believed to have the greatest likelihood of implementation over time with consideration given to funding sources, potential constraints, likely partner organizations, and perceived public reaction:
    a. Commit funds and begin permitting for an early stage project element in the identified restoration reach such as a recreational improvement or riparian planting project;
    b. Initiate long-term planning for at least one more complex late stage project element in the identified restoration reach such as resizing an undersized bridge. Planning should include identifying potential funding resources such as FEMA or state equivalent for hazard mitigation projects (e.g., increasing flood resiliency), state and federal transportation programs for resizing river crossings, and environmental agencies (EPA, Fish and Wildlife, and state equivalents) for habitat enhancement and restoring natural processes;

2) Initiate public outreach to build support for initial and long-term restoration efforts by:
    a. Developing brochure(s) detailing Volume I findings, restoration concepts, and long-term objectives of BRCSMP;
    b. Designing educational signs to be placed near the river in a heavily used area such as between Westchester County Center and the East Lot;
    c. Holding evening presentations covering general findings, plans, and objectives as well as more detailed informational sessions as detailed restoration designs are initiated;

3) Conduct repeat monitoring (on an annual basis) of all erosion hazard sites and other select locations (e.g., frequently inundated locations, impoundments or other expected areas of deposition) to document the types and rates of changes occurring along the river using at a minimum:
    a. Annually survey monumented topographic cross sections (Figure 23) of the entire channel and portions of the floodplain to document changes in channel depth and width – cross sections surveyed for the conceptual restoration design sites were not monumented but could be reoccupied using recorded GPS coordinates;
    b. Oriented matched ground photographs repeated annually from known locations and perspectives to note style of erosion, changes in or loss of vegetation, and emergence of sand/gravel bars. The monitoring can include before and after photographs of restoration as well as relocating

the position of and rephotographing historic photographs to document changes over longer time periods (Figure 24);

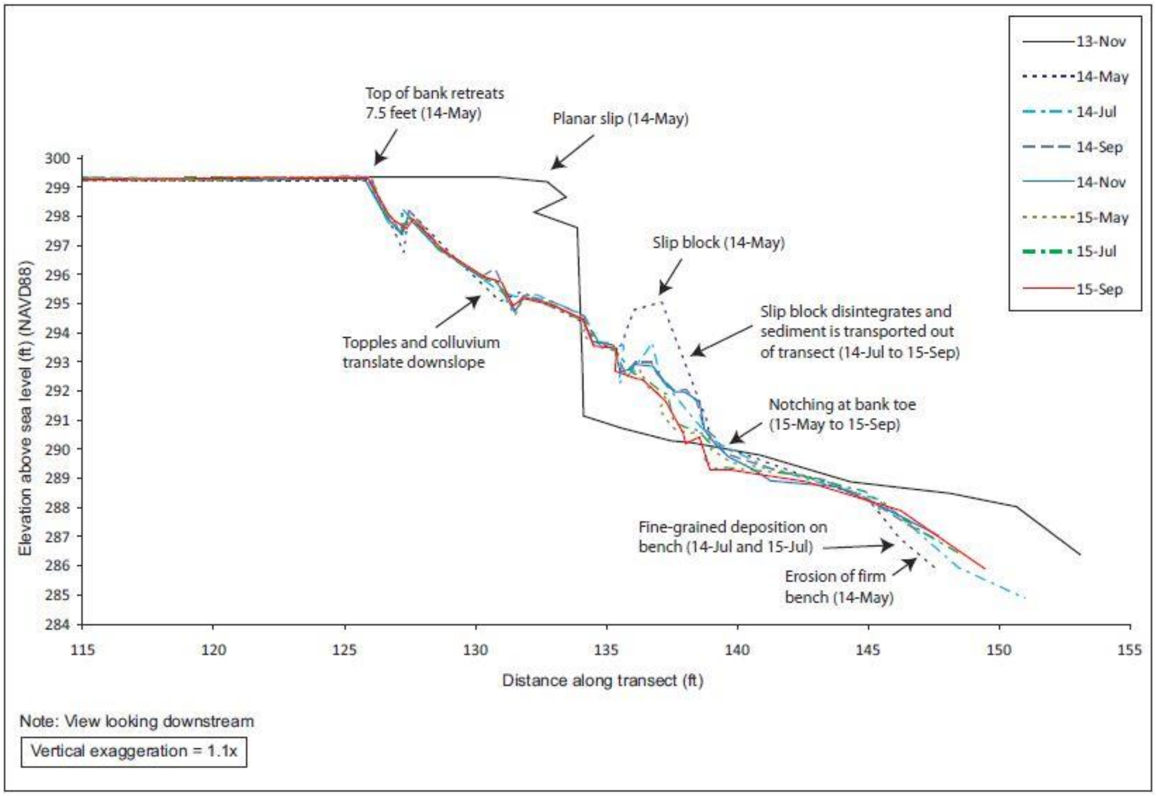

Figure 23. Repeated monitoring of a topographic cross section over a period of two years on the Connecticut River in Charlestown, NH documented the amount and style of ongoing erosion of the river bank.

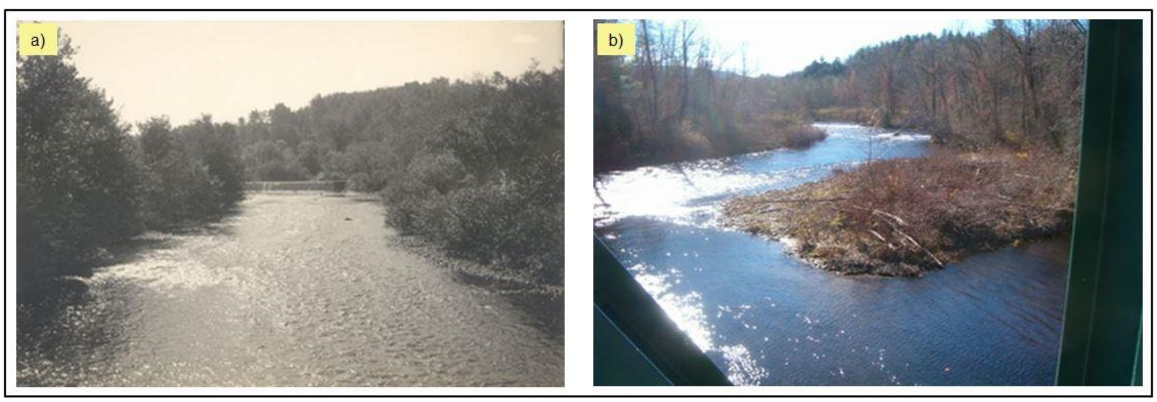

Figure 24. Matched a) historic photograph from before 1950 and b) modern photograph of the Batten Kill in Arlington, VT looking upstream from Rochester Bridge showing loss of dam and growth of gravel bar and meander at bridge.

4) Review prioritization table (Table 4) beginning with the segment with the highest aggregate score (perhaps limited to segments within the Reservation where restoration is more likely to occur) and identify: a) potential projects of varying complexity and cost, b) potential constraints complicating their implementation (e.g., removal of artificial fill to recreate floodplain access will be more difficult if buildings are present as opposed to open fields), and c) workarounds to those

constraints (e.g., elevating Parkway on a viaduct). Look to integrate adjacent segments in the planning to ensure the creation of geomorphic and ecological continuity is maximized. Select affordable and less complex projects to implement in the short-term and develop preliminary plans for more complex projects, so they are available when the opportunity arises to move them forward;

5) Create a "watch" list for prohibitively expensive or complicated restoration projects that are unlikely to move forward until other, perhaps unrelated, projects will be completed that may greatly reduce the cost and complexity of the envisioned restoration project. Such projects are most likely those related to transportation issues. For example, the resizing of a bridge is more likely to move forward when the existing bridge is slated for replacement or significant maintenance. Without the recommendations of the BRCSMP and creation of a "watch" list, such bridges may be replaced or maintained in-kind with no improvements to the crossing's dimensions or mitigation of associated flood hazards. In addition to the resizing of crossings, projects related to increasing floodplain connectivity (e.g., removing fill, elevating portions of the Parkway on a low viaduct) and removing channel obstructions (e.g., removing check dams) are also ideal candidates for placing on a "watch" list because of their expected high cost and likely need for future maintenance. Given the length of time such projects may take to materialize, the "watch" list should be reviewed and updated annually. Steps must also be taken to create an "alert" system to ensure the Planning Department and other stakeholders become aware of work in areas on the "watch" list;

6) Build partnerships with other county departments, governmental agencies, and organizations that can provide assistance with: project development and financing (e.g., emergency management and transportation agencies at the federal, state, and county level), public outreach (e.g., Bronx River Alliance), alerts for upcoming projects (e.g., other county departments), technical assistance (e.g., New York Botanical Garden for information on riparian plantings and invasive species control), and volunteer efforts (e.g., schools and civic organizations that can assist with riparian plantings, invasives control, and long-term monitoring);

7) Some of the highest priority segments (e.g., Segments BR_2A and BR_2B) are difficult to access and were not surveyed for this study nor were restoration concepts developed. Special consideration should be given to these and other difficult to access high-priority segments as to whether access can be developed to extend the recreational path (and ultimately connect with existing paths in the Bronx) and complete high priority restoration projects (e.g., invasives control, create floodplain access);

8) Identify areas where fallen trees may be allowed to remain in the river to enhance aquatic habitat without exacerbating flood hazards or threaten undersized river crossings. Such locations may invariably be where wood is already naturally accumulating, because they are difficult to access and far from existing crossings

and access points to the river. Regardless, the policies for wood removal should be reviewed with the relevant County department to determine if any areas exist where natural wood recruitment can continue undisturbed. More opportunities may arise as stream crossings are resized and become compatible with leaving wood that falls into the river untouched. A similar review of road sanding and salting procedures is recommended, particularly in priority segments for water quality improvement; and

9) Complete detailed surveying and hydraulic modeling in association with bridges under consideration for resizing to determine the current degree of backwatering behind the undersized structures and whether downstream bridges will experience increased backwatering as a result of the resizing of structures upstream.

6.0 CONCLUSIONS

The two-volume BRCSMP represents a continuation of the nearly 100-year old effort to improve the ecosystem and natural aesthetic in the Bronx River Parkway Reservation. The geomorphic and hazard assessment findings presented in Volume I were used to prioritize segments requiring restoration based on the extent to which the 8 BRCSMP objectives (Table 1) are not met. In Volume II, ten restoration alternatives were linked to the objectives (Table 5) such that appropriate actions can be taken in each segment to ensure conditions associated with priority objectives are improved. Topographic surveys were completed at multiple locations to develop 5 restoration concepts, each covering one or more segments, spread along the length of the river (Figure 17). Each concept consists of multiple elements that are envisioned to be completed in multiple stages with simpler less expensive projects (e.g., recreational improvements, riparian plantings) implemented first while more complex, and generally more impactful, projects are more carefully developed (e.g., bridge resizing, check dam removal) over a longer period (Appendix 4). These later stage projects will generally be prohibitively expensive initially, so can be placed on a "watch" list to be given more serious consideration when opportunities arise for significant funding (e.g., state hazard mitigation funds) or other projects in the area could greatly reduce their cost (e.g., road resurfacing could reduce the cost and additional disruption of installing floodplain relief culverts).

The comprehensive restoration of the Bronx River, ultimately over several decades, has the potential to create a corridor with both lateral connectivity (between the channel and floodplain) and longitudinal connectivity (no blockages by bridges or check dams down the length of the river). As the connectivity improves, the impacts to river processes and the ecosystem, resulting from urbanization and a long history of channel alterations, will be minimized and the hazards associated with flooding and erosion greatly mitigated. While this ultimate end goal may never be fully achieved, all future activities in the corridor should progress towards that end point such that all future bridge work should increase connectivity rather than constrain it, future bank stabilization should improve aquatic habitat rather than harm it, and future road work or other construction on the floodplain should improve flow conveyance on the floodplain rather than block it. By taking small strategic steps, future generations will experience a healthier river offering more enriching experiences without the same hazards facing residents today in a continuation of the historic river conservation project begun more than 100 years ago with the development of the Bronx River Parkway Reservation.

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APPENDIX 1

(Restoration Alternatives – Typical Drawings)

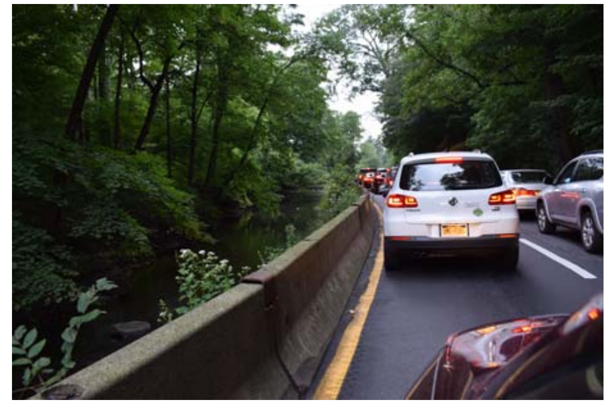
Increase floodplain connectivity

Increasng floodplain connectivity reduces flood inundation and fluvial erosion hazards at the site and in adjacent stream segments. Increasing floodplain connectivity also improves channel stability, water quality, and aquatic habitat.

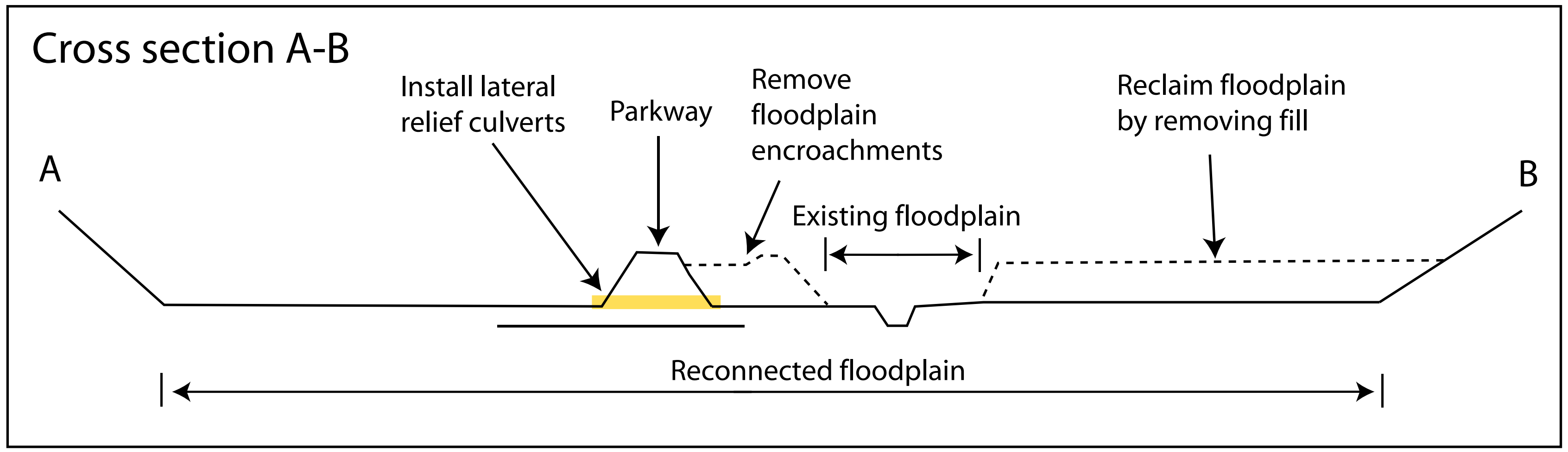
Floodplain encroachments include:

Railroad grade (BR_14C)

Artificial fill (BR_05B)

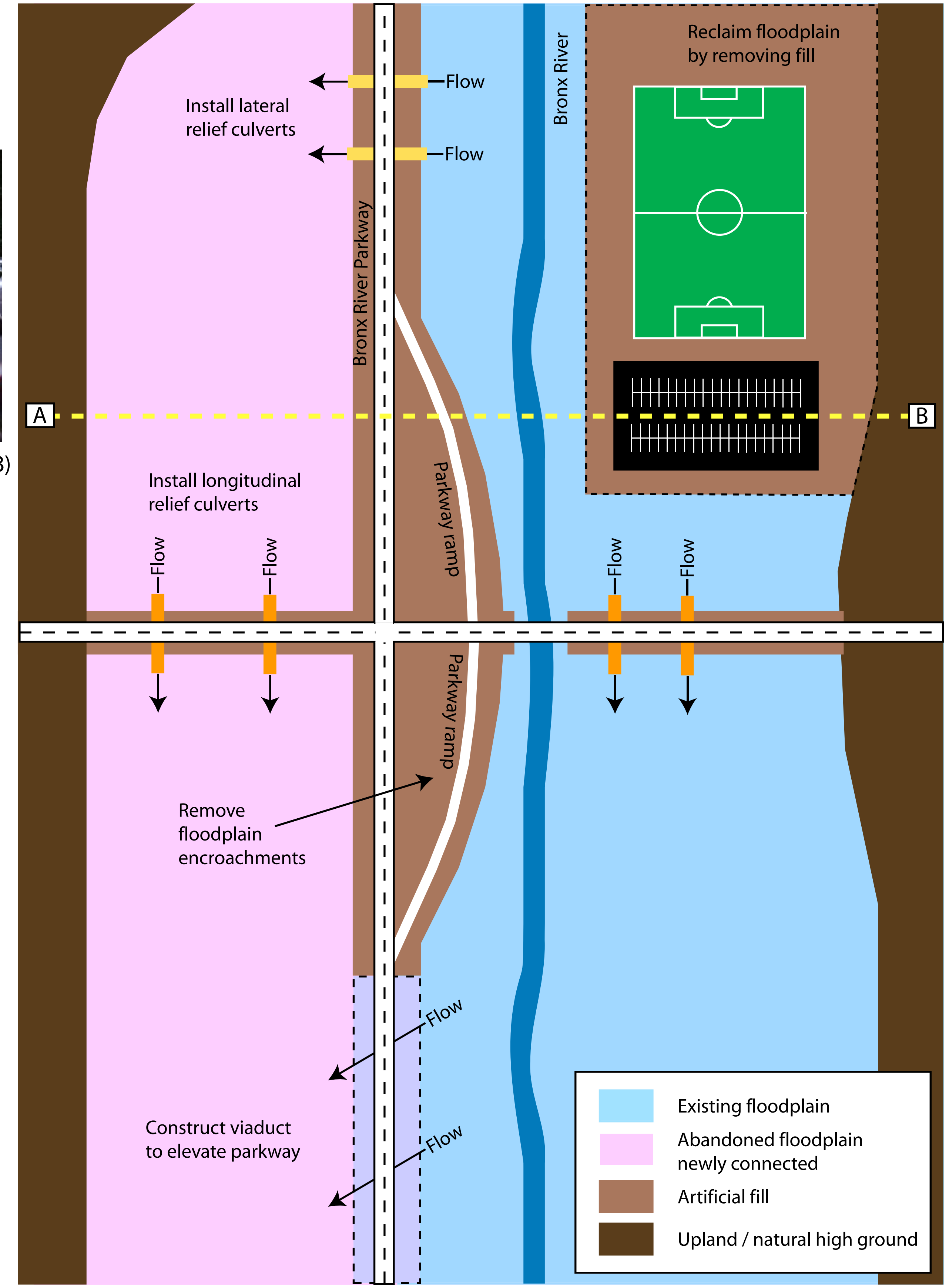


Roads including Bronx River Parkway (BR_11B)



Treatments	Priority segments
Reclaim floodplain by removing fill	BR_19, BR_05B
Remove floodplain encroachments	BR_10B
Lateral relief culverts	BR_10C, BR_10B
Longitudinal relieft culverts	BR_10G, BR_10B, BR_05D
Construct viaduct	BR_11D

Viaduct carrying portion of Parkway over channel in Mount Vernon (BR_02A). Similar viaducts could elevate parkway above floodplain.



Appendix 1: Restoration approaches - Increase floodplain connectivity.

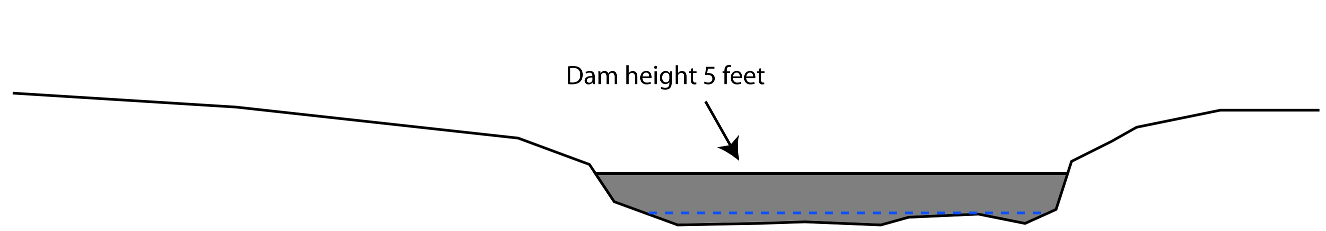
Remove channel obstructions

Removing check dams and other channel obstructions can reduce flood hazards, improve water quality, enhance aquatic habitat, and restore natural channel processes.

Tuckahoe check dam (BR_08C)

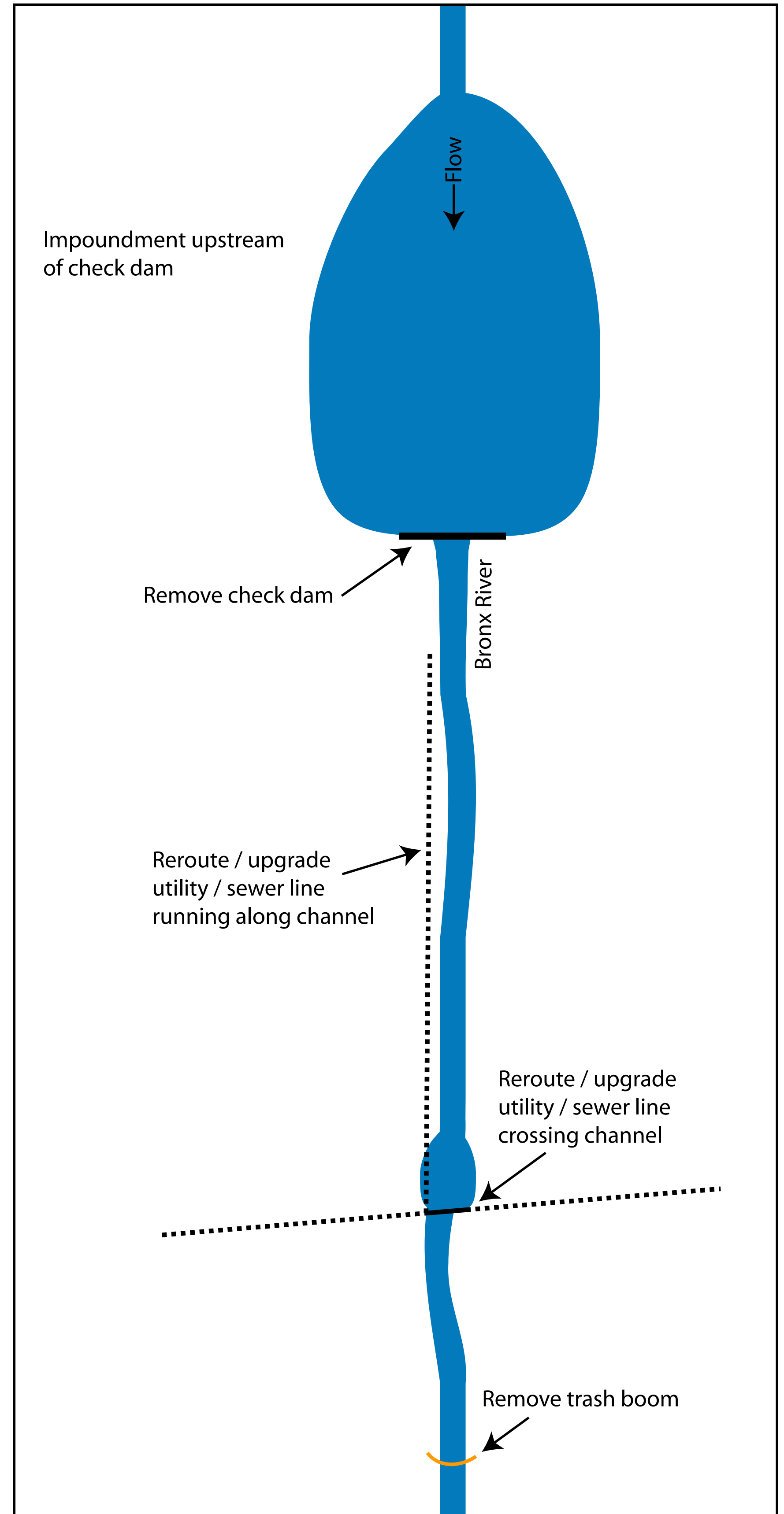
Harney Road check dam (BR_11A)

Surveyed cross section of Harney Road check dam



Removal of a concrete check dam (http://ctfishing.blogspot.com/2005/06/old-dam-removal-before-after-pictures.html)

Treatments	Priority segments
Remove check dam	BR_15A, BR_11A, BR_09, BR_8C, BR_07
Upgrade sewer / utility line	BR_17A, BR_11F, BR_10A
Remove trash boom	BR_16A, BR_10B



Stormwater outfall structures (BR_13A)

Sewer line running along Laurel Brook (LAU_02A)

Sewer line crossing channel (BR_10A)

Trash boom (BR_10B)

Appendix 1: Restoration alternatives - Remove channel obstructions.

Resize bridges and culverts

Resizing bridges and culverts can reduce flood hazards, improve water quality, enhance aquatic habitat, and restore natural channel processes.

Comparison of surveyed channel cross sections upstream of Dewitt Ave (black) and at the upstream face of the railroad bridge (red) illustrates the geomorphic and hydrologic incompatibility of the railroad bridge.

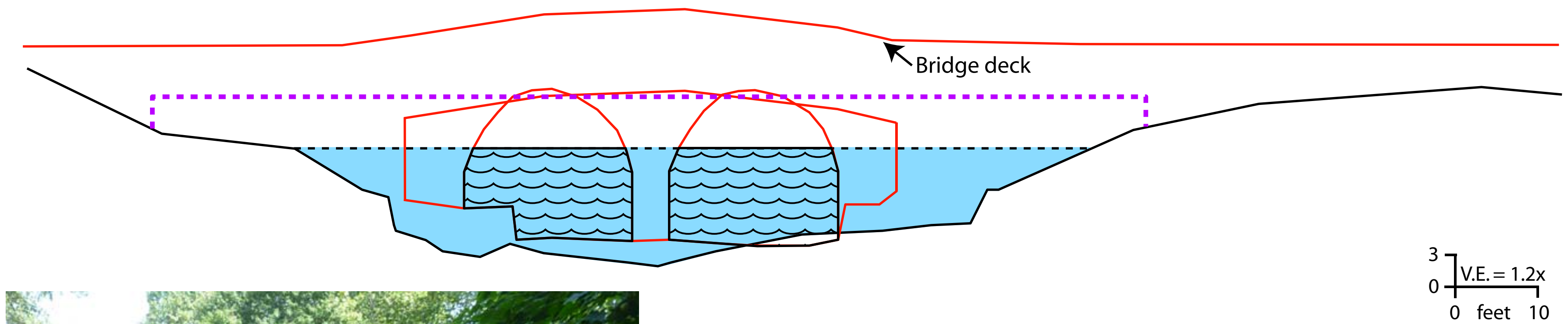
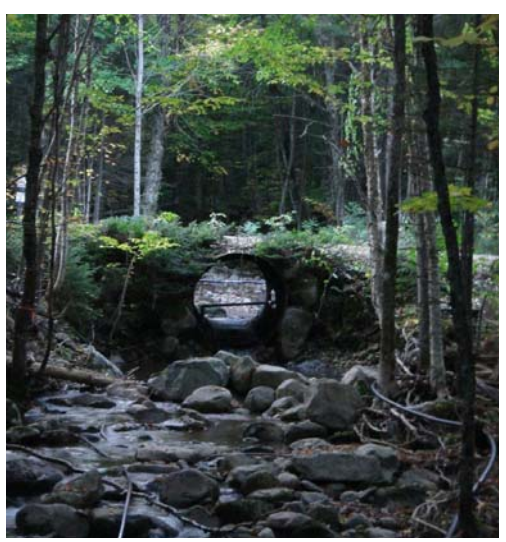


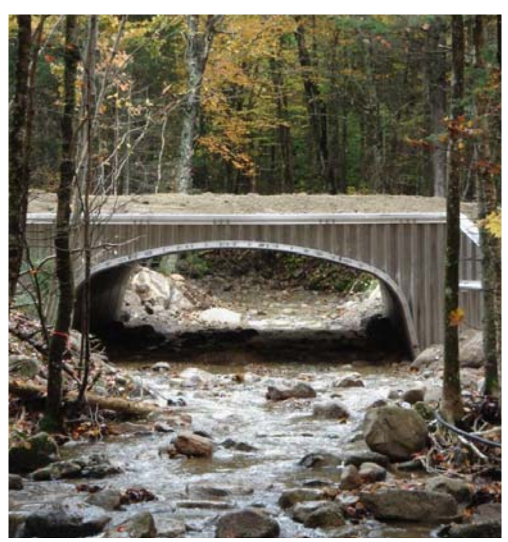
Photo of surveyed railroad bridge (BR_05C)

	Channel width$_{BF}$	Cross sectional area$_{BF}$
XS1 (us of Dewitt Ave)	96ft	700ft^2
Railroad bridge inlet	40ft	310ft^2
Idealized bridge span	120ft	875ft^2

- Estimated bankfull discharge (xs1)
- Existing span available for bankfull discharge (xs1)
- Channel cross section (xs1- us of Dewitt Ave)
- Channel cross section (railroad bridge inlet)
- Idealized span conveying 1.25x bankfull discharge



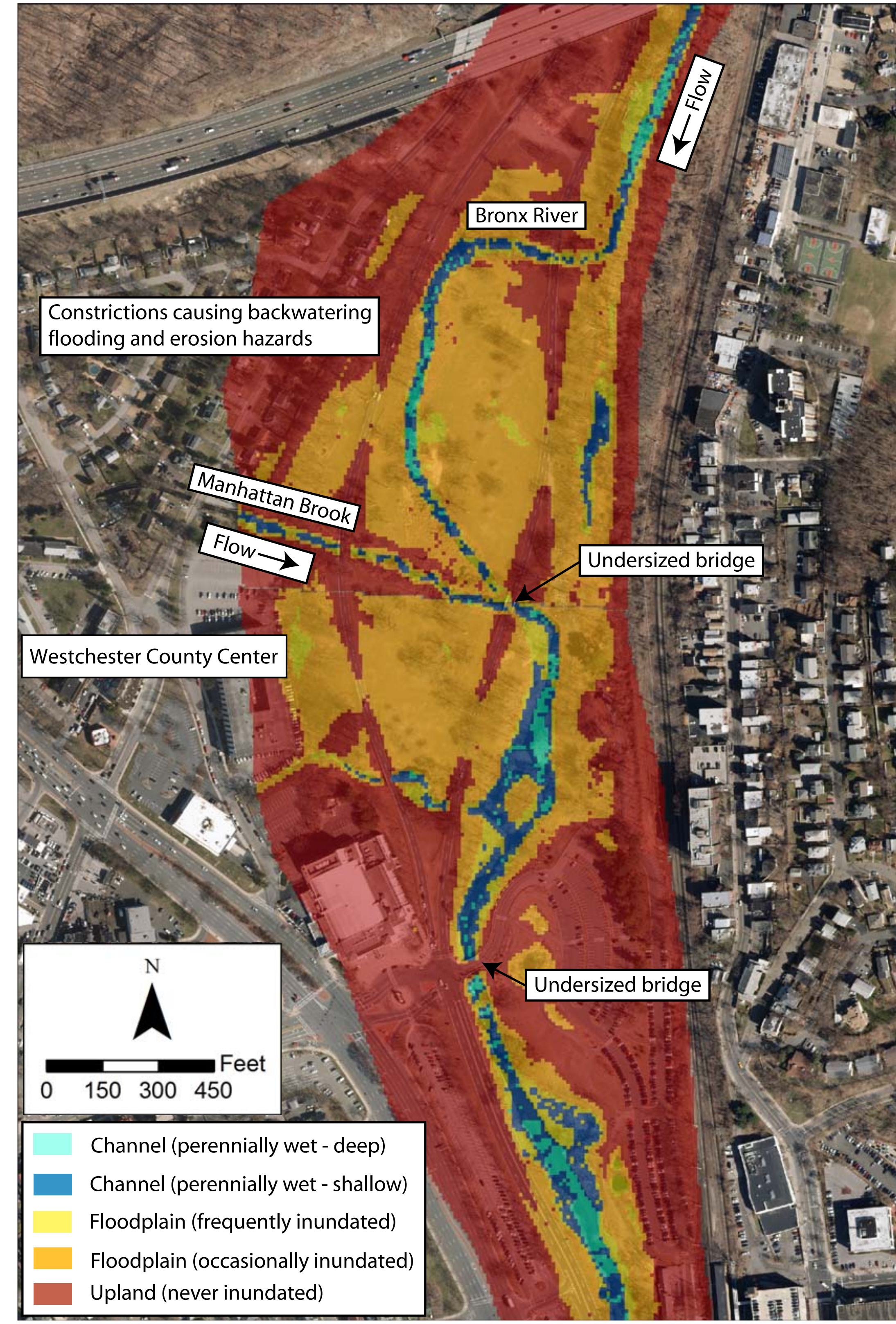
Before: Undersized stream crossing (6ft diameter) (Coos County, NH)



After: Properly sized stream crossing (22 ft span) (Coos County, NH)

Treatments	Priority segments
Resize bridge	BR_20A, BR_17A, BR_16E, BR_11B, BR_11A, BR_05C

Note: The resizing of historic bridges in the Bronx River Parkway Reservation must preserve their historic character and be reviewed by the County's Historic Preservation Advisory Committee, Planning department, and Parks, Recreation and Conservation department as well as receive approval from the NY State Historic Preservation Office.



Appendix 1: Restoration alternatives - Resize culverts and bridges.

Reestablish meandering planform

Reestablishing a meandering planform can mitigate flood and erosion hazards, enhance aquatic habitat, and restore natural channel processes.

Meanders can be reestablished by:

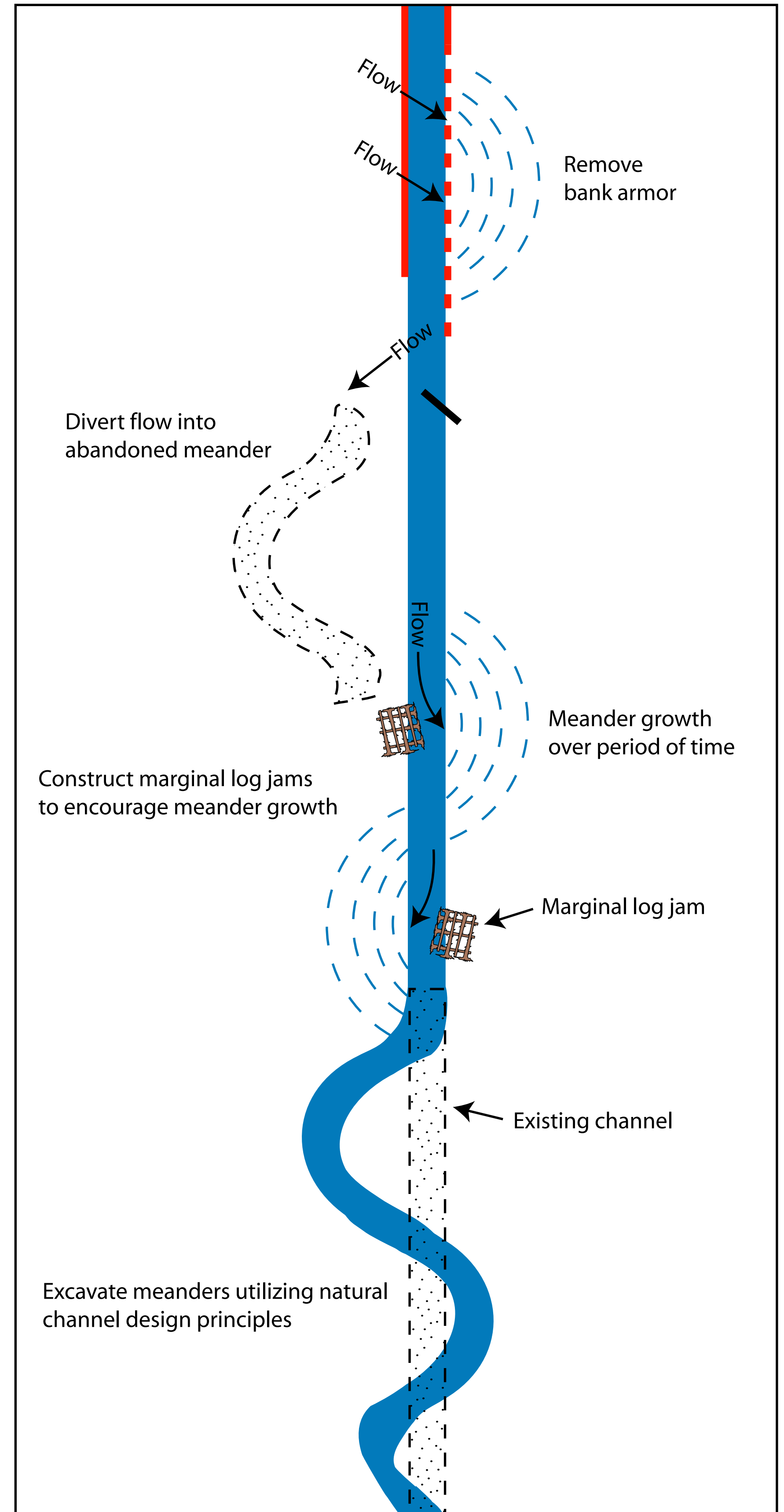
Removing bank armor along a straightened channel (BR_19)

Diverting flow into an abandoned meander (Mohawk River, Colebrook, NH)

Constructing log jams to encourage meander growth (Nash Stream, Stark, NH)

Excavating meanders utilizing natural channel design principles (http://www.landandwater.com /features/vol46no2/vol46no2_1.html)

Treatments	Priority segments
Remove bank armor	BR_19, BR_03A
Flow diversion	BR_11B
Marginal log jams	BR_17C, BR_17A, BR_15F, BR_03B
Excavate meanders	BR_10J



Artificially straightened channel (BR_05D)

Parking lot occupies former channel location (BR_19)

Wide floodplain along straightened channel (BR_10J)

Log jams diverting flow into an abandoned meander along a straightened channel (Mohawk River, Colebrook, NH)

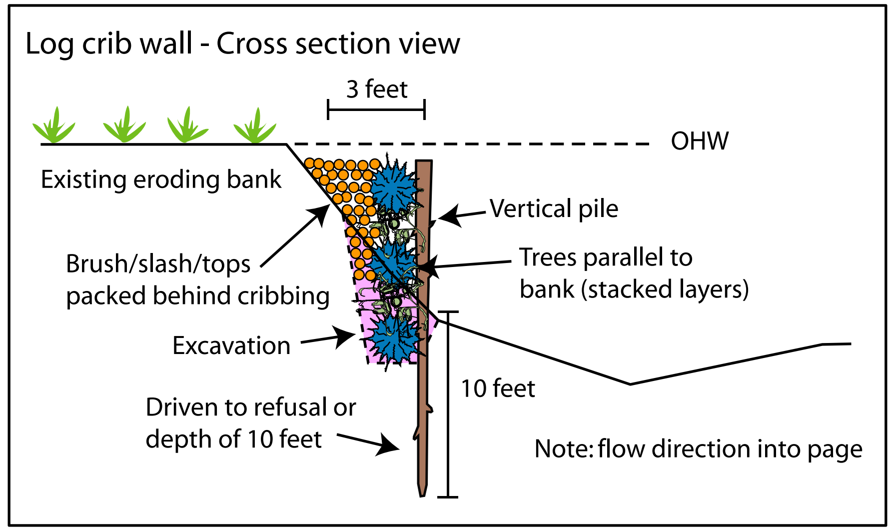
Appendix 1: Restoration alternatives - Reestablish meandering planform.

Biostabilization

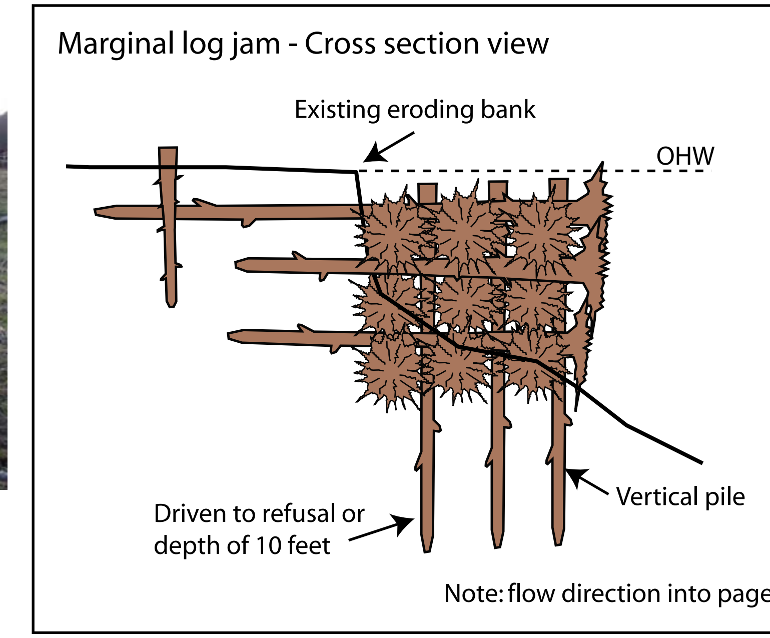
Biostabilization utilizing native materials and natural approaches can mitigate erosion hazards, enhance aquatic habitat, and improve water quality.

Biostabilization techniques include:

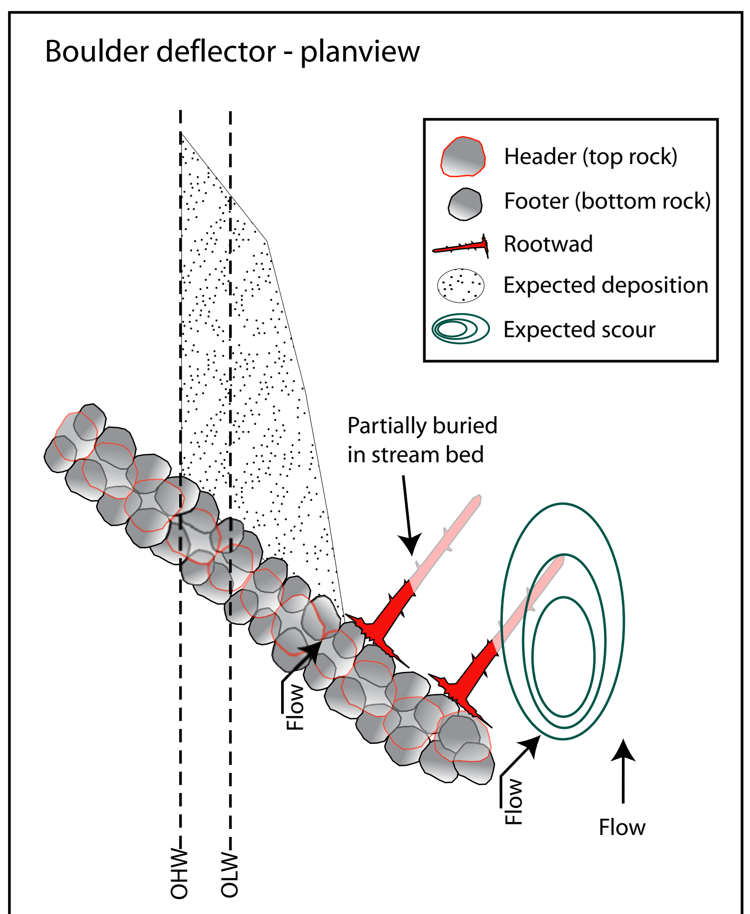
Log crib walls
(Long Creek, South Portland, ME)



Marginal log jams
(Souhegan River, Merrimack, NH)

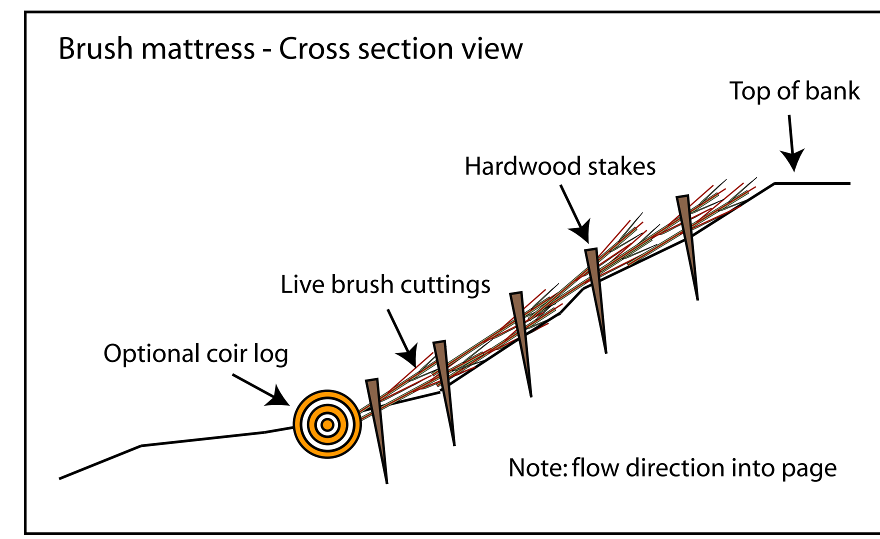


Boulder deflectors with log supports
(South River, Conway, MA)



Brush mattress sample photo from National Engineering Handbook, Streambank Soil Bioengineering Technical Supplement 14I

Brush mattresses



Treatments	Priority segments
Log crib walls	BR_16D, BR_10H, BR_06A
Boulder deflectors	BR_10D, BR_06B
Marginal log jams	BR_16F, BR_15F, BR_06B
Brush mattresses	BR_11A (after dam removal)

Appendix 1: Restoration approaches - Biostabilization.

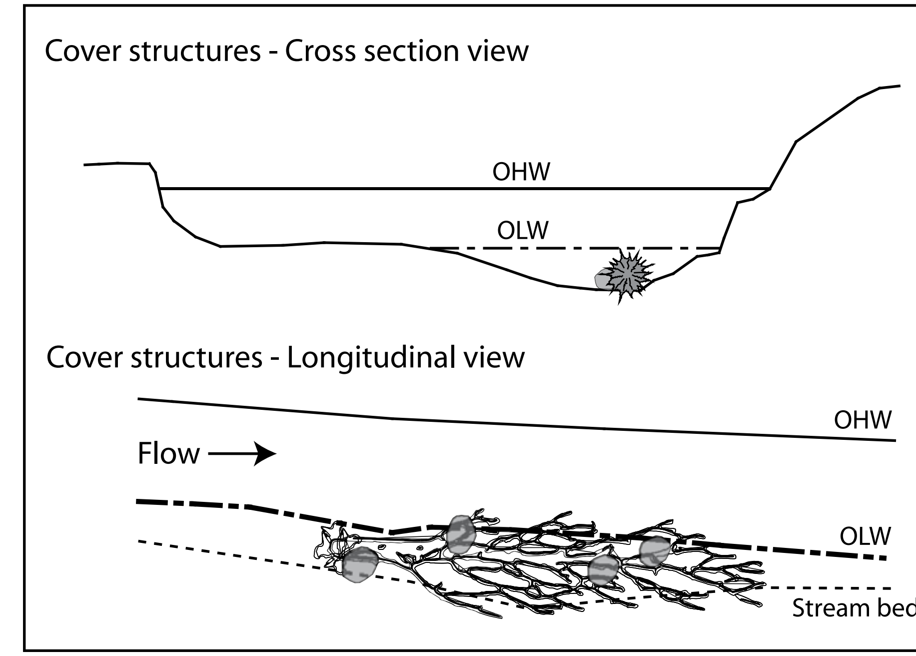
In-stream habitat enhancement

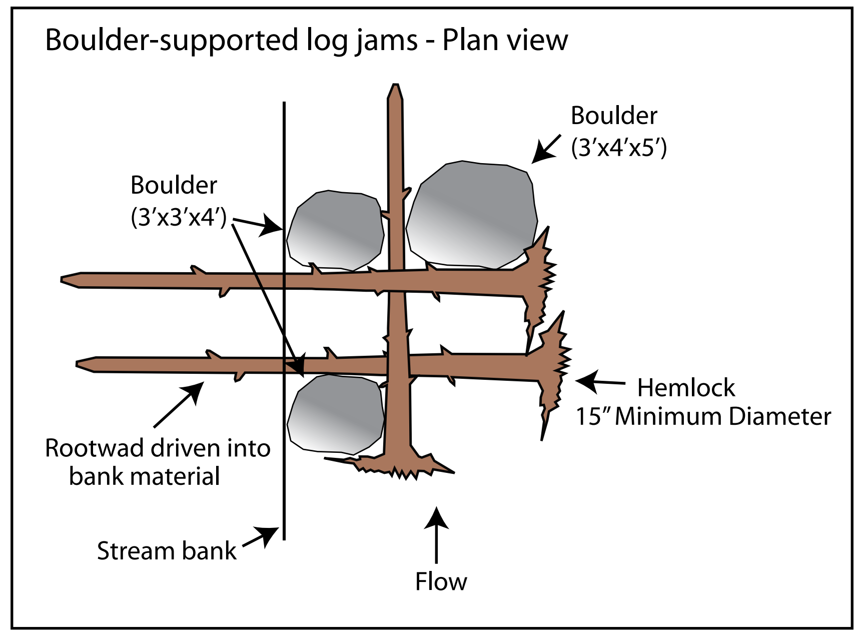
In-stream aquatic habitat can be enhanced using various restoration techniques that utilize native natural materials such as rootwads and rounded boulders.

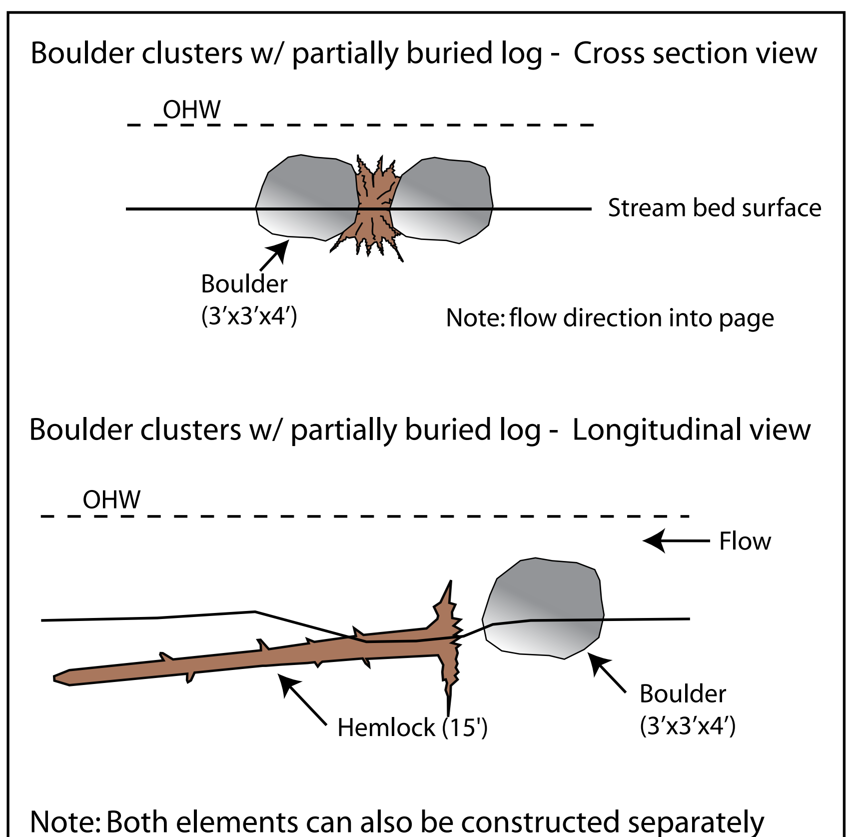
In-stream habitat structures include:

Boulder cluster w/ partially buried log
(Meduxnekeag River, Houlton, ME)

Cover structure
(Batten Kill, Arlington, VT)







Boulder-supported log jam
(Meduxnekeag River, Houlton, ME)

Mid-channel log jam (Nash Stream, Stark, NH)
(See marginal log jam design in Biostabilization typical)

Treatments	Priority segments
Isolated logs	BR_19, BR_01B
Boulder clusters	BR_10D, BR_06B
Boulder-supported log jams	BR_17C, BR_16D, BR_08A, BR_03A, BR_01B
Mid-channel log jams	BR_20A, BR_11A
Cover structures	BR_16C, BR_12F, BR_10C, BR_07

Appendix 1: Restoration alternatives - In-stream habitat enhancement.

Invasive species control and riparian plantings

Enhancing the riparian area through native plantings and invasive species eradication can yield a multitude of benefits including channel shading, wood recruitment, and increased bank stability. Native species provide food and shelter for pollinators, birds, and small mammals and enhance recreational activities for residents and visitors.

Invasive plant species along the Bronx River include:

Japanese knotweed (BR_11F)

Porcelain berry (BR_11F)

Oriental bittersweet (https://www.lhprism.org)

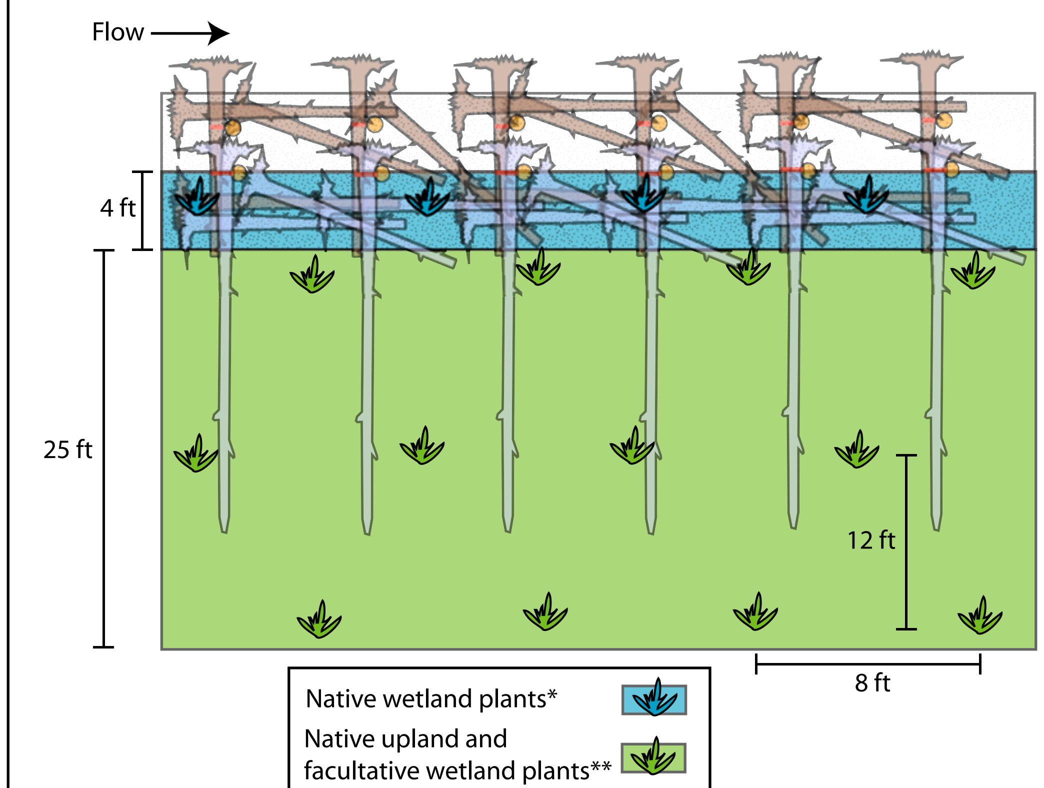
Planting native buffer (Connecticut River, Columbia, NH)

Recently planted riparian buffer (BR_10F)

Before: Mowed grass buffer along degraded channel (Monroe County, NY)

After: Restored riparian buffer planted with native plants and flowers (https://www.monroecountyswcd.org/Streamprojects.html)

Example of riparian buffer planting project - Plan view



Treatments	Priority segments
Invasive species control	BR_17A, BR_11F, BR_11A, BR_03A, BR_02B
Riparian buffer planting	BR_20A, BR_17A, BR_16D, BR_08C, BR_01B

Appendix 1: Restoration alternatives - Invasive species control and riparian plantings.

Improve recreational opportunities

Improving recreational opportunities along the Bronx River Corridor should be considered as part of any restoration or infrastructure project for the vital role these assets play in our communities.

Potential recreational improvements along the Bronx River include:

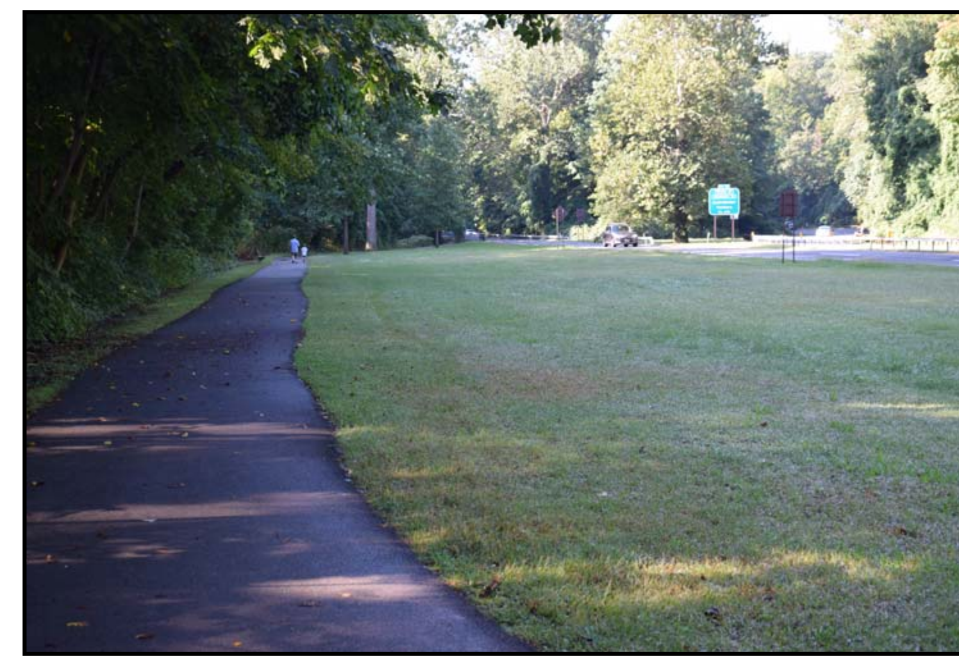
Interpretive signs (BR_10C)

Fishing (BR_09)

Boating (lower Bronx River) (https//ny.curbed.com/2016/5/26/11774066/canoeing-along-the-restored-bronx-river)

Native plants for pollinators

Nature trails (Van Cortlandt Park, Bronx) (https://www.nycgovparks.org/highlights/fall-hiking-trails)



Expanded recreational path

Treatments	Priority segments
Recreational path / nature trail	BR_19, BR_12A to BR_14B
Pollinator plants / native gardens	BR_17A
Boating	BR_11F, BR_10J
Intepretive signs	BR_16E

Appendix 1: Restoration approaches - Improve recreational opportunities.

APPENDIX 2

(Methods Used for Calculating Restoration Prioritization Base Scores)

Methods Used for Calculating Restoration Prioritization Base Scores

Appendix 2 explains the process of how the final prioritization scores shown in Table 4 were established for each objective. The final prioritization scores are the product of a base score and the prioritization weighting given to each objective. The weighting of each objective, ranging from 1 to 5 (although the lowest value assigned was "2"), is provided in Table 1. The base scores were established for each of the eight objectives in all 97 segments using data collected as part of the Volume I assessments (see Table 3) with the process for quantifying the data varying by objective. To provide a common metric that allows a comparison between objectives scored in different ways, the base scores, ranging from 1 to 4, represent the quartile divisions of scores with the segments scoring in the upper 25 percent of values for a given objective assigned a base score of 4, segments in the second highest quartile assigned a 3, segments in the third quartile assigned a 2, and a 1 assigned to segments in the lowest quartile. A higher score indicates a greater need for restoration or other activity in a particular segment to fulfill the given objective scored. The data and process used for scoring each of the eight objectives is described below. The historic status of bridges and built features (Appendix 5) was not considered in the prioritization process, but will need to be addressed in site specific restoration planning to ensure the historic character of the National Register-Listed Bronx River Parkway Reservation is preserved.

Improve water quality

Poor water quality puts stress on aquatic species, reduces the river's appeal for recreation and can pose health risks to humans and pets. During the field evaluation of the Bronx River discussed in Volume I's Section 4.3, segments were measured for their contributions towards negative water quality. Specifically a segment's contribution towards sediment and nutrient loading as well as its potential for trapping floatable human made debris (referred to as floatables) were measured.

Eroding banks are a notable source of sediments in river systems and fine sediments (i.e., silt and clay) are prone to chemically adhering to nutrients. Therefore, each eroding bank was evaluated for its potential to contribute fine sediments to the river's flow. Table A2-1 presents the measurements obtained during the field evaluation to predict a segment's contribution towards negative water quality.

Table A2-1: Water Quality Evaluation Metrics				
	Evaluation Measurements			
Evaluation value[#]	Representative Stream Bank Material	Bank Erosion Hazard Index[^]	Near Bank Stress[&]	Eroding Surface Area*
5	Silt/Clay	Extreme	Extreme	>=90%
4	Sand/Silt/Clay	Very High	Very High	90% >=70%
3	Sand/Silt	High	High	70%>=50%
2	Sand/Gravel	Moderate	Moderate	50%>=25%
1	Gravel/Cobble	Low	Low	<25%

#The higher the value, the greater the contribution towards negative water quality
^ The stream bank's potential to erode
&The stream's potential to erode the bank
* Stream bank surface area is the product of the average eroding stream bank height multiplied by the eroding bank length. Statistical percentiles were then calculated for all the measured eroding banks. The higher the percentage, the bigger the area exposed to erosion.

A numeric value was assigned to each evaluation measurement (four per eroding bank) and then multiplied together with the product referred to as the preliminary water quality objective score. Each product was then multiplied by the percentage of stream bank eroding in each segment to establish the final water quality objective score, since a segment with a higher percentage of its banks eroding contributes more towards negative water quality.

Once each segment's water quality objective score was calculated, priority levels and priority scores were assigned. A detailed table of water quality evaluation values, objective scores and weighted priority scores for each segment are presented in Annex A2-1. A brief list of the top five segments with their final water quality score and objective scores is provided in Table A2-2. The weighted score is what appears as the final prioritization score for water quality in Table 4.

Table A2-2: Water Quality Objective Scoring

Segment	Segment Water Quality Objective Score	Priority	Priority Score	Weighted Score
BR_10C	640	Extreme	4	16
BR_13B	489	Extreme	4	16
BR_15F	463	Extreme	4	16
BR_6A	410	Extreme	4	16
BR_10H	291	Extreme	4	16

Although not considered in calculating the water quality objective score, floating human-made debris (i.e., trash) is a problem along the river and trapping this debris was identified as a stakeholder priority. One popular method to trap this debris is using a debris boom, a floatable net that extends across the river. This net floats in the river until full and may require several weeks or months until needing to be emptied. Fast moving floodwaters may damage a partially filled boom, so locating these booms near areas of slower moving water is optimal. Eight segments are located at the upstream end of impoundments (areas where water velocity approaches zero) and, therefore, are potentially good locations for a debris boom: BR_05D, BR_07, BR_10B, BR_11A, BR_12A, BR_15B, BR_20B, and GS_04A (see digital supplement). A debris boom should be considered for installation when other interventions are considered to improve water quality (or other objectives) in these eight segments.

Mitigate flood and erosion hazards

As discussed in Volume I's Sections 5.3 and 5.4, two fluvial caused hazards were assessed as part of the BRCSMP: flood inundation and bank erosion. Flood inundation occurs when water overtops the river banks and spreads across the floodplain or when river water backs up through unplugged stormwater pipes and culverts and bubbles up through grates and inlets along roads and in neighborhoods. Flooding in urban areas often results in multiple problems such as unhabitable homes, closed businesses, and detrimental water quality. These negative impacts are referred to as flood hazards their mitigation was identified as one of the eight objectives in the BRCSMP.

Predicting damage or disruption caused by flooding is often a function of water levels such that, for example, when water reaches the first floor elevation of a building the need for repairs can be anticipated. To predict water elevations during a flood, a tool referred to as a hydraulic model (a software program that completes complex equations quickly) was used to calculate at what discharges water surface elevations would be higher than ground elevations near buildings or roads. Large flooding events obviously occur less frequently than smaller floods, so flooding of a building or road during a smaller more frequent flood represents a hazard with a higher level of importance to address. This level of importance, referred to as a probability of occurrence, is a function of the predicted frequency of flooding. Flooding frequency is captured using a statistic referred to as a return interval frequency. For example, the 100-year return interval flood (the flood that is used to establish flood prone areas in FEMA's flood insurance rate maps) has a probability of occurring once every one-hundred years (a probability of 0.01, 1/100) whereas a 10-year return interval flood (10-year flood) which occurs once every ten-years has a probability of 0.1 (1/10). When a building or the Bronx River Parkway is flooded in a segment during a 10-year flood (the smallest studied flood event for the BRCSMP) that segment is assigned the highest probability of occurrence with descending values for less frequently occurring floods (Table A2-3).

Table A2-3: Metrics Used for Flood Hazard Evaluation

Predicted Frequency of Flood Hazard Occurring	Probability of Occurrence	Probability of Occurrence Value	Flooding Condition	Severity Level	Severity Value
Once every 10-years	High	5	Buildings flooded	High	5
Once every 10-years to 50-years	Moderate	3			
Once every 50-years to 100-years	Low	1	Bronx River Parkway flooded	Moderate	3

The severity level (and severity value) of flooding was established by identifying the types of infrastructure potentially impacted by floodwaters. When buildings are at risk of flooding, the highest severity level and value was assigned given that flood waters in buildings cause the longest and most hazardous interruption to people's lives within the river corridor (Table A2-3). Segments where inundation of the Bronx River Parkway occurs were assigned the second highest severity value since the average daily traffic count on the Parkway consists of tens of thousands of car trips. In contrast, flooding along other roads (or areas with no buildings) was not assigned a numerical value given the low traffic counts and lack of significant (if any) hazards. The total flood score was calculated by multiplying the probability of occurrence value with the severity level value (Annex A2-2). The highest total flood score among all the segments was 25 while the lowest score was 3.

The second hazard category assessed as part of the BRCSMP was bank erosion. Erosion occurs when the physical strength of rushing water exceeds the cohesion strength of the bank material along the river. Bank erosion can be hazardous when damage to nearby infrastructure is possible such as on the Bronx River where material adjacent to and below a bridge abutment was removed resulting in the abutment's concrete cracking (Figure A2-1).

Figure A2-1: Photo of erosion removing protective material at a bridge on the Bronx River (BIN 3364910), leading to cracking of abutment's concrete.

To quantify the potential hazards associated with erosion, the distance between the top of the eroding bank and proximal infrastructure was measured during the Volume I field investigations. The shorter the distance, the sooner the erosion, in general, will reach the infrastructure and potentially cause damage. A numerical value, referred to as the probability of occurrence, was used to describe this condition. The highest numerical value was assigned to those eroding areas where the distance between the top of the bank and the proximal infrastructure was shortest with descending numerical values assigned to greater and greater distances between the erosion and nearby infrastructure (Table A2-4).

Table A2-4: Metrics Used for Erosion Hazard Evaluation

Predicted Probability of Occurrence (distance to infrastructure in feet)	Probability of Occurrence	Probability of Occurrence Value	Proximal Infrastructure	Severity Level	Severity Value
0 feet to 4 feet	High	5	Bronx River Parkway or Utility	High	5
4 feet to 10 feet	Moderate	3	Arterial Street	Moderate	3
10 feet to 30 feet	Low	1	Recreational Path	Low	1
Greater than 30 feet	Not Scored				

Next, a numerical value, referred to as the severity level, was assigned to reflect the type of infrastructure threated by the erosion. The highest numerical value was assigned to the Bronx River Parkway (the most well-traveled transportation road in the river corridor) and utilities (natural gas lines). Descending numerical values were assigned to less important infrastructure as shown in Table A2-4. The total erosion hazard score was calculated by multiplying the probability of occurrence value with the severity level value (Annex A2-3). The highest total erosion hazard score among all the segments was 25 while the lowest score was 3.

To relate the erosion and flood hazards to the 97 segments, the distance between a segment and the nearest erosion hazard was measured. This measurement was similarly repeated for flood hazards. A numerical value was assigned to reflect the distance between a segment and a flood hazard and the distance between a segment and an erosion hazard (Table A2-5). The higher the numerical value, the closer the segment was to the hazard. The distance numerical value was then multiplied by the nearest hazard's evaluation score to obtain the segment's flood hazard evaluation score and the segment's erosion hazard evaluation score with the higher of the two hazard elevation scores selected as the segment's hazard objective scoring (Annex A2-2 and Annex A2-3). The selected higher score for the 97 segments were then subdivided into the four quartile groups as described above and then multiplied by the hazard weighting factor of 5 to establish the final prioritization score displayed in Table 4.

Table A2-5: Distance Values Between Hazards and Segments	
Distance to Hazard	Distance Numerical Value
0 feet to 500 feet	3
500 feet to 2,500 feet	2
Greater than 2,500 feet	1

Enhance aquatic habitat

The Volume I analysis determined the "need" for restoration in each segment based on how closely the documented observations and measurements reflect natural river conditions. Of the 12 conditions ranked on a scale from 0 to 5 in Volume I (see Volume I Section 5.2b), three of them best reflect the aquatic habitat conditions of the segments: particle size segregation, flow complexity, and quality of pools. The average of the "need" scores for these three conditions (from Table 8 Volume I) were calculated for each segment with the base score for the "enhance aquatic habitat" objective determined by subdividing the 97 individual segment scores into the four quartile groups as described above.

Increase floodplain connectivity

The Volume I analysis determined the "need" for restoration in each segment based on how closely the documented observations and measurements reflect natural river conditions. The base score for the "increase floodplain connectivity" objective was determined by simply subdividing the 97 segment "need" scores recorded for the "floodplain access" condition (from Table 8 Volume I) into the four quartile groups as described above.

Restore natural river processes

The Volume I analysis determined the "need" for restoration in each segment based on how closely the documented observations and measurements reflect natural river conditions. Of the 12 conditions ranked on a scale from 0 to 5 in Volume I (see Volume I Section 5.2b), three of them best reflect the extent to which natural river processes are active in the segments: meander development, bank armoring, and graded profile. The average of the "need" scores for these three conditions (from Table 8 Volume I) were calculated for each segment with the base score for the "restore natural river processes" objective determined by subdividing the 97 individual segment scores into the four quartile groups as described above.

Control the spread of invasive species

Invasive species are an introduced non-native organism that flourishes and dominates its surroundings. They successfully colonize and outcompete native plants because they have left their natural predators behind and therefore have a competitive advantage over native plants. For example, Japanese knotweed (Fallopia japonica), the most pervasive invasive plant along the Bronx River (Yau et al., 2012), is not a preferred grazing food by native animals such as deer, so has a competitive advantage over other native species. Invasive species grow faster and outcompete other plants that at times result in homogenous communities of invasive riparian vegetation. A lack of plant community diversity reduces food sources for terrestrial and aquatic animal species and in-stream habitat diversity, a critical condition for healthy aquatic ecosystems.

Invasive species colonize areas and create a dense thicket that makes access to the river challenging where they represent the dominant vegetation (Figure A2-2). For these reasons invasive species control, in particular invasive plant species is desirable.

Figure A2-2. Invasive species make river access difficult (left) compared to where they are absent (right).

During the field assessment of the Bronx River, riparian composition was noted. If invasive species were the observed dominant plant, the bank was assigned a numerical value which represented the need for invasive species management (Table A2-6). Descending numerical values were assigned to conditions less suitable for an invasive species takeover. The width of riparian vegetation was also observed and recorded as mature native riparian vegetation will be resilient to invasive species colonization; riparian vegetation width is an important factor for determining a buffers health and function (CRJC 2000). Therefore, riparian vegetation of minimal width was assigned the highest numerical value (i.e. highest need for invasive species management) due to its compromised resilience to invasive colonization (Table A2-6). Descending numerical values were assigned to areas where the riparian vegetation along the river is wider. The average of the two resilience values for each segment was then calculated.

Table A2-6: Metrics Used to Calculate Invasive Scores

Observed Species Type	Need of Invasive Management	Riparian Vegetation Width (feet)	Resilience to Invasive Colonization	Canopy Cover Percentage	Resilience to Invasive Colonization
Invasive	5	0 to 10	5	0 to 10	5
No observable plant species	4	10 to 20	4	10 to 25	4
Grass	3	20 to 50	3	25 to 50	3
Grass and sedge	2	50 to 100	2	50 to 75	2
Shrub and Tree	1	greater than 100	1	Greater than 75	1

Observations regarding the type and width of riparian vegetation were not made in 32 segments where no eroding banks were present, the triggering condition for recording this information during the assessment. In lieu of this data, the percent canopy overhang was used as a surrogate for resilience to invasive colonization based on the assumption that riparian vegetation, where shaded, would be more mature and diverse. The segments with greater canopy coverage over the river were assigned the highest numerical value (Table A2-6). Descending numerical values were then assigned to greater and greater tree canopy cover. This value was only applied to segments that did not have a "need of invasive management" score or measurement of riparian vegetation width. Where the segment's average canopy cover percentage was used, this value was adopted as the segment's invasive species score before dividing the 97 segments into quartile groups as described above.

Enhance natural riparian vegetation

The Volume I analysis determined the "need" for restoration in each segment based on how closely the documented observations and measurements reflect natural river conditions. Since a shaded canopy is one of the primary benefits to the river that comes from having natural riparian vegetation growing on the banks, the base score for the "enhance natural riparian vegetation" objective was determined by simply subdividing the 97 segment "need" scores recorded for the "canopy" condition (from Table 8 Volume I) into the four quartile groups as described above.

Develop recreational opportunities

The Volume I analysis determined the "need" for recreational opportunities based on the presence (or perhaps more accurately the absence) of the recreational path and other recreational opportunities in each segment. The base score for the "develop recreational opportunities" objective was determined by simply subdividing the 97 segment "need" scores recorded for the "recreational opportunities" condition (from Table 8 Volume I) into the four quartile groups as described above.

References

Connecticut River Joint Commission (CRJC), 2000, Introduction to Riparian Buffers for the Connecticut River Watershed.

Yau, F. Larson, M., McCarthy, K., Bounds, K., Thornbrough, A., and Doroski, D, 2012, Bronx River Riparian Invasive Plant Management Plan.

Annex A2-1: Water Quality Scoring Data Table.

Segment Identification	Eroding Bank Identification	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Average Bank Height	Bank Length	Segment Length	Percentage of Stream Bank Eroding	Eroding Bank Area	Eroding Bank Area Conditional Score	Stream Bank Material Conditional Score	BEHI Conditional Score	NBS Conditional Score	Subtotal Conditional Scores	Total Conditional Score	Water Quality Score
BR_01A	EB1	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	4.3	55			238	1	4	3	2	24		
BR_01A	EB2	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	4.3	61			265	1	4	3	2	24		
BR_01A	EB3	Upstream	Sand/Silt/Clay	modbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	2.7	282			764	3	4	2	2	48		
BR_01A	EB4	Upstream	Sand/Silt/Clay	modbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	2.7	114			309	1	4	2	2	16		
BR_01A	EB5	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.3	380	2,294	19.4%	1,247	3	4	3	2	72	184	35.7
BR_01B	EB40	Upstream	Sand/Silt	exbehi	vhnbs					Downstream	Sand/Silt	exbehi	vhnbs	9.8	190			1,852	4	3	5	4	240		
BR_01B	EB41	Upstream	Sand/Gravel	highbehi	modnbs					Downstream	Sand/Silt	highbehi	modnbs	3.5	343	1,626	16.4%	1,200	3	3	3	2	54	294	48.1
BR_03A	EB35	Upstream	Sand/Silt/Clay	vhbehi	modnbs									20.0	515			10,304	5	4	4	2	160		
BR_03A	EB36	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	modbehi	modnbs	3.8	122			462	2	4	3	2	48		
BR_03A	EB37	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	6.0	169			1,016	3	4	4	2	96		
BR_03A	EB38	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.3	77			335	1	4	4	2	32		
BR_03A	EB39	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.5	589	1,974	37.3%	2,088	4	4	4	2	128	464	173.0
BR_04A	EB118	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.5	65	663	4.9%	353	1	4	4	2	32	32	1.6
BR_04B	EB42	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	vhnbs	3.5	92	860	5.4%	322	1	4	3	4	48	48	2.6
BR_04C	EB33	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.4	163			880	3	4	4	2	96		
BR_04C	EB34	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.5	112	1,671	8.2%	508	2	4	4	4	128	224	18.4
BR_05A	EB43	Upstream	Sand/Silt/Clay	highbehi	modnbs									3.0	99			296	1	4	3	1	12		
BR_05A	EB44	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	3.2	200			632	2	4	4	2	64		
BR_05A	EB45	Upstream	Sand/Silt/Clay	highbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.3	265	997	28.3%	863	3	4	3	4	144	220	62.3
BR_05B	EB46	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	3.4	454			1,533	4	5	4	4	320		
BR_05B	EB47	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	2.6	77	1,064	25.0%	202	1	5	3	2	30	350	87.3
BR_05D	EB32	Upstream	Sand/Gravel	vhbehi	modnbs					Downstream	Sand/Gravel	vhbehi	modnbs	15.0	260	1,107	11.7%	3,898	5	2	4	2	80	80	9.4
BR_06A	EB48	Upstream	Silt/Clay	vhbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	3.2	448			1,427	4	5	4	4	320		
BR_06A	EB49	Upstream	Silt/Clay	vhbehi	modnbs					Downstream	Silt/Clay	highbehi	vhnbs	3.3	426			1,386	4	5	4	4	320		
BR_06A	EB50	Upstream	Sand/Gravel	vhbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	9.0	215	1,061	51.3%	1,935	4	5	4	4	320	960	492.9
BR_06B	EB30	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.9	296			1,152	3	4	4	2	96		
BR_06B	EB31	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	10.7	421	1,014	35.4%	4,491	5	4	4	2	160	256	90.6
BR_08A	EB51	Upstream	Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	3.0	286			859	3	5	3	2	90		
BR_08A	EB52	Upstream	Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	3.9	824	1,391	39.9%	3,222	5	5	3	2	150	240	95.8
BR_10B	EB112	Upstream	Sand/Silt/Clay	vhbehi	exnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.9	271			1,609	4	4	4	5	320		
BR_10B	EB113	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	4.3	252	636	19.8%	1,091	3	4	3	2	72	392	77.6
BR_10C	EB57	Upstream	Sand/Gravel	vhbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	5.3	768			4,034	5	5	4	4	400		
BR_10C	EB58	Upstream	Silt/Clay	highbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	3.0	773	497	100.0%	2,318	4	5	3	4	240	640	640.0
BR_10D	EB53	Upstream	Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	3.5	153			534	2	5	3	2	60		
BR_10D	EB54	Upstream	Silt/Clay	vhbehi	vhnbs									4.0	106			426	2	5	4	4	160		
BR_10D	EB55	Upstream	Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	3.5	186			652	2	5	3	2	60		
BR_10D	EB56	Upstream	Silt/Clay	highbehi	modnbs					Downstream	Silt/Clay	highbehi	modnbs	3.9	162	1,042	29.1%	626	2	5	3	2	60	340	99.1
BR_10E	EB59	Upstream	Silt/Clay	highbehi	vhnbs					Downstream	Silt/Clay	highbehi	modnbs	3.5	400	365	54.8%	1,401	4	5	3	4	240	240	131.6
BR_10F	EB60	Upstream	Silt/Clay	highbehi	exnbs									3.5	526	769	34.2%	1,842	4	5	3	5	300	300	102.6
BR_10G	EB61	Upstream	Sand/Silt/Clay	vhbehi	hnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	11.7	83			969	3	4	4	2	96		
BR_10G	EB62	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.6	99	842	10.8%	558	2	4	4	2	64	160	17.3
BR_10H	EB63	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	7.5	421			3,144	5	4	4	2	160		
BR_10H	EB64	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	30.0	422	649	64.9%	12,648	5	4	4	4	320	480	311.7
BR_10I	EB65	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	6.5	134			869	3	4	4	2	96		
BR_10I	EB66	Upstream	Sand/Silt/Clay	vhbehi	modnbs									8.0	236	726	25.5%	1,888	4	4	4	2	128	224	57.0
BR_10J	EB26	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.7	112			410	2	4	4	2	64		
BR_10J	EB27	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.7	392			2,222	4	4	4	2	128		
BR_10J	EB28	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	519			2,595	5	4	4	2	160		
BR_10J	EB29	Upstream	Sand/Gravel	vhbehi	vhnbs					Downstream	Sand/Gravel	vhbehi	vhnbs	8.8	754	1,760	50.5%	6,598	5	2	4	4	160	512	258.4
BR_11A	EB67	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	8.4	60	1,069	2.8%	507	2	4	4	2	64	64	1.8
BR_11B	EB68	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.8	68	1,044	3.2%	321	1	4	4	2	32	32	1.0
BR_11C	EB117	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.0	117	519	11.3%	468	2	4	4	2	64	64	7.2
BR_11D	EB69	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay			5.0	48			241	1	4	3	2	24		
BR_11D	EB70	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	exbehi	exnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	10.0	46	346	13.6%	463	2	4	5	5	200	224	30.6
BR_11E	EB23	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	3.8	188			717	2	4	3	2	48		
BR_11E	EB24	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.8	283			1,062	3	4	4	2	96		
BR_11E	EB25	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	7.5	72	897	30.3%	543	2	4	4	2	64	208	63.1
BR_11F	EB71	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.0	85	788	5.4%	338	1	4	3	2	24	24	1.3
BR_12B	EB114	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	hnbs	4.5	125	640	9.8%	564	2	4	4	2	64	64	6.3
BR_12C	EB72	Upstream	Sand/Silt/Clay	vhbehi	hnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.5	135	739	9.1%	613	2	4	3	2	48	48	4.4
BR_13A	EB21	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	5.9	240			1,418	4	4	4	2	128		
BR_13A	EB22	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.5	466	1,424	24.8%	1,630	4	4	3	2	96	224	55.5
BR_13B	EB115	Upstream	Sand/Silt/Clay			Middle	Sand/Silt/Clay	vhbehi	vhnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.7	1130			6,401	5	4	4	4	320		
BR_13B	EB116	Upstream	Sand/Silt/Clay			Middle	Sand/Silt/Clay	vhbehi	vhnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.7	568	1,112	76.3%	3,221	5	4	4	4	320	640	488.6
BR_13B	EB116	Upstream	Sand/Silt/Clay			Middle	Sand/Silt/Clay	vhbehi	vhnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.7	568	1,112	76.3%	3,221	5	4	4	4	320	640	488.6
BR_14A	EB73	Upstream	Sand/Silt/Clay	highbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.5	87			391	1	4	3	4	48		
BR_14A	EB74	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	6.0	98	851	10.8%	586	2	4	4	2	64	112	12.1
BR_15A	EB75	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	5.5	233	1,655	7.1%	1,284	3	4	4	2	96	96	6.8

Segment Identification	Eroding Bank Identification	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Average Bank Height	Bank Length	Segment Length	Percentage of Stream Bank Eroding	Eroding Bank Area	Eroding Bank Area Conditional Score	Stream Bank Material Conditional Score	BEHI Conditional Score	NBS Conditional Score	Subtotal Conditional Scores	Total Conditional Score	Water Quality Score
BR_15B	EB76	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	4.8	158	569	13.9%	750	3	4	4	2	96	96	13.3
BR_15D	EB77	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	6.9	178			1,236	3	4	3	2	72		
BR_15D	EB78	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	5.9	143			847	3	4	3	2	72		
BR_15D	EB79	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.5	338	1,414	23.3%	1,522	4	4	4	2	128	272	63.5
BR_15E	EB80	Upstream	Sand/Silt/Clay	vhbehi	modnbs									5.0	230	467	24.7%	1,152	3	4	4	2	96	96	23.7
BR_15F	EB16	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.3	399			2,095	4	4	4	2	128		
BR_15F	EB17	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	192			961	3	4	4	4	192		
BR_15F	EB18	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	vhnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.5	838			4,635	5	4	4	4	320		
BR_15F	EB19	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.8	164			795	3	4	4	2	96		
BR_15F	EB20	Upstream	Sand/Silt/Clay	vhbehi	modnbs									4.5	236	1,768	51.7%	1,060	3	4	4	2	96	832	430.2
BR_16A	EB81	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.4	298	809	18.4%	1,608	4	4	4	2	128	128	23.6
BR_16B	EB82	Upstream	Sand/Silt/Clay							Downstream	Sand/Silt/Clay	modbehi	modnbs	5.9	75	629	6.0%	448	2	4	2	2	32	32	1.9
BR_16C	EB83	Upstream	Sand/Gravel	vhbehi	modnbs	Middle	Sand/Gravel	vhbehi	modnbs	Downstream	Sand/Gravel	vhbehi	modnbs	3.2	46	647	3.6%	147	1	2	4	2	16	16	0.6
BR_16E	EB84	Upstream	Sand/Gravel	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.6	195	357	27.3%	1,101	3	4	4	2	96	96	26.3
BR_16F	EB85	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	263	788	16.7%	1,314	3	4	4	2	96	96	16.0
BR_17A	EB86	Upstream	Sand/Silt/Clay	exbehi	exnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.3	113	650	8.7%	599	2	4	5	5	200	200	17.4
BR_17B	EB87	Upstream	Sand/Silt/Clay	vhbehi	exnbs					Downstream	Sand/Silt/Clay	vhbehi	exnbs	4.0	114			454	2	4	4	5	160		
BR_17B	EB88	Upstream	Sand/Silt/Clay	exbehi	exnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	3.5	133	880	14.0%	464	2	4	5	5	200	360	50.3
BR_17C	EB89	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.0	209			838	3	4	4	2	96		
BR_17C	EB90	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	181	927	21.1%	907	3	4	4	2	96	192	40.4
BR_17E	EB91	Upstream	Sand/Silt/Clay	exbehi	modnbs					Downstream	Sand/Silt/Clay	exbehi	modnbs	6.2	165			1,024	3	4	5	2	120		
BR_17E	EB92	Upstream	Sand/Gravel	modbehi	modnbs	Middle	Sand/Gravel	highbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.6	193			1,079	3	4	4	2	96		
BR_17E	EB93	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Gravel	vhbehi	modnbs	6.0	227			1,362	3	4	4	2	96		
BR_17E	EB94	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	modbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	5.3	47	1,192	26.5%	251	1	4	4	2	32	344	91.2
BR_17F	EB95	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.5	52			236	1	4	4	4	64		
BR_17F	EB96	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	4.7	95			442	2	4	3	2	48		
BR_17F	EB97	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	modbehi	modnbs	5.0	124	512	26.4%	619	2	4	4	2	64	176	46.5
BR_17G	EB11	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.5	93			417	2	4	4	4	128		
BR_17G	EB12	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	vhnbs	4.1	84			344	1	4	4	4	64		
BR_17G	EB13	Upstream	Sand/Silt	highbehi	modnbs					Downstream	Sand/Silt	vhbehi	modnbs	4.3	61			259	1	3	4	2	24		
BR_17G	EB14	Upstream	Sand/Silt	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.2	79			331	1	4	4	2	32		
BR_17G	EB15	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	26.4	95	816	25.3%	2,510	4	4	4	2	128	376	95.0
BR_20B	EB98	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	modbehi	modnbs	5.0	44			222	1	4	4	2	32		
BR_20B	EB99	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	5.6	54	771	6.4%	305	1	4	3	2	24	56	3.6
BR_20C	EB100	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.5	30			164	1	4	4	2	32		
BR_20C	EB101	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.7	68			316	1	4	3	2	24		
BR_20C	EB102	Upstream	Sand/Silt/Clay	vhbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	4.7	94			438	2	4	4	4	128		
BR_20C	EB103	Upstream	Sand/Silt/Clay	modbehi	modnbs									4.0	63	696	18.3%	251	1	4	2	2	16	200	36.6
BR_20D	EB104	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	modbehi	modnbs	5.4	55	787	3.5%	298	1	4	4	2	32	32	1.1
BR_20E	EB105	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	4.2	34			143	1	4	3	2	24		
BR_20E	EB106	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.6	84	644	9.2%	303	1	4	3	2	24	48	4.4
BR_20F	EB107	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	80			400	2	4	4	2	64		
BR_20F	EB108	Upstream	Sand/Silt/Clay	highbehi	modnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	76			382	1	4	4	2	32		
BR_20F	EB109	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	105			527	2	4	4	2	64		
BR_20F	EB110	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	5.0	75			376	1	4	4	2	32		
BR_20F	EB111	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	7.6	88	1,106	19.2%	669	2	4	4	2	64	256	49.2
BR_20G	EB6	Upstream	Sand/Silt/Clay	highbehi	vhnbs					Downstream	Sand/Silt/Clay	highbehi	modnbs	3.2	79			252	1	4	3	4	48		
BR_20G	EB7	Upstream	Sand/Silt	vhbehi	vhnbs					Downstream	Sand/Silt	vhbehi	modnbs	16.6	54			895	3	3	4	4	144		
BR_20G	EB8	Upstream	Sand/Silt	vhbehi	modnbs					Downstream	Sand/Silt	vhbehi	vhnbs	5.8	211			1,216	3	3	4	4	144		
BR_20G	EB9	Upstream	Sand/Silt/Clay	highbehi	vhnbs	Middle	Sand/Silt/Clay	vhbehi	vhnbs	Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.1	56			229	1	4	4	4	64		
BR_20G	EB10	Upstream	Sand/Silt/Clay	highbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	4.4	115	1,289	19.9%	509	2	4	4	2	64	464	92.4
GS_01B	EB136	Upstream	Sand/Silt/Clay	vhbehi	modnbs						Downstream	Sand/Silt/Clay	vhbehi	modnbs	3.8	210	1145	9.2%	795	3	4	4	2	96	96
GS_02A	EB137	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Left Bank	Sand/Silt/Clay			Downstream	Sand/Silt/Clay	highbehi	modnbs	3.0	1241			3,776	5	4	3	2	120	
GS_02A	EB138	Upstream	Sand/Silt/Clay	vhbehi	vhnbs						Downstream	Sand/Silt/Clay	highbehi	modbehi	3.6	186	761	93.7%	664	3	4	3	4	144	264
GS_02C	EB139	Upstream	Sand/Silt/Clay	vhbehi	modnbs	Middle	Left Bank	Sand/Silt/Clay	highbehi	modnbs	Downstream	Sand/Silt/Clay	highbehi	modnbs	5.3	697	822	42.4%	3,670	5	4	3	2	120	120
GS_03B	EB140	Upstream	Sand/Silt/Clay	highbehi	modnbs						Downstream	Sand/Silt/Clay	highbehi	modnbs	2.3	156			351	2	4	3	2	48	
GS_03B	EB141	Upstream	Sand/Silt/Clay	highbehi	modnbs						Downstream	Sand/Silt/Clay	vhbehi	modbehi	3.0	83			244	1	4	4	2	32	
GS_03B	EB142	Upstream	Silt/Clay	vhbehi	modnbs						Downstream	Sand/Silt/Clay	vhbehi	modnbs	12.0	141			1,689	4	5	4	2	160	
GS_03B	EB143	Upstream	Sand/Silt/Clay	vhbehi	modnbs						Downstream	Sand/Silt/Clay	vhbehi	modnbs	12.0	38	937	22.2%	451	2	4	4	2	64	304
GS_04A	EB134	Upstream	Sand/Silt/Clay	vhbehi	vhnbs						Downstream	Sand/Silt/Clay	highbehi	modnbs	5.1	95			478	3	4	3	4	144	
GS_04A	EB135	Upstream	Sand/Silt/Clay	vhbehi	modnbs										4.5	42	522	13.1%	190	1	4	1	2	8	152
GS_04B	EB132	Upstream	Sand/Silt/Clay	highbehi	modnbs						Downstream	Sand/Silt/Clay	highbehi	modnbs	3.0	96	352	13.6%	287	1	4	3	2	24	24
GS_05A	EB133	Upstream	Sand/Silt	vhbehi	modnbs						Downstream	Sand/Silt	vhbehi	modnbs	4.7	65	574	5.7%	307	2	3	4	2	48	48
LAU_01A	EB120	Upstream	Sand/Silt	vhbehi	modnbs					Downstream	Sand/Silt	vhbehi	vhnbs	3.5	113			394	4	3	4	4	192		
LAU_01A	EB121	Upstream	Sand/Silt/Clay	vhbehi	vhnbs									4.5	20			89	1	4	4	4	64		
LAU_01A	EB122	Upstream	Sand/Silt/Clay	vhbehi	vhnbs	Middle	Sand/Silt/Clay	vhbehi	modnbs	Downstream	Sand/Silt/Clay	vhbehi	vhnbs	4.5	164			737	5	4	4	4	320		
LAU_01A	EB123	Upstream	Sand/Silt/Clay	vhbehi	modnbs									3.5	32			112	2	4	4	2	64		
LAU_01A	EB124	Upstream	Sand/Silt/Clay	vhbehi	modnbs					Downstream	Sand/Silt/Clay	vhbehi	modnbs	3.2	154	689	26.8%	497	4	4	4	2	128	768	206.0
LAU_01B	EB125	Upstream	Sand/Silt	vhbehi	vhnbs									4.0	34			134	2	3	4	4	96		
LAU_01B	EB126	Upstream	Sand/Silt	vhbehi	vhnbs									4.0	15			62	1	3	4	4	48		
LAU_01B	EB127	Upstream	Sand/Silt	vhbehi	vhnbs									4.0	21			84	1	3	4	4	48		

Segment Identification	Eroding Bank Identification	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Point on Eroding Bank	Representative Stream Bank Material	Bank Erosion Hazard Index Score	Near Bank Stress Score	Average Bank Height	Bank Length	Segment Length	Percentage of Stream Bank Eroding	Eroding Bank Area	Eroding Bank Area Conditional Score	Stream Bank Material Conditional Score	BEHI Conditional Score	NBS Conditional Score	Subtotal Conditional Scores	Total Conditional Score	Water Quality Score
LAU_01B	EB128	Upstream	Sand/Silt	vhbehi	modnbs					Downstream	Sand/Silt	vhbehi	modnbs	5.3	68	634	10.9%	362	3	3	4	2	72	264	28.7
LAU_02A	EB129	Upstream	Sand/Silt	highbehi	vhnbs					Downstream	Sand/Silt	vhbehi	vhnbs	2.7	420			1119	5	3	4	4	240		
LAU_02A	EB130	Upstream	Sand/Silt	highbehi	vhnbs					Downstream	Sand/Silt	highbehi	vhnbs	1.0	377			377	3	3	3	4	108		
LAU_02A	EB131	Upstream	Sand/Silt	highbehi	vhnbs					Downstream	Sand/Silt	highbehi	vhnbs	2.0	83	687	64.1%	167	2	3	3	4	72	420	269.2
LAU_03A	EB119	Upstream	Sand/Silt	vhbehi	modnbs					Downstream	Sand/Silt	highbehi	modnbs	2.9	109	676	8.1%	321	3	3	4	2	72	72	5.8

Annex A2-2: Flood Hazard Scoring Data Table.

Segment Identification	Hazard Description 1	Hazard Description 2	Flood Hazard Identification Number	Distance to Flood Hazard Point	Probability of Hazard Occurring Score	Severity if Hazard Occurred Score	Probability of Hazard Occurring Numerical	Severity if Hazard Occurred Numerical	Total Flood Numerical	Total Flood Score	Priority Score	Priority Numerical
BR_01A	BKW 10 year 4-12'		1	3223	High	Mod	5	3	15	High	Low	1
BR_01B	BKW 10 year 4-12'		1	1605	High	Mod	5	3	15	High	High	3
BR_02A	BKW 10 year 4-12'		1	48	High	Mod	5	3	15	High	Extreme	4
BR_02B	BKW 10 year 4-12'		1	57	High	Mod	5	3	15	High	Extreme	4
BR_03A	BKW 10 year 4-12'		1	1339	High	Mod	5	3	15	High	High	3
BR_03B	BKW 10 year 4-12'		1	3261	High	Mod	5	3	15	High	Low	1
BR_04A	BKW 10 year 4-12'		1	4135	High	Mod	5	3	15	High	Low	1
BR_04B	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	3607	High	High	5	5	25	Extreme	Low	1
BR_04C	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	2027	High	High	5	5	25	Extreme	High	3
BR_05A	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	1479	High	High	5	5	25	Extreme	High	3
BR_05B	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	580	High	High	5	5	25	Extreme	High	3
BR_05C	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	208	High	High	5	5	25	Extreme	Extreme	4
BR_05D	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	26	High	High	5	5	25	Extreme	Extreme	4
BR_06A	BKW 10 year 4-12'		3	13	High	Mod	5	3	15	High	Extreme	4
BR_06B	BKW 10 year 4-12'		3	54	High	Mod	5	3	15	High	Extreme	4
BR_06C	BKW 10 year 4-12'		3	1037	High	Mod	5	3	15	High	High	3
BR_07	Buildings in AE (21 Homes) 100-Year	BKW 10 year 0-1	4	64	Low	High	1	5	5	Moderate	Moderate	2
BR_08A	Buildings in AE (21 Homes) 100-Year	BKW 10 year 0-1	4	66	Low	High	1	5	5	Moderate	Moderate	2
BR_08B	Buildings in AE (2 Commercial Scarsdale Road), 50-year		5	14	Mod	High	3	5	15	High	Extreme	4
BR_08C	Buildings in AE (2 Commercial Scarsdale Road), 50-year		5	64	Mod	High	3	5	15	High	Extreme	4
BR_08D	Buildings in AE (2 Commercial Scarsdale Road), 50-year		5	897	Mod	High	3	5	15	High	High	3
BR_09	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	585	Low	High	1	5	5	Moderate	Moderate	2
BR_10A	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	5	Low	High	1	5	5	Moderate	Moderate	2
BR_10B	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	88	Low	High	1	5	5	Moderate	Moderate	2
BR_10C	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	696	Low	High	1	5	5	Moderate	Moderate	2
BR_10D	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	1188	Low	High	1	5	5	Moderate	Moderate	2
BR_10E	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	2145	Low	High	1	5	5	Moderate	Moderate	2
BR_10F	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	2486	Low	High	1	5	5	Moderate	Moderate	2
BR_10G	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	3244	Low	High	1	5	5	Moderate	Low	1
BR_10H	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	4010	Low	High	1	5	5	Moderate	Low	1
BR_10I	2 buildings in AE (River House on Pondfield Road) 100-Year	BKW 10 year 2-4	6	4648	Low	High	1	5	5	Moderate	Low	1
BR_10J	BKW 10 year 1-2'		7	4251	Low	Mod	1	3	3	Low	Low	1
BR_10K	BKW 10 year 1-2'		7	3644	Low	Mod	1	3	3	Low	Low	1
BR_11A	BKW 10 year 1-2'		7	2825	Low	Mod	1	3	3	Low	Low	1
BR_11B	BKW 10 year 1-2'		7	1918	Low	Mod	1	3	3	Low	Moderate	2
BR_11C	BKW 10 year 1-2'		7	1445	Low	Mod	1	3	3	Low	Moderate	2
BR_11D	BKW 10 year 1-2'		7	1137	Low	Mod	1	3	3	Low	Moderate	2
BR_11E	BKW 10 year 1-2'		7	252	Low	Mod	1	3	3	Low	Moderate	2

BR_11F	BKW 10 year 1-2'		7	25	Low	Mod	1	3	3	Low	Moderate	2
BR_12A	BKW 10 year 1-2'		7	514	Low	Mod	1	3	3	Low	Moderate	2
BR_12B	BKW 10 year 1-2'		7	1854	Low	Mod	1	3	3	Low	Moderate	2
BR_12C	BKW 10 year 1-2'		7	2431	Low	Mod	1	3	3	Low	Moderate	2
BR_12D	BKW 10 year 1-2'		7	3131	Low	Mod	1	3	3	Low	Low	1
BR_12E	BKW 10 year 1-2'		7	3937	Low	Mod	1	3	3	Low	Low	1
BR_12F	BKW 10 year 2-4		8	3488	Mod	Mod	3	3	9	Moderate	Low	1
BR_13A	BKW 10 year 2-4		8	2070	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_13B	BKW 10 year 2-4		8	976	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_14A	BKW 10 year 2-4		8	190	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_14B	BKW 10 year 2-4		8	13	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_14C	BKW 10 year 2-4		8	529	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_15A	BKW 10 year 2-4		8	1882	Mod	Mod	3	3	9	Moderate	Moderate	2
BR_15B	BKW 10 year 2-4		8	3469	Mod	Mod	3	3	9	Moderate	Low	1
BR_15C	BKW 10 year 2-4		8	3998	Mod	Mod	3	3	9	Moderate	Low	1
BR_15D	BKW 10 year 1-2'		9	3469	Low	Mod	1	3	3	Low	Low	1
BR_15E	BKW 10 year 1-2'		9	3041	Low	Mod	1	3	3	Low	Low	1
BR_15F	BKW 10 year 1-2'		9	1288	Low	Mod	1	3	3	Low	Moderate	2
BR_16A	BKW 10 year 1-2'		9	571	Low	Mod	1	3	3	Low	Moderate	2
BR_16B	BKW 10 year 1-2'		9	5	Low	Mod	1	3	3	Low	Moderate	2
BR_16C	BKW 10 year 1-2'		9	50	Low	Mod	1	3	3	Low	Moderate	2
BR_16D	Buildings in AE (Old Kensico Road) (Homes 5) 10-Year	BKW 10 year 1-2'	10	1	High	High	5	5	25	Extreme	Extreme	4
BR_16E	Buildings in AE (Old Kensico Road) (Homes 5) 10-Year	BKW 10 year 1-2'	10	22	High	High	5	5	25	Extreme	Extreme	4
BR_16F	Buildings in AE (Old Kensico Road) (Homes 5) 10-Year	BKW 10 year 1-2'	10	350	High	High	5	5	25	Extreme	Extreme	4
BR_17A	Buildings in AE (Old Kensico Road) (Homes 5) 10-Year	BKW 10 year 1-2'	10	987	High	High	5	5	25	Extreme	High	3
BR_17B	BKW 10 year 1-2'		11	1448	Low	Mod	1	3	3	Low	Moderate	2
BR_17C	BKW 10 year 1-2'		11	532	Low	Mod	1	3	3	Low	Moderate	2
BR_17D	BKW 10 year 1-2'		11	80	Low	Mod	1	3	3	Low	Moderate	2
BR_17E	BKW 10 year 1-2'		11	36	Low	Mod	1	3	3	Low	Moderate	2
BR_17F	BKW 10 year 0-1		12	183	Low	Mod	1	3	3	Low	Moderate	2
BR_17G	BKW 10 year 1-2'		13	27	Low	Mod	1	3	3	Low	Moderate	2
BR_18	BKW 10 year 1-2'		13	2	Low	Mod	1	3	3	Low	Moderate	2
BR_19	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	2	High	High	5	5	25	Extreme	Extreme	4
BR_20A	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	18	High	High	5	5	25	Extreme	Extreme	4
BR_20B	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	659	High	High	5	5	25	Extreme	High	3
BR_20C	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	1301	High	High	5	5	25	Extreme	High	3
BR_20D	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	1943	High	High	5	5	25	Extreme	High	3
BR_20E	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	2537	High	High	5	5	25	Extreme	Low	1
BR_20F	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	3159	High	High	5	5	25	Extreme	Low	1
BR_20G	Buildings in AE (Homes 6) (Edge Park Road) 10-Year	BKW 10 year 1-2'	14	4067	High	High	5	5	25	Extreme	Low	1
GS_01A	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	855	High	High	5	5	25	Extreme	High	3
GS_01B	BKW 10 year 4-12'		3	843	High	Mod	5	3	15	High	High	3
GS_01C	BKW 10 year 4-12'		3	1192	High	Mod	5	3	15	High	High	3
GS_02A	BKW 10 year 4-12'		3	1491	High	Mod	5	3	15	High	High	3
GS_02B	BKW 10 year 4-12'		3	2059	High	Mod	5	3	15	High	High	3
GS_02C	BKW 10 year 4-12'		3	2585	High	Mod	5	3	15	High	Low	1
GS_03A	BKW 10 year 4-12'		3	3313	High	Mod	5	3	15	High	Low	1
GS_03B	BKW 10 year 4-12'		3	3739	High	Mod	5	3	15	High	Low	1
GS_03C	BKW 10 year 4-12'		3	4588	High	Mod	5	3	15	High	Low	1
GS_04A	BKW 10 year 4-12'		3	5108	High	Mod	5	3	15	High	Low	1
GS_04B	Buildings in AE (21 Homes) 100-Year	BKW 10 year 0-1	4	5571	Low	High	1	5	5	Moderate	Low	1
GS_05A	Buildings in AE (21 Homes) 100-Year	BKW 10 year 0-1	4	5601	Low	High	1	5	5	Moderate	Low	1
GS_05B	Buildings in AE (21 Homes)	BKW 10 year 0-1	4	5627	Low	High	1	5	5	Moderate	Low	1

	100-Year											
LAU_01A	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	1405	High	High	5	5	25	Extreme	Low	1
LAU_01B	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	1421	High	High	5	5	25	Extreme	Low	1
LAU_02A	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	1764	High	High	5	5	25	Extreme	Low	1
LAU_02B	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	2434	High	High	5	5	25	Extreme	Low	1
LAU_03A	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	2951	High	High	5	5	25	Extreme	Low	1
LAU_03B	Buildings in AE (43 buildings Millard Ave, Parkway Rd) 10-Year	BKW 10 year 4-12'	2	3251	High	High	5	5	25	Extreme	Low	1

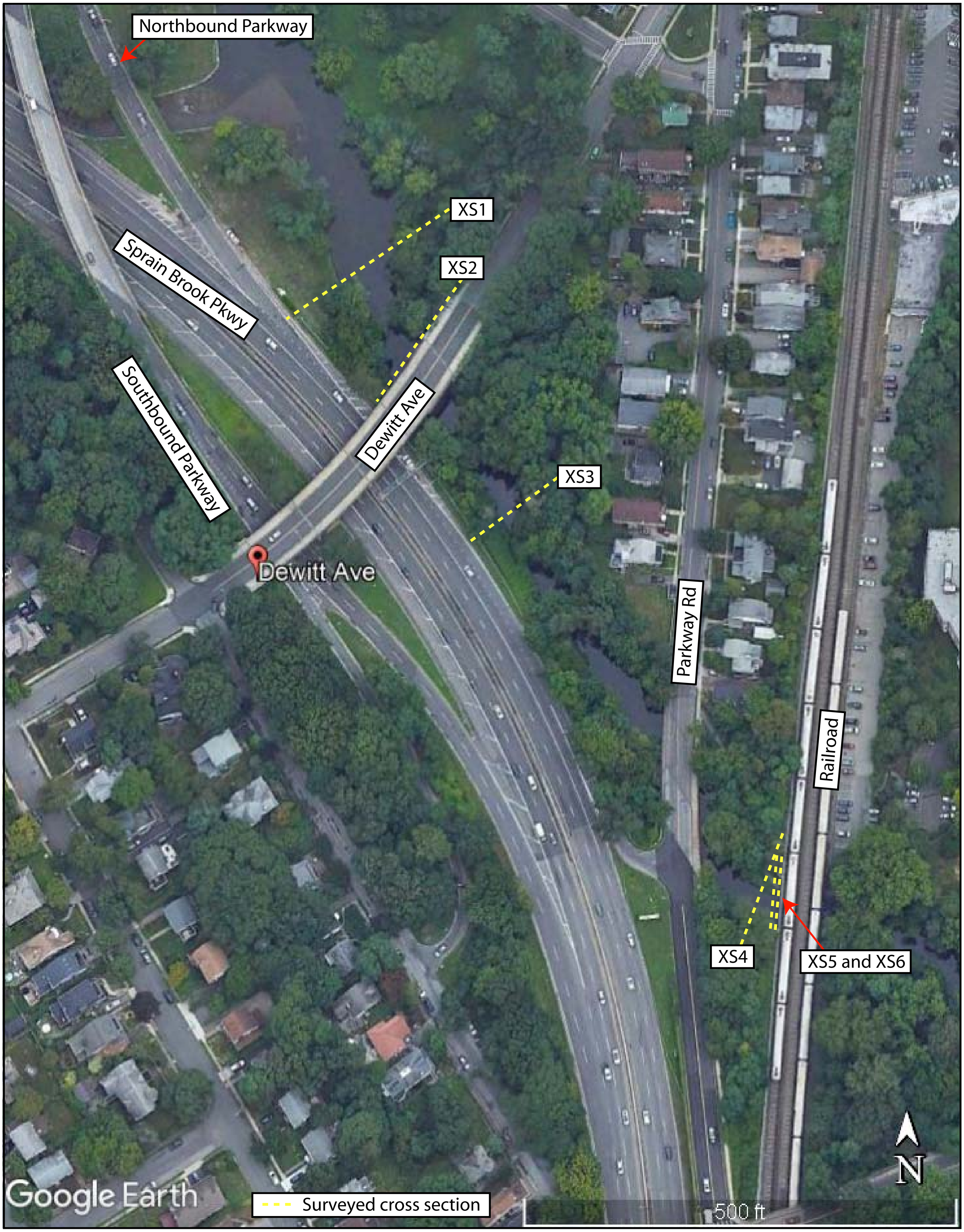
Annex A2-3: Erosion Hazard Scoring Data Table.

Segment Identification	Distance From Top of Eroding Bank to Infrastructure	Probability of Hazard Occurring Score	Probability of Hazard Occurring Numerical	Infrastructure Type	Severity if Hazard Occurred Score	Severity if Hazard Occurred Numerical	Total Erosion Hazard Numerical	Total Erosion Hazard Score	Erosion Hazard Identification Number	Distance to Erosion Hazard	Priority Score	Priority Numerical
BR_01A	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E03	21	Moderate	2
BR_01B	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E03	259	Moderate	2
BR_02A	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E04	1411	High	3
BR_02B	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E04	111	Extreme	4
BR_03A	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E04	26	Extreme	4
BR_03B	0	low	1	N/A	Low	1	1	Low	E06	16	Moderate	2
BR_04A	0	low	1	N/A	Low	1	1	Low	E06	644	Moderate	2
BR_04B	0	low	1	N/A	Low	1	1	Low	E06	1273	Moderate	2
BR_04C	0	low	1	N/A	Low	1	1	Low	E07	99	Moderate	2
BR_05A	0	low	1	N/A	Low	1	1	Low	E07	28	Moderate	2
BR_05B	0	low	1	N/A	Low	1	1	Low	E07	804	Moderate	2
BR_05C	0	low	1	N/A	Low	1	1	Low	E07	1631	Moderate	2
BR_05D	0	low	1	N/A	Low	1	1	Low	E07	1777	Moderate	2
BR_06A	0	low	1	N/A	Low	1	1	Low	E07	2697	Low	1
BR_06B	0	low	1	N/A	Low	1	1	Low	E07	3729	Low	1
BR_06C	0	low	1	N/A	Low	1	1	Low	E07	4622	Low	1
BR_07	0	low	1	N/A	Low	1	1	Low	E07	5029	Low	1
BR_08A	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	4207	Low	1
BR_08B	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	3751	Low	1
BR_08C	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	3037	Low	1
BR_08D	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	2594	Low	1
BR_09	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	926	Moderate	2
BR_10A	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	257	Moderate	2
BR_10B	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	21	Moderate	2
BR_10C	6	moderate	3	Bronx River Parkway	Extreme	5	15	High	E10	4	Extreme	4
BR_10D	6	moderate	3	Bronx River Parkway	Extreme	5	15	High	E10	292	Extreme	4
BR_10E	2	high	5	Recreation Pathway	Low	1	5	Moderate	E11	351	Moderate	2
BR_10F	2	high	5	Recreation Pathway	Low	1	5	Moderate	E11	35	Moderate	2
BR_10G	2	high	5	Recreation Pathway	Low	1	5	Moderate	E11	413	Moderate	2
BR_10H	4	high	5	Recreation Pathway	Low	1	5	Moderate	E12	449	Moderate	2
BR_10I	4	high	5	Recreation Pathway	Low	1	5	Moderate	E12	13	Moderate	2
BR_10J	15	low	1	Recreation Pathway	Low	1	1	Low	E13	9	Moderate	2
BR_10K	15	low	1	Recreation Pathway	Low	1	1	Low	E13	942	Moderate	2
BR_11A	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	1504	High	3
BR_11B	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	599	High	3
BR_11C	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	171	Extreme	4
BR_11D	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	138	Extreme	4
BR_11E	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	186	Extreme	4
BR_11F	10	moderate	3	Bronx River Parkway	Extreme	5	15	High	E14	1075	High	3
BR_12A	25	low	1	Aqueduct Drive	Moderate	3	3	Low	E15	135	Moderate	2
BR_12B	25	low	1	Aqueduct Drive	Moderate	3	3	Low	E15	24	Moderate	2
BR_12C	25	low	1	Aqueduct Drive	Moderate	3	3	Low	E15	458	Moderate	2
BR_12D	25	low	1	Aqueduct Drive	Moderate	3	3	Low	E15	1154	Moderate	2
BR_12E	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E16	1179	Moderate	2
BR_12F	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E16	652	Moderate	2
BR_13A	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E16	16	Moderate	2
BR_13B	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E16	769	Moderate	2
BR_14A	25	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E16	1871	Moderate	2
BR_14B	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	2509	Low	1
BR_14C	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	1155	Moderate	2
BR_15A	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	16	Moderate	2
BR_15B	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	436	Moderate	2
BR_15C	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	969	Moderate	2
BR_15D	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	1822	Moderate	2
BR_15E	30	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E17	3159	Low	1
BR_15F	8	moderate	3	Bronx River Parkway	Extreme	5	15	High	E18	1493	High	3
BR_16A	8	moderate	3	Bronx River Parkway	Extreme	5	15	High	E18	824	High	3
BR_16B	8	moderate	3	Bronx River Parkway	Extreme	5	15	High	E18	216	Extreme	4
BR_16C	8	moderate	3	Bronx River Parkway	Extreme	5	15	High	E18	15	Extreme	4
BR_16D	8	moderate	3	Bronx River Parkway	Extreme	5	15	High	E18	425	Extreme	4
BR_16E	4	high	5	Recreation Pathway	Low	1	5	Moderate	E19	595	Moderate	2
BR_16F	4	high	5	Recreation Pathway	Low	1	5	Moderate	E19	15	Moderate	2
BR_17A	4	high	5	Recreation Pathway	Low	1	5	Moderate	E19	127	Moderate	2

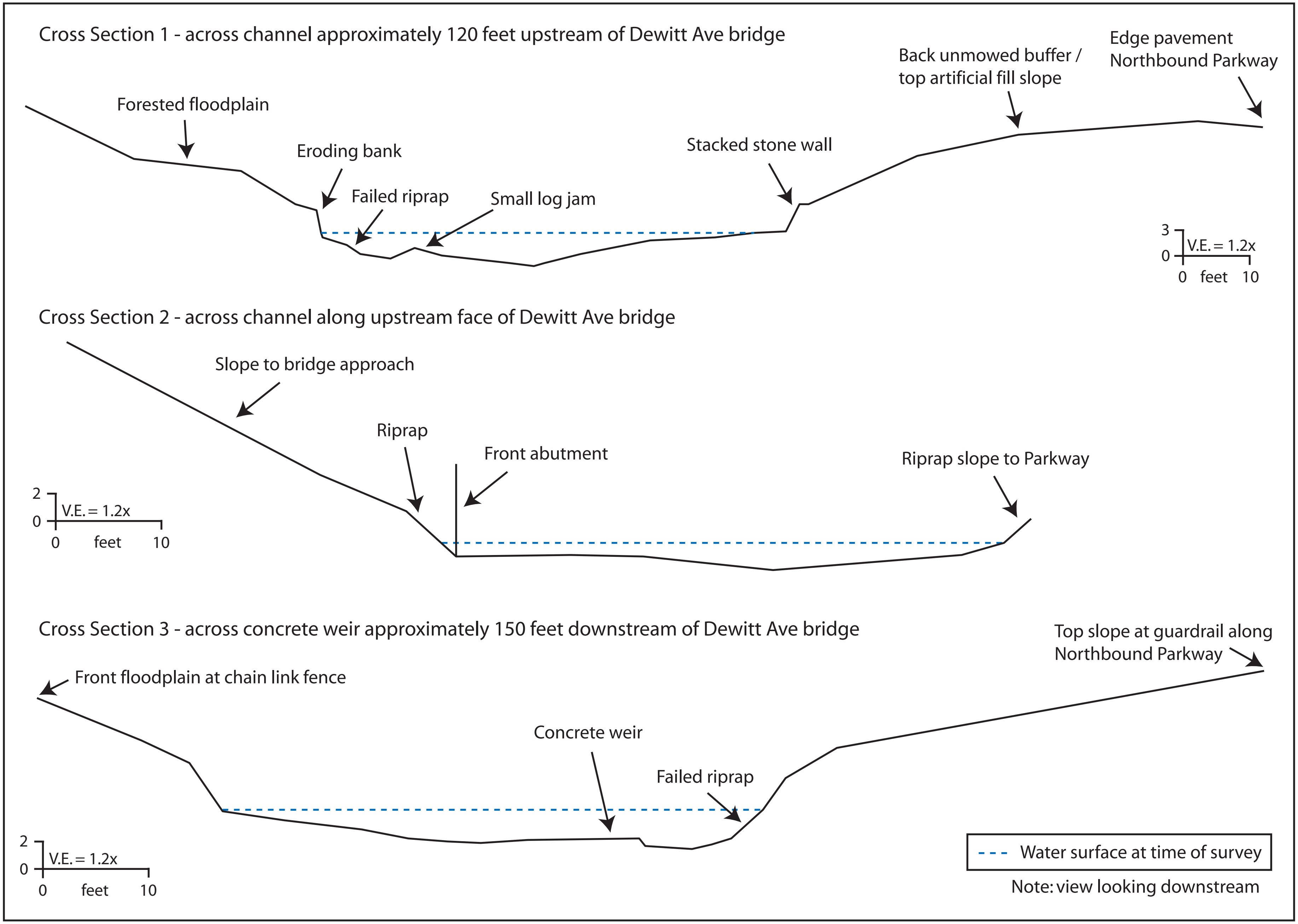
Segment Identification	Distance From Top of Eroding Bank to Infrastructure	Probability of Hazard Occurring Score	Probability of Hazard Occurring Numerical	Infrastructure Type	Severity if Hazard Occurred Score	Severity if Hazard Occurred Numerical	Total Erosion Hazard Numerical	Total Erosion Hazard Score	Erosion Hazard Identification Number	Distance to Erosion Hazard	Priority Score	Priority Numerical
BR_17B	20	low	1	Natural Gas Compressor	High	5	5	Moderate	E20	457	Moderate	2
BR_17C	20	low	1	Natural Gas Compressor	High	5	5	Moderate	E20	9	Moderate	2
BR_17D	3	high	5	Arterial Road	Moderate	3	15	High	E21	134	Extreme	4
BR_17E	3	high	5	Recreation Pathway	Low	1	5	Moderate	E22	1	Moderate	2
BR_17F	60	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E24	10	Moderate	2
BR_17G	20	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E25	4	Moderate	2
BR_18	20	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E25	457	Moderate	2
BR_19	20	low	1	Bronx River Parkway	Extreme	5	5	Moderate	E25	631	Moderate	2
BR_20A	15	low	1	Recreation Pathway	Low	1	1	Low	E26	324	Moderate	2
BR_20B	15	low	1	Recreation Pathway	Low	1	1	Low	E26	9	Moderate	2
BR_20C	15	low	1	Recreation Pathway	Low	1	1	Low	E26	421	Moderate	2
BR_20D	40	low	1	Rail Road	High	5	5	Moderate	E27	14	Moderate	2
BR_20E	40	low	1	Rail Road	High	5	5	Moderate	E27	114	Moderate	2
BR_20F	8	moderate	3	Recreation Pathway	Low	1	3	Low	E28	1	Moderate	2
BR_20G	8	moderate	3	Recreation Pathway	Low	1	3	Low	E28	437	Moderate	2
GS_01A	0	low	1	N/A	Low	1	1	Low	E07	2664	Low	1
GS_01B	0	low	1	N/A	Low	1	1	Low	E07	2876	Low	1
GS_01C	0	low	1	N/A	Low	1	1	Low	E07	3791	Low	1
GS_02A	0	low	1	N/A	Low	1	1	Low	E07	4179	Low	1
GS_02B	0	low	1	N/A	Low	1	1	Low	E07	4876	Low	1
GS_02C	0	low	1	N/A	Low	1	1	Low	E07	5498	Low	1
GS_03A	0	low	1	N/A	Low	1	1	Low	E07	6313	Low	1
GS_03B	0	low	1	N/A	Low	1	1	Low	E07	6753	Low	1
GS_03C	0	low	1	N/A	Low	1	1	Low	E07	7681	Low	1
GS_04A	0	low	1	N/A	Low	1	1	Low	E07	8254	Low	1
GS_04B	0	low	1	N/A	Low	1	1	Low	E07	8711	Low	1
GS_05A	0	low	1	N/A	Low	1	1	Low	E07	8979	Low	1
GS_05B	2	high	5	Recreation Pathway	Low	1	5	Moderate	E08	8540	Low	1
LAU_01A	0	low	1	N/A	Low	1	1	Low	E07	799	Moderate	2
LAU_01B	0	low	1	N/A	Low	1	1	Low	E07	1390	Moderate	2
LAU_02A	0	low	1	N/A	Low	1	1	Low	E07	1937	Moderate	2
LAU_02B	0	low	1	N/A	Low	1	1	Low	E07	2379	Moderate	2
LAU_03A	0	low	1	N/A	Low	1	1	Low	E07	2689	Low	1
LAU_03B	0	low	1	N/A	Low	1	1	Low	E07	2545	Low	1

APPENDIX 3

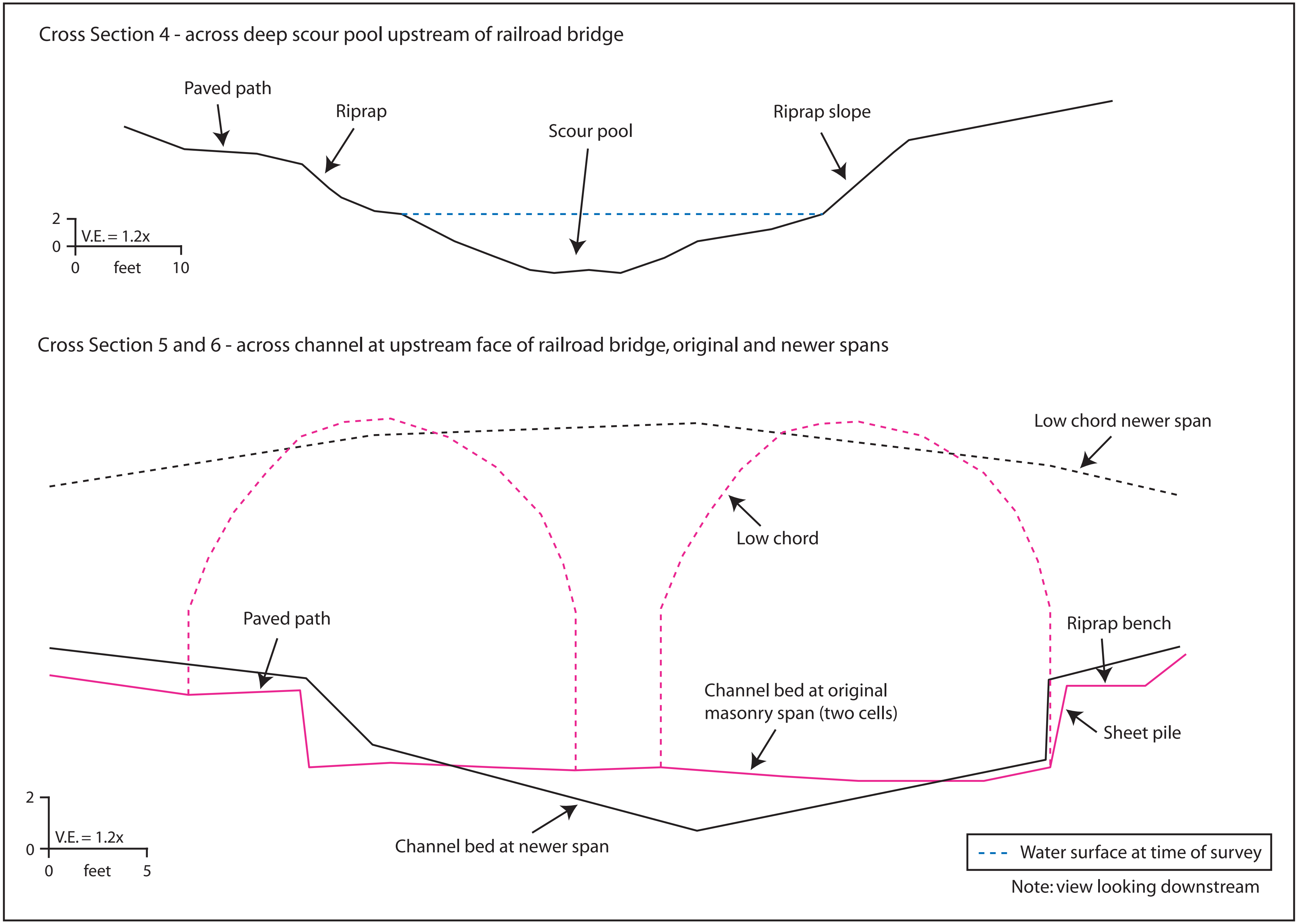
(Topographic Survey Data)



Appendix 3. Existing conditions plan view - Dewitt Ave area.



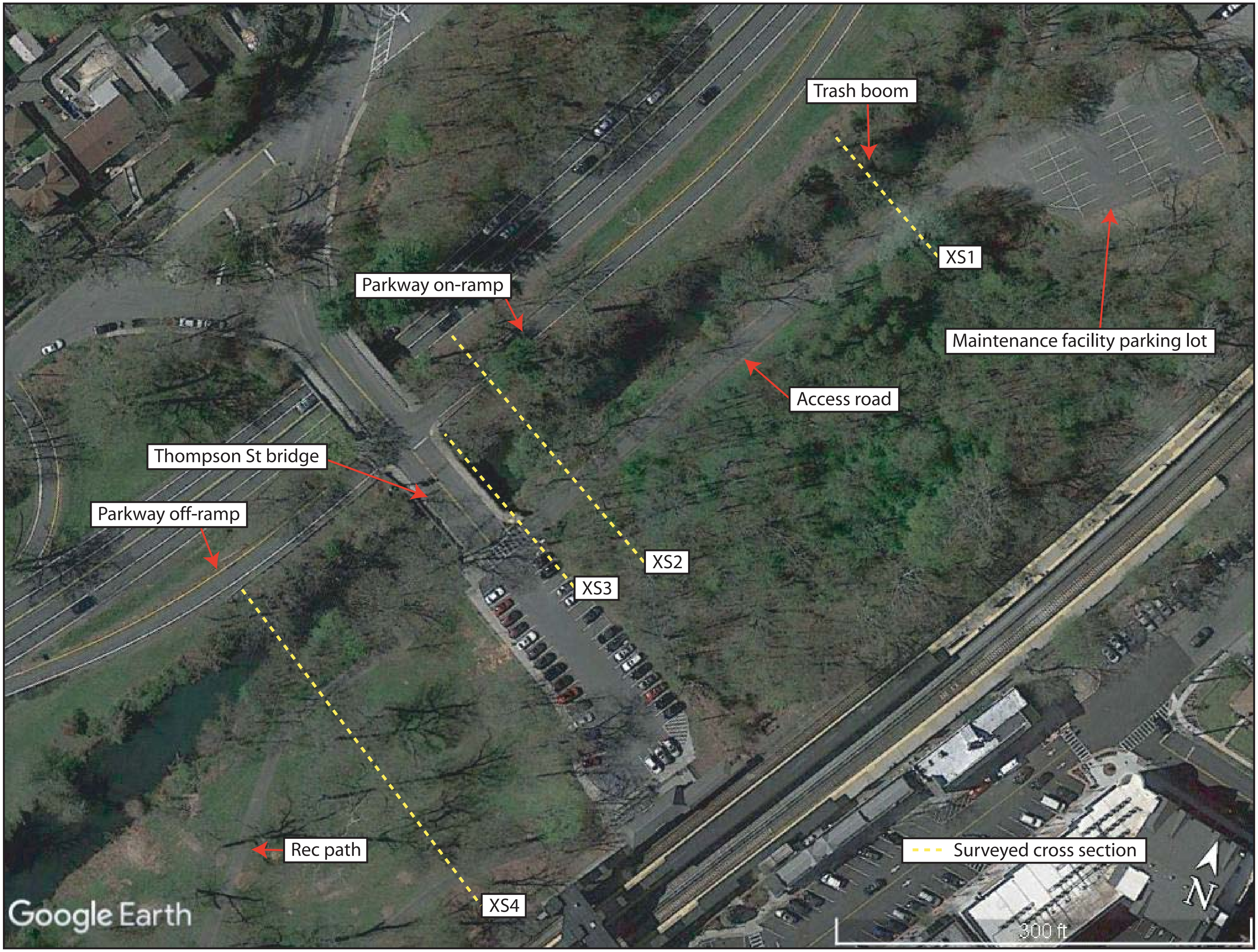
Appendix 3. Surveyed channel cross sections - Dewitt Ave area. 1 of 2.



Appendix 3. Surveyed channel cross sections - Dewitt Ave area. 2 of 2.

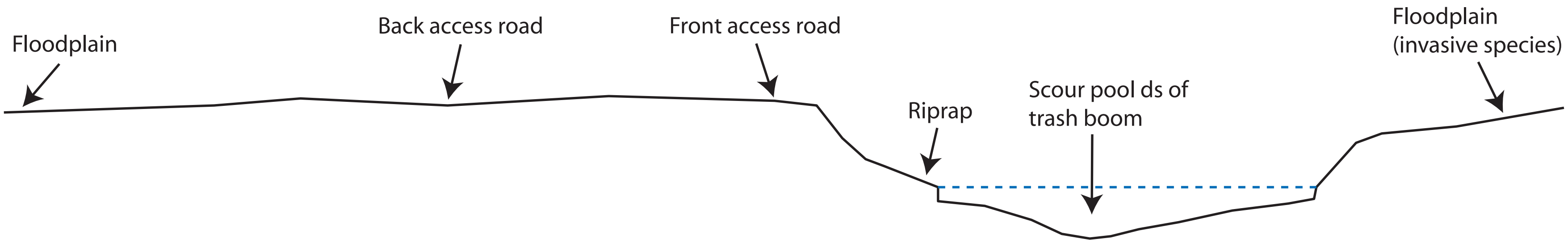
Field Geology Services
Fluvial Geomorphology

Tau Engineering PC

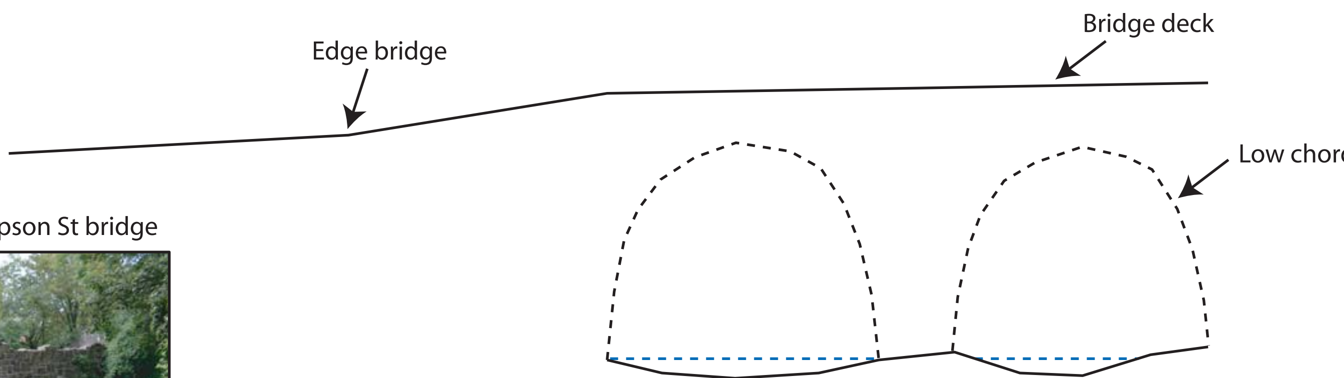


Appendix 3. Existing conditions plan view - Crestwood area.

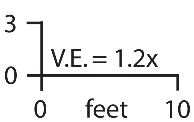
Cross Section 1 - across access road to Park Maintenance Facility and scour pool associated with trash boom



Cross Section 3 - at upstream face of Thompson St bridge



Downstream view of Thompson St bridge

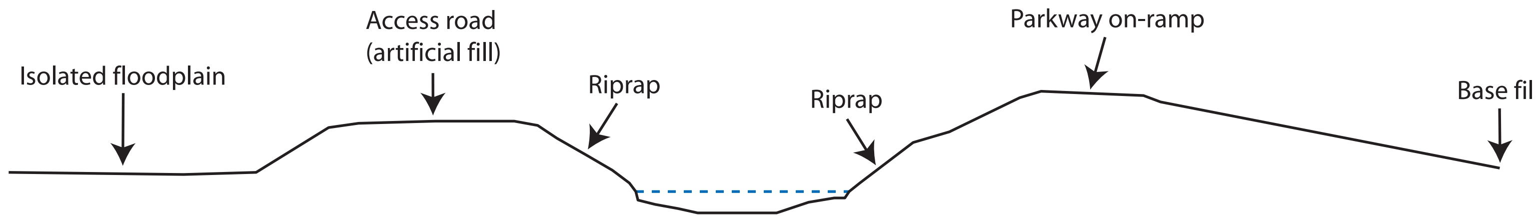


- - - Water surface at time of survey

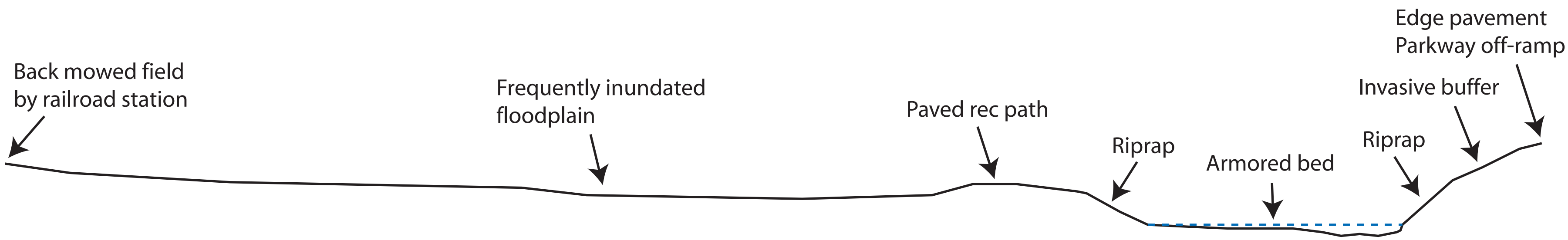
Note: view looking downstream

Appendix 3. Surveyed channel cross sections - Crestwood area. 1 of 2.

Cross Section 2 - across access road to Park Maintenance Facility and Parkway on-ramp 50 ft upstream of Thompson St bridge



Cross Section 4 - across open parkland area 150 ft downstream of Thompson St bridge



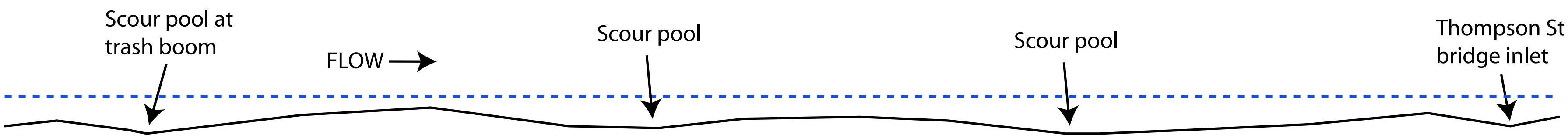
5
0 V.E. = 1.2x
0 feet 20

Water surface at time of survey

Note: view looking downstream

Appendix 3. Surveyed channel cross sections - Crestwood area. 2 of 2.

Longitudinal Profile - from Harney Road impoundment through constructed meander downstream



Water surface slope = 0.00 percent

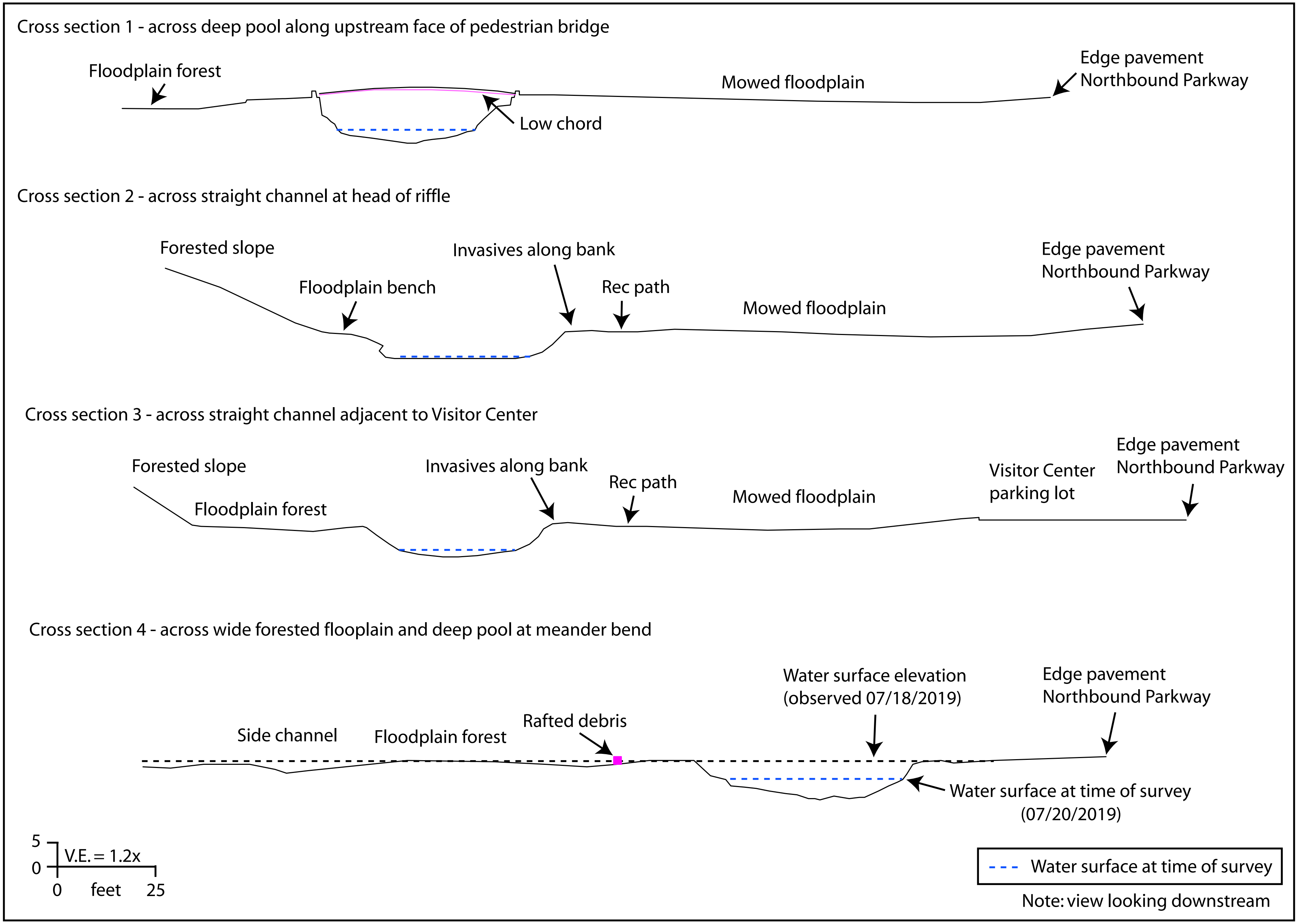
Trash boom at high flows (July 18, 2019)

5
0 V.E. = 3.1x
0 feet 40

--- Water surface at time of survey

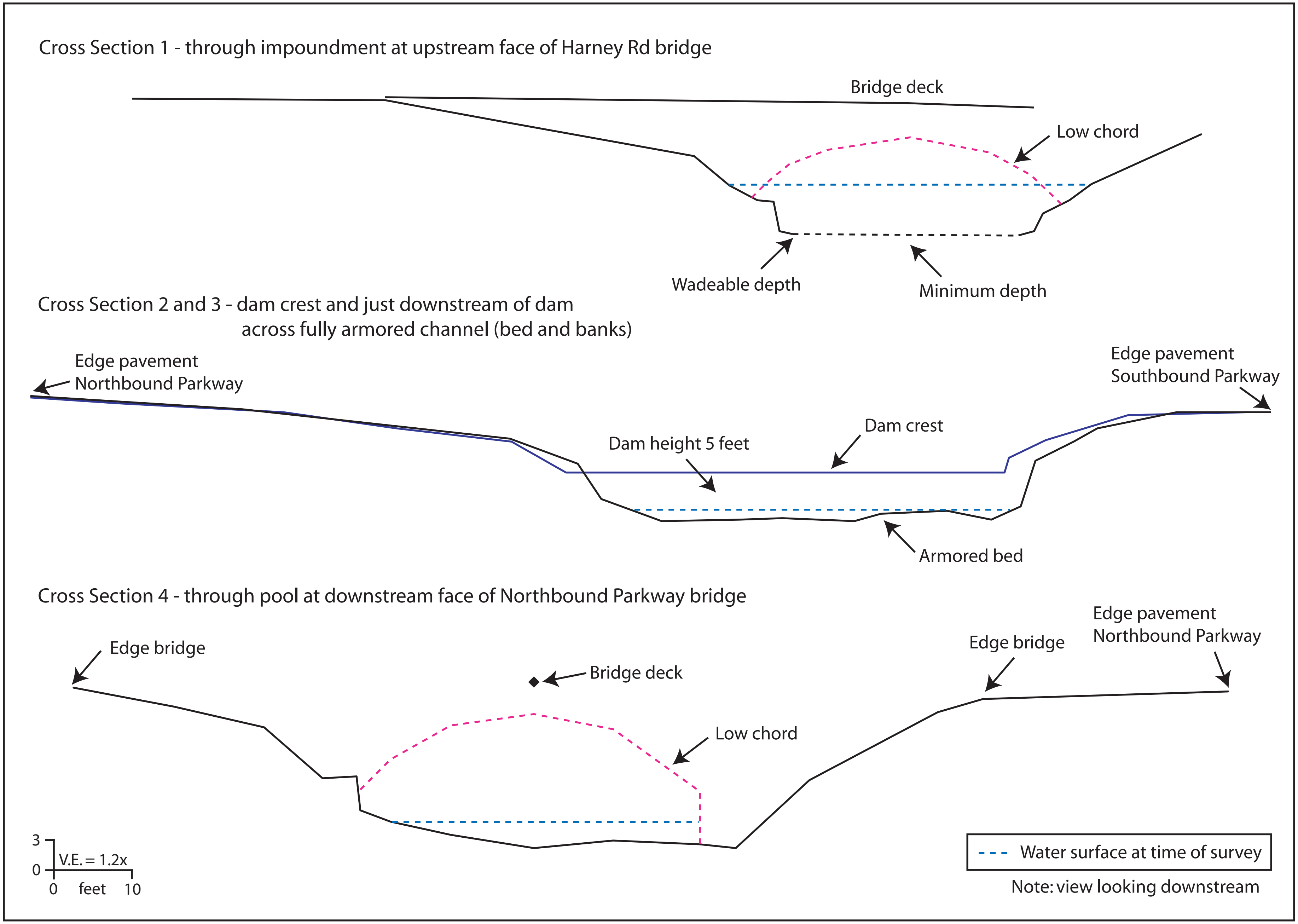
Appendix 3. Surveyed longitudinal profile - Crestwood area.

Existing conditions plan view - Visitor Center area downstream of Harney Road.



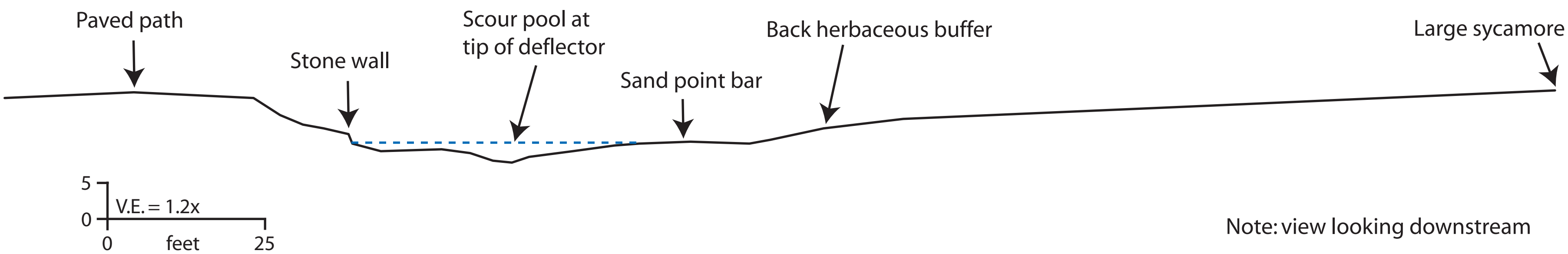
Appendix 3. Surveyed channel cross sections - Visitor Center downstream of Harney Road.

Appendix 3. Existing conditions plan view - Harney Road area.

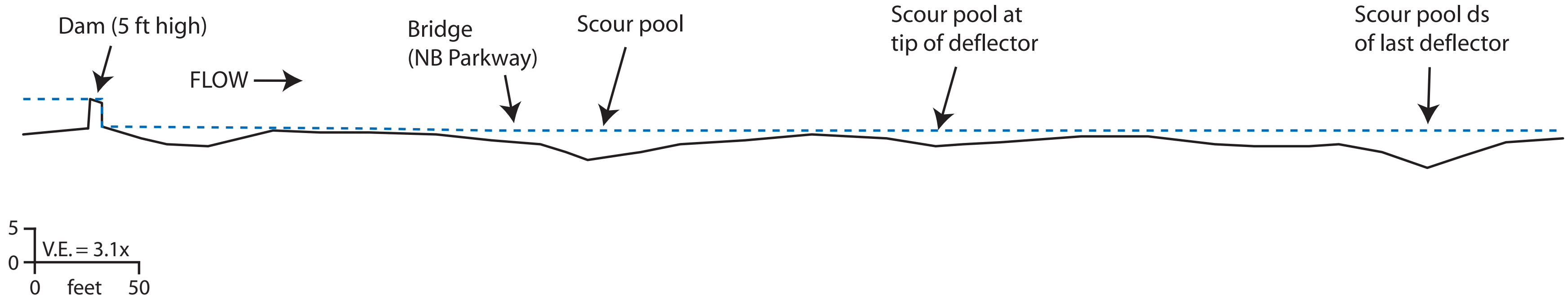


Appendix 3. Surveyed channel cross sections - Harney Road area. 1 of 2.

Cross Section 5 - through constructed meander adjacent to stone deflector

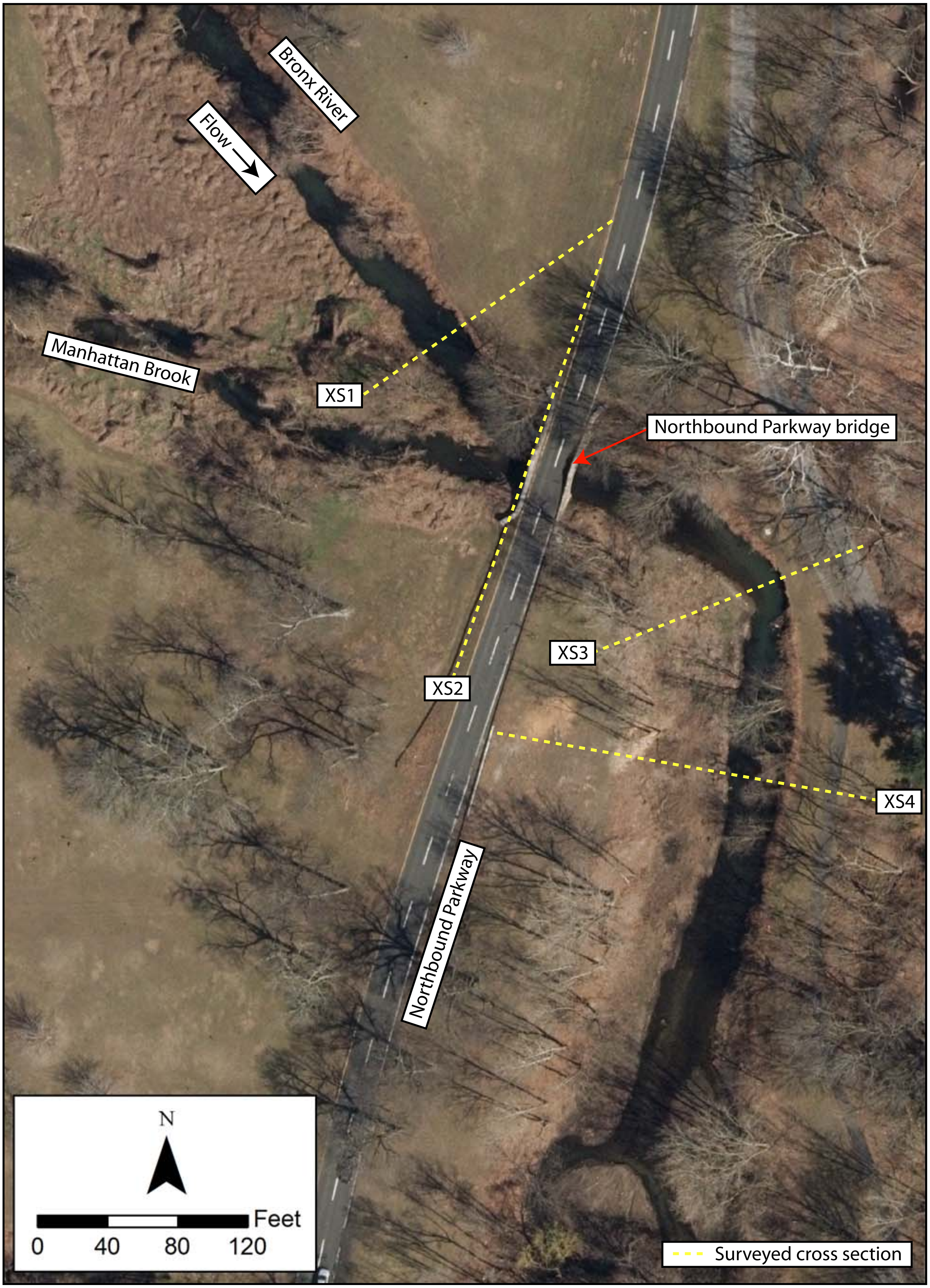


Longitudinal Profile - from Harney Road impoundment through constructed meander downstream

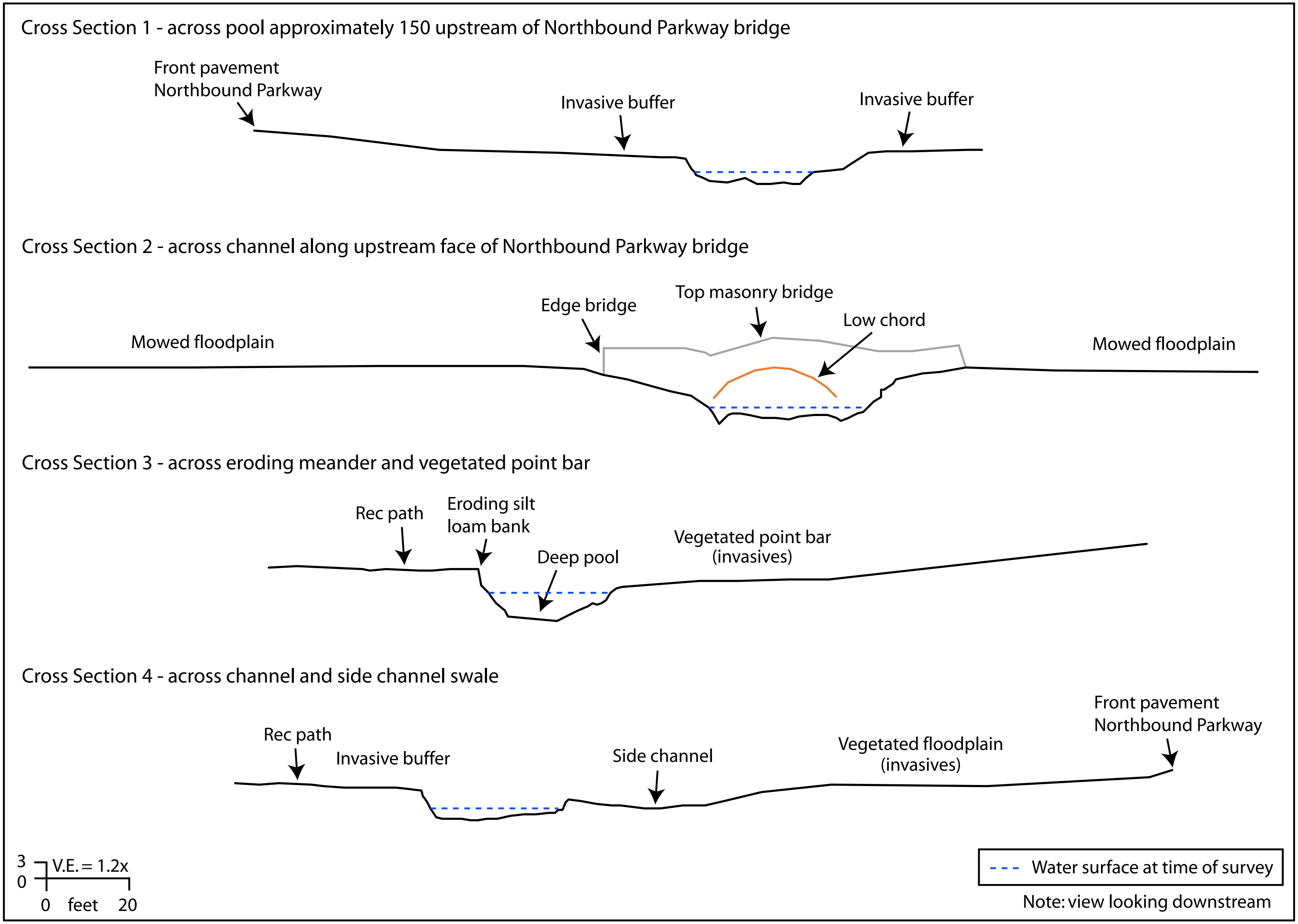


Water surface at time of survey

Appendix 3. Surveyed channel cross sections and longitudinal profile - Harney Road area. 1 of 2.



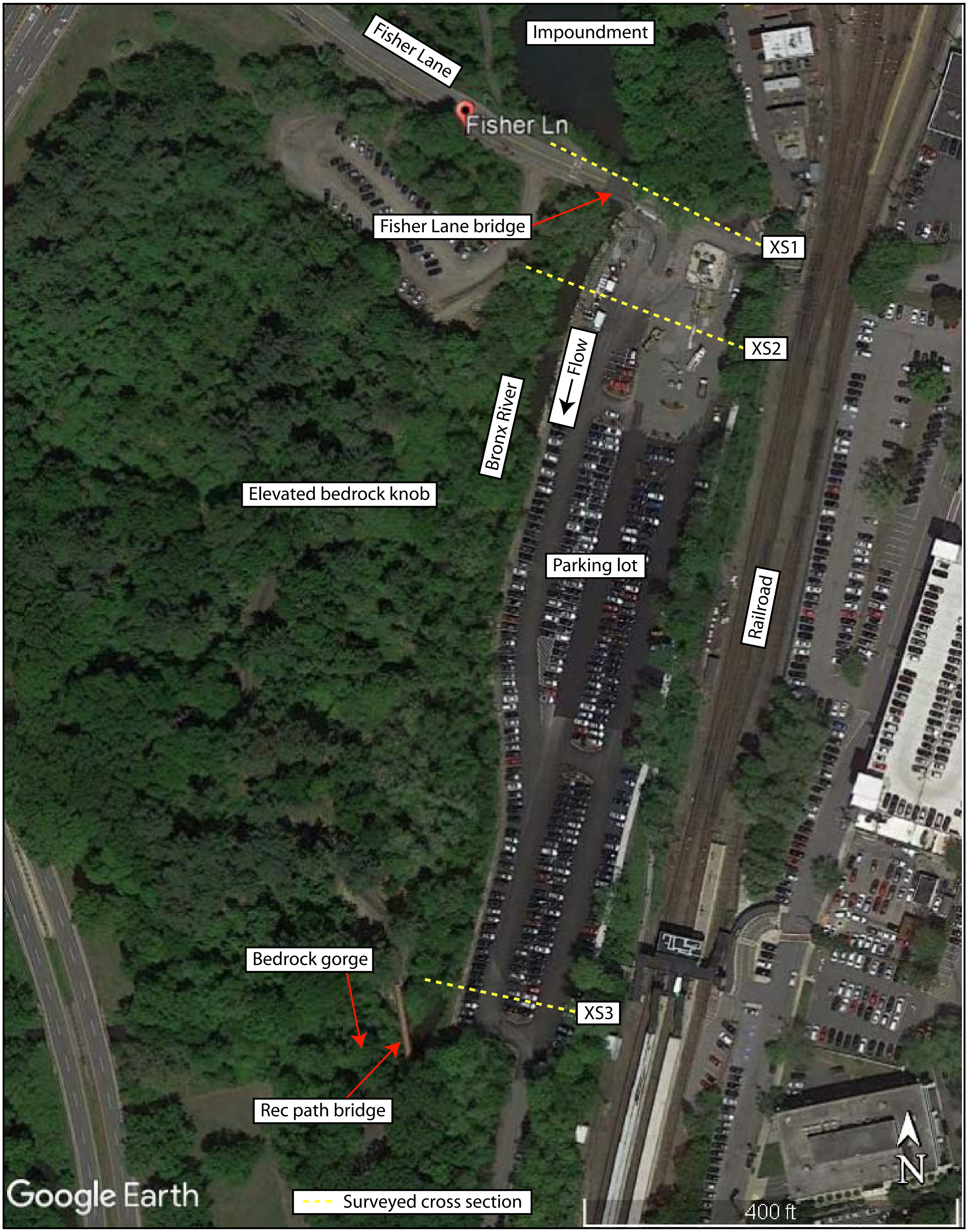
Appendix 3. Existing conditions plan view - County Center area.



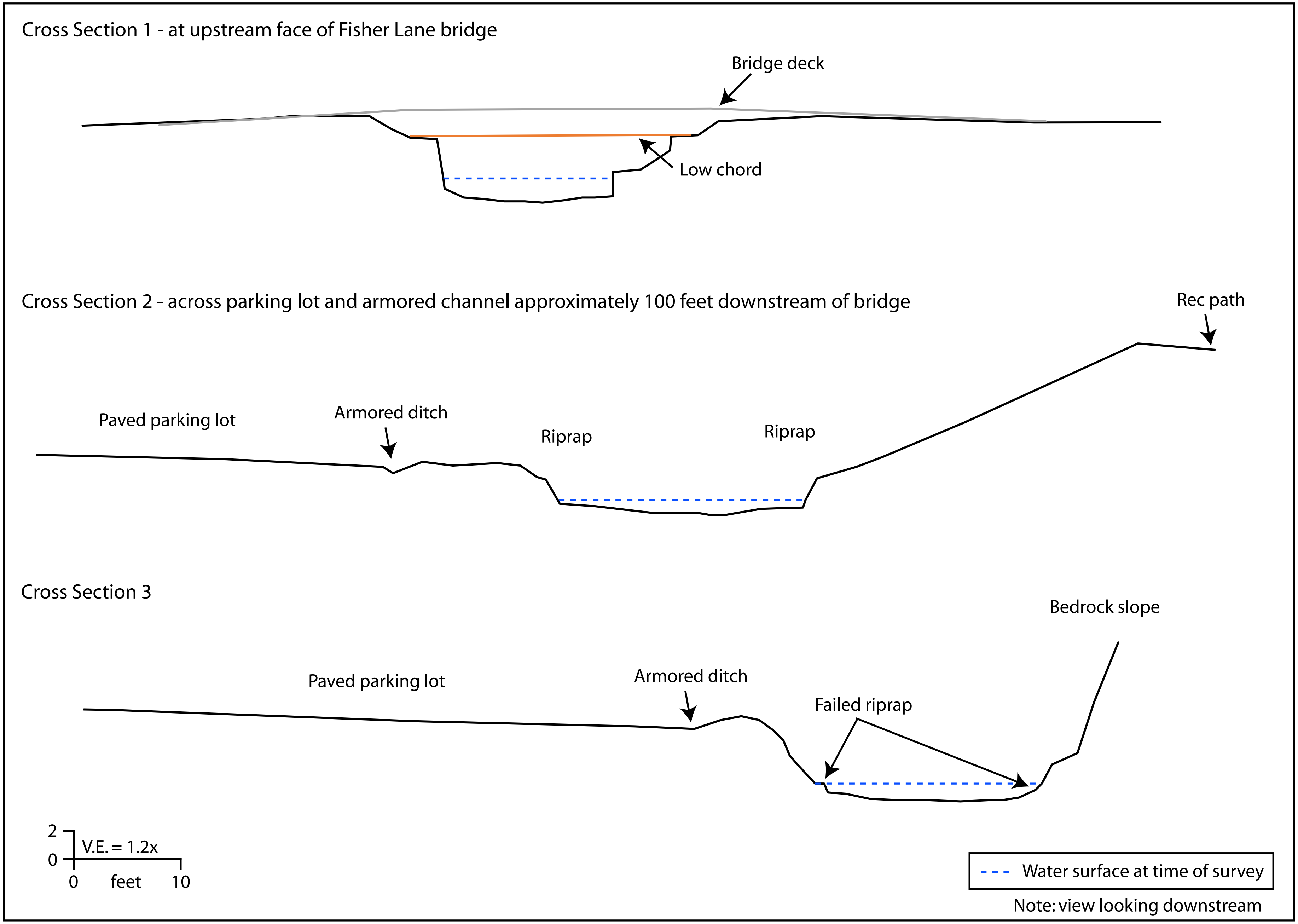
Appendix 3. Surveyed channel cross sections - County Center area.

Field Geology Services
Fluvial Geomorphology

Tau Engineering PC

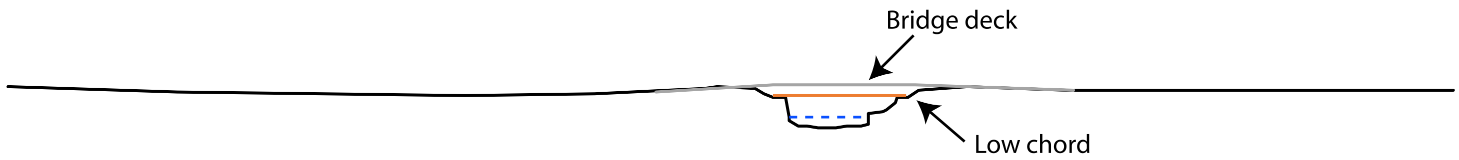


Appendix 3. Existing conditions plan view - Fisher Lane area.

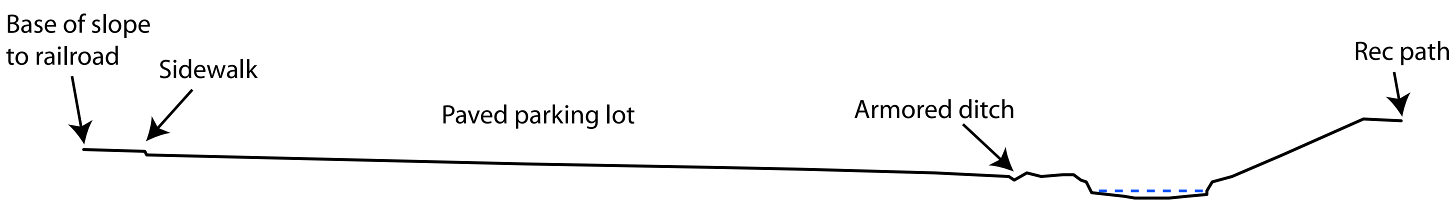


Appendix 3. Surveyed channel cross sections - Fisher Lane area. 1 of 2.

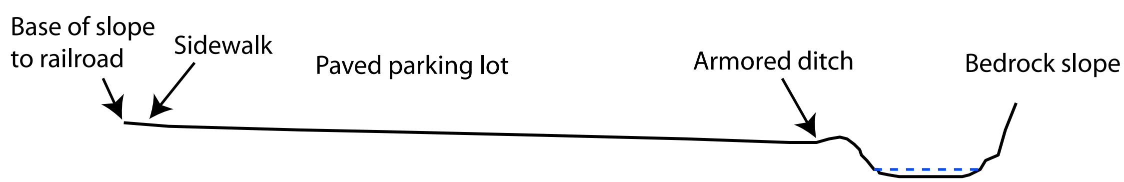
Cross Section 1 - at upstream face of Fisher Lane bridge



Cross Section 2 - across parking lot and armored channel approximately 100 feet downstream of bridge



Cross Section 3 - across southern end of parking lot, upstream of bedrock gorge



3 V.E. = 1.2x
0
0 feet 20

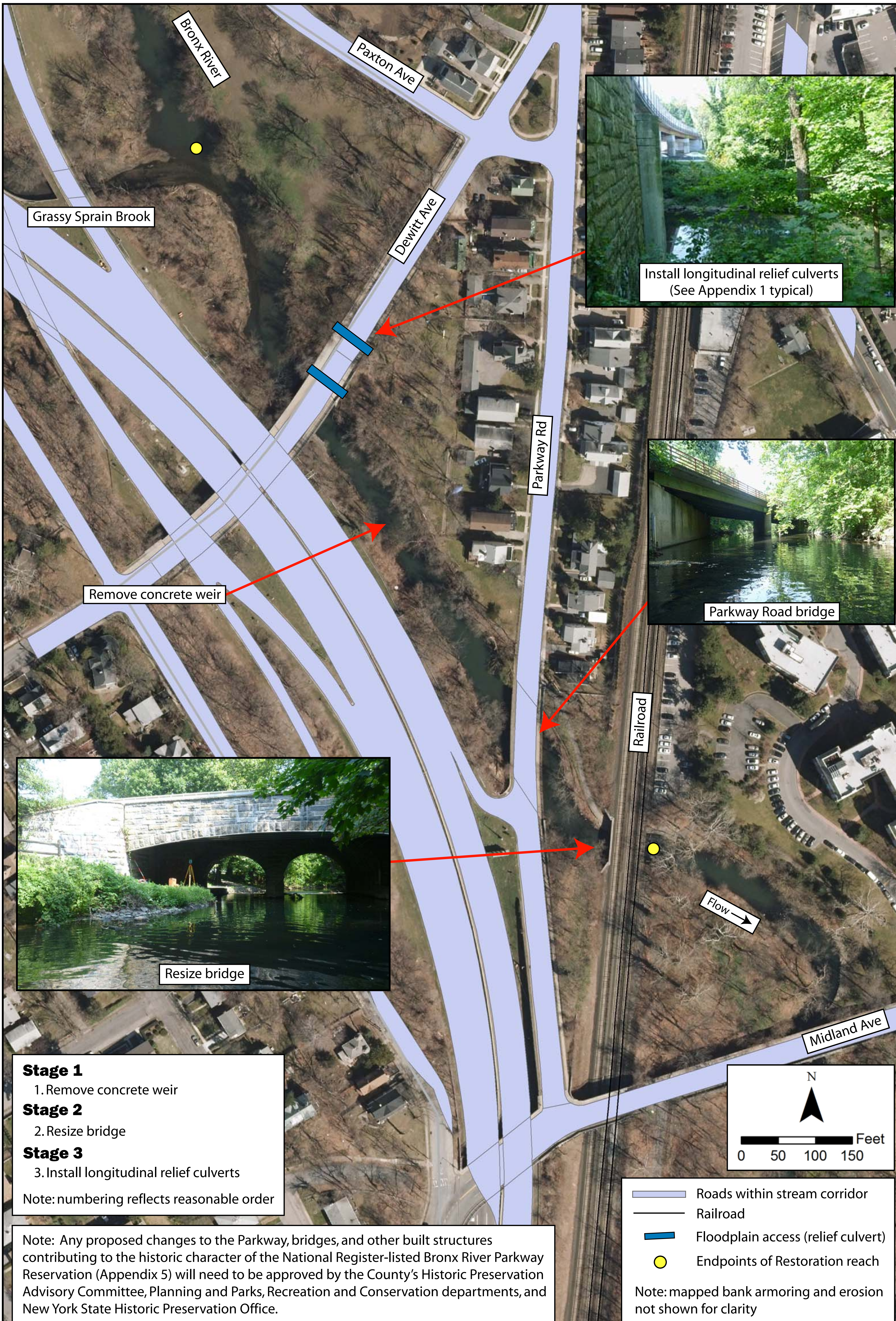
Water surface at time of survey

Note: view looking downstream

Appendix 3. Surveyed channel cross sections - Fisher Lane area. 2 of 2.

APPENDIX 4

(Restoration Concepts)



Appendix 4. Conceptual design overview map - Dewitt Avenue.

Opinion of probable implementation costs - Dewitt Avenue

Stage #	ID	Work Item	Length / Quantity	Total cost
1	1-1	Remove concrete weir	80 ft	$49,930
Subtotal Stage 1				$49,930
2	2-1	Resize railroad bridge	67 ft span	$4,536,000
Subtotal Stage 2				$4,536,000
3	3-1	Install longitudinal relief culverts	2 @ 24ft x 60ft	$453,600
Subtotal Stage 3				$453,600
Construction Total				$5,039,530
Contingency (20%)				$1,007,906
Survey, Geotechnical, Permitting and Design Services (20%)				$1,007,906
Grand Total				$7,055,342

Cost basis (assumptions)

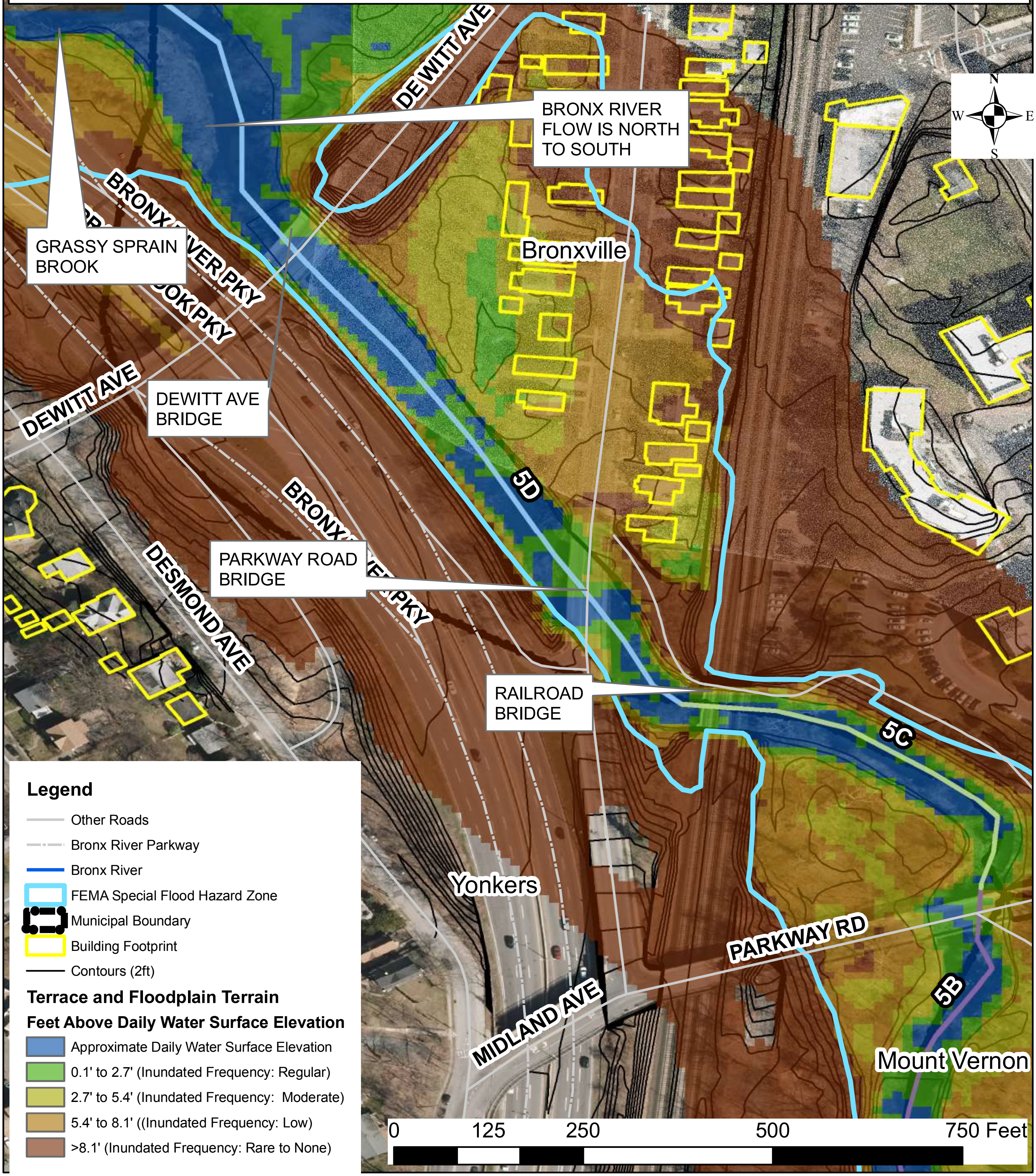
1-1 Assume excavation 4ft by 4ft by 80ft (47 CY) at $150 per CY (professional judgement); plus reroute utility/sewer line 80ft at $536 per linear ft (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)

1-2 Assume 48ft wide by 150ft long (7200 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c); apply 2X multiplier to account for railroad ROW issues

1-3 Assume 2 pre-cast concrete box culverts at 24ft span by 60ft long (2880 SF) at $157.50 per SF (0.5X multiplier for USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c) and 2.25X multiplier Arkansas value (https://www.arkansashighways.com/roadway_design_division/Cost%20per%20Mile%20(JULY%202014).pdf)

Appendix 4. Opinion of probable implementation costs - Dewitt Avenue.

MAP TITLE: DEWITT AVE TERRACE AND FLOODPLAIN TERRAIN (TAFT) MAP
DATE: 1/8/20
BY: GDF
NOTE: 1. REGULAR INUNDATED FLOODPLAINS LOCATED NORTH AND SOUTH OF DEWITT AVE SHOW FLOODPLAIN FILL AND A CONSTRICTION.
2. RAILROAD BRIDGE APPEARS TO CONSTRICT FLOODPLAIN WITH MODERATE TO LOW FREQUNTLY INUNDATED FLOODPLAINS LOCATED SOUTHEAST OF BRIDGE.



Appendix 4. Conceptual design overview map - Crestwood Station / Thompson Street.

Opinion of probable implementation costs - Crestwood Station/Thompson Street

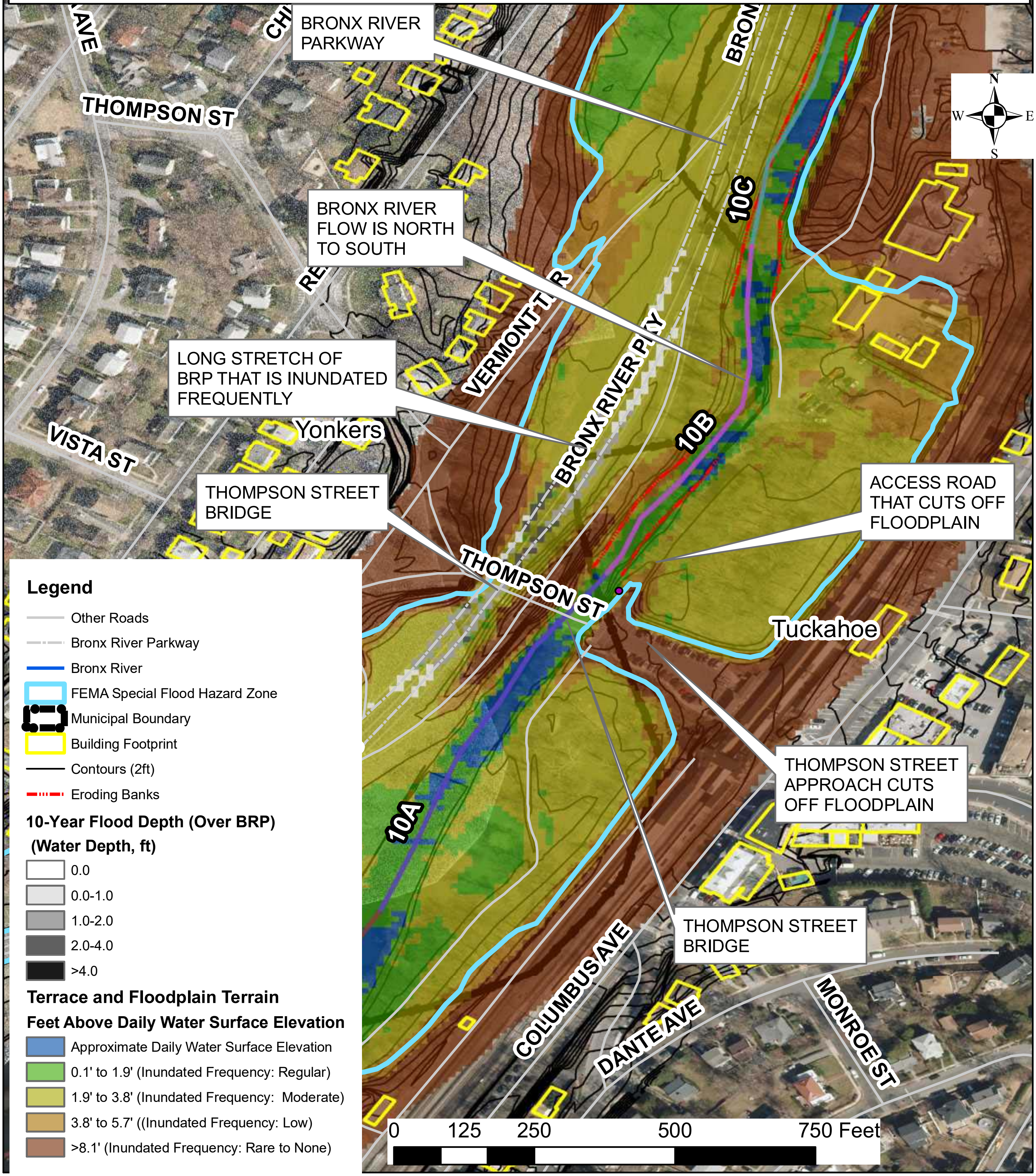
Stage #	ID	Work Item	Length / Quantity	Total cost
1	1-1	Control invasives	2 acres	$12,000
Subtotal Stage 1				$12,000
2	2-1	Upgrade sewer pipe crossing	70 ft	$37,520
2	2-2	Construct log crib walls (LB)	270 ft	$162,000
2	2-3	Construct log crib walls (RB)	270 ft	$162,000
Subtotal Stage 2				$361,520
3	3-1	Resize Thompson St bridge	58 ft span	$1,323,000
3	3-2	Install longitudinal relief culverts	2 @ 18ft x 120ft	$680,400
3	3-3	Install lateral relief culverts	2 @ 25ft x 60ft	$472,500
3	3-4	Restore meanders	500 ft	$264,825
Subtotal Stage 3				$2,740,725
Construction Total				$3,114,245
Contingency (20%)				$622,849
Survey, Geotechnical, Permitting and Design Services (20%)				$622,849
Grand Total				$4,359,943

Cost basis (assumptions)

1-1 Assume 2.0 acres at $6,000 per acre (Long View Forest personal communication)
2-1 Assume reroute sewer line 70ft at $536 per linear ft (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)
2-2 Assume 270ft log crib wall at $600 per linear ft (professional judgement)
2-3 Assume 270ft log crib wall at $600 per linear ft (professional judgement)
3-1 Assume 42ft wide by 100ft long (4200 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)
3-2 Assume 2 pre-cast concrete box culverts at 18ft span by 120ft long (4320 SF) at $157.50 per SF (0.5X multiplier for USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c) and 2.25X multiplier Arkansas value (https://www.arkansashighways.com/roadway_design_division/Cost%20per%20Mile%20(JULY%202014).pdf
3-3 Assume 2 pre-cast concrete box culverts at 25ft span by 60ft long (3000 SF) at $157.50 per SF (0.5X multiplier for USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c) and 2.25X multiplier Arkansas value (https://www.arkansashighways.com/roadway_design_division/Cost%20per%20Mile%20(JULY%202014).pdf
3-4 Assume excavation 500ft long by 50ft wide by 5.5ft deep (5093 CY) at $25 per CY (professional judgement); plus channel stabilization 500 linear ft at $275 per linear ft (professional judgement)

Appendix 4. Opinion of probable implementation costs - Crestwood Station/Thompson Street.

MAP TITLE: CRESTWOOD STATION/THOMPSON STREET TERRACE AND FLOODPLAIN TERRAIN (TAFT) MAP
DATE: 1/10/20
BY: GDF
NOTE: 1. REGULARLY INUNDATED FLOODPLAINS LOCATED NORTH AND SOUTH OF THOMPSON STREET ARE DISCONNECTED BY THOMPSON STREET.
2. THE BRONX RIVER PARKWAY GOES UNDER THOMPSON STREET ON THE WEST BANK. THIS IS FREQUENTLY INUNDATED. THOMPSON STREET COMPLETELY CUTS OFF FLOOD FLOWS ON THE EAST BANK.



Appendix 4. Conceptual design overview map - Harney Road / Garth Woods.

Opinion of probable implementation costs - Harney Road/Garth Woods

Stage #	ID	Work Item	Length / Quantity	Total cost
1	1-1	Control invasives	2.5 acres	$15,000
Subtotal Stage 1				$15,000
2	2-1	Install lateral relief culverts	2 @ 25ft x 60ft	$472,500
2	2-2	Remove concrete weir	60 ft	$15,638
2	2-3	Enhance in-stream habitat (upstream)	1760 ft	$156,000
2	2-4	Access old meander	750 ft	$348,900
2	2-5	Restore meanders	3 @ 450 ft	$746,250
Subtotal Stage 2				$1,739,288
3	3-1	Resize bridge #1 (Northbound Pkwy)	60 ft span	$1,058,400
3	3-2	Resize bridge #2 (Harney Rd)	60 ft span	$2,425,500
3	3-3	Remove check dam	60 ft	$113,000
3	3-4	Elevate parkway	1300 ft	$9,828,000
3	3-5	Resize bridge #3 (Northbound Pkwy)	60 ft span	$1,209,600
3	3-6	Enhance in-stream habitat (downstream)	1760 ft	$156,000
3	3-7	Develop boating opportunities	LS	$18,000
Subtotal Stage 3				$14,808,500
Construction Total				$16,562,788
Contingency (20%)				$3,312,558
Survey, Geotechnical, Permitting and Design Services (20%)				$3,312,558
Grand Total				$23,187,903

Cost basis (assumptions)

1-1 Assume 2.5 acres at $6,000 per acre (Long View Forest personal communication)

2-1 Assume 2 pre-cast concrete box culverts at 25ft span by 60ft long (3000 SF) at $157.50 per SF (0.5X multiplier for USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c) and 2.25X multiplier Arkansas value

2-2 Assume excavation 20 CY at $150 per CY (professional judgement); plus armored riffle 60ft wide by 80ft long (178 SY) at $71 per SY (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)

2-3 Assume 16 boulder supported log jams at $6000 per structure and 24 partially buried logs at $2500 per structure (professional judgement)

2-4 Assume excavation 70ft wide by 3.5ft deep by 750ft long (6806 CY) at $25 per CY (professional judgement); plus channel plug, channel filling and roughness elements over 650 linear ft at $275 per ft (professional judgement)

2-5 Assume excavation of 3 meanders each 450ft long by 50ft wide by 6ft deep (5000 CY) at $25 per CY (professional judgement); plus channel stabilization 3 X 450 linear ft at $275 per linear ft (professional judgement)

3-1 Assume 24ft wide by 140ft long (3360 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

3-2 Assume 55ft wide by 140ft long (7700 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

3-3 Assume excavation 60ft wide by 4ft wide by 6ft deep (53.3 CY) at $150 per CY (professional judgement); plus 3 rock weirs at $35,000 (professional judgement)

3-4 Assume elevate 1300ft long section of Parkway by 24ft wide (31,200 SF) at at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

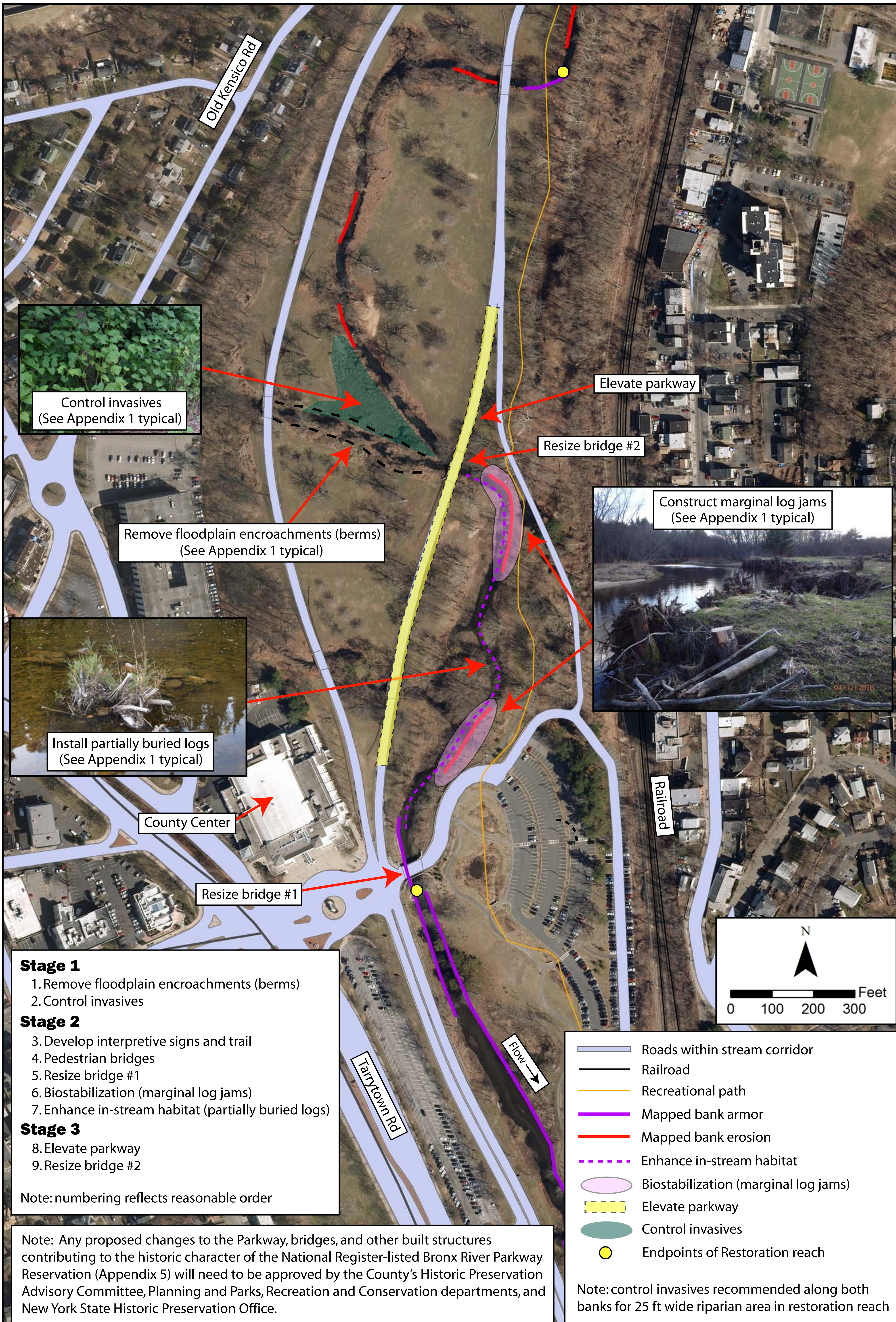
3-5 Assume 24ft wide by 160ft long (3840 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

3-6 Assume 16 boulder supported log jams at $6000 per structure and 24 partially buried logs at $2500 per structure (professional judgement)

3-7 Assume 2 boat access points at $9,000 per location (professional judgement)

Appendix 4. Opinion of probable implementation costs - Harney Road/Garth Woods.


MAP TITLE: HARNEY ROAD/GARTH WOODS
TERRACE AND FLOODPLAIN
TERRAIN (TAFT) MAP
DATE: 1/10/20
BY: GDF
1. BRONX RIVER FLOW
IS NORTH TO SOUTH
POPHAM ROAD BRIDGE
11F
Scarsdale
11E
BRONX RIVER PARKWAY
BRONX RIVER PARKWAY
11D
BRONX RIVER FLOW IS NORTH TO SOUTH
11C
11B
FLOODPLAIN FILL NORTHBOUND LANE BRP
OLD MEANDERBEND IN GARTH WOODS
LOW LYING FLOODPLAIN POSSIBLE WETLAND
Eastchester
Yonkers
11A
HARNEY ROAD BRIDGE
NORTHBOUND LANE OF BRP
10K
FLOODPLAIN FILL WITH PROXIMAL ERODING BANKS
BRONX RIVER PARKWAY
10J
FLOODPLAIN FILL WITH PROXIMAL ERODING BANKS
10I
N
W
E
S
0 125 250 500 750 Feet
Legend
BronxErodingBanks
Other Roads
Bronx River Parkway
Bronx River
FEMA Special Flood Hazard Zone
Municipal Boundary
Building Footprint
Contours (2ft)
Terrace and Floodplain Terrain
Feet Above Daily Water Surface Elevation
Approximate Daily Water Surface Elevation
0.1' to 1.9' (Inundated Frequency: Regular)
1.9' to 3.8' (Inundated Frequency: Moderate)
3.8' to 5.7' ((Inundated Frequency: Low)
>8.1' (Inundated Frequency: Rare to None)



Appendix 4. Conceptual design overview map - County Center.

Opinion of probable implementation costs - County Center

Stage #	ID	Work Item	Length / Quantity	Total cost
1	1-1	Remove floodplain encroachments (berms)	600 ft	$23,775
1	1-2	Control invasives	3.5 acres	$21,000
Subtotal Stage 1				$44,775
2	2-1	Develop recreational trail	1 mi	$236,000
2	2-1	Develop interpretive signs	6 signs	$21,000
2	2-2	Pedestrian bridge #1	160 ft span	$300,000
2	2-3	Pedestrian bridge #2	40 ft span	$75,000
2	2-4	Resize bridge #1	48 ft span	$826,875
2	2-5	Biostabilization (marginal log jams)	460 ft	$200,000
2	2-6	Enhance in-stream habitat (partially buried logs)	1000 ft	$75,000
Subtotal Stage 2				$1,733,875
3	3-1	Elevate parkway	1100 ft	$8,316,000
3	3-2	Resize bridge #2	48 ft span	$826,875
Subtotal Stage 3				$9,142,875
Construction Total				$10,921,525
Contingency (20%)				$2,184,305
Survey, Geotechnical, Permitting and Design Services (20%)				$2,184,305
Grand Total				$15,290,135

Cost basis (assumptions)

1-1 Assume 711 CY at $150 per CY excavation (professional judgement); plus $6,000 clearing and grubbing (0.5 acres) (Contractor CD Davenport past quote from 2016)

1-2 Assume 3.5 acres at $6,000 per acre (Long View Forest personal communication)

2-1 Assume 1 mi paved trail (8 ft wide) at $220,000 per mile plus $3200 per year maintenance for 5 years (https://www.americantrails.org/resources/construction-and-maintenance-costs-for-trails) Assume 6 signs at $3,500 per sign (http://www.lewisandclark.org/grants/docs/NFS_Interpretive_Sign_Planning.pdf)

2-2 Assume 160ft span with abutments, steel span and wood deck (8ft wide) at $1875 per linear ft (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)

2-3 Assume 40ft span with abutments, steel span and wood deck (8ft wide) at $1875 per linear ft (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)

2-4 Assume 35ft wide by 75ft long (2625 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

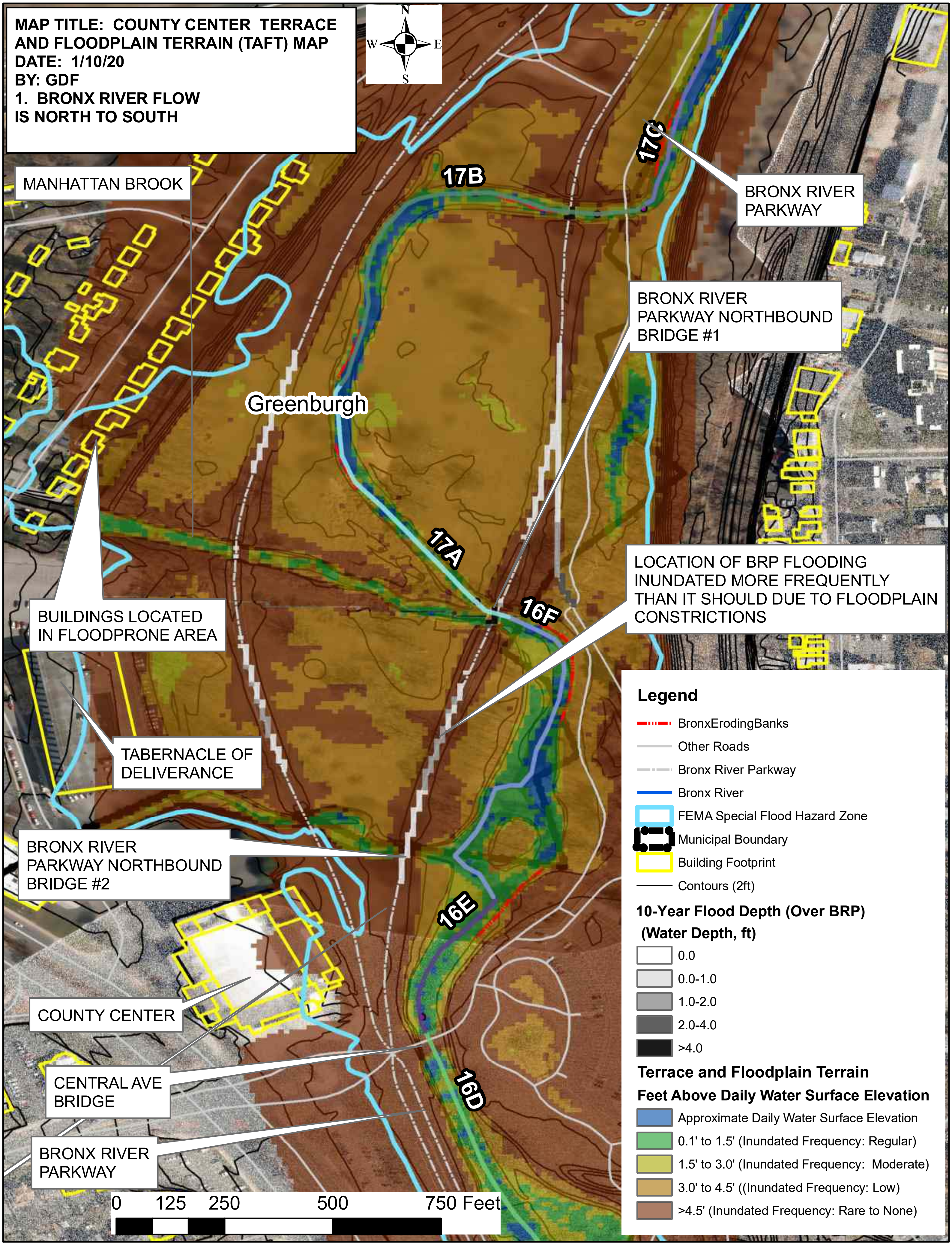
2-5 Assume 8 marginal log jams at $25,000 per structure (professional judgement)

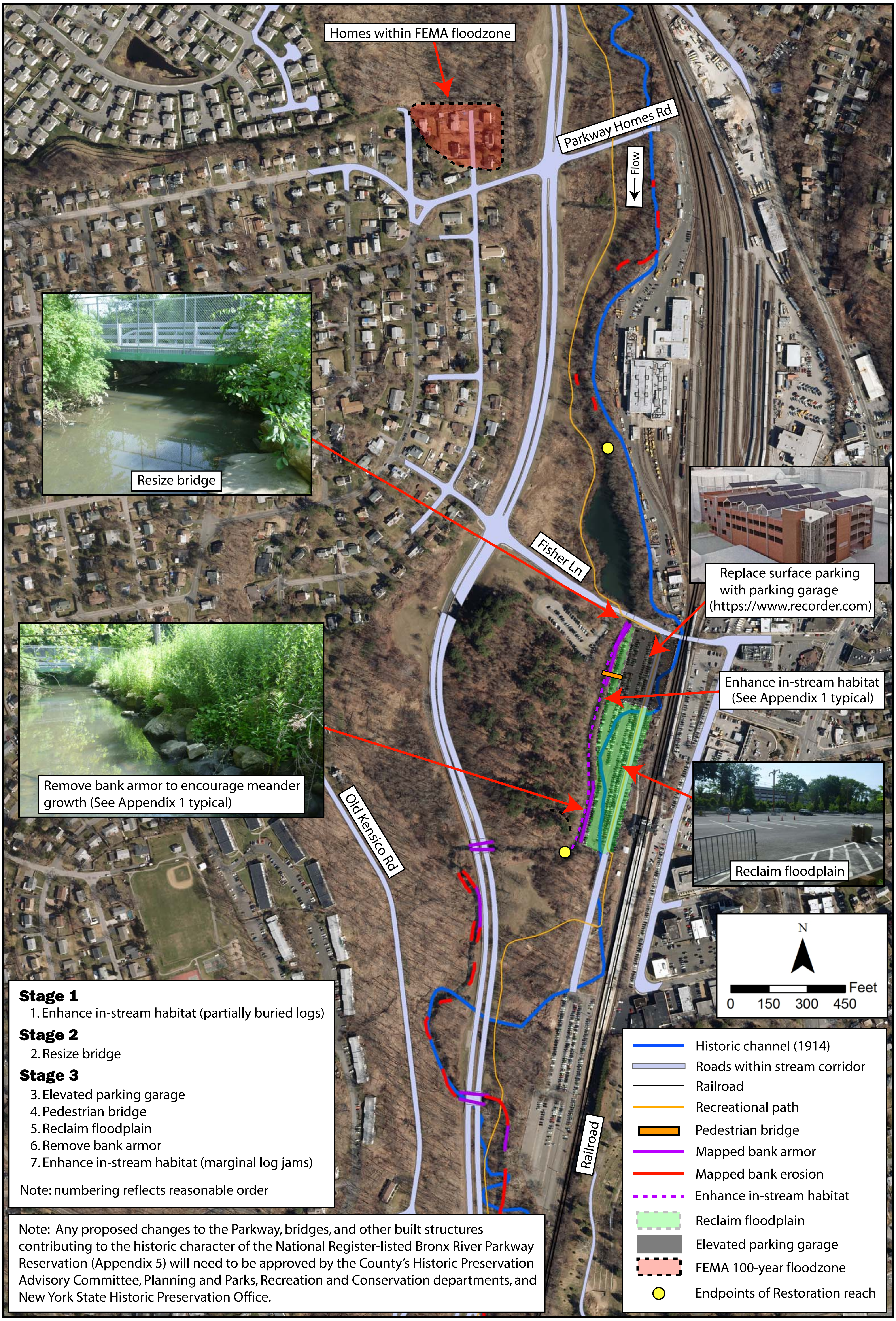
2-6 Assume 30 partially buried logs at $2,500 per structure (professional judgement)

3-1 Assume elevate 1100ft long section of Parkway by 24ft wide (26,400 SF) at at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

3-2 Assume 35ft wide by 75ft long (2625 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

Appendix 4. Opinion of probable implementation costs - County Center.


MAP TITLE: COUNTY CENTER TERRACE AND FLOODPLAIN TERRAIN (TAFT) MAP
DATE: 1/10/20
BY: GDF
1. BRONX RIVER FLOW IS NORTH TO SOUTH
N
W
E
S
MANHATTAN BROOK
17B
17C
BRONX RIVER PARKWAY
BRONX RIVER PARKWAY NORTHBOUND BRIDGE #1
Greenburgh
17A
16F
LOCATION OF BRP FLOODING INUNDATED MORE FREQUENTLY THAN IT SHOULD DUE TO FLOODPLAIN CONSTRICTIONS
BUILDINGS LOCATED IN FLOODPRONE AREA
TABERNACLE OF DELIVERANCE
BRONX RIVER PARKWAY NORTHBOUND BRIDGE #2
16E
COUNTY CENTER
CENTRAL AVE BRIDGE
16D
BRONX RIVER PARKWAY
0 125 250 500 750 Feet
Legend
BronxErodingBanks
Other Roads
Bronx River Parkway
Bronx River
FEMA Special Flood Hazard Zone
Municipal Boundary
Building Footprint
Contours (2ft)
10-Year Flood Depth (Over BRP)
(Water Depth, ft)
0.0
0.0-1.0
1.0-2.0
2.0-4.0
>4.0
Terrace and Floodplain Terrain
Feet Above Daily Water Surface Elevation
Approximate Daily Water Surface Elevation
0.1' to 1.5' (Inundated Frequency: Regular)
1.5' to 3.0' (Inundated Frequency: Moderate)
3.0' to 4.5' ((Inundated Frequency: Low)
>4.5' (Inundated Frequency: Rare to None)



Appendix 4. Conceptual design overview map - Fisher Lane / North White Plains Station.

Opinion of probable implementation costs - Fisher Lane/North White Plains Station

Stage #	ID	Work Item	Length / Quantity	Total cost
1	1-1	Walking trails	0.57 mi (3000 ft)	$134,520
1	1-2	Enhance in-stream habitat (partially buried logs)	900 ft	$62,500
Subtotal Stage 1				$197,020
2	2-1	Resize Fisher Lane bridge	41 ft span	$453,600
Subtotal Stage 2				$453,600
3	3-1	Elevated parking garage	400 spaces	$11,850,000
3	3-2	Pedestrian bridge	100 ft span	$187,500
3	3-3	Reclaim floodplain	2 acres	$238,680
3	3-4	Remove bank armor	250 ft	$2,500
3	3-5	Enhance in-stream habitat (marginal log jams)	450 ft	$100,000
Subtotal Stage 3				$12,378,680
Construction Total				$13,029,300
Contingency (20%)				$2,605,860
Survey, Geotechnical, Permitting and Design Services (20%)				$2,605,860
Grand Total				$18,241,020

Cost basis (assumptions)

1-1 Assume 3000ft paved trail (8ft wide) at at $220,000 per mile plus $3200 per year maintenance for 5 years (https://www.americantrails.org/resources/construction-and-maintenance-costs-for-trails)

1-2 Assume 25 partially buried logs at $2,500 per structure (professional judgement)

2-1 Assume 24ft wide by 60ft long (1440 SF) at $315 per SF from USDOT Federal Highway Administration bridge replacement unit costs (New York State) (https://www.fhwa.dot.gov/bridge/nbi/sd2018.cfm#c)

3-1 Assume 300ft by 125ft garage and 4 floors with 100 spaces per floor (150,000 SF) at $79 per SF from 2017 survey of NYC parking garage construction costs (https://denver.streetsblog.org/wp-content/uploads/sites/14/2017/10/2017-Cost-Article.pdf)

3-2 Assume 100ft span with abutments, steel span and wood deck (8ft wide) at $1875 per linear ft https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf

3-3 Assume 2 acres excavation at depth of 2ft (6450 CY) at $25 per CY (professional judgement); plus topsoil 6 inches deep (1613 CY) at $30 per CY (professional judgement); plus seeding, fertilizer and watering (9680 SY) at $3 per SY (https://www.fairfaxcounty.gov/landdevelopment/sites/landdevelopment/files/assets/documents/pdf/publications/unit-price-schedule.pdf)

3-4 Assume 100 CY at $25 per CY (professional judgement)

3-5 Assume 4 marginal log jams at $25,000 per structure (professional judgement)

Appendix 4. Opinion of probable implementation costs - Fisher Lane/North White Plains Station.

MAP TITLE: FISHER LANE TERRACE AND FLOODPLAIN TERRAIN (TAFT) MAP
DATE: 1/16/20
BY: GDF
NOTE: 1. FLOW IS FROM NORTH TO SOUTH.
2. WIDTH OF REGULAR INUNDATED FLOODPLAIN AND MODERATE INUNDATED FLOODPLAIN CONSTRICTS NOTABLY AT FISHER LANE.
3. THERE IS LITTLE TO NO REGULAR INUNDATED FLOODPLAIN DOWNSTREAM OF FISHER LANE IN SEGMENT 19.

APPENDIX 5

(Historic Structures within the Restoration Concept Areas)

Historic Structures

Dewitt Avenue Conceptual Design Area

Bridges and Structures	Architect	Age	Contributing Component
Dewitt Ave. over Bronx River	?	?	Non-contributing
Railroad Bridge over Bronx River	?	?	Appears to pre-date the BRPR. Railroad property
Midland Ave. over Bronx River	?	?	Appears to pre-date the BRPR
Midland Ave. over Rail Road	?	?	Appears to pre-date the BRPR
Concrete weir in Bronx River	?	?	Appears Original

Crestwood Station/Thompson Street Conceptual Design Area

Bridges and Structures	Architect	Age	Contributing Component
Thompson Street over Parkway and BR	Charles Stoughton	c. 1925	Yes, Original to BRPR

Harney Road/Garth Woods Conceptual Design Area

Bridges and Structures	Architect	Age	Contributing Component
Popham Road-Ardsley Road Bridge	Charles Stoughton	c. 1925	Yes, Original to BRPRC
Check dam south of Popham Road	Unknown	?	Yes, Original to BRPRC
Parkway NB slab bridge over BR	?	c. 1925	Yes, Original to BRPRC
Harney Road Bridge	Charles Stoughton		Modified c. 1995; original stone elements retained from original designed by Charles Stoughton
Parkway NB South of Harney Road	Likely Charles Stoughton	c. 1925	Yes, Original to BRPRC
Check dam south of Harney Road	?		Yes, Original to BRPRC
Slab bridge over BR north of Leewood Drive			Modified

County Center Conceptual Design Area

Bridges and Structures	Architect	Age	Contributing Component
Parkway NB over BR north of Manhattan Brook	Charles Stoughton	c. 1925	Yes, Original to BRPRC
Parkway SB over Manhattan Brook	Gilmore Clark	c. 1925	Yes, Original to BRPRC
Parkway NB over Manhattan Brook	Gilmore Clark	c. 1925	Yes, Original to BRPRC
Parkway SB over Fulton Brook	Gilmore Clark	c. 1925	Yes, Original to BRPRC
Parkway NB over Fulton Brook	Gilmore Clark	c. 1925	Yes, Original to BRPRC
County Center parking lot access over BR	?	c. 1925	Yes, Original to BRPRC

Fisher Lane Conceptual Design Area

Bridges and Structures	Architect	Age	Contributing Component
Fisher Lane over BR	?	c. 1925	Yes, Original with some reconstruction in 1987
Parkway over BR South of Fisher Lane – NB &SB	?	?	Original with some reconstruction in 1987
Parkway over BR North of Cemetery Road	?	?	Original with some reconstruction in 1987