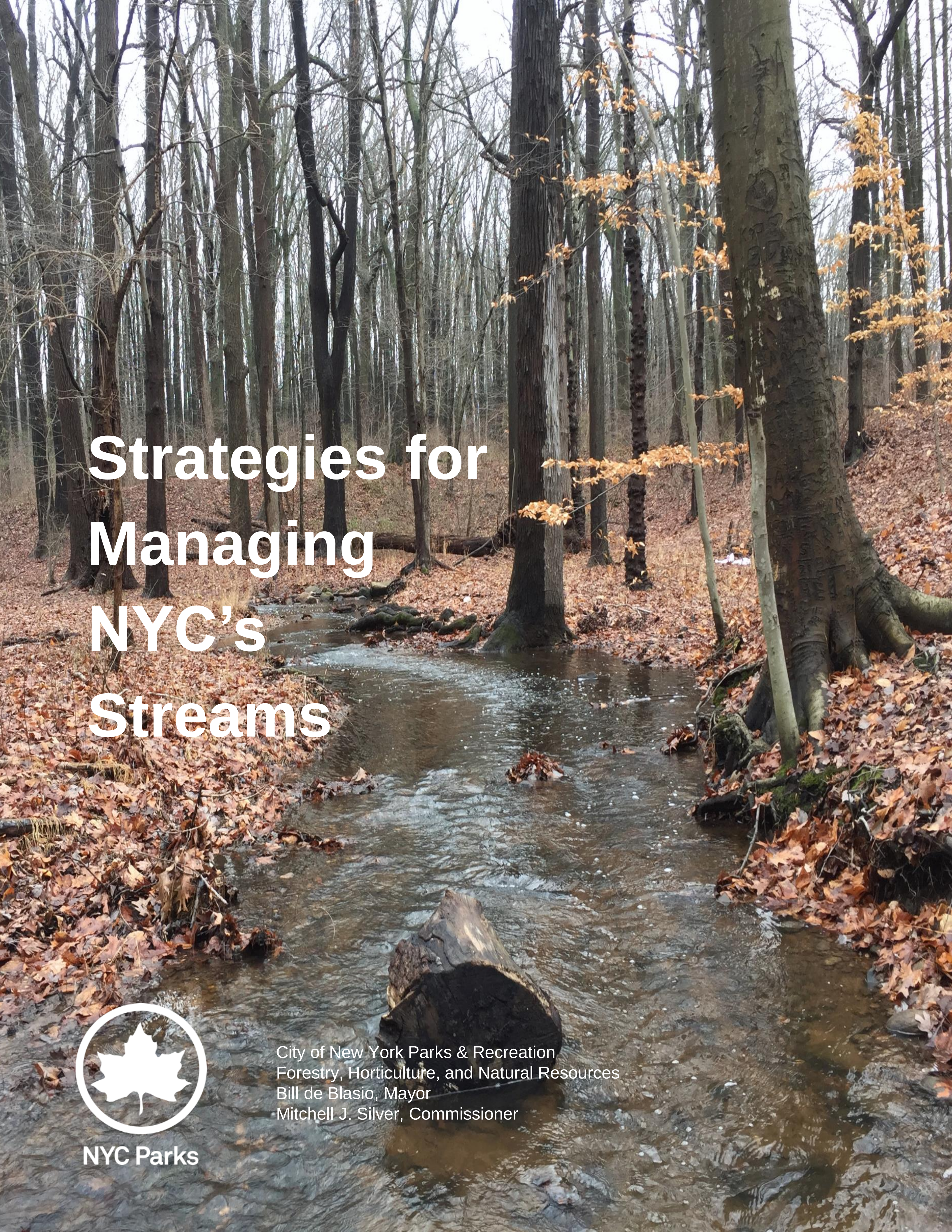
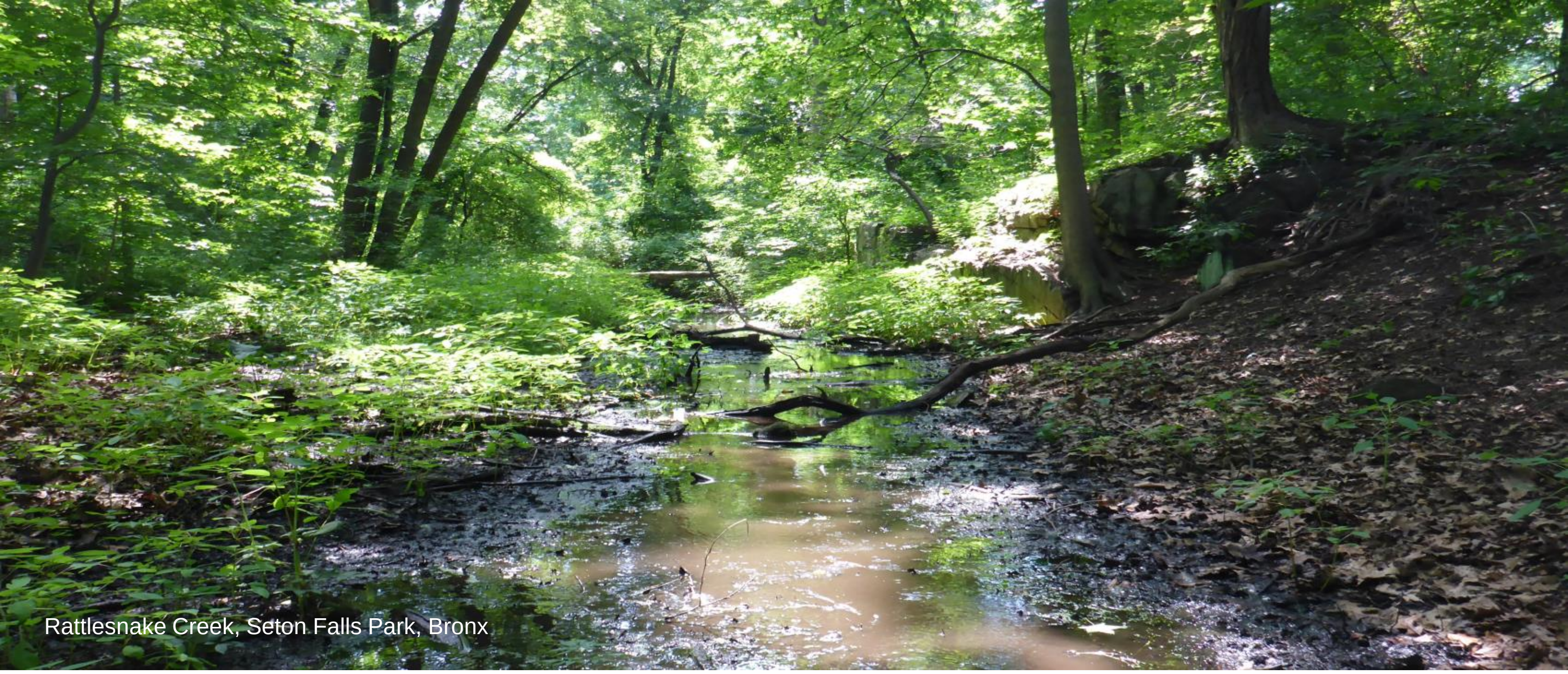


Strategies for Managing NYC's Streams

NYC Parks

City of New York Parks & Recreation
Forestry, Horticulture, and Natural Resources
Bill de Blasio, Mayor
Mitchell J. Silver, Commissioner



Rattlesnake Creek, Seton Falls Park, Bronx

EXECUTIVE SUMMARY

BACKGROUND

Historically, nearly 250 miles of streams flowed through New York City (NYC)'s wetlands and forests to the estuary that had been stewarded by the Lenape, Rockaway, and Canarsie tribes for centuries. These streams supported diverse cold-water fisheries and provided habitat, food, and clean water for fish, wildlife, and people. Manhattan, The Bronx, and Staten Island contained most of NYC's freshwater streams. Fewer were evident in Queens and Brooklyn, likely due to porous sandy soils generated from the retreat of the last glaciers and the far inland reach of tidal streams through coastal marshes of Jamaica Bay and the Long Island Sound.

Beginning in the 1600s, European colonists began damming streams in NYC for mills, irrigation, and related water control. Later, other industry and development cleared forests and left stream banks denuded. In the 1800s and 1900s, streams were treated as sewers to facilitate rapid population growth and development, and stream water quality eventually declined so dramatically that some streams posed a public health threat. As a result, many streams were buried and piped underground in addition to being straightened, armored, and confined to support roads, railways, and a burgeoning harbor. Development also resulted in many new miles of urbanized stream channels, some constructed to drain land and convey floodwater, and others created inadvertently, as stormwater runoff from developed areas carved gullies and eroded new channels into hillslopes.

Despite these alterations, stricter environmental regulations beginning in the 1970s resulted in significant improvements in water quality, and NYC's remaining streams, together with the City's forests, provide critical ecosystem services to both communities surrounding them and the fish and wildlife they support. Streams transport sediment and nutrients throughout the landscape, providing habitat and food for birds, fish, eel, salamanders, dragonflies, and other wildlife. Streams also regulate air temperatures, absorb and convey floodwaters, and provide spaces for respite, education, and recreation for the communities that surround them.

OBJECTIVES

This project inventories and characterizes the stream resources across NYC for the first time and assesses the condition of those streams on NYC Parks' property. Our goal was to increase our understanding of these streams to improve appreciation of these resources and to identify needs and opportunities for their restoration and management both on parkland and in their surrounding watersheds.

Two-Lined Salamander, Staten Island

APPROACH

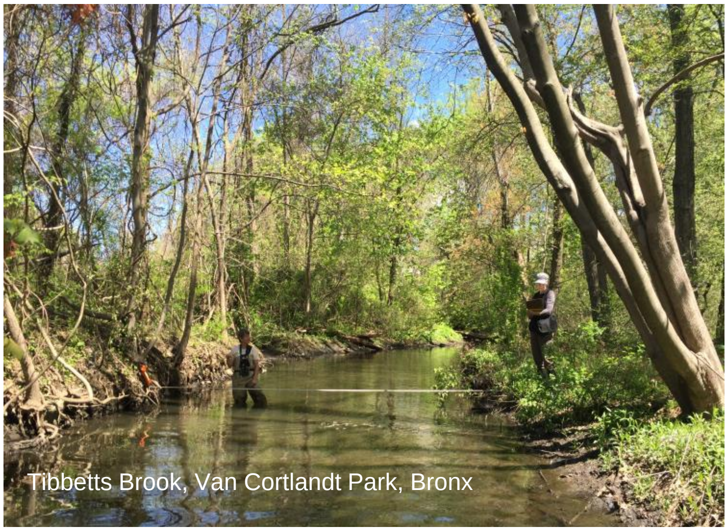
In 2017, NYC Parks contracted the University of Vermont to develop a map that updates the location and extent of streams in the landscape. Next, we developed a rapid stream assessment protocol, based on widely used standard protocols, to characterize and classify our highly urban streams in NYC's parks. To evaluate stream condition, we divided streams into shorter relatively uniform segments, or reaches, where we could collect representative information.

At each stream reach we collected field data on specific metrics that serve as indicators of the stream's health, or condition, and indicators of potential threats, or impacts, to stream condition. Landscape level metrics were also collected for each stream reach using GIS analyses. Metrics representing condition included the species of benthic invertebrates in the stream and the vegetation cover on the stream banks and in the stream corridor. Metrics representing impacts to streams included the number of pipe outlets to the stream, and the percent of impervious area in the surrounding watershed. We analyzed these data to develop an index of condition and impacts for individual reaches compared to others citywide.

RESULTS

Today NYC has over 112 miles of streams, including perennial and ephemeral streams, historical streams, and newly constructed channels and stormwater gullies (Table 1). Approximately 39 miles of historical streams remain, less than one-sixth of the original total stream length. Most are found in Staten Island, where over one-third of historical stream miles remain. In contrast, Manhattan has less than one percent of its historical sixty miles of streams. The 73 miles of new streams in NYC include drainage swales, ditches, constructed channels, and impoundments, many of which would not be considered streams outside of our highly urban context. Over half (60 miles) of today's streams are on NYC Parks property. Of those 60 miles, we sampled 25.9 miles. Reaches that were impounded, too small to meet our assessment criteria, or inaccessible were not assessed.

The health of NYC's streams varies dramatically from relatively natural streams in comparatively good condition to artificially constructed, concrete-bedded streams in very poor condition. When comparing all streams, we found that streams in the least developed watersheds are in better condition, with fewer threats, while those in highly developed watersheds are generally in worse condition and face greater threats due to unmanaged stormwater. These threats include impacts related to higher frequency and volume of stormwater runoff from impervious surfaces, including scour, sedimentation, and water pollution. While the benthic invertebrate communities living in our streams indicate that over 80 percent of our streams are highly impacted compared to those in more rural areas, NYC still contains stream habitat supporting fish and wildlife that must be protected for future generations.



Tibbetts Brook, Van Cortlandt Park, Bronx

Table 1. Miles of historic, newly mapped, and buried stream miles in each borough of NYC.

Linear Miles	Brooklyn	Bronx	Manhattan	Queens	Staten Island	Total
Historical streams	1.0	67.2	61.6	26.8	83.8	240.4
Buried streams	1.0	58.1	61.3	26.1	54.8	201.3
Remaining historical streams	0.0	9.1	0.4	0.7	29.0	39.2
Current streams*	0.8	14.6	0.4	6.7	89.3	111.8

*Note: Current streams include newly mapped streams, such as swales, small headwaters, or channels generated from stormwater drainage, as well as remaining historical streams.

RECOMMENDATIONS

Based on the data collected at the stream reaches we assessed, we recommend specific strategies and actions aimed at reducing threats and maintaining or improving the condition of the streams at the reach, buffer, and watershed scales. Approximately 30 percent of NYC Parks' streams are in relatively good health. The highest priority management action for these streams is to ensure they are well protected from future potential impacts associated with development or poor upstream land management. Approximately 13 percent of the streams in NYC parkland require better buffer management to help reduce apparent stressors that degrade stream conditions, and approximately 51 percent would most benefit from a focus on improved stormwater management to address impairments. Finally, about 5 percent of streams require larger rehabilitation or reconstruction projects due to more severe impacts.

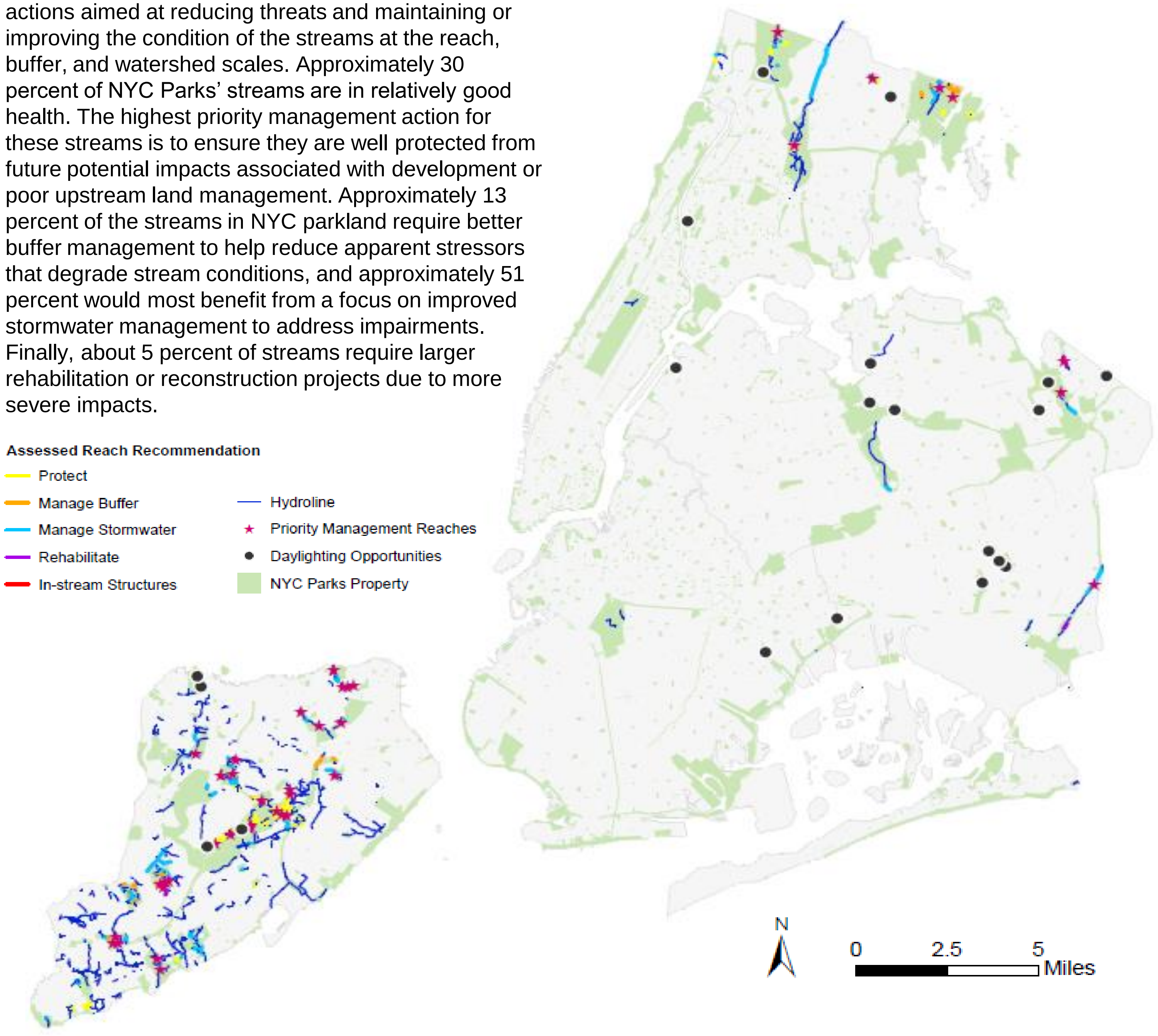


Figure 1. Map of NYC hydrolines and assessed streams, and associated management recommendations on NYC Parkland.

Table 2. Proposed management actions for assessed reaches in NYC Parks.

Management Action	Total stream length assessed (mi)	Percent of total length	Total # of reaches assessed	Percent of total # of reaches	Priority reach length (mi)
Protect	7.9	30.4%	67	37.0%	2.1
Manage buffer	3.4	13.3%	28	15.5%	1.6
Manage stormwater	13.1	50.5%	78	43.1%	1.6
Rehabilitate	1.4	5.3%	7	3.9%	1.2
In-stream structures	0.1	0.4%	1	0.6%	0.7
TOTAL	**25.9**		**181**		**7.2**

Strategy 1: Protect and Restore Our Existing Streams

Approximately 30 percent of NYC Parks stream miles sampled are in good condition, or health, and should be prioritized for protection. Often these streams are home to sensitive species, such as the rare two-lined salamander, and flow through our healthiest forests. NYC Parks seeks to protect all streams, but where streams are in good condition, our focus must be on preventing any new impacts that may degrade them. To reduce threats to our remaining freshwater streams and protect the wildlife that inhabits them, we recommend protection from the reach to the watershed scale. We recommend continuing efforts to avoid direct impacts, and protecting land in the floodplain, riparian buffer, and upstream watershed from development that could reduce vegetation cover or increase impervious surfaces. For example, even a large parking lot can generate enough direct runoff to severely impact a high-quality stream. In addition, we recommend protecting and enhancing in-stream habitat for fish and aquatic species, particularly where streams are otherwise in relatively good condition. We also recommend improving hydrologic connectivity between stream reaches, e.g. where they are intersected by roadways with culverts.

Five percent of NYC Parks' stream miles are moderately or severely degraded or altered. These streams are in poor condition and experience significant impacts, and they may require costly rehabilitation to attain valuable ecosystem services or functions. Examples include streams severely damaged by excessive stormwater leaving banks steep and denuded, and floodplains characterized by invasive species. These streams may require complete reconstruction and a watershed approach to stormwater management.

Strategy 2: Manage and Restore Buffers

Another 13 percent of NYC Parks' stream miles are threatened by poor conditions in the stream buffer. Riparian buffers surrounding streams are critical for creating shade, absorbing flood flows, filtering stormwater, and providing habitat. Our healthiest streams tend to flow through forests with an understory dominated by native spring ephemerals, such as trout lily, that are indicative of high-quality forests. Streams surrounded by lawns or highways often have poor water quality or have high sedimentation from stormwater runoff carrying soil and pollutants to our waterways. Managing the surrounding buffers may include removing invasive species, managing pests, such as tree-boring beetles that kill trees, and establishing a native ground cover and forest structure.

Strategy 3: Restore Watershed Hydrology in the Landscape

Fifty-one percent of stream miles on NYC Parks property have been identified as good candidates for stormwater management. Managing stormwater through green infrastructure upstream in the developed watershed can help restore natural hydrology of historical stream watersheds by capturing and slowing stormwater and allowing it to be evapotranspired by vegetation and infiltrated into the soil, rather than discharged directly to the stream. Green stormwater infrastructure techniques include aboveground vegetated rain gardens or bioswales and belowground detention.

Stormwater runoff from impervious surfaces carries pollutants such as road contaminants, sediment, nutrients, and floatable garbage into our streams. In addition to poor water quality, the frequency and velocity of runoff leads to stream habitat degradation.

In highly developed watersheds, a major investment in green infrastructure retrofits is needed to help detain stormwater at a broad scale. Less developed watersheds, or streams with relatively specific stormwater impacts, such as those associated with a specific building or parking lot in an undeveloped watershed, may only require relatively localized stormwater interventions to improve downstream habitat conditions.

Native buffers, like those in Wolfe's Pond Park (top), protect water quality. Where streams lack native buffers, such as, where streams flow through golf courses (bottom), streams may experience higher pollutants from fertilizers and pesticides that impact wildlife.

Daylighting Streams

Another strategy for restoring NYC's streams is to daylight, or re-construct and resurface, a stream that was buried or piped underground. Daylighting can be extremely costly, particularly where there is development above the buried stream; therefore, it is included as an additional option for feasible locations but is not included in our above strategy framework. In some cases, however, streams have been piped into the combined stormwater and sewer system and thus contribute to combined sewer overflows. When daylighting includes removing streamflow from the sewer system, it can result in significant water quality benefits. At Tibbetts Brook in the Bronx, the New York State Department of Environmental Conservation, NYC Department of Environmental Protection, NYC Parks, and community groups are proposing to remove Tibbetts Brook from the Combined Sewer System. Approximately 12 other buried streams may have potential opportunities for daylighting, but none have been seriously assessed to date.

Regulatory Gaps

Approximately 30 to 40 percent of NYC's streams are small headwaters and are not protected via state or federal regulation, leaving them vulnerable to development and other impacts. State regulations limit protections to those that can be navigated by a single person vessel and federal regulations limit protections to "Waters of the United States," which include some navigable and non-navigable perennial and intermittent streams. These regulations leave nearly 30 miles of seasonally flowing headwater streams unprotected that provide vital habitat to birds and amphibians.

CONCLUSIONS & NEXT STEPS

Recommendations outlined in this report will inform long-term plans for comprehensively managing NYC's streams and wetlands. By disseminating maps and other data produced from this project to City and State agencies, planners, designers, land managers, and regulators can be made more aware of resources requiring low-impact development and further protection. The Natural Areas Conservancy has developed a publicly available Nature Map which highlights the location, size, and condition of natural resources in NYC, including forests, freshwater wetlands, salt marshes, and streams.

In addition, maps, summary results from these assessments, and management recommendations will be shared with groups within the agency and with non-governmental organizations that provide environmental outreach and education. Outreach and education are critical to communicating to the public that NYC's streams manage flooding, help deliver clean water to the New York harbor, and support rare habitat. NYC's natural areas and water bodies also provide communities opportunities for exploration, beauty, and respite. Ensuring communities have connections to their local waterways and providing the training and tools to be good stewards of the natural environment is critical to ensuring future generations experience the social and ecological benefits that our streams provide.

LaTourette Park, Staten Island

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Cover Photo: Wolfe’s Pond Park, Staten Island

1. Introduction

Streams and freshwater wetlands in New York City (NYC) are vibrant ecosystems that provide essential benefits to both local communities and wildlife. NYC's streams protect water quality, regulate temperatures, retain and channel floodwaters, and provide essential habitat for wildlife such as birds, frogs, salamanders, and dragonflies. They also provide opportunities for education, recreation, and respite, along with beauty and variation in our built and natural landscapes. Despite their importance and protection by existing state and federal regulations, our streams and wetlands are at risk from development and other impacts that may degrade their structure and ecological functions.

In the 1600s, when Europeans arrived, NYC had nearly 250 miles of streams and thousands of acres of wetlands that had been stewarded by the Lenape, Rockaway, and Canarsie tribes for centuries. Few of these streams remain as they historically existed, and those remaining have been largely modified from their original state. Today NYC also has new stream channels,[2] including both small ephemeral headwater channels formed by erosion or ditching, and larger channels constructed to manage the increasing volume of stormwater generated from development. New York City Department of Parks & Recreation (NYC Parks) manages over half of the freshwater streams in the city, highlighting a need for a comprehensive management framework.

NYC's freshwater streams have been filled, altered due to straightening and armoring, and often partially piped to support the development of our city and harbor. Development has further degraded the biota and habitat our streams provide due to invasive species, stormwater runoff, and other stressors. Effective impervious area—the impervious area directly connected to streams by drainage infrastructure during development—is one of the primary factors leading to the degradation of many urban streams.[3] Stormwater runoff carries contaminants and garbage from roads and lawns and causes physical disturbance through erosion and sedimentation—disturbance that favors invasive and pollution-tolerant plants and animals. As the climate changes, heavier and more frequent rain events will exacerbate stormwater impacts to our streams.[4]

In addition to streams, NYC has between 1,700 and 2,700 acres of freshwater wetlands,[5,6] representing less than 10 percent of the city's historical wetlands.[7,8] NYC Parks manages almost half of those wetlands, including lakes and ponds, emergent, shrub-scrub, and forested wetlands. These wetlands vary in size and in their connections to streams and stormwater

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[2] GroundPoint Technologies, LLC. 2018. Citywide Hydrography Mapping.

[3] Walsh, C.J., Roy, A.H., Feminella, J.W., Cottingham, P.D., Groffman, P.M., and R.P. Morgan. 2005. The urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society 24(3): 706-723.

[4] Talke, S.A., Orton, P., and D.A. Jay. 2014. Increasing storm tides in New York Harbor, 1844-2013. Geophysical Research Letters 41(9):3149-3155.

[5] US Fish and Wildlife Service. 2009. National Wetlands Inventory.

[6] New York State Department of Environmental Conservation. Freshwater Wetlands Maps. 1995.

[7] Regional Plan Association. 2002. Tidelands of the New York New Jersey Harbor Estuary.

[8] New York City, Mayor's Office of Long-term Planning & Sustainability (NYC OLTPS). 2012. Wetlands Strategy.

runoff from surrounding development. Stormwater can impact wetland water quality, for example, through high nutrient loads that can cause algal blooms and lead to low oxygen conditions, or through sedimentation that can fill wetlands, reducing habitat favorable to native plants, fish, and wildlife. Freshwater wetlands that are connected via surface water to streams are considered in this report.

From 2016 to 2018, NYC Parks and the Natural Areas Conservancy completed an assessment of freshwater streams on city parkland aimed at 1) evaluating their current condition and the potential impacts from stormwater on their physical and biotic functions and 2) developing recommendations for conservation and management. To cover dozens of stream miles on NYC Parks property with limited resources, we used rapid field and desktop assessment methods informed by established protocols.[9,10] We synthesized our assessment data to describe the condition of and impacts to each stream reach and developed recommendations aimed at addressing these conditions.

This report presents a summary of our assessment approach, results describing existing conditions and impacts, and recommendations for protecting and managing NYC's freshwater streams. The purpose of this document is to provide a foundation for a long-term freshwater stream and wetlands conservation and management strategy and to inform short- and long-term restoration and management recommendations at the site and landscape scales. Recommendations from this report should be considered by city resource managers, regulatory agencies, and community advocates when evaluating the impacts of development and stormwater management strategies. This work also supports efforts to create a more livable, resilient city as described in city planning documents such as the NYC Wetlands Strategy[11] and OneNYC,[12] and will inform a comprehensive framework in development by NYC Parks for managing NYC's streams and wetlands citywide.

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[9] Ohio EPA. 2012. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams. Version 3.0. Ohio EPA Division of Surface Water, Columbus, Ohio. 117 pp.

[10] Rosgen, D.L. 1994. A classification of natural rivers. CATENA 22(3): 169-199.

[11] New York City, Mayor's Office of Long-term Planning & Sustainability (NYC OLTPS). 2012. Wetlands Strategy.

[12] New York City. 2015. OneNYC.

2. Stream Characterization and Assessment

2.1 Study Objectives and Approach

This project aimed to identify and confirm locations of streams, assess their condition and impacts, and use those results to identify management strategies. The goal was to cover as much ground as possible and glean the range of stream conditions citywide. We used a variety of metrics to evaluate the physical and biotic stream conditions and considered direct threats to conditions, primarily from stormwater runoff. We used assessment results to develop condition, or health, and impact, or threat, scores to compare streams to one another and categorize them based on the level and type of intervention needed to improve condition. These categories informed management strategies to restore, enhance, or maintain stream function.

Study Design and Site Locations

We developed a rapid assessment protocol to assess and locate as many streams as possible on NYC Parks' property across 24 watersheds (Table 1). We used newly developed stream hydrography maps to locate streams.[13] We walked the length of each stream on parkland to confirm its location and identify any unmapped tributaries or gullies. We subdivided each stream into individual reaches, or sections, with similar geomorphic features, such as order, slope, channel geometry, bed sediment, and similar surrounding bank and riparian vegetation (Figure 1). We determined reach extents in the field and assigned a unique identifier to each reach.

For this very rapid assessment, we tended to "lump" reaches together when delineating their extent versus "splitting" them apart. We walked as many streams on Parks property as we could within a 6-month timeframe, covering nearly 50 percent of the total stream extent on parkland. Given our extremely urban context, we assigned no maximum length to reaches; since particularly long, straightened, and channelized streams were relatively homogenous, and subdividing these streams would have provided little new information. However, to avoid assessing many small reaches, the minimum reach length was defined as 20 times the stream's bankfull width. Streams flowing through small wetlands and impoundments without distinct stream channel forms were typically not assessed.

To assess each reach, we collected a series of field and desktop metrics in the stream channel, along the banks, and within the buffer and drainage area to evaluate reach condition and potential impacts from stormwater. We began with standard stream assessment protocols but modified them to allow us to assess an individual reach in approximately one hour.

2.2 Field Assessment

We collected data on geomorphic, habitat, and biotic metrics in each stream reach. A subset of these metrics informed the stream condition and impacts scores we developed for each stream. Table 2 contains a list of metrics collected, along with a description of how we used the data in our analyses. Appendix A provides assessment protocols and Appendix B a glossary of terms.

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[13] GroundPoint Technologies, LLC. 2018. Citywide Hydrography Mapping.

To characterize each reach, we sampled three transects perpendicular to streamflow, roughly evenly spaced across the length of the reach, to capture variability within the reach and allow for comparisons between reaches and different streams. We sampled physical metrics at all transects, and completed more intensive sampling, such as benthic invertebrates, bed substrate size, and riparian vegetation, at the middle transect (Figure 1).

Physical and Geomorphic Metrics

To characterize the physical and geomorphological aspects of the reach, we measured stream geometry, including bankfull width and depth, and bed substrate.[14] To evaluate bank stability and the potential risk of erosion and incision at each reach, we assessed bank substrate (e.g. natural or armored), bank angle, bank height, rooting depth, and flood prone width,[15] or entrenchment ratio, which indicates how connected a stream is to its floodplain (Figure 2). We collected these metrics at all three transects, except for bed substrate, which we only collected at the middle transect.

Habitat Metrics

To assess habitat complexity and determine the types of organisms that a stream might support, we counted the number of pools and large woody debris within the bankfull channel. To evaluate riparian vegetation condition along the banks, we assessed the percent of canopy cover, which indicates the extent of stream shading and cooling, by taking canopy photos at approximately 6 feet from the stream bed at each transect. We visually estimated percent cover of Japanese knotweed, which indicates disturbance, throughout the reach within 10 feet of each bank using midpoints of cover class values.[16] We intended to estimate the cover of the top five native and invasive species within each structural layer (canopy, midstory, understory); however, we removed these metrics from analyses due to inconsistencies in data collection.

Biotic Metrics

To evaluate overall water quality and stream disturbance, we sampled three biotic metrics in the stream bed at the middle transect of each reach: the presence or absence of salamanders, a rapid assessment index of benthic invertebrates using the Headwater Macroinvertebrate Field Evaluation Index (HMFEI), and the Ephemeroptera, Plecoptera, Trichoptera (EPT) Index. To sample benthic invertebrates, we modified a rapid assessment method developed by the Ohio Environmental Protection Agency for assessing stream benthic invertebrate communities.[17] Our modified procedure differed from a benthic index of biotic integrity (B-IBI) in that it used less extensive sampling and relied on pollution-tolerance (or index) values for each taxon developed by more intensive sampling in nearby geographical areas. We sampled benthic

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[14] Rosgen, D.L. 1994. A classification of natural rivers. *Catena*, 22, 169-199.

[15] Rosgen, D.L. 2001. A Practical Method of Computing Streambank Erosion Rate. Proceedings of the 7th Federal Interagency Sedimentation Conference, Vol. 2, pp. 9-15, March 25, 2001, Reno, NV.

[16] Jennings et al. 2009. Standards for associations and alliances of the U.S. National Vegetation Classification. Ecological Monographs 79:173–199.

[17] Ohio EPA. 2012. Field Evaluation Manual for Ohio's Primary Headwater Habitat Streams. Version 3.0. Ohio EPA Division of Surface Water, Columbus, Ohio. 117 pp.

macroinvertebrates by conducting a 5-meter long kick sample, divided into 1-meter segments. We identified all species collected in the field where possible; otherwise, samples were preserved in ethanol and identified in the lab to the lowest taxonomic level possible.

We based our methods on the HMFEI and the Stream Quality Monitoring Assessment Form (Appendix A) given the small size of our reaches. This index, developed for use in rapid field assessment, assigns scores of 1 to the most pollution-tolerant organisms such as Diptera (chironomid) larvae, 2 to moderately tolerant organisms such as Isopoda, and 3 to the least tolerant/most sensitive organisms such as Ephemeroptera nymphs.

Within our sampling approach, we also utilized the Ephemeroptera, Plecoptera, Trichoptera (EPT) Index of stream quality.[18] These insect orders have a low pollution tolerance and therefore represent a proxy for high water quality.

2.3 Landscape Assessment

To evaluate stream condition and impacts to streams from the surrounding landscape, we completed a series of landscape-level analyses using ArcGIS and available spatial data. Landscape analyses allowed us to evaluate historical stream loss, impervious surface coverage within the drainage area of each reach, and vegetation cover in the buffers adjacent to streams.

Historical Stream Loss

To assess the condition and potential impacts to NYC's current freshwater streams, it was important to understand the historical extent of streams prior to NYC's extensive urbanization. To quantify the historical extent of freshwater streams, we used data from the Welikia Project, which aims to understand the historical extent and ecology of NYC's streams, wetlands, and forests when the Europeans first arrived in 1609, and the earlier paper maps were drawn.[19] We compared the extent of those historical streams to the historical extent of tidal wetlands, to identify streams likely to be estuarine. Next, we compared the historical stream extent to the current stream hydrography maps using ArcGIS and calculated changes in stream length. Some caveats to this analysis should be noted. First, the Welikia data is derived from a compilation of historical maps from different dates and cartographers, so mapping may be inconsistent; for example, while larger streams may be well-mapped, smaller headwater streams may be inconsistently captured. Next, what was considered a stream historically in NYC's early undeveloped landscape may not match our current definitions given our urbanized context. Finally, some streams may have been relocated, shifted position over time, or mapped incorrectly, so we applied a 250-foot buffer around historical streams for this analysis. We considered streams lost if they appeared in the historical layers but not the current layers.

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[18] Lenat, D.R. 1988. Water quality assessment using a qualitative collection method for benthic macroinvertebrates. J.N. Am. Benthological Soc. 7: 222-233.

[19] Wildlife Conservation Society. 2017. Welikia Project.

Buffer Characterization

To evaluate the ability of the riparian buffer adjacent to the reach to support buffering functions for each reach, we used land cover data[20] to assess the percentage of natural vegetation cover within a 30-meters surrounding each reach. Natural cover includes tree canopy, grassland, wetland, and fresh and marine water land use classifications, but does not include developed land (e.g., buildings, pavement, or lawn). Natural vegetation cover within the buffer promotes the infiltration of stormwater runoff and mitigates nonpoint source pollution of contaminants in stormwater runoff through soil infiltration and plant uptake.[21]

Impervious Surface Cover in the Drainage Area

To understand the surrounding land use contributing to the hydrology of each reach, we calculated the topographic drainage area using spatial analysis extensions in ArcGIS and the percent impervious cover within that drainage area using available land cover data.[22] Impervious surface cover within the drainage area is a known indicator of urbanization impact to streams.[23, 24] However, not all impervious surfaces are connected to storm drains and routed to streams. Some impervious surfaces drain to lawns, rain gardens, or vegetated surfaces, such as forests. Other impervious surfaces drain to combined sewer systems (CSOs) that discharge to the estuary and not smaller streams. The impervious area that is connected to pipes or drainage infrastructure that discharge to streams or sewers is known as effective impervious area. Highly developed landscapes like NYC with complex sub-surface drainage make effective imperviousness very difficult to determine, so we use total impervious area.

To represent total impervious area draining to a reach, we could remove the CSO drainage area, since it is draining separately. However, the number of reaches draining CSO areas is relatively small and would not impact management recommendations significantly, so we consider drainage areas driven by surface topography for our analyses.

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[20] O'Neil-Dunne, J.P.M., MacFaden, S.W., Forgione, H.M. and J.W.T. Lu. 2014. Urban ecological land-cover mapping for New York City. Final report to the Natural Areas Conservancy. Spatial Informatics Group, University of Vermont, Natural Areas Conservancy, and New York City Department of Parks & Recreation. 22 pp.

[21] Fennessy, M.S. and J.K. Cronk. 1997. The effectiveness and restoration potential of riparian ecotones for the management of nonpoint source pollution, particularly nitrate. Critical Reviews in Environmental Science and Technology 27(4): 285-317.

[22] O'Neil-Dunne, J.P.M., MacFaden, S.W., Forgione, H.M. and J.W.T. Lu. 2014. Urban ecological land-cover mapping for New York City. Final report to the Natural Areas Conservancy. Spatial Informatics Group, University of Vermont, Natural Areas Conservancy, and New York City Department of Parks & Recreation. 22 pp.

[23] Booth, D.B., Karr, J.R., Schauman, S., Konrad, C.P., Morley, S.A., Larson, M.G., and S.J. Burges. 2004. Reviving Urban Streams: Land Use, Hydrology, Biology, and Human Behavior. Journal of the American Water Resources Association 40(5): 1351-1364.

[24] U.S. Environmental Protection Agency Office of Water Recovery Potential Screening. 2011. Recovery Potential Metrics Summary Form – Watershed Percent Impervious Cover. https://www.epa.gov/sites/production/files/2015-11/documents/rp2wshedimperv1109.pdf.

Table 1. Watersheds examined in each borough and park.

Borough	Watershed Name (Abbreviation)	Park Name(s)
Bronx	East River – Bronx River (ERBRW)	Bronx Park
Bronx	Harlem River (HR2)	Van Cortlandt
Bronx	Hudson River (HR)	Riverdale
Bronx	Long Island Sound – Hutchinson River (LISHR)	Seton Falls, Givans Creek Woods
Bronx	Long Island Sound 1 (LIS1)	Pelham Bay
Queens	Alley Creek – Little Neck Bay (ACLNB)	Alley Pond
Queens	East River – Flushing Bay 1 (ERFB1)	Flushing Meadows-Corona
Queens	Jamaica Bay – Cornell Hassock Creek (JBCHC)	Brookville
Queens	Udalls Cove (UC)	Udall’s Cove, Gabblers Creek
Staten Island	Arthur Kill North (AKN)	Staten Island Industrial Park
Staten Island	Arthur Kill – Richmond Creek North – a (AKRCNA)	Willowbrook, Freshkills
Staten Island	Arthur Kill – Richmond Creek North – b (AKRCNB)	LaTourette, Bloodroot Valley, High Rock, King Fisher
Staten Island	Arthur Kill – Richmond Creek South (AKRCS)	Arden Woods
Staten Island	Arthur Kill South – 1c (AKS1C)	South Shore Country Club
Staten Island	Arthur Kill South – 2a (AKS2A)	Long Pond, Fairview
Staten Island	Kill Van Kull East (KVKE)	Snug Harbor Cultural Center, Allison Pond, Goodhue, Silver Lake
Staten Island	Kill Van Kull West (KVKW)	Mariners Marsh, Clove Lakes
Staten Island	Lower New York Bay – New Creek (LNYB – NC)	Last Chance Pond, Midland Field, New Creek, High Rock
Staten Island	Raritan Bay (RB)	Long Pond, Butler Manor, Hybrid Oak Woods, Conference House
Staten Island	Raritan Bay –Annandale Beach (RBAB)	Blue Heron
Staten Island	Raritan Bay – Arbutus Lake (RBAL)	Bunker Ponds
Staten Island	Raritan Bay – Great Kills Harbor (RBGKH)	Siedenburg; King Fisher
Staten Island	Raritan Bay – Lemon Creek (RBLC)	Lemon Creek, Bloomingdale
Staten Island	Raritan Bay – Wolfes Pond (RBWP)	Wolfes Pond

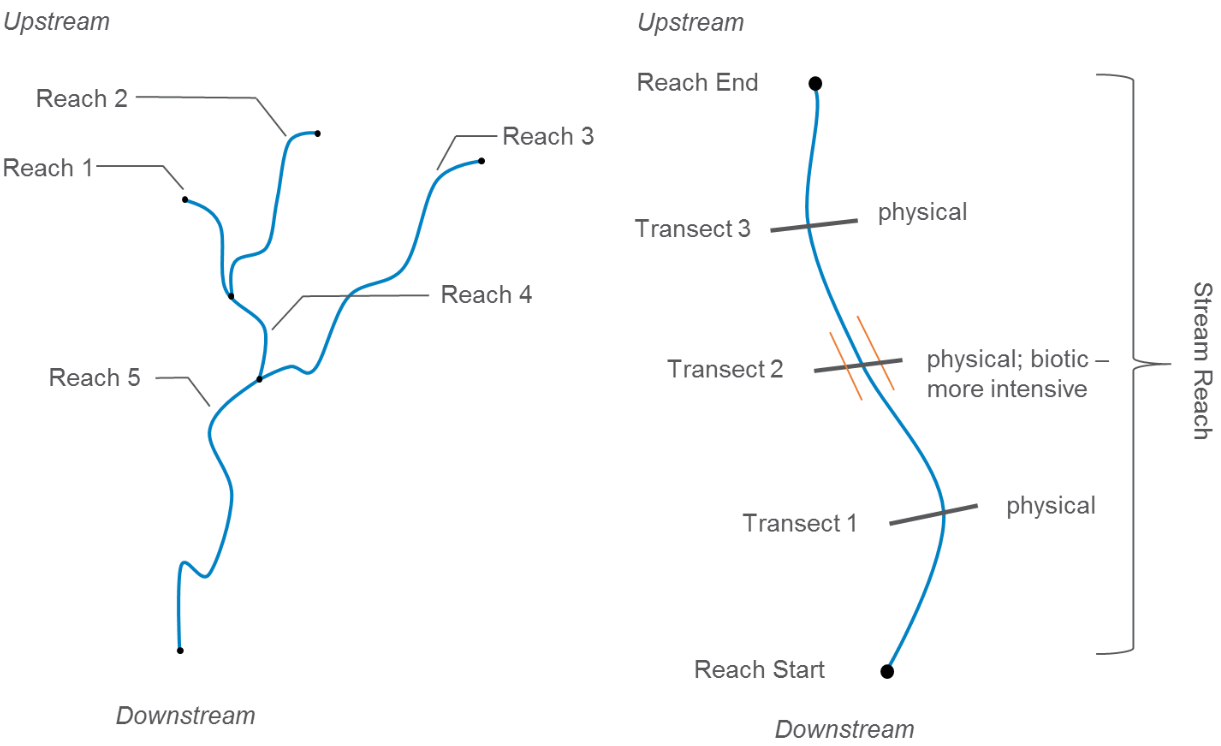

Figure 1. Configuration of stream reaches along a stream (left) and sampling transects along an individual stream reach (right). A new reach is designated at the confluence (black dots) of another stream channel, and/or when the geomorphological characteristics of the stream differ.

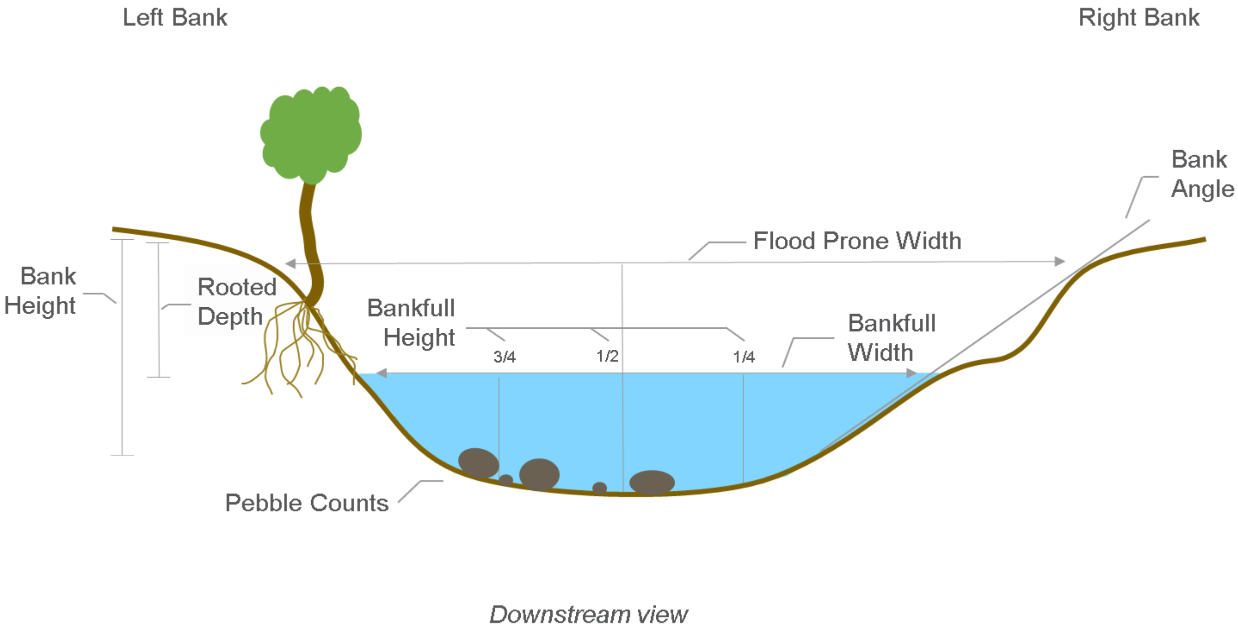

Figure 2. Physical assessment metrics assessed to evaluate channel geometry.

Table 2. Assessment metrics collected and their indication of stormwater or stream condition.

Metric Category	Field Metric	Calculated Metric	Metric Definition	Character-ization	Condition Indicator	Stormwater Impact Indicator
LANDSCAPE	N/A	Stream Order	A classification of the stream based on its position in the watershed. First-order streams refer to the smallest tributaries that flow into a larger system. The stream that a first-order tributary flows into would be considered second-order, and so on.	X		
	N/A	Stream Slope	Elevation at upstream reach end minus minimum elevation at downstream reach start, divided by the reach length.	X		
	N/A	Sinuosity	Ratio of valley slope to channel slope (desktop-determined using ArcGIS and the following definition as provided by the Rosgen Stream Classification). The greater the number, the higher the sinuosity, and the curvier the stream is.	X		
	N/A	Percent Impervious Area Within the Drainage Area	Total impervious surface areas in the watershed divided by the total land area of the watershed.			X
	N/A	Percent Natural Cover in 30 m Buffer	Linear distance (100 feet) from the stream center line to the right and left banks. Natural vegetation is defined by the NAC's Ecological Cover Type Map (Level 2) and excludes impervious or developed surfaces, landscaped trees, and lawns. Natural cover types include forests, wetlands, grasslands, and bare soil.		X	X
PHYSICAL	Bankfull Width	Average Bankfull Channel Width	Width of the active channel at the elevation typical of a 1-2 year recurrence interval flood, as evidenced in the field by break in slope, change in vegetation, and water marks.	X		
	Bankfull Depth	Average Bankfull Channel Depth	Average of the three bankfull depth measurements (1/4 (Right Bank); 1/2; 3/4 (Left Bank)).	X		
	Bankfull Width; Bankfull Depth	Average Bankfull Width to Depth	Ratio of the average width to depth of each transect.	X		
	Flow Type	Flow Type	Estimate of frequency of surface water flow in the reach, using the categories of ephemeral (seasonal flow (ephemeral) or perennial (continuous/year-round)).	X		

	Field Metric	Calculated Metric	Metric Definition	Characterization	Condition Indicator	Stormwater Impact Indicator
	Pebble Count	Bed Substrate Size – D50	Median particle size (D50) on the channel bed based on Pebble Count method; 100 randomly selected particles (gravel, cobbles and boulders) measured along the intermediate “b” axis.	X		
	Flood prone Width	Entrenchment Ratio	Width of the channel at twice the highest bankfull depth. Used to calculate Entrenchment Ratio, which is flood prone width divided by the bankfull width.		X	
HABITAT	Percent Cover of Canopy Shading the Channel	Percent Cover of Canopy from Image Analysis	Average percentage of stream shading by riparian vegetation. Measured by photos taken of the canopy in the center of the stream at three transects.		X	
	Percent Cover of Japanese knotweed on Stream Banks	Percent Cover of Knotweed on Banks	Average percentage of Japanese knotweed cover on banks within 10 feet of the stream channel, based on the respective midpoints of the following cover class ranges: 0-5% = 2.5%; 6-12.5% = 8.75%; 12.6-25% = 18.75%; 26-50% = 37.5%; 51-75% = 67.5%; 76-100% = 87.5%.		X	
	Riffle Depth; Pool Depth	Residual Pool Depth	Closest pool upstream at each transect: The difference between the measured water depth in the pool and the water depth at the riffle downstream of the pool.	X		
	Count of Pools	Total Number of Pools	Total pool count within each stream reach. The number of pools is normalized by reach length.	X		
	Count of Large Woody Debris (LWD)	Total Number of LWD	Total large woody debris count in the bankfull channel within each reach. Metric was normalized by stream reach width.		X	
BIOTIC	Salamanders	Presence/ Absence	Presence of salamanders in streams.		X	
	Abundance, diversity	EPT	Total number of families of the Ephemeroptera, Plecoptera, Trichoptera (EPT) order represented in one kick sample.		X	X
	Kick Sample: abundance, diversity	Benthic Indices	A calculated index which assigns a weighted value to benthic invertebrates found in a stream through sampling. Weights are associated with water quality and can help evaluate water pollution. Indices are derived from rapid assessment protocol in Maryland and Ohio. The sum of scores for each taxon found based on its tolerance to pollution. Sampled via 5 one-meter kick samples.		X	

	Field Metric	Calculated Metric	Metric Definition	Character-ization	Condition Indicator	Stormwater Impact Indicator
BANK STABILITY	Bank Type	Bank Type	Type of bank material and condition, using the categories: armored, vegetated, cut, or unstable	X		
	Average Bank Angle	Average Bank Angle	Average angle of the right and left banks.	X	X	X
	Average Bank Height	Average Bank Height	Vertical height of the stream bank, measured between its toe at the digging level and the height at which the bank plateaus. Bank height is measured at the edge of the stream bed.	X		X
	Average Rooting Depth	Average Rooting Depth	Vertical height of the stream bank that is rooted and therefore resistant to erosion. This is measured from the top of the bank.	X		X
	Bank Height; Bankfull Height	Average Bank Height to Bankfull Height	Ratio of bank height/bankfull height.	X		X
	Rooting Depth; Bank Height	Average Rooting Depth to Bank Height	Ratio of rooting depth/bank height.	X	X	
CONCERNS	Number of Outfalls/ Discharge Pipes	Total number of Outfalls/ Stormwater Inputs	Number of outfalls/stormwater pipes tallied per reach.			X
	Presence of Erosion and Sedimentation	Presence /Absence	Observation of erosion, sedimentation, and scour along reach.			X
	Presence of Garbage	Presence /Absence	Observation of garbage and non-natural debris along reach.			X

3. Analysis

We used field and landscape data to classify each reach and stratified as needed, to evaluate the condition and potential impact from unmanaged stormwater.

Classification of NYC's Streams

Typical geomorphic-based stream classification systems, such as those developed by Rosgen[25] or Montgomery and Buffington,[26] were developed for more mountainous regions and were not appropriate for our small urban streams. For example, these classifications rely on longitudinal characteristics such as slope, which do not vary much in NYC's relatively flat terrain. As a result, we classified NYC's streams into three categories based on sediment size: silt/sand, sand/gravel, and gravel/cobble. Silt/sand, sand/gravel, and gravel/cobble are defined as having a median particle size (D50) range of <0.2mm, 0.2mm-2.0mm, and >2.0mm, respectively. These sediment categories generally corresponded to their position within the landscape and to what organisms we would expect to find inhabiting each stream. Cobble- and gravel-bedded streams are typically riffle-pool streams that are steeper and found at higher elevations in the glacial terminal moraine that stretches across Brooklyn, Queens, and Staten Island. Gravel- and sand-bedded streams found along the well-drained glacial outwash soils in the coastal plain are less steep and form smaller pools and riffles that provide varied habitat for fish and insects. Sand- and silt-bedded streams are extremely flat, slower flowing, have less oxygenated water, and are often associated with freshwater wetlands or impoundments. NYC also has highly altered sections of streams lined with rock or concrete placed historically to reroute or stabilize the stream.

Conditions and Impact Index Development

Of those reaches sampled, we selected eight quantitative metrics for developing stream condition and impact indices. Six metrics (entrenchment ratio, percent natural cover in 30 meter buffer, percent knotweed cover on banks, percent in-stream canopy cover, benthic index, and EPT) informed reach condition and two metrics (percent impervious area in the drainage area and pipe counts) informed the potential impacts to the reach from stormwater inputs from surrounding development (Table 3; Figure 3). While most of the metrics collected for this study were generalizable for all reaches, the sediment-based classification allowed us to stratify benthic invertebrate data more appropriately. Benthic communities differ greatly between a silt-bedded stream and a gravel/cobble-bedded stream. Clinging taxa, which require more dissolved oxygen and are less pollution tolerant, would be found attached to cobbles. Taxa inhabiting a silt-bedded stream are more likely to be burrowing organisms adapted to less dissolved oxygen (and potentially higher pollutant tolerance) in the water column.

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[25] Rosgen, D.L. 1994. A classification of natural rivers. CATENA 22(3): 169-199.

[26] Montgomery, D.R. and J.M. Buffington. 1997. Channel-reach morphology in mountain drainage basins. Geological Society of America Bulletin 109(5): 596-611.

To develop indices for each reach, we assigned a z-score to each metric, which normalizes the dataset around the average and standard deviation for that metric. Equation 1 is used to calculate the z-score:

Eq. 1 $$Z = \frac{X-\mu}{\sigma}$$

where Z is the z-score, X is the raw score, μ is the mean, and σ is the standard deviation.

Next, we weighed each z-score based on importance. All metrics received a weight of 1, except for percent in-stream canopy cover and pipe counts. The canopy was not a significant driver of condition, and pipe counts did not quantify the volume of stormwater reaching each stream; therefore, we assigned a 0.5 weighting to both metrics. Next, we summed those weighted scores and divided by the sum of metrics to calculate a total condition and impact index for each reach (Figure 3). We plotted the total condition and impact scores against each other (Figure 4).

The position of a reach in the condition and impact matrix helps visualize the likely recommended management actions – this management framework is discussed further in Section 5. Conceptually, reaches with high condition and low impact scores represent those with the highest priority for protection since they are the most likely streams to be self-sustaining in the long-term. Reaches with low condition and high impact scores may require the highest level of intervention to improve viability and may represent a lower priority due to cost and low likelihood of success.

To evaluate this approach and ensure that the selected metrics were not conflicting or influencing each other, we ran correlation analyses. No metrics were significantly correlated except benthic indices and EPT, which was expected given they both inform macroinvertebrate community composition. Next, we analyzed the metrics to determine the influence of each metric in explaining variability between reaches using non-metric multidimensional scaling (NMDS). NMDS provides a framework for explaining trends in non-normally distributed environmental data by grouping response variables and highlighting their contribution to the total variation in the data.[27] We ran NMDS analyses using the R software with packages MASS,[28] permute,[29] vegan,[30] scatterplot3d,[31] reshape2,[32] and ggplot2.[33]

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[27] McCune, B. and J.B. Grace. 2002. Analysis of Ecological Communities. MjM Software, Gleneden Beach, Oregon. 304 pages.

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[29] Simpson, G.L. 2016. permute: Functions for Generating Restricted Permutations of Data. R package version 0.9-4. https://CRAN.R-project.org/package=permute.

[30] Oksanen, J., Guillaume Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymos, P., Stevens, M.H.H., Szoecs, E., and H. Wagner. 2018. Vegan: Community Ecology Package. R package version 2.5-1. https://CRAN.R-project.org/package=vegan.

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[32] Wickham, H. 2007. Reshaping Data with the reshape Package. Journal of Statistical Software, 21(12), 1-20. URL http://www.jstatsoft.org/v21/i12/.

[33] Wickham, H. 2009. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

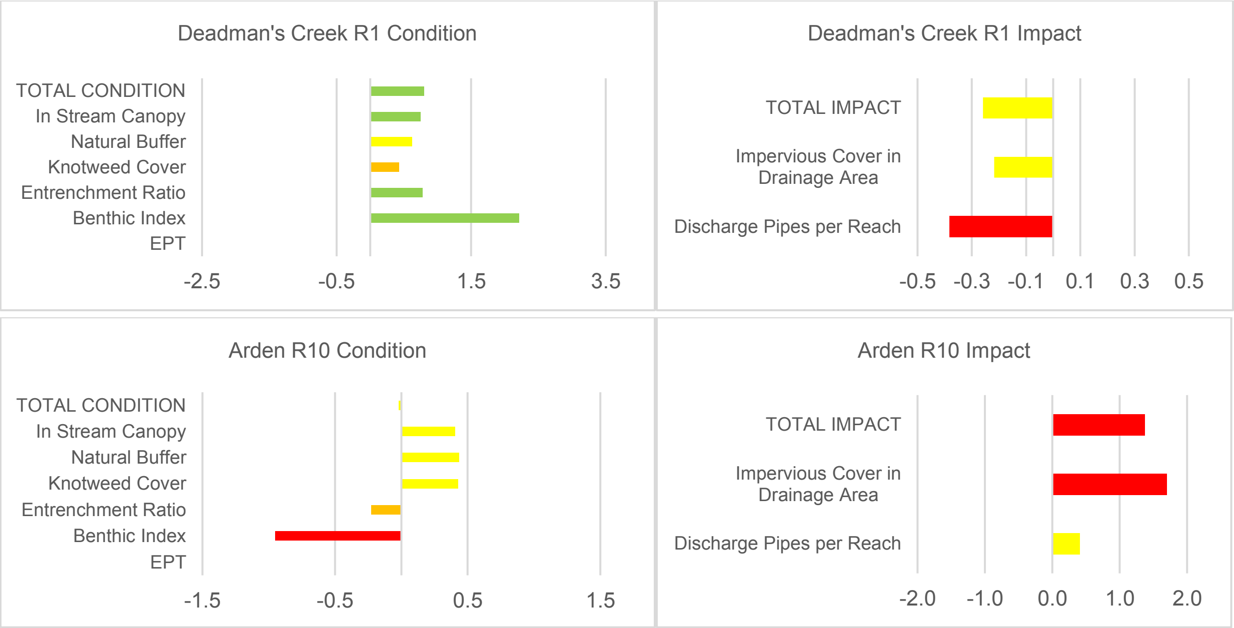

Figure 3. Example of the condition and impact metrics and z-scores for two reaches. Deadman's Creek (R1) is a high-condition stream (characterized by green bars) with relatively low impacts from unmanaged stormwater (yellow bars). Arden Heights (R10) is a low to moderate condition stream (yellow, orange, and red bars) that is highly impacted by unmanaged stormwater (red bars).

Table 3. Stream assessment field and desktop metrics used in informing condition and impact index scores and the function each metric addresses.

Metric	**Condition / Impact**	**Justification**
Entrenchment Ratio	Condition	Indicates down-cutting or incision, which is indicative of erosive flows, and degree of connection of the stream to its floodplain.
Percent Natural Cover in 30m Buffer	Condition	Indicator of riparian vegetation or soil as opposed to impervious surface or lawn that provides little ecological benefit to capture sheet flow.
Percent Knotweed Cover on Banks	Condition	Indicates native plant community quality. Knotweed reduces native plant diversity and is correlated with greater erosion potential and greater disturbance.[34]
Percent In-Stream Canopy Cover	Condition	Shade regulates temperature in the stream for aquatic fauna[35] and provides organic matter used as food and habitat by consumers.[36]
Benthic Index	Condition	Indicates water quality through a value assigned to each taxon.
EPT	Condition	Indicates relative water quality.
Percent Impervious Area in the Drainage Area	Impact	Indicates the potential impacts of urbanization and development on water resources.[37]
Pipe Counts	Impact	Indicates potential stormwater and pollutants entering the stream.[38]

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[34] Arnold, E.G. and L. Toran. 2018. Effects of Bank Vegetation and Incision on Erosion Rates in an Urban Stream. Water 10(4): 482; doi:10.3390/w10040482. http://www.mdpi.com/2073-4441/10/4/482/htm.

[35] Moore, R.D., Spittlehouse, D.L. and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. Journal of the American Water Resources Association 41:813-834.

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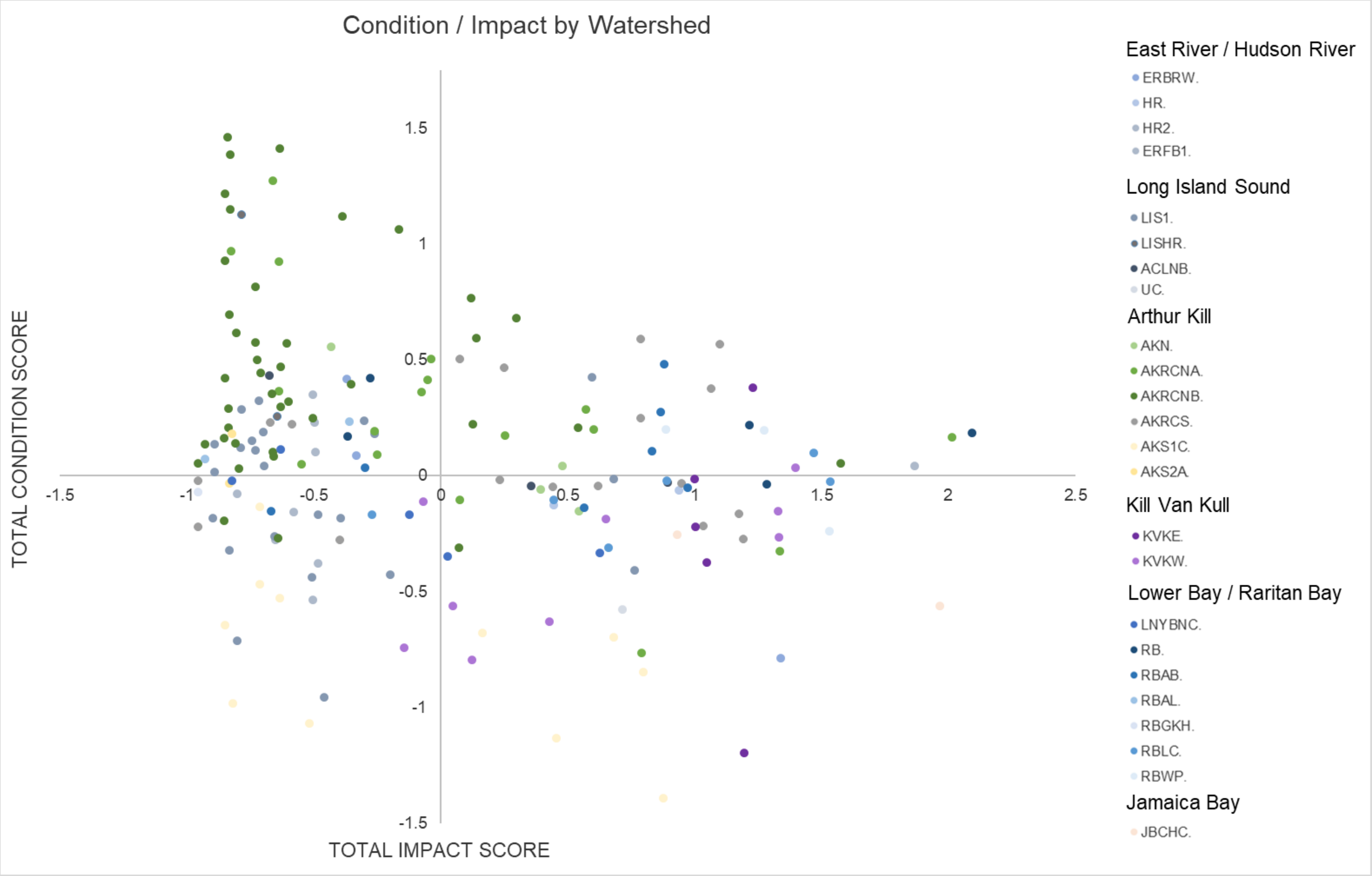

Figure 4. The condition and impact indices for all assessed stream reaches. In total, 181 stream reaches were assessed across 24 watersheds. Each reach score is color coded by watershed. Names and abbreviations for individual watersheds are found in Table 1.

4. Results & Discussion

We assessed a total of 181 reaches within 24 watersheds, for a total of 25.9 stream miles within NYC Parks jurisdiction. Staten Island contained the most assessed reaches (136), while the Bronx and Queens had 38 and 7, respectively. No streams were assessed in Brooklyn and Manhattan, as very few or no streams remain in those boroughs. Stream classification by substrate yielded 91 silt/sand, 53 sand/gravel, 34 gravel/cobble, and three concrete reaches, totaling 10.4, 8.9, 6.4, and 0.3 stream miles respectively.

NYC today has over 112 miles of streams, including perennial and ephemeral streams, historical streams, and newly created channels. Over half of these current stream miles (73 miles) include small headwater channels, drainage swales, ditches, constructed channels, and impoundments (see Appendix B for a glossary of terms and Figure 5 for examples of stream types). Over half of the total stream miles today – 59.9 miles in total – are on NYC Parks property. At least 11.2 miles of the streams mapped today on parkland originate from stormwater runoff, either through gully erosion or as constructed stormwater swales, and many others are stormwater impoundments.

Nearly 85 percent of NYC's historical streams were buried through filling or piping underground to support development (Table 4, Figure 6).[39] Of the streams not buried, the most significant alterations generally include straightening to accommodate transportation infrastructure. Of those remaining reaches, 39 miles of streams maintain their relative historical flow path. Staten Island, the city's least developed borough, retained the most streams with the fewest historical alterations. In contrast, Manhattan, the city's most developed, saw the most extreme loss—only 0.4 miles remaining of its historical 62 miles (Table 4). Queens and Brooklyn both contained relatively few freshwater streams historically, likely because they are dominated by sandy glacial outwash soils with high infiltration rates that naturally absorb rainwater and result in less runoff. Manhattan, the Bronx, and Staten Island are more geologically complex, with more impermeable near-surface bedrock and surficial springs and seeps that concentrate runoff, which can erode to form streams.

Appendix C shows recommendation results by watershed and priority reaches, as well as a table of reach-specific primary and secondary recommended actions.

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[39] Wildlife Conservation Society. 2017. Welikia Project.

Channelized straightened stream (Goodhue Park, SI) Pool-riffle stream (LaTourette Park, SI)

Impoundment (Freshkills, SI) Swale (Pelham Bay Park, Bronx)

Figure 5: Examples of common NYC stream types found during our assessment.

Table 4. Miles of historic, newly mapped, and buried stream miles in each borough.

Linear Miles	Brooklyn	Bronx	Manhattan	Queens	Staten Island	Total
Historical streams	1.0	67.2	61.6	26.8	83.8	240.4
Buried streams	1.0	58.1	61.3	26.1	54.8	201.3
Remaining historical streams	0.0	9.1	0.4	0.7	29.0	39.2
Current streams*	0.8	14.6	0.4	6.7	89.3	111.8

*Note: Current streams include newly mapped streams, such as swales, small headwaters, or channels generated from stormwater drainage, as well as remaining historical streams.

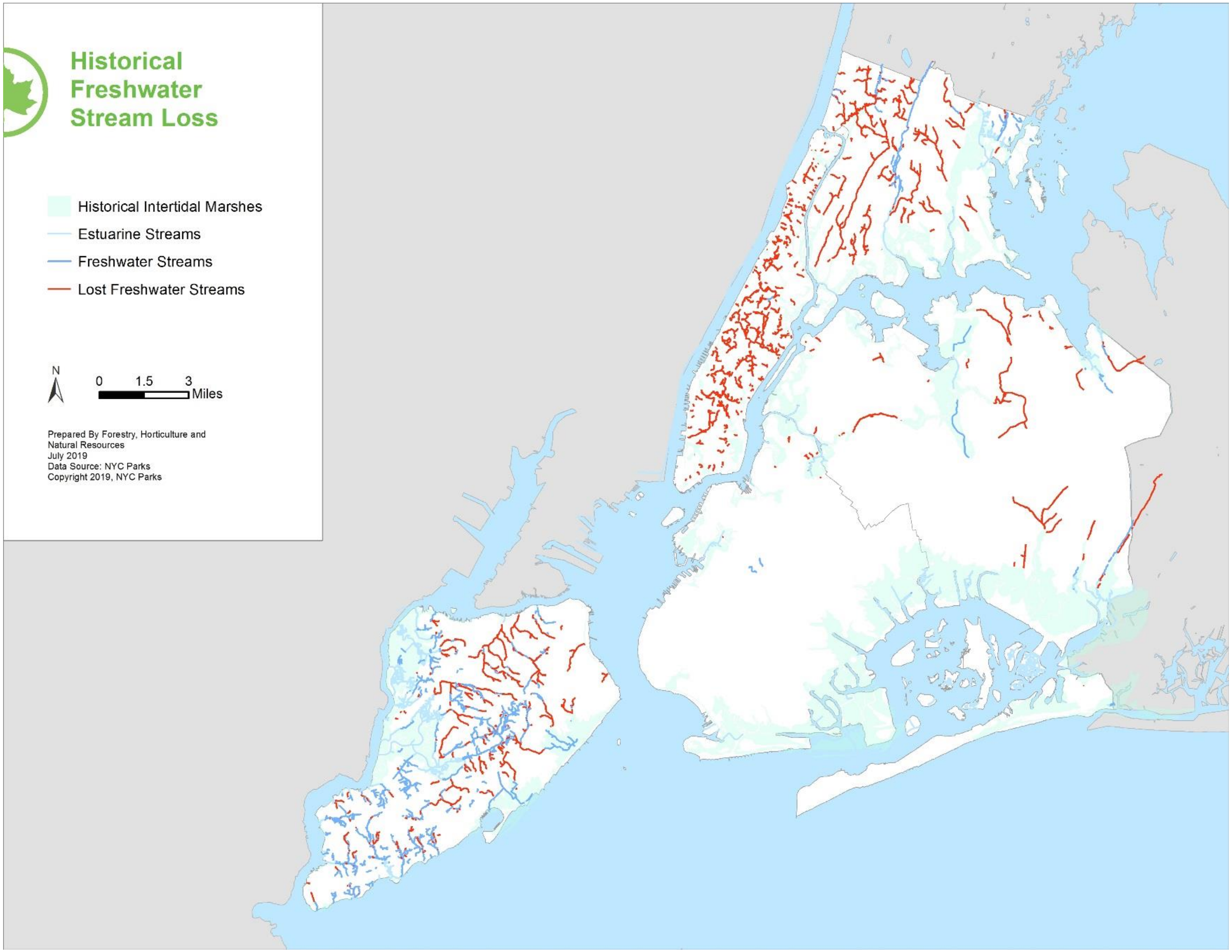

Figure 6. Location and extent of historical freshwater streams in NYC.[38] Estuarine, or tidal, streams were not considered.

4.1 Stream Conditions

Each metric measured informs some element of stream condition, encompassing stream geometry, vegetation, and habitat suitability. Once combined, these metrics reveal a more comprehensive overview of the stream's condition (Figure 3).

Entrenchment Ratio

Entrenchment ratios in our assessed streams ranged from 1.12 to over 2.20. Entrenchment ratios in 13 reaches were less than 1.4, indicating that these reaches were highly eroded, potentially due to high stormwater inputs in their watershed. These reaches were generally not in steep landscapes where down-cutting, or incision, would have occurred naturally due to the slope, or energy gradient. Rather, high volumes of concentrated flows, typically associated with develop, eroded the channel bed, leaving it disconnected from its former floodplain.

Riparian Vegetation

The absence of riparian vegetation cover and poor vegetation structure can indicate bank instability and stormwater and soil disturbance.[40] Given difficulties with species identification across multiple observers, we focused our analysis on Japanese knotweed, an easy-to-identify invasive species. Forty-four assessed reaches contained Japanese knotweed, with coverage ranging between 2.5 percent and 87.5 percent, indicating that the buffer condition is highly variable between reaches. A high presence of knotweed correlates to the highest impact sites and a lack of knotweed corresponds to low stormwater influence. The literature describes how streambank erosion, which can be exacerbated by heavy storm flows, plays a significant role in Japanese knotweed spread.[41]

Canopy cover indicates stream shading and potential temperature regulation. Canopy cover was highly variable, with an average cover of 66 percent and a median of 73 percent. Canopy cover across all reaches ranged from 0 to 92 percent. Where low cover values were found in streams flowing through emergent wetlands, which naturally lack tree canopy, canopy values were removed from the condition index. Where streams flowed through lawn dominated golf courses lacking canopy that may otherwise exist, lower cover values remained in the index.

The percent cover derived from the landscape level (natural buffer) metric allowed us to evaluate the varying potential for vegetation to function as a buffer across reaches. Natural buffers serve to slow and infiltrate runoff prior to reaching the stream, reducing the changes for sediment and pollutants to enter the stream. The mean cover for the natural buffer was 77 percent, and the median value was 92 percent, meaning many of our streams contain a largely natural buffer within 100 feet on either side of the stream channel.

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[40] Arnold, E.G. and L. Toran. 2018. Effects of Bank Vegetation and Incision on Erosion Rates in an Urban Stream. Water 10(4): 482; doi:10.3390/w10040482. http://www.mdpi.com/2073-4441/10/4/482/htm.

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Headwater Macroinvertebrate Field Evaluation Index (HMFEI)

Benthic indices served as a proxy for water quality and overall stream disturbance across a variety of stream types. Using the HMFEI, we summed pre-determined scores assigned to each taxon to calculate the index value. Higher scores indicate taxa found in higher condition streams. Overall index scores for each reach ranged from 0 to 21, with the median of 2 and a mean of 3.85. The Ohio EPA HMFEI rates streams across a poor, fair, good, and excellent scale; based on the required scores for these classifications, our streams range from poor to good condition, and do not include any in excellent condition (Table 5).

While the HMFEI rates over 80 percent of our streams as poor condition, those impacts vary based on substrate, which we used to classify streams. Gravel/cobble streams had the highest proportion of moderately condition streams; the other substrate sizes primarily showed poor condition. Appendix A contains protocol sheets for benthic invertebrates.

Table 5. Percent of assessed HMFEI stream condition by substrate size category.

Substrate	**HMFEI Condition Level by Stream Reach**		
	Poor (%)	**Fair (%)**	**Good (%)**
Gravel/cobble	71	26	3
Sand/gravel	91	4	4
Silt/Sand	91	7	1

Ephemeroptera, Plecoptera, Trichoptera (EPT) Index

We used EPT indices as an additive metric to identify and differentiate between our highest quality streams. These insect orders have a low pollution tolerance and therefore represent a proxy for high water quality. We calculated the EPT index as the total number of families belonging to the three orders. We documented Ephemoroptera (mayflies), Plecoptera (stoneflies), or Trichoptera (caddisflies) in only 29 reaches (only 16 percent of assessed reaches) with EPT indices ranging from 0 to 3 with a median of 0.25. This result indicates that our streams are generally severely impacted.

The New York State benthic macroinvertebrate assessment protocol considers streams with 0-1 EPT species severely impacted, 2-5 moderately impacted, 6-10 slightly impacted, and >10 non-impacted. However, our EPT cannot be directly compared to the NYS protocol because we conducted a more rapid sample; rather than counting the number of EPT species in a 100-organism subsample collected in the field and identified in the lab, we counted each organism we found by sorting in the field and bringing those we could not identify back to the lab for further analysis. Our EPT values may be particularly low due to sampling outside the ideal seasonal window (August and September rather than our sampling in June and July) and are expected to be low given our urban context. In several instances, not all Trichoptera in a sample were identified to family, necessitating the assumption that the unidentified caddisfly might fall into the same family as one of the identified caddisflies, thus potentially lowering our count.

Because we sampled a smaller area, we did not always collect 100 organisms in each sample, which in many cases would have been impossible. In addition, we identified Trichoptera to family, not species. Thus, our counts of EPT taxa are likely lower than they would be if we identified caddisflies to species.

LaTourette Reach 17 and Deadman's Creek Reach 2, both in the Staten Island Greenbelt, contained the highest number of EPT families (3). Four reaches – LaTourette North Reach 5, Deadman's Creek Reach 1 (also in the Greenbelt), Goodhue Reach 2, and Clove Lakes Reach 1 (on the north shore of Staten Island) – fell within the "moderately impacted" category. Only four reaches in the Bronx and one in Queens contained any EPT organisms.

In the Staten Island Greenbelt, we found three reaches containing stoneflies, considered the least tolerant to pollution of the three EPT orders, and three separate reaches containing Ephemoroptera. We documented Trichoptera in 26 reaches representing five families (Hydropsychidae, Lepidostomatidae, Limnephilidae, Philopotamidae, and Thremmatidae). Hydropsychidae was most common and is often associated with reaches downstream of dams, such as the Clove Lakes reaches where we found hundreds. Of the families we found, Lepidostomatidae is the least tolerant of pollution; we identified this family at only three reaches, all in the Greenbelt.

When the mean EPT Family Richness, or mean number of EPT families, is calculated separately for streams in the three particle-size categories, streams with intermediate particle size substrate (sand/gravel) contain the most pollution intolerant organisms, and the fine-substrate (silt/sand) streams the fewest (Table 6). Cobble/gravel streams, against expectations, did not have the highest EPT Family Richness. Looking at the individual taxa included in the EPT index, we see that Ephemeroptera and Plecoptera follow the predicted trend of greatest frequency (percent of reaches occupied) in gravel/cobble streams, decreasing with particle size (Table 7). As expected, Trichoptera frequency did not vary much with substrate size, because Trichoptera vary more in their pollution tolerance than the two other EPT orders.

Table 6. Average HMFEI and EPT family richness values for streams by substrate size category.

Substrate	Average Index Values Per Reach	
	HMFEI	**EPT Family Richness**
Gravel/cobble	6.1	0.3
Sand/gravel	6.0	0.4
Silt/Sand	5.9	0.2

Sensitive Benthic Invertebrates Other Than EPT

We found invertebrates from four families that are considered intolerant of organic pollution (HMFEI index value = 3). As with the EPT organisms, Staten Island contains most of the reaches with these taxa. The least tolerant of these are the larvae of the Coleoptera family Psephenidae (water pennies) and larvae of the Megaloptera family Corydalidae (hellgramites).

We found Psephenidae in three reaches, all on Staten Island, in LaTourette, Allison Pond, and Deere parks. Two reaches, one in LaTourette Park and one in Long Pond Park, contained Corydalidae. The Elmidae (riffle beetles) are slightly more tolerant than the Psephenidae and Corydalidae, but again were found only on Staten Island, in four reaches in the Greenbelt and three in southern Staten Island. The Lymnaeidae (pond snails), the most tolerant of the taxa rating 3 on the HMFEI scale, were found in five reaches in the Greenbelt and one reach in Pelham Park in the Bronx. The frequencies of these taxa in streams categorized by substrate size do not follow expected patterns, where less tolerant organisms are generally found in gravel/cobble streams (Table 7).

Salamanders

We found stream-breeding salamander species in 14 of 181 reaches sampled, all but two in the Staten Island Greenbelt. The most common species was the northern two-lined salamander, *Eurycea bislineata*, found in 11 reaches. Although all stream salamander species are sensitive to siltation, canopy loss, warming, and organic pollution,[42] *E. bislineata* is least affected by these stressors. The two streams outside of Staten Island, Azalea Brook Reach 1 in the New York Botanical Garden in the Bronx and Tulip Creek Reach 1 in Alley Pond Park in Queens, had only this species. The northern dusky salamander, *Desmognathus fuscus*, is considered less tolerant, but also is typical to small streams and seeps. We only found this species in the Great Swamp Reach 4 in the Greenbelt, a low-lying area with numerous seeps. The northern red salamander, *Pseudotriton ruber*, the least tolerant of the three species found in this study, occurred in two reaches, both in LaTourette Park in the Greenbelt. We found salamanders in approximately equal frequencies in cobble/gravel and gravel/sand streams, but less often in silt/sand streams, as expected (Table 7). Through previous studies we know that stream-breeding salamanders are present in many of the other reaches we assessed,[43] even though we did not locate them through this rapid sampling.

Table 7. Percent of streams occupied by sensitive taxa, by substrate size category.

Substrate	**Percent of Stream Reaches with Taxon**							
	Salamander	**Corydalidae**	**Elmidae**	**Ephemeroptera**	**Lymnaeidae**	**Plecoptera**	**Psephenidae**	**Trichoptera**
Gravel /Cobble	11.1	0	3.7	**3.7**	7.4	3.7	0	18.5
Sand /Gravel	12.2	0	7.3	**2.4**	0	2.4	4.9	19.5
Silt / Sand	8	2.7	4	**1.3**	4	1.3	1.3	17.3

Condition Index

We found the highest quality streams in the Staten Island Greenbelt, within the Arthur Kill – Richmond Creek North b watershed (Figure 4). This watershed is the least developed in the

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[42] Orser, P.N. and D.J. Shure. 1972. Effects of urbanization on the salamander Desmognathus fuscus fuscus. Ecology 53:1148-1154.

[43] NYC Parks, unpublished data.

City; streams generally have a dense canopy, vegetated riparian buffer, minimal bank erosion and invasive plant cover, and the most pollution sensitive benthic organisms. All three sediment types (silt/sand, sand/gravel, and gravel/cobble) are found in Greenbelt streams, hosting a variety of benthic organisms.

One of the poorest condition streams was also found in Staten Island, at the South Shore Golf Course, within the Arthur Kill South 1c watershed. This stream's scores were primarily reduced by the high presence of Japanese knotweed and few benthic invertebrates. Pelham Bay Park in the Long Island Sound-Hutchinson River watershed also contains some poor condition reaches, due to inadequate riparian buffers and excessive stormwater inputs. Golf courses predominantly surround these reaches. Highly developed watersheds, such as the Kill Van Kull and Arthur Kill Richmond Creek South, also contained moderate to low-condition reaches due to Japanese knotweed, poor condition natural buffers, and unmanaged stormwater from the surrounding area. The impacts of impervious cover are discussed further in Section 4.2.

Overall silt/sand bottom stream reaches had the highest condition score (average = 0.23, n=91), followed closely by gravel/cobble (average = 0.20, n=34). Sand/gravel bottom streams had the lowest condition score (average = 0.10, n=53).

A non-metric multidimensional (NMDS) analysis indicated that the highest condition streams have a native natural buffer along the banks with dense canopy cover. The high condition score streams are more tightly clustered within the NMDS analysis than the medium- and low-condition streams. This result is not surprising, given that increasing urbanization may be associated with an increasing number and intensity of stressors.

4.2 Stream Impacts

Potential Stormwater Impacts

The potential for stormwater impacts varied across stream reaches. Impervious surface cover percentages within the drainage area ranged from 0 percent in small headwater reaches (Arden R17) to 64 percent in the densest neighborhood drainage areas (Conference House R1; Figure 7). The mean value was 18 percent and the median was 10 percent. The amount of effective impervious area within a watershed is correlated with stream impacts due to the increased volume and rate of discharge into the stream and the increased pollutant load. As a stream's watershed becomes increasingly developed, the macroinvertebrate populations most sensitive to water quality disappear, resulting in more pollution-tolerant species and decreasing biotic indices. Studies suggest that impervious cover between 10 percent and 20 percent in the watershed begins to cause stream degradation and reduced biotic diversity.[44] The impervious cover in the watersheds surrounding most of NYC's streams exceeds these thresholds.

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[44] U.S. Environmental Protection Agency Office of Water Recovery Potential Screening. 2011. Recovery Potential Metrics Summary Form – Watershed Percent Impervious Cover. https://www.epa.gov/sites/production/files/2015-11/documents/rp2wshedimperv1109.pdf.

The number of stormwater pipes observed ranged between 0 and 18 per reach. Only 76 of 181 (42 percent) reaches had stormwater pipes observed upstream of the reach. Since streams often originate outside of parkland, we did not count pipes outside of parkland that contribute to condition downstream, unless evident on infrastructure records; as a result, these counts likely underrepresent potential stormwater impacts from pipes. We found the most pipes in Pelham Bay Park; however, many are for landscape drainage for the golf course versus storm sewer outfalls. We did not investigate the discharge volume or size of pipes investigated. Therefore, our analysis is limited to assessing the potential contribution of stormwater from in-reach pipes but does not evaluate the actual magnitude of stormwater inputs.

Impact Index

Raritan Bay – Wolfes Pond, Kill Van Kull East, and Raritan Bay watersheds contained the highest impact reaches. These watersheds are highly developed, with 41 percent, 43 percent, and 64 percent impervious area, respectively. Conversely, the Staten Island Greenbelt within the Arthur Kill – Richmond Creek North b watershed, which is the least developed watershed, contained the lowest impact reaches and correspond to the highest condition streams.

The streams classified as sand/gravel had the highest average impact scores (0.14), followed by silt/sand (0.09) and gravel/cobble (0.07). In these stream types, finer sediments are most likely to be transported and deposited on the channel bed during storm flows. Embeddedness (or the amount of fine sediments on the stream bed surrounding larger cobbles and boulders) can be used to inform condition, as it may be a proxy for water and habitat quality;[45] however with the time and resources available, we were unable to assess this characteristic.

Stormwater Impacts to Connected Wetlands

Based on GIS analyses, approximately 1,200 acres of National Wetlands Inventory (NWI) mapped wetlands are connected to streams throughout NYC. Of those wetlands, approximately 663 acres receive stormwater inputs based on their connection to stormwater impacted streams and may be vulnerable to further degradation and development in their watersheds (Table 8).

Table 8. Total acres of NWI mapped wetlands in NYC with potential to be impacted by stormwater.

NWI Wetland Type	Acres Receiving Stormwater	Percent Receiving Stormwater	Total Acres
Freshwater Emergent Wetland	156	38%	407
Freshwater Forested/Shrub Wetland	210	29%	718
Freshwater Pond	115	27%	421
Lake	163	36%	449
Riverine	20	90%	22
TOTAL	**663**		**2,017**

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[45] Style, T. and C. Fischenich. 2002. Techniques for Measuring Substrate Embeddedness. ERDC TN-EMRRP-SR-36. https://sav.el.erdc.dren.mil/elpubs/pdf/sr36.pdf.

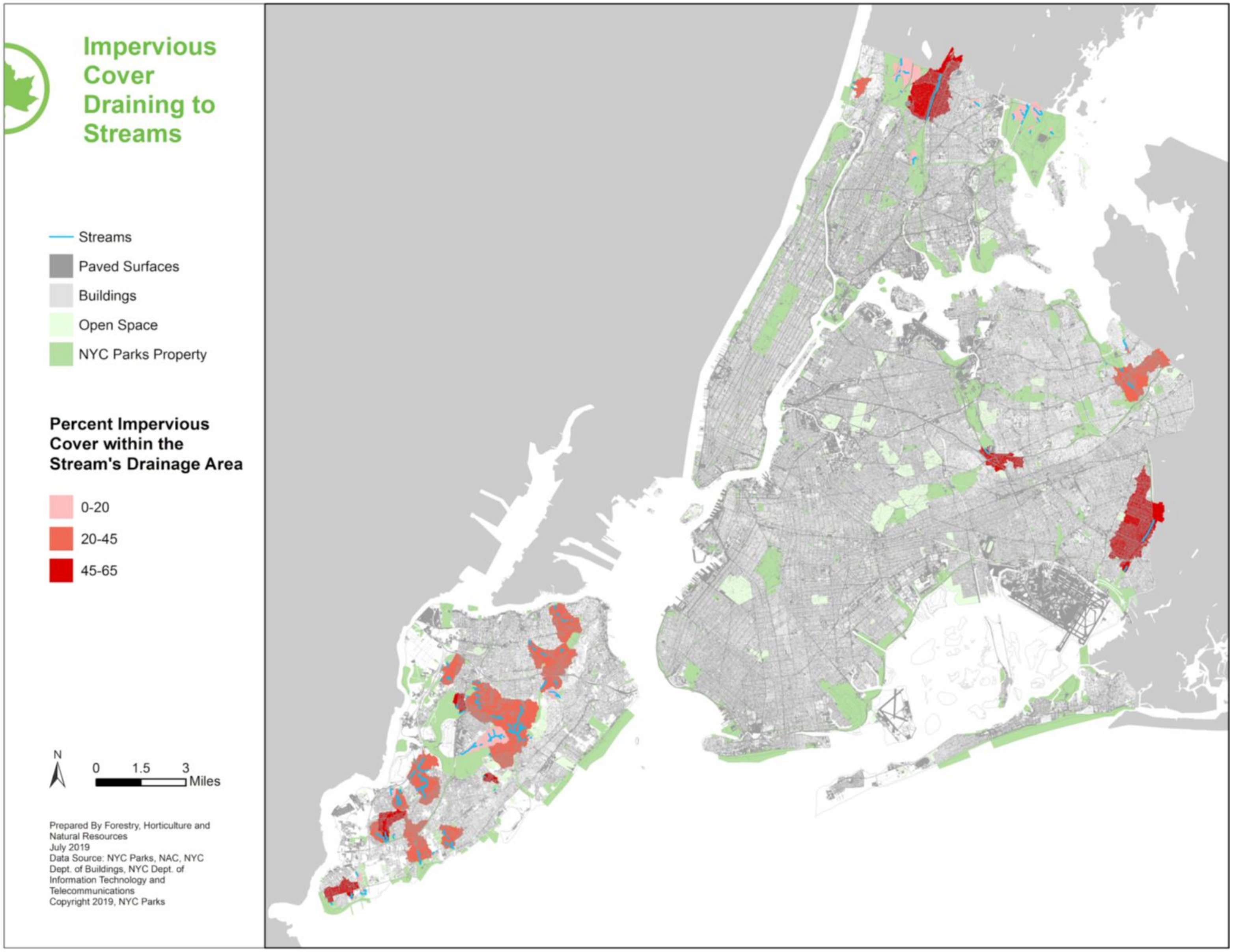


Figure 7. Percent impervious surface in the drainage area for individual reaches.

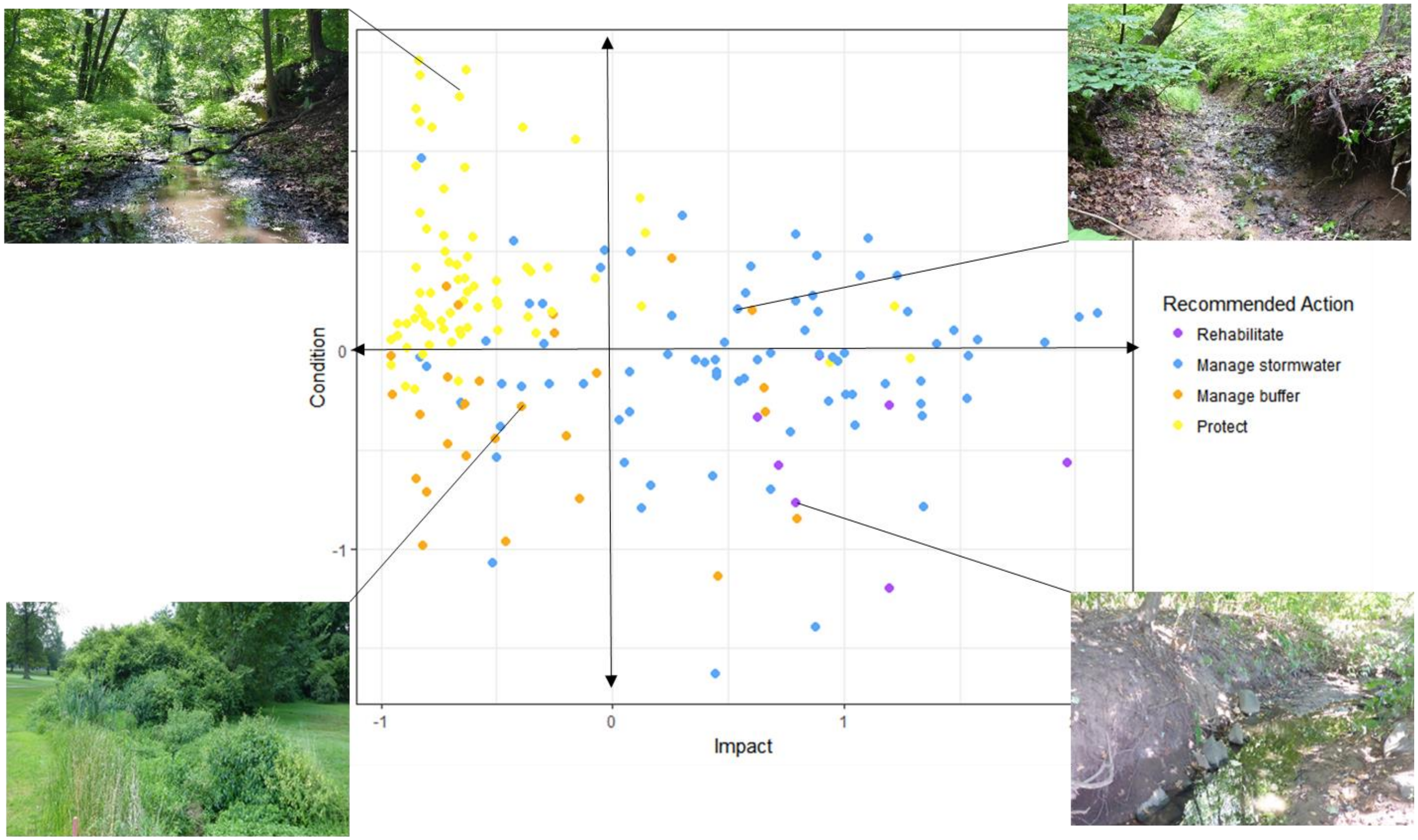
5. A Framework for Stream Protection and Management in NYC

Plotting stream reach conditions against impacts (Figure 4 and Figure 8) provided a framework for proposing overarching management strategies for each stream reach. Generally, reaches with high condition and low impact scores represent those with the highest priority for protection. Reaches with low condition and high impact scores may require the highest level of intervention to improve stream conditions and reduce potential impacts. Because multiple factors influence condition and impact, and multiple actions may be necessary to improve condition, we further evaluated reaches based on individual metrics to propose management actions for each reach. Conceptually, we lumped these actions into four categories: Protect; Manage Stormwater; Manage Buffer; and Rehabilitate or Reconstruct (Figure 9).

Management actions assigned to each reach aim at improving condition and reducing impacts. We prioritized actions to protect existing high-quality habitat in a watershed and where stream conditions are good to moderate. We also prioritized actions based on feasibility and cost-effectiveness and considered the context of adjacent land use. For example, where streams have been straightened and confined for road construction, the opportunity to expand stream buffers may be limited. Table 9 provides a summary of the extent of recommendations and priorities for NYC's streams.

Table 9. Length of total and priority stream length for each recommended management action for streams assessed in NYC Parks

Management Action	Total stream length assessed (mi)	Percent of total length	Total # of reaches assessed	Percent of total # of reaches	Priority reach length (mi)
Protect	7.9	30.4%	67	37.0%	2.1
Manage buffer	3.4	13.3%	28	15.5%	1.6
Manage stormwater	13.1	50.5%	78	43.1%	1.6
Rehabilitate	1.4	5.3%	7	3.9%	1.2
In-stream structures	0.1	0.4%	1	0.6%	0.7
TOTAL	**25.9**		**181**		**7.2**



Higher Condition / Lower Impact These streams represent those with the highest priority for protection, since they are the most likely to be self-sustaining and provide important ecosystem services in the long-term.

Higher Condition / Higher Impact These streams are in moderate to high condition, but experience high impact from stormwater. This classification provides opportunities for stormwater management through green infrastructure or stormwater source control.

Lower Condition / Lower Impact These streams experience lower impacts from stormwater, but tend to have insufficient canopy cover or buffer, or an abundance of invasive species. They require management of the buffer to restore stream condition.

Lower Condition / Higher Impact These streams are in poor condition and experience large effects of stormwater inputs. The highest level of intervention to improve viability, likely involving partial stream rehabilitation or reconstruction; however in these reaches, full recovery may never be possible.

Figure 8. Management actions for each stream reach based on their condition and impact scores. Each dot represents an analyzed stream reach, and the figure shows how the conceptual model was applied to actual stream reach data.

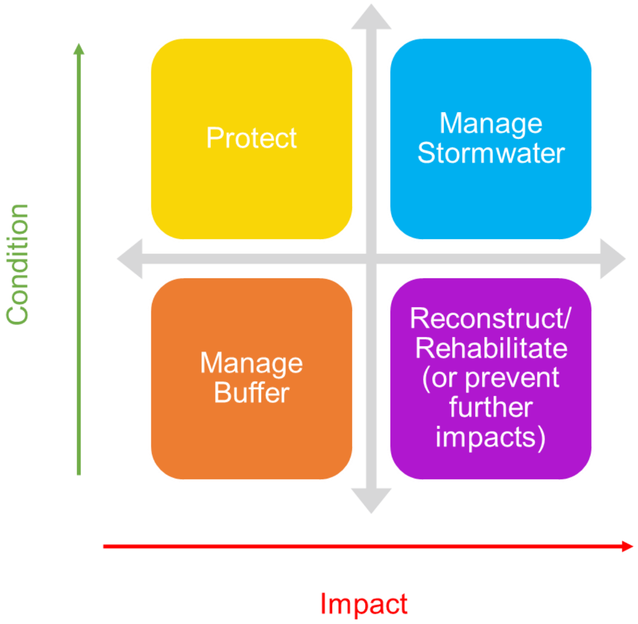


Figure 9. Conceptual model for management actions for NYC's streams.

5.1 Management Strategies

To implement this framework citywide across varying conditions, impacts, needs, and priorities, we developed a tiered approach to address impacts at multiple scales – the stream reach, the stream buffer, and the watershed/landscape. Each scale requires a different implementation strategy and management actions. Priority projects identified include sites with high condition, resources in need of protection, and feasibility of project implementation.

Strategy 1: Protect and Restore Our Existing Streams

Action 1: Protect High-Condition Streams from Impacts

While NYC Parks aims to protect all streams from impact or degradation, low-impact/high-condition streams are the highest priority for protection (Table 10), since they are the most likely to provide the highest quality habitat. These streams are ideal reference sites for restoration and typically occur in the least-developed watersheds. Management interventions may still be required for long-term protection and management but improving and sustaining existing functions is the highest priority. Forested parkland typically dominates the drainage areas for these streams; however, they may still be at risk of stormwater impacts from surrounding development. Headwaters are especially vulnerable where regulations are limited. In order to reduce risk, we must work with regulatory agencies to ensure regulations are enforced, including those for protection of wetlands and waterways and new regulations for managing stormwater in separately sewered drainage areas. To maximize protections, new policies and interagency coordination may be necessary. For example, in priority watersheds, such as Arthur Kill-Richmond Creek North b, we must restrict effective impervious area expansion and ensure green infrastructure is sufficient to reduce discharge stormwater from high frequency (e.g. less than 1-year recurrence interval) storms.

Table 10. Highest priority reaches and watersheds for protection.

Watershed	Reach Code	Reach Length (mi)	Drainage Area (mi^2)	Percent Impervious Cover in Drainage Area
AKRCNA	GreatSwamp.R4	0.22	0.11	6.9%
AKRCNA	Willowbrook.R1	0.16	0.01	6.4%
AKRCNB	BucksHollow.R2	0.11	0.11	7.0%
AKRCNB	DeadmansCreek.R1	0.22	0.46	11.9%
AKRCNB	LaTouretteNorth.R17	0.06	0.35	2.7%
AKRCNB	DeadmansCreek.R4	0.07	0.29	11.5%
AKRCNB	LaTouretteNorth.R5	0.03	0.31	2.5%
AKRCNB	LaTouretteNorth.R7	0.11	0.34	2.7%
AKRCNB	LaTouretteSouth.R1	0.17	0.61	3.0%
ERBRW	AzaleaBrook.R1	0.19	0.06	11.6%
KVKW	CloveLakes.R1	0.18	1.46	35.9%
LIS1	PelhamNorth.R4	0.28	0.14	3.0%
LISHR	RattlesnakeCreek.R2	0.07	0.03	3.8%
RBWP	WolfesPond.R3	0.27	0.92	40.8%
TOTAL		**2.14**	**5.2**	

Action 2: Reconstruct or Rehabilitate Reaches in Poor Condition

High-impact/low-condition reaches require the highest level of intervention to improve aesthetics and ecological function (Table 11). This may involve partial rehabilitation or reconstruction of the stream, often to manage or reduce impacts of heavy stormwater inputs.[46] These types of projects would typically be completed through partnerships with NYC Department of Environmental Protection (NYC DEP) alongside upgrades to storm sewers or other stormwater management projects.

In high-impact/low-condition reaches, ecological and geomorphic functions may be so degraded that upstream green infrastructure may be insufficient to improve functions, particularly for habitat provisioning. For these reaches, site-specific objectives must be defined, as full recovery

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[46] U.S. Environmental Protection Agency Office of Water Recovery Potential Screening. 2011. Recovery Potential Metrics Summary Form – Watershed Percent Impervious Cover. https://www.epa.gov/sites/production/files/2015-11/documents/rp2wshedimperv1109.pdf.

may never be possible.[47,48] For example, objectives for rehabilitation may be to stabilize and revegetate denuded banks, introduce a grade control structure to prevent future channel incision, or establish native woody species on a stream bank.

In reaches where there is limited prospect of improving geomorphic or ecological functions, complete reconstruction of the channel might be more effective in helping to improve downstream conditions rather than achieving the highest quality conditions within the reach itself. For example, a highly degraded or incised reach might be reconstructed to resist erosion, slow stormwater, and meet a social goal of regrading a potentially dangerous gully that could undermine adjacent property. A more extreme example is where a reach could be a candidate for reconstruction as a stormwater impoundment, in order to manage stormwater or protect downstream resources.[49] This would be a priority where downstream flooding must be managed, and other valuable functions may never be re-attained through restoration.

Table 11. Priority reaches to reconstruct or rehabilitate.

Watershed	Reach Code	Reach Length (mi)
ACLNB	AlleyCreek.R6	0.16
AKRCNA	Willowbrook.R5	0.12
AKRCS	ArdenWoods.R10	0.33
KVKE	Snug.R2	0.13
LNYBNC	ReedsBasket.R0	0.08
UC	Gabblers.R1	0.35
TOTAL		**1.17**

Action 3: Improve Habitat Complexity

In moderate-impact/moderate-condition reaches, where structural complexity within the streambed is low, in-stream structures such as large-woody debris or boulders may improve habitat complexity. These structures increase hydraulic complexity and roughness and provide refuge for fish and help increase oxygenation. Such interventions may be suitable even where stormwater impacts vary (Table 12).

Improving habitat complexity is rarely a sufficient action to improve stream conditions on its own. Instead, improving complexity should usually be considered in conjunction with other actions. In the long-term, the management of a healthy riparian corridor can contribute to improving habitat complexity by allowing trees to mature and fall into the stream corridor where

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[47] Walsh, C.J., Fletcher, T.D., and A.R. Ladson. 2005. Journal of the North American Benthological Society 24(3):690-705.

[48] Paul, M.J. and J.L. Meyer. 2001. Streams in the urban landscape. Annual Review of Ecology and Systematics 32:333-365.

[49] Pehek, E. and R. Mazor. 2008. Effects of a Stormwater Impoundment on Streamside Salamander Populations on Staten Island, New York. Herpetological Conservation 3:85-93.

they become large woody debris and create habitat naturally. As discussed below, a diverse native vegetation structure can also contribute to in-stream habitat complexity.

Table 12. Priority reaches to install in-stream structures.

Watershed	**Reach Code**	**Reach Length (mi)**
AKRCNB	LaTouretteSouth.R1	0.17
AKRCNB	LaTouretteSouth.R6	0.12
RBLC	Bloomingdale.R5	0.22
RBLC	Bloomingdale.R6	0.21
TOTAL		**0.72**

Action 4: Improve Hydrologic and Habitat Connectivity

Transportation infrastructure can lead to fragmented ecosystems by impeding and degrading their function. Freshwater stream and wetland systems are particularly vulnerable to such impacts, as development increases stormwater and intense rain events become more frequent. A recent study of culverts within the Hudson River Estuary watershed shows that 42 percent of culverts in the areas will be at greater risk of flooding under future climate change conditions.[50] Examples of undersized or improperly maintained culverts in NYC are shown in Figure 10. As increasing storm intensity and flood frequency present an emerging threat throughout NYC, communities look to road raising and culvert improvements to mitigate flooding. Infrastructure projects that create or extend barriers in the landscape should include ecologically and hydrologically sensitive design features. Appropriately sizing culverts to accommodate flood flows and including eco-passageways in designs facilitates wildlife movement and hydrologic connectivity under roadways, rail lines, and berms.

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[50] Truhlar, A.M., Marjerson, R.D., Gold, D.F., Watkins, L., Archibald, J.A., Lung, M.E., Meyer, A., and M.T. Walter. 2020. Rapid Remote Assessment of Culvert Flooding Risk. J. Sustainability Water Build Environ. 6(2): 06020001.

a) Constricted culvert at Clove Lakes

b) Blocked culvert in Van Cortlandt

c) Broken culvert at LaTourette

d) Undersized culvert causing flooding at Shore Road in the Bronx.

Figure 10. Examples of issues caused by inadequately sized culverts throughout NYC.

Strategy 2: Manage and Restore Buffers

Action 1: Increase the Width of Native Riparian Buffers

In low- to moderate-condition/low- to moderate-impact reaches with poor buffers (e.g., too small, dominated by invasive species), increasing the area and structure of native vegetation surrounding the stream can improve conditions. Increased vegetation cover and structural complexity creates roughness and slows runoff, allowing stormwater to infiltrate into the soil before reaching the stream. This process also reduces overland sheet flow carrying sediment and pollutants into the channel that could impact sensitive species. Reaches in need of this intervention are generally in golf courses or active use parkland with lawns and low to moderate canopy cover. These sites would benefit from active management over several years to restore a riparian forest through planting and managing invasive species while young plants establish.

Species composition of buffers varies in these reaches. Where native species are present, reduced mowing may contribute significantly to improving the buffer condition (Action 1A; Table 13); however, where invasive species or degraded lawn dominate, more intensive management may be necessary (Action 1B). Priority reaches contain thriving benthic communities and moderate stormwater inputs (Table 13). One priority reach contains rare stream salamanders and native emergent wetland vegetation at Silver Lake Golf Course. This observation presents an opportunity to work with golf course managers to protect amphibian populations.

Action 2: Restore or Improve Riparian Mid-Story Condition

In low-condition streams lacking a native mid-story, planting native shrubs and young trees can improve the condition of the riparian buffer. The midstory is a critical component of forest structure, supporting the next generation of forest. NYC forests generally contain a high percentage of native canopy trees, but native plants are less prevalent in the mid- and understory layers and canopy regeneration is often poor.[51] We recommend this intervention where canopy is present, but the midstory is largely absent, or dominated by invasive species. We differentiate between midstory restoration and management based on invasive species prevalence; management involves targeted invasive plant removals to allow for natural regeneration (Action 2A), whereas restoration requires significant invasive plant removal and replanting (Action 2B). Both actions utilize NYC Parks crews and volunteers, as appropriate.

Action 3: Manage Invasive Pests and Deer within the Riparian Buffer

Sites requiring larger-scale interventions (Action 3) may need contractors to clear extensive invasive species or restore native forests from a lawn with no canopy. In low-condition streams with variable impacts, a priority action is to manage invasive species within the riparian buffer. Actions in these streams requires large-scale capital projects using contractors to restore buffers or manage pests that threaten native trees, such as deer or emerald ash borer (EAB).

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[51] Pregitzer, C.C., Forgione, H.M., King, K.L., Charlop-Powers, S. and J. Greenfeld. 2018. Forest Management Framework for New York City. Natural Areas Conservancy, New York, NY.

Contractors may be necessary pervasive invasive plants like Japanese knotweed dominate or can easily thrive in the absence of native canopy. In many instances, successful buffer restoration may also require stormwater management or improvements to instream habitat. For example, where flashy (fast, high intensity) storm flows carry heavy sediment loads, knotweed establishment is facilitated by frequent disturbance. In this instance, the source of the problem—heavy sediment laden storm flows—must be addressed to affect sustained change. This is especially true along the Bronx River and in the brackish reaches of Harbor Brook.

Managing a healthy forest canopy, through invasive pest management, can also help protect stream condition. For example, management of emerald ash borer (EAB), which infests and kills ash trees, is critical since ash is a keystone species for many forested freshwater wetlands and floodplain forests. To date, EAB infestations have been confirmed in the natural areas of Staten Island and along the Bronx River corridor. Analysis of forest composition combined with widespread infestations in street trees on Staten Island and southeast Queens indicate many forests on Staten Island are at risk from the impacts of EAB infestations.

Deer herbivory management is also critically related to stream riparian condition, as deer tend to browse the midstory and seedling layer, reducing vegetation which stabilizes streambanks, traps sediment, and provides critical shade and habitat along streams. Deer impacts are especially evident on Staten Island (Arden Woods, Willowbrook) and the Bronx (Pelham Bay Park), where the impacts of deer need to be controlled to assure forest regeneration.[52]

Table 13. Priority buffer management reaches and associated actions.

Watershed	Reach Code	Action	Reach Length (mi)
AKRCNA	Willowbrook.R2	2A	0.06
AKRCNB	RichmondCreek.R1	2A	0.24
AKRCS	ArdenWoods.R21	2A	0.02
AKRCS	ArdenWoods.R22	2A	0.10
AKRCS	ArdenWoods.R23	2B	0.29
AKRCS	ArdenWoods.R8	2A	0.05
KVKE	Allison.R1	2A	0.14
KVKE	Goodhue.R1	2B	0.04
KVKE	Goodhue.R2	2B	0.06
KVKW	CloveLakes.R3	3	0.19
KVKW	SilverLake.R0	1A	0.06
LIS1	ShoreRdSouth.R1	2B	0.05

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[52] Pregitzer, C.C., Forgione, H.M., King, K.L., Charlop-Powers, S. and J. Greenfeld. 2018. Forest Management Framework for New York City. Natural Areas Conservancy, New York, NY

HR2	Tibbets.R4	2B	0.26
TOTAL			**1.56**

Strategy 3: Restore Watershed Hydrology in the Landscape

Action 1: Construct Green Infrastructure to Manage Stormwater

In high-impact/moderate- to high-condition reaches, green infrastructure, including bioswales, rain gardens, or subsurface detention systems, can be utilized to detain and treat stormwater before it reaches downstream waterways (Table 14). Heavy storm flows can erode banks, widen streams, and carry pollutants, including fertilizer, oil, and other contaminants directly into our streams. Constructing green infrastructure in or near parking lots, along right of ways, or even in lawns adjacent to streams may help detain stormwater and reduce the velocity and level of contaminants in storm flows entering streams. Green infrastructure is particularly critical in recently developed watersheds, such as Bloomingdale, where heavy sedimentation is visible, but ecological conditions have not yet been severely degraded. Over time, unmanaged stormwater is likely to degrade the stream condition and reduce function.[53] Green infrastructure is also a strategy where protecting downstream habitat is critical, such as in Deadman's Creek.

Green infrastructure can be installed at different scales to reduce stormwater runoff. At the reach-scale, a few green infrastructure practices may be used to reduce localized impacts to an individual reach or protect downstream habitat. For example, rain gardens could be installed at locations where they can capture larger impervious areas at once, such as parking lots or large sections of road where watershed-scale disturbances are not pervasive. We recommend this strategy at five sites on or adjacent to parkland in the watersheds draining to three streams (Table 14). At these sites, each rain garden would be designed to mitigate the full volume of stormwater generated by the site's impervious area during a 1.25" rain event.[54]

Across a watershed, green infrastructure could be used to artificially restore historical hydrology and include building out, or retrofitting, neighborhoods using a wide number and range of practices, including bioretention systems such as rain gardens and bioswales throughout the right-of-way of neighborhood streets. We recommend neighborhood build outs in the watersheds of two priority stream reaches with significant upstream development: Arden Woods and Bloomingdale (Table 14). We estimate two right-of-way rain gardens can be installed per block in the watersheds draining to these reaches, accounting for some existing tree conflicts.

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[53] Novotny, V., Bartosova, A., O'Reilly, N., and T. Ehlinger. 2005. Unlocking the relationship of biotic integrity of impaired waters to anthropogenic stresses. Water Research 39:184-198.

[54] NYC Department of Environmental Protection. 2019. NYC Green Infrastructure On-site Design Manual.

Other Opportunities, Actions, and Recommendations

Daylight Buried Streams

Stream daylighting refers to the restoration of buried or piped streams. Where parkland or other open space already exists, there may be opportunities to daylight streams, or return their flow above ground. Daylighting can help remove the burden of stormwater flow from combined or separate sewer systems, help manage localized flooding, and re-establish stream functions, including providing passive recreational and educational opportunities. Daylighting potential exists in watersheds of all sizes and conditions (Figure 11; Table 15). An example is Tibbetts Brook in the Bronx, where the New York State Department of Environmental Conservation (NYS DEC), NYC DEP, NYC Parks, and community groups are proposing to remove Tibbetts Brook from the Combined Sewer System. Approximately 12 other buried streams may have potential opportunities for daylighting, but none have been seriously assessed to date.

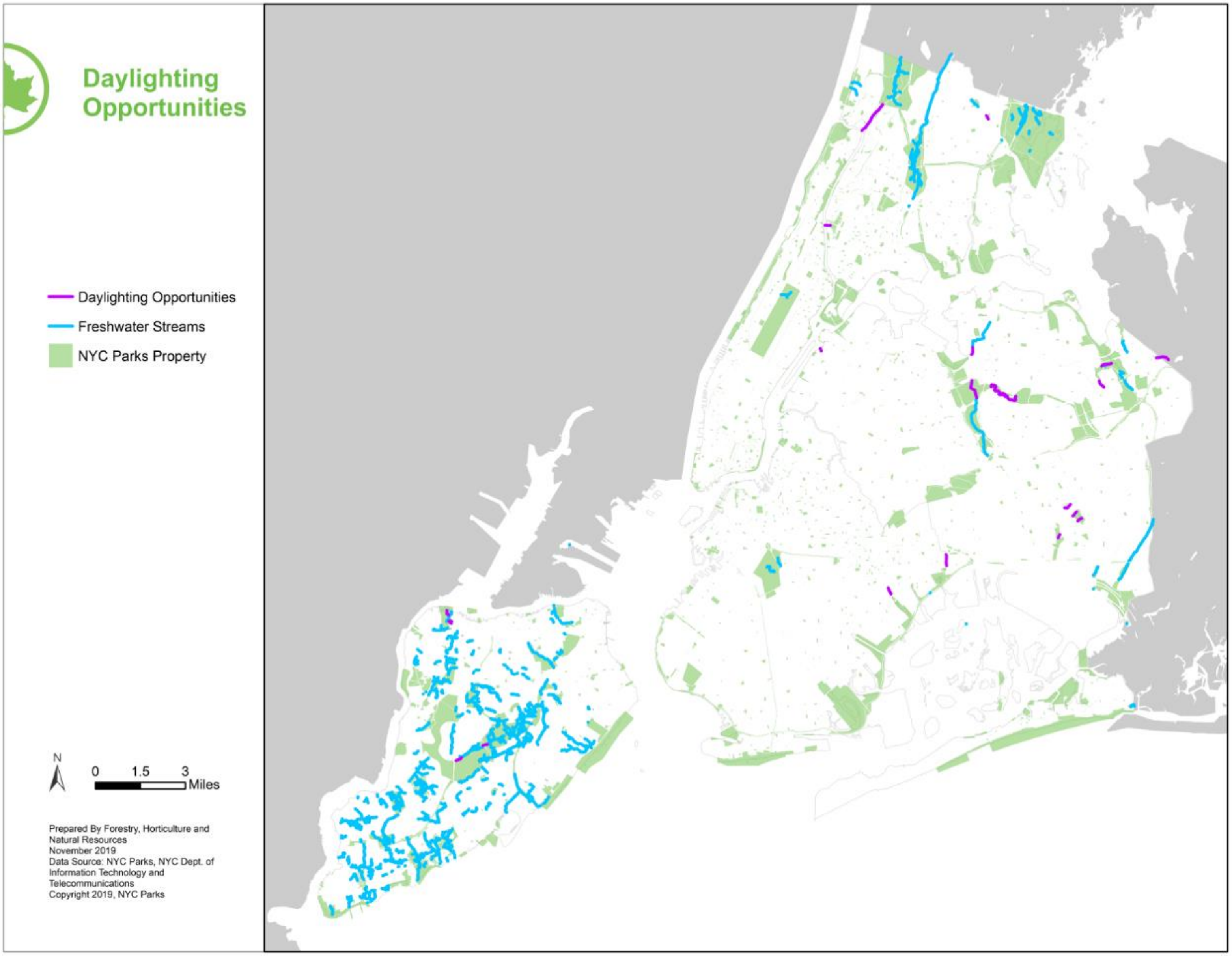
Table 14. Priority reaches for managing stormwater. Number in parenthesis refers to the number of green infrastructure (GI) opportunities for the reach.

Watershed	**Reach Code**	**Action**	**Reach Length (mi)**	**Drainage Area (mi2)**	**Percent Impervious Cover in Drainage Area**
AKRCNB	Deadmans.R6	GI (1)	0.20	0.07	27%
AKN	IndustrialPark.R1	GI (2)	0.20	0.05	29%
RBWP	WolfesPond.R10	GI (2)	0.08	0.52	52%
AKRCS	ArdenWoods.R10	Buildout	0.33	0.08	43%
RBLC	Bloomingdale.R4	Buildout	0.29	0.46	48%
JBCHC	Brookville.R2	Buildout	0.79	0.42	41%
TOTAL			**1.89**	**1.60**	

Table 15. Opportunities for stream daylighting by watershed.

Watershed	**Stream Name**
AKRCNB	LaTourette South
HR2	Tibbets Brook
JBCHC	Fresh Creek
JBCHC	Pugsley Creek
LISHR	Rattlesnake / Givans Creek
ERBRW	Bronx River tributaries
JBCHC	Spring Creek
JBCHC	Baisley Pond
ERFB1	Flushing Creek

KVKW	Mariners Marsh
ACLNB	Lake Success
ACLNB	Oakland Lake
ERFB1	Socrates Park



Prepared By Forestry, Horticulture and Natural Resources
November 2019
Data Source: NYC Parks, NYC Dept. of Information Technology and Telecommunications
Copyright 2019, NYC Parks

Figure 11. Opportunities for stream daylighting.

Address Regulatory Gaps

Despite federal and state protections, many small streams and wetlands on private property remain vulnerable because they do not meet size thresholds for legal protection. For example, approximately 86 acres small freshwater wetlands and 14 miles of streams exist, primarily on private property, that are not protected from development, direct filling, piping, or other impacts. In addition, over 16 miles of small streams and 600 acres of freshwater wetlands on NYC Parks' property receive no regulatory protection.

NYS DEC's Protection of Waters Program protects all streams falling under "navigable waters of the State" under the New York State Environmental Conservation Law. "Navigable waters of the State" are those on which a vessel with a capacity of at least one person can be operated. NYS DEC also classifies streams based on stream use and water quality; streams of the highest quality are afforded extra protection through "Stream Disturbance Permits." The United States Army Corps of Engineers (USACE) regulates impacts to "waters of the United States" (WOTUS), which include some navigable and non-navigable perennial and intermittent streams. Regulated impacts generally include obstruction or alteration of navigable WOTUS, and deposition of fill or dredged material in navigable or non-navigable WOTUS.

Streams on private property (13.8 miles, Table 16) are at risk of future development, and another 23.9 miles of headwater streams and swales in public property do not qualify for federal or state protection. Comparison of aerial imagery shows several instances of streams which have been filled due to development since 1996, presumably due to a lack of regulation. Freshwater streams provide critical ecosystem services and enjoyment for New Yorkers; despite once being prevalent in the NYC landscape, development continues to fill and impact streams. The continued loss of freshwater streams in NYC suggests stricter regulations inclusive of all small streams and wetlands within the city could be beneficial in maintaining these important remaining resources.

In NYC, regulations should be expanded to protect direct impacts to all ephemeral streams and to better regulate increases in impervious area, thereby reducing the quantity and quantity of unmanaged stormwater reaching streams. While underground systems (e.g. hydrodynamic separator water quality units) meet the requirements set forth in the NY State Stormwater Management Design Manual[55], they often are not maintained to meet water quality requirements. Similarly, while culverts may be sized appropriately to pass recommended storm magnitudes, NYC's urbanized environment presents unique challenges for keeping such infrastructure free of debris and sediment blockages. NYC Parks advocates for the use of above ground structures wherever possible; when this is not feasible due to space limitations, maintenance to ensure proper operation of underground systems must be considered for the long-term duration of the practice.

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[55] New York State Department of Environmental Conservation. 2015. New York State Stormwater Design Manual. dec.ny.gov/docs/water_pdf/swdm2015entire.pdf.

Table 16. Stream type and length by property owner.

Ownership	Channel (mi)	Headwater Stream / Swale (m)	Impoundment (mi)	Wetland (mil)	Total (mi)
Public (incl. NYC Parks)	63.2	23.9	6.1	0.9	94.1
NYC Parks	37.4	16.5	5.4	0.6	59.9
Right of Way	2.7	1.7	0	0	4.4
Private	8.1	5	0.5	0.2	13.8
TOTAL	**74.0**	**30.6**	**6.6**	**1.1**	**112.3**

Advocate and Educate for Stream Protection

NYC's streams absorb and convey floodwater, support diverse fish and wildlife, and help clean water flowing to the New York harbor. They also provide excellent opportunities for the public to participate in recreation, like paddling, fishing and bird watching, and to experience natural beauty and respite. Advocacy and education surrounding stream protection in NYC is paramount to ensuring these systems are preserved for future generations, especially considering limited stream protection regulations in highly fragmented urban systems. This requires outreach from environmental groups to communities, as well as coordination among government agencies to ensure effective protection and implementation of regulations. The Natural Areas Conservancy has developed a publicly available Nature Map which highlights the location, size, and condition of the streams in NYC, as well as forests, freshwater wetlands and salt marshes.[56] By considering maps and recommendations from this stream assessment project, planners, designers, land managers, and regulators can help select designs and practices that can better protect streams from negative impacts of development.

In addition, the maps and recommendations from our assessments are resources that will be shared with groups within agencies at the City and State level, as well as with non-profits that provide local environmental outreach and education for students, such as NYC H2O and the Greenbelt Conservancy. Providing communities with connections to and knowledge about their local waterways, as well as the education and tools they need to be good stewards of the natural environment, is critical to ensuring future generations experience the social and ecological benefits that our streams provide.

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[56] Natural Areas Conservancy. 2019. Natural Areas Map. https://naturalareasnyc.org/map.

6. Summary and Next Steps

Streams in NYC have seen dramatic historical loss, and a concerted effort is needed to protect and restore the critical ecological and societal functions that our remaining streams provide. We used the results of our stream assessment and analysis to provide an overview of and framework for understanding stream management needs within NYC Parks. Approximately 30 percent of NYC Park streams, by length, are in relatively good condition. The highest priority management action for these streams is to ensure they are well protected from future potential impacts through development or poor upstream land management. Approximately 13 percent of the streams on NYC parkland require better buffer management to help reduce apparent stressors that degrade stream conditions, and approximately 51 percent would most benefit from a focus on improved stormwater management to address impairments. Finally, about 5 percent of streams, by length, require larger rehabilitation or reconstruction projects due to severe impacts.

We intend for this framework to guide future planning and lay the groundwork for the next steps involving identifying stream and reach specific restoration, management, and design objectives, which require in-depth site and watershed analysis. Including streams in a citywide framework for managing our forests and wetlands is essential for supporting the health and productivity of our connected ecological resources long-term.

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8. Appendices

A. Field Assessment Protocols
B. Glossary of Terms
C. Recommended Management Actions by Reach and Associated Maps

Appendix A. Field Assessment Protocols

1.0 Introduction

NYC freshwater wetlands and streams are threatened by a host of stressors, yet we lack adequate tools to protect this resource. Over 80% of the historic freshwater wetlands and streams in NYC have been lost or filled. Those remaining provide critical ecosystem services including maintaining populations of aquatic and wetland dependent plants and animals. Despite their importance, our remaining wetlands and streams are at risk from eutrophication, invasive species, hydrologic disturbance, and encroachment on to public lands. These threats are intensified by the increased frequency and severity of storms due to climate change, as well as NYC's interest in expanding green infrastructure to manage stormwater. At some sites, NYC Parks is under pressure to retrofit existing wetlands to increase stormwater detention and reduce flooding or Combined Sewer Overflows—an action that may degrade wetland ecosystems (Pehek 2008, 2015b).

To counteract these threats, we need greater information about the extent of our freshwater wetlands and streams and their connectivity. We know smaller headwater streams are poorly mapped, and the existing National Wetland Inventory (NWI) maps for NYC are particularly inaccurate for forested palustrine and riparian wetland types. NWI maps also lack information on how wetlands are hydrologically connected and vulnerable to impacts from stormwater runoff. Our proposed research and surveys accomplished through this project will be critical to the establishment of local guidelines to adequately protect and restore freshwater wetlands and streams, particularly in urban areas.

This project follows the EPA's tiered monitoring framework to assess the condition of ecological resources. First, we will collect landscape level remote sensing data to update and refine stream maps for New York City; secondly, we will verify the location of streams in the field and collect physical and biological rapid assessment data to characterize streams and assess their condition; thirdly, we will analyze data to develop recommendations to inform restoration and protection efforts. Using mapping, landscape analysis, and rapid assessment data, we will classify streams according to their position in the watershed, size, impacts from stormwater and other stressors, and associated vegetation and connectivity. This will provide a foundation for developing guidelines for protection, management, restoration efforts, and identify further data collection and analysis needs. Our analysis will help us identify where wetlands and streams are vulnerable to stormwater runoff impacts, helping to inform implementation of NYC's new Municipal Separate Storm Sewer System (MS4) permit. A workflow for field data collection, analysis, and outputs is outlined in Figure 1.

1.1 Project Schedule

Spring 2016: Project begins.
Summer 2016: Develop and test stream assessment protocols.
Fall-Winter 2016: Receive QAPP approvals and complete draft remote sensing freshwater and stream hydrography mapping.
Spring-Fall 2017: Complete field verification of stream and wetland mapping and identify restoration opportunities.
Winter 2017: Finalize remote sensing freshwater and stream maps and complete landscape analyses, complete data analysis, and develop a conceptual model for stormwater impacts.

Spring 2018: Identify data gaps, develop guidelines for restoration and protection, and produce final project report.

1.2 Project Objectives and Research Questions

Project Objectives:

1. Produce updated stream hydrography and freshwater wetland maps for New York City.
2. Field verify stream hydrography and freshwater maps generated from remote sensing and collect data on stream condition using rapid assessment protocols, e.g. verify correct location and extent of streams and wetlands.
3. Produce a report that identifies stormwater management, restoration opportunities, and information gaps.
4. Develop preliminary guidelines that will inform NYC Wetland Strategy (2012) and green infrastructure planning for stream protection.

Questions this protocol will address:

1. Are all NYC streams and wetlands mapped?
    a. Are the locations and extents accurate?
2. What is the characterization of NYC streams?
    a. What is the channel geometry of each stream reach?
    b. What is the average sediment composition of each stream reach?
    c. Is the stream reach natural or altered?
    d. What is the channel initiation point, e.g. storm drain, wetland, pond, seep, etc.?
    e. What are the bank and riparian vegetation composition and is it consistent throughout each reach?
3. What is the average condition of NYC streams?
    a. What is the condition of banks and streams?
    b. Does the stream support multiple microhabitats?
    c. What benthic invertebrates are found in streams, and are they indicative of high quality or impacted streams?
    d. Are NYC stream banks dominated by native species, or invasive species, such as knotweed, that may affect bank stability?
4. How are streams and wetlands connected?
    a. Are streams and wetlands connected and is that connection altered by roads, trails, dams or impoundments, stormwater inputs, etc.?
    b. Using data collected in the summer of 2014 in connected freshwater wetlands and newly connected stream assessment data what can we infer about connectivity and other impacts?
    c. Are streams connected to the estuary, and if not, are there opportunities to restore tributary connections?
    d. Are streams and/or tributaries buried, and if so, are there opportunities for daylighting to restore connections?
5. Which streams and wetlands receive unmanaged stormwater input, and which are the most vulnerable to stormwater input?
6. Which streams and wetland receive managed stormwater input, and what is their condition?
7. Are there buried streams flowing into the stormwater system that are potentially triggering CSOs?

8. Aside from stormwater, are there other stressors to streams and wetlands we should be managing for, such as increased buffer width, golf course management, etc.?

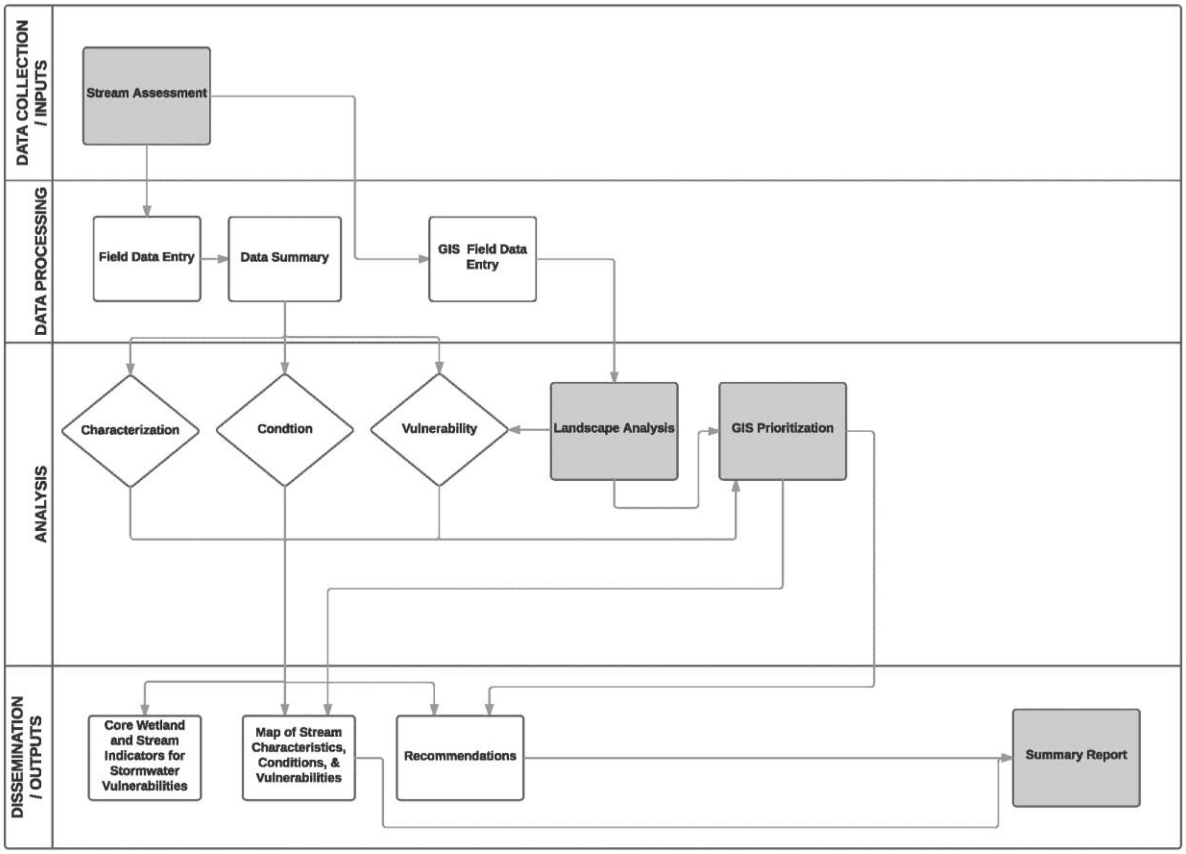

Figure 1. Stream assessment workflow: field data collection, data processing and analyses, and data dissemination.

2.0 Sampling Design

Streams on NYC Parks' property will be assessed throughout the city and the location verified based on newly generated stream hydrography maps produced by GroundPoint LLC in support of this project. Streams will be subdivided into reaches for assessment. A reach can be defined as a continuous section of a stream with similar geomorphic features. Reaches will be selected based on criteria outlined below and identified with a code to distinguish stream reaches from one another; all field and landscape data generated throughout the course of the project will be associated with the reach code. Three transects will be sampled in each reach to facilitate characterization of the reach, capture variability, and allow for comparison among individual stream reaches.

2.1 Desktop/Landscape Reach Selection

1. Each reach will be delineated at the desktop level prior to field sampling and reviewed with in-house staff with knowledge of the stream. Criteria for selection includes:
    - Stream Order
    - Stream Slope
    - Meander Width

- Valley Width
- Land Use
- Soils & Habitat (if applicable)

2. Each reach will be assigned a reach code, as follows:
   a. Borough.Watershed.ParkNumber.StreamName.StreamOrder.ReachNumber
      a. Borough: BK = Brooklyn; BX = Bronx; MN = Manhattan; QN = Queens; SI = Staten Island
      b. Watershed: NYC watersheds are displayed in Table 1 below:

Table 1. NYC watersheds by Borough

Borough	**Watershed Name**	**Park Name(s)**
Brooklyn	Jamaica Bay – Paerdegat Basin	Prospect Park
Bronx	East River – Bronx River West	Bronx Park, Van Cortlandt Park
Bronx, Manhattan	Harlem River 2	Van Cortlandt Park, Riverdale Park, Inwood Hill Park
Bronx	Long Island Sound – Hutchinson River	Seton Falls Park, Givans Creek Woods, Pelham Bay Park
Queens	Alley Creek Little Neck Bay	Alley Pond Park
Queens	East River – Flushing Bay 1	Flushing Meadows Corona Park, Willow Lake, Forest Park
Queens	East River – Flushing Bay 2	Cunningham Park, Kissena Park
Queens	Newtown Creek	Highland Park
Queens	Queens 4	Udall’s Cove, Gabblers Creek
Staten Island	Arthur Kill North	Graniteville Swamp, Staten Island Industrial Park, Saw Mill Creek Marsh
Staten Island	Arthur Kill – Richmond Creek North	LaTourette Park, Willowbrook Park, Bloodroot Valley, High Rock Park, King Fisher, Freshkills Park
Staten Island	Arthur Kill – Richmond Creek South	Arden Woods
Staten Island	Arthur Kill South – 1c	South Shore Country Club
Staten Island	Arthur Kill South – 2a	Long Pond Park, Fairview Park
Staten Island	Kill Van Kull East	Snug Harbor Cultural Center, Allison Pond Park, Goodhue, Silver Lake Park
Staten Island	Kill Van Kull West	Mariners Marsh, Clove Lakes Park
Staten Island	Lower New York Bay – New Creek	Last Chance Pond Park, Midland Field Park, New Creek
Staten Island	Lower New York Bay – South Creek	Ocean Breeze Park
Staten Island	Lower New York Bay – Oakwood Beach	Oakwood Beach, Willow Brook Parkway,
Staten Island	Raritan Bay	Long Pond Park, Butler Manor, Hybrid Oak Woods, Conference House
Staten Island	Raritan Bay –Annandale Beach	Blue Heron Park

Staten Island	Raritan Bay – Arbutus Lake	Arbutus Lake, Bunker Ponds Park, Kingdom Pond Park
Staten Island	Raritan Bay – Great Kills Harbor	Siedenburg Park
Staten Island	Raritan Bay – Lemon Creek	Lemon Creek, Bloomingdale Park
Staten Island	Raritan Bay – Wolfes Pond	Wolfes Pond, Huguenot Ponds Park
Staten Island	Upper New York Bay – Staten Island	Eibs Pond Park, Bradys Pond Park

c. Park Number: Parks property number based on ParksGIS geodatabase (ParksGIS.DPR.Property feature class)
d. Stream Name: If a mapped stream, ensure stream name matches with previously NYC Parks mapped streams
e. Stream Order: Desktop determined and field verified (1st, 2nd, 3rd…)
f. Reach Number: Arbitrarily assigned in the field, Reach 1 (R1), being the farthest downstream
    i. Reach numbers will be further subdivided if there are unmapped tributaries found along the reach, e.g. Reach 1, Tributary 1 (R1T1)

2.2 Field Reach Selection

1. Take hard copy map or digital map in field with delineated reaches.
2. Observe reach. Verify all criteria by which the reach was stratified in the field. Is it consistent with the desktop assessment?
    a. If yes, GPS the upstream and downstream ends of reach and proceed with field sampling, as outlined in the next section of this protocol. The beginning and end of each reach will be GPS'ed in the field using a Trimble GeoXT or Toughbook with backpack attachment.
    b. If no, and if the reach identified at the desktop level appears to be multiple reaches, based on differing geomorphic features, the stream will be further subdivided in the field. To apply criteria for subdivision, continue to number 3 below.
3. Criteria for field reach subdivision includes, but is not limited to, changes in:
    a. Stream Type
    b. Continuity
    c. Channel Geometry
    d. Bed Sediment Composition
    e. Bank and Riparian Vegetation

Use the following guidelines to inform reach subdivision in the field:

i. Stream Type: Observe the stream type of the reach. Is the reach dominated by one stream type (step/pool; planebed/straight; pool/riffle; braided; dune/ripple; channelized; natural backwater impoundment / wetland; artificial backwater impoundment)? Definitions are as follows:
    - **Artificial backwater impoundment:** a low gradient area due to an artificial downstream obstruction, such as a dam, blockage, or other impoundment.
    - **Braided:** braided stream systems are comprised of multiple channels with bars or islands meeting and dividing them within a pair of floodplain banks. Although similar to meandering stream systems, braided stream systems typically contain

an abundant bedload supply, erodible banks, and high stream power. They also tend to be finer-bedded than the other types with more dynamic conditions.

- **Channelized:** channelized reaches have engineered channel modifications usually intended to increase flow to provide floodwater protection during high water flows. Channelized streams tend to be trapezoidal with minimal roughness. Channelized streams may or may not have armored (stone/cobble on the bank slope) banks.
- **Dune-ripple:** dune-ripple channels are most commonly associated with low-gradient, sand-bed channels. These channels exhibit mobile bedforms created by significant sediment transport.
- **Meandering:** Sinuous, low-gradient stream.
- **Natural backwater impoundment / wetland:** an extremely low gradient area within a riparian corridor due to natural downstream obstruction, such as woody debris or a natural dam/topography.
- **Pool/riffle:** stream complexes containing a series of riffles and pools. Riffles are shallower, higher velocity regions containing coarser bed materials and having more rectangular cross-sectional profiles. Riffle areas contain shallow, rocky surface disturbances. Pools are deeper, lower velocity regions containing finer bed materials and have more asymmetric cross-sectional profiles.
- **Step-pool:** typical of mountainous regions, step-pool morphology is defined as a regular series of steps, similar to a staircase, in the bed of a stream.

a. If yes, proceed to number ii below.
b. If no, and if the reach identified at the desktop level appears to be multiple reaches, based on differing geomorphic features, the stream will be further subdivided in the field in this order:
    i. Divide the reach into two dominate stream types. The reach must be longer than 20 x the stream width.
    ii. Divide the reach into the three or more dominant stream types. The reach must be longer than 20 x the stream width.

ii. <u>Continuity (e.g. unmapped culverts):</u> Observe continuity of the reach. Is it interrupted by geomorphic, physical, topographic, and/or geographic features (e.g. culverts, roads, berms, changes in gradient, sinuosity, etc.)?
    a. If yes, sub-divide the reach, using the interruptions as reach starts and ends.
    b. If no, proceed to number iii below.

iii. <u>Channel Geometry:</u> Observe the stream banks. Is the width and depth of the channel consistent throughout the reach? Is the bank height relatively consistent?
    a. If yes, proceed to number iv below.
    b. If no, sub-divide the reach. Some interruptions are typical, e.g. large woody debris, pools, erosion, etc., and may cause some changes in the channel geometry. If the stream does not transition back within a few feet, the reach may need to be sub-divided.

iv. <u>Bed Sediment Composition:</u> Observe the bed sediment in the stream channel. Is it consistent throughout the reach, and appropriate for the stream type? For example, a pool/riffle stream may have sand bottom pools and cobbles along riffles, this is natural and should be assessed as one reach.

        a. If yes, proceed to number v below.
        b. If no, the reach may need to be subdivided. Some interruptions are typical, e.g. silt trapped from debris, pools, etc. If the stream does not transition back within a few feet, the reach may need to be sub-divided.
    v. Bank and Riparian Vegetation: Observe the vegetation along the banks and floodplain. Is it consistent throughout the reach?
        a. If yes, proceed with field sampling.
        b. If no, sub-divide the reach, using the below criteria (this should be avoided if possible):
            i. Observe the bank and floodplain vegetation. Is it relatively consistent throughout the reach? If there is a noticeable transition from a floodplain forest to a large palustrine wetland, the reach may require further subdivision.
            ii. Make a note in the datasheet and add a, b, c, as necessary to the reach code.

4. While walking the reach, the stream reach footprint may be inaccurate and/or unmapped streams may be encountered.
    a. If the stream was previously mapped and its footprint is accurate, check the appropriate box located on the field assessment datasheet or tablet. Mapped streams will be identified from the following shapefile created in 2010:

Feature Dataset:	CitywideGIS.DPR.Physical
Feature Class:	CitywideGIS.DPR.Hydro_Centreline

    b. If the mapped stream footprint is not accurate, re-map the stream footprint using a Trimble GeoXT or Toughbook with backpack attachment.
    c. If only the extent (start or finish) of the stream is incorrect, a GPS point may be dropped to denote the correct stream extent. Stream shapefiles will be corrected in the office.
    d. If a stream is unmapped, observe the stream length and origin. If the stream is determined to be significant, use the following criteria outlined in Section 2.2 to delineate the reach(es).

3.0 Sampling Protocol

In the field, navigate to the downstream-most section of your reach and walk upstream – try to observe the full reach-length identified. GPS the reach start (downstream-most point) and take a photo facing in the downstream direction. Each reach will be selected at the desktop level prior to field sampling and reviewed with in-house staff with knowledge of the stream; however, reach stratification of unmapped streams and/or further reach stratification in the field may be required. Follow the instructions outlined in Section 2.2 in order to delineate a reach that can be defined as a continuous section of a stream with similar geomorphic features.

All data and observations should be recorded using a field assessment datasheets (Appendix A) or tablet while walking upstream.

3.1 Site Assessment Information

1. Record assessment date and evaluators by first and last name.
2. Verify all criteria by which the reach was stratified in the field.
3. Record weather and temperature.

3.2 Physical & Habitat Assessment

After observing the reach, note stream characteristics. Is the channel flowing? Is the flow continuous? How can the channel best be characterized? Is the channel altered?

3.2.a. Stream Reach Characteristics

4. Note the observed flow at time of assessment and dominant stream type.

Surface Flow

- Record the flow regime as follows:
    - surface flow present;
    - no visible water in the reach;
    - surface flow is absent, but water is present in pools; or
    - Intermittent flow present (stream is intermittently above and below ground).

Dominant Stream Type

- Record the dominant stream type as follows: step/pool; planebed/straight; pool/riffle; braided; dune/ripple; channelized; natural backwater impoundment / wetland; artificial backwater impoundment. Refer to the definitions in Sect. 2.2, Step 3.i if needed.

3.2.b Stream Features & Concerns

5. Begin walking upstream and tally physical characteristics. Tally the following physical characteristics within the stream reach: a) pools, b) large woody debris, c) odors, d) oil sheen (unnatural only), and any notable stream features (e.g. springs, seeps, etc), or characteristics of concern (outfalls, erosion, etc. as outlined in section 3.2.b & 3.3). If areas are significant (springs or seeps), are of particular concern, or can be addressed through a volunteer or Capital project, GPS the extent of the concern.
    a. Pools
    In a pool/riffle stream, begin counting pools at the downstream end of the reach. Record the number of pools in the blank for "Reach Start – T1 Total Pools".
        1. Check the box if there are no pools between the reach start and Transect 1.
        2. Check the box if water is presently flowing between the reach start and Transect 1.
    b. Large Woody Debris
    While walking upstream, begin counting pieces of large woody debris (LWD) greater than 10 cm diameter at breast height (DBH) predominantly within (at least 50 percent) the bankfull channel between reach start, Transects 1, 2, and 3, and reach end. LWD should be capable of capturing leaves, or providing habitat structure, e.g. if it falls across the top of the bank, above bankfull depth, LWD should not be included. Record the number of pools in the blank for "Reach Start – T1 Total LWD".

6. GPS physical features or concerns: while walking upstream, document the following physical characteristics (Table 2) using the handheld Trimble GeoXT GPS unit or ToughBook with backpack attachment.

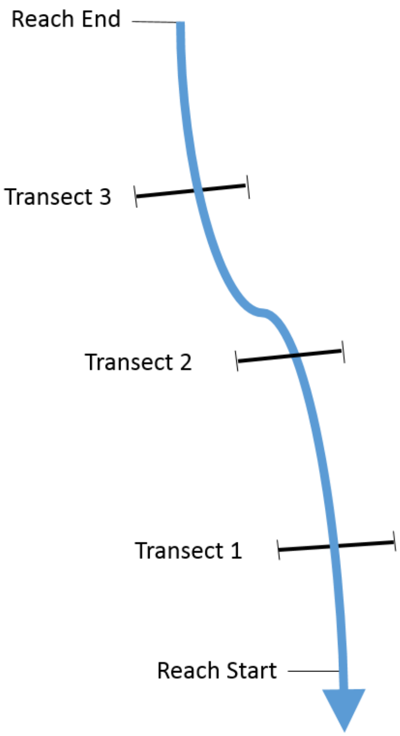

Figure 2: Schematic diagram of a typical reach with Reach Start downstream of Reach End, as the stream is assessed and transect data is collected traveling upstream. The arrow represents the direction of flow.

Table 2. Spatial data collection methods for physical characteristics and concerns.

Physical Characteristics	**GPS data collection / Site map notation**
Infrastructure	
Weir	Point and data
Culvert	Point and data
Concerns	
Discharge Pipes/outfalls	Point and data*
Debris Dumping	Point and data
Gullies	Polyline and data
Industrial or domestic spills/discharges	Point and data
Evidence of burning fire	Point and data
Habitat Features	
Springs	Point
Seeps	Point

*Note: Data collected included the diameter of the pipe at minimum. If in a Municipal Separate Sanitary Sewage System (MS4) drainage area, outfall data collection should be in accordance with the MS4 mapping protocol. Also note if there is flow during dry weather.

c. Discharge Pipes/outfalls

2. Throughout the reach, GPS the location of all stormwater and unmanaged discharge pipes, and outfalls, the diameter, and note any concerns, in accordance with the datasheet (Appendix A).

3. In an MS4 drainage area, GPS the location of each outfall and record the diameter of the pipe.

a. Erosion & Sedimentation
   1. Throughout the reach, observe if erosion and sedimentation is a significant concern on either bank. At the end of the reach assessment document the information below in accordance with the datasheet (Appendix A).

b. Garbage & Debris
   1. Throughout the reach, observe garbage and debris is a significant concern in the stream and/or in the floodplain. At the end of the reach assessment document the information below in accordance with the datasheet (Appendix A).

7. Approximately a quarter of the way up the reach, select the first transect (T1).
   a. Each transect should be representative of the stream reach. Three (3) total transects will be established per reach for data collection. Transects should be approximately equidistant throughout the reach and selected using best professional judgement (Figure 2). Transects should be relatively similar in respect to channel geometry, bank vegetation, channel substrate, etc. Multiple transects will serve to facilitate comparisons between reaches rather than streams.
      i. Avoid placing transects along stream bends.
      ii. In a riffle-pool stream, place transects only in riffles.
      iii. In a step-pool system, place transects in runs.
      iv. If a stream is not dominated by erosion, do not place a transect on a highly eroded bank.

3.2.c Physical Stream Characterization Data Collection

8. GPS the midpoint of Transect 1 and take three photos:
   1) datasheet heading for the transect (T1, T2, etc.) to facilitate photo relabeling in the office;
   2) looking downstream; and
   3) looking up at the canopy at a height of approximately 6 feet. The canopy cover photo will be processed following Pontius and Hallett (2014)] to quantify stream shading.

9. Set up the transect line and record channel geometry, bank condition, pool depths and bank vegetation.

Channel Geometry & Bank Condition

For all measurements recorded in this section, use an approximate 5-foot buffer downstream and upstream of each transect to inform data collection in order to collect data that best represents the stream.

10. **Bankfull Channel Width:** Lay out a 50 or 100 m reel tape perpendicular to stream flow and record measurements at the width and depth of the bankfull channel.
    <u>NOTE:</u> All members of the field team should agree on the bankfull depth for consistency. Select Bankfull height based on the occurrence of woody perennial vegetation, breaks in slope, water marks, and the appearance of litter or debris on banks. Woody species are selected as they are more likely to grow above disturbance from the frequent (~1-2 year) recurrence interval of bankfull flow versus herbaceous species, which are more able to colonize quickly between flow events. Bankfull elevation should be consistent throughout the reach.
    a. Ensure the measuring tape is level across the stream and record bankfull width of Transect 1.
    b. Measure channel depth – from the top of the tape at bankfull to the channel bed – at three (3) points across the transect starting from the right bank (right-hand side of the bank looking downstream): ¼ bankfull width, ½ bankfull width, and ¾ bankfull width and record on the datasheet.
    c. Take the maximum recorded depth from bankfull elevation to the stream bed and multiply it by 2. Measure and record the width of the floodprone zone at this height, ensuring the measuring tape is level. If the floodplain width at twice bankfull height is greater than twice the width, check the box and do not record the width; this assumes the channel is not entrenched.

11. **Bank Heights and Rooted Depths:** At each transect, measure and record the height of the right and left banks, as well as the average depth of exposed roots (any root type). If the bank is vegetated and roots are not exposed, assume the bank is rooted to the average base of vegetation. Right bank is designated as the right-hand side of the bank looking downstream. Left bank is designated as the left-hand side of the bank looking downstream.

12. **Bank Slopes:** At each transect, measure and categorize the slope of the right and left banks using a clinometer or equivalent using the following categories:

- 0 – 15 degrees,
- 15 – 30 degrees,
- 30 – 45 degrees,
- 45 – 60 degrees,
- 60 – 80 degrees,
- 80 – 90 degrees, or
- >90 degrees.
  - If the bank is undercut, or greater than 90 degrees, record 95 on the datasheet or form on the tablet.

13. Refer to Figure 3 below for a schematic depiction of channel geometry data collection at each transect.

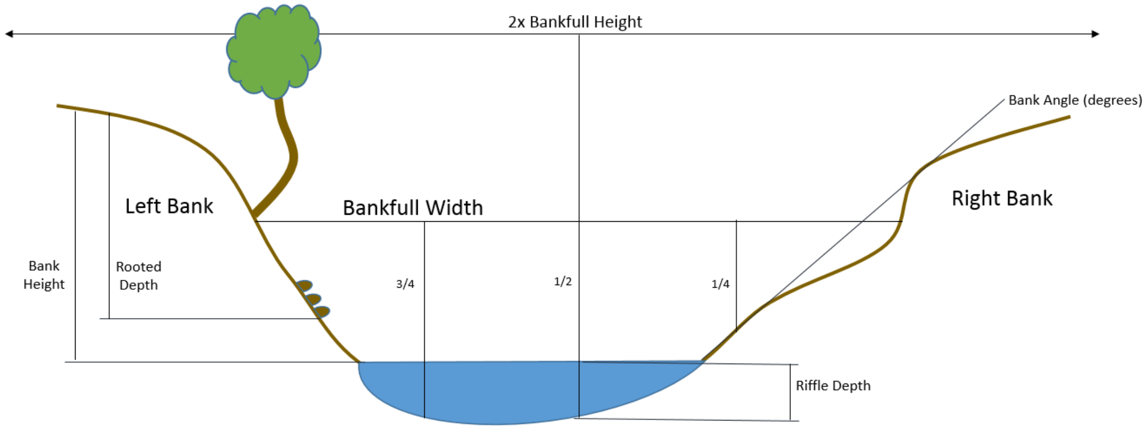

Figure 3: Schematic diagram depicting channel geometry measurements collected at each transect.

Residual Pool Depth

14. At Transect 1, collect data to calculate residual pool depth.
    a. Measure the depth of the riffle crest (cm) and record.
    b. Immediately Upstream from Transect 1, measure the depth of the nearest pool (cm) and record.
    c. Measure the distance from the riffle crest to the pool (m) and record.

Vegetation

15. At transect 2 only, look up and observe the canopy directly overhead, as well as 10 m directly upstream and downstream of the transect. Canopy may extend approximately 5 m into the floodplain.
    a. Record the average percentage of **canopy cover, as an absolute value**.
    b. Of that canopy vegetation, record (up to) the five most abundant riparian species that make up the canopy and their percent covers of the bank as the midpoint of the following ESA cover class ranges:
        i. 0-1%=0.50%
        ii. 1-5% = 2.50%
        iii. 5-12.5% = 8.75%
        iv. 12.5-25% = 18.75%
        v. 25-50% = 37.5%
        vi. 50-75% = 67.5%
        vii. 75-100% = 87.5%
16. At each transect, observe the left and right **bank vegetation**, 10 m in each direction (upstream and downstream) of the transect.
    a. Record the average percentage of the banks that are covered by vegetation, leaf litter and bare ground as the midpoint of the cover class ranges in (16 b).
    b. Of that bank vegetation, record (up to) the five most abundant understory species that make up the banks and their percent covers of the bank as the midpoint of the following cover class ranges:

    i. 0-1%=0.50%
    ii. 1-5% = 2.50%
    iii. 5-12.5% = 8.75%
    iv. 12.5-25% = 18.75%
    v. 25-50% = 37.5%
    vi. 50-75% = 67.5%
    vii. 75-100% = 87.5%

17. Repeat steps 5-7 for Transect 1 – Transect 2.
18. Approximately half way up the reach, select the second transect (T2).
19. Establish Transect 2 (T2).
20. At Transect 2, repeat steps 8-16.
21. At Transect 2, collect substrate size data and complete a faunal assessment.

<u>Substrate Size</u>

22. At Transect 2, conduct a pebble count (Wolman 1954), as described below, if applicable. Pebble counts will not be completed in a solely sand or silt bottom stream.
    - Sand particles range from 2 to 0.05 mm and have a gritty feel when rubbed between the fingers.
    - Silt particles range from 0.05 to 0.002 mm, and the particles cannot be differentiated by fingers.
    - Clay particles are smaller than 0.002 mm, are smooth and sticky, and may be molded into shapes or form ribbons.

    a. Start sampling at the downstream end of the sampling area. The sampling area should be a riffle in a riffle in in a pool riffle stream. The sampling area should be typical of the reach (if no bars or riffles are present). Sampling should support portions of the stream bed that may move. For example, do not sample in pools if the stream is a pool/riffle or step/pool system and avoid stream banks and areas that could confound the sample with colluvial sediments.
    b. Bend down, and without looking, pick up the first particle your index finger touches.
    c. Measure the intermediate axis (not the shortest or longest). Measure embedded or those too large to be moved in place by measuring the smaller of the two exposed axes.
    d. Record the measurement in millimeters (mm). If the material is organic (leaves, sticks, detritus, etc.) or artificial (brick, asphalt, concrete), indicate type of sediment **and** particle size.
    e. Take one step across the channel towards the opposite bank and repeat.
    f. Continue to pick up and record particles from bank to bank in a zig-zag pattern moving upstream until the size of 100 particles is recorded.
    g. For analysis, the standard Wentworth Size Classification will be used:
        i. Clay/silt: 0.19 mm
        ii. Sand: 1.9 mm
        iii. Gravel: 2 – 64 mm
        iv. Cobble: 64.1 – 256 mm
        v. Boulder: 256.1 – 4096 mm
        vi. Bedrock: >4096 mm

3.2 Faunal Data Collection

Faunal Assessment

Although we will not conduct thorough faunal sampling of each stream reach, we will semi-quantitatively survey invertebrates and salamanders in each stream reach using kick-sampling as follows:

23. Identify the first riffle upstream of Transect 2. This will be the sampling location for the reach.
24. Strain a small amount of water from the stream through a D-frame aquatic net with 500-micron mesh into a white plastic dishpan or bucket. The water should reach about 5 cm up the sides of the dishpan/bucket. Remove any debris or invertebrates retained in the net before moving to step 3. This will reduce temperature shock for any invertebrates found in samples and reduce mortality of sampled organisms.
25. Beginning at the downstream end of the identified riffle and working upstream, collect five 1-meter sub-samples. To collect each sub-sample:
    a. Place a folding ruler or meter stick on and parallel to the stream bank to delineate each meter-long sub-sampling area;
    b. Place the flat portion of the frame of a D-frame aquatic net (30 cm in diameter) on the bottom of the stream, with the opening facing upstream and the person sampling standing upstream of the net; and
    c. Walk backwards, kicking vigorously to agitate the substrate and dislodge organisms, for 1 meter, and then swiftly pick up the net with the opening facing up. Very large rocks or woody debris that cannot be moved, or are too large to kick into the net, should be examined for clinging invertebrates after picking up the net. Any invertebrates observed should be manually removed from the large rocks or debris and placed in the net. Picking up the net after each meter allows the retention of highly-mobile fauna such as salamanders and, potentially, small fish. Additional detail on kick-sampling technique can be found in Stranko et al. (2012).
26. Identify and tally the number of larvae and juvenile/adult salamanders in the net after each sample and release. Identify small salamander larvae by inspecting the gills with a hand lens. If fish are caught, also identify and tally them, and then release. Fish species included in the protocol are those we have documented in past surveys; however this method is not geared towards capturing fish, we will only tally those caught in kick sampling.
27. After releasing salamanders and fish, place the rest of the first sample into the white plastic container. Make sure that invertebrates clinging to the mesh are removed and placed in the dishpan or bucket.
28. Move upstream of the first sampling area and repeat steps 23 through 25 for sub-samples 2 through 5.
29. Remove and inspect large rocks or organic debris in the bucket. Place any invertebrates found clinging to rocks or debris into the dishpan. Pick invertebrates from the remaining sample using forceps and identify to order using the Stroud macroinvertebrate key. Tally the number of different types of invertebrate (“morpho-species”) within each taxonomic group identified in the key (order for most insects) on the data sheet. Collect one large

individual of each “morpho-species” as a voucher and for later identification. Place this individual in a vial containing 70% ethyl alcohol and label with a strip of Write-in-Rain paper on which the identity of the stream reach, the date, and the collector’s initials are written.

30. Categorize the number of invertebrate individuals in each taxonomic group as:
    - A: 1-9;
    - B: 10-99; or
    - C: 100 or more.
31. Return the remaining contents of the container to the riffle from which it was sampled.

Continued Physical Data Collection

32. Repeat steps 5-7 for Transect 2 – Transect 3.
33. Approximately three-quarters of the way up the reach, select the last transect (T3).
34. Establish Transect 3 (T3).
35. At Transect 3 repeat steps 8-16.
36. Repeat steps 5-7 for Transect 3 to the end of the reach.
37. GPS the end of the reach. At the reach end take a photo facing upstream.

3.3 Restoration Opportunities

1. Data Collection

Throughout the reach, stream features and concerns that may be suitable for restoration action by volunteers, in-house crew, and/or contractors will be recorded on the restoration opportunities datasheet (Appendix A).

At the end of each reach assessment, the group will collaboratively complete the restoration opportunities datasheet, which includes documenting the:

- location of concern area;
- presence and absence of stream features and concerns and severity/urgency when applicable;
- invasive vegetation severity and percent cover;
- rare spp native vegetation (if any);
- appropriate restoration actions and their associated effort level (volunteer, in-house, or contractor);
- project feasibility and constraints.

The following additional information associated with stream features will also be recorded:

- diameter of pipes
- width of buffer

The following stream features and/or concerns will be GPS’d (see datasheet):

- Gullies;
- culverts;
- wiers;
- dumping;

- direct discharge pipes (septic or sewage, stormwater, or unmanaged discharge);
- industrial or domestic spills/discharges; and
- evidence of burning/fire.

Data collected on site-specific constraints will inform the feasibility of the project work and type:

- *Stewardship Project Constraints:*
    - Evidence of contamination (drums, odor, unnatural oil sheen, paint cans, fertilizer, etc.);
    - Site Access: trail access, terrain, and distance to road
    - Sensitivity (e.g. 1 Million Trees Area or areas with species of conservation concern or need);
    - Site Capacity (# of volunteers); and
    - Questionable or illicit debris (e.g. glass, needles);
    - Vegetation hazards: severity of poison ivy and thorny plants
- *Contractor Project Constraints:*
    - Terrain
    - Tree Removals
    - Distance to road

The team will record additional observations or site knowledge in the “Comments” section of the datasheet.

2. Data Analysis

Stream Features and concerns will categorized into health- or threat-indicating metrics with associated scores, where:

- Absence of stream feature or concern = 0 score
- Presence of stream feature or concern = 1 score
    - Prioritization will be based on the stream feature condition or severity of the concern

3. Restoration Project Recommendations

Data collected will inform project recommendations for volunteers/in-house restoration work, and contractor/Capital restoration work as following:

- *Project Types: Volunteer/In-house Restoration Work:*
  Stream Features and/or Concerns:
    - Debris removal;
    - Invasives removal, cutting, or other management;
    - Stormwater and/or runoff gully repair;
    - Erosion control fabric installation and planting;
    - Trail reconstruction or improved stream crossings;
    - Access control or trail closure: signs of off-road vehicles, mountain biking, trail cuts, desire lines by people or wildlife;
    - Freshwater wetland restoration and planting; and

    - Cut bank repair/restoration.

- *Project Type: Contractor/Capital Restoration Work:*
  Stream Features and/or Concerns:
    - Repair and/or re-design of undersized culverts and degraded weirs, channelization;
    - Debris/dumping removal by contractors;
    - Invasives removal/management by contractors;
    - Severe cut bank repair/restoration by contractors;
    - Freshwater wetland restoration and planting;
    - Unnatural dam removal;
    - Stormwater inputs: extensive stormwater and/or runoff gully repair, poor quality habitat upstream of high quality habitat;
    - Formation of algae surface mats; and
    - Evidence of burning/fire.

4.0 Data Analysis and Interpretation

Three (3) transects were selected for each reach to capture some variability in assessment and allow for us to compare reaches to one another. Benthics and pebble counts were only completed in one representative section of each reach.

The data collected throughout this study will serve primarily as a characterization or inventory of NYC streams, so descriptive statistics will primarily be used in analysis. In addition, each metric will be analyzed to determine whether any metric was more influential than others in order to explain the variability between reaches. Specific variables within reaches may also be categorized and analyzed between stream order or watershed.

We will use multivariate statistics to reduce the data down to the largest, most significant trends. In order to do this, we will analyze the relativized data with a non-parametric multivariate procedure appropriate for non-normally distributed data - non-metric multidimensional scaling (NMDS) (McCune and Grace, 2002). NMDS is analogous to a Principal Coordinates Analysis in that it seeks to explain trends in environmental data by grouping response variables and explaining their contribution to the total variation in the data. The analysis will be run in R (R Core Team, 2013) using the NMDS package for R (Oksanen et al., 2015).

Each metric will be analyzed as described below:

PHYSICAL CHARACTERISTICS

<u>Channel Geometry</u>
The width and depth of creeks will be averaged by reach and visualized in graphs and/or tables.
<u>Entrenchment Ratio</u>
Twice bankfull depth will be averaged by reach and visualized in graphs and/or tables. Data may be further stratified using standard ratios to describe severity of entrenchment.
<u>Bed Sediment</u>
Bed sediment will be averaged by reach and visualized in graphs and/or tables. Data will be analyzed using standard procedures outlined by Wollman (1954) to calculate D_{50}, and D_{84} if applicable.

Residual Pool Depth

Residual pool depth is calculated as the pool depth, less the depth of the downstream riffle crest. Residual pool depth will be averaged by reach and visualized in graphs and/or tables. Data will be analyzed using standard procedures outlined by Lisle (1987).

HABITAT METRICS

Pool Count

Number of pools will be summed by reach and standardized by stream length and visualized in graphs and/or tables.

Large Woody Debris Count

Number of pieces of large woody debris will be summed by reach and visualized in graphs and/or tables. Frequency and function of large woody debris may be standardized based on stream width (Bilby and Ward 1989).

Canopy Cover

Canopy cover will be extracted from photos using standard protocols for managing forest decline used by Pontius and Hallett (2014) to derive an absolute canopy cover value for each stream. Values will be averaged by reach and visualized in graphs and/or tables.

Bank Vegetation

Bank vegetation will primarily be used as a qualitative measurement to describe stream condition. Percent cover of invasive species along the banks may be averaged by stream reach and visualized in graphs and/or tables.

Benthic Assessment

Faunal metric calculations:

Presence/absence of the three salamander species (Table 3) is used to assign a class to headwater streams. Salamanders are the top vertebrate predator in headwater streams, replacing fish, which are the top predators for lower reaches. Use the methods of the Ohio EPA (2009) for assigning a headwater stream class to each reach. Each salamander species is associated with a headwater stream class:

Table 3. Species of salamanders found in headwater streams.

Species	**Headwater Stream Class**
Northern dusky salamander	2 (intermittent or perennial flow; warm-water adapted)
Northern two-lined salamander	3 (perennial flow; cool-water adapted)
Northern red salamander	3 (perennial flow; cool-water adapted)

Class 1 salamanders are primarily terrestrial, and would not be captured using our in-stream sampling techniques. One species, the eastern red-backed salamander, may use non-flowing stream channels for foraging, especially in dry weather periods, but we will not include them in our stream assessment calculations. A particular reach's class can be calculated by averaging the classes of each species present in that reach. For example, if both northern dusky and two-lined salamanders are present, the class would be 2-1/2 ((2+3)/2). If northern two-lined and northern red salamanders are present, the class would be 3.

In the absence of salamanders, benthic invertebrates will be used to characterize streams. Invertebrates will be identified using Merritt et al. (2008), Peckarsky et al. (1990), and Smith (2001). Invertebrate data will be scored by assigning an index value to each taxon captured in the kick-samples. We will use different index values for headwater streams and higher-order (non-headwater) streams. In lieu of a rapid benthic sampling method for New York State, the following scoring methods will be used: for non-headwater streams, use the scoring method developed by the Maryland Department of Natural Resources (1999), and for headwater streams, the scoring method in Ohio EPA (2009). Use the index values in Table 4 that correspond to the stream type where the sample was collected (headwater vs. non-headwater).

Table 4. Indices for aquatic taxa.

Taxon	**Non-headwater Stream Index Value**	**Headwater Stream Index Value**
Aquatic worms (flatworms, leeches, earthworms)	1	1
Mayfly nymphs (Ephemeroptera)	3	3
Stonefly nymphs (Plecoptera)	3	3
Caddisfly larvae (Trichoptera)	3	3
Fishfly larvae (Corydalidae)	3	3
Alderfly larvae (Sialidae)	-	1
Damselfly larvae (Zygoptera)	2	1
Dragonfly larvae (Anisoptera)	2	2
Riffle beetle adults (Dryopidae, Elmidae, Ptilodactylidae)	3	2
Riffle beetle larvae	2	2
Water penny larvae (Psephenidae)	3	3
Other beetles (Coleoptera)	2 (larvae only)	1
Midge larvae (Chironomidae)	1	1
Blackfly larvae (Simuliidae)	1	1
Cranefly larvae (Tipulidae)	2	3
Other fly larvae (Diptera)	-	1
Crayfish (Decapoda)	2	2
Scuds (Amphipoda)	2	1
Sowbugs (Isopoda)	2	1
Snails (Gastropoda)	1 (Physidae) or 2 (all other snails)	1
Clams (Bivalvia)	2	1
Water mites (Arachnida)	-	1

For non-headwater streams, add the index values for all taxa present in the kick-samples. The resulting cumulative index value (Table 5) is used to assign a stream quality to the reach:

Table 5. Cumulative index classification for stream quality rating.

Cumulative Index Value	**Stream Quality**
>22	Excellent
17-22	Good
11-16	Fair
< 11	Poor

For headwater streams, the cumulative index (Table 6) is calculated similarly by adding the index values of all taxa present, with the exception of mayflies, stoneflies and caddisflies. For these taxa, the tally of the number of morpho-species is multiplied by 3, then added to the cumulative index for all the other taxa. The resulting values are used to assign a stream reach to a headwater class as follows:

Table 6. Cumulative index classification for headwater streams.

Cumulative Index Value	Headwater Stream Class
>19	3
7-19	2
< 7	1

The headwater class derived from invertebrate samples can then be averaged with the headwater class from salamander samples.

BANK CONDITION

Bank Erosion Potential

The following metrics may be collected in the field to inform bank erosion potential, as outlined by Rosgen (s.d.), but may also be stand-alone metrics.

Bank Slope

Bank slope will be averaged by reach and visualized in graphs and/or tables.

Ratio: Bank Height to Bankfull Height

Ratio of bank height to bankfull height will be averaged by reach and visualized in graphs and/or tables.

Ratio: Root Depth to Bank Height

Ratio of root depth to bank height will be averaged by reach and visualized in graphs and/or tables.

Bank Height

Bank height will be averaged by reach and visualized in graphs and/or tables.

Rooting Depth

Rooting depth will be averaged by reach and visualized in graphs and/or tables.

Bank Vegetation

Bank vegetation will primarily be used as a qualitative measurement to describe stream condition. Percent cover of invasive species along the banks may be averaged by stream reach and visualized in graphs and/or tables.

STORMWATER CONCERNS

Outfalls

The number of stormwater outfalls into each reach will be averaged by reach and visualized in graphs/and or tables, as well as maps. The number of outfalls may be additive if an outfall discharges into an upstream reach and additional outfalls discharge downstream, e.g. this will be a reach specific metric.

CONDITIONS AND VULNERABILITY INDEX

All metrics may be included into an index of stream condition and vulnerability. Condition and vulnerability metrics were selected based on Rosgen (s.d.) and other studies (Table 7), but may be adjusted in the index based on professional judgement and knowledge of individual reaches and streams. Indicators will be standardized by z-scores or “standard scores”, centers the values at zero by subtracting the mean from each value and standardizing the range of values by dividing those values by the standard deviation. The equation is represented by, $z= x - \mu\sigma$, where x is the raw value, μ is the mean of the raw values, and σ is the standard deviation. This standardization is commonly used on environmental data and is appropriate when there is a need to adjust for differences in variance and measurement units among variables in order to place them on equal footing to one another (McCune and Grace 2002; Legendre and Fortin, 1989). By applying this standardization, the index allows one to compare stream reaches relative to one another, but it does not represent an absolute metric of its condition. Simply for visualization purposes, breaks in the z-scores were selected to show which reaches were highest or lowest condition on maps and charts for each indicator:

Individual indicator variables for condition

- $z < -1$ lowest (red)
- $-1 \leq z < -0.5$ lower (orange)
- $-0.5 \leq z < 0.5$ average (yellow)
- $0.5 \leq z < 1$ higher (green)
- $1 \leq z$ very highest (blue)

Table 7. Field and landscape metrics, data types, and their proposed use in analysis.

	Metric	**Primary Data**	**Secondary Data**	**Tertiary Data**	**Characterization**	**Condition**	**Vulnerability**	**Collection Method**
LANDSCAPE	Stream Order	Absolute Value			X			Landscape Collection
	Stream Slope	Absolute Value	Average	Stratify	X			Landscape Collection
	Sinuosity	Absolute Value	Average		X			Landscape Collection
	Meander Width Ratio	Absolute Value	Ratio		X			Landscape Collection
	Meander Pattern	Absolute Value	Category		X			Landscape Collection
	Valley Width	Absolute Value	Average	TBD	X			Landscape Collection
	Land Use	Category				X	X	Landscape Collection
	Percent Impervious Area	Absolute Value	Category				X	Landscape Collection
	Riparian Buffer Width	Absolute Value	Average	Category			X	Landscape Collection
PHYSICAL	Channel Width	Absolute Value	Average	Stratify	X	X		Field Data Collection
	Channel Depth	Absolute Value	Average	Stratify	X	X		Field Data Collection
	Stream Type	Category			X			Field Data Collection
	Flow Regime	Category			X			Field Data Collection
	Bed Sediment	Absolute Value	Average, Variation	Stratify	X	X		Field Data Collection
	Entrenchment Ratio	Category			X	X	X	Field Data Collection
	Twice Bankfull Width	Absolute Value	Average	Stratify	X	X	X	Field Data Collection
HABITAT	Bank Vegetation	Values		Stratify		X	X	Field Data Collection
	Floodplain Vegetation	Values		Stratify		X	X	Field Data Collection
	Pool Habitat	Category				X		Field Data Collection
	Residual Pool Depth	Absolute Value	Average	Stratify				Field Data Collection
	Number of Pools	Absolute Value	Average	Stratify				Field Data Collection
	Large Woody Debris	Absolute Value	Average	Stratify		X		Field Data Collection
	Faunal Assessment	Index						Field Data Collection
	Species Diversity & Abundance	Index				X		Field Data Collection
	Salamander Presence	Category				X	X	Field Data Collection
BANK CONDITION	Bank Erosion Potential	Index				X	X	Field Data Collection
	Bank Slope	Category	Average			X	X	Field Data Collection
	Bank Height	Absolute Value	Average	Stratify		X	X	Field Data Collection
	Rooting Depth	Absolute Value	Average	Stratify		X	X	Field Data Collection
	Percent Cover of Bank Vegetation	Absolute Value	Average	Stratify	X	X	X	Field Data Collection
CONCERNS	Outfalls	Absolute Value	Category				X	Field Data Collection
	Erosion/Sedimentation	Qualitative					X	Field Data Collection
	Invasive Species	Qualitative					X	Field Data Collection
	Garbage/Debris	Qualitative					X	Field Data Collection

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6.0 Equipment

Item	Quantity
datasheets	1 set per reach
clipboard	1
site maps	1
50 meter reel tape	1
chaining pin	1
folding metric ruler with units in mm, cm, dm, m	2
clinometer	1
D-frame aquatic net, 30 cm diameter	1
plastic basin	1
small dip net	1
1 oz sampling vials	1 per reach
handheld Trimble GeoXT GPS unit with backpack antenna	1, 2 if available

Appendix A. Datasheets

I. Metadata

Date: **Time:** **Evaluators:**

Park Name:

Borough:

Stream Name: **Mapped Stream** Yes No

Reach #:

II. Field Assessment

Minimum survey length = 20 x stream width

Make all observations while walking UPSTREAM

GPS Upstream and Downstream Ends of Reach

FLOW CONDITIONS	Surface Flow	**Current Weather:**
(Circle One)	Some visible flow, but incontinuous.	**Past 48 hr. weather:**
	No Flow	
	Intermittent flow (stream flows above and below ground)	

DOMINANT STREAM TYPE (Circle one)

Pool/ riffle	Natural Backwater	Step-pool	Artificial Backwater/impoundment
Dune/Ripple	Channelized (% of reach armored: ______%)	Meandering	Braided

DOMINANT WETLAND TYPE (Circle One)

PEM PFO PSS PUB None

☐ Were new wetlands mapped? ☐ Do wetlands still need to be mapped/verified?

III. Brief Site Description and Drawing *(Include description of site, approximate scale of drawing, adjacent land use, vegetation zonation, location of Assessment Area, trails, and exact location of any permanent monitoring plot.)*

REACH CODE & DATE

CHANNEL GEOMETRY & POOLS

Measure the width and depth of the channel at bankfull and width at 2X bankfull. If 2X bankfull is >2x the bankfull width, check >2x.

Tally the # of pools between transects. Measure depth of nearest pool upstream of the transect. Note location (straight reach, bend, obstruction, etc.)

If riffle/pool stream, and transect falls in a pool, shift upstream to next riffle and GPS location.

Take 3 photos at each transect of: (1) datasheet heading for the transect (T1, T2, etc.); (2) downstream view and (3) canopy cover at approximately 6 feet above ground surface.

Reach Start - T1							
Est. Total Pools:	____________	0	1-5	6-10	11+	(Y/N)	Pools
Est. Pieces of LWD:	____________	0	1-5	6-10	11+	(Y/N)	Flowing Water

Transect 1	Bankfull Width (m)	Bankfull Depth (cm)	Bank Type	BankHeight (cm)	RBAngle(circle one)	LBAngle(circle one)	RootedDepth (cm)	2X Bankfull Width	Riffle Depth (cm)		
	_____________	¼L :_______ (RB)	Natural	RB __________	0-15°	0-15°	RB __________	____________	____________	(Y/N)	Floodplain Width at 2x Bankfull Ht > 2x Bankfull Width
		½L: _______	Armored	LB __________	16-31°	16-31°	LB __________				
		¾L :_______ (LB)	____________		32-45°	32-45°					
1st Pool upstream of T1	Distance from T (m)	Depth (cm)			46-60°	46-60°				(Y/N)	Took canopy pic
	____________	____________			61-75°	61-75°				(Y/N)	Took downstream pic
					76-90°	76-90°					
					90°+	90°+					

T1-T2							
Est. Total Pools:	____________	0	1-5	6-10	11+	(Y/N)	Pools
Est. Pieces of LWD:	____________	0	1-5	6-10	11+	(Y/N)	Flowing Water

Transect 2	Bankfull Width (m)	Bankfull Depth (cm)	Bank Type	BankHeight (cm)	RBAngle(circle one)	LBAngle(circle one)	RootedDepth (cm)	2X Bankfull Width	Riffle Depth (cm)		
	_____________	¼L :_______ (RB)	Natural	RB __________	0-15°	0-15°	RB __________	____________	____________	(Y/N)	Floodplain Width at 2x Bankfull Ht > 2x Bankfull Width
		½L: _______	Armored	LB __________	16-31°	16-31°	LB __________				
		¾L :_______ (LB)	____________		32-45°	32-45°					
1st Pool upstream of T2	Distance from T (m)	Depth (cm)			46-60°	46-60°				(Y/N)	Took canopy pic
	____________	____________			61-75°	61-75°				(Y/N)	Took downstream pic
					76-90°	76-90°				(Y/N)	Pebble Count
					90°+	90°+				(Y/N)	Benthics

T2-T3							
Est. Total Pools:	____________	0	1-5	6-10	11+	(Y/N)	Pools
Est. Pieces of LWD:	____________	0	1-5	6-10	11+	(Y/N)	Flowing Water

Transect 3	Bankfull Width (m)	Bankfull Depth (cm)	Bank Type	BankHeight (cm)	RBAngle(circle one)	LBAngle(circle one)	RootedDepth (cm)	2X Bankfull Width	Riffle Depth (cm)		
	_____________	¼L :_______ (RB)	Natural	RB __________	0-15°	0-15°	RB __________	____________	____________	(Y/N)	Floodplain Width at 2x Bankfull Ht > 2x Bankfull Width
		½L: _______	Armored	LB __________	16-31°	16-31°	LB __________				
		¾L :_______ (LB)	____________		32-45°	32-45°					
1st Pool upstream of T3	Distance from T (m)	Depth (cm)			46-60°	46-60°				(Y/N)	Took canopy pic
	____________	____________			61-75°	61-75°				(Y/N)	Took downstream pic
					76-90°	76-90°					
					90°+	90°+					

T3-Reach End							
Est. Total Pools:	____________	0	1-5	6-10	11+	(Y/N)	Pools
Est. Pieces of LWD:	____________	0	1-5	6-10	11+	(Y/N)	Flowing Water

* RB= Right Bank

* LB= Left Bank

REACH CODE & DATE

VEGETATION

			RB (use cover class ranges)	LB (use cover class ranges)
Transect 2		Canopy (% cover, absolute value): ___________%	Bank (% cover): _______________%	_______________%
0-1%	(use cover class ranges)	spp 1: _________________________________ (________%)	spp 1: _________________________________ (________%)	_________________________________ (________%)
1-5%		spp 2: _________________________________ (________%)	spp 2: _________________________________ (________%)	_________________________________ (________%)
5-12.5%		spp 3: _________________________________ (________%)	spp 3: _________________________________ (________%)	_________________________________ (________%)
12.5-25%		spp 4: _________________________________ (________%)	spp 4: _________________________________ (________%)	_________________________________ (________%)
25-50%		spp 5: _________________________________ (________%)	spp 5: _________________________________ (________%)	_________________________________ (________%)
50-75%			Bare Ground (% cover): _______________%	_______________%
75-100%			Leaf Litter (% cover): _______________%	_______________%

SUBSTRATE - Pebble Count

Conduct a pebble count in a zig zag pattern nearest Transect 2. Do Pebble Count before Benthic Sampling.

Measure sediment in cm (note mm if used). Count and measure particles beneath LL, but record presence of LL as well. (Si=Silt; S=Sand; A=Artificial Material; LL=Leaf Litter; BG=Bareground)

Pebble Count Completed (Y/N): IF NO, WHY? ____

CM/MM (Circle One)

1 _____________
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99 _____________
100 _____________

REACH CODE & DATE

BENTHIC SAMPLING

DO PEBBLE COUNT BEFORE KICK-SAMPLING! Collect five 1-m kick samples beginning at the downstream end of the first riffle upstream from Transect 2. Identify and tally salamanders, fish, and crustaceans after each sample and release. Dump the rest of each sample into the white plastic container and tally invertebrates after all five samples have been collected.

If uncertain of species, collect a sample in vial and label with: **Park Name, Stream Name, Reach Number, and Date**

Kick sample conducted? **Yes** **No** **Flow at time of sampling?** **Yes** **No**

Specimens found in kick sample? **Yes** **No**

Sample Collected (for lab ID)? **Yes** **No** **Total # vials collected: ________**

INVERTEBRATES				
Taxon		Tally (individuals)	Total # of Individuals (estimate if >30)	Abundance Code (A = 1-9; B = 10-99; C = 100 or more)
Aquatic worms-flatworms, earthworms (Oligochaeta)	Spp 1			
	Spp 2			
	Spp 3			
Leeches (Hirudinea)	Spp 1			
	Spp 2			
	Spp 3			
Mayfly nymphs (Ephemeroptera) *collect 1 sample of each type*	Spp 1			
	Spp 2			
	Spp 3			
Stonefly nymphs (Plecoptera) *collect 1 sample of each type*	Spp 1			
	Spp 2			
	Spp 3			
Caddisfly larvae (Trichoptera) *collect 1 sample of each type*	Spp 1			
	Spp 2			
	Spp 3			
Fishfly/Dobsonfly larvae (Megaloptera Corydalidae)				
Alderfly larvae (Megaloptera Sialidae)				
Damselfly nymphs (Odonata Zygoptera)	Spp 1			
	Spp 2			
	Spp 3			
Dragonfly larvae (Odonata Anisoptera)	Spp 1			
	Spp 2			
	Spp 3			
Riffle beetle adults (Dryopidae, Elmidae, Ptilodactylidae)	Spp 1			
	Spp 2			
	Spp 3			
Riffle beetle larvae	Spp 1			
	Spp 2			
	Spp 3			
Water penny larvae(Psephenidae)				
Other beetle adults (Coleoptera)	Spp 1			
	Spp 2			
	Spp 3			
Other beetle larvae (Coleoptera)	Spp 1			
	Spp 2			
	Spp 3			
Midge larvae (Diptera Chironomidae)	Spp 1			
	Spp 2			
	Spp 3			
Blackfly larvae(Diptera Simuliidae)				
Cranefly larvae (Diptera Tipulidae)	Spp 1			
	Spp 2			
	Spp 3			
Other fly larvae (Diptera)	Spp 1			
	Spp 2			
	Spp 3			

INVERTEBRATES (continued)				
Taxon		Tally (individuals)	Total # of Individuals (estimate if >30)	Abundance Code (A = 1-9; B = 10-99; C = 100 or more)
Crayfish (Decapoda)				
Scuds (Amphipoda)	Spp 1			
	Spp 2			
	Spp 3			
Sowbugs (Isopoda)	Spp 1			
	Spp 2			
	Spp 3			
Pouch snails-left (Gastropoda Physidae)	Spp 1			
	Spp 2			
	Spp 3			
Ramshorn snails-flat (Gastropoda Planorbidae)	Spp 1			
	Spp 2			
	Spp 3			
Other snails-right (Gastropoda Lymnaeidae)	Spp 1			
	Spp 2			
	Spp 3			
Fingernail clams (Bivalvia Sphaeridae)				
Other clams (Bivalvia)	Spp 1			
	Spp 2			
Water mites (Arachnida)	Spp 1			
	Spp 2			
	Spp 3			

VERTEBRATES (raise net each meter to count)				
	Number of Individuals			
Salamanders:	Larvae (with gills)	Juvenile/ Adult (no gills)	**Fish:**	Number of Individuals
Northern two-lined			Black-nosed dace	
Northern dusky			American eel	
Northern red			Bluegill	
Other			Goldfish	
Unknown			Other	

SAMPLES COLLECTED FOR LAB ID		
Description	# Ind. Found	Abundance code
Sample 1-		
Sample 2-		
Sample 3-		
Sample 4-		
Sample 5-		
Sample 6-		
Sample 7-		
Sample 8-		
Sample 9-		

Park Name: **Stream Name:** **Date:**

RESTORATION OPPORTUNITIES

Indicate the presence or absence of stressors (circle **Y** for Yes or **N** for No) and the restoration opportunity/ies (circle the appropriate restoration action). GPS location of stressor as indicated in the "GPS Action" columns, and document severity/urgency and effort in the appropriate columns. Use the "Comments" section to further describe existing conditions, indicate the need for further investigation, and to document additional stressors or restoration opportunities and actions.

Work Area:	**FW Wetland type:**	PEM	PFO		**Stream type:**	Natural Backwater	Pool/riffle	Step-pool	Dune/Ripple
		PUB	PSS			Artificial backwater / impoundment	Channelized	Braided	Meandering

CONCERNS			**SERVERITY**			**RESTORATION ACTION**							**GPS ACTION**	**EFFORT**		
Levees, berms along reach	Y	N	Low	Medium	High	None	Removal	Repair					None	Volunteer	In-house	Capital / contractor
Channelization	Y	N	Low	Medium	High	None	Investigate upstream cause	Remove physical barriers	Repair engineered channelization infrastructure if structure is vital				None	Volunteer	In-house	Capital / contractor
Ditches along reach	Y	N	Low	Medium	High	None	Investigate						None	Volunteer	In-house	Capital / contractor
Vegetation die-off from increased ponding or old wier	Y	N	Low	Medium	High	None	Investigate or identify historical conditions	Drainage management	Habitat conversion (freshwater wetland)				None	Volunteer	In-house	Capital / contractor
Unstable banks (undercutting, slumping, sliding, calving)	Y	N	Low	Medium	High	None	Investigate upstream cause (e.g. golf course)	Install Rip Rap / native material revetment	Install in-stream structures (log or rock vanes)	Install erosion control fabric and native planting	Install BMP	Trails	None	Volunteer	In-house	Capital / contractor
Surface erosion	Y	N	Low	Medium	High	None	Install native plantings within buffer	Install erosion control fabric and native plantings on bank	Close trails or desire lines	Install BMP	None	None	None	Volunteer	In-house	Capital / contractor
Inorganic sediment inflow, vegetation burial	Y	N	Low	Medium	High	None	Identify source of accretion	Install BMP	Re-grade, then native vegetation planting				None	Volunteer	In-house	Capital / contractor
Organic sedimentation, vegetation burial	Y	N	Low	Medium	High	None	Identify source of accretion	Re-grade, then native vegetation planting					None	Volunteer	In-house	Capital / contractor
Turbidity in the water column	Y	N	Low	Medium	High	None	Install native plantings within buffer	Erosion control fabric and native plantings along the bank	Install BMP	Related to known water quality issues			None	Volunteer	In-house	Capital / contractor
Formation of algal or Lemma sp., Surface mats, or benthic algal growth	Y	N	Low	Medium	High	None	Install barley	Fertilizer/nutrient management	Install erosion control measures	Install BMP			None	Volunteer	In-house	Capital / contractor
Signs of off-road vehicles, mountain biking, trail cuts, construction impacts, desire lines by people or wildlife	Y	N	Low	Medium	High	None	Trail Closures / trail blockages	Install guard rails					None	Volunteer	In-house	Capital / contractor
Dumping of garbage, construction debris, organic waste, or other debris capable of collecting water	Y	N	Low	Medium	High	None	Debris Removal - contractor	Debris Removal - hand	Identify source of organic waste (e.g human mismanagement)	Access control	Install signs		Point/ Polygon	Volunteer	In-house	Capital / contractor
Industrial or domestic spills/discharges (odors, foam, oil sheen)	Y	N	Low	Medium	High	None	Investigate source	Excavation of contaminated soil	Re-grade and native vegetation planting				Point	Volunteer	In-house	Capital / contractor
Evidence of burning/fire	Y	N	Low	Medium	High	None	Investigation	Native vegetation planting	Community education				Point/ polygon	Volunteer	In-house	Capital / contractor
Construction Impacts: ______________________	Y	N	Low	Medium	High	None	Report to Borough Operations						Point	N/A	N/A	N/A

CONCERNS			**SERVERITY**			**RESTORATION ACTION**							**GPS ACTION**	**EFFORT**		
Deer Browsing	Y	N	Low	Medium	High	N/A							None	N/A	N/A	N/A
STREAM FEATURES			**SERVERITY**			**RESTORATION ACTION**							**GPS ACTION**	**EFFORT**		
Gullies	Y	N	N/A			None	Volunteer Repair	Contractor Repair	Stormwater inputs	Trails			Point	Volunteer	In-house	Capital / contractor
Culverts	Y	N	N/A			None	Repair	Re-design undersized culverts					Point	Volunteer	In-house	Capital / contractor
Wiers	Y	N	N/A			None	Repair	Re-design					Point	Volunteer	In-house	Capital / contractor
Dam	Y	N	N/A			None	Physical barrier causing blockage, Debris Removal - volunteer	Physical barrier causing blockage, Debris Removal - capital	None (natural)				None	Volunteer	In-house	Capital / contractor
Direct discharge pipes (circle type and record diameter)																
Septic/sewage: Diam___________	Y	N	N/A			None	Investigate	Install storage vault or tank	Install BMP				Point	Volunteer	In-house	Capital / contractor
Stormwater: Diam___________	Y	N	N/A			None	Investigate	Install storage vault or tank	Install BMP				Point	Volunteer	In-house	Capital / contractor
Unmanaged discharge: Diam_______	Y	N	N/A			None	Investigate	Install storage vault or tank	Install BMP				Point	Volunteer	In-house	Capital / contractor
Buffer - Left Bank	Y	N	<10m	10 - 30 m	>30m	None	Install BMP to address direct stormwater runoff	Install erosion control fabric and native plantings on buffer		Land Management: reduced mowing			None	Volunteer	In-house	Capital / contractor
Buffer - Right Bank	Y	N	<10m	10 - 30 m	>30m	None	Install BMP to address direct stormwater runoff	Install erosion control fabric and native plantings on buffer		Land Management: reduced mowing			None	Volunteer	In-house	Capital / contractor
Invasive Vegetation																
1. spp: ___________________________________			Low	Medium	High	0-5 %	5-25 %	26-50%	51-75%	76-100%			N/A	Volunteer	In-house	Capital / contractor
2. spp: ___________________________________			Low	Medium	High	0-5 %	5-25 %	26-50%	51-75%	76-100%			N/A	Volunteer	In-house	Capital / contractor
3. spp: ___________________________________			Low	Medium	High	0-5 %	5-25 %	26-50%	51-75%	76-100%			N/A	Volunteer	In-house	Capital / contractor
Rare Spp / Native Vegetation																
1. spp: ___________________________________						2. spp: ___________________________________			3. spp: ___________________________________							

FEASIBILITY AND CONSTRAINTS: First determine is the location is suitbale for Stewardship or Capital Restoration. If yes, fill out the remaining informaion.																
1) Suitable for stewarding?	Yes (fill out info below)			No						**2) Suitable for capital restoration?**		Yes (fill out info below)			No	
Stewardship Site Access:						**Vegetation Hazards:**	**Severity**			**Contractor Site Access:**						
- Terrain	Easy		Moderate		Difficult	- Poison ivy	Low	Medium	High	- Terrain		Easy		Moderate	Difficult	
- Trail Access	Easy		Moderate		Difficult	- Thorny plants	Low	Medium	High	- Tree Removals		Easy		Moderate	Difficult	
- Distance to road	Close		Moderate		Far					- Distance to road		Close		Moderate	Far	
Sensitivity (e.g. 1 Million Trees Area, rare species habitat):						Yes, ______________________________		No		**COMMENTS:**						
Evidence of Contamintion:						Yes, known contamination	Evidence of contamination	No evidence of contamination								
Questional Debris:						Low	Moderate	Severe								
Site Capacity (# of volunteers):	1 to 5	5 to 10				10 to 20	20 to 30	30+								

3. Macroinvertebrate Scoring Sheet:

THE HEADWATER MACROINVERTEBRATE FIELD EVALUATION INDEX (HMFEI) SCORING SHEET

Indicate Abundance of Each Taxa Above each White Box.
Record HMFEI Scoring Value Points Within each Box.
For EPT taxa, also indicate the different taxa present.

Key: V = Very Abundant (> 50); A = Abundant (10 -50); C = Common (3 -9); R = Rare (< 3)

Sessile Animals (**Porifera, Cnidaria, Bryozoa**) (HMFEI pts = 1) ☐	Crayfish (**Decapoda**) (HMFEI pts = 2) ☐	Fishfly Larvae (**Corydalidae**) (HMFEI pts = 3) ☐
Aquatic Worms (**Turbellaria, Oligochaeta, Hirudinea**) (HMFEI pts = 1) ☐	Dragonfly Nymphs (**Anisoptera**) (HMFEI pts = 2) ☐	Water Penny Beetles (**Psephenidae**) (HMFEI pts = 3) ☐
Sow Bugs (**Isopoda**) (HMFEI pts = 1) ☐	Riffle Beetles (**Dryopidae, Elmidae, Ptilodactylidae**) (HMFEI pts = 2) ☐	Cranefly Larvae (**Tipulidae**) (HMFEI pts = 3) ☐
Scuds (**Amphipoda**) (HMFEI pts = 1) ☐	Larvae of other Flies (**Diptera**) Name: (HMFEI pts = 1) ☐	EPT TAXA* Total No. EPT Taxa = ______
Water Mites (**Hydracarina**) (HMFEI pts = 1) ☐	Midges (**Chironomidae**) (HMFEI pts = 1) ☐	Mayfly Nymphs (**Ephemeroptera**) Taxa Present: [HMFEI pts = No. Taxa (x) 3] ☐
Damselfly Nymphs (**Zygoptera**) (HMFEI pts = 1) ☐	Snails (**Gastropoda**) (HMFEI pts = 1) ☐	
Alderfly Larvae (**Sialidae**) (HMFEI pts = 1) ☐	Clams (**Bivalvia**) (HMFEI pts = 1) ☐	Stonefly Nymphs (**Plecoptera**) Taxa Present: [HMFEI pts = No. Taxa (x) 3] ☐
Other Beetles (**Coleoptera**) (HMFEI pts = 1) ☐	Other Taxa :	
Other Taxa:	Other Taxa:	Caddisfly Larvae (**Trichoptera**) Taxa Present: [HMFEI pts = No. Taxa (x) 3] ☐
Other Taxa:	Other Taxa	

*Note: EPT identification based upon Family or Genus level of taxonomy

Voucher Sample ID______________________

Time Spent (minutes):______________________

Notes on Macroinvertebrates: (Predominant Organisms: Other Common Organisms: Diversity Estimate)

____

____

____

Final HMFEI Calculated Score (Sum of All White Box Scores) = ☐

IF Final HMFEI Score is > 19, Then CLASS III PHWH STREAM
IF Final HMFEI Score is 7 to 19, Then CLASS II PHWH STREAM
IF Final HMFEI Score is < 7, Then CLASS I PHWH STREAM

STREAM QUALITY ASSESSMENT FORM

LOCATION
STREAM
SAMPLE #

LOCATION

COUNTY
TOWNSHIP/CITY
DATE
TIME

GROUP OR INDIVIDUALS
NO. OF PARTICIPANTS

DESCRIBE WATER CONDITIONS (COLOR, ODOR, BEDGROWTHS, SURFACE SCUM, ETC.)

HACH KIT RESULTS (if used) AND OTHER OBSERVATIONS

USE BACK OF FORM IF NECESSARY

WIDTH OF RIFFLE

WATER DEPTH

WATER TEMP. (°F)

BED COMPOSITION OF RIFFLE (%)

SILT ☐ SAND ☐ GRAVEL (¼"- 2") ☐

COBBLES (2"- 10") ☐ BOULDERS (> 10") ☐

MACROINVERTEBRATE TALLY

ESTIMATED COUNT LETTER CODE

A = 1 to 9
B = 10 to 99
C = 100 or more

GROUP 1 TAXA	LETTER CODE	GROUP 2 TAXA	LETTER CODE	GROUP 3 TAXA	LETTER CODE
WATER PENNY LARVAE		DAMSELFLY NYMPHS		BLACKFLY LARVAE	
MAYFLY NYMPHS		DRAGONFLY NYMPHS		AQUATIC WORMS	
STONEFLY NYMPHS		CRANE FLY LARVAE		MIDGE LARVAE	
DOBSONFLY LARVAE		BEETLE LARVAE		POUCH SNAILS	
CADDISFLY LARVAE		CRAYFISH		LEECHES	
RIFFLE BEETLE ADULT		SCUDS			
OTHER SNAILS		CLAMS			
		SOWBUGS			
NUMBER OF TAXA *(times)* INDEX VALUE 3		NUMBER OF TAXA *(times)* INDEX VALUE 2		NUMBER OF TAXA *(times)* INDEX VALUE 1	

CUMULATIVE INDEX VALUE

STREAM QUALITY ASSESSMENT

EXCELLENT (> 22) ☐ GOOD (17-22) ☐

FAIR (11-16) ☐ POOR (< 11) ☐

Conversion of New York State tolerance values to stream macroinvertebrate quality index values for caddisfly families.

Family	**Tolerance Value**	**General Index Value**
Apataniidae	3	2
Brachycentridae	1	3
Calamoceratidae	3	2
Dipseudopsidae	5	1
Glossosomatidae	1	3
Goeridae	3	2
Helicopsychidae	3	2
Hydropsychidae	4	2
Hydroptilidae	4	2
Lepidostomatidae	1	3
Leptoceridae	4	2
Limnephilidae	3	2
Molannidae	6	1
Odontoceridae	0	3
Philopotamidae	3	2
Phryganeidae	4	2
Polycentropodidae	6	1
Psychomyiidae	2	3
Rhyacophilidae	1	3
Sericostomatidae	3	2
Uenoidae	3	2

NOTE:

Tolerance values 0-2 = index value of 3
Tolerance values 3-4 = index value of 2
Tolerance values 5-6 = index value of 1

Appendix B. Glossary of Terms

Bank Height – The vertical height of a stream bank in centimeters, measured between its toe at the digging level and the height at which the bank plateaus. Bank height is measured at the edge of the stream bed.

Bank Slope or Angle – The angle formed by the slope of the bank, measured in degrees of deviation from the horizontal toe of the stream bank.

Bank Vegetation – The average percentage of the left and right banks, 10 m in either direction from each transect, that is directly covered by vegetation, estimated top-down and excluding layered vegetation. The five most abundant understory plant species that are growing on the bank and their respective percent covers are also recorded. Both the total vegetation and individual species percent covers are recorded as the midpoint of the following cover class ranges: 0-5% = 2.5%; 6-12.5% = 8.75%; 12.6-25% = 18.75%; 26-50% = 37.5%; 51-75% = 67.5%; 76-100% = 87.5%.

Bankfull Channel – The portion of a stream that conveys water during a 1-year flood event. The width is measured in meters, the depth is measured at ¼, ½, and ¾ intervals in centimeters, to form a pentagonal cross section.

Bankfull Width – The distance, measured in meters, across an active channel at the height of a 1-year flood event.

Bankfull Depth – The depth, measured in centimeters, of a streambed measured at ¼ bankfull width, ½ bankfull width, and ¾ bankfull width and averaged.

Twice Bankfull Width – The width, measured in meters, of the stream channel at twice the height of the greatest bankfull depth.

Benthic Index – Scoring system that correlates macroinvertebrate benthos abundance code with an associated taxa pollution tolerance value.

Benthic Indicators – Species whose presence, abundance, and diversity may correlate with pollution levels and therefore serve as a proxy for water quality.

Benthic Species Abundance – The number of individuals of each morpho-species found in a kick sample, tallied, and then assigned an abundance code, based on the tally number counted (A = 1-9; B = 10-99; C = 100 or more).

Canopy Cover – The average percentage by which the uppermost layer of riparian vegetation covers, or shades, the stream, 10m in either direction from each transect line is recorded as an absolute value. The five most abundant riparian species that are growing on the bank or within approximately 5 m of the floodplain, and their respective percent covers are also recorded, as the midpoint of the following cover class ranges: 0-5% = 2.5%; 6-12.5% = 8.75%; 12.6-25% = 18.75%; 26-50% = 37.5%; 51-75% = 67.5%; 76-100% = 87.5%.

Channel Geometry – Characteristics of the stream channel or bed, such as width, depth and shape.

Classification of Wetland Areas (US Fish and Wildlife Service National Wetland Inventory) –

PEM (Palustrine Freshwater Emergent Wetland)	Wetlands characterized by rooted herbaceous and grass-like plants which stand erect above the water or ground surface (excluding mosses and lichens), including marshes, meadows, and fens. Emergent wetlands can be further described by the presence of persistent or non-persistent vegetation.
PFO (Palustrine Freshwater Forested Wetland)	Wetland dominated by woody vegetation 20 feet or taller. Forested wetlands, e.g. forested swamps, generally include a canopy of trees, an understory of young trees and shrubs, and an herbaceous layer.
PSS (Palustrine Freshwater Shrub Wetland)	A scrub-shrub wetland is dominated by woody vegetation less than 20 feet tall, including tree shrubs, young trees, and stunted trees or shrubs.
PUB (Palustrine Unconsolidated Bottom)	Areas of water with at least 25% cover of particles smaller than stones (less than 6-7 cm), and a vegetative cover less than 30%.
Isolated Wetland	Wetlands without a permanent surface water connection to larger water bodies. Isolated wetlands contribute to groundwater recharge and floodwater retention, and because they serve as nutrient sinks, they help to maintain water quality. They also provide habitat for plants and animals.
Connected Wetland	Wetlands with permanent surface water connection to larger water bodies. This category includes mudflats, littoral zones, and intertidal marshes.

Colluvial Sediments – Sediment that has been deposited in the stream by erosion and/or runoff from the banks.

Continuity – Continuity of a reach means the stream bed and banks are relatively uniform in physical characteristics throughout the length of the reach. If part of the reach is very different from the rest, then that reach should be broken down into separate reaches, based on physical similarities/continuity.

Cowardin System of Wetland Classification – A classification system developed in 1979 that categorizes wetlands into two general types: coastal (tidal or estuarine wetlands) and inland (non-tidal, freshwater, and palustrine wetlands). The classification further classifies systems into subsystems, classes, subclasses, and modifiers.

Cut Banks – A river-cut cliff featured on the outside of a bank, which continually experiences erosion.

D_{50} – The median grain size calculated from a pebble count that can be used as a representative value for comparing grain size across samples.

D_{84} – The 84th percentile value of grain size calculated from a pebble count that can be used as a representative value for comparing grain size across samples.

Ditch – A narrow channel dug in the ground, typically used for drainage alongside a road or the edge of a field.

Dominant Stream Type – The type of stream (i. e. step-pool, plane-bed/straight, pool-riffle, etc.) that most closely represents the entire reach under assessment.

Drainage Area Type – The type of sewer drainage system (i.e. combined sewer systems or separate sewer systems like MS4s) that collects groundwater in the area adjacent to the stream.

Dredging/Excavation – Digging of sediment within a stream (stockpiling or removal typically follow this effort).

Entrenchment Ratio – The width of the flood prone area width of the channel measured at 2x the highest bankfull depth, divided by the bankfull width.

Ephemeral stream – Stream that has flowing water for brief periods following rainfall events.

Flow Conditions – Amount of continuity of surface water flow in the stream channel.

Surface Flow	Present flow in the stream
Some Visible Flow	Visible, but discontinuous flow
No Flow	Surface flow absent, but water is present in pools

Freshwater Pond (Palustrine Unconsolidated Bottom) – Areas of water with at least 25% cover of particles smaller than stones (less than 6-7 cm), and a vegetative cover less than 30%.

Gradient – Stream gradient is the slope of a stream (gradient=vertical height of a longitudinal profile/distance of a longitudinal profile).

Green Infrastructure Opportunities – A dataset of polygons or attributes of green infrastructure opportunities (i.e. bioswales) in wetland, stream, or non-wetland area adjacent to or surrounding the wetland or stream reach (NYCDEP).

Gullies – Narrow, steep, cut channels formed by running water.

Headwater Stream – A smaller tributary that feeds into a stream system, characterized by a stream order of first, second or third.

Hydrography – The science of surveying and mapping bodies of water, such as lakes, rivers, and seas.

Impoundment - A body of water confined within an enclosure, as a reservoir.

Intermittent stream – Stream that ceases to flow in dry periods and does not have continuously-flowing water year-round.

Isolated Wetland – Wetlands without a permanent surface water connection to larger water bodies. Isolated wetlands contribute to groundwater recharge and floodwater retention, and because they serve as nutrient sinks, they help to maintain water quality. They also provide habitat for plants and animals (NYS DEC).

Lake (Lacustrine Unconsolidated Bottom) – Wetlands and deepwater habitats that are generally permanently flooded, natural or artificial lakes and reservoirs. They exhibit the following characteristics: 1) situated in a topographic depression or a dammed river channel; 2) lacking trees, shrubs, persistent emergent plants, emergent mosses, or lichens with greater than 30% area coverage; and, 3) total area exceeds 20 acres.

Land Use – Reaches are designated/characterized based on land use (among others), which refers to the type of property the stream is located on and the surrounding land's designated use (recreational, housing, agricultural, etc.).

Large Woody Debris – Naturally placed large wooden debris (fallen logs, branches, tree stumps, etc.) greater than 10cm in diameter, in over 50% of the bankfull channel, that perform key functions such as the dissipation of flow energy, stabilization of bedforms and channel banks, entrapment of sediment, formation of pools, and habitat provisioning.

Left Bank – The left side of the bank when looking downstream.

LiDAR – LiDAR (Light Detection and Ranging) is a surveying technology that measures distance by illuminating a target with a laser light.

Max Elevation at Reach End – The maximum surface elevation as measured at the reach end, where surface elevation should be highest within the reach.

Meander Pattern – A characterization of how the stream has deviated from a linear course, based on geographic features, such as meander width, meander wavelength, radius of curvature, and amplitude.

Meander Width – Reaches are designated/characterized based on meander width, which is measured as the ratio of the distance the stream has deviated from a linear course to the bankfull width.

Min Elevation at Reach Start – The minimum surface elevation as measured at the reach start, where surface elevation should be lowest within the reach.

Municipal Separate Storm Sewer System (MS4) – In separate sewer areas (separate stormwater and sewer infrastructure systems) within NYC, as stormwater flows over impervious surfaces and transports pollutants like oils, chemicals, sediments, and pathogens, it is conveyed directly into NYC's waterways via streets, curbs, ditches, catch basins, gutters, storm drains, etc. (NYC DEP). MS4 discharge impacts on NYC stream and freshwater wetland systems include poor water quality and sedimentation.

National Wetlands Inventory (NWI) – The NWI, established by the U.S. Fish and Wildlife Service, has been producing wetland maps and geospatial wetland data since 1974. The two focuses of the NWI are: 1) map or digital database preparation and delivery to the public, and 2) projecting and reporting on national wetland trends using a probability-based sampling design.

Object-Based Remote Sensing Technology – Object-based, or object-oriented, image analysis (OBIA) classifies objects of different shape and scale via a process known as multi-resolution segmentation. These objects can be classified by texture, context, and geometry, which is more meaningful than the traditional pixel-based segmentation.

Outfalls – The discharge point, or outlet, of a stream into a body of water. This includes MS4s pipes, which take account of PVC, concrete pipes, swales, ditches, etc., in accordance with the Municipal Separate Sanitary Sewage System (MS4) mapping protocol.

Perennial stream – Stream that has continuous flow in part of its stream bed all year round in years of normal rainfall.

Pools – Areas within a stream where water is slower than the stream's average flow, and deeper than the stream's average depth. Ideally, pools are tallied while walking upstream for the purposes of this protocol.

Pool Depth – The greatest depth of a single pool, usually found near the center.

Presence/Absence of Salamanders – The presence or absence of three salamander species (northern dusky salamander, northern two-lined salamander, and northern red salamander), which are the top vertebrate predators in headwater streams, is used to assign a class to headwater streams.

Ratio of Bank Height to Bankfull Height – Calculated as the bank height divided by the bankfull height, or the bankfull depth. A higher ratio suggests a higher risk of bank erosion.

Ratio of Root Depth to Bank Height – Calculated as rooted depth divided by bank height. A smaller ratio suggests a higher risk of bank erosion.

Reach Code – A unique identifier to distinguish and label stream reaches, identified as follows: Borough.Watershed.ParkNumber.StreamName.StreamOrder.ReachNumber.

Reach End – The furthest upstream point where the assessed reach comes to an end.

Reach Length – The total length of the reach assessed, from reach start to reach end.

Reach Slope – The average change in surface elevation along the reach, calculated by dividing reach length by the difference between the max elevation at reach end and the min elevation at reach start.

Reach Start – The furthest downstream point where assessment of the reach begins.

Residual Pool Depth – The difference between the measured depth of the nearest pool upstream to each transect and the riffle depth at the same transect.

Restoration Opportunities – A dataset of polygons and attributes of restoration opportunities (i.e. bank stabilization, debris removal by volunteers or contractors) in wetland, stream, or non-wetland areas adjacent to or surrounding the wetland or stream reach.

Riffle – Section of a stream with decreased depth and a rapid surface flow interrupted by debris. Usually between pools in a riffle/pool stream system.

Riffle Depth – The average depth of a stream across a single riffle.

Right Bank – The right side of the bank when looking downstream.

Riparian – Located on or along the stream bank.

Riparian Buffer Width – The extent of the area on either side of the stream that is covered in riparian vegetation.

Riverine Wetland – A Riverine system includes all wetlands and deepwater habitats contained within a channel, with two exceptions: 1) wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and 2) habitats with water containing ocean-derived salts in excess of 0.5 ‰.

Road Crossing – Roads that cross over streams, with engineered infrastructure that typically shrinks the width of the stream.

Rooted Depth – The portion of the vertical height of a stream bank that is rooted and therefore resistant to erosion. This is measured in centimeters from the top of the bank.

Sedimentation – Sediment deposition featured on the inside of a bank.

Seeps – Water, usually groundwater, which emerges from an ill-defined area/broader area. Can contribute to streams if the stream is flowing below the local water table. Seeps may be indicated by the presence of lower riparian vegetation.

Sinuosity – The ratio of valley slope to channel slope (desktop-determined using ArcGIS and the following definition as provided by the Rosgen Stream Classification). The greater the number, the higher the sinuosity, and the curvier the stream is.

Siphons/Pumps – Presence of human-made siphons or pumps within a stream.

Springs – Groundwater that emerges from the earth, typically at a single point. Can be connected to a stream by a stream branch.

Stormwater – A product of rain and snow melt, which is transported over impervious surfaces such as rooftops, streets, and sidewalks (NYC DEP). Stormwater impacts on NYC stream and freshwater wetland systems include sedimentation, poor water quality, etc.

Stream Classification –

Silt / sand	Benthic taxa indicative of low-oxygen conditions are found in streams of this substrate type.
Sand / gravel	Benthic taxa that burrow are found in streams of this substrate type.
Gravel / cobble	Benthic taxa that cling to rocks are found in streams of this substrate type. Gravel / cobble streams show a higher abundance of mayflies, stoneflies, and caddisflies, as well as salamanders found in the moraine.
Concrete	No biota are expected in concrete-bottom streams.

Stream Concerns – Factors that may degrade the quality and/or aesthetics of a stream, or indicators of such factors.

Stream Order – A classification of the stream based on its relative size that is used to identify reaches. First-order streams refer to the smallest tributaries that flow into a larger system. The stream that a first-order tributary flows into would be considered second-order, and so on.

Stream Reach – A Stream Reach is a general term for a length of a stream that is uninterrupted and exhibits homogeneous physical characteristics.

Stream Slope – Reaches are designated/characterized based on stream slope (among others), which measures the changes in elevation along a stream. Stream slope partly dictates stream type and the direction and speed of flow.

Substrate Size – The size of the material in the stream bed, measured in centimeters along the intermediate axis.

Swale – A shallow channel with gently sloping sides, either natural or manmade,

Pebble Count – A survey of 100 individual pieces of sediment, measured along the intermediate axis, in the vicinity of Transect 2 of each Stream Reach. Protocols used follow the Wolman Pebble Count (1984).

Trail Crossing – Trails, created by human or wildlife traffic, that are not mapped by NYC Parks via the NRG_Trails database (NRG_Trails.NRG.Trails feature class; NRG GIS and Analytics Team). Total crossing number will be calculated using unmapped crossings and this database.

Transect – A cross-section of the stream that is assessed in detail. Three transects, spaced evenly throughout the reach and representative of the surrounding areas, are assessed along each reach.

Valley Width – In addition to bankfull width, the valley width of a stream includes the width of the surrounding flood plain on either side of the stream.

Watershed – A stream's watershed is the entire surrounding land area from which water may flow into the stream. Each stream is located within a watershed, which is used to identify reach code.

Weir – A man-made barrier that stretches the width of a river, designed to retard flow and manage water levels.

Appendix C. Recommended Management Actions by Reach and Associated Maps

Table 1. Primary and secondary recommended management actions for each assessed stream reach.

Reach Code	Watershed	Primary Recommendation	Secondary Recommendation
QN.ACLNB.Q001.Alley.R1	ACLNB.	Manage stormwater	
QN.ACLNB.Q001.TulipCreek.R1	ACLNB.	Protect	
QN.ACLNB.Q001.Alley.R6	ACLNB.	Rehabilitate	
SI.AKN.R143.IndustrialPark.R3	AKN.	Manage stormwater	
SI.AKN.R143.IndustrialPark.R6	AKN.	Manage stormwater	
SI.AKN.R143.IndustrialPark.R1	AKN.	Manage stormwater	
SI.AKN.R143.IndustrialPark.R5	AKN.	Manage stormwater	
SI.AKRCNA.R030.Willowbrook.R21	AKRCNA.	Manage stormwater	
SI.AKRCNA.R030.Willowbrook.R22	AKRCNA.	Manage stormwater	
SI.AKRCNA.R030.Willowbrook.R2	AKRCNA.	Manage buffer	
SI.AKRCNA.R030.Willowbrook.R7	AKRCNA.	Manage stormwater	
SI.AKRCNA.R047.GreatSwamp.R3	AKRCNA.	Manage stormwater	
SI.AKRCNA.R030.Willowbrook.R3	AKRCNA.	Manage buffer	
SI.AKRCNA.R030.Willowbrook.R20	AKRCNA.	Protect	
SI.AKRCNA.R047.GreatSwamp.R2	AKRCNA.	Protect	
SI.AKRCNA.R047.GreatSwamp.R4	AKRCNA.	Protect	
SI.AKRCNA.R047.GreatSwamp.R1	AKRCNA.	Protect	
SI.AKRCNA.R030.Willowbrook.R9	AKRCNA.	Manage stormwater	
SI.AKRCNA.R017.WTDavis.R1	AKRCNA.	Manage stormwater	Manage buffer
SI.AKRCNA.R030.Willowbrook.R4	AKRCNA.	Manage stormwater	Manage buffer
SI.AKRCNA.R017.WTDavis.R2	AKRCNA.	Manage stormwater	
SI.AKRCNA.R030.Willowbrook.R5	AKRCNA.	Rehabilitate	
SI.AKRCNA.R030.Willowbrook.R1	AKRCNA.	Protect	
SI.AKRCNA.R030.Willowbrook.R6	AKRCNA.	Manage stormwater	
SI.AKRCNB.R047.BucksHollow.R2	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R17	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R2	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R6	AKRCNB.	Manage stormwater	
SI.AKRCNB.R013.LaTouretteNorth.R5	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteSouth.R2	AKRCNB.	Protect	
SI.AKRCNB.R047.RichmondCreek.R5	AKRCNB.	Manage stormwater	
SI.AKRCNB.R013.LaTouretteSouth.R1	AKRCNB.	Protect	In-stream structures
SI.AKRCNB.R013.LaTouretteNorth.R1	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R3	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R7	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteSouth.R5	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R18	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R4	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R3	AKRCNB.	Protect	

Reach Code	Watershed	Primary Recommendation	Secondary Recommendation
SI.AKRCNB.R047.BucksHollow.R3	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteSouth.R3	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R2	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R16	AKRCNB.	Protect	
SI.AKRCNB.R047.BucksHollow.R4	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R1	AKRCNB.	Protect	
SI.AKRCNB.R047.BucksHollow.R5	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R35	AKRCNB.	Protect	
SI.AKRCNB.R047.BucksHollow.R1	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R4	AKRCNB.	Protect	
SI.AKRCNB.R129.DeadmansCreek.R0	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R15	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteSouth.R7	AKRCNB.	Protect	
SI.AKRCNB.R140.KingFisher.R1	AKRCNB.	Manage stormwater	
SI.AKRCNB.R013.LaTouretteNorth.R6	AKRCNB.	Protect	
SI.AKRCNB.R047.RichmondCreek.R4	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R36	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteSouth.R9	AKRCNB.	Protect	
SI.AKRCNB.R013.LaTouretteNorth.R30	AKRCNB.	Protect	
SI.AKRCNB.R047.RichmondCreek.R3	AKRCNB.	Protect	
SI.AKRCNB.R088.WalkerPond.R1	AKRCNB.	Protect	
SI.AKRCNB.R013.RichmondCreekSouth.R1	AKRCNB.	Manage stormwater	
SI.AKRCNB.R013.LaTouretteSouth.R6	AKRCNB.	In-stream structures	Protect
SI.AKRCNB.R047.RichmondCreek.R1	AKRCNB.	Manage buffer	
SI.AKRCNB.R047.RichmondCreek.R2	AKRCNB.	Protect	
SI.AKRCS.R120.ArdenWoods.R23	AKRCS.	Manage buffer	
SI.AKRCS.R120.ArdenWoods.R1.2	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R120.ArdenWoods.R7	AKRCS.	Manage stormwater	Protect
SI.AKRCS.R120.ArdenWoods.R8	AKRCS.	Manage buffer	Protect
SI.AKRCS.R120.ArdenWoods.R6	AKRCS.	Manage stormwater	Protect
SI.AKRCS.R120.ArdenWoods.R22	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R120.ArdenWoods.R16	AKRCS.	Protect	
SI.AKRCS.R120.ArdenWoods.R1.1	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R017.Freshkills.R1	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R120.ArdenWoods.R21	AKRCS.	Manage buffer	
SI.AKRCS.R017.Freshkills.R2	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R120.ArdenWoods.R1	AKRCS.	Manage stormwater	Manage buffer
SI.AKRCS.R120.ArdenWoods.R17	AKRCS.	Manage buffer	
SI.AKRCS.R120.ArdenWoods.R10	AKRCS.	Rehabilitate	Manage stormwater
SI.AKRCS.R120.ArdenWoods.R18	AKRCS.	Manage stormwater	
SI.AKRCS.R120.ArdenWoods.R15	AKRCS.	Manage buffer	

Reach Code	Watershed	Primary Recommendation	Secondary Recommendation
SI.AKRCS.R120.ArdenWoods.R20	AKRCS.	Manage stormwater	
SI.AKRCS.R120.ArdenWoods.R19	AKRCS.	Manage stormwater	
SI.AKRCS.R017.FreshkillsSouth.R1	AKRCS.	Manage stormwater	
SI.AKS1C.R104.SouthShore.R12	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R11	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R10	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R8	AKS1C.	Manage stormwater	Manage buffer
SI.AKS1C.R104.SouthShore.R5	AKS1C.	Manage stormwater	
SI.AKS1C.R104.SouthShore.R4	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R2	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R9	AKS1C.	Manage stormwater	Manage buffer
SI.AKS1C.R104.SouthShore.R3	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R7	AKS1C.	Manage buffer	
SI.AKS1C.R104.SouthShore.R6	AKS1C.	Manage stormwater	
SI.AKS2A.R027.LongPond.R1	AKS2A.	Protect	
SI.AKS2A.R027.LongPond.R2	AKS2A.	Manage stormwater	
BX.ERBRW.X004.BronxRiver.R1	ERBRW.	Manage Stormwater	Manage buffer
BX.ERBRW.X002.AzaleaBrook.R1	ERBRW.	Protect	
BX.ERBRW.X002.AzaleaBrook.R2	ERBRW.	Protect	
QN.ERFB1.Q084.WillowLake.R1	ERFB1.	Manage stormwater	
BX.HR.X142.Riverdale.R1	HR.	Manage stormwater	
BX.HR.X142.Riverdale.R2	HR.	Protect	
BX.HR2.X092.Tibbets.R3	HR2.	Manage buffer	
BX.HR2.X092.Croton.R2	HR2.	Protect	
BX.HR2.X092.MjrDeegan.R1	HR2.	Manage stormwater	
BX.HR2.X092.Croton.R3	HR2.	Protect	
BX.HR2.X092.Tibbets.R1	HR2.	Protect	
BX.HR2.X092.Tibbets.R2	HR2.	Manage stormwater	
BX.HR2.X092.Tibbets.R4	HR2.	Manage buffer	
BX.HR2.X092.Croton.R1	HR2.	Manage stormwater	
QN.JBCHC.Q008.Brookville.R2	JBCHC.	Manage Stormwater	
QN.JBCHC.Q008.Brookville.R1	JBCHC.	Rehabilitate	
SI.KVKE.R116.Snug.R1	KVKE.	Manage stormwater	Manage buffer
SI.KVKE.R169.Goodhue.R2	KVKE.	Manage stormwater	Manage buffer
SI.KVKE.R052.Allison.R1	KVKE.	Manage stormwater	Manage buffer
SI.KVKE.R169.Goodhue.R1	KVKE.	Manage stormwater	Manage buffer
SI.KVKE.R116.Snug.R2	KVKE.	Rehabilitate	Manage buffer
SI.KVKW.R005.CloveLakes.R1	KVKW.	Manage stormwater	
SI.KVKW.R005.CloveLakes.R2	KVKW.	Manage stormwater	
SI.KVKW.R022.SilverLake.R0	KVKW.	Manage buffer	
SI.KVKW.R005.CloveLakes.R3	KVKW.	Manage stormwater	Manage buffer

Reach Code	Watershed	Primary Recommendation	Secondary Recommendation
SI.KVKW.R115.DeerePark.R2	KVKW.	Manage buffer	
SI.KVKW.R022.SilverLake.R1	KVKW.	Manage stormwater	
SI.KVKW.R022.SilverLake.R3	KVKW.	Manage stormwater	
SI.KVKW.R022.SilverLake.R2	KVKW.	Manage stormwater	
SI.KVKW.R115.DeerePark.R1	KVKW.	Manage buffer	
BX.LIS1.X039.ShoreRdNorth.R3	LIS1.	Manage buffer	
BX.LIS1.X039.PelhamNorth.R4	LIS1.	Manage stormwater	Protect
BX.LIS1.X039.PelhamNorth.R9	LIS1.	Protect	
BX.LIS1.X039.PelhamNorth.R7	LIS1.	Protect	
BX.LIS1.X039.PelhamNorth.R5	LIS1.	Manage stormwater	
BX.LIS1.X039.ShoreRdNorth.R1	LIS1.	Manage buffer	
BX.LIS1.X039.PelhamNorth.R11	LIS1.	Protect	
BX.LIS1.X039.ShoreRdSouth.R2	LIS1.	Protect	
BX.LIS1.X039.OrchardBeach.R5	LIS1.	Protect	
BX.LIS1.X039.BartowPell.R1	LIS1.	Protect	
BX.LIS1.X039.OrchardBeach.R6	LIS1.	Protect	
BX.LIS1.X039.PelhamNorth.R10	LIS1.	Manage stormwater	
BX.LIS1.X039.PelhamNorth.R8	LIS1.	Protect	
BX.LIS1.X039.PelhamNorth.R3	LIS1.	Manage stormwater	
BX.LIS1.X039.PelhamNorth.R1	LIS1.	Manage stormwater	
BX.LIS1.X039.OrchardBeach.R7	LIS1.	Protect	
BX.LIS1.X039.PelhamNorth.R2	LIS1.	Manage stormwater	
BX.LIS1.X039.ShoreRdSouth.R1	LIS1.	Manage buffer	
BX.LIS1.X039.PelhamSouth.R1	LIS1.	Manage stormwater	
BX.LIS1.X039.ShoreRdNorth.R2B	LIS1.	Manage buffer	
BX.LIS1.X039.ShoreRdNorth.R2A	LIS1.	Manage buffer	
BX.LIS1.X039.PelhamSouth.R2	LIS1.	Manage buffer	
BX.LIS1.X039.PelhamNorth.R6	LIS1.	Manage buffer	
BX.LISHR.X046.RattlesnakeCreek.R2	LISHR.	Protect	
BX.LISHR.X046.RattlesnakeCreek.R1	LISHR.	Protect	
SI.LNYBNC.R088.HighRock.R2	LNYBNC.	Protect	
SI.LNYBNC.R118.ReedsBasket.R1	LNYBNC.	Manage stormwater	
SI.LNYBNC.R118.ReedsBasket.R2	LNYBNC.	Manage stormwater	
SI.LNYBNC.R118.ReedsBasket.R0	LNYBNC.	Rehabilitate	
SI.LNYBNC.R088.HighRock.R3	LNYBNC.	Protect	
SI.RB.R006.ButlerManor.R1	RB.	Protect	
SI.RB.R006.ConferenceHouse.R1	RB.	Manage stormwater	
SI.RB.R136.HybridOak.R1	RB.	Protect	
SI.RB.R006.ButlerManor.R2	RB.	Protect	
SI.RB.R136.HybridOak.R2	RB.	Protect	
SI.RBAB.R119.BlueHeron.R5	RBAB.	Manage stormwater	

Reach Code	Watershed	Primary Recommendation	Secondary Recommendation
SI.RBAB.R119.BlueHeron.R1	RBAB.	Manage stormwater	
SI.RBAB.R119.BlueHeron.R6	RBAB.	Manage stormwater	
SI.RBAB.R119.BlueHeron.R4	RBAB.	Manage stormwater	
SI.RBAB.R119.BlueHeron.R3	RBAB.	Protect	
SI.RBAB.R119.BlueHeron.R8	RBAB.	Manage stormwater	
SI.RBAB.R119.BlueHeron.R7	RBAB.	Manage stormwater	
SI.RBAL.R132.BunkerPonds.R2	RBAL.	Manage stormwater	
SI.RBAL.R132.BunkerPonds.R1	RBAL.	Protect	
SI.RBGKH.R121.Siedenburg.R1	RBGKH.	Protect	
SI.RBLC.R106.Bloomingdale.R5	RBLC.	Manage stormwater	In-stream structures
SI.RBLC.R106.Bloomingdale.R4	RBLC.	Manage stormwater	
SI.RBLC.R106.Bloomingdale.R6	RBLC.	Manage stormwater	In-stream structures
SI.RBLC.R106.Bloomingdale.R8	RBLC.	Manage stormwater	
SI.RBLC.R106.Bloomingdale.R1	RBLC.	Manage stormwater	
SI.RBLC.R106.Bloomingdale.R7	RBLC.	Manage buffer	
SI.RBWP.R031.WolfesPond.R3	RBWP.	Manage stormwater	
SI.RBWP.R031.WolfesPond.R4	RBWP.	Manage stormwater	
SI.RBWP.R031.WolfesPond.R10	RBWP.	Manage stormwater	
QN.UC.Q452.Gabblers.R1	UC.	Rehabilitate	

Freshwater Wetlands & Streams

East & Bronx River Watersheds

▢ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N 0 0.5 1 Miles

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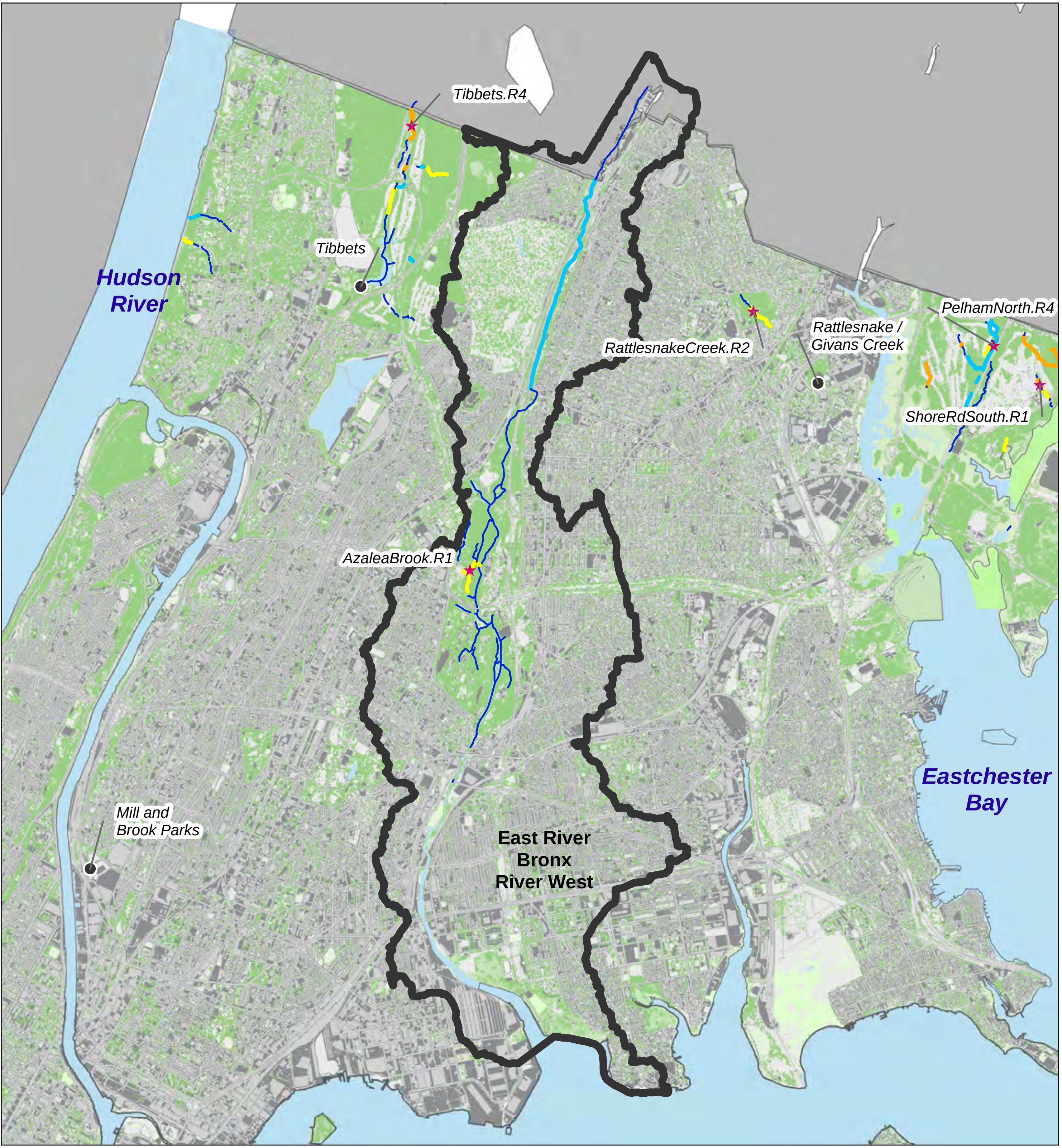

Freshwater Wetlands & Streams

Hudson & Harlem River Watersheds

▢ Watershed

— Hydroline

Assessed Reach Recommendation

🟨 Protect

🟧 Manage Buffer

🟦 Manage Stormwater

🟪 Rehabilitate

🟥 In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N
0 0.25 0.5 Miles

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Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Long Island Sound Watersheds

- ☐ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N

0 0.25 0.5 Miles

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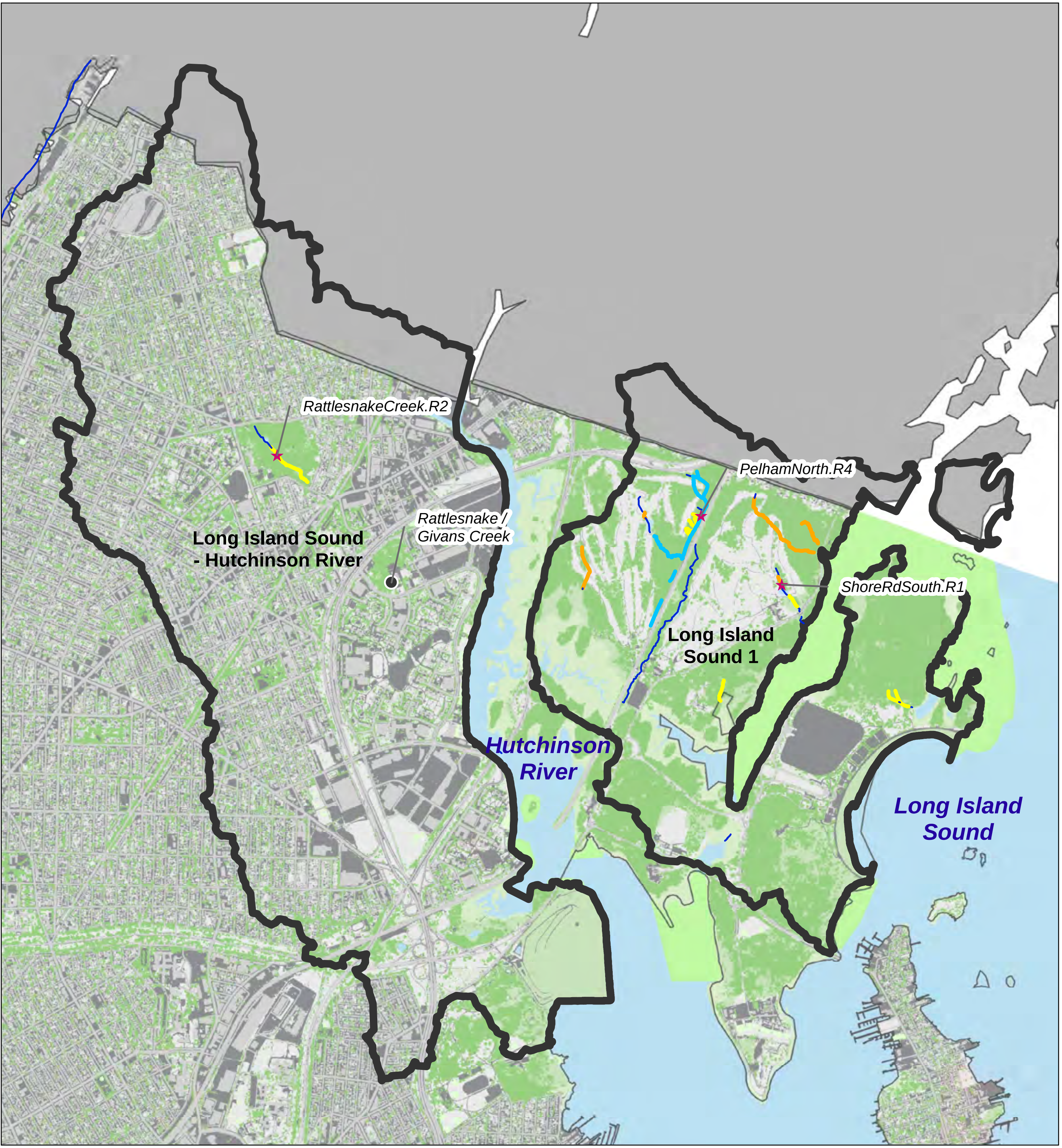

Freshwater Wetlands & Streams

Alley Creek Udalls Cove Watersheds

▢ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N 0 0.25 0.5 Miles

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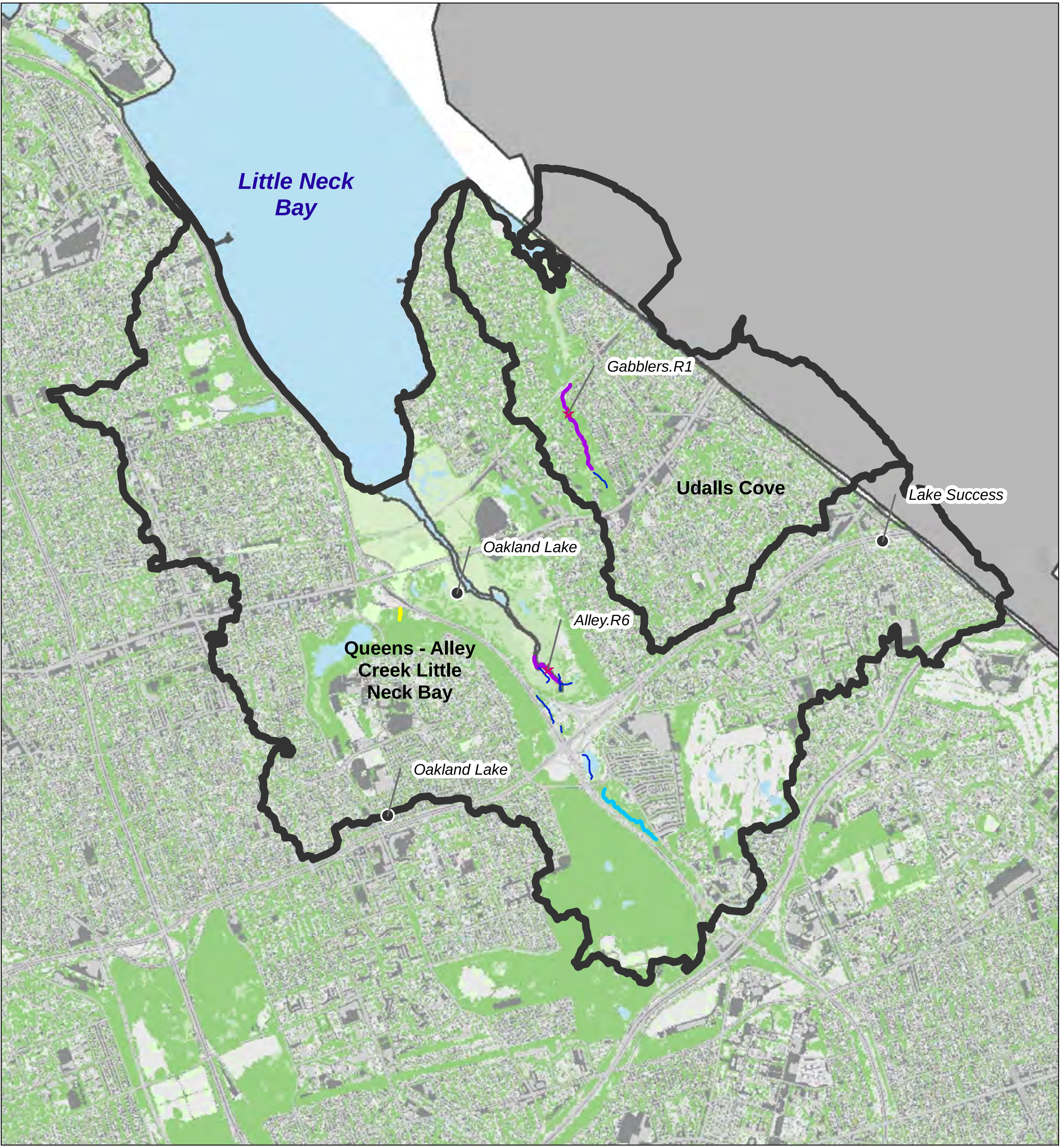

Freshwater Wetlands & Streams

East River Flushing Bay Watershed

- ▢ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N

0 0.5 1 Miles

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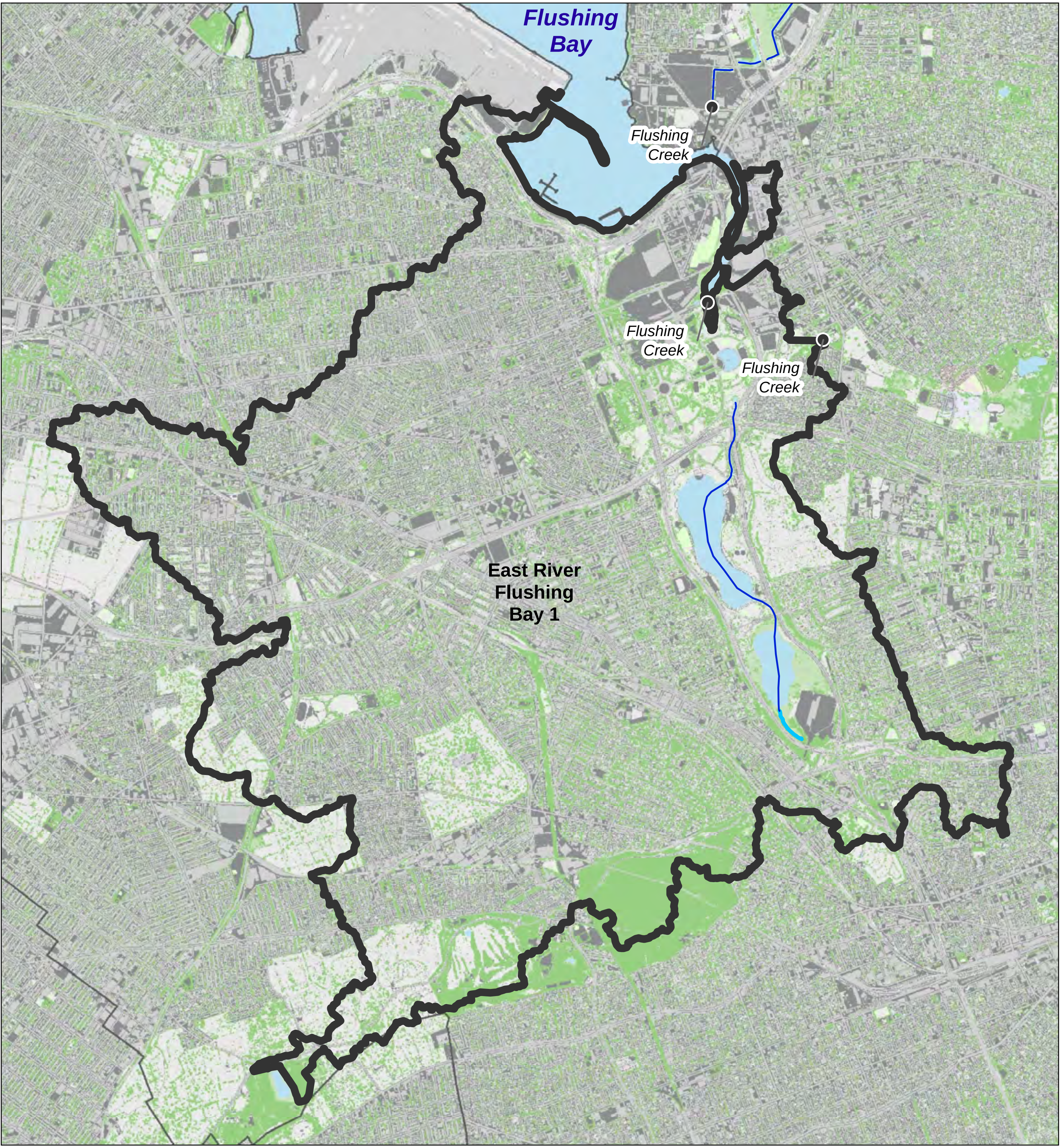

Freshwater Wetlands & Streams

Jamaica Bay Watershed

- ▢ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N 0 0.5 1 Miles

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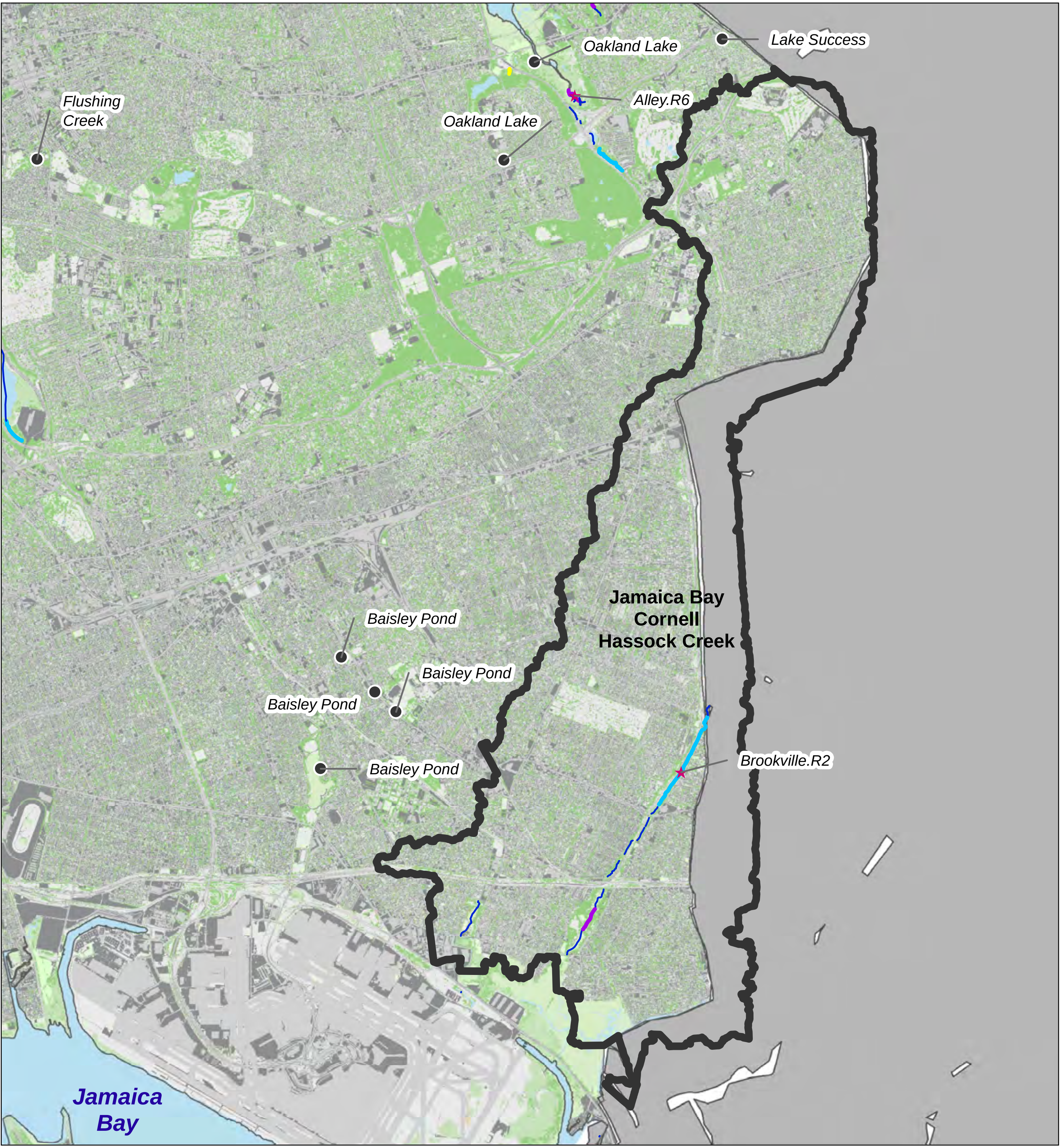

Freshwater Wetlands & Streams

Arthur Kill North Watershed

- ▣ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N

0 0.25 0.5 Miles

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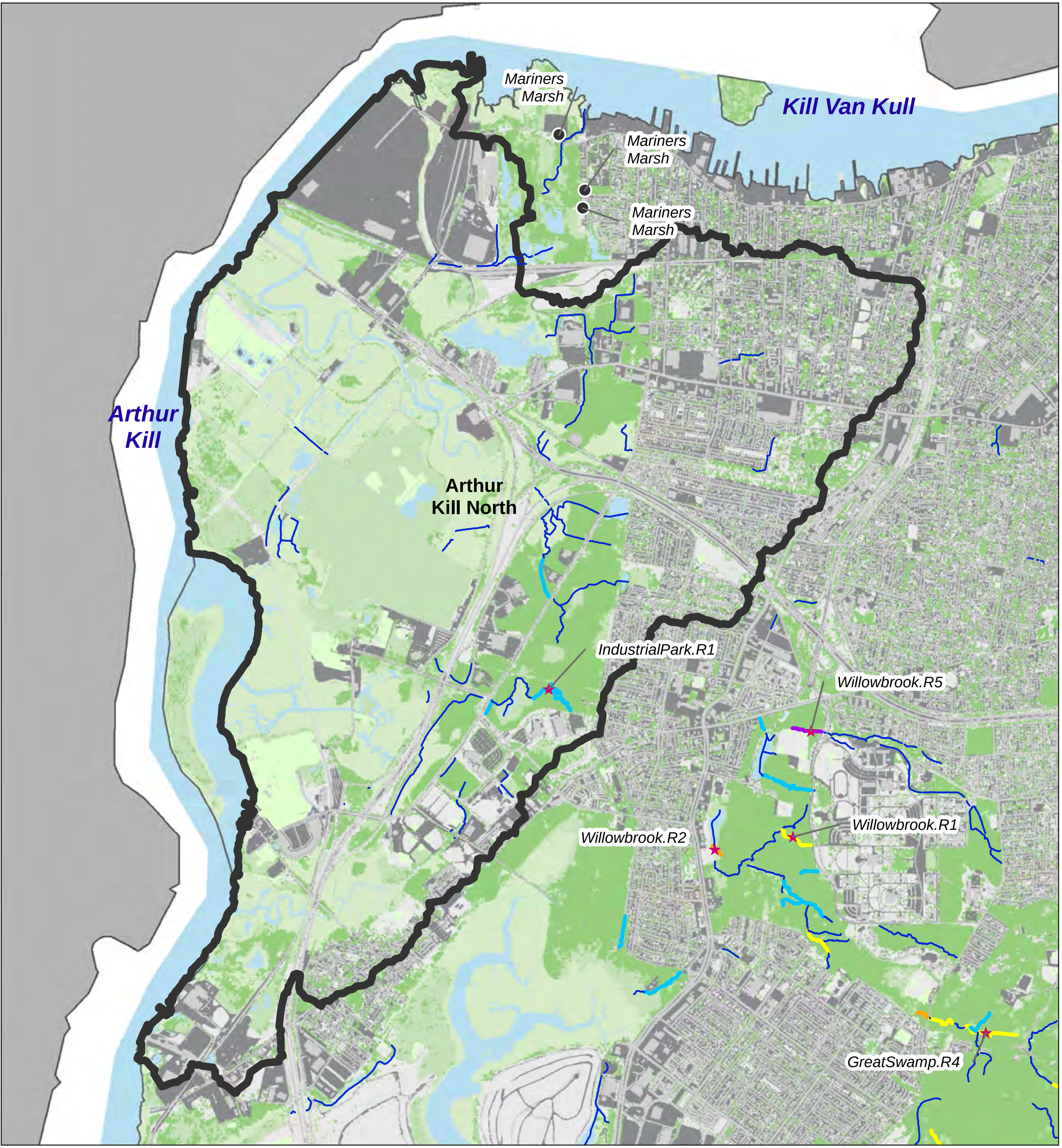

Freshwater Wetlands & Streams

Richmond Creek North Watersheds

▢ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N

0 0.5 1 Miles

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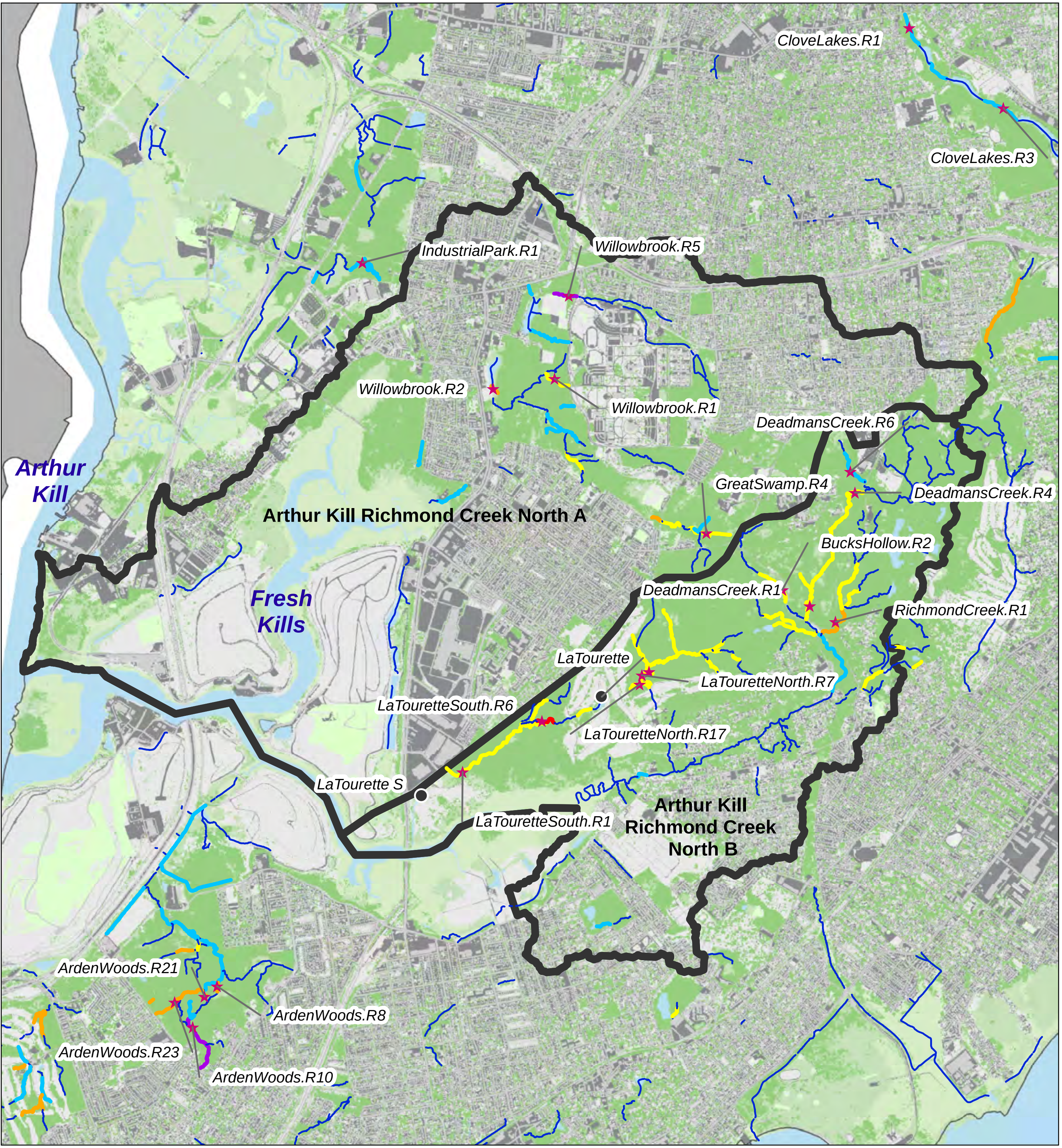

Freshwater Wetlands & Streams

Richmond Creek South Watershed

Watershed

Hydroline

Assessed Reach Recommendation

Protect

Manage Buffer

Manage Stormwater

Rehabilitate

In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N 0 0.25 0.5 Miles

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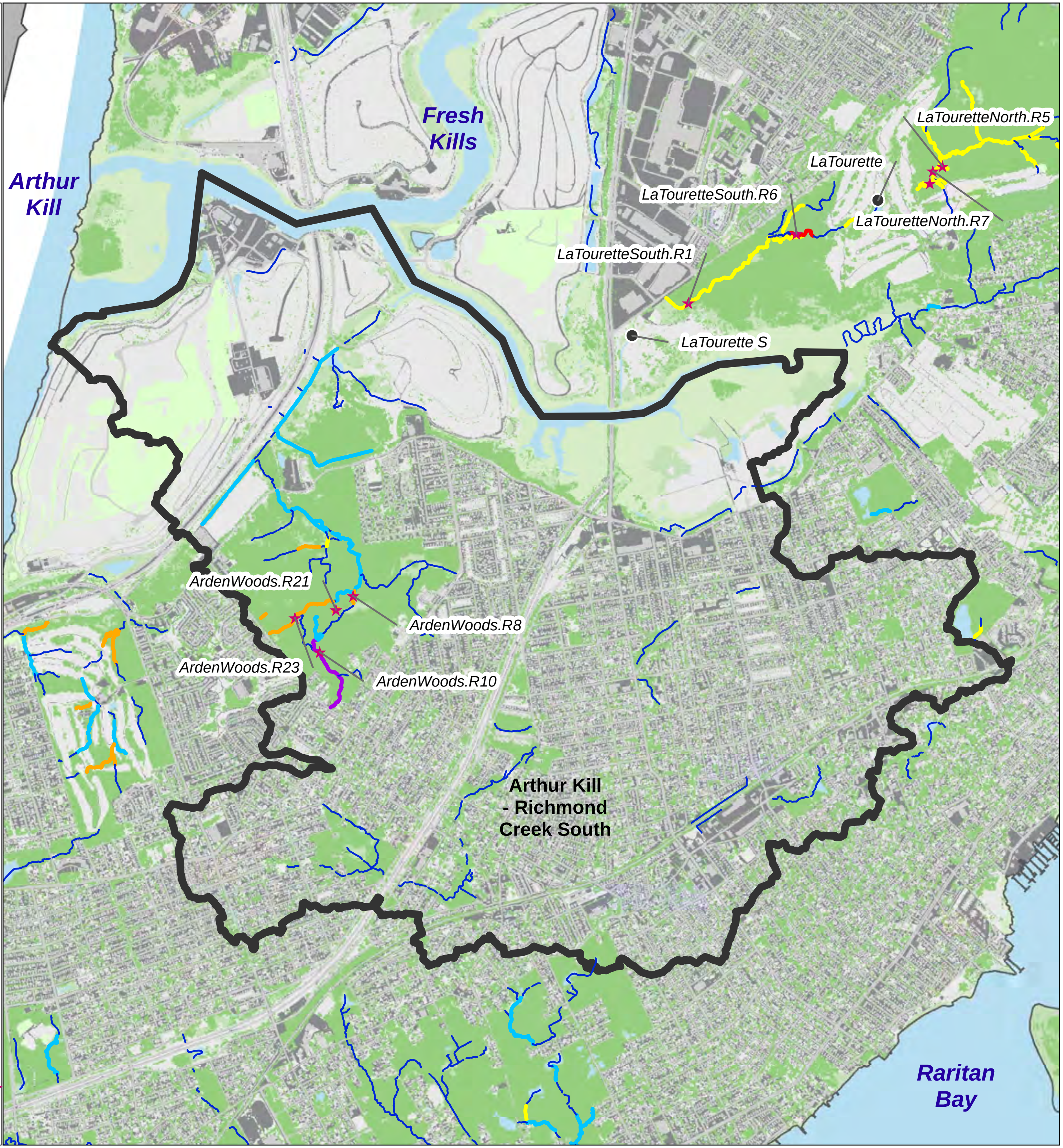

Freshwater Wetlands & Streams

Arthur Kill South Watersheds

- ▢ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N 0 0.25 0.5 Miles

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November 2020
Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Kill Van Kull Watersheds

▢ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N

0 0.5 1 Miles

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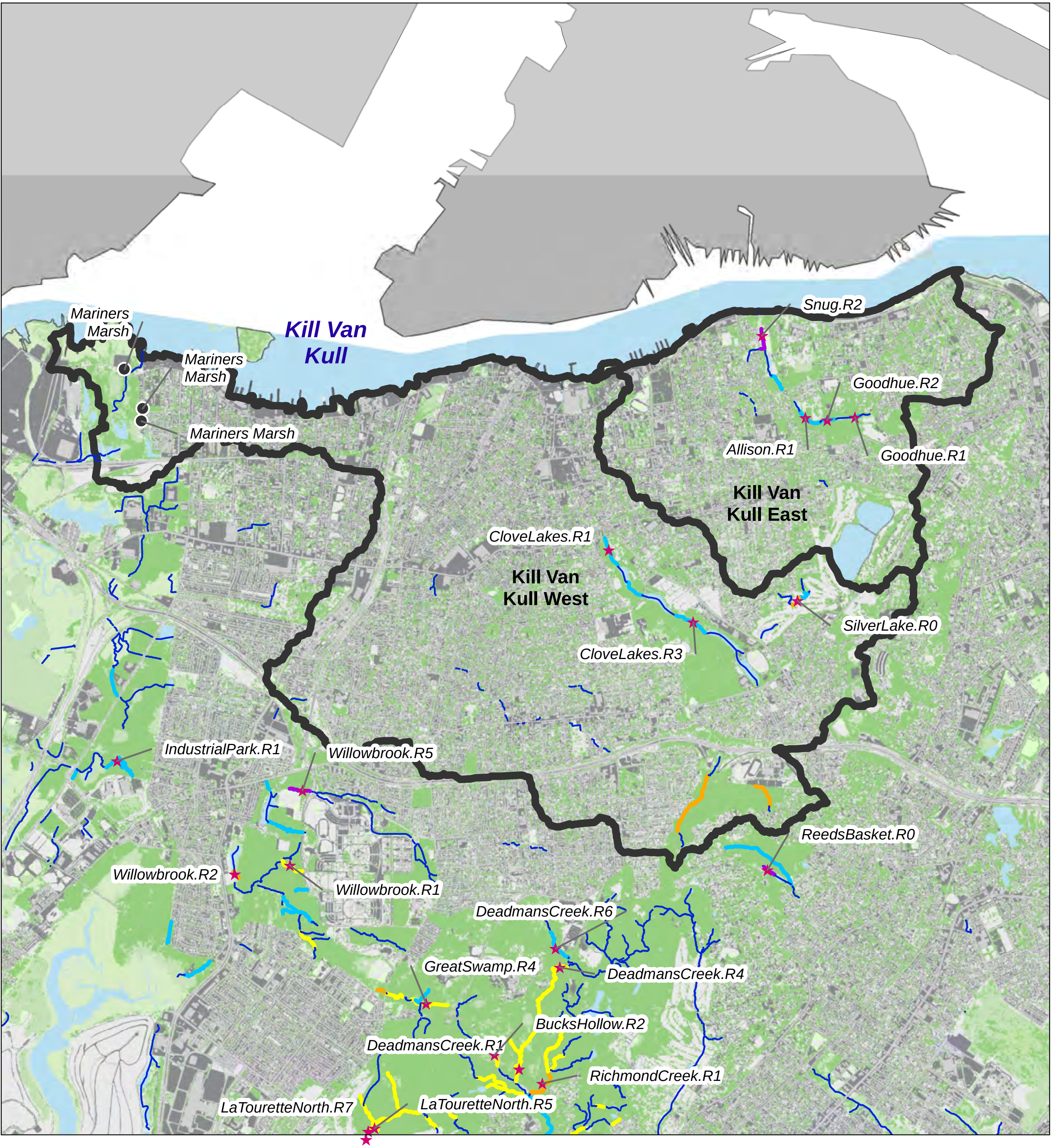
November 2020
Data Source: NYC Parks, NAC



Freshwater Wetlands & Streams

Lower New York Bay Watershed
New Creek

□ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N

0 0.25 0.5 Miles

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Freshwater Wetlands & Streams

Raritan Bay Watershed

- ⬛ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N

0 0.25 0.5 Miles

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Freshwater Wetlands & Streams

Raritan Bay Watersheds
Arbutus Lake and Annadale Beach

- ▢ Watershed
- — Hydroline

Assessed Reach Recommendation

- — Protect
- — Manage Buffer
- — Manage Stormwater
- — Rehabilitate
- — In-stream Structures
- ★ Priority Management Reaches
- ● Daylighting Opportunities

N 0 0.15 0.3 Miles

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Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Raritan Bay Watershed
Great Kills Harbor

▢ Watershed

— Hydroline

Assessed Reach Recommendation

— Protect

— Manage Buffer

— Manage Stormwater

— Rehabilitate

— In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N

0 0.25 0.5 Miles

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Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Raritan Bay Watersheds
Lemon Creek and Wolfe's Pond

▢ Watershed

— Hydroline

Assessed Reach Recommendation

- Protect
- Manage Buffer
- Manage Stormwater
- Rehabilitate
- In-stream Structures

★ Priority Management Reaches

● Daylighting Opportunities

N 0 0.25 0.5 Miles

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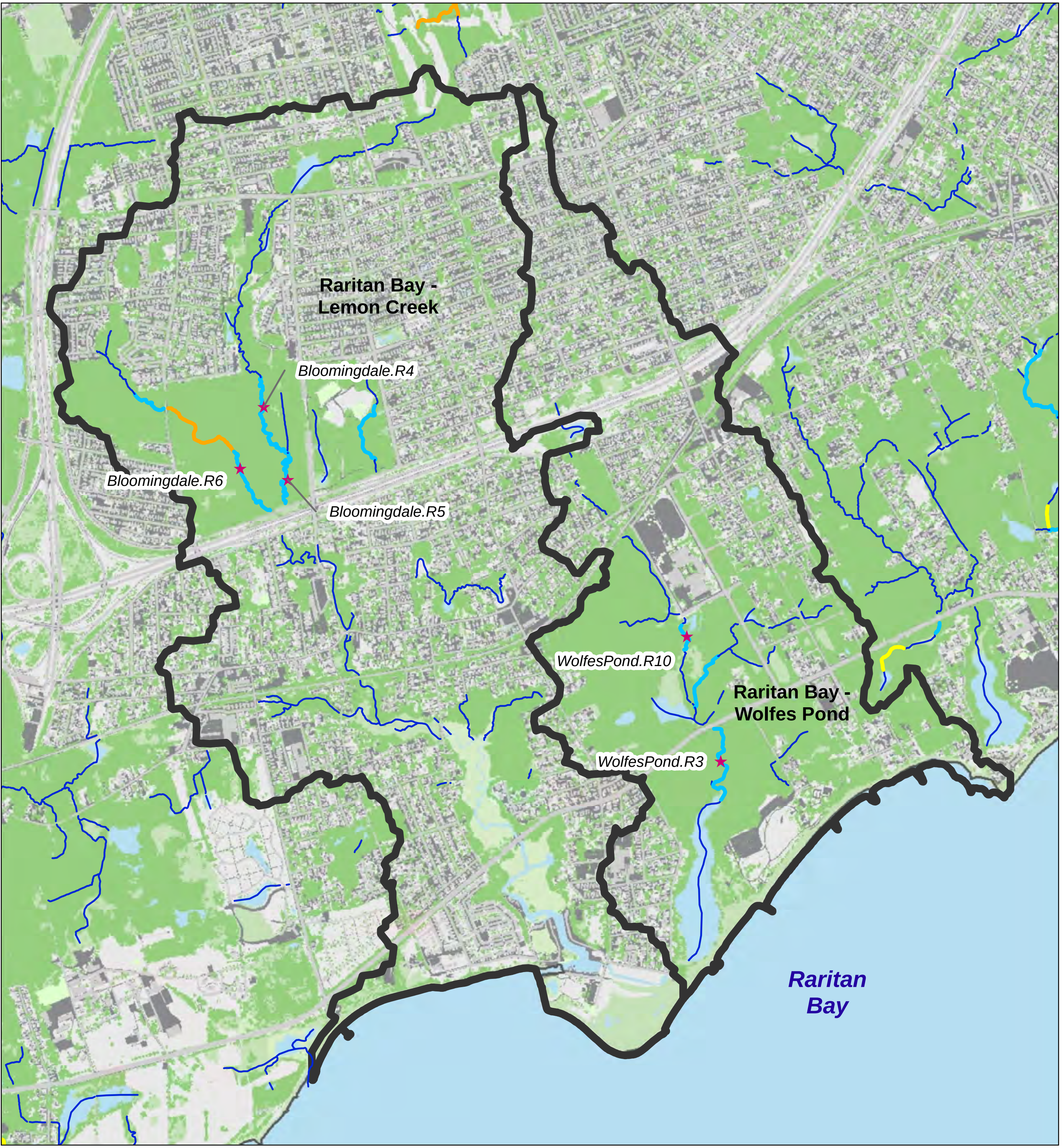

Freshwater Wetlands & Streams

Bronx
Stream Type Classification

Stream Type

━ channel

━ swale

━ impoundment

━ wetland

N

0 0.5 1 Miles

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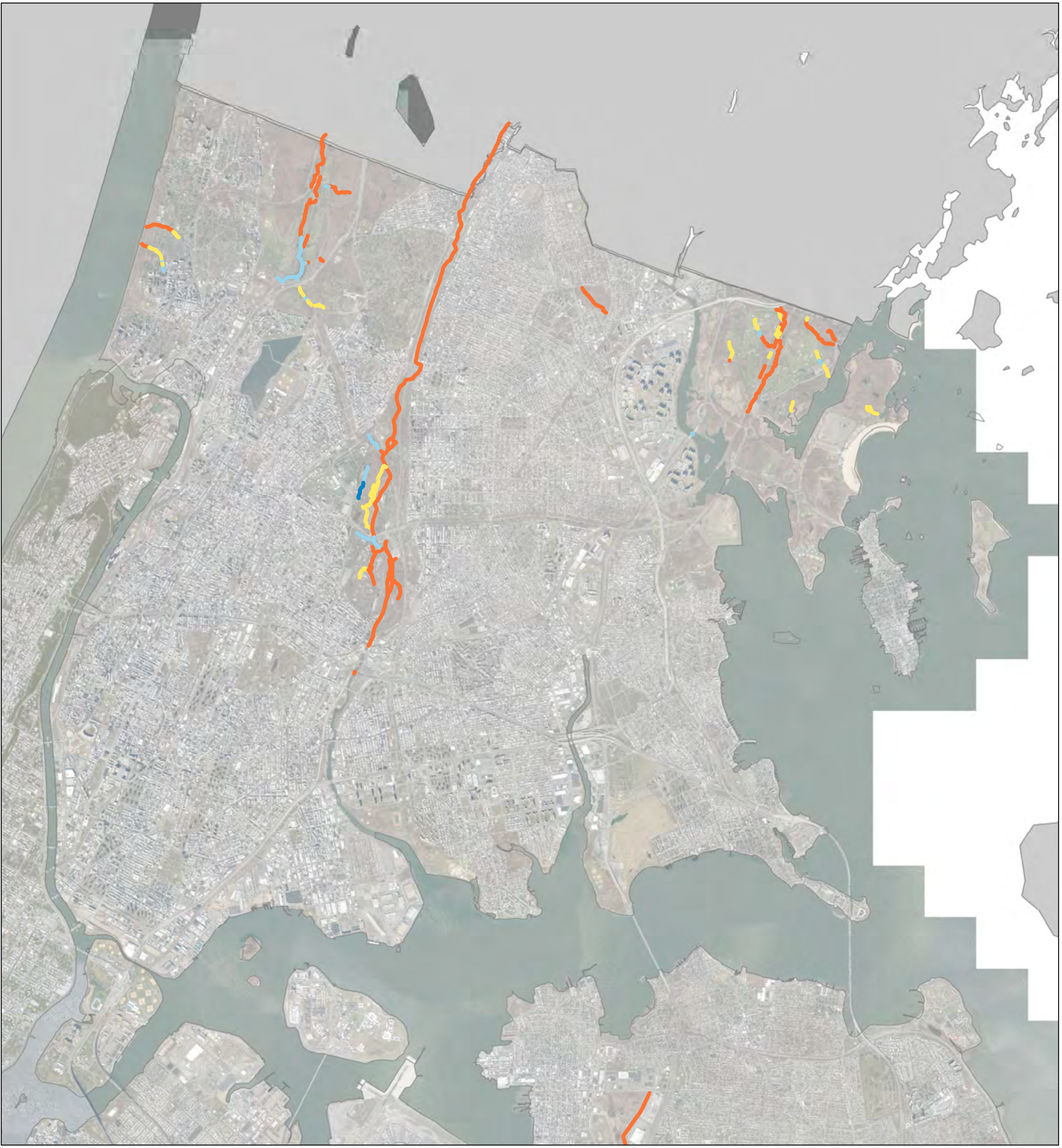
November 2020
Data Source: NYC Parks, NAC



Freshwater Wetlands & Streams

Queens
Stream Type Classification

Stream Type

- channel
- swale
- impoundment
- wetland

N

0 1 2 Miles

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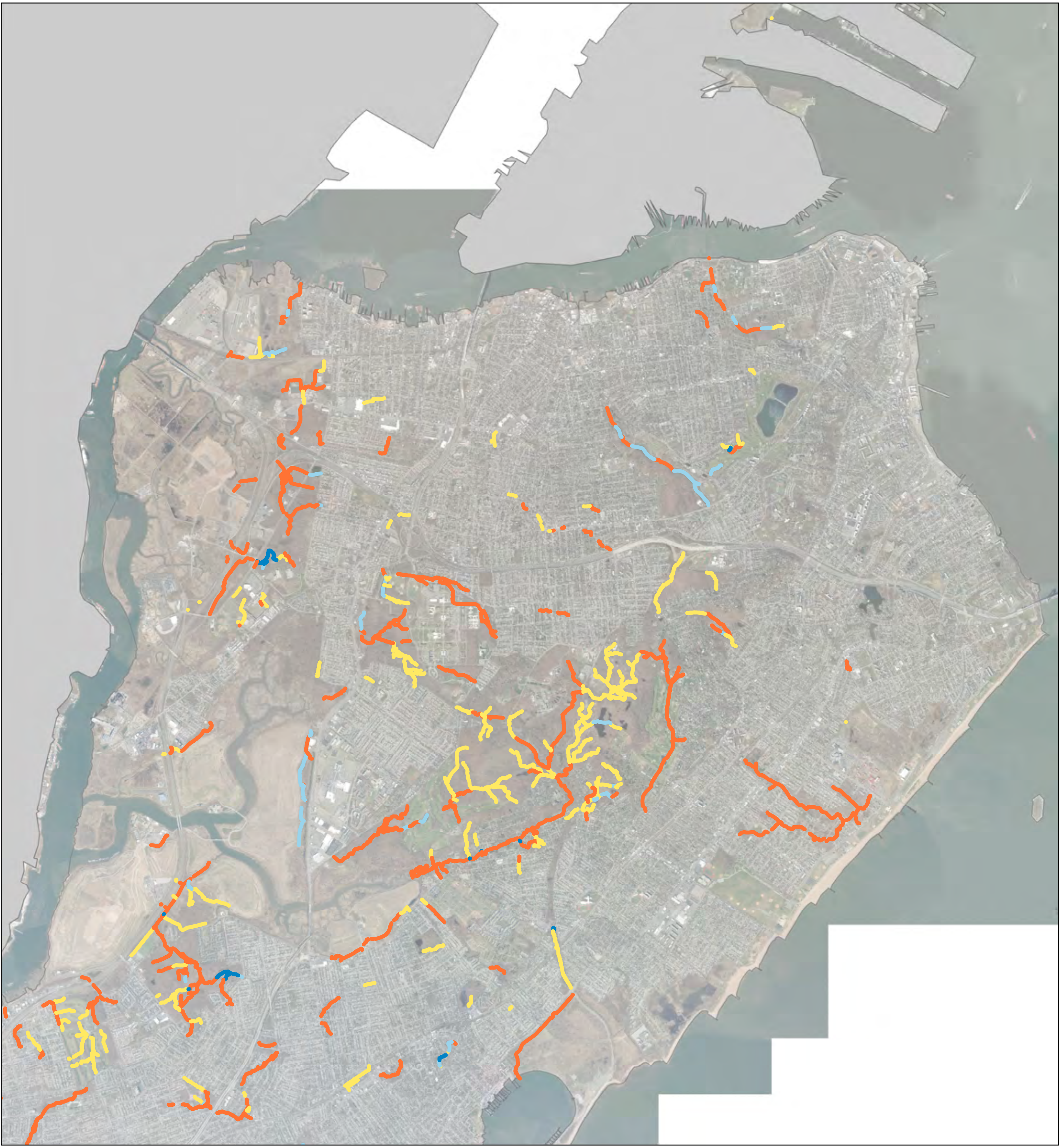
November 2020
Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Northern Staten Island
Stream Type Classification



Stream Type

- ━ channel
- ━ swale
- ━ impoundment
- ━ wetland

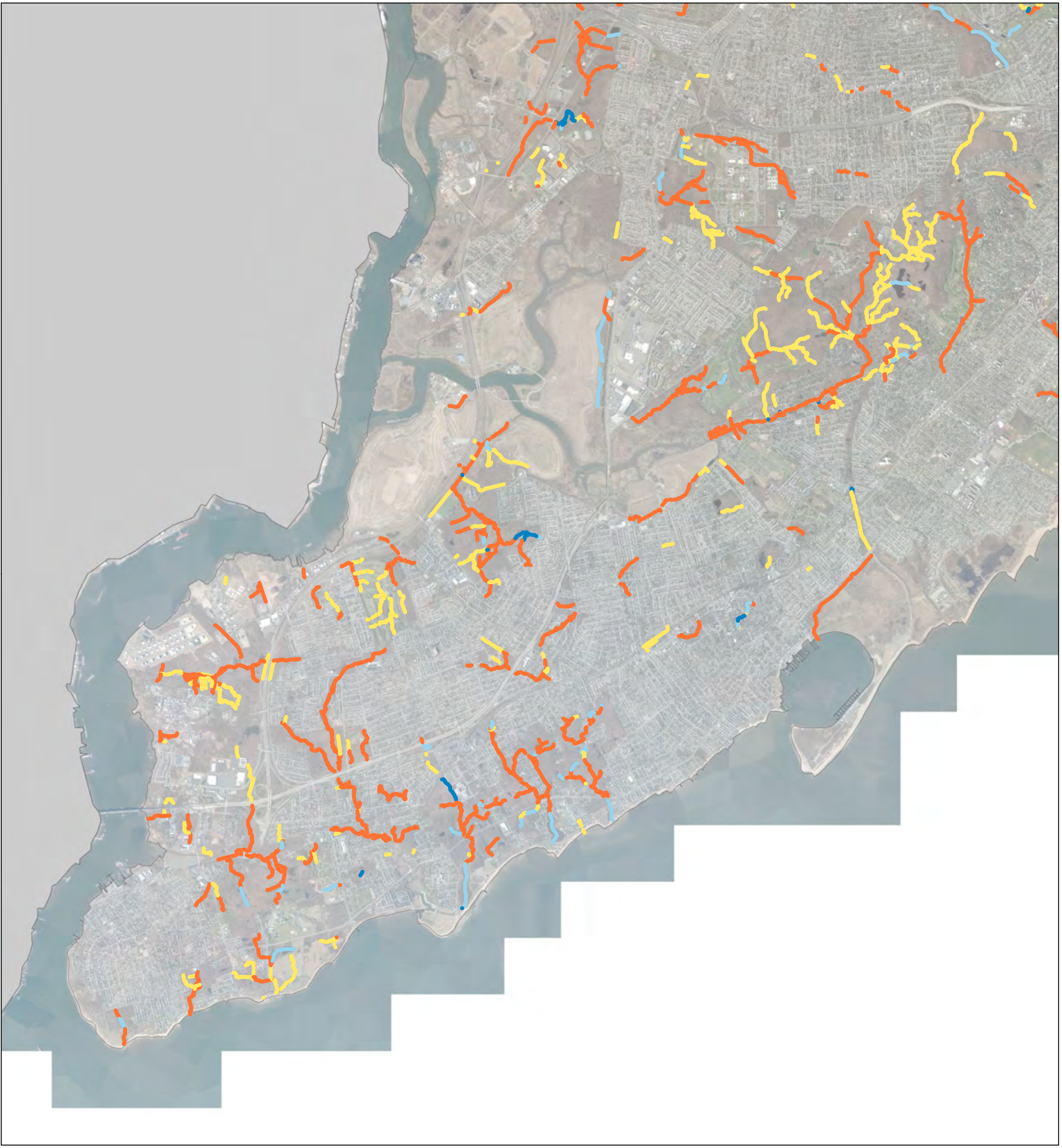
N

0 0.5 1 Miles

Prepared By Forestry, Horticulture and Natural Resources
November 2020
Data Source: NYC Parks, NAC

Freshwater Wetlands & Streams

Southern Staten Island
Stream Type Classification



Stream Type

- channel
- swale
- impoundment
- wetland

N

0 0.5 1 Miles

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