ROADMAP FOR PERVIOUS PAVEMENT IN NEW YORK CITY

A STRATEGIC PLAN FOR THE NEW YORK CITY DEPARTMENT OF TRANSPORTATION

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MASTER OF SCIENCE IN
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TERMINOLOGY

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BGY	Billion Gallons Per Year
BMP	Best Management Practices
CPI	Capital Project Initiation
CSO	Combined Sewer Overflow
GIS	Geographic Information System
MGY	Million Gallons Per Year
NYC DEP	New York City Department of Environmental Protection
NYC DCP	New York City Department of City Planning
NYC DDC	New York City Department of Design and Construction
NYC DOT	New York City Department of Transportation
NYC DPR	New York City Department of Parks and Recreation
NYC OMB	New York City Office of Management and Budget
NYS DEC	New York State Department of Environmental Conservation
SPDES	State Pollutant Discharge Elimination System
US EPA	United States Environmental Protection Agency

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Executive Summary

Every year, billions of gallons of sewage pollute New York City's waterways due to combined sewer overflows. Combined sewers are found across New York City and are designed to collect stormwater runoff and sanitary sewage in the same pipe system. During heavy rainfall or snowmelt events, stormwater enters the sewers where it mixes with sanitary sewage, which may overwhelm the system, requiring that both substances be dumped into nearby waterways, untreated.

Combined sewer overflows are a serious sustainability problem for a number of reasons. Dumping untreated sewage into waterways is a public health hazard. It can also cause unwanted stress on fragile coastal ecosystems. Moreover, it's a menace to urban assets like waterfronts, beaches and parks and can be detrimental to property values.

In 2007, Mayor Bloomberg introduced PlaNYC to prepare the City for one million more residents, strengthen the economy, combat climate change and enhance the quality of life for all New Yorkers by 2030.[1] Updated in 2011, this document brought together over twenty-five City agencies to address ten key priority areas, introduced over a hundred new initiatives and challenged New York City to become a global leader in sustainable urban governance.[2] PlaNYC pledged to improve the quality of the City's waterways to increase opportunities for recreation and restore coastal ecosystems.[3] To do so, it committed to making a transformative investment in green infrastructure that captures or detains stormwater before it can enter and overwhelm the sewer system, thereby reducing combined sewer overflows.[4] The New York City Department of Transportation Street Design Manual, released in 2009, and the Sustainable Stormwater Management Plan of 2008 further laid the groundwork for green infrastructure.[5,6]

In response, the New York City Department of Environmental Protection published its Green Infrastructure Plan in 2010, which outlined two specific goals: firstly, to reduce combined sewer overflows by an additional 3.8 billion gallons per year; and secondly, to capture the first inch of rainfall on 10% of the impervious areas in combined sewer watersheds by leveraging green infrastructure installations, such as pervious pavement; it also specified more specific spending goals than were included in the original PlaNYC.[7] In 2010, the New York City Department of Transportation updated its Street Design Manual to develop higher quality streets and set out design guidelines giving equal weight to transportation, community and environmental goals.[8]

Streets and sidewalks comprise an estimated 125 square miles—or 33.6% of all impervious surfaces—in the City.[9] As such, the New York City Department of Transportation has a significant role to play in achieving the goals set forth in PlaNYC, the Green Infrastructure Plan and the Street Design Manual. This Capstone Workshop project was commissioned by the New York City Department of

Transportation's Directors of Capital Planning and Green Infrastructure to identify the most appropriate locations for the application of pervious pavements in NYC, thereby reducing combined sewer overflows and contributing to the 10% capture goals on impervious surfaces in combined sewer overflow areas. As such, the team focused on several core objectives:

- Identify domestic and international precedents for the successful installation of pervious pavement in urban areas
- Isolate best management practices for the design, construction and monitoring of urban pervious pavement installations
- Develop criteria to select the most appropriate roadway locations for the installation of pervious pavement
- Aggregate appropriate relevant data, creating a database of GIS maps
- Conduct site visits to identify preliminary locations
- Conduct a cost-benefit analysis to identify which installation types are suitable to each location and quantify achievable combined sewer overflow reductions
- Recommend appropriate locations, installation options and material types
- Draft preliminary Capital Project Initiation documents
- Craft a project roadmap outlining an implementation strategy through 2030

In consultation with the client, it was agreed that the team would focus their efforts on identifying demonstration locations in two of seven priority New York City watersheds: Flushing Bay and Newtown Creek. This permitted a targeted analysis of two areas where combined sewer overflows were highly problematic. Subsequently, the methodology for site selection devised by the team could be adapted and applied to a broader scope of New York City locations to achieve long-term PlaNYC objectives.

WORK TIMELINE

To deliver on the project, the team divided the work into three phases:

Phase A: Research and Data Collection

Conducted a systematic literature review on green infrastructure, pervious pavement, street design and permeable pavement construction techniques. Successful US and international case studies were identified and exploratory interviews were scheduled with select civil engineers and urban planners. From this data, the team identified best management practices for New York City.

Phase B: Analysis and Site Selection

Building on the findings from Phase A and guidance from the client, a set of site selection criteria was developed. These criteria informed the types of geographic information system (GIS) data layers that were compiled to assist the team in isolating preliminary road-segment blocks within both priority watersheds that were ideal and appropriate for the installation of pervious pavement. Once these preliminary locations were chosen, the team conducted site visits to verify current road conditions, validated the preliminary selections, and integrated the cost benefit analysis to make specific recommendations for each site. These findings were distilled into 15 final site recommendations.

Phase C: Implementation Plan

Based on Phases A and B, an implementation plan was jointly developed with the Directors of Green Infrastructure and Capital Planning at the New York City Department of Transportation. The plan included a phased installation timeline, potential agency partnerships, project risk mitigation approaches, and prospective funding sources. This was done to assist the client in conceptualizing a cohesive strategy and sequencing the necessary actions needed in order to ensure the project's successful completion.

KEY RECOMMENDATIONS

Based on the work completed in Phases A, B and C, it is suggested that the Department of Transportation:

- Divide the implementation of the pervious pavement installations into three work phases that align with the timing of the Green Infrastructure Plan's phased targets for the capture of rainwater from impervious surfaces.
  - 2012-2015 (DEP target: 1.5% capture): 12 installations
  - 2015-2020 (DEP target: 4% capture): 80+ installations
  - 2020-2030 (DEP target: 10% capture): 400-1000+ installations
- Install demonstration sites in the following areas:
  - Flushing Bay Watershed: 6 blocks
  - Newtown Creek Watershed: 4 blocks
  - (The demonstration sites are located strictly within the selected priority watersheds as per the scope of this project)
- Adhere to best management practices, including:
  - Pavement Type: pervious asphalt is recommended for New York City
  - Site Selection: use the three criteria categories outlined in this report
  - Design: ensure sufficient depth and thickness of the application
  - Maintenance: vacuum, weed and/or pressure wash the installation
  - Monitoring: track infiltration rate, water quality, and durability
- Maximize the full stormwater management potential of the New York City Department of Transportation's 33.6% jurisdictional share of impervious surfaces in New York City (approximately 125 square miles).[10] While the goals included in PlaNYC are ambitious, the Department of Transportation is encouraged to embrace the opportunity to demonstrate global leadership in the use of green infrastructure. In doing so, it stands not only to improve the quality of the City's waterways, expand opportunities for recreation and repair coastal ecosystems, but also to position New York City as a pioneer in using sustainable street design to solve one of the City's most pressing sustainability challenges.

INTRODUCTION

PROBLEM STATEMENT: COMBINED SEWER OVERFLOWS IN NYC AND GREEN INFRASTRUCTURE SOLUTIONS

New York City is one of the world's great waterfront cities, with over 520 miles of waterfront.[11] To ensure their cleanliness, the New York City Department of Environmental Protection (NYC DEP) treats 1.3 billion gallons of water a day over the course of a year using hundreds of miles of sewer pipes, 113 pump stations, and 14 wastewater treatment plants.[12] This system provides ample capacity for managing the City's wastewater in dry weather and even during the average storm. However, during heavy rainfall or snowmelt events, stormwater enters the sewers rapidly, causing the system to become overwhelmed. If the volume of wastewater in the system exceeds its capacity, it is forced to directly divert untreated excess volume to local waterways. This event is known as a combined sewer overflow (CSO). New York City's combined sewer system has 422 sewer regulators capable of discharging CSOs.[13] As of 2008, CSOs were responsible for approximately 27 billion gallons of discharge; enough to fill almost 41,000 Olympic sized swimming pools.[14]

As CSO events can pollute New York City's sensitive and valuable waterways, it is important to understand where they occur – also known as outfalls - and to quantify the volumes of discharge. To this end, NYC DEP has defined 3 tiers of CSO outfalls based on the volume of annual discharge, as can be seen in Table 1 below. Over 50 per cent of all CSOs are concentrated at large-discharge "Tier 1" sites.[15]

Table 1: Tiers of Combined Sewer Overflow Outfall[16]

Outfall Tier	Annual Discharge	% of all CSO volumes
1	> 500mgy*	50%
2	250mgy - 500mgy*	20%
3	50.7mgy - 250mgy*	10%

*Millions of gallons per year.

Policy Drivers to Address Combined Sewer Overflows

In 2007, Mayor Bloomberg introduced PlaNYC to prepare the City for one million more residents, strengthen the economy, combat climate change and enhance the quality of life for all New Yorkers by 2030.[17] PlaNYC pledged to improve the quality of the City's waterways, to increase opportunities for recreation and to restore coastal ecosystems.[18] To do so, it committed to making a transformative investment in green infrastructure that captures or detains stormwater before it can enter and overwhelm the sewer system, thereby reducing combined sewer overflows.[19] In response, the New York City Department of Transportation (NYC DOT) updated its Street Design Manual with stormwater management strategies, including permeable pavements and surfaces, and sustainable design that supports PlaNYC initiatives into the core processes of street design. [20] These strategies will play a role in meeting targets laid out by NYC DEP in its 2010 Green Infrastructure Plan, which outlined two specific goals for 2030: firstly, to reduce CSOs by an additional 3.8 billion gallons per year; and secondly, to capture the first inch of rainfall on 10% of the impervious areas in combined-sewer watersheds by leveraging green infrastructure installations, such as pervious pavement.[21] Accordingly, NYC DEP proposed interim milestones to measure its progress:

- 1.5% impervious area capture by 2015
- 4% impervious area capture by 2020
- 7% impervious area capture by 2025
- 10% impervious area capture by 2030[22]

Underpinning the stormwater management initiatives in PlaNYC is the fact that New York City's combined sewer system, like every other combined system in New York State, must have a State Pollutant Discharge Elimination System (SPDES) permit issued by the New York State Department of Environmental Conservation (NYS DEC).[23] The Federal Water Pollution Control Act, or Clean Water Act, which was put in place in 1948 and expanded in 1987, laid out the groundwork for regulation of polluting activity on waterways and for programmatic water quality improvement.[24] NYS DEC has the authority to enforce CSO requirements under the Wet Weather Water Quality Act and has developed fifteen best management practices that require the control of CSO discharges to obtain SPDES permits.[25] If the compulsory milestones are missed or required practices are not followed, NYS DEC has the authority to assess a $200,000 fine per infraction.[26]

NYS DEC's primary role, however, in dealing with CSOs is the enforcement of a 2005 Consent Order, updated in 2011, that requires NYC DEP to improve the water quality of New York City's surrounding waterways.[27] This order requires the construction of various cost-effective grey and green infrastructure projects, and the development of specific long-term control plans.[28] The long-term control plans are to be drafted in accordance with the 1994 Environmental Protection Agency's CSO Control Policy, which lays out best practices and requirements for minimizing CSOs.[29] The Green Infrastructure Plan impacts were incorporated into the 2011 Consent Order update under NYC Council Local Law 630 and in an agreement between NYS DEC and the NYC DEP, firmly placing green infrastructure in the policy framework for managing CSOs.[30,31]

Rationale for Green Infrastructure

This policy context has lead to a long period of large capital investment to reduce the volume discharged in CSOs each year. Conventional efforts to reduce CSOs have required the construction of additional "grey" or traditional infrastructure, for example, storage tunnels, large storage tanks and new wastewater treatment plants.[32] The average cost for grey-infrastructure reductions of CSOs is $1.75/gal and individual projects can require billions of dollars of capital.[33] While planned grey infrastructure investment is expected to lower CSO releases from the current level of 30bgy to 19.8bgy by 2030, there are diminishing returns on additional grey-infrastructure investment beyond what is planned, and new projects rapidly begin to fail cost-effectiveness tests.[34]

On the other hand, applications of pervious pavement in CSO-intensive watersheds can achieve substantial reductions in CSOs, which displace the need for costly grey infrastructure.[35] The NYC DEP estimates that preventing 1 inch of precipitation from becoming runoff could reduce CSOs by 1.5 billion gallons per year.[36] As such, PlaNYC calls for an investment of $1.5 billion in green infrastructure by 2030.[37] NYS DEC and NYC DEP have allocated $2.4 billion over the next eighteen years to green infrastructure that manages stormwater. Moreover, incorporating green infrastructure strategies will reduce CSO volume by an additional 2 billion gallons more than an all-grey infrastructure strategy.[38] This means that the average expected cost per gallon of CSO reduced at $1.60/gal for green infrastructure reductions is lower than $1.75/gal for grey infrastructure.[39] NYC DOT has a key role to play in implementing cost-effective green infrastructure strategies for reducing CSOs insofar as:

- Streets and sidewalks make up 33.6% of impervious surfaces in NYC[40]
- NYC DOT maintains jurisdiction over streets
- NYC DOT and NYC DEP may partner to install green infrastructure on thousands of streets by 2030 to meet their share of policy targets

PROJECT SCOPE AND OBJECTIVES

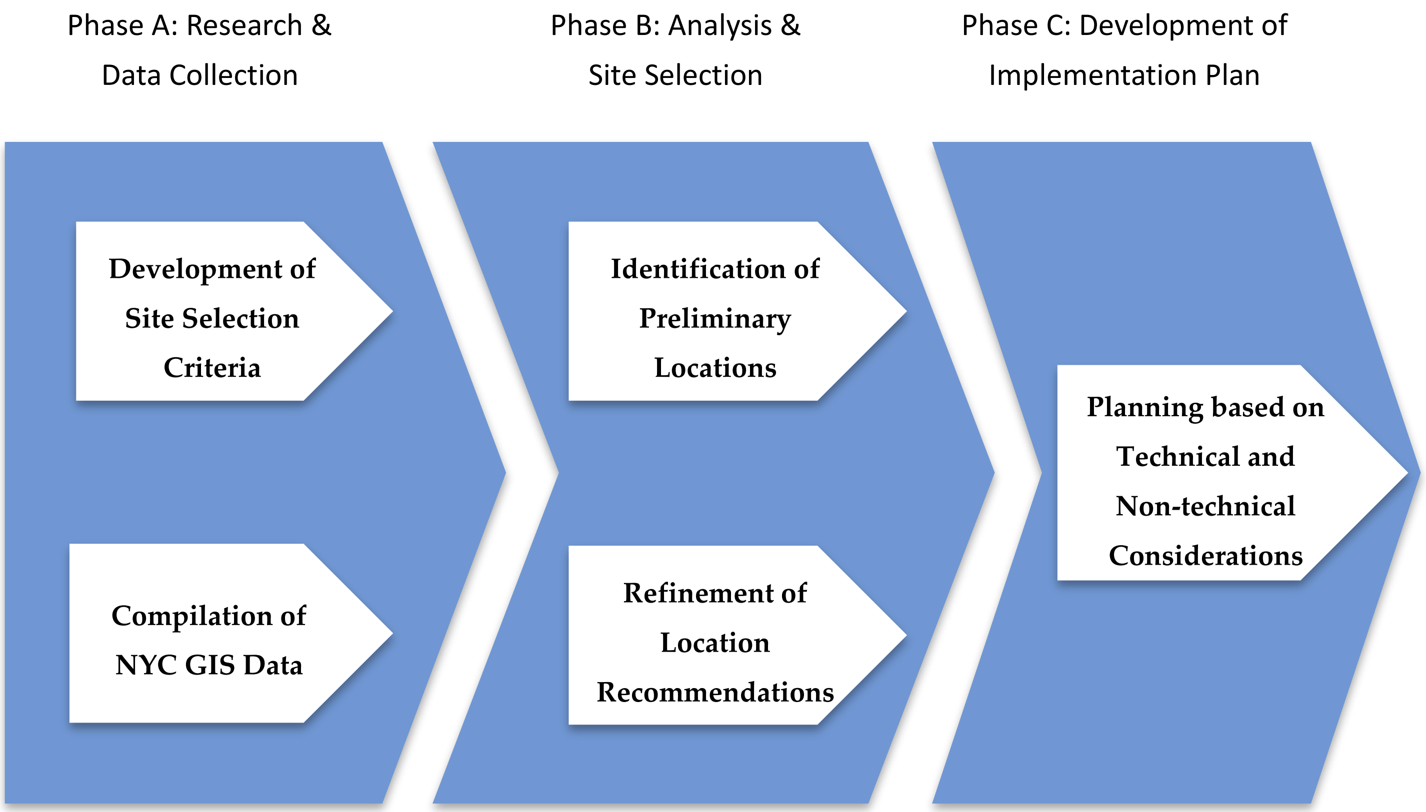
This Capstone Workshop project was commissioned by the NYC DOT's Capital Program Management division to identify the most appropriate locations for the application of pervious pavements in NYC and thereby reduce the instances of combined sewer overflows. As such, the group focused on several core objectives:

- Identifying domestic and international precedents for the successful installation of pervious pavement in urban areas
- Isolating best management practices for the design, construction and monitoring
- Developing criteria to select the most appropriate roadway locations for installation
- Aggregating relevant data and creating a database of GIS maps
- Visiting sites to identify preliminary locations
- Conducting a cost-benefit analysis to identify which installation types are suitable to each location and quantifying potential CSO volume reductions
- Recommending appropriate locations, installation types and material types
- Drafting a preliminary Capital Planning Initiation document
- Crafting a project roadmap outlining an implementation strategy

PROJECT APPROACH AND METHODS

A dynamic approach was implemented to produce the deliverables described above. The team implemented a three-phase, multi-task strategy and divided into overlapping subgroups to accomplish each task, as illustrated in Figure 1.

Figure 1: Three Project Phases



Phase A: Research and Data Collection

The analysis began by conducting a systematic literature review on green infrastructure, pervious pavement, street design and construction techniques. To expedite this process, the client provided a robust set of previously compiled documents to which any additional relevant literature was added. Simultaneously, the team began to research and identify other cities where pervious pavement had been installed. This culminated in a comprehensive assessment of 80+ domestic and international case studies. Once the most relevant cases were identified, exploratory interviews were scheduled with municipal staff members that were familiar with or responsible for the pervious pavement initiatives, mostly civil engineers and urban planners. The review consisted of 12 initial projects, including conversations with practitioners in 6 cities. A conversation guide was developed to ensure that consistent data was collected from each exchange and organized into a customized template designed by the team to present the findings in a user-friendly format. The following case studies were selected to be included in the final analysis based on specific criteria (see Section 6: Case Studies Illustrating Best Management Practices):

Table 2: Case Studies

United States Case Studies	International Case Studies
Chandler, AZ	Vancouver, Canada
Portland, OR	Germany
Tallahassee, FL	Japan
Philadelphia, PA	
Salem, OR	
Olympia, WA	

From the systematic literature review and the case study assessment, the team identified relevant best management practices for New York City. These were aggregated into four main categories: pavement types, site selection, design and maintenance (see Section 5: Best Management Practices in Highly Urban Conditions).

Phase B: Analysis and Site Selection

Building on the findings from Phase A and guidance from the client, a custom set of site selection criteria were chosen to reflect New York City's unique geo-technical, built environment and roadway considerations (see Figure 2: Pervious Pavement Site Selection Approach).

These criteria informed the types of geographic information system (GIS) data layers that were compiled to assist the team in isolating the preliminary road segment blocks within each priority watershed. With the help of the client and faculty at Columbia University, the GIS data was collected, organized and integrated into a single map file that can be used to determine the precise city block locations for the appropriate installation of pervious pavement.

Once these preliminary locations were chosen, the team conducted site visits to verify the current road conditions, validate the preliminary selections identified in the maps, and determine which installation types would be recommended at each site. These findings were distilled into 15 final site recommendations for the consideration of NYC DOT.

Phase C: Development of Implementation Plan

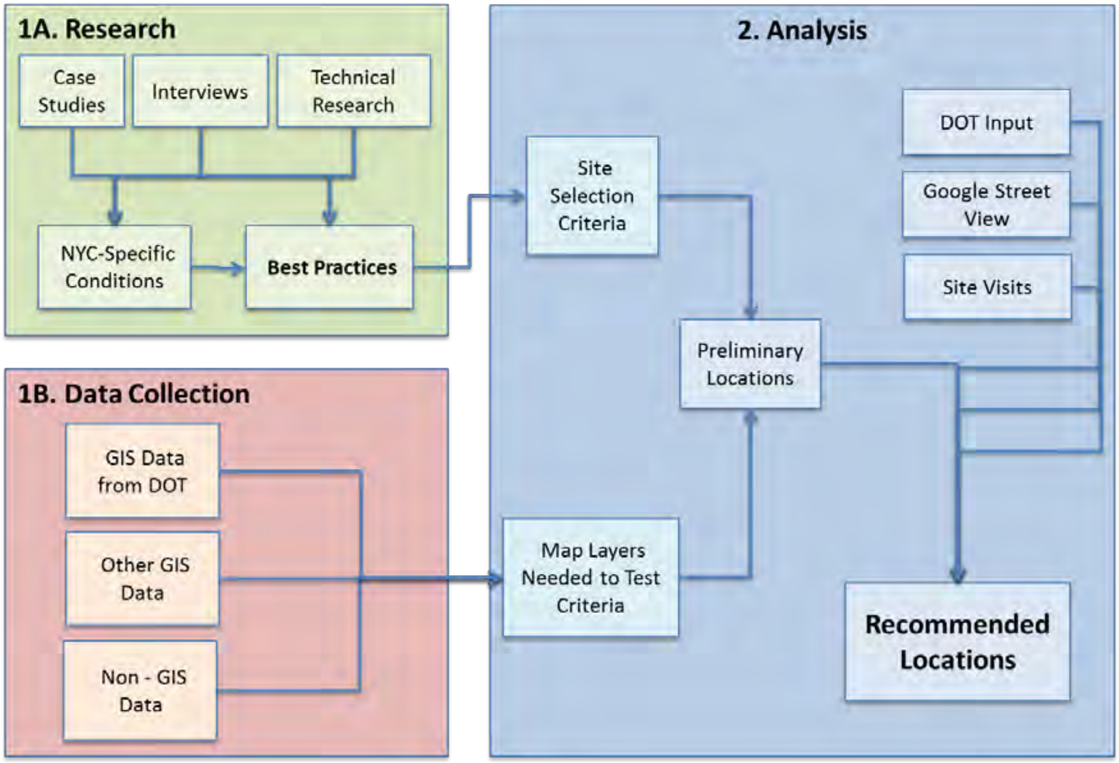
Based on Phases A and B, the team facilitated a strategy session at the NYC DOT headquarters with the Directors of Green Infrastructure and Capital Planning to jointly develop an Implementation Plan. This was done in order to create a phased installation timeline corresponding to policy targets, identify potential agency partnerships, mitigate project risks, and to identify prospective funding sources. Additionally, the exercise assisted the client in conceptualizing a cohesive strategy and sequencing the necessary actions needed in order to ensure the project's successful completion.

PROJECT DELIVERABLES

The project deliverables agreed upon with the client include:

- A full report on pervious pavement, including recommended installation locations and an implementation plan
- GIS maps
- Domestic and international case studies
- Best management practices
- Capital Planning Initiation documents and cost-benefit analysis
- Presentations to relevant staff at NYC DOT

Figure 2: Pervious Pavement Site Selection Approach



Pervious Pavement: Technical Primer and Considerations

PERVIOUS PAVEMENT MATERIAL AND INSTALLATION TYPES

Pervious Asphalt

Pervious asphalt, also known as pervious, permeable, or open-graded asphalt, is standard asphalt with reduced sand or fines that leave stable air pockets for water to drain through. When installed over an aggregate storage bed, pervious asphalt reduces stormwater runoff volume, rate, and pollutants.[41] It is typically recommended for "low speed and low volume applications" such as "walkways, sidewalks, driveways, parking lots and low-volume roadways."[42] On roadways, pervious asphalt is especially beneficial if underlying utilities need to be accessed frequently since asphalt is easy to remove and reapply compared to other pavement applications such as concrete.[43]

Pervious Concrete

Pervious concrete, also known as porous, gap-graded, or enhanced porosity concrete, is concrete with reduced sand or fines that allows water to drain through it.[44] When applied over an aggregate storage bed, pervious concrete can also achieve the same stormwater management objectives as pervious asphalt,

Because of their different structural qualities, the choice between asphalt and concrete depends on a number of factors. As with pervious asphalt, pervious concrete has been successfully installed in low speed and low volume applications such as walkways, sidewalks, driveways, parking lots and low-traffic roadways. However, pervious concrete can be designed to handle heavy loads, which makes it more appropriate in areas with high or heavy traffic volumes. The major drawbacks to pervious concrete are that it requires a longer curing time than asphalt, is difficult to remove and reapply and is very susceptible to surface abrasion.[45]

Installation Types

There are numerous installation configurations that can be used to take advantage of the water infiltration properties of different pervious pavement material types. Three main installation types include: curb-to-curb pervious asphalt roadway, pervious asphalt parking lanes with impervious asphalt middle travel lanes, and pervious gutter strips. In the case of the pervious asphalt parking lane installation, the middle travel lane does not have to be excavated and runoff from the middle lane can be handled by the pervious parking lanes provided the impervious surface area is not more than twice the pervious surface area (for example, a roadway that is 40 feet from curb to curb with 8 foot parking lanes would need a 24 foot width of impervious area versus a 16 foot width of pervious area, or 1.5 times as much).[46] Figure 3 from Portland, Oregon's Westmoreland neighborhood illustrates a pervious asphalt parking lane application next to a curb-to-curb application.

Figure 3: Pervious asphalt parking lane (left) and curb to curb (right)

Photo courtesy of the Portland Bureau of Environmental Services[47]

BENEFITS AND CHALLENGES OF PERVIOUS PAVEMENT INSTALLATIONS

Installing pervious pavement can be an effective way to manage stormwater runoff that causes combined sewer overflows. Compared to traditional pavement, pervious pavement has many benefits when used to replace or augment traditional stormwater management infrastructure. There are also challenges associated with a pervious pavement installation, as noted in Table 3 below.

Table 3: Benefits and Challenges of Pervious Pavement

Benefits	Challenges
• Reduces occurrences of flooding. • Increases groundwater recharge by allowing rainwater to penetrate traditionally impervious surfaces. • Reduces stormwater runoff, flow rate and temperature. • Provides filtration of stormwater. • Reduces contaminants from roadway from reaching surface waterways. • Reduces soil erosion. • Lowers requirements for traditional	• Increases initial cost of installation. • Increases maintenance requirement related to guarding against clogging from construction sites and winter sanding. • Decreases roadway wear-life. • Increases water table pollution concerns due to contaminants from roadway seeping into groundwater. • Potentially compromises integrity of subsurface utilities (such as pipes and cables) by introducing increased water.

stormwater management infrastructure by reducing the volume of stormwater that reaches drain sites. • Reduces maintenance in cold climates related to buckling and cracking. • Reduces need for salting/sanding in cold climates due to reduction in standing water on roadway. • Increase in road traction when wet, which improves roadway safety. • Sound reduction/mitigation.	• Functionality of pervious pavement can be compromised by utility cuts into roadway that are improperly restored. • Paving contractors will need to adjust their specs, processes and equipment to provide pervious mixes.

[48]

General Criteria for Site Selection

If the application is not installed or sited properly, some or all of these benefits will not be realized. To ensure that an application of pervious pavement functions as designed, it is necessary to limit installation sites that meet the topographic and geologic design recommendations.

Soils underlying the reservoir course should have minimum infiltration rates of 0.5 inches per hour to allow stormwater to percolate into the ground as designed. [49] The soil types required to achieve these infiltration rates should have a high sand content and have silt/clay content less than 40% and clay content less than 20%. Hydrologic Soil Groups (HSG) A and B would perform well whereas less permeable HSG soil groups C and D might require an underdrain or overflow strip.[50] Also, a minimum of a three-foot separation from the bottom of the pervious pavement installation to the bedrock and/or seasonal high water table is required to provide adequate drainage area during all seasons.[51]

The gradient of the installation site should also be minimized to achieve the desired performance. Pervious pavement should not be installed on sites that have a gradient of more than 5 per cent.[52] Finally, appropriate separation from existing subterranean infrastructure is required (e.g. wells, septic tanks, subways, basements, etc.)[53]

General Design Considerations

In order to function properly, installations of pervious pavement must adhere to particular design specifications. The mix of asphalt or concrete, for example, will depend on the site characteristics and desired functionality. Sub-street structure considerations must be assessed for the choke course, open-graded base reservoir, open-graded sub-base reservoir, and subgrade. Moreover, the native soil type must be evaluated, as described above, and the requirement for optional sub-street structure layers must be assessed, including an under-drain or geotextile.

Below, Figure 4 shows a typical pervious asphalt installation. As this figure demonstrates, the thickness of the layers can vary.

Figure 4: Typical Porous Asphalt Section[54]

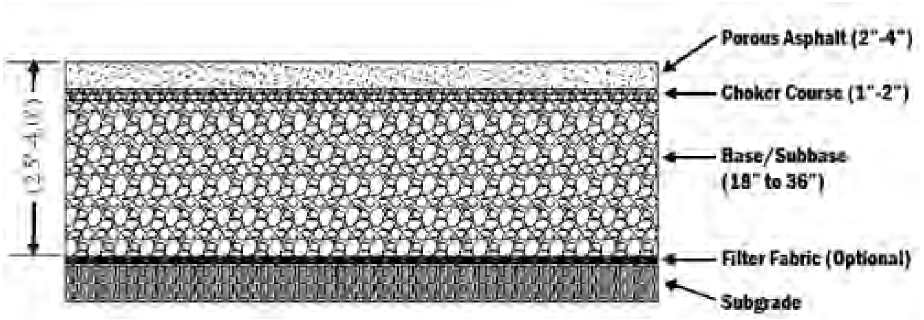
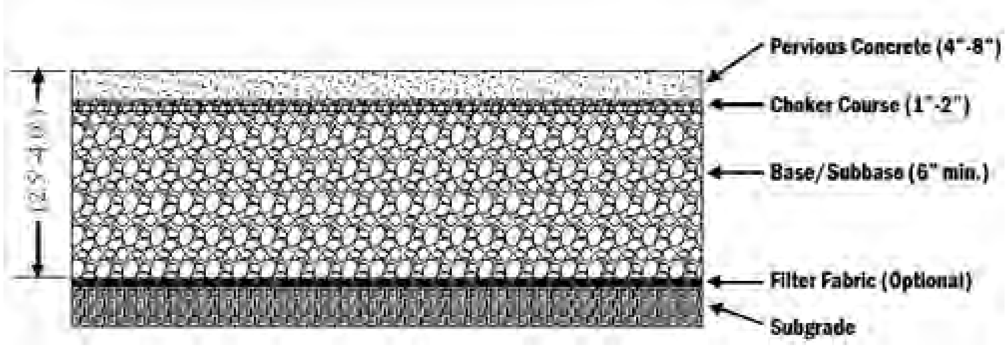


Figure 5 shows a typical pervious concrete installation. While the layers are similar, there are two significant distinctions. The concrete layer thickness requirement is double that of an asphalt installation, however the base/sub-base minimum requirement is much lower.

Figure 5: Typical Porous Concrete Section[55]



Technical information related to material mix and sub-street layer construction can be found in Appendix 5.

Maintenance

Clogging is the most prevalent maintenance concern for pervious pavement applications. Fine particles in runoff can clog the pores in the permeable road surface thereby reducing the stormwater infiltration rate. Because clogging increases over time, the hydrologic value of the pervious pavement application will decrease if not maintained properly.

Maintenance recommendations for pervious pavement vary in practice and frequency. Most applications require regular vacuum sweeping; however, pressure washing and weed removal may also be required on a less frequent basis.[56,57]

Freezing and thawing is a major contributor to the breakdown of conventional pavement. Because pervious pavements allow water to percolate into the ground without pooling long enough to freeze, they are less affected by the freeze/thaw cycle. This effect is further enhanced by the temperature-regulating effect of air voids in the porous asphalt. A typical pervious asphalt parking lot can have a life span of over 30 years (for comparison, a conventional pervious asphalt parking lot life is approximately 15 years) and pervious concrete can last 20 to 40 years.[58]

Sand should not be applied on pervious pavement in cold climates where snow and ice are typical road issues. Road salt can be used on pervious pavement, although pervious pavement does not prevent potentially harmful chlorides from entering the ground water.[59] However, pervious pavement can reduce the need for road salt use by up to 75 percent due to enhanced temperature regulation it provides.[60]

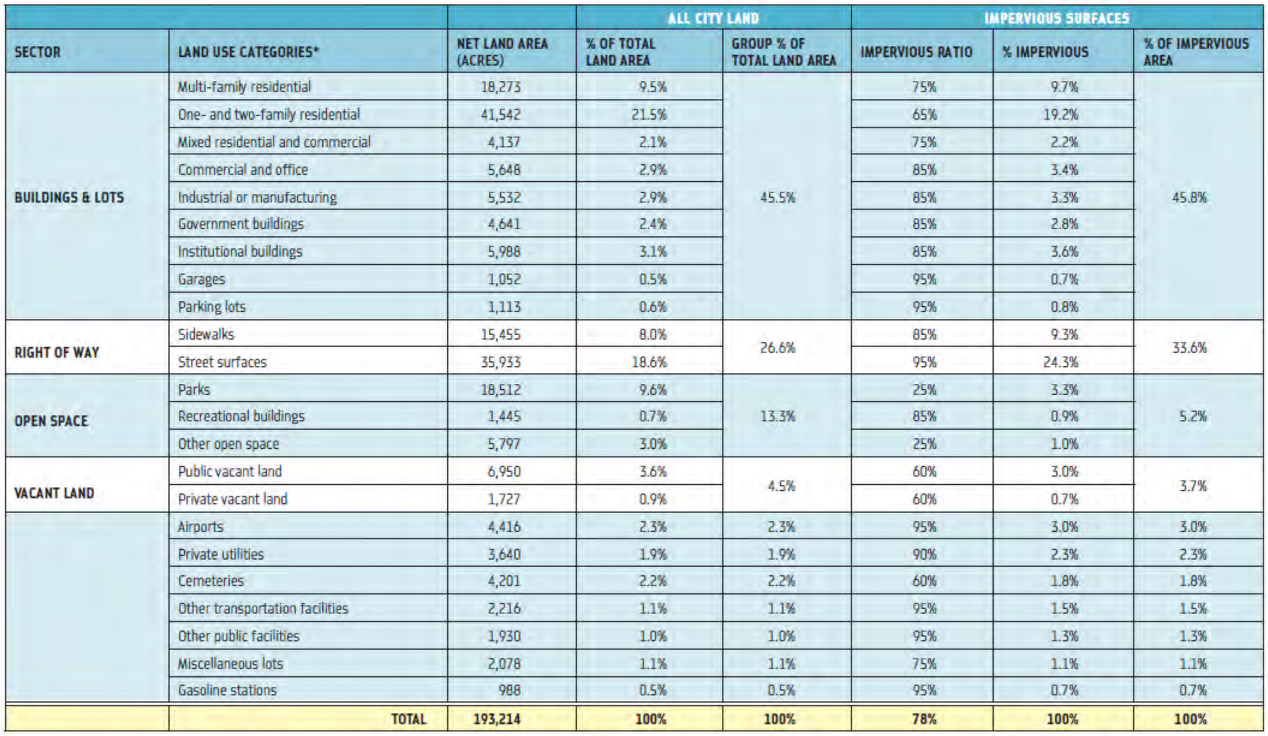
NYC: CHALLENGES AND OPPORTUNITIES FOR STORMWATER MANAGEMENT

High Impervious Urban Density

The first characteristic that sets New York City apart from a typical urban landscape is its dense, impervious surfaces. Seventy two per cent of New York City is covered by impervious surfaces, presenting a unique stormwater management challenge (see Table 4).[61] The high volumes of surface runoff, combined with the age and design of the current sewage system all contribute to weakening the City's ability to deal with its stormwater effectively.

Street surfaces comprise an estimated 24.3% of all impervious surface in the City, and sidewalks an additional 9.3% - for a right of way total of 33.6% (see Table 4). This means the NYC DOT is uniquely positioned to make a transformational change in using pervious pavements to combat CSOs.

Table 4: New York City Land Area Weighted by Impervious Surfaces



			ALL CITY LAND		IMPERVIOUS SURFACES		
SECTOR	LAND USE CATEGORIES*	NET LAND AREA (ACRES)	% OF TOTAL LAND AREA	GROUP % OF TOTAL LAND AREA	IMPERVIOUS RATIO	% IMPERVIOUS	% OF IMPERVIOUS AREA
BUILDINGS & LOTS	Multi-family residential	18,273	9.5%	45.5%	75%	9.7%	45.8%
	One- and two-family residential	41,542	21.5%		65%	19.2%	
	Mixed residential and commercial	4,137	2.1%		75%	2.2%	
	Commercial and office	5,648	2.9%		85%	3.4%	
	Industrial or manufacturing	5,532	2.9%		85%	3.3%	
	Government buildings	4,641	2.4%		85%	2.8%	
	Institutional buildings	5,988	3.1%		85%	3.6%	
	Garages	1,052	0.5%		95%	0.7%	
	Parking lots	1,113	0.6%		95%	0.8%	
RIGHT OF WAY	Sidewalks	15,455	8.0%	26.6%	85%	9.3%	33.6%
	Street surfaces	35,933	18.6%		95%	24.3%	
OPEN SPACE	Parks	18,512	9.6%	13.3%	25%	3.3%	5.2%
	Recreational buildings	1,445	0.7%		85%	0.9%	
	Other open space	5,797	3.0%		25%	1.0%	
VACANT LAND	Public vacant land	6,950	3.6%	4.5%	60%	3.0%	3.7%
	Private vacant land	1,727	0.9%		60%	0.7%	
	Airports	4,416	2.3%	2.3%	95%	3.0%	3.0%
	Private utilities	3,640	1.9%	1.9%	90%	2.3%	2.3%
	Cemeteries	4,201	2.2%	2.2%	60%	1.8%	1.8%
	Other transportation facilities	2,216	1.1%	1.1%	95%	1.5%	1.5%
	Other public facilities	1,930	1.0%	1.0%	95%	1.3%	1.3%
	Miscellaneous lots	2,078	1.1%	1.1%	75%	1.1%	1.1%
	Gasoline stations	988	0.5%	0.5%	95%	0.7%	0.7%
	TOTAL	193,214	100%	100%	78%	100%	100%

*Analysis by the Mayor's Office of Long Term Planning and Sustainability, based on MapPLUTO data and other City information.[62]

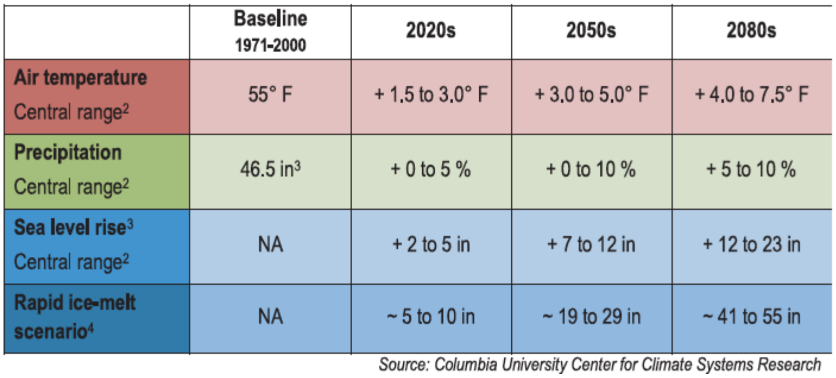
Traffic Considerations

Traffic patterns and volumes are an important consideration in NYC insofar as high population density and mixed zoning create heavy automotive traffic. A byproduct of heavy traffic is street-surface pollution caused by vehicles that leak oil, fuel, antifreeze, and other hazardous substances. When it rains, these contaminants are washed from the streets into the sewer. During a CSO event, they ultimately end up in the river as pollutants. Heavy traffic also creates conditions where paved surfaces require frequent maintenance and repair.[63] The density of sub-street utility infrastructure exacerbates the issue as utility companies needing access below ground frequently dig up streets—new and old—. This signals the need for strong inter-agency communication and coordination.[64]

Climate Change

Climate change presents another challenge in New York City, particularly as it relates to the projected impact on the City's patterns of temperature and precipitation. Currently, the City receives between 43 to 50 inches of precipitation per year without much variation from month to month, creating year-round runoff due to rain, snow, sleet, and hail.[65] However, climate change is expected to result in increasingly warmer temperatures and more frequent extreme weather events, as can be seen in Tables 3 and 4. According to the New York City Panel on Climate, precipitation is projected to increase by up to 5% by 2020 and up to 10% by 2050, which means that the current stormwater management system will continue to be overwhelmed, presumably resulting in ever-increasing risk of CSO events. [66]

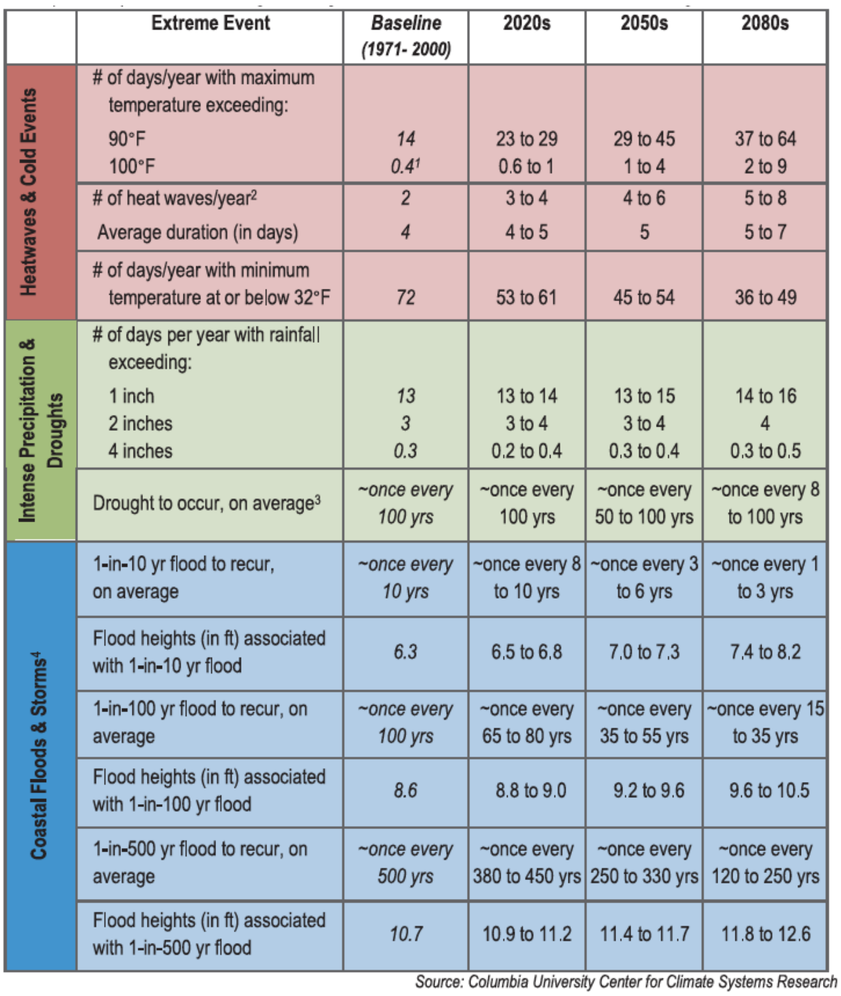
Table 5: Baseline Climate and Mean Annual Changes[67]



	Baseline 1971-2000	2020s	2050s	2080s
Air temperature Central range[2]	55° F	+ 1.5 to 3.0° F	+ 3.0 to 5.0° F	+ 4.0 to 7.5° F
Precipitation Central range[2]	46.5 in[3]	+ 0 to 5 %	+ 0 to 10 %	+ 5 to 10 %
Sea level rise[3] Central range[2]	NA	+ 2 to 5 in	+ 7 to 12 in	+ 12 to 23 in
Rapid ice-melt scenario[4]	NA	~ 5 to 10 in	~ 19 to 29 in	~ 41 to 55 in

Source: Columbia University Center for Climate Systems Research

Table 6: Quantitative Changes in Extreme Events[68]



	Extreme Event	*Baseline (1971- 2000)*	2020s	2050s	2080s
Heatwaves & Cold Events	# of days/year with maximum temperature exceeding: 90°F 100°F	 *14* *0.4*[1]	 23 to 29 0.6 to 1	 29 to 45 1 to 4	 37 to 64 2 to 9
	# of heat waves/year[2] Average duration (in days)	2 *4*	3 to 4 4 to 5	4 to 6 5	5 to 8 5 to 7
	# of days/year with minimum temperature at or below 32°F	*72*	53 to 61	45 to 54	36 to 49
Intense Precipitation & Droughts	# of days per year with rainfall exceeding: 1 inch 2 inches 4 inches	 *13* *3* *0.3*	 13 to 14 3 to 4 0.2 to 0.4	 13 to 15 3 to 4 0.3 to 0.4	 14 to 16 4 0.3 to 0.5
	Drought to occur, on average[3]	*~once every 100 yrs*	~once every 100 yrs	~once every 50 to 100 yrs	~once every 8 to 100 yrs
Coastal Floods & Storms[4]	1-in-10 yr flood to recur, on average	*~once every 10 yrs*	~once every 8 to 10 yrs	~once every 3 to 6 yrs	~once every 1 to 3 yrs
	Flood heights (in ft) associated with 1-in-10 yr flood	*6.3*	6.5 to 6.8	7.0 to 7.3	7.4 to 8.2
	1-in-100 yr flood to recur, on average	*~once every 100 yrs*	~once every 65 to 80 yrs	~once every 35 to 55 yrs	~once every 15 to 35 yrs
	Flood heights (in ft) associated with 1-in-100 yr flood	*8.6*	8.8 to 9.0	9.2 to 9.6	9.6 to 10.5
	1-in-500 yr flood to recur, on average	*~once every 500 yrs*	~once every 380 to 450 yrs	~once every 250 to 330 yrs	~once every 120 to 250 yrs
	Flood heights (in ft) associated with 1-in-500 yr flood	*10.7*	10.9 to 11.2	11.4 to 11.7	11.8 to 12.6

Source: Columbia University Center for Climate Systems Research

Additional Weather Stresses

The typically cold, snowy winters in New York City create a freeze/thaw cycle that can cause heaving or cracking of conventional asphalt and concrete.[69] The use of road salt to manage roadway ice has highly corrosive effects on automobiles, roads, bridges and other infrastructure as well as the surrounding vegetation.[70] Road salt also often contains secondary components such as nitrogen, phosphorous and metals higher than natural concentrations, which has raised concerns about their impacts on both the environment and infrastructure.[71] As mentioned earlier, some of the benefits of pervious pavement are its resilience in cold weather conditions and its reduced need for de-icing measures such as salting.

Organizational Coordination and Synergy

Another challenge New York City faces stems from the complexity of managing the infrastructure of such a large city. Currently the City agencies are developing protocol and determining the responsibilities of each agency for the operation and maintenance of stormwater management infrastructure on streets and sidewalks.

To provide some historical context, the Leventhal Memo of 1983 assigned agency jurisdiction for the cleaning of certain categories of City-owned properties. [72] The memo designates the NYC DOT as responsible for maintaining hard surfaces, the New York City Department of Parks and Recreation (NYC DPR) for medians with plants and similar vegetated areas, the Department of Sanitation for sweeping the streets and cleaning non-landscaped traffic islands and medians, and the NYC DEP for cleaning sediment and debris from catch basins with a fleet of specialized vacuum trucks.[73] Sidewalks were later deemed to be the responsibility of adjacent landowners by the NYC DOT.[74] Over time, each of the agencies' functions has evolved, often coming into conflict regarding duties not addressed in the memo. NYC DEP, for example, has allocated funds to NYC DPR for the maintenance of right-of-way bioswales. This was addressed in the Three-Party Green Infrastructure Maintenance of Understanding signed in January by NYC DEP, NYC DPR, and NYC DOT.[75] However, permeable pavement maintenance responsibilities have yet to be negotiated.

PERVIOUS PAVEMENT CASE STUDIES

Numerous examples of pervious pavement installations and application types exist domestically and internationally. To capture and summarize relevant findings for New York City, the team developed a set of criteria to assess the success of various case studies and then used case studies to identify best management practices in highly urban environments.

OVERVIEW: METHODOLOGY AND CRITERIA FOR CASE STUDY SELECTION

The criteria for a successful case study were developed in collaboration with the client who narrowed the study scope to include only examples of urban roadway applications that use either pervious asphalt or pervious concrete (or both) installations. Retrofit applications in which pervious solutions replace existing and similar infrastructure were preferred but not required.

Table 7: Pervious Pavement Case Study Selection Criteria

Criteria for Applicability to NYC
▪ Urban (similar to QNS, BKN)
▪ Roadway
▪ Materials: 1. asphalt, 2. concrete
▪ Climate similar to NYC

Criteria for Installation Success
▪ Durability
▪ Permeability (min 1/2 inch/hr)
▪ Runoff reduced by target amount
▪ Positive return on investment

Once identified, the successful case studies were documented in a user-friendly template. The template includes:

- **Geographic location** – the city and state, or for international cases, the country and city as well as the street location of the application
- **Climate description** – the average temperature and precipitation of the location.
- **Goal description** – the stated goal of the installation (e.g. CSO avoidance, ground water contamination avoidance, etc.)
- **Installation area** – total area of installation provided in as specific terms as possible (e.g. number of blocks, square footage, etc.)
- **Installation cost** – cost of pavement installation
- **Maintenance requirements** – specific maintenance activities
- **Maintenance costs** – cost of maintenance activities
- **Traffic** – typical speed, frequency, and/or profile of vehicles on roads where pervious pavement has been applied
- **Goals achieved** – degree to which the installation is a success, as described within the case study itself or per interviewee(s)

- **Water-quality benefit** – measurement of particles and contaminants removed from stormwater (when provided)
- **Permeability** – measured infiltration rate of installation
- **Durability** – installation durability issues

These categories were selected based on their relevance and the availability of data. Unfortunately, data was often incomplete, but was nevertheless useful when determining best practices and developing potential applications in NYC. Interviewees included practitioners from a range of backgrounds and served to fill in missing data on specific installations. Interviewees are identified in Table 8, below.

Table 8: Interviewees

Name	Position	Organization
Matthew Lebens	Project Engineer	Minnesota Department of Transportation
Lawrence Mastsumoto	Engineer	Minneapolis Department of Transportation
Peter Reilly	Civil Engineer	Philadelphia Water Department
Peter Brennert	Engineer	Streets Design Branch, City of Vancouver
Jonas Moon	Engineer	Streets Design Branch, City of Vancouver
Yuko Nishida	Planner	Bureau of Environment, Tokyo Metropolitan Government

DOMESTIC CASE STUDIES SUMMARY

Pervious asphalt and concrete options have been available for many years but only recently have they been adopted in the US, primarily driven by State and City policies that are continuously evolving towards sustainability and include green infrastructure targets not dissimilar from those laid out in PlaNYC. Most of the adopting localities cited a goal to reduce CSO events as well as to improve the quality of life for residents as the main reasons to pursue the installation of pervious pavement projects.

While, many of the installations identified were small-scale pilot projects, several were more ambitious projects that can prove informative to pervious pavement demonstration installations in NYC. Although many of the cases were recently installed and therefore do not yet have conclusive data on full project lifetime, we were able to glean insights from them in terms of best management and maintenance practices for our recommended sites. On-going monitoring of these efforts and check-ins with interviewees will prove informative for NYC DOT as they develop a larger rollout of pervious pavement installations.

INTERNATIONAL CASE STUDIES SUMMARY

Pervious pavements have been widely applied internationally, most notably in Europe in Germany, the UK, Belgium and the Netherlands. In Asia, Japan began using pervious pavement as early as 1973 in Tokyo,[76] and in the 1980s pervious pavements became a nationwide standard with an accompanying street-construction manuals specific to pervious pavements.[77,78] China also undertook great efforts to install pervious pavement in its major cities prior to the Summer 2008 Olympic Games and is exploring future urban installations.[79] Australia has installed a number of pilot sites over the past decade and is now ramping up its efforts by conducting intensive research, organizing study tours to Europe, and designing more demonstration projects. [80]

We identified three primary international cases: Vancouver, Canada, Japan and Germany. They were chosen because of their similarities with NYC in climate and urban density. Moreover, Japan and Germany were attractive cases insofar as they are international leaders in the application of pervious pavement and have both systematized approaches to its installation. As of 2005, Japan has installed 538.2 million ft^2 of pervious pavement (including all materials). [81] Germany, which began installing pervious pavement in the mid 1980's, is now installing 193.75 million ft^2 per year, by far the fastest rate in the world.[82] The City of Vancouver carried out its City Lane Program in 2011 using porous asphalt on city roadways to improve infiltration.[83]

Apart from pervious concrete and porous asphalt, a wide range of materials and construction methods are used internationally, including pavers, porous blocks, green apertures and structural grass.[84,85] In Germany and Japan, additional benefits reportedly include noise reduction, enhanced safety (especially on highways) and reduced urban heat-island effect.[86]

BEST MANAGEMENT PRACTICES IN HIGHLY URBAN CONDITIONS

Our case studies and expert interviews have lead to several best management practices that can be applied in New York City for stormwater management and CSO abatement.

Best Management Practice: Pavement Type

Because of NYC's significant sub-street utility infrastructure and the frequent need to remove and reapply street surface material, it's recommended that the NYC DOT use pervious asphalt. Compared to concrete, asphalt provides relative ease of surface layer application and will be least disrupted by frequent utility trenching.

Domestically we identified several pervious asphalt installations in cities that have traffic and weather similarities to New York City. While these sites are small in scale and more recent installations, monitoring their progress and exchanging information with subject-matter experts will allow best practices to develop.

Internationally, the research shows a commonly adopted method of using mixed pervious pavement materials in multiple layers to improve durability and performance. Japan has used a pervious asphalt-concrete blend with high-viscosity asphalt cement, bitumen and asphalt rubber since 1987 on many of its highways and some city roadways.[87] Evaluations of road conditions demonstrate remarkable performance of this mixed material against rutting, even in regions with heavy traffic volume.[88] In general, these pavements can endure traffic pressure and perform as well as regular asphalt for more than 10 years in warm regions and for 7-10 years in cold regions.[89] The City of Vancouver, Canada completed a pilot project of its City Lane program in 2011 that used a mixed ratio of porous asphalt in 4 layers to improve the durability of the pervious pavement on a city road (see Appendix 2 for more information on this project in Vancouver).

Best Management Practice: Site Selection

All installation sites must meet the minimum criteria listed in Section 4. Ideal installation sites are low-traffic zones and should also not have been resurfaced within the last five years, per Directive 10 from The City of New York Office of the Comptroller Internal Control and Accountability Directs-Charges to the Capital Projects Fund.[90]

Both domestically and internationally, installations exist within major urban cities, including Philadelphia and Seattle, as well as in Japan and Germany on city roadways and on intersections with regular urban traffic volumes.

Best Management Practice: Design

To maximize durability, asphalt and choke-layer thickness should follow details and specifications for installation. When possible, base and sub-base layer thickness should be determined based on the hydrologic drainage area.

Domestically, pervious pavements have not been used widely enough to develop any national standards, however, Peter Reilly of the Philadelphia Water Department emphasized that the design is the most important phase and gives engineers the opportunity to create setups that support heavily trafficked roadways.[91] It could prove worthwhile for NYC DOT to investigate international standards in more detail for potential adoption.

Internationally, industry standards are important drivers to ensure the adoption of the best possible designs and achieve satisfying construction quality and performance. Germany has set infiltration-capacity limits for new installations to ensure adequate runoff absorption. In Japan, standards exist for pervious pavement thickness, aggregate size, permeability, and noise reduction requirements (see Appendix 2 for more details on these standards).

High-level construction guidelines have also helped to standardize the use of pervious pavements. In Japan, the Road Association issued the "Guidelines for Porous Asphalt Pavement" in 1996 (this guideline has been updated to its latest version in 2006). [92] The "Japan Porous Asphalt-Concrete Mixture Design Guide" was issued in the same year.[93] Since pervious pavement is also used on busy intersections in Japan, a custom developed epoxy-based surface treatment is applied manually on intersections to improve durability. The "top-coat" treatment consists of two types of base resin and hardening agent, one for use in the summer and another for winter respectively.[94] Lessons from Japan also show that if the base course is not properly sealed, oil leakage from vehicles can cause potholes and strip the base.[95]

Best Management Practice: Maintenance

Clogging is the primary maintenance concern and best practices include: sweeping, vacuuming, pressure washing and weeding.[96] Regular monitoring will be required to measure performance and to develop a maintenance schedule suitable for New York City's requirements. During winter weather, sand should not be used on pervious asphalt. Sand will clog the pores and sub-street filtration reservoir, which can severely hinder the infiltration rate of the installation.

NYC DEP, NYC DPR and NYC DOT should continue to investigate the options for maintaining pervious asphalt and consider partnering with the Department of Sanitation to do so. The pervious roads will likely need to be specially signed to alert City street maintenance employees of the salt and sand restrictions.[97] It is fine to use snowplows on pervious pavement in the winter months.[98] Snow chain usage should be carefully regulated, however, and snowplows with steel blades can do damage to pervious pavements. In the Hokkaido region of Japan, steel-bladed ploughs are used to remove ice, but the steel scrapers have caused significant reductions in pavement thickness in only a few years and regular repair is therefore needed.[99]

Domestically, conventional sweeping, hand-pulled "goat" sweeping, vacuuming, and weeding are common maintenance methods.[100] Jet washing has shown promise in restoring designed infiltration rates after clogging has occurred. [101] The Philadelphia case study indicates that cleaning can occur as infrequently as two to three times a year and still be effective. [102]

Internationally, we note that Japan has been designing specialized cleaning machines for pervious pavements since 1993.[103] Some of these machines use water streams at an angle of 90 degrees to the road surface and others have water jets mounted on rotating devices.[104] One of most widely used machines in Japan is called "Spec-keeper," which sprays water on the pavement at the edges of a "curtain" of high pressure air to enhance the suction of the washing water at a high speed. Dirt and particles are separated from the water and the water is collected and re-used.[105] Notably, all three international cases share responsibility for care of pervious pavement with building owners and have used this partnership as an opportunity to educate residents about stormwater management.[106,107,108]

Best Management Practice: Monitoring

Monitoring falls into two categories: environmental performance and structural performance. The first priority for environmental monitoring should be to verify the extent to which the initial infiltration rate is sustained. To monitor water quality, monitoring wells should be installed within the pervious pavement application area. "These sampling stations utilize a nested design to capture the infiltrating water at depths three and five feet below the parking lot surface. Each station is comprised of two infiltration catchment and sampling components. The catchment portion is a five cm deep stainless steel box that collects water either three or five feet below the ground surface. This water is gravity fed into an adjacent one-gallon glass bottle, which is retrieved from the surface via an eight-inch diameter PVC pipe."[109]

Structural monitoring includes monitoring the durability of the installation (distress, density, strength, strain, spalling, etc.) and operational metrics such as friction, skid resistance, spray, and sound absorption. Durability testing can leverage ASTM standard tests, using visual inspection or tools such as strain gauges and laser equipped surface evaluation devices.[110] Operational parameters such as skid resistance value and friction coefficients can also leverage ASTM standard tests.

RECOMMENDATIONS: LOCATIONS AND INSTALLATION TYPES

SITE SELECTION CRITERIA

Site selection criteria were based on initial consultation with NYC DOT, and supplemented by an assessment of technical literature and research of successful case studies. Fifteen key elements were grouped into three categories: geotechnical, transport network, and built environment as shown in Table 9, below.

NYC DOT further narrowed the scope of analysis to two watersheds within Queens and Brooklyn, the Flushing Bay Watershed and the Newtown Creek Watershed. Planned road reconstruction within these watersheds coincided with the time frame being considered for pervious pavement demonstration projects allowing the two projects to be carried out simultaneously. The initial analysis using GIS mapping was performed for all priority watersheds within Queens and Brooklyn, but the project scope was limited to the two watersheds indicated by NYC DOT.

Table 9: Site Selection Criteria

Category	Criteria	Preferred	Acceptable
Geotechnical	**Depth to bedrock**	**5′ or greater**	**5′ or greater**
	Depth to water table	**6′ or greater**	**4′ to 6′**
	Slope	**0 - 3%**	**3 - 5%**
	Soil permeability	**0.5″ per hour or greater**	**0.1 - 0.5″ per hour**
	Hydrologic soil group	**A or B**	**A or B**
	Soil clay content	**Less than 20%**	**Less than 20%**
Transport Network	**Major road**	**No**	**No**
	Bus route	**No**	**No**
	Truck route	**No**	**No**
	Subway line	**No**	**No**
	Railroad line	**No**	**No**
Built Environment	**Building setback**	**10′ or greater**	**10′ or greater**
	Residential zoning	**Yes**	**Yes**
	Street tree density	**Less than 3 trees / K sq. ft.**	**Less than 3 trees / K sq. ft.**
	Pavement condition	**Fair**	**Poor**

RECOMMENDED INSTALLATION TYPES

As with site selection criteria, recommendations for pervious pavement material and installation types were based on consultations with NYC DOT, assessment of technical literature, and consideration of pertinent case studies. NYC DOT identified a number of factors as being critical for the success of pervious pavement demonstration projects. The material used must be able to withstand the weight and volume of traffic anticipated on local roads within the priority watersheds. Construction time should be minimized to decrease the amount of disruption to vehicular traffic. Pavement material should be easily removed and replaced to facilitate sub-surface on-going utility maintenance. Finally, responsibility for cleaning and maintenance is to be negotiated prior to installation of demonstration projects.

Material and Placement

Pervious asphalt was the material deemed most likely to meet the requirements of NYC DOT. As discussed in the review of technical literature on page 13, pervious asphalt requires less construction time due to the short period required for curing, and provides easier access to sub-surface utilities than pervious concrete. Roadway placement of pervious asphalt, as opposed to sidewalk placement, was recommended to ensure that responsibility for cleaning and maintenance resided with an NYC agency as mentioned above, and not with individual property owners.

Installation Types

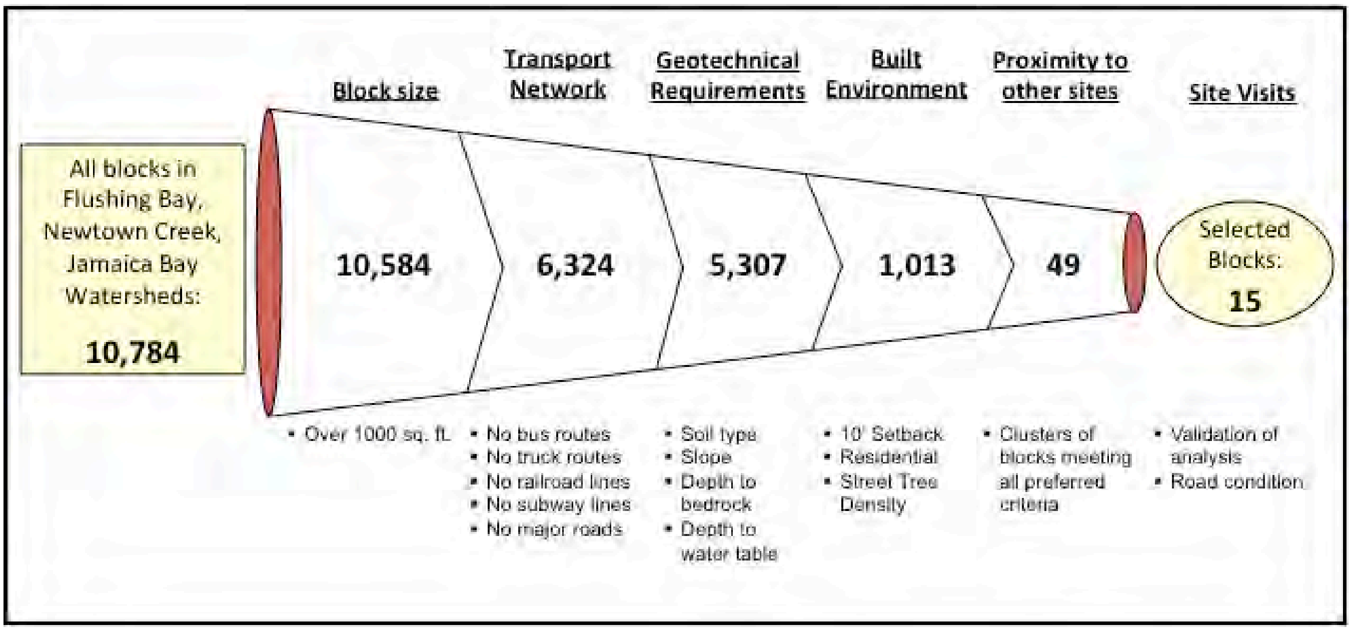
Three types of installation of pervious asphalt within roadways were recommended.

1. Full Roadway: The roadway surface from curb to curb would be reconstructed down to the sub-base level, and repaved with pervious asphalt, allowing infiltration of stormwater into the soil.
2. Parking Lane: The parking lanes would be reconstructed down to the sub-base level, and repaved with pervious asphalt; the concrete base layer below the traffic lanes would remain intact and be repaved with standard asphalt.
3. Gutter Strip installation: A one foot wide strip adjacent to the roadway curbs would be reconstructed down to the sub-base level, and repaved with pervious asphalt; the concrete base layer below the remainder of the parking lanes and the traffic lanes would remain intact and be repaved with standard asphalt.

PROPOSED LOCATIONS AND PRIORITIZATION

Recommendations of proposed sites for pervious pavement were based on an analysis of mapping data using geographic information system software. The data consisted of publicly available data sets relating to the geology, hydrology and built environment of NYC, as well as data sets and maps provided by NYC DOT relating to the location of priority watersheds and the traffic designation of roadways within Queens and Brooklyn. The GIS analysis was performed in 5 steps as illustrated in Figure 6, below.

Figure 6: Steps of Analysis



The GIS analysis aggregated data relating to site selection criteria to segments of roadway of approximately one city block in size. The first step of the analysis eliminated roadway segments below 1000 square feet in area, typically intersections and small access roads.

The second step eliminated those segments of roadway that were crossed by transportation routes such as bus routes, truck routes, subway lines, and railroad lines, or that were designated by NYC DOT or commercial street maps as major roads. By avoiding these parts of the transport network in Queens and Brooklyn, sites that experienced large traffic volume or frequent traffic from heavy weight vehicles could be removed from consideration. Removing sites crossed by railroad and subway lines avoided bridges, tunnels, and overhead or subsurface structures.

The third step of the analysis eliminated segments of roadway that had slopes, or depths to bedrock and water table that were outside the ranges established by the site selection criteria. The remaining roadway segments were ranked into two tiers, preferred, or acceptable, depending upon their geotechnical characteristics compared to the site selection criteria.

Soil characteristics were not taken into consideration for ranking preliminary sites due to the lack of comprehensive data, though the soil characteristics for the recommended sites were reported. Soil testing of recommended sites for pervious pavement demonstration projects will be needed to confirm that the reported soil characteristics are correct.

The fourth step of the analysis removed those roadway segments that were located in non-residential zoning districts, or in residential zoning districts with building setbacks (the distance from the street right-of-way to the face of buildings) less than ten feet. The density of street trees was estimated by comparing number of trees within ten feet of the roadway to the area of the roadway segment. Segments with more than three trees per 1,000 square feet were eliminated from consideration.

Finally, roadway segments were sorted by pavement condition as reported by NYC DOT. Roadway segments reported as in “Fair” or “Poor” condition were selected for site surveys to verify conditions. This is the case because streets in poor or fair condition are more in need of resurfacing with or without pervious paving, so it is more cost-effective to target these segments than to resurface streets that are already in good condition.

The GIS portion of the analysis yielded approximately 500 roadway segments in the Flushing Bay and Newtown Creek Watersheds in first tier of results. These sites are illustrated in Figures 7 and 8, below. Since the GIS analysis was conducted on all of Queens and Brooklyn roadway segments in the Jamaica Bay Watershed were also identified and are illustrated in Figure 9, below. Clusters of preferred sites were identified and from these were selected 45 individual sites for site surveys to verify conformance with site selection criteria and to collect additional data relating to road condition. A final set of 15 sites was chosen after site documentation. These final sites are illustrated in Figures 10, 11, and 12, below.

The GIS analysis and data collected from site surveys was made available to the NYC DOT for their use in selecting sites for pervious pavement demonstration projects. As their green infrastructure efforts continue, this information can inform their selection of additional sites for pervious pavement in the Flushing Bay, Newtown Creek and Jamaica Bay Watersheds.

Figure 7: Preliminary Pervious Pavement Site Recommendations in the Flushing Bay Watershed

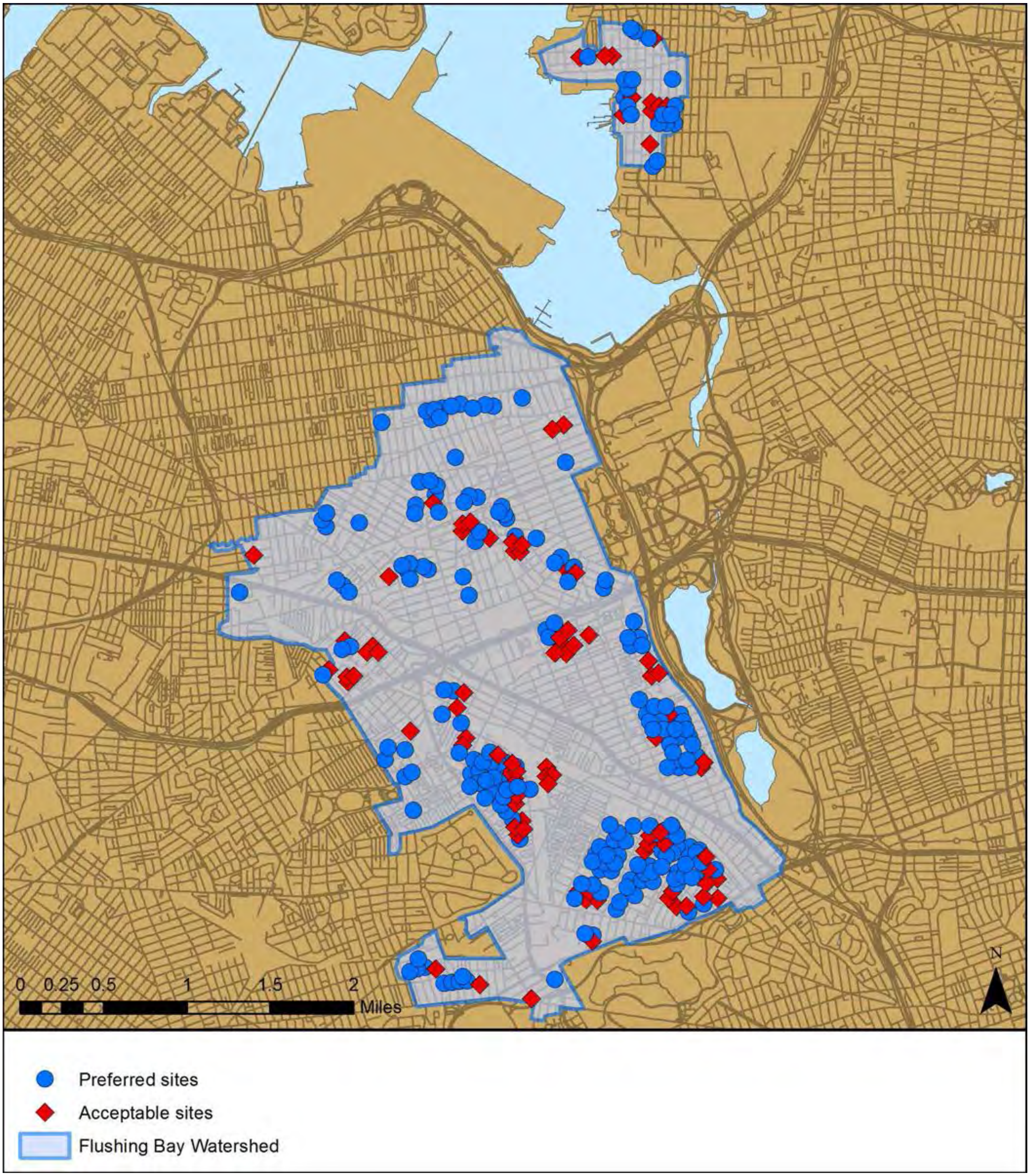


Figure 8: Preliminary Pervious Pavement Site Recommendations in the Newtown Creek Watershed

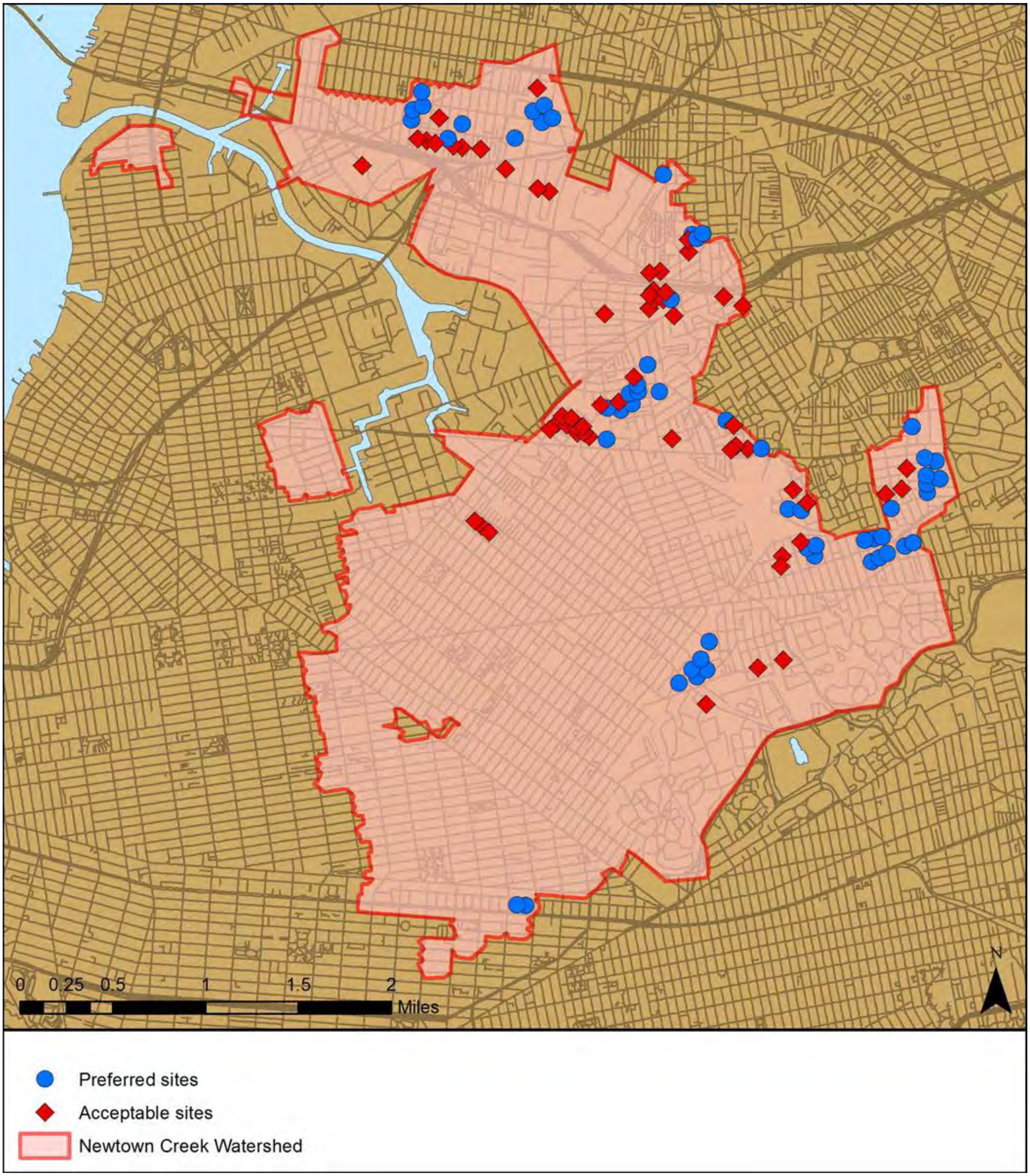


Figure 9: Preliminary Pervious Pavement Site Recommendations in the Jamaica Bay Watershed

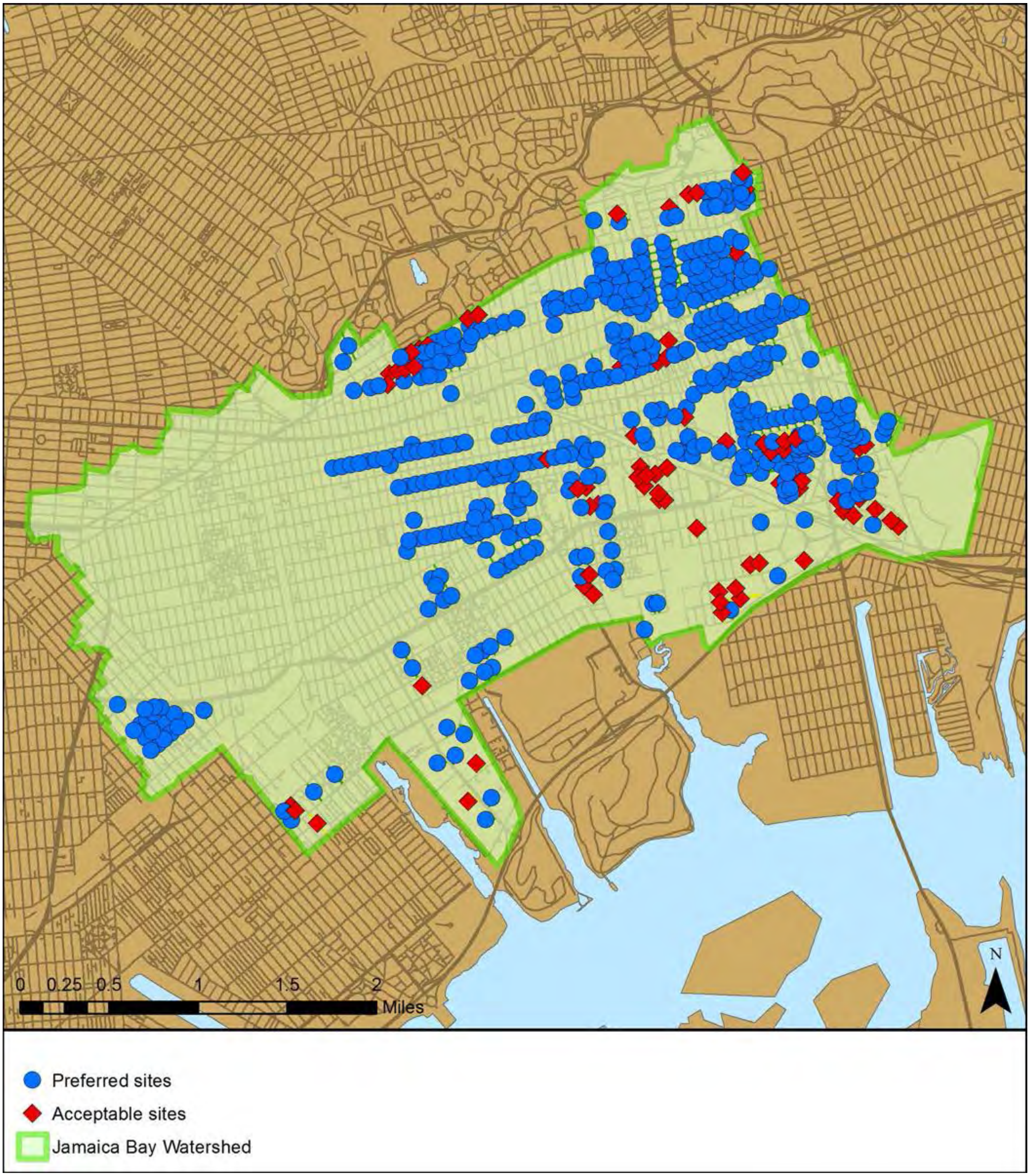


Figure 10: Final Pervious Pavement Site Recommendations in the Flushing Bay Watershed

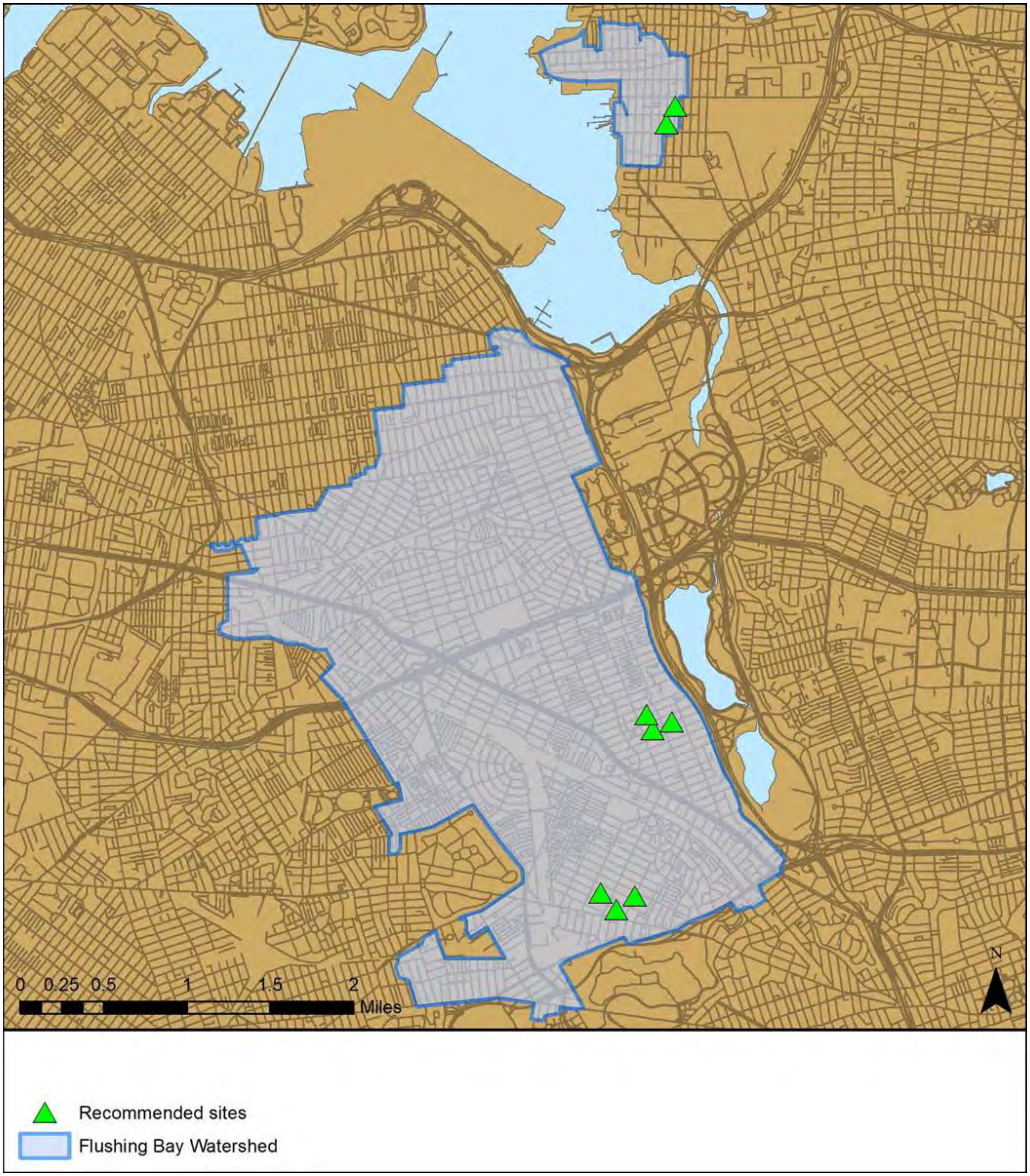


Figure 11: Final Pervious Pavement Site Recommendations in the Newtown Creek Watershed

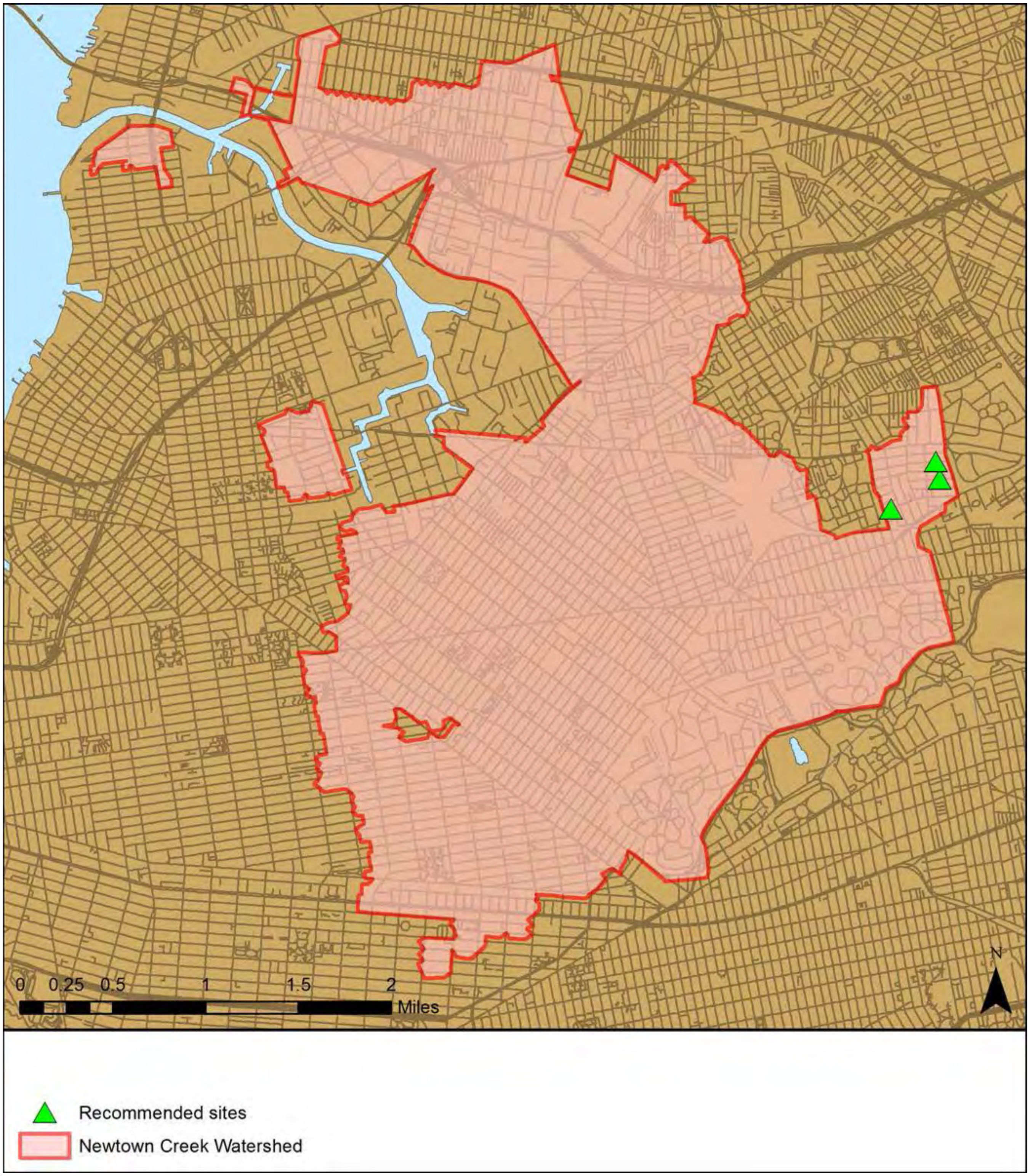
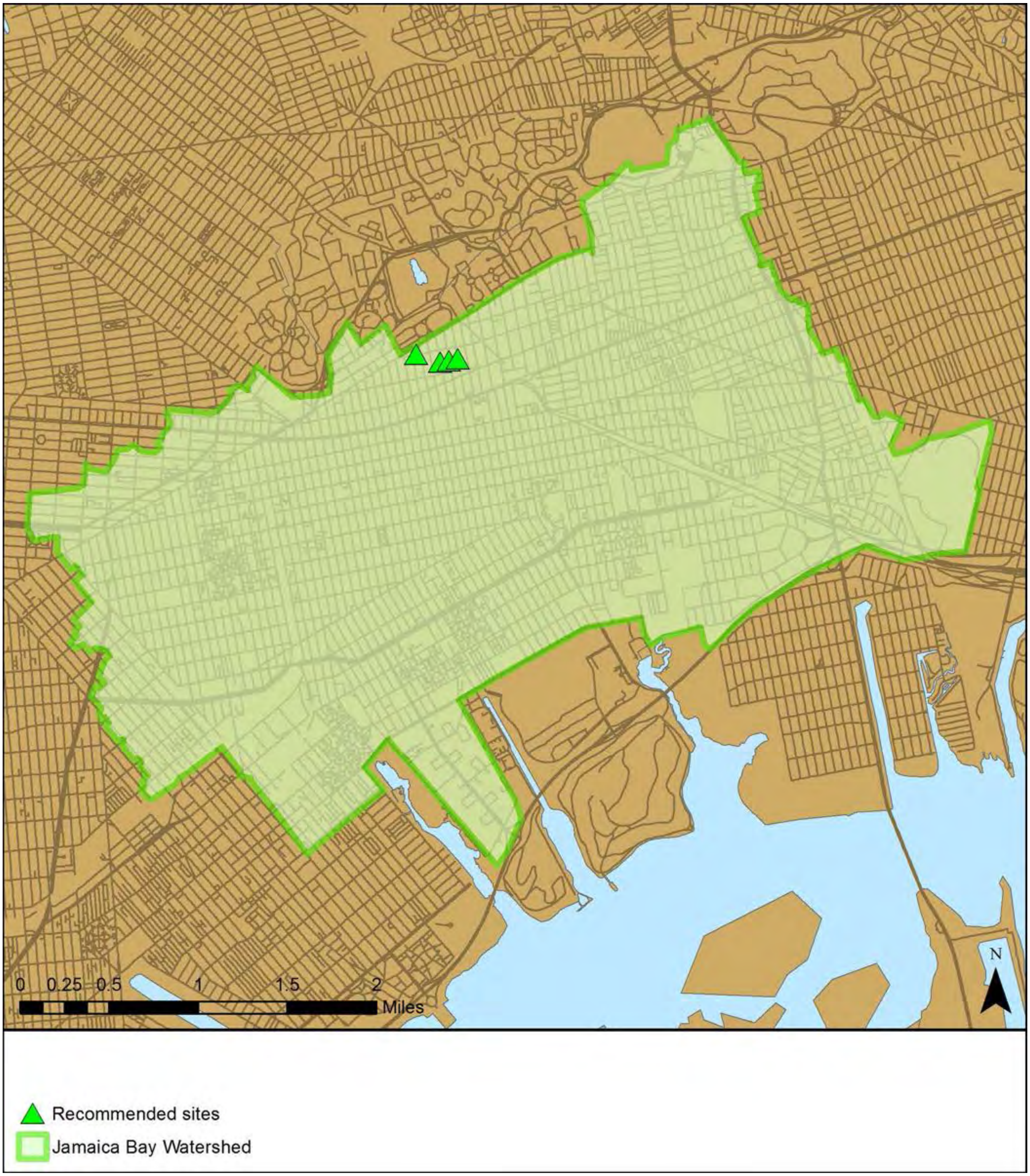


Figure 12: Final Pervious Pavement Site Recommendations in the Jamaica Bay Watershed

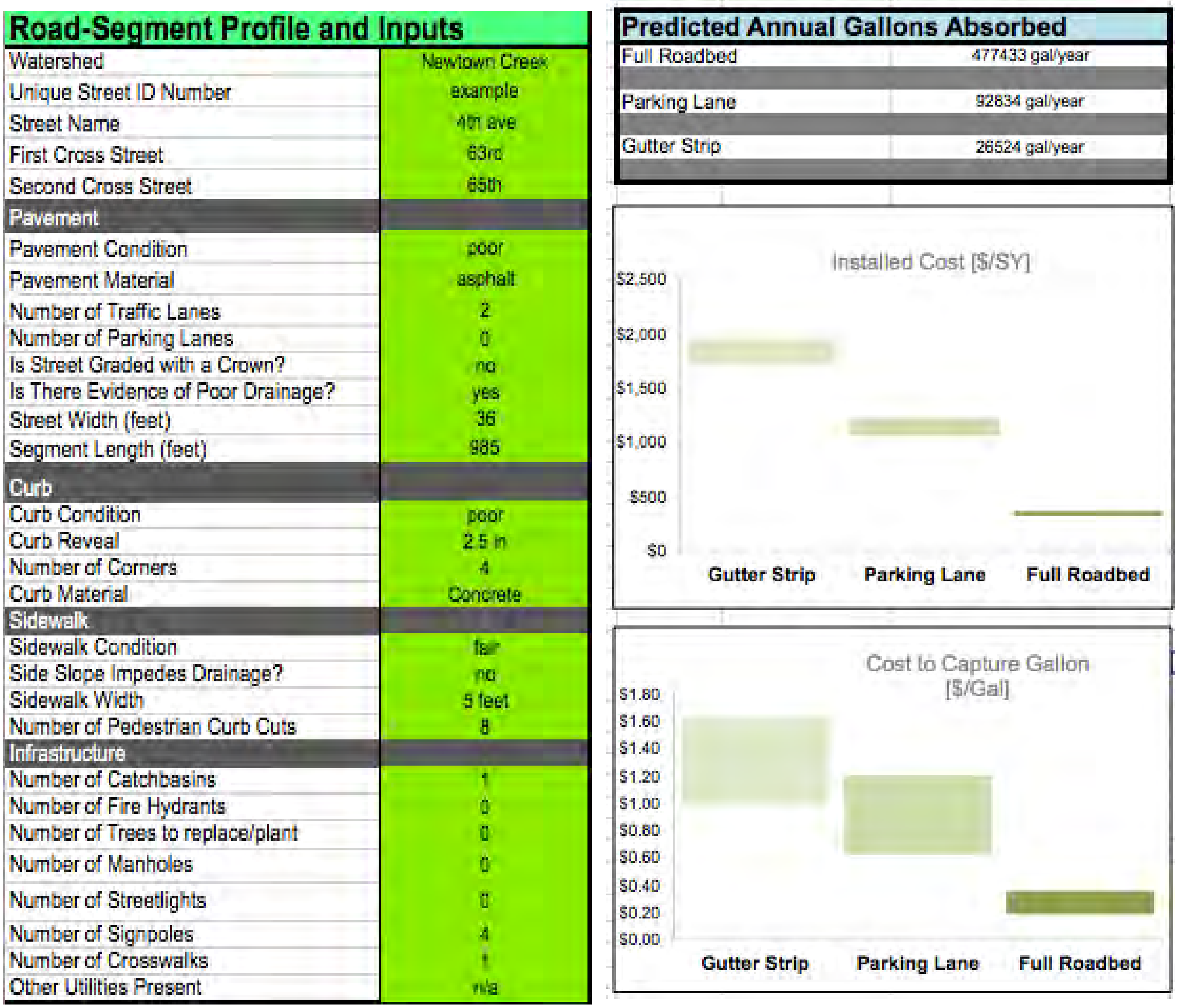


COST BENEFIT ANALYSIS AND CPI

Cost-Benefit Methodology and Model Design

The key criteria for designing our cost-benefit model is that it quickly arrive at accurate conceptual costs given site visit data and that it be able to predict the absorptive benefits of any potential pervious asphalt installation—and further, to evaluate the costs and benefits for three different levels of project complexity: gutter-strip, parking-lane, or full-roadbed installations. Being able to compare between these three installation types for specific road segments identified by the GIS analysis informed the recommendations for the 15 specific segments that are recommended for Phase 1 of DOT's implementation plan. Examples of Inputs and Outputs are given in Figure 11, below.

Figure 11: Example Inputs and Outputs for Cost-Benefit Model



Road-Segment Profile and Inputs

Watershed	Newtown Creek
Unique Street ID Number	example
Street Name	4th ave
First Cross Street	63rd
Second Cross Street	65th
Pavement	
Pavement Condition	poor
Pavement Material	asphalt
Number of Traffic Lanes	2
Number of Parking Lanes	0
Is Street Graded with a Crown?	no
Is There Evidence of Poor Drainage?	yes
Street Width (feet)	36
Segment Length (feet)	985
Curb	
Curb Condition	poor
Curb Reveal	2.5 in
Number of Corners	4
Curb Material	Concrete
Sidewalk	
Sidewalk Condition	fair
Side Slope Impedes Drainage?	no
Sidewalk Width	5 feet
Number of Pedestrian Curb Cuts	8
Infrastructure	
Number of Catchbasins	1
Number of Fire Hydrants	0
Number of Trees to replace/plant	0
Number of Manholes	0
Number of Streetlights	0
Number of Signpoles	4
Number of Crosswalks	1
Other Utilities Present	n/a

Predicted Annual Gallons Absorbed

Full Roadbed	477433 gal/year
Parking Lane	92834 gal/year
Gutter Strip	26524 gal/year

The inputs correspond directly with GIS data and observations obtained during team site visits. By putting these values into the green input fields of the model, costs are computed for the three installation types. At the core of these calculations is a conceptual cost estimate that was provided by NYC DOT and refined after further discussions. This calculator allows estimation for all excavation, construction costs, design and engineering costs and additional site-specific costs, such as removing and relocating catch basins and manholes are factored in if this work would be required. To model the potential absorption of each installation type, the annual precipitation was assumed to be the National Weather Service average of 47.25 inches per year and storm event occurances were modeled based on 2000 storm data for New York City.[111,112] Cost ranges were constructed by adding a 20% contingency cost to each initial conceptual cost estimate and these ranges were combined with absorbptive data to arrive at a key metric for project evaluation, cost to capture a gallon of precipitation. Having this metric for proposed projects allows us to directly to compare our proposals to the benchmark of cost-effective grey infrastructure and expected green infrastructure costs for our two target watersheds per the Green Infrastructure Plan.

Findings

Using the model, the total cost to implement the recommendations for 15 sites spread across 3 different watersheds would be close to $11 million. This is for a breakdown if 9 full-roadway installations, 3 parking-lanes, and 3 gutter-strips. The average cost per full roadway installation is $930,000, the average parking-lane installation is $710,000 and the less complex gutter-strip installation is $240,000. However, the key metric for evaluation should be cost per gallon of CSO avoided, as this metric factors in the benefits of pervious pavement installations. With this in mind, the full-roadway installation is nearly always most favorable as the additional absorptive capacity justifies the higher cost. However, gutter strip installations and parking-lane installations still prove worthwhile in cases in which project cost is a key consideration or for roadway segments that are already in good condition. In such cases, a less invasive gutter-strip or parking-lane installation can still provide the benefit of CSO avoidance without high capital cost or extensive roadwork.

As can be seen from Figure 12, the pervious pavement installations in our recommended sites are, on the whole, in line with green and grey infrastructure strategies for CSO avoidance, and in some cases they perform even better than the Green Infrastructure Plan benchmark for Green Infrastructure performance.[113]

Figure 12: Cost per gallon of CSO Avoided, Recommendations versus Green Infrastructure Plan Projections

CPI

Using the cost-benefit model information above, the Capital Project Initiation (CPI) document will allow NYC DOT to define the scope and begin to secure funding for Phase 1 demonstration projects.

Indirect Benefits

In addition to reductions in CSO volume, as noted in many of the case studies cited earlier, there are many indirect, and more difficult to quantify, benefits that can be tied to increased applications of pervious pavements in NYC. For example, as these installations begin to reduce CSO volumes, they will also help to improve the water quality of New York's waterways, thereby increasing surrounding property values.[114] Additionally, as was found in the Japanese case study, pervious pavements can reduce tire noise, enhance safety—as pervious surfaces reduce the spray from moving vehicles and increase traction - provide better nighttime visibility, and reduce the heat island effect by creating an overall cooler pavement surface.[115,116] Another important impact for NYC is that CSO management might help stabilize rent prizes as dealing with CSOs is a cost that is passed to customers in the form of higher water costs. Because landlords pay most water bills, increases in costs provide a legal basis by which landlords can argue for rent increases, hence reducing CSOs reduces the potential for increases in the cost of water and rent hikes. [117]

Implementation Roadmap

CURRENT STATUS – PERVIOUS PAVEMENT IN NYC

Currently, there are a handful of small pervious pavement projects either recently implemented or planned in New York City, but these don't yet approach the scale of what is needed to achieve the targeted reduction in stormwater runoff. Many are parking lots or pedestrian areas. This is similar to the level of development of pervious pavement installation in many US cities, as seen in the domestic case studies of Appendix 1.

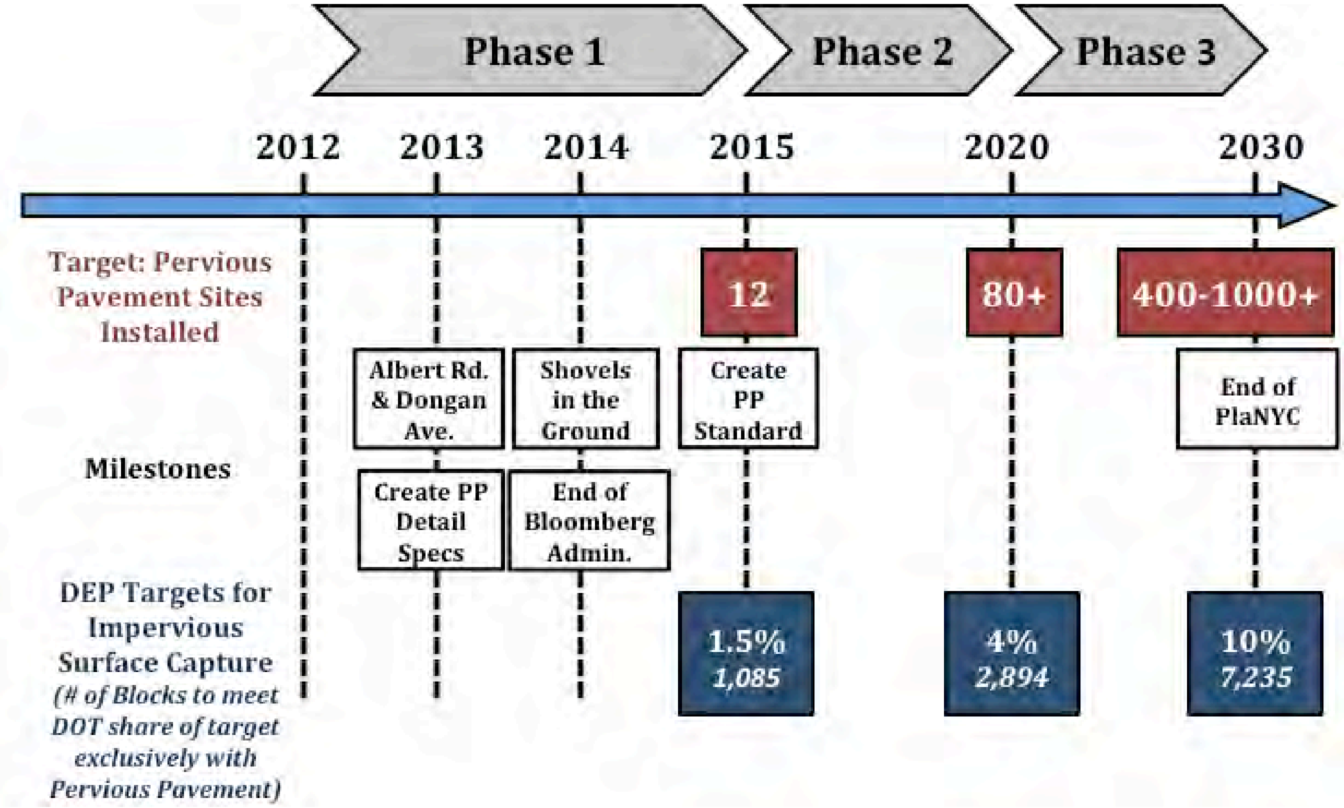
Vision for New York City

New York City has an opportunity to *pave the way* for the rest of the United States by becoming the first and leading American city to install pervious pavement in a significant volume. In doing so, it stands not only to improve the quality of the City's waterways, expand opportunities for recreation and repair coastal ecosystems, but also to position New York City as a pioneer in using sustainable street design to solve one of the City's most pressing sustainability challenges, combined sewer overflow.

GAP ANALYSIS

Given that streets and sidewalks make up approximately a third of the impervious surfaces in NYC's priority watersheds, NYC DOT has an opportunity to contribute significantly to the targeted 10% stormwater capture from impervious surfaces in combined sewer areas by 2030. However, in light of the short timeframe before the NYC DEP's first intermediate target in 2015, the NYC DOT should begin installing demonstration projects as soon as possible such that the projects prove they can perform satisfactorily and effectively contribute towards achieving these goals. Thereafter, the NYC DOT should rapidly expand the scale of its installations throughout all priority watersheds. To achieve this, the following timeline has been developed.

Figure 13: Implementation Plan, 2012 – 2030



TACTICAL PLAN

As noted above, the tactical implementation plan through 2030 includes three phases; a preliminary phase where demonstration sites are installed and monitored, followed by two subsequent phases where the NYC DOT rapidly expands the breadth of its pervious pavement installations in accordance with the targets set by NYC DEP. It should be noted that the magnitude of this expansion directly depends on the NYC DOT's degree of responsibility for reducing CSOs and the extent of the corresponding funding and other resources allocated for pervious pavement installations. While abating CSOs in NYC will undoubtedly require a portfolio of solutions implemented by a cross-section of City departments, it is recommended that the NYC DOT rely on the installation of pervious pavement as the principal way in which it contributes to these reductions.

Assuming that the NYC DOT is given full responsibility for its share of impervious surface capture in combined sewer watersheds, below are the number of city blocks of pervious pavement that should be installed in order to meet the targets:

- 2012-2015 (1.5% capture): 1,085 installations
- 2015-2020 (4% capture): 2,894 installations
- 2020-2030 (10% capture): 7,235 installations

Insofar as the first intermediate target is fast approaching, the NYC DOT is encouraged to install its demonstration sites as soon as possible in order to begin the monitoring and evaluation process. Meanwhile, the NYC DOT should begin to mobilize the necessary resources to aggressively expand its installations for Phases 2 and 3, compensating for the target shortfall in Phase 1. If and where there exists a chasm between the number of installations required to meet NYC DOT's share of the target and funding available for pervious pavement projects, it is paramount that other CSO abatement compensatory projects be implemented. If this does not occur, then the City risks reneging on its goal for stormwater capture and CSO reduction.

Phase 1 Detailed Action Plan

1. Columbia: Site Recommendations
2. Columbia/DOT: Draft CPI Documentation
3. DOT: Determine In-House Capability
4. DOT: Finalize Street Limits
5. DOT: Determine In-House Capacity
6. DOT: Scope (Design Details)
7. DOT/DEP: Funding Negotiations & Approvals
8. DOT: Capital Budget Allocations
9. DOT: Issue CPI Documentation
10. DOT/DEP/DDC: Pre-Monitoring Device Installation
11. DDC: Design & Construction
12. DDC/DOT/DEP: Public Outreach

Synergies and Risks

Pervious pavement is one green infrastructure solution that the NYC DOT is looking to implement in a complex policy environment. It is prudent to assess risks and identify ways to mitigate them, as well as understanding positive contributors to the success of this initiative. Primary project risks include:

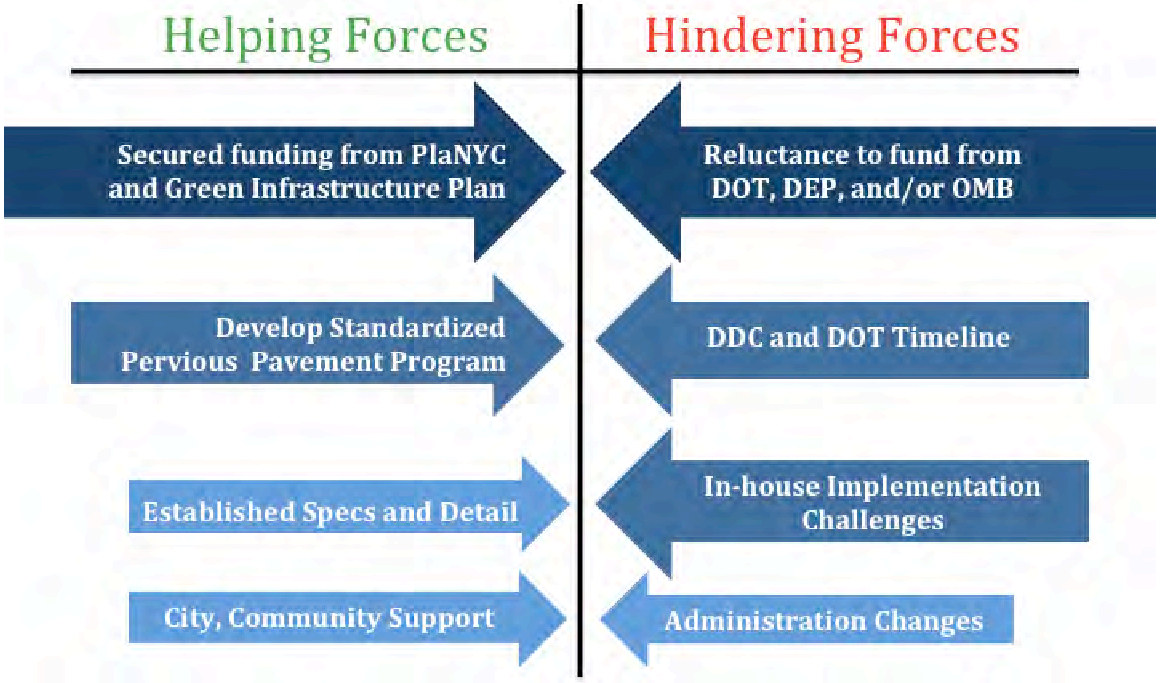
1. Potential lack of funding
2. Potential lack of DOT and DDC capacity to meet the ambitious timeline required to keep up with targeted stormwater capture targets
3. Potential challenges related to the change of administration in 2014

Risk Mitigation

In order to secure funding, the benefits of these pervious pavement installations should be made transparent and be well supported. This report contributes to this through the cost-benefit analysis and documentation of successful case studies of pervious pavement installation.

By completing a significant number of demonstration installations before the Bloomberg administration leaves office, budgeting sufficient funds for monitoring and reporting on their performance, and completing the planning for future phases outlined in this document, the potential for disruption can be minimized insofar as green infrastructure strategies will be integrated as a fundamental tool by which the City cost-effectively meets its objectives.

Figure 14: Helping and Hindering Forces Brainstorming Exercise, DOT/Columbia



COORDINATION WITH PARTNER AGENCIES

To be successful, NYC DOT will need to coordinate and interact with various agencies within New York City. NYC DOT will need to get buy-in from these agencies to make the pervious pavement demonstration projects a success. The following agencies have been identified as those whose constituents can benefit from as well as help with this effort:

- Department of Sanitation
- Department of City Planning
- Department of Design and Construction
- Department of Parks and Recreation
- New York City Housing Authority
- New York City Office of Management and Budget
- Department of Environmental Protection

NYC DEP is one of the largest construction agencies in the City and awards more than $1 billion in contracts for construction, construction-related services, and engineering services annually. NYC DEP should collaborate with NYC DOT on the selection of sites and targeting the appropriate CSOs and in the monitoring of pervious pavement installations. NYC DEP is also in a position to fund proposed projects that will meet the goals established in the Consent Order.[118] As CSO events affect different watersheds, NYC DEP can incorporate pervious pavements in sewer and water projects they might have planned in the priority areas. Moreover, NYC DEP offers a wide range of resources not only providing labor but can enlist a variety of experts they employ (engineers and hydrologists) when installing demonstration projects.

The Department of Sanitation (DSNY) is responsible for maintaining cleanliness in New York City streets. NYC DEP and NYC DOT should engage DSNY early to get buy-in on the idea of maintaining pervious streets and ensure they have adequate maintenance, potentially with some cost sharing with DOT/DEP. DSNY can potentially be the agency responsible for the maintenance of these demonstration projects of pervious pavement through all Phases.

The New York Department of City Planning (NYC DCP) is an agency that promotes strategic growth, transit-oriented development, and sustainable communities in the City, and that establishes policies and zoning regulations applicable citywide.[119] As pervious pavements increase in prevalence, NYC DOT can evaluate zoning and policy strategies for facilitating and expanding the use of these pavements in other places around the city. Specifically, pervious asphalt can be made a requirement for different neighborhoods and business districts or maintenance requirements by private property owners can be incorporated as part of the NYC zoning code. NYC DCP issued a proposed Zoning Text Amendment for the use of porous materials at school locations in low-density districts. The School Construction Authority and NYC DOT and NYC Department of Parks and Recreation are working together to develop a standard pervious paver detail for these locations.[120]

The Department of Design and Construction (DDC) currently manages a design and construction portfolio of over $4.6 billion of the City's capital construction projects.[121] Projects range from streets, highways, sewers, and water mains to public safety, health, and human service facilities, as well as cultural institutions and libraries. NYC DOT should enlist the help of DDC with the design and construction of pervious pavement projects. If pervious pavements are determined successful following an established monitoring period, NYC DOT will expand their program. [122]

The Department of Parks and Recreation (NYC DPR), maintains NYC parks and also manages City-owned facilities, and provides sports programs for children.[123] Green infrastructure installations such as bioswales and bioretention technologies have been incorporated in NYC DPR projects around the city. To benefit from a more comprehensive systems approach, the NYC DOT and NYC DPR can partner on the installation of pervious pavement projects at NYC DPR facilities and Parks, and in areas where a combination of green infrastructure techniques can be implemented to alleviate CSOs in priority watersheds.

NYC DOT should also seek to partner with community organizations with an interest in using pervious pavements for stormwater management. An example of this is Living City Block Gowanus, an organization that is seeking to create a sustainability-focused organization in an area of the Gowanus watershed. Living City Block will be making energy and retrofit related efforts but also has CSO reduction targets in its footprint.[124] NYC DOT should reach out to this organization and others like it to help validate pervious pavement as a stormwater reduction strategy and for potential help in monitoring and maintaining installations in its footprint.

PROSPECTIVE PROJECT FINANCING

The conservative cost estimate of repairing, replacing, and updating New York State's municipal wastewater infrastructure is $36.2 billion over the next 20 years. To date, New York State has invested over $11 billion in wastewater infrastructure.[125] Updating the infrastructure is needed to protect modern, reliable, and efficient wastewater treatment systems that are critical to protect water bodies, public health and prospects for future economic growth.

In 2011, NYC DEP had offered grants for community-based green infrastructure projects. These grants are meant to encompass techniques that detain stormwater runoff from impervious surfaces through capture and controlled release, infiltration into the ground and or vegetative uptake and evapotranspiration.[126] A variety of methods have been selected to achieve these results and grant applicants can choose to implement a variety of projects including green roofs, blue roofs, combination roofs, Right-of-Way bioswales, permeable pavers and perforated pipes.[127] The proposed project must be eligible for capital funding completed in a year and manage at least 1 inch of rainfall on the impervious tributary area. Funds not only cover the cost of design, but also cover labor and materials.

This grant requires applicants to provide a three-year maintenance plan to ensure functionality and establishment for vegetated projects on sidewalks and maintenance activities should include removing sediment, cleaning blockages/floatables, vegetation maintenance, and weeding. Since this project is only applicable to private property owners, businesses and 501(c) 3 organizations, this is an opportunity for NYC DOT to partner with a community-based organization in these priority watersheds, thereby hiring people and businesses from the community to help install pervious asphalt in the streets or pervious concrete on sidewalks or pedestrian pavilions.[128] While funds are not budgeted for maintenance, there is also an optional monitoring portion of this grant that ensures NYC DEP will provide assistance.[129]

The EPA on the other hand provides a Source Reduction Assistance (SRA) Grant. The EPA has issued a request for proposals announcing EPA's Regional Pollution Prevention Program Offices will provide up to $147,000 *per region* or $1,470,000 in funding for fiscal year 2012 supporting pollution prevention or source reduction projects that will begin in 2013.[130] The Regions will issue the awards in the form of grants and/or cooperative agreements. The motivation for drafting the plan was to provide a workable framework for addressing climate change, sustainability, and business efficiency and integration activities.[131] The deadline for this grant was April 10th, 2012, however NYC DOT should look to see if this grant opportunity would be available in the future.[132]

EPA also provides a Pollution Prevention Grant Program grant program, which provides technical assistance projects to help businesses identify better environmental strategies and solutions for reducing or eliminating waste at the source. EPA anticipates it will award approximately $4.1 million in total program funding during FY 2012.[133] The goal of this grant is to help businesses adopt pollution practices that look to reduce pollution at the source and/or conserving water and energy resources.[134] The plan was drafted to provide a workable framework to address present day environmental issues such as climate change, sustainability, and business efficiency and pollution prevention integration.

Since this grant opportunity is marketed toward businesses, NYC DOT should investigate if partnerships are permitted and/or appropriate, even if not explicitly stated in the grant. It is suggested that NYC DOT partner with businesses in priority watershed regions such as the Gowanus to make a case for conserving and protecting NYC waterways by installing pervious pavements on their streets. By installing these pavements it will also promote business efficiency by decreasing the amount of flooding and flood damage to local businesses, as well as creating a cleaner and dryer environment, therefore decreasing the amount of CSO events. Under the "resource conservation" provision the proposal submitted must describe how project activities will reduce the use of raw materials, conserve energy, water or other resources. The deadline for this grant was Tuesday April 24th, 2012. [135]

Another grant that NYC DOT might utilize is the Building Capacity to Implement EPA Voluntary Guidelines for K-12 State, Tribal and Territorial School Environmental Health Programs. This grant incorporates high performance elements in schools that can save money, address environmental health concerns, and demonstrate stewardship of taxpayer dollars. In priority watershed areas where CSOs are frequent events, there are a number of schools where agencies can demonstrate the viability of pervious pavement projects, while contributing to the reduction of CSOs in the area. The EPA anticipates awarding approximately five cooperative agreements, each not to exceed $150,000.[136] The applications for 2012 had to be submitted before May 1, 2012.[137] It is suggested NYC DOT partner with the Department of Education in future years.

In addition to these grant opportunities there are two additional agencies NYC DOT should be able to secure financing from— the Transitional Finance Authority and the NYC Water Finance Authority.[138] The Transitional Finance Authority issues bonds and borrows more to finance a portion of the New York City ten-year capital plan. The Water Finance Authority provides funding to finance capital projects related to supplying and purifying the City's high-quality drinking water and maintain safe wastewater collection and treatment.[139] At the discretion on NYC DEP, NYC DOT can partner with this agency to either get funding and/or work on projects to keep NYC waters clean and safe for the public since reducing CSO events is a priority for both agencies.

CONCLUSION

New York City is a pioneer in everything from green buildings to school lunches. So it is no surprise that New York City has set ambitious green infrastructure goals; looking to quickly vault itself to a national leadership role. Success will require a multi-pronged green infrastructure strategy – including extensive use of pervious pavement to capture rainfall on streets and sidewalks.

To date, New York is on par with a number of other U.S. cities – Chicago, Philadelphia, Portland – which have experimented with pervious pavement on a small scale, mostly in pilot projects on parking lots and pedestrian zones. What New York City's DOT lacked at the start of this project in January 2012 was:

1. Best management practices for pervious pavement
2. A decision tool to identify the best locations for pervious pavement in NYC
3. A pervious pavement implementation plan for the next two decades

Through this project, collaborating with a team from Columbia University's Sustainability Management Master's program, NYC DOT now has all three of these. Best management practices and case studies have been compiled, reviewed, and summarized for reference and to support NYC DOT's funding proposals. The GIS siting decision tool includes 20 data layers, corresponding to all critical criteria for pervious pavement site selection. Using this data asset, sites throughout the priority watersheds in Brooklyn and Queens have been identified and classified as "preferred" and "acceptable". An initial implementation plan has been developed to aid NYC DOT in getting this initiative up and running, ensuring risks are mitigated and partners are engaged.

It is our hope that this project plays a role in accelerating NYC DOT's development of capabilities and experience related to pervious pavement, and that by 2030 New York City is recognized as a world-class city for green infrastructure, rendering CSOs into a part of the City's past.

APPENDICES

APPENDIX 1: DOMESTIC CASE STUDIES

Case name: Chandler, AZ[140]

http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ227-first.pdf

Applicability

Setting	☐Urban x Roadway ☐Retrofit
Application	x Permeable Asphalt ☐Permeable Concrete

Location

Geographic Location	City: Chandler State: Arizona Street location: Jct. I-10/Mesa Highway
Climate Description	Ave Temp (87°F)[141]: Ave Precipitation (in): .60 inches[142]

Project Description

Goal Description	A three lane 3500 linear ft. portion of the urban highway was constructed of porous pavement. This project was installed by the US DOT and once completed was handed over to the Arizona DOT Project F045-1 (4), Jct. I-10/Mesa Highway consisted of widening and reconstruction 1.47 mi. of State Route 87. [143] The work included removing existing asphalt concrete pavement The northbound lanes were paved in porous asphalt. The southbound lanes were paved in dense asphalt for comparison.[144]
Material Used	Porous asphalt
Installation Area	Jct. I-10/Mesa Highway Located within the northbound lanes of the northern 3,500 ft. of the project limits between Station 105+ 00 and 140+00 on the State Route 87. The experimental section has termini approximately 500 ft. and 4,000 ft. south of Elliot Road.[145]
Installation Cost	Not provided
Maintenance Req's	Not provided
Maintenance Costs	Not provided
Traffic	Highway Traffic

Measures of Success

Goals Achieved	There was no standing water along the interstate. Arizona DOT had a visual review of the pavement, and saw no visual pavement, cracking distortion, of the pavement. The surface of the pavement had been observed during rainstorms in October 9, 10 and 11, 1987. Although the pavement was wet there was no standing or excess water on its surface. The surface of the conventional pavement within the area was also reviewed and water could be seen on the surface along with water flowing on the curb.[146]
Water Quality Benefit	ADOT observed the porous pavement during several rainstorms, the elimination of water spray from car and truck tires. There was also a reduction of water on the pavement surfaces therefore decreasing hydroplaning and reducing skid related accidents. [147] Instead of flooding the interstate, the water now has somewhere to go.[148]
Permeability	The initial infiltration rate of the porous asphalt surface was 77 inches per hour. Four years after installation the infiltration rate had declined to 38-40 inches per hour with the lower values in the wheel tracks.[149]
Durability	Not provided

Case Study Name: Portland - SE 21st Avenue and SE Rex Street & North Gay Street[150]

http://www.portlandonline.com/bes/index.cfm?a=196785&c=44953

Applicability

Setting	☐Urban × Roadway ☐Retrofit
Application	X Permeable Asphalt ☐Permeable Concrete

Location

Geographic Location	City: Portland State: Oregon Street location: South East 21st Avenue South East Rex Street North Gay Street
	Ave Temp (°F): 53.6 [151]Ave Precipitation (in): 36.3[152]

Project Description

Goal Description	As an alternative to the standard approach of capturing stormwater in a pipe, treating it and then discharging it to a surface stream, the Environmental Services Department in 2004 paved three blocks of streets in the Westmoreland neighborhood with permeable pavement. It is the reduce CSO to the Willamette River, reduce basement flooding cause by rain storms that overload sewers and that pervious pavements would allow stormwater to be absorbed filtered and cleaned before recharging groundwater.[153] The first use of this type of permeable paving material on a public street in Portland, although similar materials are used locally in parking lots and private driveways. [154] Environmental Services paved 1,000 feet of street surface with interlocking concrete blocks. These concrete blocks look like bricks but are actually high-strength concrete. One block of SE Knapp Street was paved curb-to-curb with permeable blocks. The other streets – SE Rex Street and SE 21st Avenue – were paved with a center strip of standard asphalt and permeable pavement in both curb lanes. A fourth block was paved curb-to-curb with standard asphalt
Material Used	Between Wygant Street and Humboldt Street, porous concrete curb-to-curb. Between Humboldt Street and Alberta Street, porous concrete in both curb lanes, standard concrete in the middle travel lanes. Between Alberta and Webster, porous asphalt curb-to-curb. Between Webster and Sumner, porous asphalt in the curb lanes only
Installation Area	4 Blocks
Installation Cost	Environmental Services received grants from the federal Environmental Protection Agency (EPA) in 2002 and 2003 to allow the City to test new ways of handling storm water The cost was $400,000, $212,500 paid by grants from EPA. $47,000 was also used to replace a water main pipe.[155]
Maintenance Req's	Sweepers will be used to clean the streets and keep them free of weeds and debris.
Maintenance Costs	$400 per vacuum sweep [156]
Traffic	Residential traffic is usually found on these streets. [157]

Measures of Success

Goals Achieved	No formal progress reports have been published however based on materials that we received from the stormwater management team, the goals of this project have been achieved.[158]
Water Quality Benefit	No information given
Permeability	Varied depending on street/application type [159]
Durability	Significant reduction in absorption rate due to surface crusting, clogging, flow of binder into voids.[160]

Case Study Name: Florida Interstate[161]

http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BD521_02_rpt4.pdf

Applicability

Setting	☐Urban x Roadway ☐Retrofit
Application	☐Permeable Asphalt x Permeable Concrete

Location

Geographic Location	City: Tallahassee State: Florida Street location: Interstate
Climate Description	Ave Temp 67.2°F[162] Ave Precipitation 65.7in [163]

Project Description

Goal Description	Pervious concrete shoulder constructed along a rest stop on Interstate 4 in Central Florida. The shoulder was 90 ft. long and 10 ft. wide. The depth of pervious concrete was 10 inches. A 12 inch deep reservoir consisting of select pollution controls materials was used beneath the pervious concrete.
Material Used	Portland cement pervious concrete
Installation Area	Shoulder on Interstate 4 in Central Florida
Installation Cost	The initial cost of pervious concrete can be up to 1.5 times that of other conventional paving methods due to the fact that skilled labor is needed to install the concrete properly.
Maintenance Req's	No information given
Maintenance Costs	No information given
Traffic	500 Axels a week – Highway Traffic[164]

Measures of Success

Goals Achieved	The demonstration project using pervious concrete was considered a success based on wear, water quantity and had been recommended for similar locations. There was no visual wear noted on the concrete. An embedded single ring infiltrometer was used to monitor the infiltration rates. The rate of infiltration did not decrease with time. The amount of water from the collection pipe nearest the edge of pavement was about 50 times the volume from the collection pipe seven feet from the edge of pavement.[165]
Water Quality Benefit	Based on this project being a success water quality considerations had been recommended for other similar locations. [166]
Permeability	An acceptable rate of infiltration for these designs is 1.5 inches per hour. The average rates of infiltration over one year for the Florida demonstration project was 2.5 inches per hour at a head of zero to one inch, 4.8 inches per hour at a six inch head and 6.3 inches per hour at a nine inch head, therefore making this a great option to decrease CSO events.[167]
Durability	No information given

Case Study Name: Philadelphia, PA.[168]

Applicability

Setting	☐Urban × Roadway ☐Retrofit
Application	x Permeable Asphalt ☐Permeable Concrete

Location

Geographic Location	City: Philadelphia State: Pennsylvania Street location: 800 block of Percy Street
Climate Description	Ave Temp 53.4°F[169] Ave Precipitation 41.4in[170]

Project Description

Goal Description	Pilot project used on small block about 225 ft. long. There is light traffic on this block with a small store located at the end of the block that receives a truck delivery every couple of weeks.
Material Used	Pervious Asphalt
Installation Area	➢ 225 ft. long narrow street, ➢ Standard paving profile in Philadelphia is 3 inches for asphalt.
Installation Cost	Approximately for a full 8 inches 2(2 mix) $110 sq. yard including choker stone needed so the paver has a base to ride on storage stone underneath not included
Maintenance Req's	one time maintenance - walk behind goat sweeper
Maintenance Costs	No information provided
Traffic	Approximately 10 cars a day – Light traffic.

Measures of Success

Goals Achieved	stallation of the pervious pavement has been fully in place for about 6 months. It has snowed since then however where the snow was removed the pervious surface stayed clear and dry. Salt was not used on the road however the Water Department did notice a little.
Water Quality Benefit	According to interview with Philadelphia Water Department this pilot project was initiated to look at different green infrastructure strategies to help prevent CSO events.
Permeability	Philadelphia Water Department still waiting on final lab reports; however the pervious project was designed originally to take 16-20 inches of water an hour. The top wearing course less porosity, however there was more porosity with the binder and choker.
Durability	Philadelphia Water Department waiting on reports per interview with Peter Reilly of the Philadelphia Water Department.

Case Study Name: Salem, OR[171]

http://www.lcog.org/documents/sub_action/LID_CaseStudy_PringleCreekGreenStr.pdf

Applicability

Setting	☐Urban × Roadway ☐Retrofit
Application	x Permeable Asphalt ☐Permeable Concrete

Location

Geographic Location	City: Salem State: Oregon Street location: 2110 Strong Rd SE
Climate Description	Ave Temp 63.75°F[172] Ave Precipitation (in): 4.95[173]

Project Description

Goal Description	Pringle Creek, a tributary of the Willamette, runs through the community. There are 150 homes of various types slated for development on 32 acres, 12 of which are dedicated open space. These homes were designed to maximize environmental sustainability, requiring a LEED-H Silver standard or higher. The pavement in this area is impermeable, causing water to flow over it. Traditional curbs channel water down the street to a receiving storm sewer, where it is rapidly moved to a stream or river, therefore pervious asphalt was used to decrease the storm water from entering the stream.
Material Used	Pervious Asphalt
Installation Area	2110 Strong Rd SE, Salem, Oregon
Installation Cost	The cost of designing and installing porous pavement was slightly higher than the cost of installing traditional pavement, mainly due to the expense of innovative engineering. The cost to lay the material is similar in comparison, as the same equipment and virtually the same mixes are used in the application. However, as the street system functions as the driving surface as well as the actual storm water conveyance system, the need for buried pipe, gutters, drains and curbs is eliminated, a cost of nearly $250,000 that Pringle Creek Community did not incur.
Maintenance Req's	The Homeowners Association is responsible for street maintenance. A vacuum truck can clean the streets annually or as needed for a minimal cost (less than $400 for entire project site)
Maintenance Costs	less than $400 for entire project site
Traffic	Minimal Traffic – Residential Street

Measures of Success

Goals Achieved	
Water Quality Benefit	The porous pavement allows rainwater to soak through the pavement into the subsoil. Any pollutants on the street will be broken down by microbes in the soil, eventually yielding clean water that will either be stored as groundwater or percolate into the stream through the soil
Permeability	No information available
Durability	No information available

Case Study Name: Olympia, WA

http://olympiawa.gov/city-utilities/storm-and-surface-water/science-and-innovations/~/media/Files/PublicWorks/Water-Resources/North_Street_Reconstruction_Project_Porous_Concrete_Summar.ashx

Applicability

Setting	☐Urban X Roadway ☐Retrofit
Application	☐Permeable Asphalt X Permeable Concrete

Location

Geographic Location	City: Olympia State: Washington Street location: North Street
Climate Description	Ave Temp 49.7°F[174]: Ave Precipitation 50.6in[175]

Project Description

Goal Description	The city of Olympia completed a street enhancement project on North Street in 1999. The project involved rehabilitating the existing roadway pavement, stripping two new 5 foot bicycle lanes and building 1500 feet on 5.5 ft. wide new sidewalk. The sidewalk was adjacent to an existing roadway.
Material Used	Porous Concrete
Installation Area	1500 ft. of 5 ½ ft. wide new sidewalk.[176]
Installation Cost	$25 per square yard – total cost $10,000 (additional engineering cost associated with the mix design and yard.[177]
Maintenance Req's	The city of Olympia had educated it's employees on how to maintain the sidewalk [178]
Maintenance Costs	Awaiting answer from Washington DOT.
Traffic	Pedestrian traffic

Measures of Success

Goals Achieved	
Water Quality Benefit	Olympia's Storm and Surface Water Plain aims to protect and improve water quality, maintain and prevent further degradation of aquatic habit and minimize flooding.[179]
Permeability	
Durability	For the North Street Project a 3/8-inch to Number 10 washed round aggregate was used. The aggregate to water ratio (pound/pound) was 0.32. The aggregate to cement ratio in (pounds) was 4.5: 1. Polypropylene fibers, air entrainment and water reducing/retarding admixtures where used in the design mix. Final void content was around 12% and the 28-day compressive strengths are 2,400 psi. The final appearance of the porous concrete material is similar to exposed aggregate. Expansion joints where placed every 20 feet while crack control scores were placed every 5 feet before the concrete set. The finished surface was immediately covered with plastic and left to cure for up to 7days.
Additional Information	Porous concrete has Division Street, Boulevard Road, Bush Street, Birch Avenue, Brawne Avenue, Percival Street, Bigelow Avenue, Miller Avenue, San Francisco Avenue, 5th Avenue, State Avenue, and 21st Avenue. The City of Olympia, Washington has installed over 7,500 square yards or about two miles of porous concrete sidewalk to date, with more projects coming each year.

Case Study Name: Olympia, WA[180]

http://olympiawa.gov/~/media/Files/PublicWorks/Water-Resources/RW%20Johnson%20Porous%20Pavement%20Improvements.ashx

http://olympiawa.gov/city-utilities/storm-and-surface-water/science-and-innovations/~/media/Files/PublicWorks/Water-Resources/RWJohnsonASCEPresentation_PerviousConcreteBicycleLanes.ashx

Applicability

Setting	☐Urban X Roadway ☐Retrofit
Application	☐Permeable Asphalt X Permeable Concrete

Location

Geographic Location	City: Olympia State: Washington Street location: RW Johnson Boulevard
Climate Description	Ave Temp 49.7°F Ave Precipitation 50.6in:

Project Description

Goal Description	Due to increasing land cost, increasing stormwater requirements and the need to improve the roadways in Olympia have lead engineers to look for a more creative way to manage stormwater runoff. Traditionally stormwater management requires the purchase of land for building stormwater ponds; often this land is not available or prohibitively expensive.
Material Used	Porous Concrete
Installation Area	Two pervious concrete bicycle lanes adjacent to two asphalt vehicle lanes. The bicycle lane was designed with a gutter slope and a system of overflow catch basins installed to remove standing water from roadway surface and direct it into the adjacent stormwater facility. (Cite)
Installation Cost	Pervious Concrete Lane Average Cost $140 sy Pervious Concrete Sidewalk – Cost $92.25sy
Maintenance Req's	The pavement can be effectively cleaned with conventional sweeping and vacuum machines.
Maintenance Costs	No information provided
Traffic	Bicycle and pedestrian traffic.

Measures of Success

Goals Achieved	The city considered the RW Johnson project a success and a significant step forward in the incorporation of permeable pavements into our roadway designs. (Cite)
Water Quality Benefit	Olympia was looking at other alternatives in stormwater management
Permeability	The soil analysis generates an infiltration rate of 2 inches an hour
Durability	Concrete's flexural strength to range from 300-700 lbs per sq. inch (psi) with an average of 550 psi. Pavement designed for a 30 year life with subgrade strength of 150 to 200 psi. As a result Olympia required a 7.5 inch concrete pavement section.

APPENDIX 2: INTERNATIONAL CASE STUDIES[181]

http://www3.telus.net/public/a6a47567/CounrtyLaneFlyer.PDF

Case name: Vancouver, Canada

Applicability

Setting	X Urban ☒Roadway ☒Retrofit
Application	X Permeable Asphalt Permeable Concrete

Location

Geographic Location	City: Vancouver State: British Columbia Street: Lane South of 18th Avenue from Ash Street to Tupper Street
Climate Description	Ave Temp (°F): 52[182] Ave Precipitation (in): 47.2[183]

Project Description

Goal Description	A pilot project of the City Lane Program in Vancouver was carried out in 2010 and construction was completed in 2011. In 2003, Vancouver did a Country Lane Program on three of its roadways in the suburban area to reduce stormwater runoff using pervious pavement and it was successful. This pilot program of City Lane is designed to use pervious pavement on roadways in the city to reduce CSOs as well as aesthetic value. Since the project was only completed last year, there are not much monitoring and evaluation information yet, but the Street Design Division of the City of Vancouver is planning to do this job.
Material Used	Porous asphalt, hot bin mixture as the following: Bin 4 (38 mm to 12.5 mm) - 9.8% Bin 3 (12.5 mm to 6.3 mm) - 52.9% Bin 2 (6.3 mm to 2 mm) - 23.2% Bin 1 (2 mm minus) - 9.0% The asphalt content was 5.10%
Installation Area	1 block
Installation Cost	No information given
Maintenance Req's	No information given. Monitoring will be launched soon.
Maintenance Costs	N/A
Traffic	No information given

Measures of Success

Goals Achieved	N/A
Water Quality Benefit	N/A
Permeability	N/A
Durability	N/A

Case Study Name: Tokyo, Japan[184]

http://www.ipl-airquality.nl/data/actie-asfalt-geluidsvermindering-japan.pdf

Applicability

Setting	☒ Urban ☒Roadway ☒Retrofit
Application	☒Permeable Asphalt ☒Permeable Concrete

Location

Geographic Location	City: Tokyo Country: Japan
Climate Description	Ave Temp (°F): 61.34[185] Ave Precipitation (in): 55.35[186]

Project Description

Goal Description	The major goals of adopting pervious pavement in Japan are[187]: ➢ To reduce stormwater runoff and to avoid city flooding ➢ To improve driver safety by providing better skid resistance ➢ To reduce traffic noise to the maximum of 90dB ➢ To mitigate urban heat island effect
Material Used[188]	➢ Porous asphalt, porous concrete, porous asphalt-concrete (PAC) with high-viscosity modified bitumen/rubber binder. ➢ Porous asphalt has air voids embedded ranging from 17-23% ➢ Thickness range for single layer porous pavement is 40-50mm with maximum aggregate size below 5, 8, 10, or 13mm. ➢ Standards for two-layer pavements are: 20mm top-layer with 5 or 8mm maximum aggregate size, and 30 mm bottom-layer with 10 or 13mm maximum aggregate size.
Installation Area	All footpaths are covered by porous pavement since 1983.[189]
Installation Cost	Not Provided.
Maintenance Req's	Regular to frequent cleaning (weekly or bi-weekly is preferred) to prevent clogging using high-speed with high-pressure water machines or high-pressure air blow machines.[190]
Maintenance[191] Costs	➢ $0.82/ft^2/year for high-pressure water machines (in 2005 dollars) ➢ $0.5/ ft^2/year for high-pressure air blow machines (in 2005 dollars).
Traffic	Pervious pavement is used on urban roadways, highways and busy intersections in Tokyo.

Measures of Success

Goals Achieved	Tokyo has successfully managed the stormwater runoff problem by installing massive amount of pervious pavement in the urban setting. It also helped to limit tire noise in the city under 89dB or 90dB after one year of construction.[192] Micro-climate in the city is being well adjusted.
Water Quality Benefit	No information given
Permeability	33.8oz/15sec (1000ml/15sec) and showed a good performance after five years of installation.[193]
Durability	Generally the same as regular asphalt pavement. 7-10 years in cold regions, more than 10 years in warmer regions.[194]

Case Study Name: Stuttgart, Germany[195]

http://www.switchurbanwater.eu/outputs/pdfs/W51_GEN_MAN_D5.1.5_Manual_on_WSUD.pdf

Applicability

Setting	☐ Urban ☒ Roadway ☒ Retrofit
Application	☐ Permeable Asphalt ☒ Permeable Concrete

Location

Geographic Location	City: Stuttgart Country: Germany The Hohlgrabenäcker new development district.
Climate Description	Ave Temp (°F): 53[196] Ave Precipitation (in): 28.3[197]

Project Description

Goal Description	The major goal to install pervious pavement in Hohlgrabenäcker is to limit stormwater runoff from the site to the public sewer to 30% and therefore avoid flooding. The requirement was set up by the Stuttgart municipality[198]. It is also designed to save conventional stormwater management costs by incorporating other green infrastructure such green roofs and cisterns to combat severe storm events.[199]
Material Used	Porous concrete and greened apertures.[200]
Installation Area	All sidewalks and residential streets in a residential community of 265 single family houses and nine apartment buildings.[201]
Installation Cost	$450,000 (in 2010 dollars).[202]
Maintenance Req's	Shared responsibility between city agencies and homeowners. Department of Streets will clean the streets, footpaths and underground drains, while pervious pavements installed on private properties are kept clean by residents.[203]
Maintenance Costs	No information given.
Traffic	Moderate residential traffic.[204]

Measures of Success

Goals Achieved	The community utilized an integrated stormwater management system to successfully meet the 30% discharge goal set by the city government when the construction was completed in 2010. They also reduced the impervious surface area in the community to a total of 20%. Moreover, by installing pervious pavement, residents were able to save $10,380 per year because of the reduction in stormwater fees.[205]
Water Quality Benefit	No information given。
Permeability	The permeability standard of German law is 270 l/(s'ha), pervious pavement under regular cleaning can reach a rate between 1545 l/(s'ha) to 5276 l/(s'ha).[206]
Durability	No information given.

APPENDIX 3: RECOMMENDED SITES

<table>
<tr><th colspan="4">Recommended Site No. 1</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>69th Road</td><td colspan="2" rowspan="16"> </td></tr>
<tr><td>First Cross Street</td><td>75th Street</td></tr>
<tr><td>Second Cross Street</td><td>73rd Place</td></tr>
<tr><td>Watershed</td><td>Newtown Creek</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>29.8 feet</td></tr>
<tr><td>Length</td><td>450.0 feet</td></tr>
<tr><td>Area</td><td>13412 sq. feet</td></tr>
<tr><td>No. of corners</td><td>6</td></tr>
<tr><td>No. of traffic lanes</td><td>2</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Poor</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Good</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>8.4 feet</td></tr>
<tr><td>No. of manholes</td><td>6</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>3</td><td>Curb material(s)</td><td>Concrete, steel</td></tr>
<tr><td>No. of street signs</td><td>6</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>6</td><td>Curb reveal, average</td><td>3 inches</td></tr>
<tr><td>No. of live street trees</td><td>6</td><td>Maximum slope</td><td>2.9%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>1</td><td>Min. depth to bedrock</td><td>478 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>6</td><td>Min. depth to watertable</td><td>105 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Repaving of cracked asphalt

Potholes and cracking of asphalt

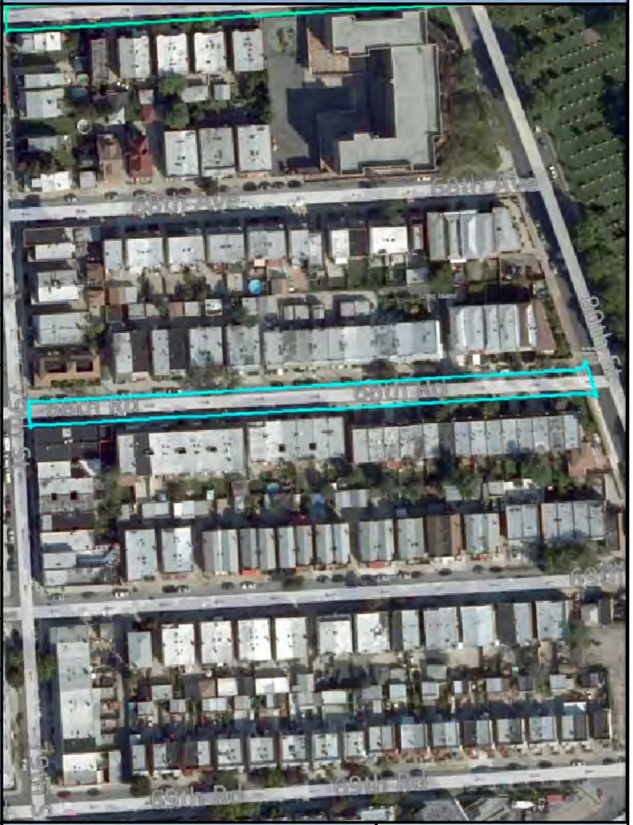
Missing curbs and raveling surface

Tree roots grow out on curbs

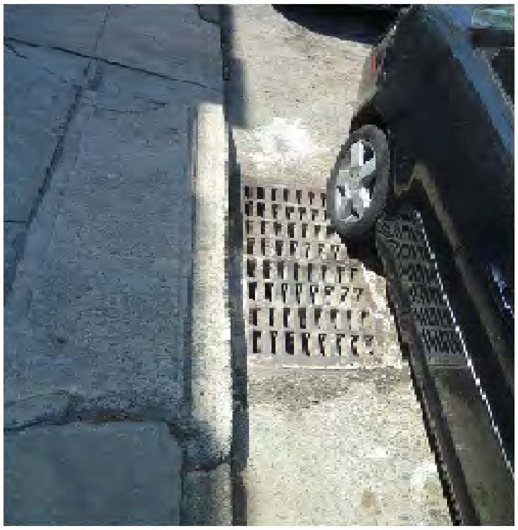
Catch basin with a lot of trash

Cracking asphalt with no curbs at all

Recommended Site No. 2

Location		Map	
Street	68th Road		
First Cross Street	79th Street		
Second Cross Street	80th Street		
Watershed	Newtown Creek		
Attributes			
DOT road designation	Local		
Zoning	Residential		
Width	30.3 feet		
Length	725 feet		
Area	21980 sq. feet		
No. of corners	4		
No. of traffic lanes	1		
No. of parking lanes	2		
Pavement crown	Yes		
Pavement material	Asphalt		
Pavement condition	Fair		
Evidence of poor drainage	No	Sidewalk material(s)	Concrete
No. of catchbasins	4	Sidewalk condition	Fair
No. of fire hydrants	2	Sidewalk width, average	10.2 feet
No. of manholes	7	Sidewalk drainage impaired	Yes
No. of streetlights	6	Curb material(s)	Concrete, steel
No. of street signs	3	Curb condition	Fair
No. of tree pits	15	Curb reveal, average	4 inches
No. of live street trees	14	Maximum slope	1.2%
No. of pedestrian crossings	2	Min. depth to bedrock	489 feet
No. of sidewalk ramps	4	Min. depth to watertable	104 feet
Overhead utility lines	Yes	Hydrologic soil group	C
Emergency call box	No	Soil permeability	Moderately slow

Repavement and patches of asphalt



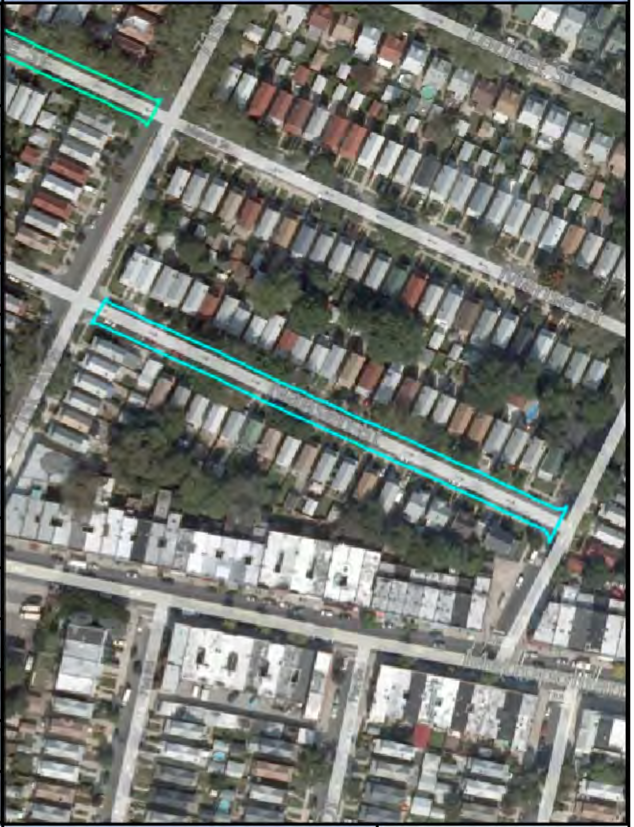
Catch basin with broken asphalt around it

Broken curb due to tree roots and parking

Cracking sidewalk and broken gutter

Craking and holes through crossing lines and manhole

Newly painted pedestrain crossing line and broken asphalt

<table>
<tr><th colspan="4">Recommended Site No. 3</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>Nansen Street</td><td colspan="2" rowspan="16"></td></tr>
<tr><td>First Cross Street</td><td>72nd Avenue</td></tr>
<tr><td>Second Cross Street</td><td>71st Avenue</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>30.0 feet</td></tr>
<tr><td>Length</td><td>660.4 feet</td></tr>
<tr><td>Area</td><td>19813 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Fair</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>4.0 feet</td></tr>
<tr><td>No. of manholes</td><td>17</td><td>Sidewalk drainage impaired</td><td>Yes</td></tr>
<tr><td>No. of streetlights</td><td>3</td><td>Curb material(s)</td><td>Concrete</td></tr>
<tr><td>No. of street signs</td><td>10</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>0</td><td>Curb reveal, average</td><td>2.5 inches</td></tr>
<tr><td>No. of live street trees</td><td>16</td><td>Maximum slope</td><td>1.6%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>511 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>68 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Faded pedestrain crossing line and uneven pavement

Cracks and wear-outs on the road

Note:

This road has a lot of existing repairing and construction, it is in fair shape in general, but needs repaving due to age.

<table>
<tr><th colspan="4">Recommended Site No. 4</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>67th Drive</td><td colspan="2" rowspan="16">
</td></tr>
<tr><td>First Cross Street</td><td>79th Street</td></tr>
<tr><td>Second Cross Street</td><td>80th Street</td></tr>
<tr><td>Watershed</td><td>Newtown Creek</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>30.0 feet</td></tr>
<tr><td>Length</td><td>582.2 feet</td></tr>
<tr><td>Area</td><td>17466 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Fair</td></tr>
<tr><td>No. of fire hydrants</td><td>1</td><td>Sidewalk width, average</td><td>9.2 feet</td></tr>
<tr><td>No. of manholes</td><td>5</td><td>Sidewalk drainage impaired</td><td>Yes</td></tr>
<tr><td>No. of streetlights</td><td>5</td><td>Curb material(s)</td><td>Conc., steel, blue.</td></tr>
<tr><td>No. of street signs</td><td>8</td><td>Curb condition</td><td>Poor</td></tr>
<tr><td>No. of tree pits</td><td>8</td><td>Curb reveal, average</td><td>3 inches</td></tr>
<tr><td>No. of live street trees</td><td>6</td><td>Maximum slope</td><td>2.3%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>481 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>3</td><td>Min. depth to watertable</td><td>103 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Cracking and holes on the crosswalk.

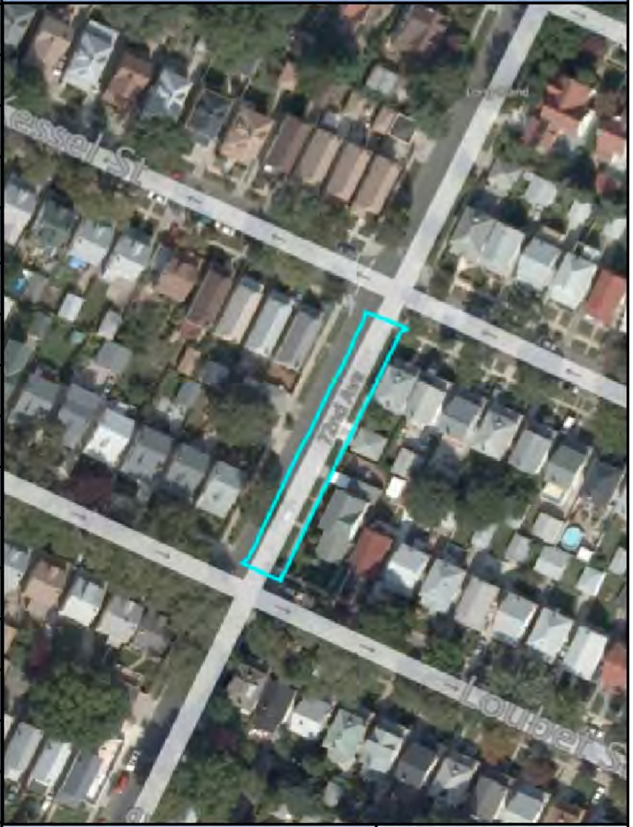
Patches on the broken asphalt.

Missing curb and a dead tree.

Re-pavement around the catch basin.

Patches and cracking surrounding the manhole and catch basin.

Missing curbs around the driveway sign.

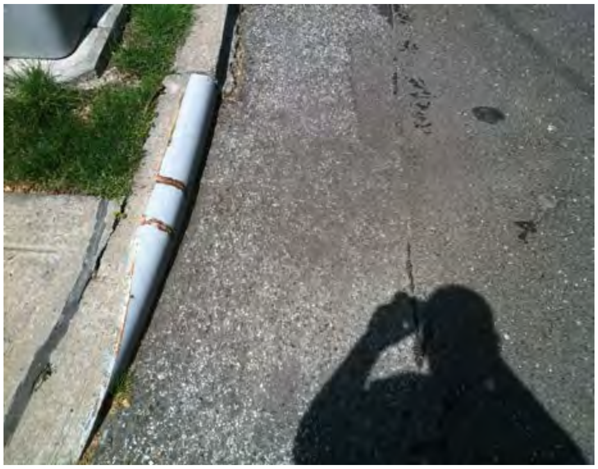
<table>
<tr><th colspan="4">Recommended Site No. 5</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>72nd Avenue</td><td colspan="2" rowspan="16">
</td></tr>
<tr><td>First Cross Street</td><td>Kessell Street</td></tr>
<tr><td>Second Cross Street</td><td>Loubet Street</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>30.1 feet</td></tr>
<tr><td>Length</td><td>217.0 feet</td></tr>
<tr><td>Area</td><td>6528 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>2</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Poor</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Good</td></tr>
<tr><td>No. of fire hydrants</td><td>1</td><td>Sidewalk width, average</td><td>4.0 fet</td></tr>
<tr><td>No. of manholes</td><td>7</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>1</td><td>Curb material(s)</td><td>Concrete</td></tr>
<tr><td>No. of street signs</td><td>3</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>0</td><td>Curb reveal, average</td><td>2.5 inches</td></tr>
<tr><td>No. of live street trees</td><td>6</td><td>Maximum slope</td><td>1.2%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>516 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>71 feet</td></tr>
<tr><td>Overhead utility lines</td><td>No</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Cracked asphalt on road surface.

Segmented curbs around the lawn.

Cracking and patches of the asphalt.

Re-pavement and deterioration of the asphalt



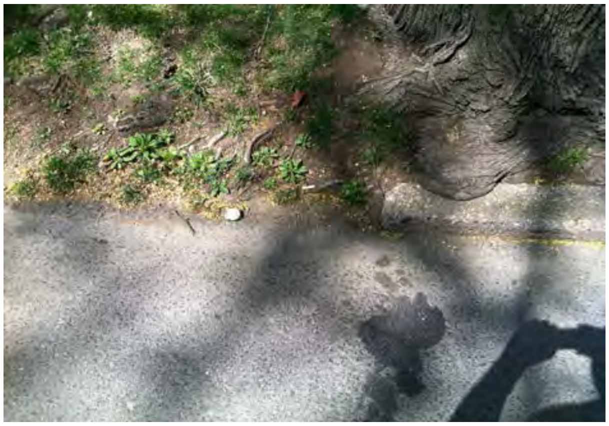
Reconstruction of the curb and the stripping la

Catch basin in a generally good

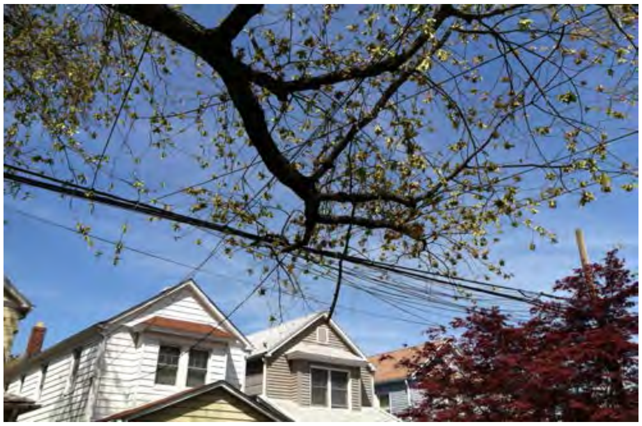
<table>
<tr><th colspan="4">Recommended Site No. 6</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>Manse Street</td><td colspan="2" rowspan="16"></td></tr>
<tr><td>First Cross Street</td><td>70th Avenue</td></tr>
<tr><td>Second Cross Street</td><td>71st Avenue</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>30.3 feet</td></tr>
<tr><td>Length</td><td>621.4 feet</td></tr>
<tr><td>Area</td><td>18849 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>Yes</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>4</td><td>Sidewalk condition</td><td>Good</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>5.0 feet</td></tr>
<tr><td>No. of manholes</td><td>12</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>3</td><td>Curb material(s)</td><td>Concrete</td></tr>
<tr><td>No. of street signs</td><td>9</td><td>Curb condition</td><td>Poor</td></tr>
<tr><td>No. of tree pits</td><td>0</td><td>Curb reveal, average</td><td>3 inches</td></tr>
<tr><td>No. of live street trees</td><td>25</td><td>Maximum slope</td><td>2.1%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>495 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>56 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Large area of asphalt patches on the road and around catch basin.

Asphalt re-pavement on the road.

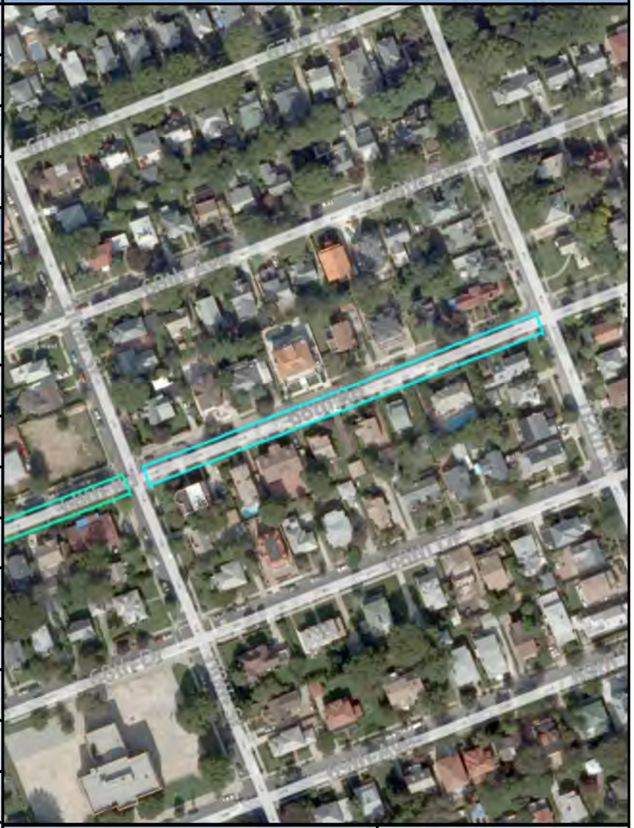


Tree roots impeding onto the curbs and destroy them.



Complicate network of overhead wires.

Abandoned manhole sealed into the ground.

<table>
<tr><th colspan="4">Recommended Site No. 7</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>68th Road</td><td colspan="2" rowspan="16"></td></tr>
<tr><td>First Cross Street</td><td>110th Street</td></tr>
<tr><td>Second Cross Street</td><td>112th Street</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>29.7 feet</td></tr>
<tr><td>Length</td><td>634.9 feet</td></tr>
<tr><td>Area</td><td>18834 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Good</td></tr>
<tr><td>No. of fire hydrants</td><td>1</td><td>Sidewalk width, average</td><td>4.4 feet</td></tr>
<tr><td>No. of manholes</td><td>7</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>5</td><td>Curb material(s)</td><td>Concrete</td></tr>
<tr><td>No. of street signs</td><td>10</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>1</td><td>Curb reveal, average</td><td>2.5 inches</td></tr>
<tr><td>No. of live street trees</td><td>12</td><td>Maximum slope</td><td>2.0%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>474 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>76 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
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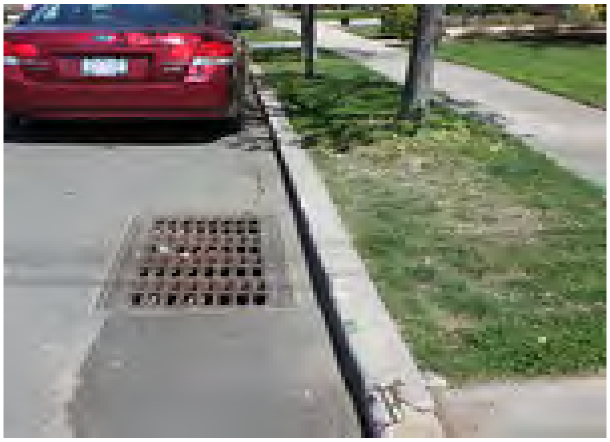


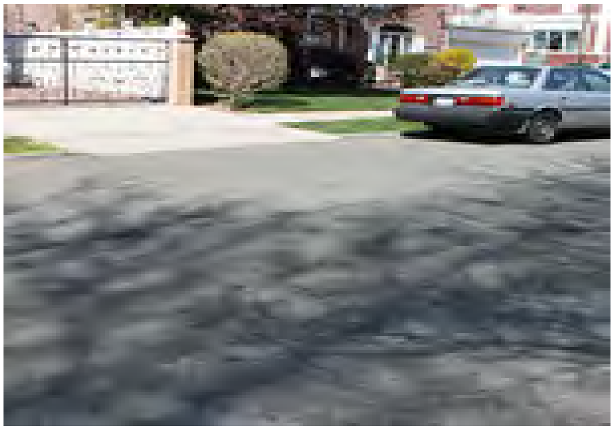
Re-pavement around the catch basin.

The broken sidewalk and curbs with weeds in the cracks.

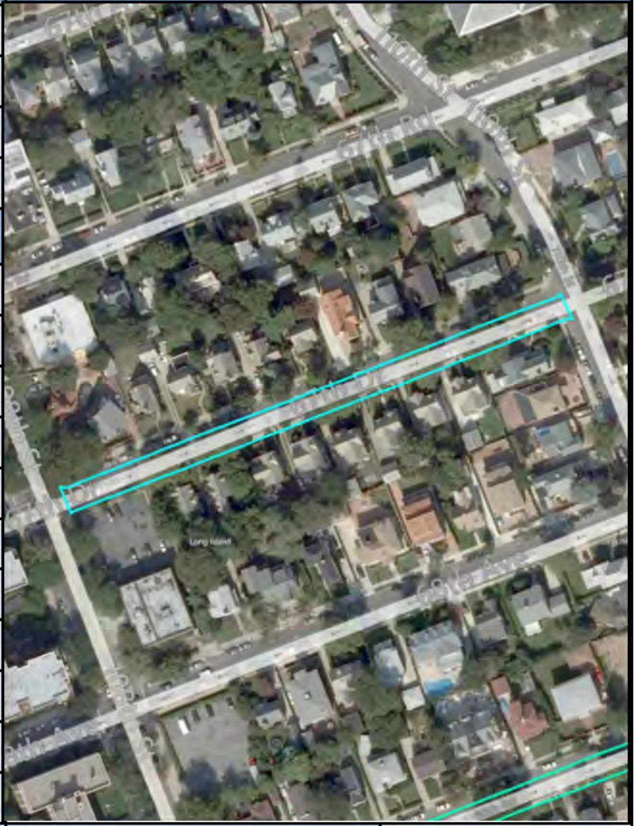
Cracking and patches of the asphalt.

Segmented curbs and raveling asphalt surface.

Big cracking and damage on the asphalt.



Repaved parking lane.

<table>
<tr><th colspan="4">Recommended Site No. 8</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>67th Drive</td><td colspan="2" rowspan="16"></td></tr>
<tr><td>First Cross Street</td><td>108th Street</td></tr>
<tr><td>Second Cross Street</td><td>110th Street</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>29.8 feet</td></tr>
<tr><td>Length</td><td>634.9 feet</td></tr>
<tr><td>Area</td><td>18834 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Concrete</td></tr>
<tr><td>No. of catchbasins</td><td>0</td><td>Sidewalk condition</td><td>Good</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>4.8 feet</td></tr>
<tr><td>No. of manholes</td><td>6</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>3</td><td>Curb material(s)</td><td>Concrete</td></tr>
<tr><td>No. of street signs</td><td>8</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>0</td><td>Curb reveal, average</td><td>4 inches</td></tr>
<tr><td>No. of live street trees</td><td>22</td><td>Maximum slope</td><td>2.0%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>1</td><td>Min. depth to bedrock</td><td>466 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>76 feet</td></tr>
<tr><td>Overhead utility lines</td><td>No</td><td>Hydrologic soil group</td><td>C</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Tree roots impeding on roadway

Manhole

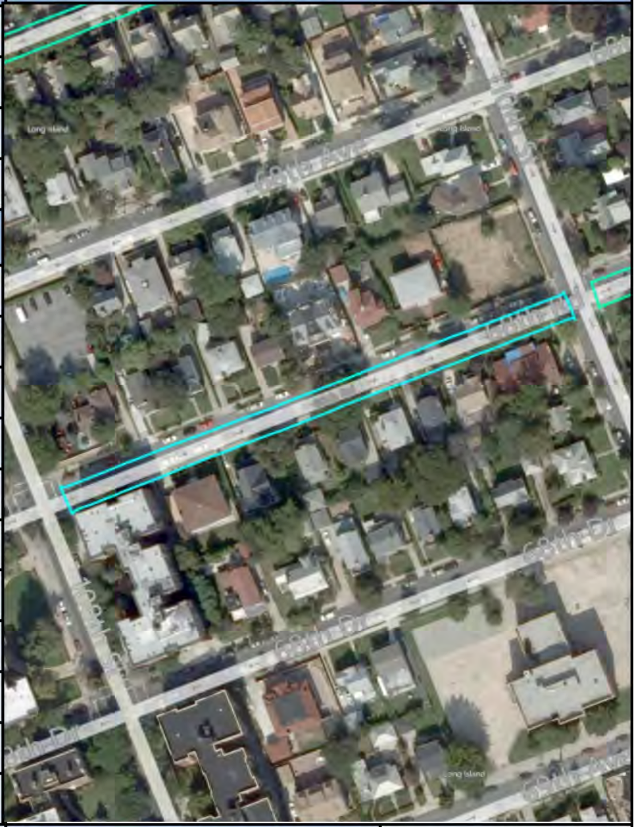
Sidewalk damage from adjacent construction

Gutter lane in need of repair

Grooving and patching in street

Cracked curb in need of repair

Recommended Site No. 9

Location		Map	
Street	68th Road		
First Cross Street	108th Street		
Second Cross Street	110th Street		
Watershed	Flushing Bay		
Attributes			
DOT road designation	Local		
Zoning	Residential		
Width	30.8 feet		
Length	596.7 feet		
Area	18397 sq. feet		
No. of corners	4		
No. of traffic lanes	1		
No. of parking lanes	2		
Pavement crown	Yes		
Pavement material	Asphalt		
Pavement condition	Fair		
Evidence of poor drainage	No	Sidewalk material(s)	Concrete
No. of catchbasins	3	Sidewalk condition	Good
No. of fire hydrants	2	Sidewalk width, average	5.0 feet
No. of manholes	11	Sidewalk drainage impaired	No
No. of streetlights	5	Curb material(s)	Concrete
No. of street signs	9	Curb condition	Poor
No. of tree pits	0	Curb reveal, average	1.5 inches
No. of live street trees	11	Maximum slope	2.6%
No. of pedestrian crossings	1	Min. depth to bedrock	474 feet
No. of sidewalk ramps	4	Min. depth to watertable	78 feet
Overhead utility lines	Yes	Hydrologic soil group	C
Emergency call box	Yes	Soil permeability	Moderately slow

Tree roots impeding on roadway

Tree roots impeding on roadway

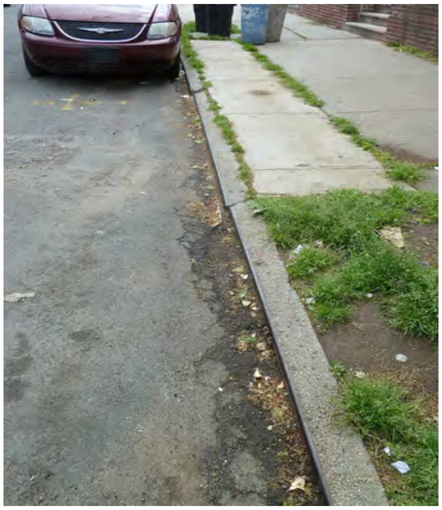
Depression in pavement in x-walk

Patched pavement

Pavement worn and cracking

Patched and rippled pavement

<table>
<tr><th colspan="4">Recommended Site No. 10</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>125th Street</td><td colspan="2" rowspan="16"> </td></tr>
<tr><td>First Cross Street</td><td>22nd Avenue</td></tr>
<tr><td>Second Cross Street</td><td>23rd Avenue</td></tr>
<tr><td>Watershed</td><td>Flushing Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>24.5 feet</td></tr>
<tr><td>Length</td><td>519.8 feet</td></tr>
<tr><td>Area</td><td>12734.9 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Poor</td></tr>
<tr><td>Evidence of poor drainage</td><td>Yes</td><td>Sidewalk material(s)</td><td>Conc., bluestone</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Fair</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>12.2 feet</td></tr>
<tr><td>No. of manholes</td><td>4</td><td>Sidewalk drainage impaired</td><td>Yes</td></tr>
<tr><td>No. of streetlights</td><td>2</td><td>Curb material(s)</td><td>Concrete, steel</td></tr>
<tr><td>No. of street signs</td><td>4</td><td>Curb condition</td><td>Poor</td></tr>
<tr><td>No. of tree pits</td><td>4</td><td>Curb reveal, average</td><td>3 inches</td></tr>
<tr><td>No. of live street trees</td><td>8</td><td>Maximum slope</td><td>2.4%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>1</td><td>Min. depth to bedrock</td><td>284 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>75 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>B</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderate</td></tr>
</table>



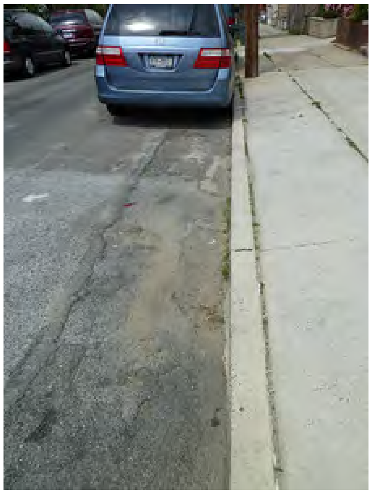
Curb Condition

Side walk condition

Pavement patching and cracking

Pothole

Cracking in x-walk



Parking lane condition

Recommended Site No. 11

Location		Map	
Street	126th Street		
First Cross Street	20th Avenue		
Second Cross Street	22nd Avenue		
Watershed	Flushing Bay		
Attributes			
DOT road designation	Local		
Zoning	Residential		
Width	24.7 feet		
Length	525.5 feet		
Area	12962 sq. feet		
No. of corners	4		
No. of traffic lanes	1		
No. of parking lanes	2		
Pavement crown	Yes		
Pavement material	Asphalt		
Pavement condition	Poor		
Evidence of poor drainage	No	Sidewalk material(s)	Concrete
No. of catchbasins	0	Sidewalk condition	Fair
No. of fire hydrants	2	Sidewalk width, average	9.6 feet
No. of manholes	4	Sidewalk drainage impaired	Yes
No. of streetlights	4	Curb material(s)	Concrete, steel
No. of street signs	2	Curb condition	Fair
No. of tree pits	6	Curb reveal, average	3 inches
No. of live street trees	10	Maximum slope	2.5%
No. of pedestrian crossings	1	Min. depth to bedrock	273 feet
No. of sidewalk ramps	2	Min. depth to watertable	69 feet
Overhead utility lines	Yes	Hydrologic soil group	B
Emergency call box	Yes	Soil permeability	Moderate

Broken Manhole

Repaved Sections

Worn down pavement

Tree impeding on roadway

Roadway cracking

Large potholes

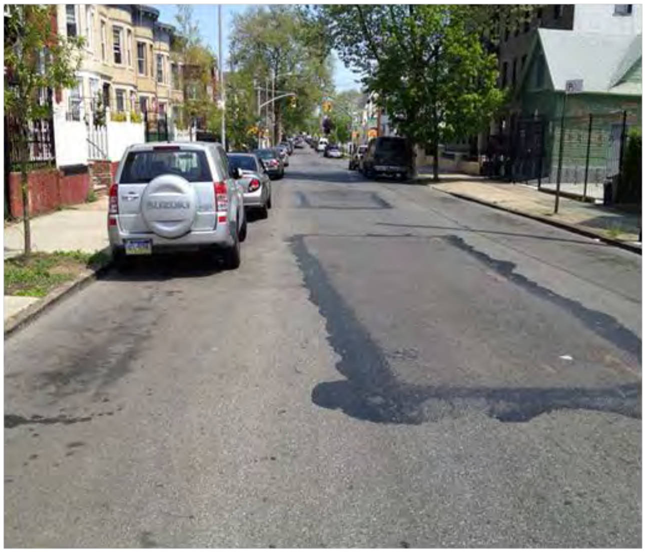
Recommended Site No. 12			
Location		**Map**	
Street	Ridgewood Ave.		
First Cross Street	Cleveland Street		
Second Cross Street	Ashford Street		
Watershed	Jamaica Bay		
Attributes			
DOT road designation	Local		
Zoning	Residential		
Width	30.0 feet		
Length	226.7 feet		
Area	6799.7 sq. feet		
No. of corners	4		
No. of traffic lanes	1		
No. of parking lanes	2		
Pavement crown	No		
Pavement material	Asphalt		
Pavement condition	Poor		
Evidence of poor drainage	No	Sidewalk material(s)	Conc., bluestone
No. of catchbasins	2	Sidewalk condition	Fair
No. of fire hydrants	1	Sidewalk width, average	10.0 feet
No. of manholes	5	Sidewalk drainage impaired	Yes
No. of streetlights	3	Curb material(s)	Conc., steel, blue.
No. of street signs	3	Curb condition	Fair
No. of tree pits	6	Curb reveal, average	3 inches
No. of live street trees	7	Maximum slope	2.4%
No. of pedestrian crossings	1	Min. depth to bedrock	460 feet
No. of sidewalk ramps	4	Min. depth to watertable	53 feet
Overhead utility lines	Yes	Hydrologic soil group	B
Emergency call box	No	Soil permeability	Moderately slow

Re-work around catch basin

Sidewalk cracking near roadway surface

Uneven repaving

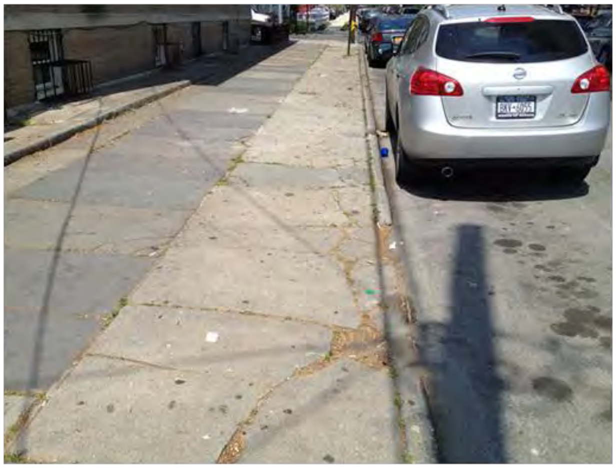
Severe cracking on sidewalk



Uneven roadway

Pothole near manhole cover

<table>
<tr><th colspan="4">Recommended Site No. 13</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>Essex Street</td><td colspan="2" rowspan="16"> </td></tr>
<tr><td>First Cross Street</td><td>Arlington Ave.</td></tr>
<tr><td>Second Cross Street</td><td>Ridgewood Ave.</td></tr>
<tr><td>Watershed</td><td>Jamaica Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>29.9 feet</td></tr>
<tr><td>Length</td><td>668.3 feet</td></tr>
<tr><td>Area</td><td>19994 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Conc., bluestone</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Poor</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>10.3 feet</td></tr>
<tr><td>No. of manholes</td><td>16</td><td>Sidewalk drainage impaired</td><td>Yes</td></tr>
<tr><td>No. of streetlights</td><td>4</td><td>Curb material(s)</td><td>Conc., steel, blue.</td></tr>
<tr><td>No. of street signs</td><td>9</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>9</td><td>Curb reveal, average</td><td>2 inches</td></tr>
<tr><td>No. of live street trees</td><td>10</td><td>Maximum slope</td><td>1.3%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>466 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>47 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>B</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>



Old sidewalk and roadway

Sidewalk cracking near roadway surface

Uneven repaving

Utility uneven repave

Uneven roadway

Large cracks in roadway

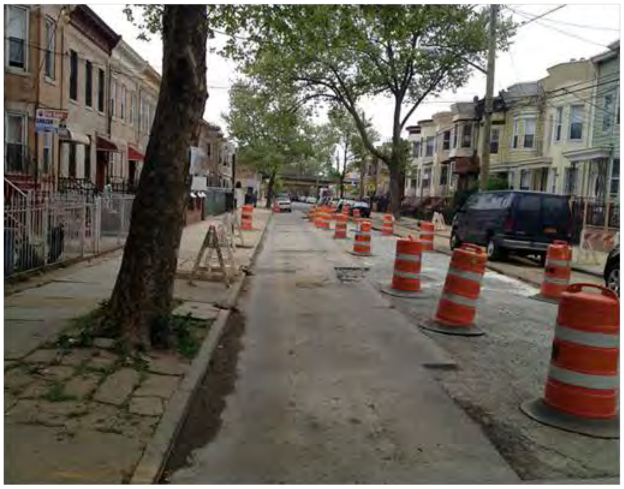
<table>
<tr><th colspan="4">Recommended Site No. 14</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>Shepherd Avenue</td><td colspan="2" rowspan="16"> </td></tr>
<tr><td>First Cross Street</td><td>Ridgewood Ave.</td></tr>
<tr><td>Second Cross Street</td><td>Arlington Ave.</td></tr>
<tr><td>Watershed</td><td>Jamaica Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>29.8 feet</td></tr>
<tr><td>Length</td><td>668.0 feet</td></tr>
<tr><td>Area</td><td>19928 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Poor</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Conc., bluestone</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Fair</td></tr>
<tr><td>No. of fire hydrants</td><td>2</td><td>Sidewalk width, average</td><td>10.8 feet</td></tr>
<tr><td>No. of manholes</td><td>8</td><td>Sidewalk drainage impaired</td><td>Yes</td></tr>
<tr><td>No. of streetlights</td><td>4</td><td>Curb material(s)</td><td>Conc., steel, blue.</td></tr>
<tr><td>No. of street signs</td><td>11</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>9</td><td>Curb reveal, average</td><td>2.5 inches</td></tr>
<tr><td>No. of live street trees</td><td>9</td><td>Maximum slope</td><td>1.4%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>470 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>49 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>B</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

Utility Construction

Utility Construction

Holes due to construction

Utility Construction



Utility Construction – torn roadway

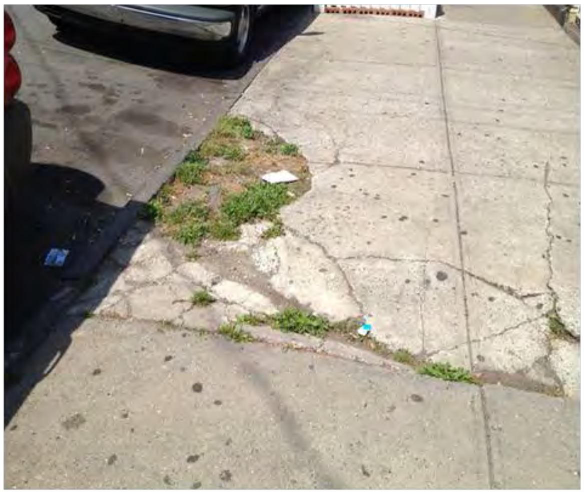
Utility backfill

<table>
<tr><th colspan="4">Recommended Site No. 15</th></tr>
<tr><th colspan="2">Location</th><th colspan="2">Map</th></tr>
<tr><td>Street</td><td>Linwood Street</td><td colspan="2" rowspan="16"></td></tr>
<tr><td>First Cross Street</td><td>Ridgewood Ave.</td></tr>
<tr><td>Second Cross Street</td><td>Arlington Ave.</td></tr>
<tr><td>Watershed</td><td>Jamaica Bay</td></tr>
<tr><th colspan="2">Attributes</th></tr>
<tr><td>DOT road designation</td><td>Local</td></tr>
<tr><td>Zoning</td><td>Residential</td></tr>
<tr><td>Width</td><td>30.2 feet</td></tr>
<tr><td>Length</td><td>670.8 feet</td></tr>
<tr><td>Area</td><td>20236 sq. feet</td></tr>
<tr><td>No. of corners</td><td>4</td></tr>
<tr><td>No. of traffic lanes</td><td>1</td></tr>
<tr><td>No. of parking lanes</td><td>2</td></tr>
<tr><td>Pavement crown</td><td>Yes</td></tr>
<tr><td>Pavement material</td><td>Asphalt</td></tr>
<tr><td>Pavement condition</td><td>Fair</td></tr>
<tr><td>Evidence of poor drainage</td><td>No</td><td>Sidewalk material(s)</td><td>Conc., bluestone</td></tr>
<tr><td>No. of catchbasins</td><td>2</td><td>Sidewalk condition</td><td>Fair</td></tr>
<tr><td>No. of fire hydrants</td><td>3</td><td>Sidewalk width, average</td><td>11.0 feet</td></tr>
<tr><td>No. of manholes</td><td>11</td><td>Sidewalk drainage impaired</td><td>No</td></tr>
<tr><td>No. of streetlights</td><td>4</td><td>Curb material(s)</td><td>Conc., steel, blue.</td></tr>
<tr><td>No. of street signs</td><td>12</td><td>Curb condition</td><td>Fair</td></tr>
<tr><td>No. of tree pits</td><td>19</td><td>Curb reveal, average</td><td>3 inches</td></tr>
<tr><td>No. of live street trees</td><td>21</td><td>Maximum slope</td><td>1.3%</td></tr>
<tr><td>No. of pedestrian crossings</td><td>2</td><td>Min. depth to bedrock</td><td>463 feet</td></tr>
<tr><td>No. of sidewalk ramps</td><td>4</td><td>Min. depth to watertable</td><td>46 feet</td></tr>
<tr><td>Overhead utility lines</td><td>Yes</td><td>Hydrologic soil group</td><td>B</td></tr>
<tr><td>Emergency call box</td><td>No</td><td>Soil permeability</td><td>Moderately slow</td></tr>
</table>

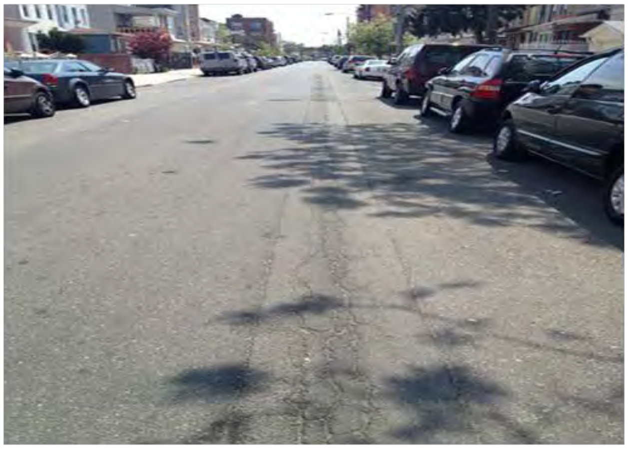
Utility poor repave

Cracks in roadway

Utility Re-work



Broken Sidewalk and curb



Cracking roadway

Utility re-work

APPENDIX 4: GIS ANALYSIS AND METHODOLOGY DETAIL

Data Sources, Spatial References and Analysis Methodology Detail

The objective of this appendix section is twofold:

1. To provide confidence in the GIS analysis conducted by providing transparency into sources and operations completed.
2. To ensure that NYC DOT can replicate the analysis for additional watersheds when needed.

Data Sources

Forty-one data sets from ten different sources were obtained and reviewed for usefulness in validating site selection criteria and building maps of the designated watersheds with sufficient detail to allow site selections to be made. Ultimately 20 data sets from seven sources were used in the analysis.

Table 4.1: Data Sets and Sources Utilized

GIS Data Utilized

Basemap
Geotechnical
Transport Network
Built Environment

Type of Data	Data Set Name	Format	Source	Date
Borough boundaries	NYBB	Vector	NYC DCP	2012
Roadbed	Roadbed	Vector	NYC DOITT	2007
Street centerlines	Street_Centerline	Vector	NYC DOITT	2006
DEP priority watersheds	Priority_Watershed	Vector	NYC DOT	2010
Depth to bedrock	Bedrock_Depth	Raster	NYC DOT	2010
Depth to watertable	LI_Groundwater_Conditions_2006	Raster	USGS	2006
Topography	NYC_1_3	Raster	USGS	1999
Soil type	NYC_Recon_Soil_Survey	Vector	NYCSWCD	2006
Major roads	YellowStreets	Vector	NYC DOT	n.a.
Roadway designations	DOT_Road_Designations	Raster (PDF)	NYC DOT	2000
Truck routes	TruckRoute2009	Vector	CommunityCartography	2009
Truck routes	DOT_NYCLocalAndThruTruckRoutes	Vector	NYC DOT	2010
Bus routes	BusRoute2009	Vector	CommunityCartography	2009
Subway lines	Subway2009	Vector	CommunityCartography	2009
Railroad lines	Railroad	Vector	NYC DOITT	2007
Street trees	All_Street_Trees_20111020	Vector	NYC DPR	2012
Zoning districts	NYZD, NYCO	Vector	NYC DCP	2012
Pavement condition	Road_Condition	Vector	NYC DOT	2012

Spatial References

GIS data selected for use in the analysis were projected into uniform vertical and horizontal reference frames to allow for spatial analysis and avoid errors. The horizontal frame of reference used was the

GCS North American 1983 using the projection NAD 1983 Stateplane New York Long Island FIPS 3104 Feet.. The vertical frame of reference was the North American Vertical Datum of 1983.

All GIS data utilized were clipped to the borough boundaries of Queens and Brooklyn, provided by NYC DCP, during the initial steps of the analysis. The data were further clipped to the boundaries of the DEP priority CSO watersheds, provided by NYC DOT, for the final steps of the analysis.

Analysis Methodology

The GIS data set Roadbed, derived from the NYC DCP LION data set of NYC roadways, was used at the base unit of analysis. The Roadbed data set provided area data relating to each segment of roadway in NYC. Information derived from analysis of other data sets was appended to the Roadbed database.

The GIS analysis focused on three sets of criteria: transport network, geotechnical, and built environment. Data sets were matched to each specific criterion in each of these three areas to provide the most complete analysis possible given the available data. Where data sets were incomplete, outdated, or of a resolution too low to provide actionable conclusions, the steps of the analysis were attempted and the results included in this appendix, but not utilized for the preliminary or final site recommendations.

The goal of the analysis of elements of the transport network of Queens and Brooklyn was to determine sites for pervious pavement that would be least likely to encounter high traffic volume of heavy weight vehicles, thus minimizing the potential for damage and wear to the pavement. The analysis was accomplished by comparing the layers of data for DOT road designations, major roads as published in commercial maps, DOT designated truck routes, MTA bus routes, MTA subway lines, and railroad lines to the Roadbed data set. In the case of DOT road designations, data were not available in vector format. Image files of maps provided by NYC DOT were imported into the GIS software and aligned with the vector data. A proxy layer of data was created using the Street Centerline data set from NYC DCP LION, and this layer was edited to add values for the DOT road designations. The transport network data were aligned with the Roadbed data set and compared. Where roadbed segments were intersected by elements of the transport network those segments were assigned values that would remove them from the selection of potential sites for pervious pavement.

The goal of the analysis of geotechnical data was to determine sites for pervious pavement with geologic and hydrologic characteristics that would allow for optimal infiltration of stormwater runoff. Geotechnical data were available in vector format for soils information, and raster format for elevation, depth to bedrock and depth to watertable. The raster files were clipped to the borough boundaries, and then subjected to different processes to provide data needed for site selection. Maximum slope of roadbed segments was determined by applying a process to the elevation raster data that calculated slope values for each pixel of the raster. The maximum slope value for all pixels underlying each roadbed segment was determined and this value was assigned to the corresponding roadbed segment. Depths to bedrock and watertable were determined by applying map algebra to each of those raster data sets, in combination with the elevation raster data set, to determine the minimum depths from the land surface for each pixel of the raster data. The minimum depths to bedrock and watertable for each roadbed segment were determined and those values were assigned to the corresponding roadbed segment. The Roadbed data could then be analyzed to select the roadbed segments that conformed to all criteria relating to slope, depth to bedrock, and depth to watertable. Two of the geotechnical criteria, slope, and depth to watertable, had ranges of preferred and acceptable values. The selection of sites for these criteria are ranked into first and second tiers, depending on the values determined. This ranking follows through to the preliminary selection of potential sites.

Analysis of the soils data proved more problematic. The most complete data found was from the New York City Soil Reconnaissance Survey conducted by the New York City Soil and Water Conservation District in 2006. This data was mapped at a scale of 1:62,500 providing a resolution of data on the order of tens of acres. This resolution was too low to allow for selection of sites on the order of 1 – 9 acres. There were also many mapping units in the priority watersheds that did not have adequate data relating to permeability and hydrologic soil group due to the highly urbanized environment extant at the time of the survey. The steps of the GIS analysis relating to soil characteristics was conducted, and reported here, but the results were not used in the selection of sites for pervious pavement. Richard Shaw of the Natural Resource Conservation Service of the USA, who assisted NYCSWCD in mapping the results of the soil survey, reports that a higher resolution map of soils in New York City is being prepared and may be published in 2013. Use of this data, once published, may allow NYC DOT to make more accurate site selections based on soil characteristics.

Analysis of data relating to the built environment was broken into steps looking at three types of information; zoning districts, street tree density, and pavement condition.

The goals of the analysis of zoning districts were to avoid high traffic, heavy vehicle locations such as commercial districts and industrial sites, as well as to avoid potential sources of contaminated runoff, such as automobile service stations. Zoning district information was available in vector format from NYC DCP, and provided the spatial distribution of residential zoning districts in Queens and Brooklyn. Utilizing published descriptions of the building setbacks for different types of residential zoning districts, the residential zoning districts were sorted into two categories, districts with building setbacks of 10 feet or greater from parcel boundaries, and districts with setbacks of less than 10 feet. Roadbed segments were analyzed to select those that were entirely within residential zoning districts with building setbacks of 10 feet or greater. The second step of the zoning district analysis used the spatial distribution of commercial overlay districts. Roadbed segments were selected as potential pervious pavement sites if they were more than 20 feet away from a commercial overlay district.

The goal of the analysis of street tree density was to determine potential sites for pervious pavement that were least likely to cause reduced infiltration of stormwater runoff due to leaf litter clogging the voids of the pavement. Street tree location data in vector format were made available by NYC DPR, and used to calculate the number of trees within 10 feet of any roadbed segment. The surface area and number of trees per roadbed segment were used to calculate the number of trees per thousand square feet for each roadbed segment. Discussions with NYC DOT lead to the use of 3 trees per thousand square feet as the threshold for appropriate pervious pavement site selection.

The goal of the analysis of pavement condition was to determine which potential sites for pervious pavement were likely to need pavement resurfacing. The identified sites would be given priority in site selection. Data relating to pavement condition was made available by NYC DOT, but was identified as not being complete or up-to-date. Site surveys conducted by the project team found many discrepancies between the data and actual conditions in the field. The GIS analysis was conducted and reported in this appendix, but the results were not used in the selection of preliminary or final sites for pervious pavement.

Once each step of the analysis for transport network criteria, geotechnical criteria, and built environment criteria was completed the resulting selections of sites were compared. The preliminary sites were determined by isolating only those sites that met all of the criteria, excluding soil characteristics and pavement condition. The sites were ranked into two tiers as a result of the analysis relating to slope and depth of watertable. The preliminary site selections for each priority watershed in Queens and Brooklyn were mapped and are included in this appendix. Of particular note is the fact that all roadbed segments in the Gowanus Canal Watershed were removed from consideration due to the residential zoning districts in that watershed all having building setbacks less than 10 feet.

The maps of preliminary sites for pervious pavement were reviewed to find clusters of sites that could be investigated through site surveys. Over 30 sites were selected for surveying, and of these 25 had pavement in fair or poor condition by the estimation of the project team. These 25 sites appeared to be good candidates for placement of pervious pavement. From this group of 25 sites a final selection of 15 sites was made. These sites are mapped in this appendix, and detailed survey information on each final site is presented in Appendix 3.

Figure 4.1: Flushing Bay Watershed Transport Network Criteria: NYC DOT Road Designations

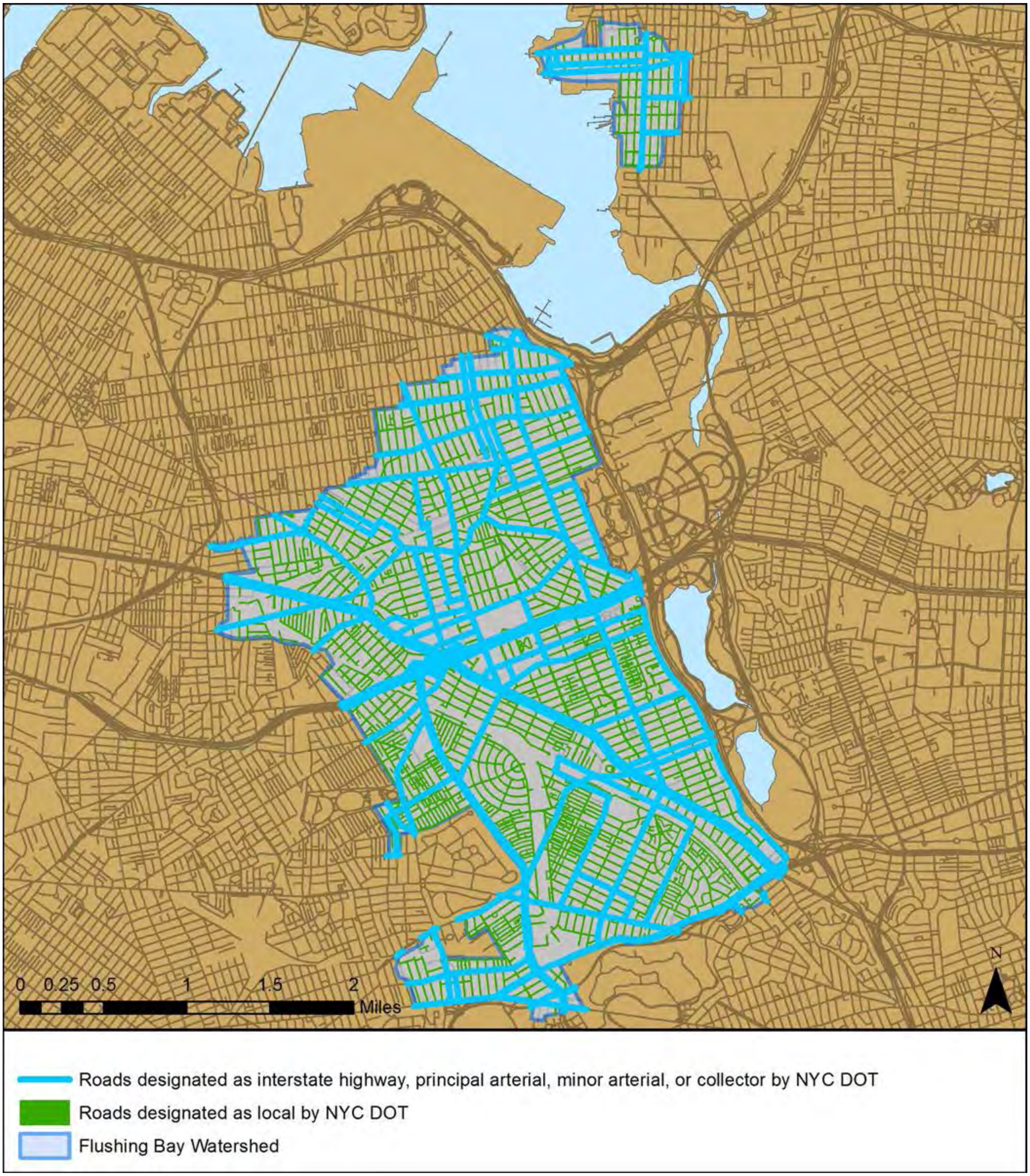


Figure 4.2: Flushing Bay Watershed Transport Network Criteria: Major Roads

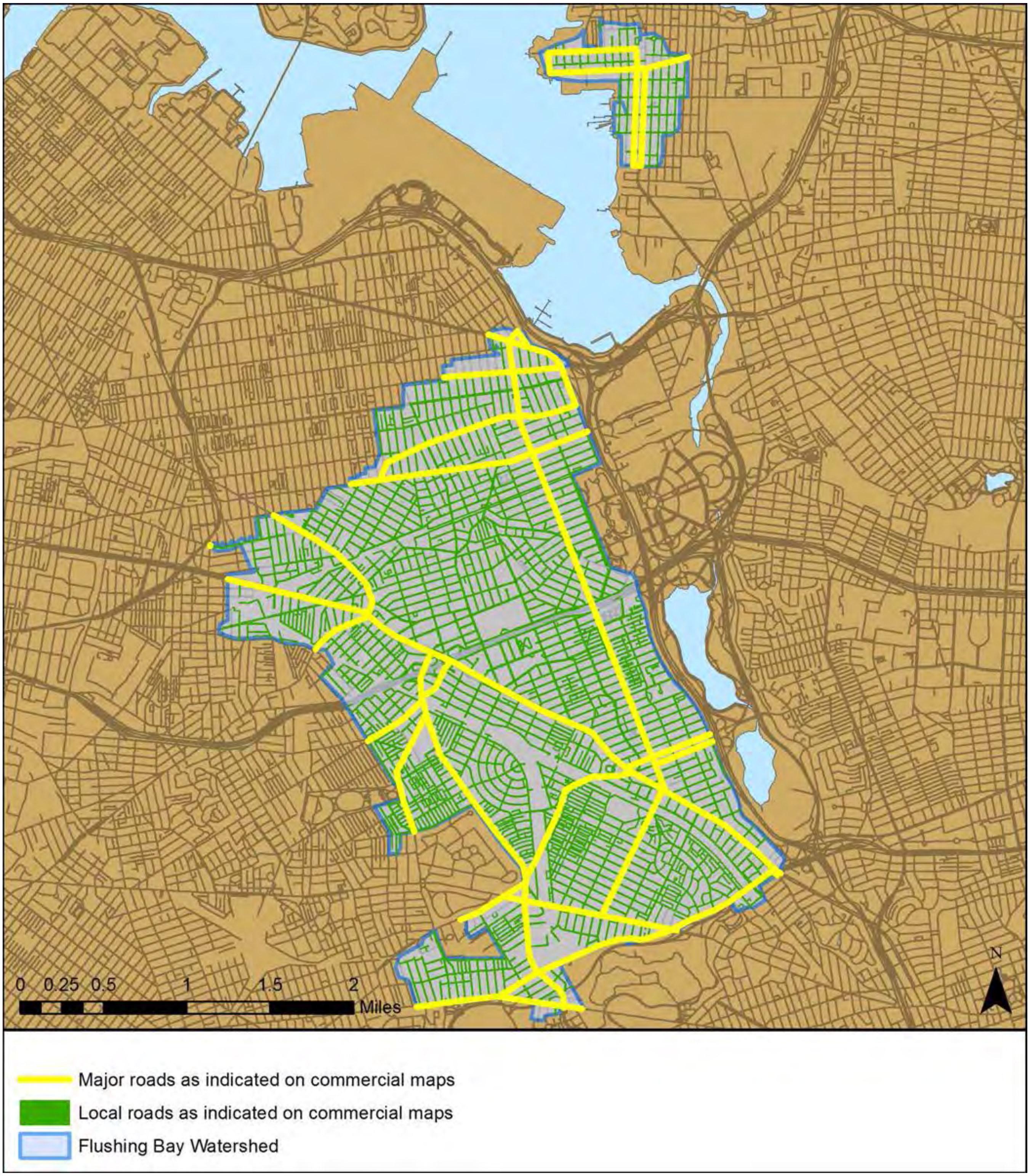


Figure 4.3: Flushing Bay Watershed Transport Network Criteria: Truck Routes

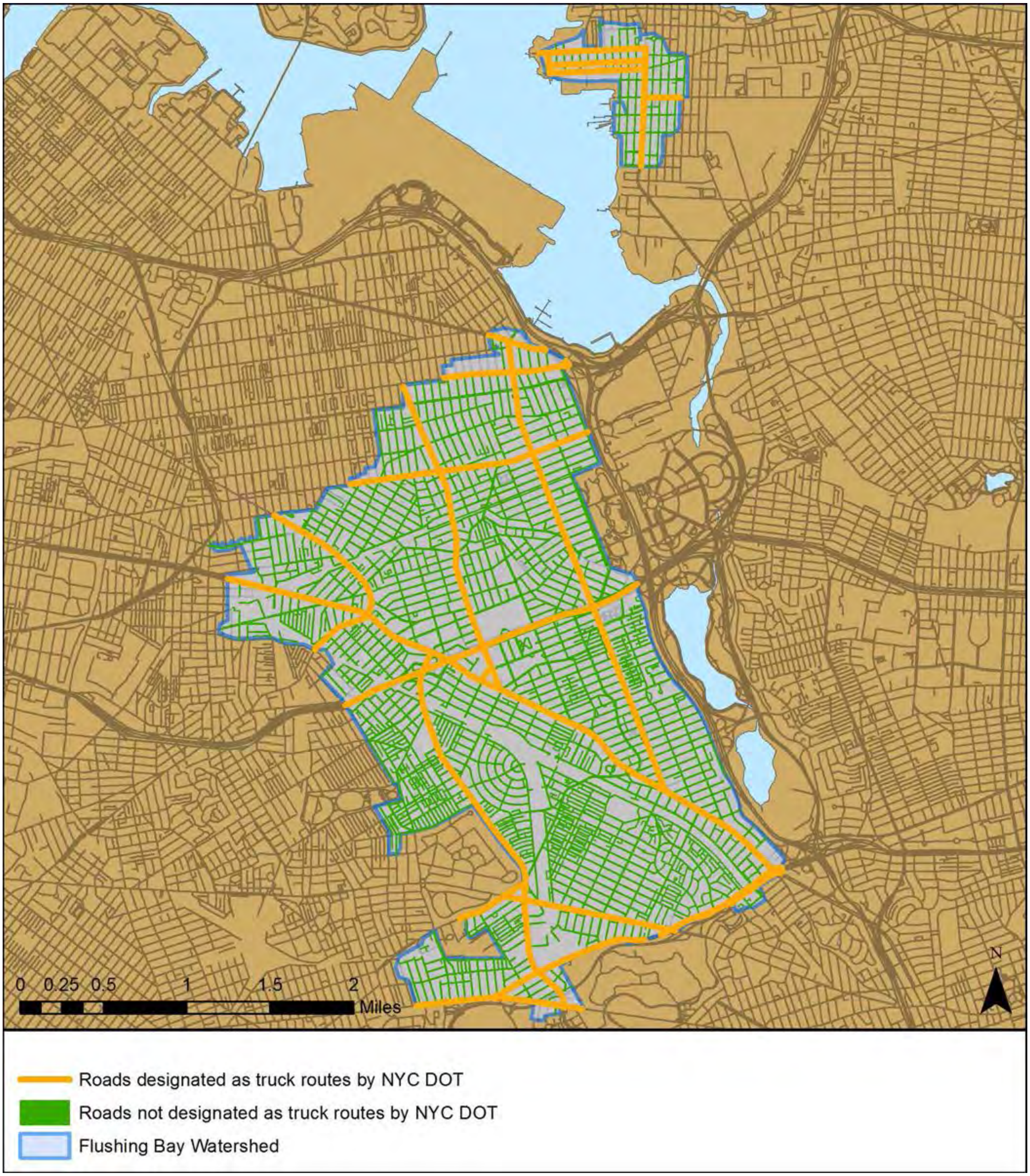


Figure 4.4: Flushing Bay Watershed Transport Network Criteria: Bus Routes

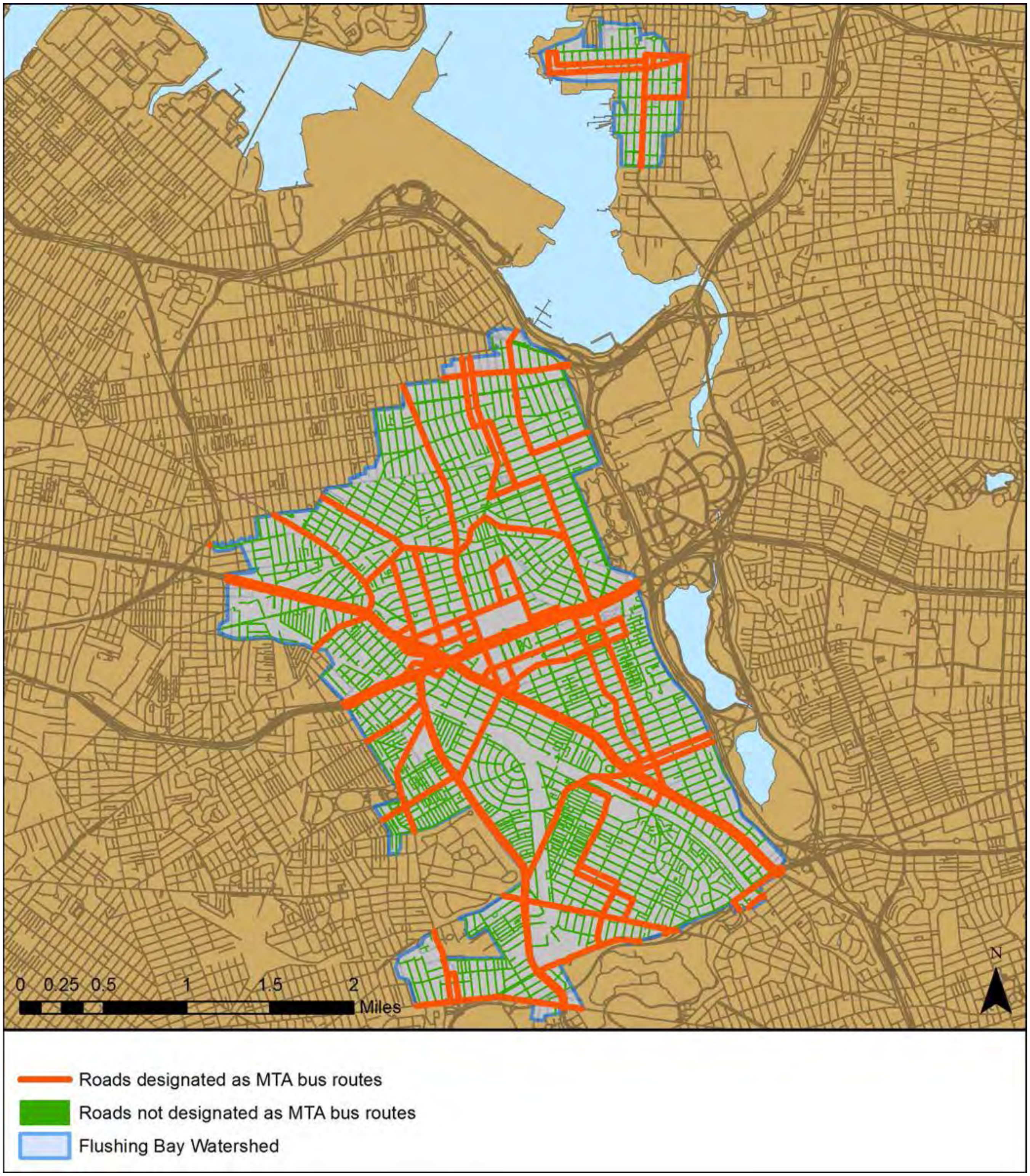


Figure 4.5: Flushing Bay Watershed Transport Network Criteria: Subway Lines

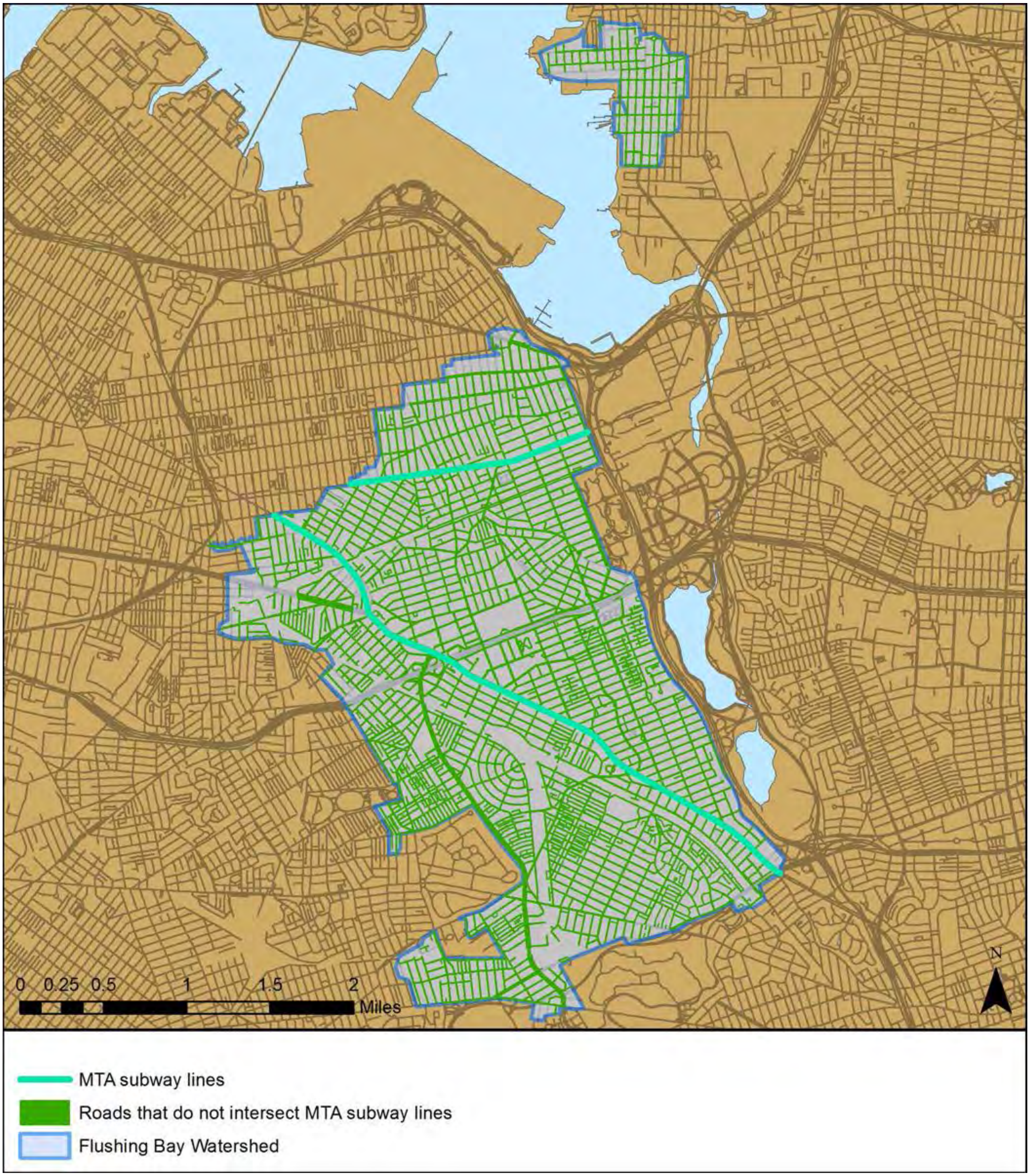


Figure 4.6: Flushing Bay Watershed Transport Network Criteria: Railroad Lines

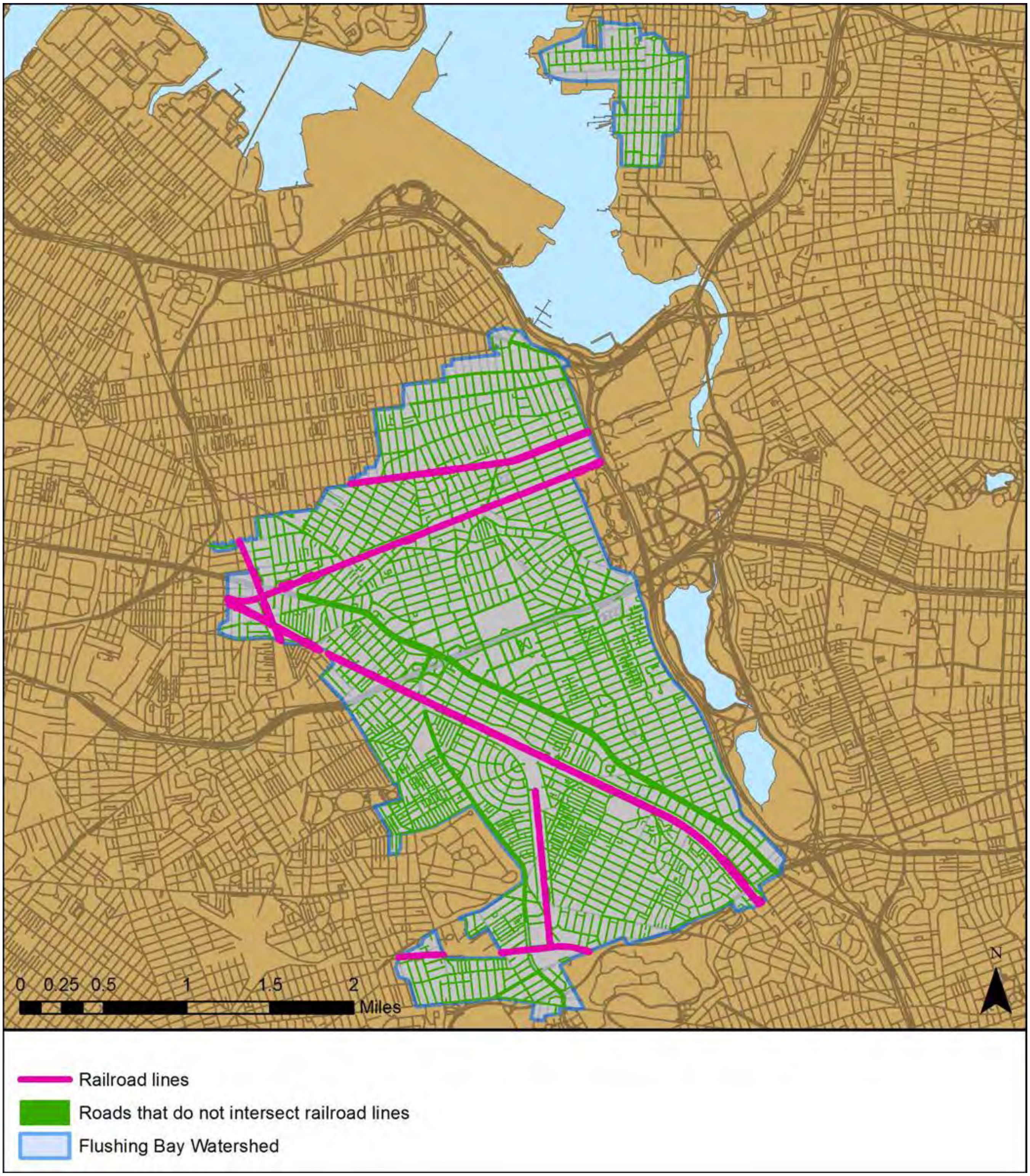


Figure 4.7: Flushing Bay Watershed Transport Network Criteria: Combined Criteria

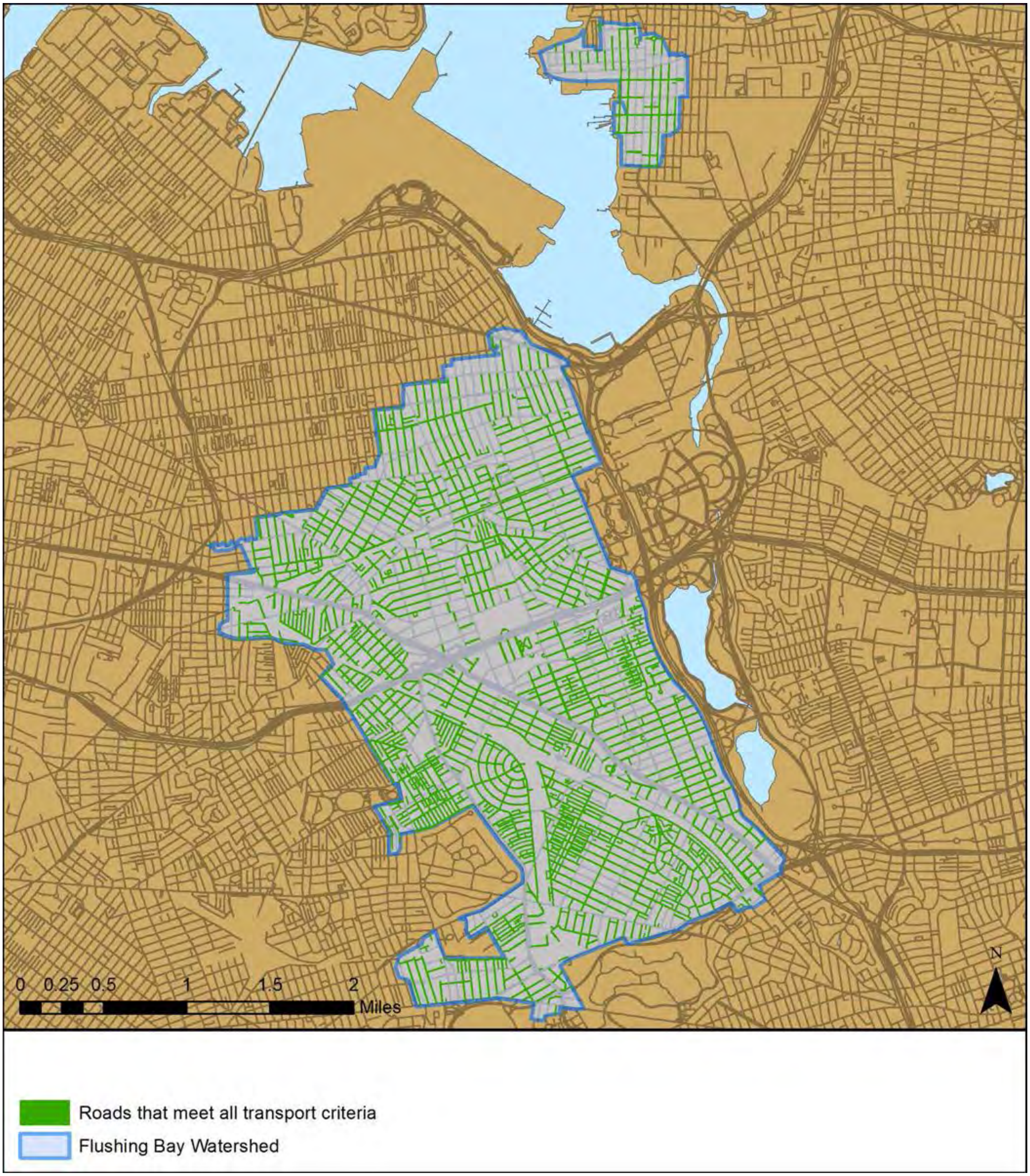


Figure 4.8: Flushing Bay Watershed Geotechnical Criteria: Slope

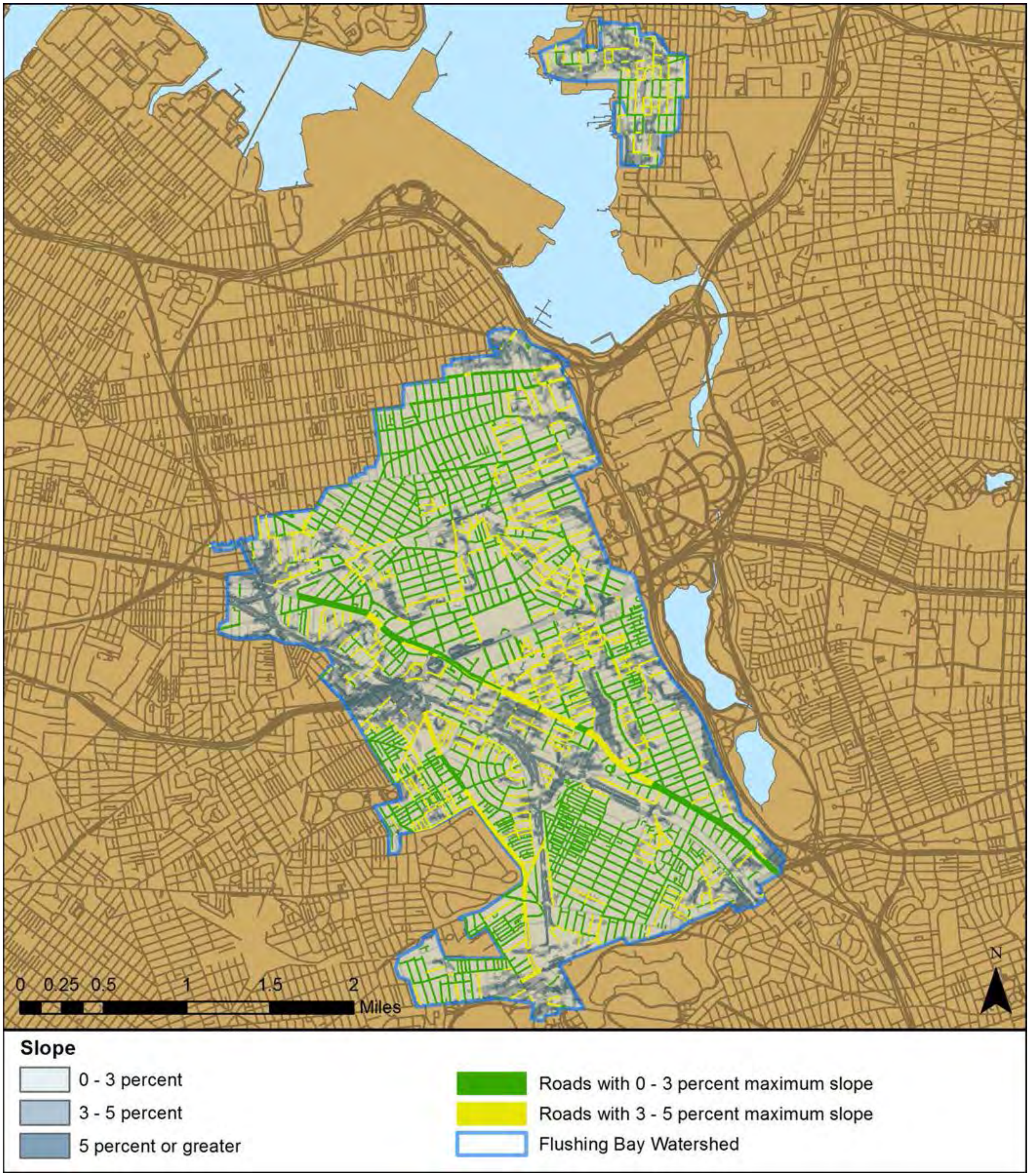


Figure 4.9: Flushing Bay Watershed Geotechnical Criteria: Depth to Bedrock

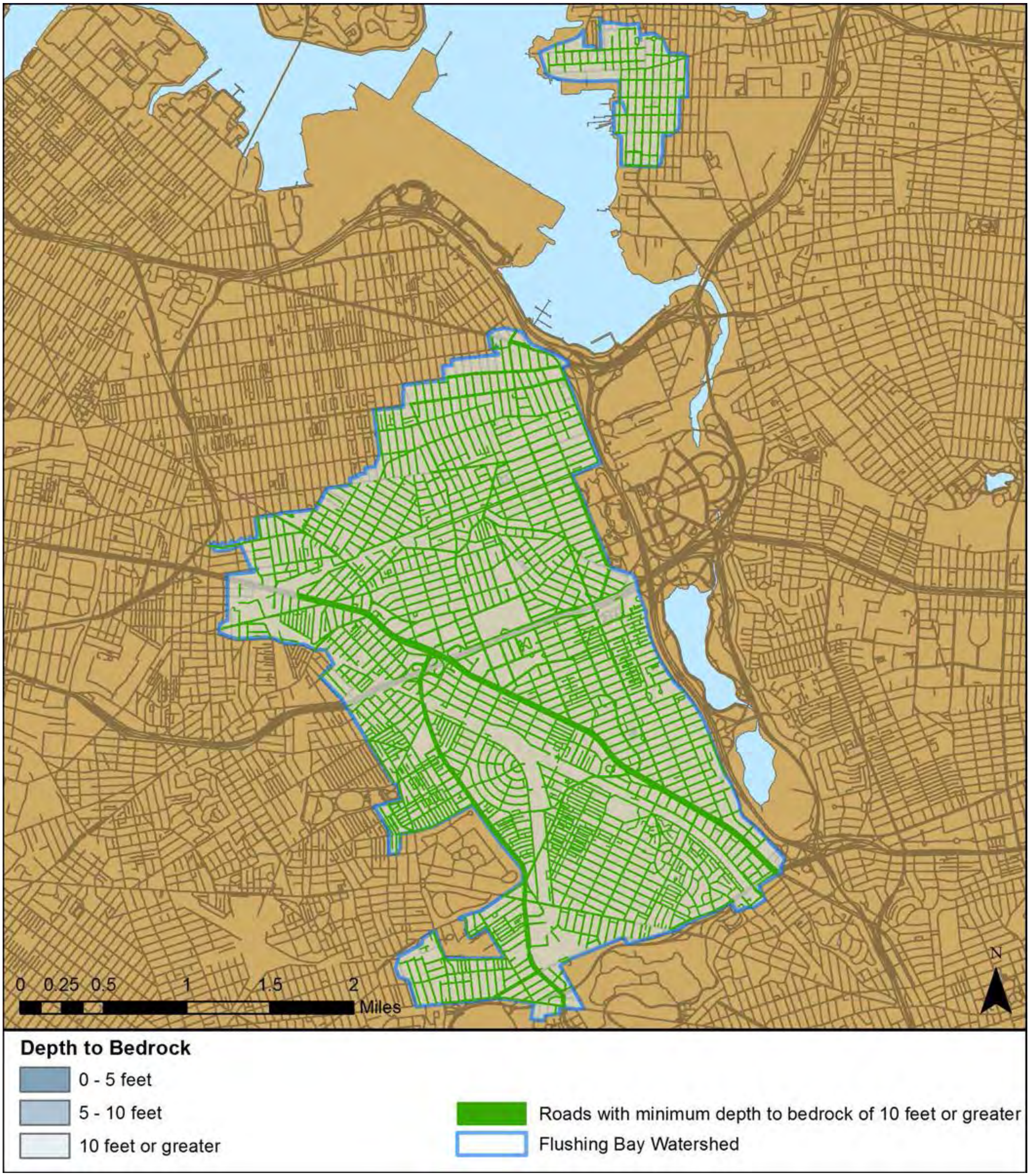


Figure 4.10: Flushing Bay Watershed Geotechnical Criteria: Depth to Watertable

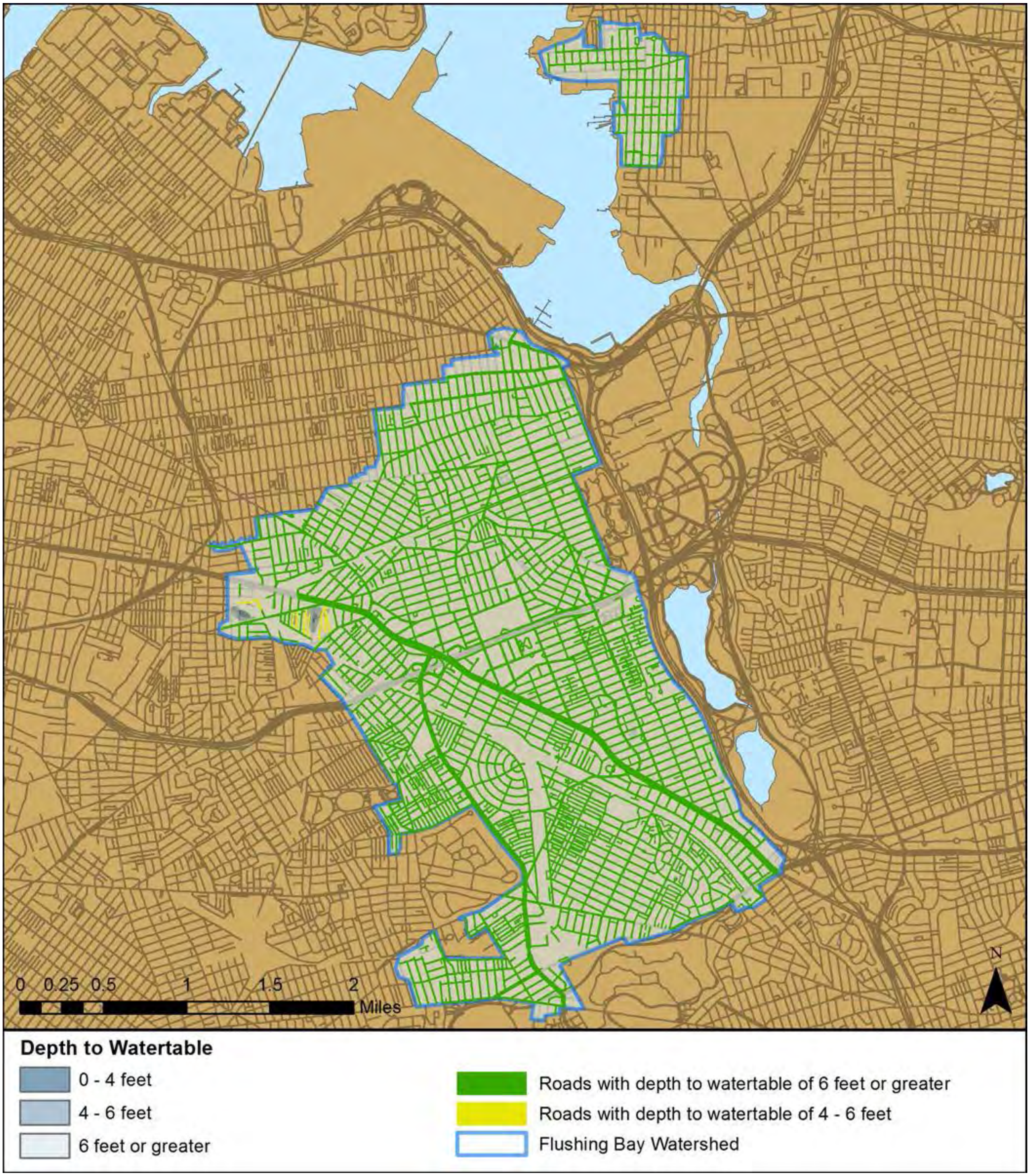


Figure 4.11: Flushing Bay Watershed Geotechnical Criteria: Soil Permeability

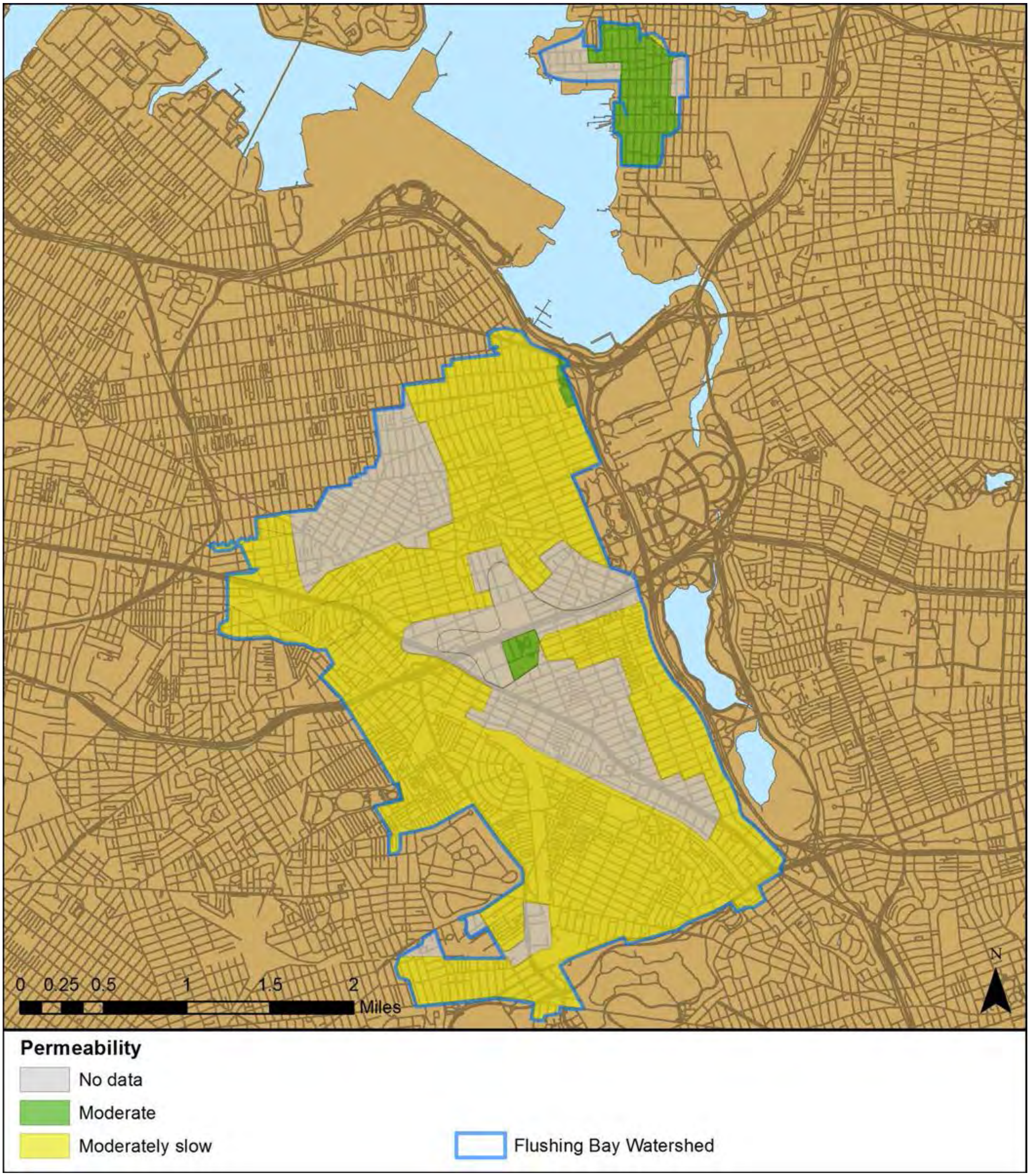


Figure 4.12: Flushing Bay Watershed Geotechnical Criteria: Hydrologic Soil Group

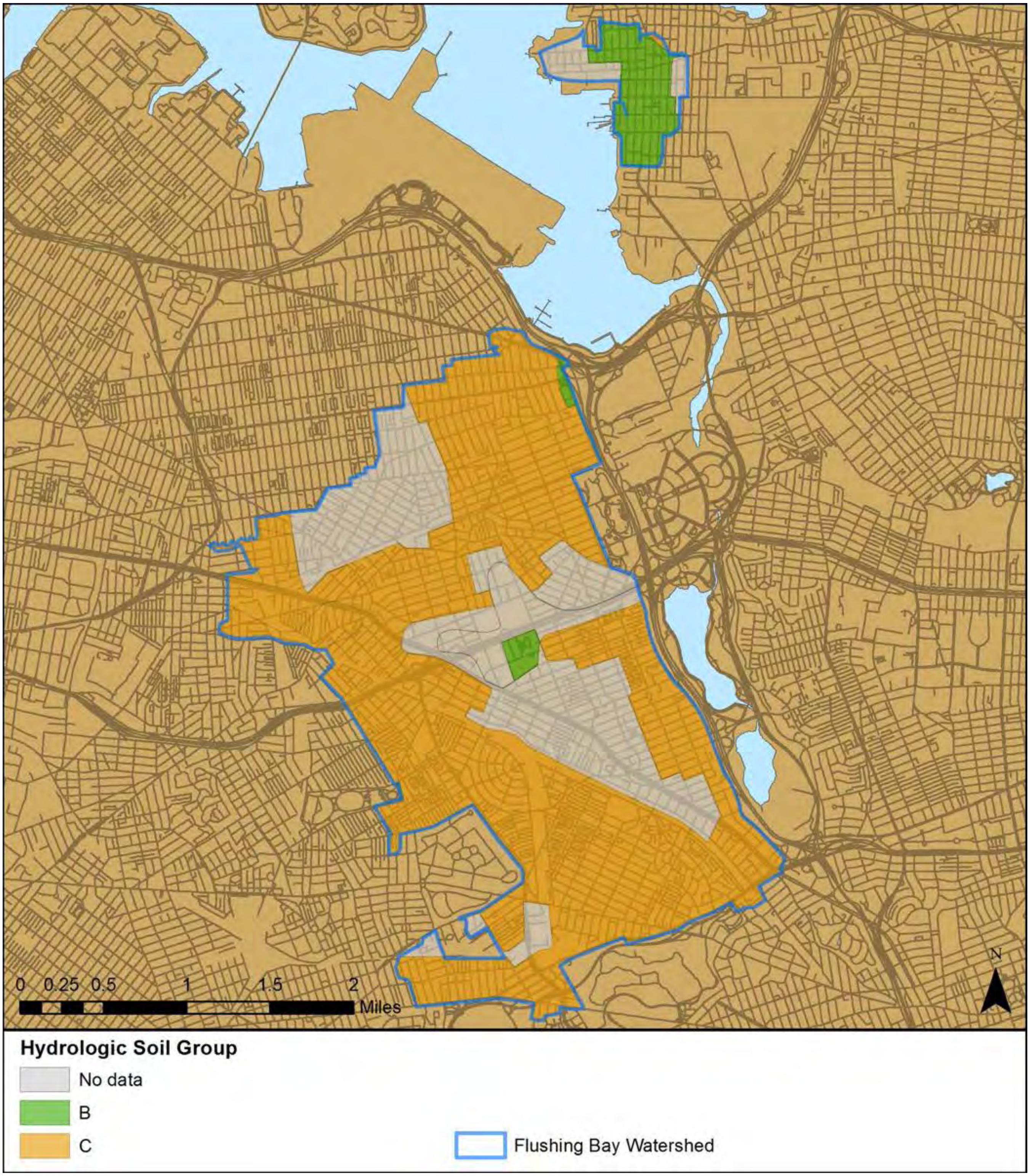


Figure 4.13: Flushing Bay Watershed Geotechnical Criteria: Combined Criteria Excluding Soils

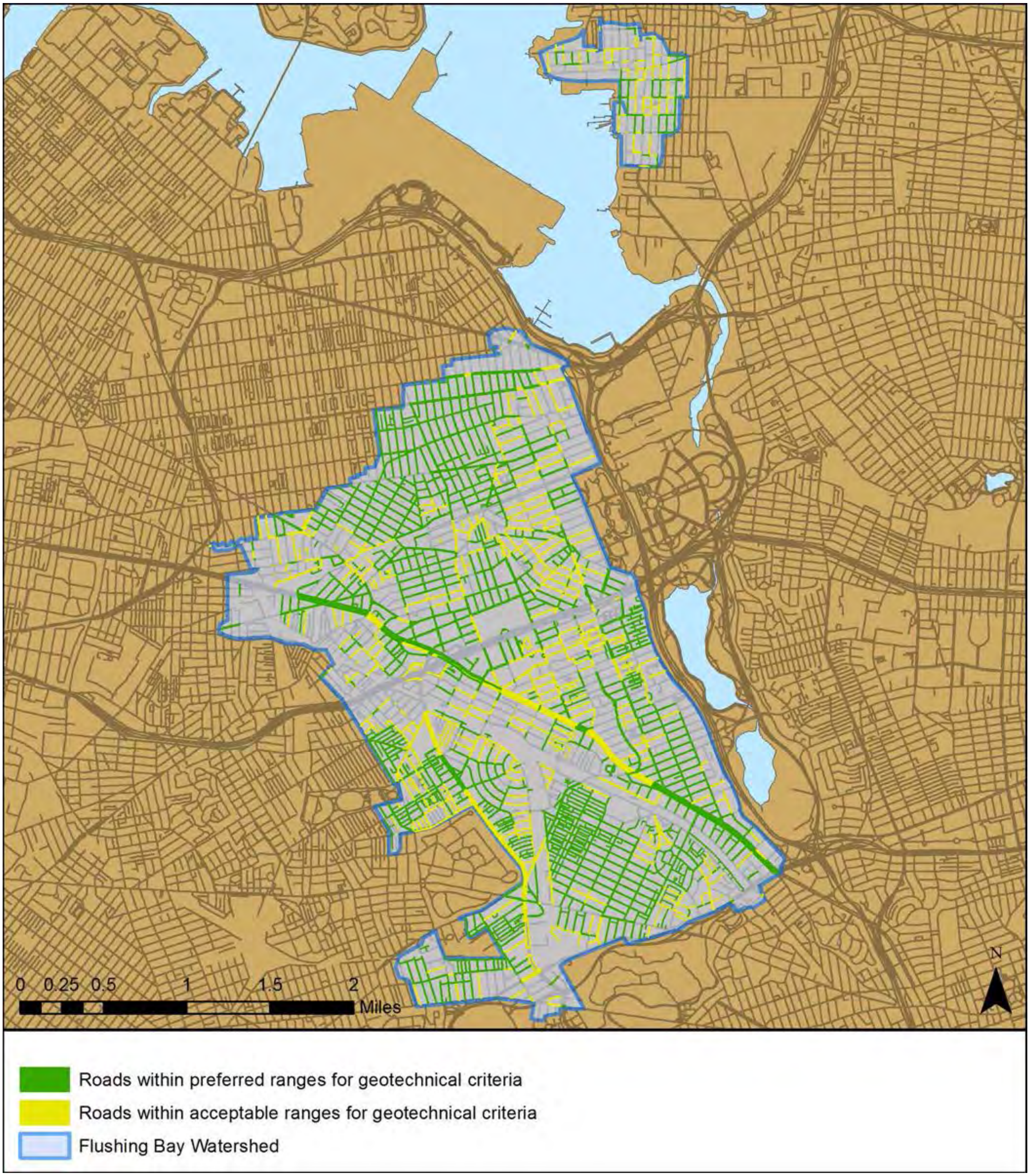


Figure 4.14: Flushing Bay Watershed Built Environment Criteria: Residential Zoning Districts with Building Setbacks of 10′ or Greater

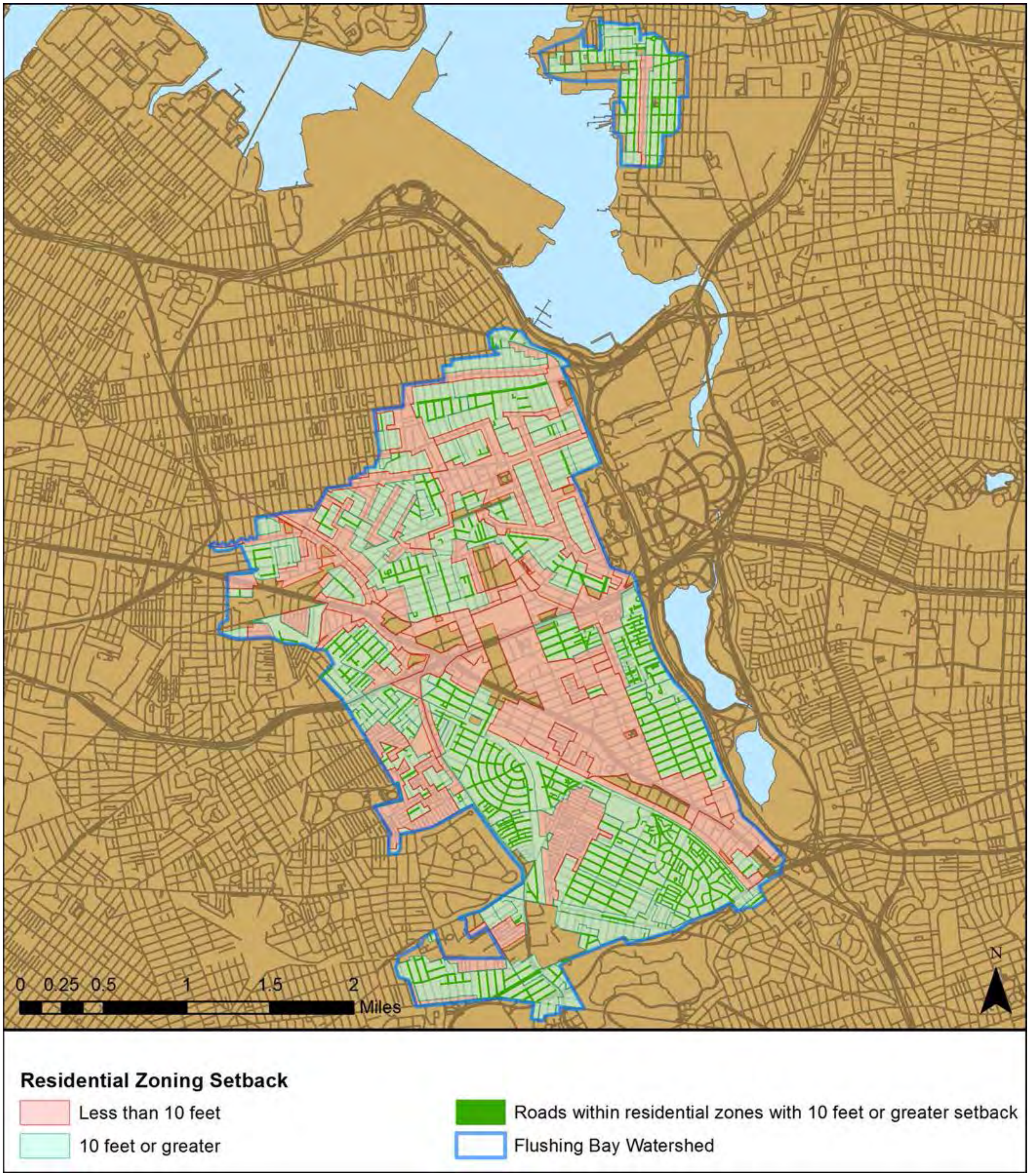


Figure 4.15: Flushing Bay Watershed Built Environment Criteria: Commercial Overlay Districts

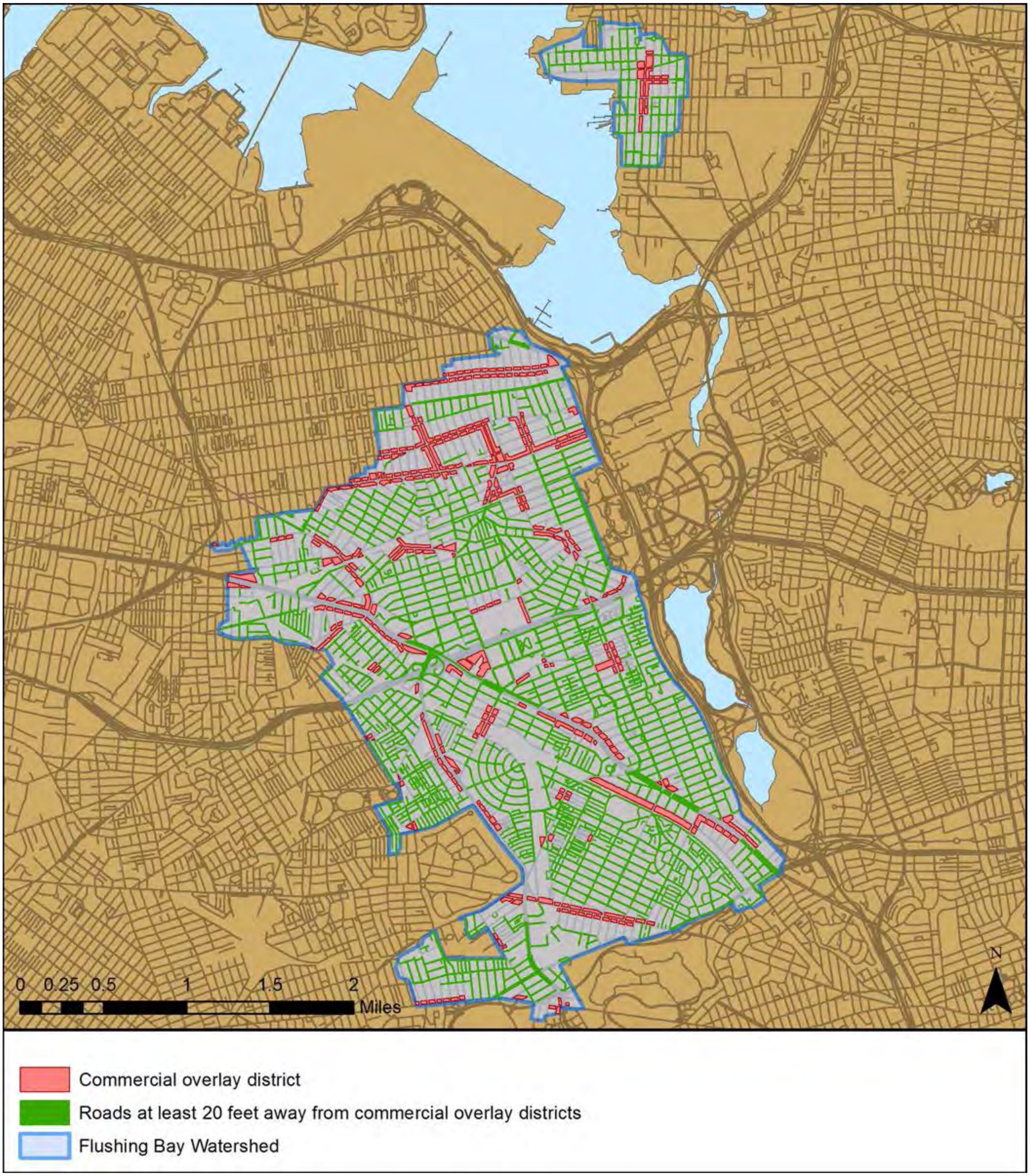
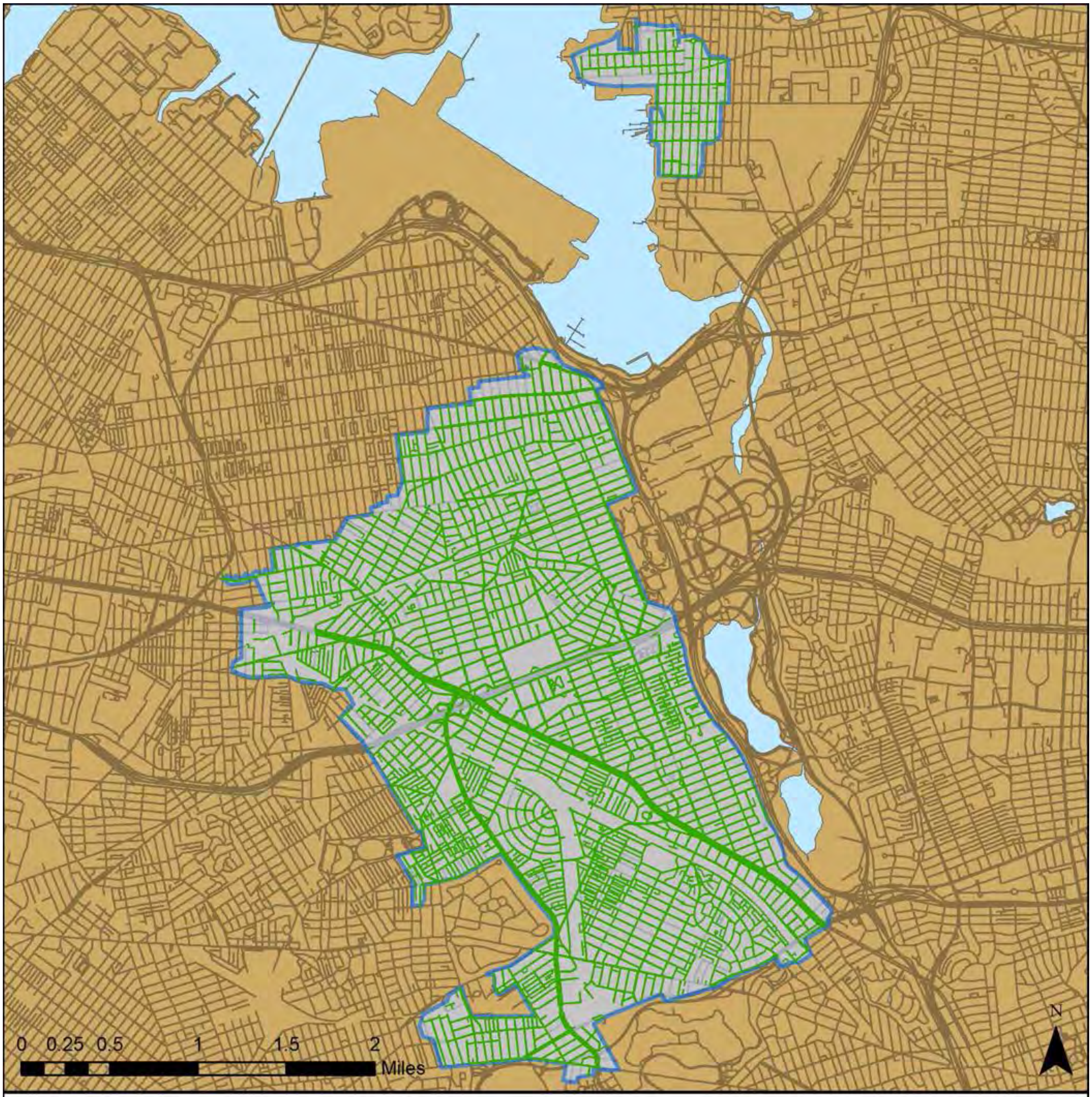


Figure 4.16: Flushing Bay Watershed Built Environment Criteria: Street Tree Density



🟩 Roads with fewer than 3 trees per thousand square feet of pavement

▭ Flushing Bay Watershed

Figure 4.17: Flushing Bay Watershed Built Environment Criteria: Pavement Condition

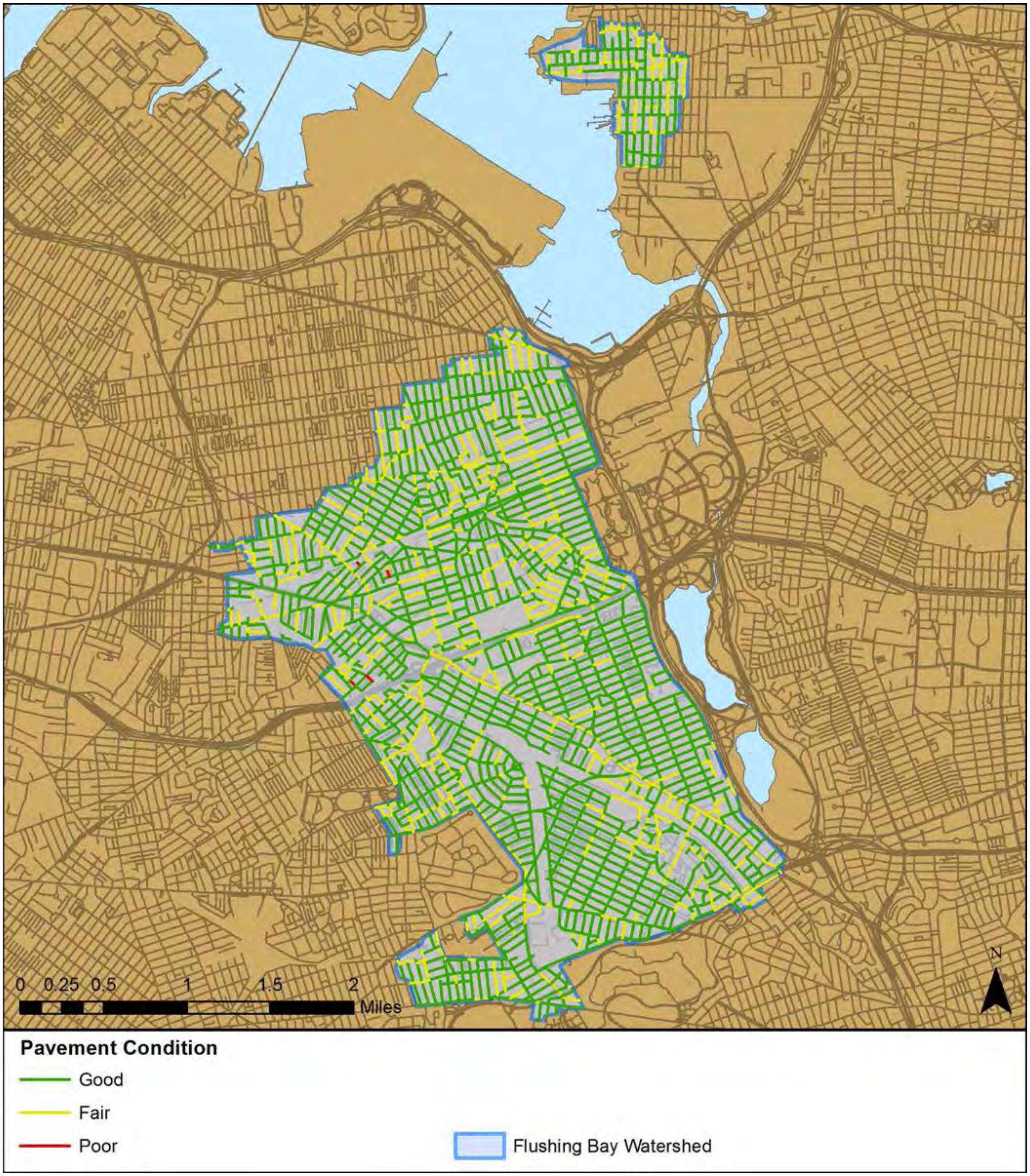


Figure 4.18: Flushing Bay Watershed Built Environment Criteria: Combined Criteria Excluding Pavement Condition

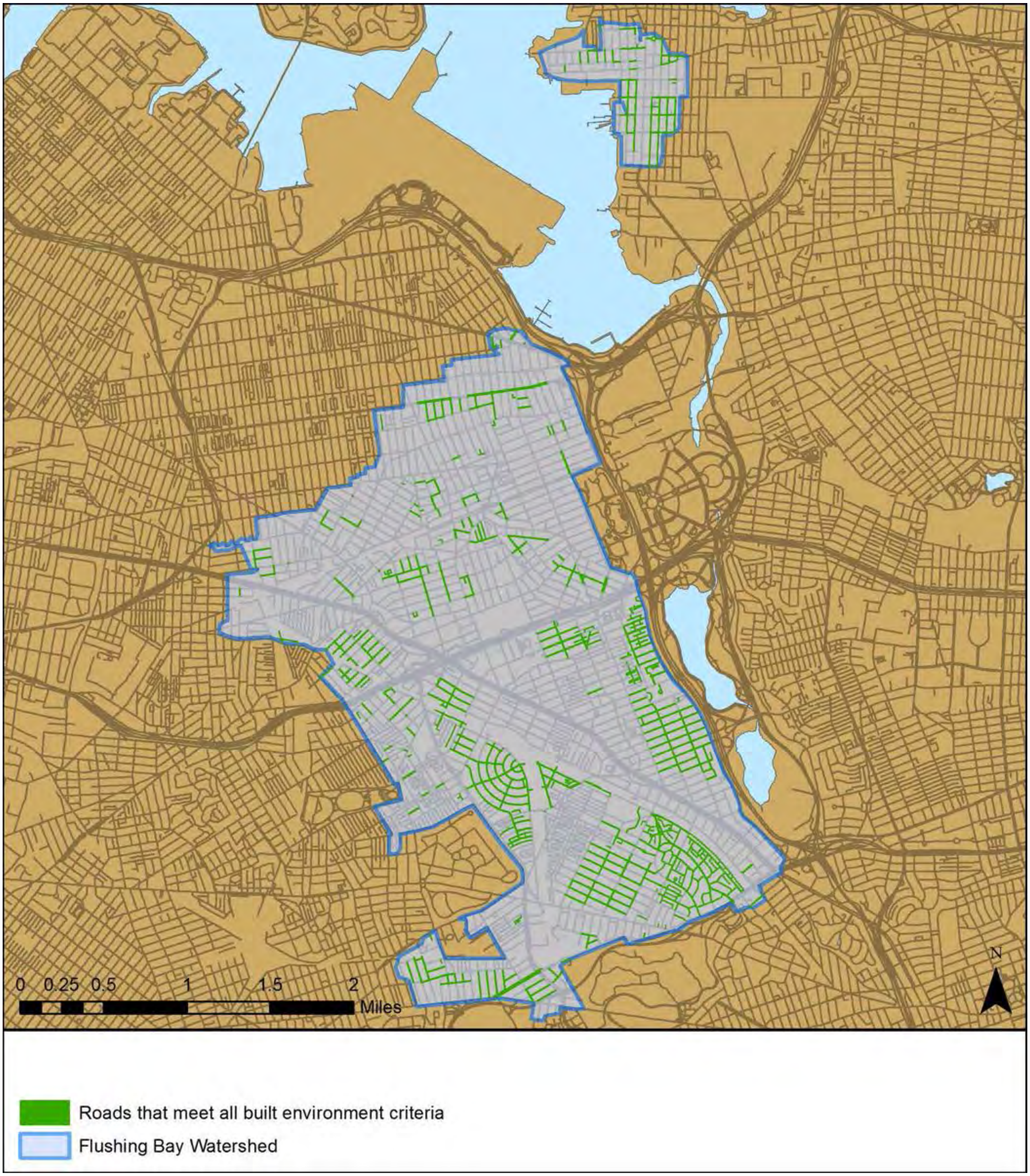


Figure 4.19: Flushing Bay Watershed Preliminary Pervious Pavement Site Recommendations

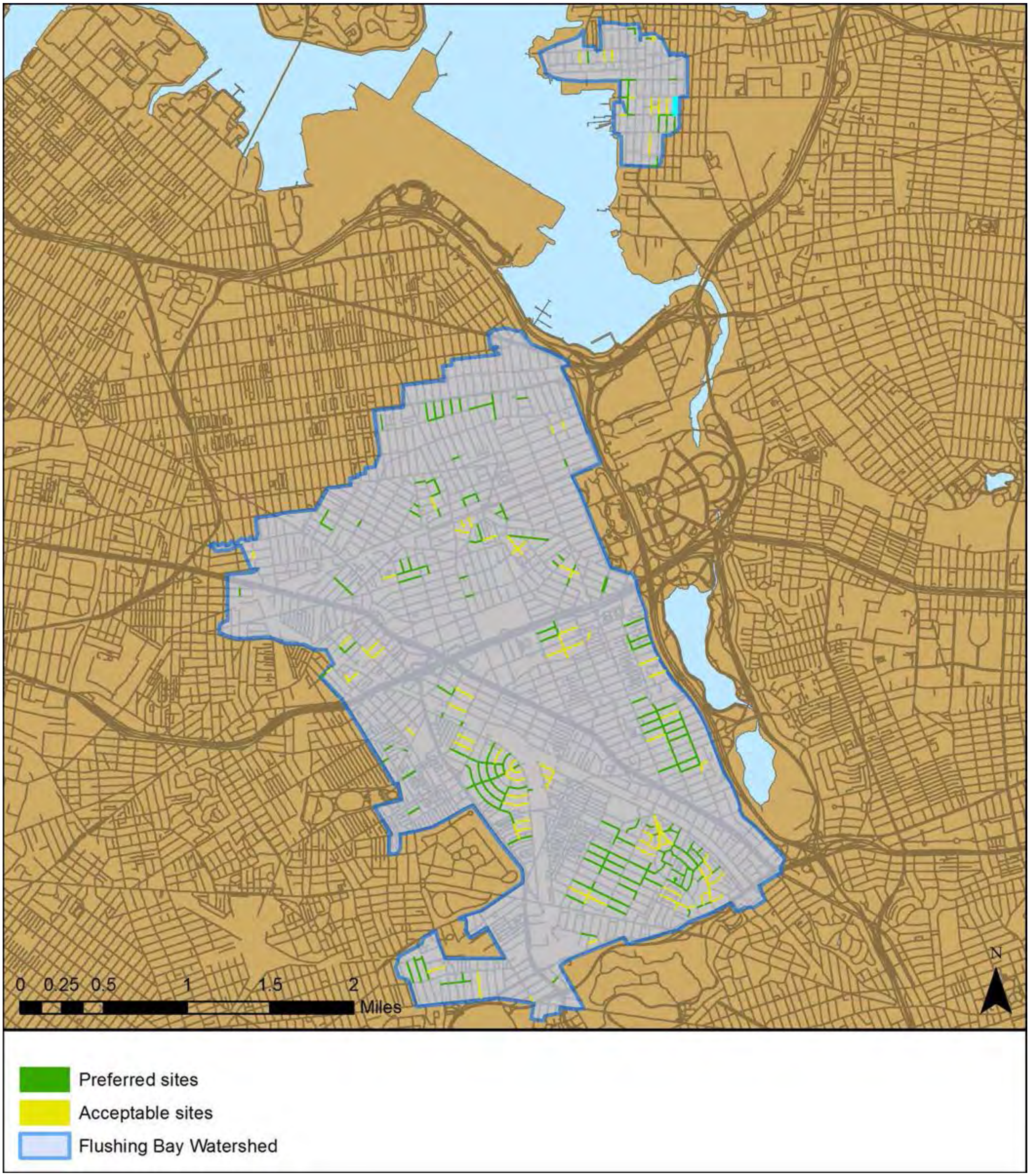


Figure 4.20: Flushing Bay Watershed Final Pervious Pavement Site Recommendations

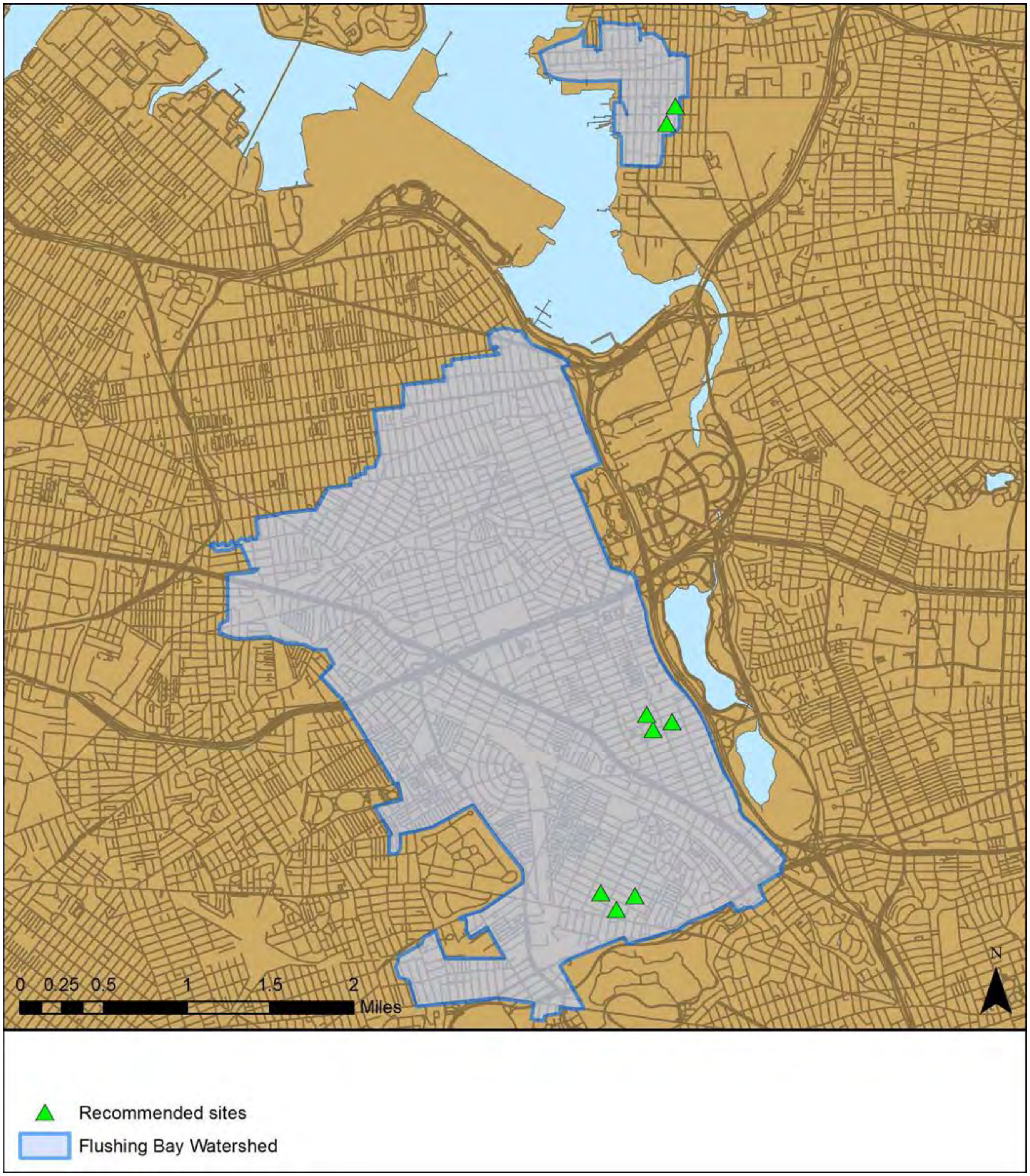


Figure 4.21: Newtown Creek Watershed Transport Network Criteria: NYC DOT Road Designations

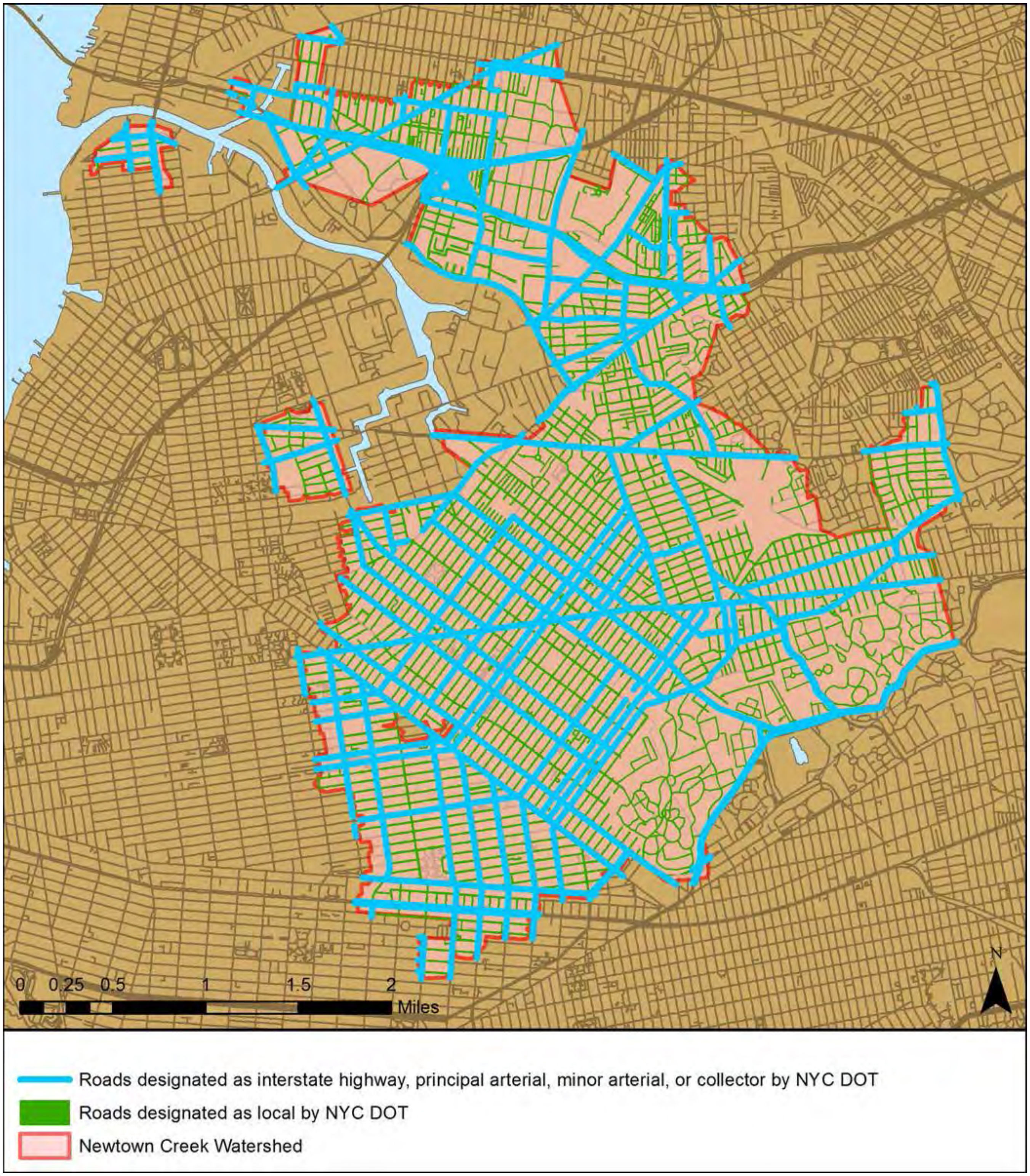


Figure 4.22: Newtown Creek Watershed Transport Network Criteria: Major Roads

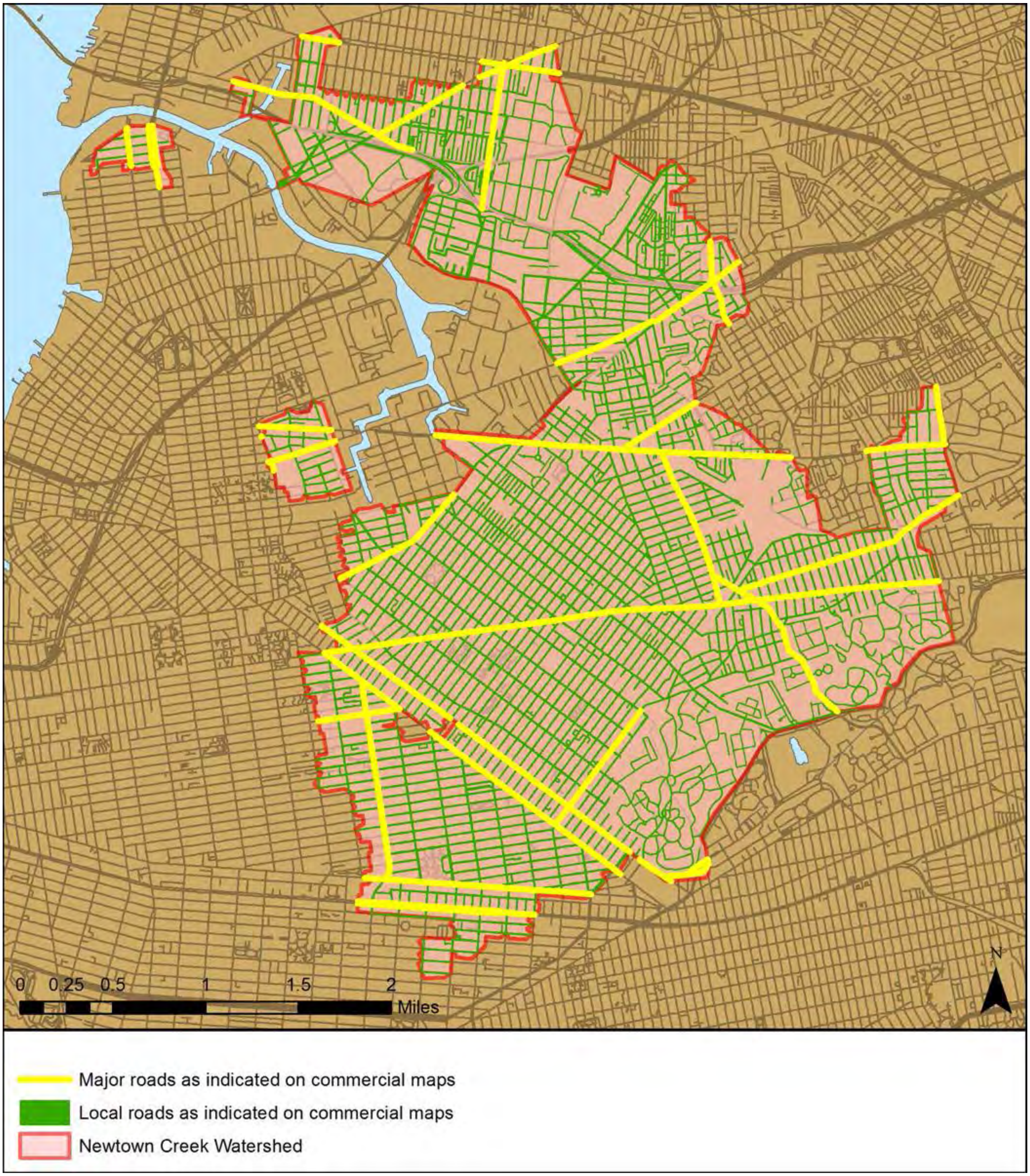


Figure 4.23: Newtown Creek Watershed Transport Network Criteria: Truck Routes

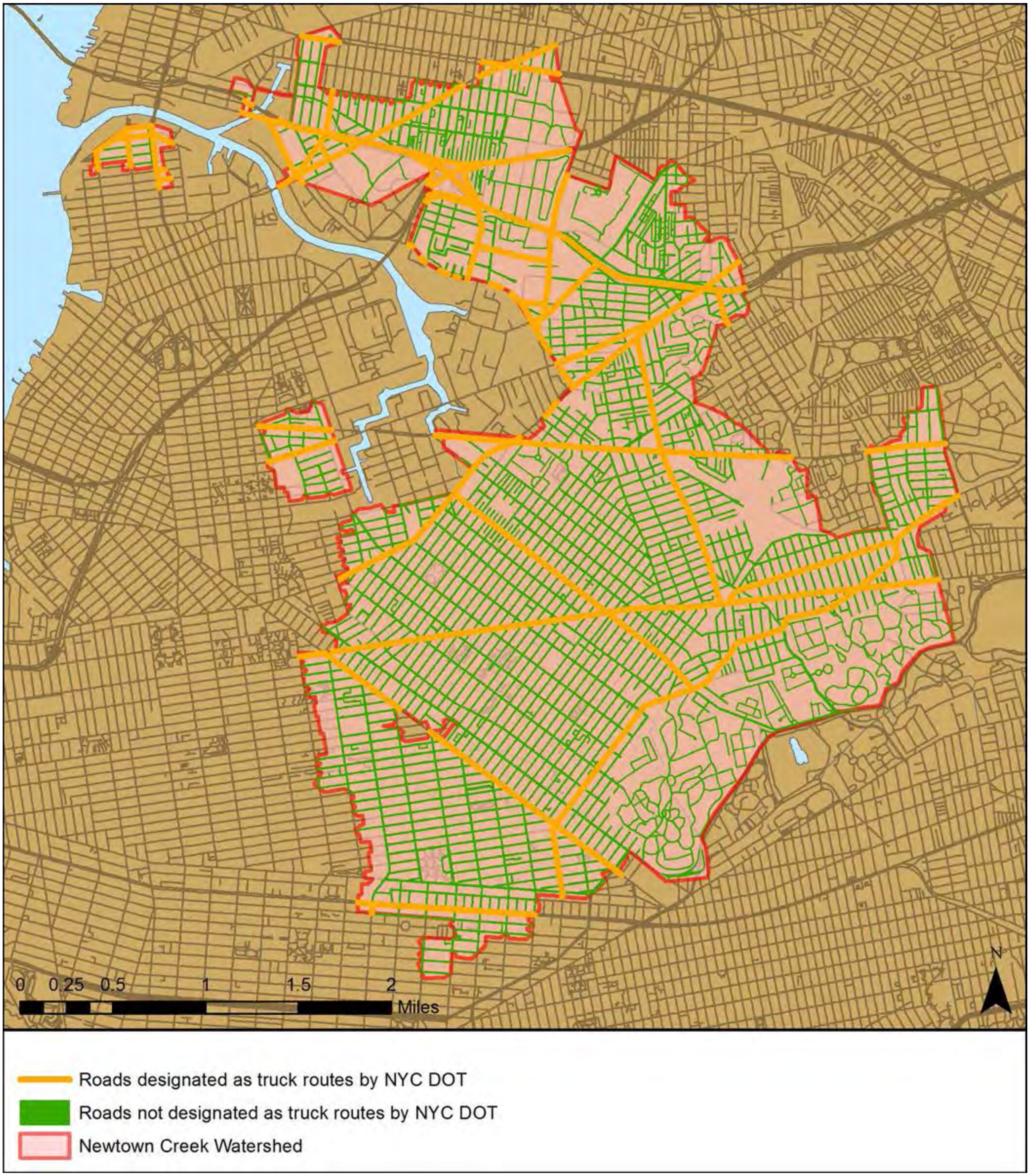


Figure 4.24: Newtown Creek Watershed Transport Network Criteria: Bus Routes

Figure 4.25: Newtown Creek Watershed Transport Network Criteria: Subway Lines

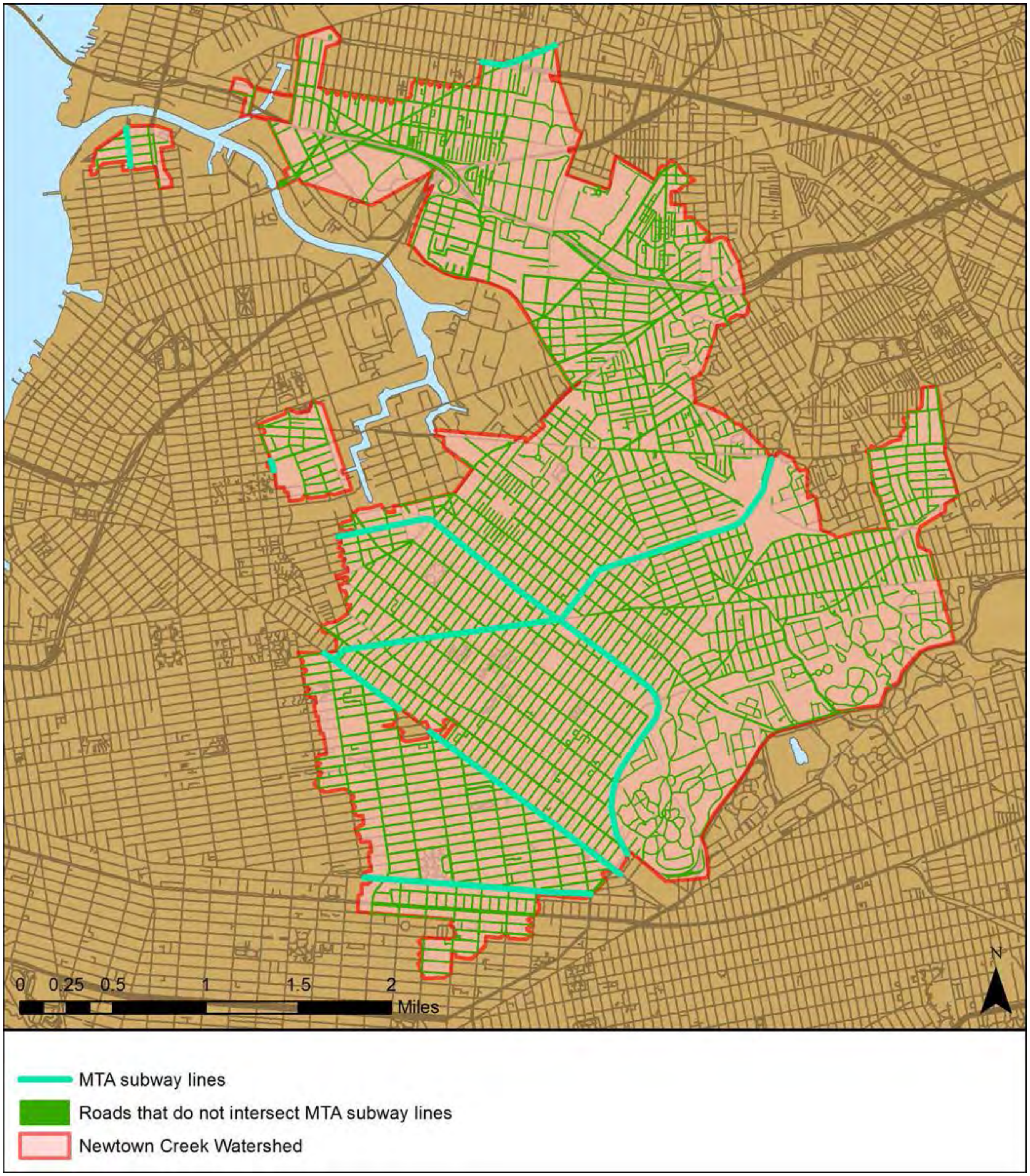


Figure 4.26: Newtown Creek Watershed Transport Network Criteria: Railroad Lines

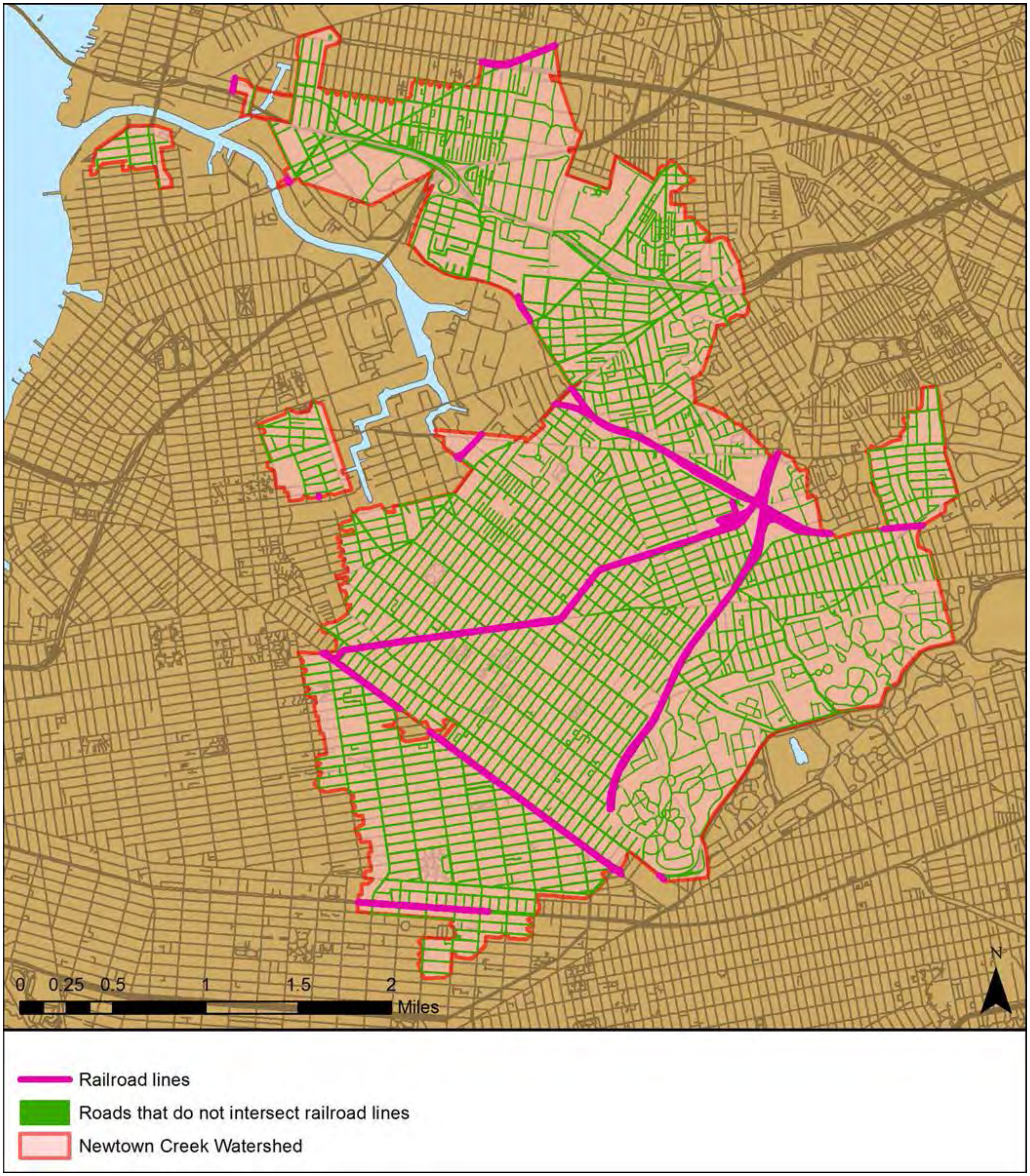


Figure 4.27: Newtown Creek Watershed Transport Network Criteria: Combined Criteria

Figure 4.28: Newtown Creek Watershed Geotechnical Criteria: Slope

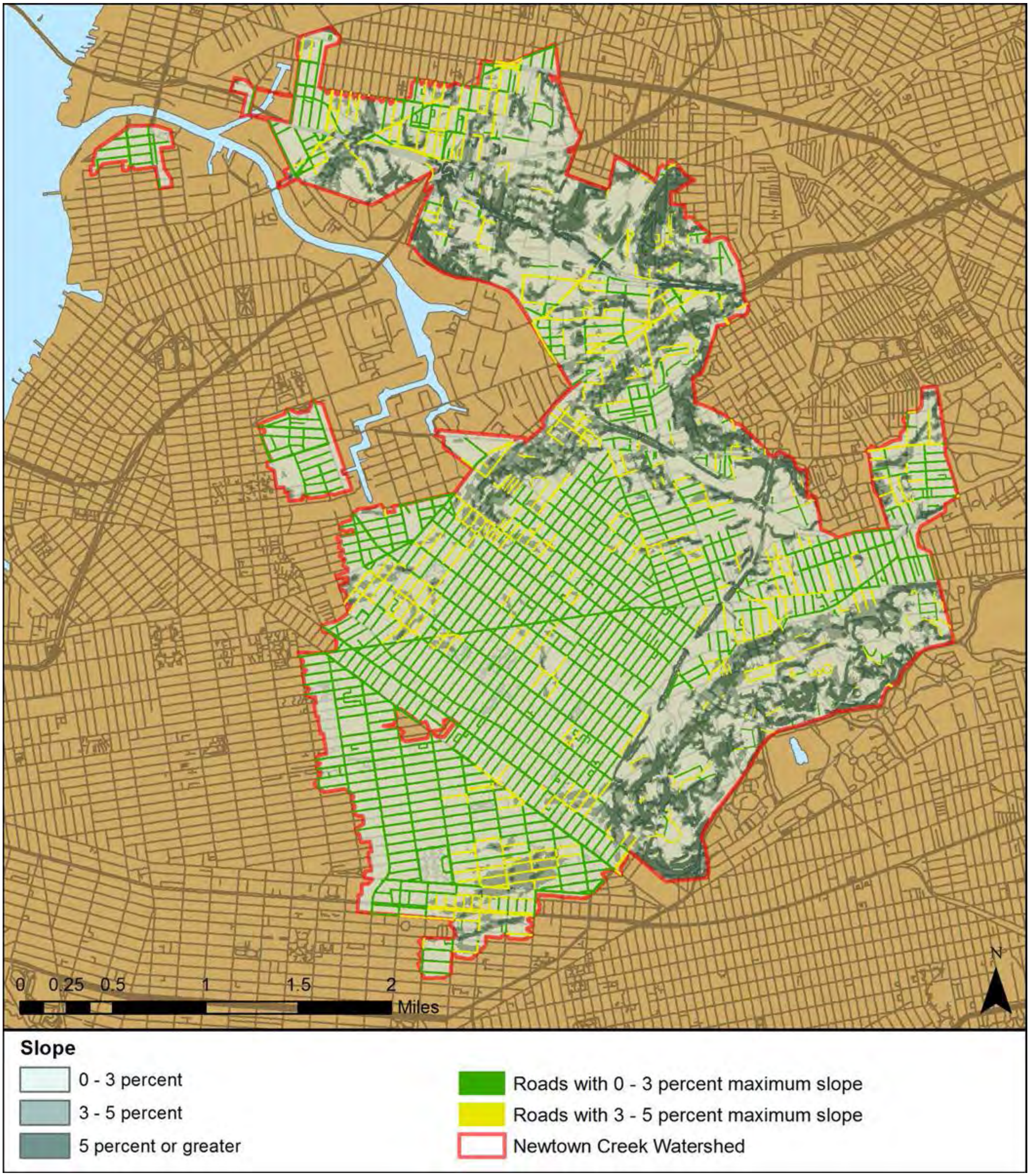


Figure 4.29: Newtown Creek Watershed Geotechnical Criteria: Depth to Bedrock

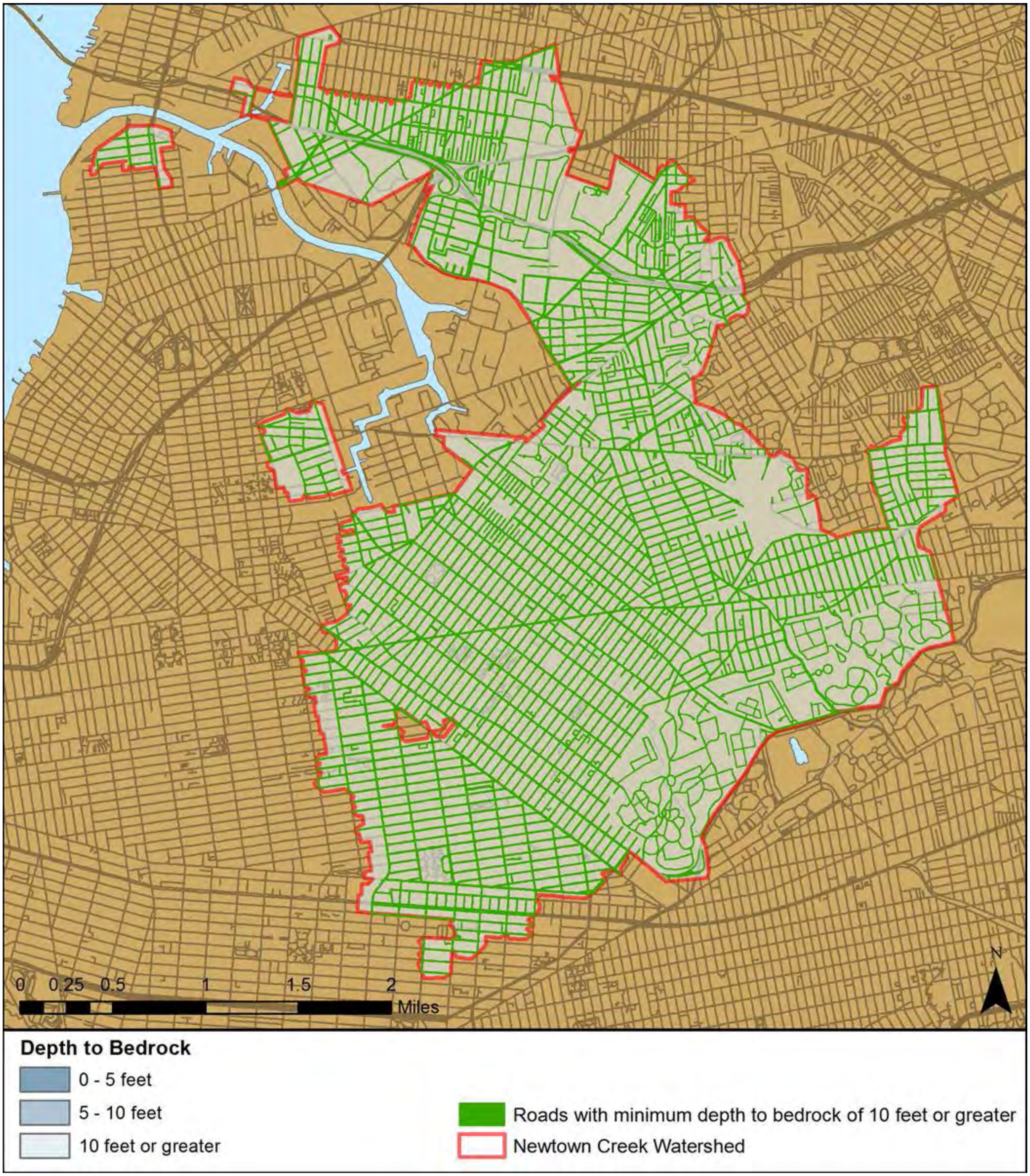


Figure 4.30: Newtown Creek Watershed Geotechnical Criteria: Depth to Watertable

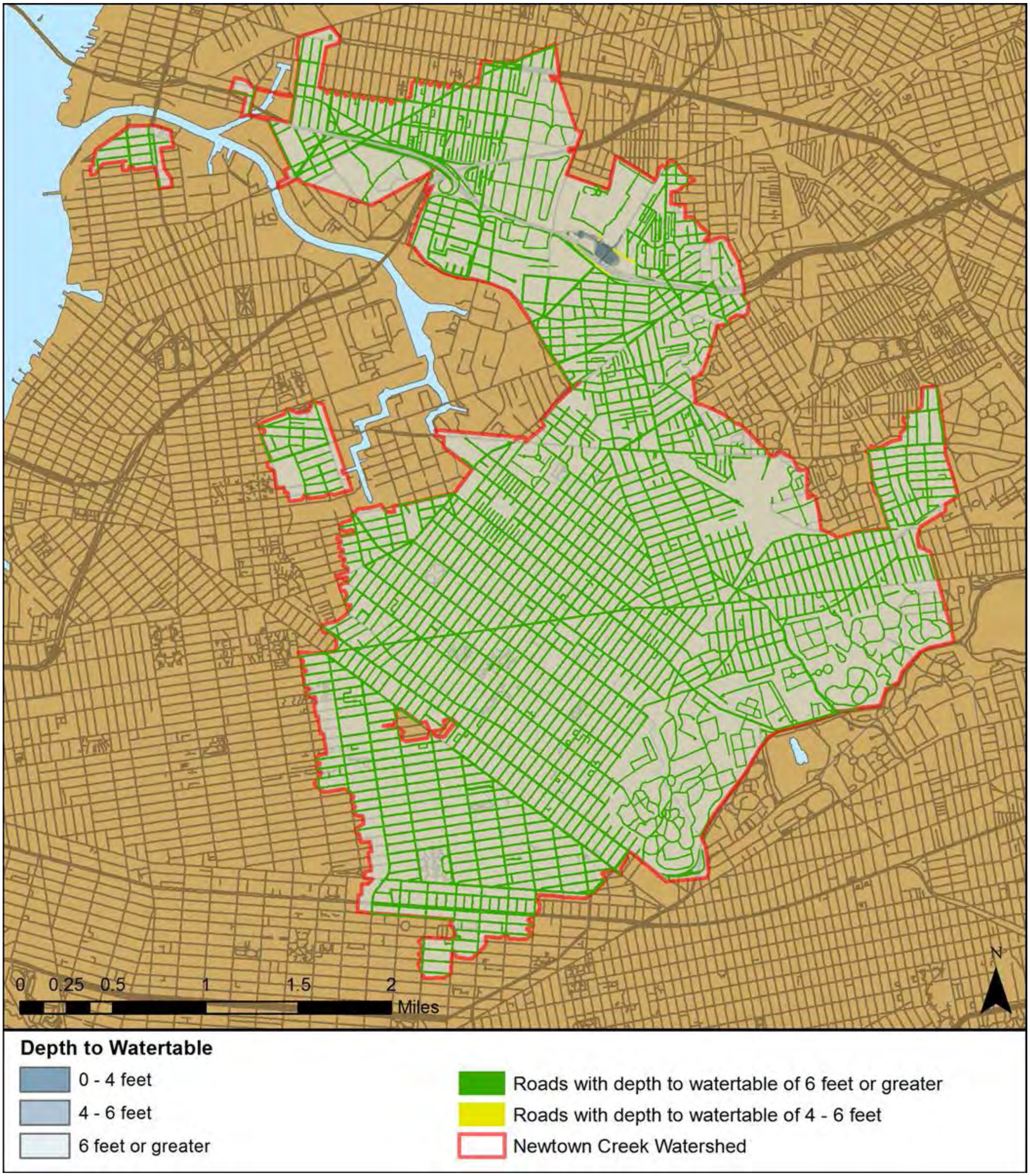


Figure 4.31: Newtown Creek Watershed Geotechnical Criteria: Soil Permeability

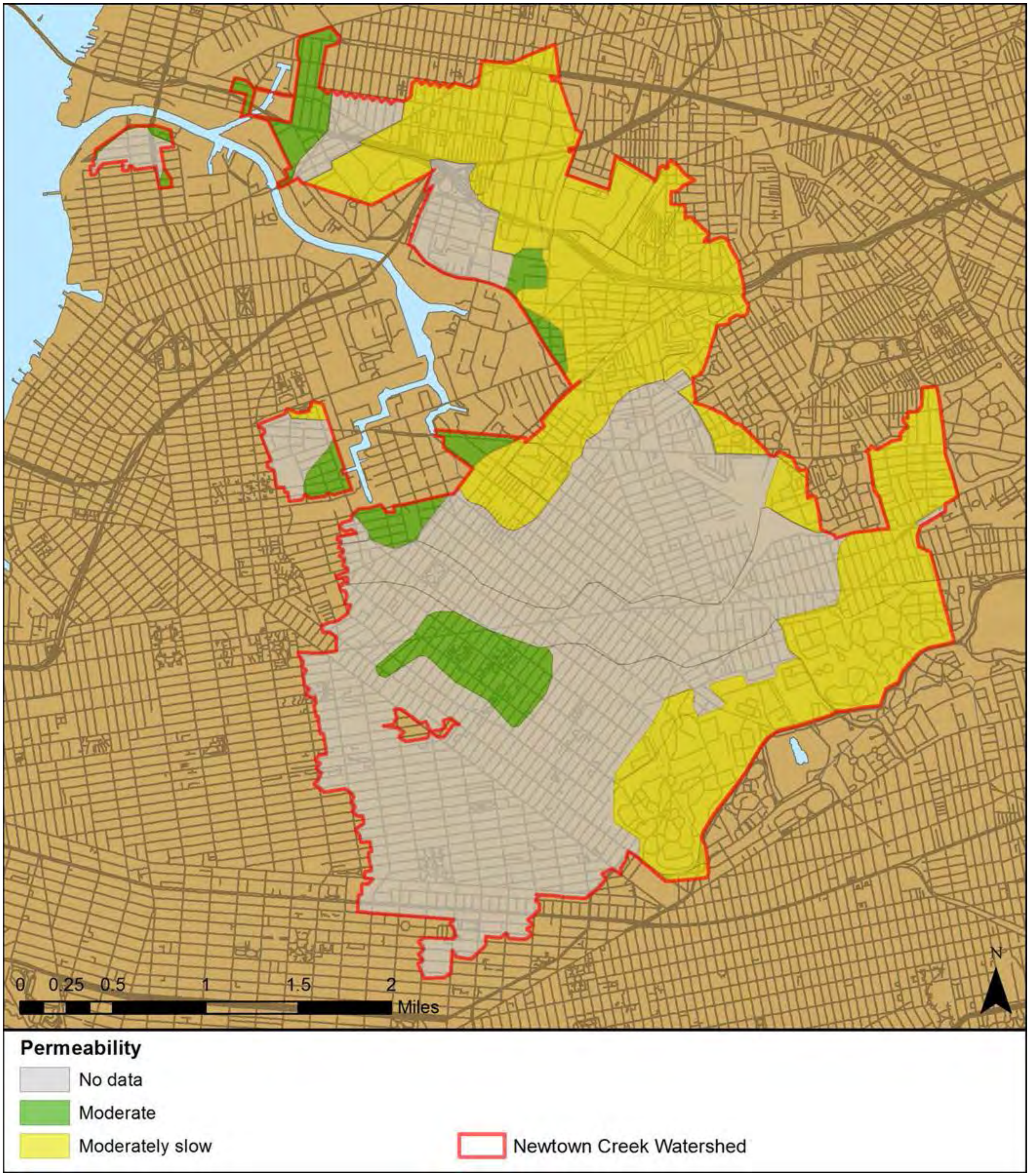


Figure 4.32: Newtown Creek Watershed Geotechnical Criteria: Hydrologic Soil Group

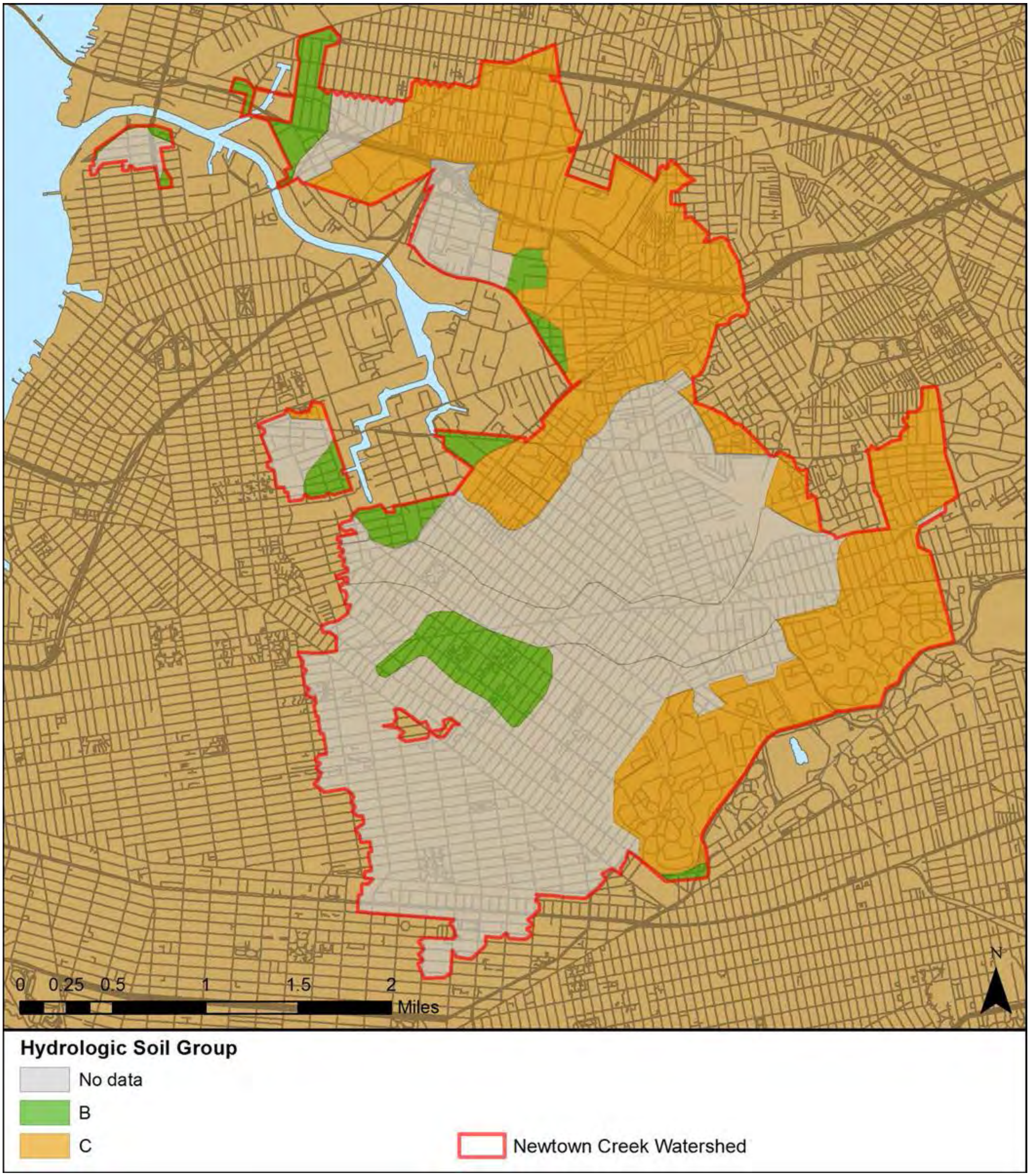


Figure 4.33: Newtown Creek Watershed Geotechnical Criteria: Combined Criteria Excluding Soils

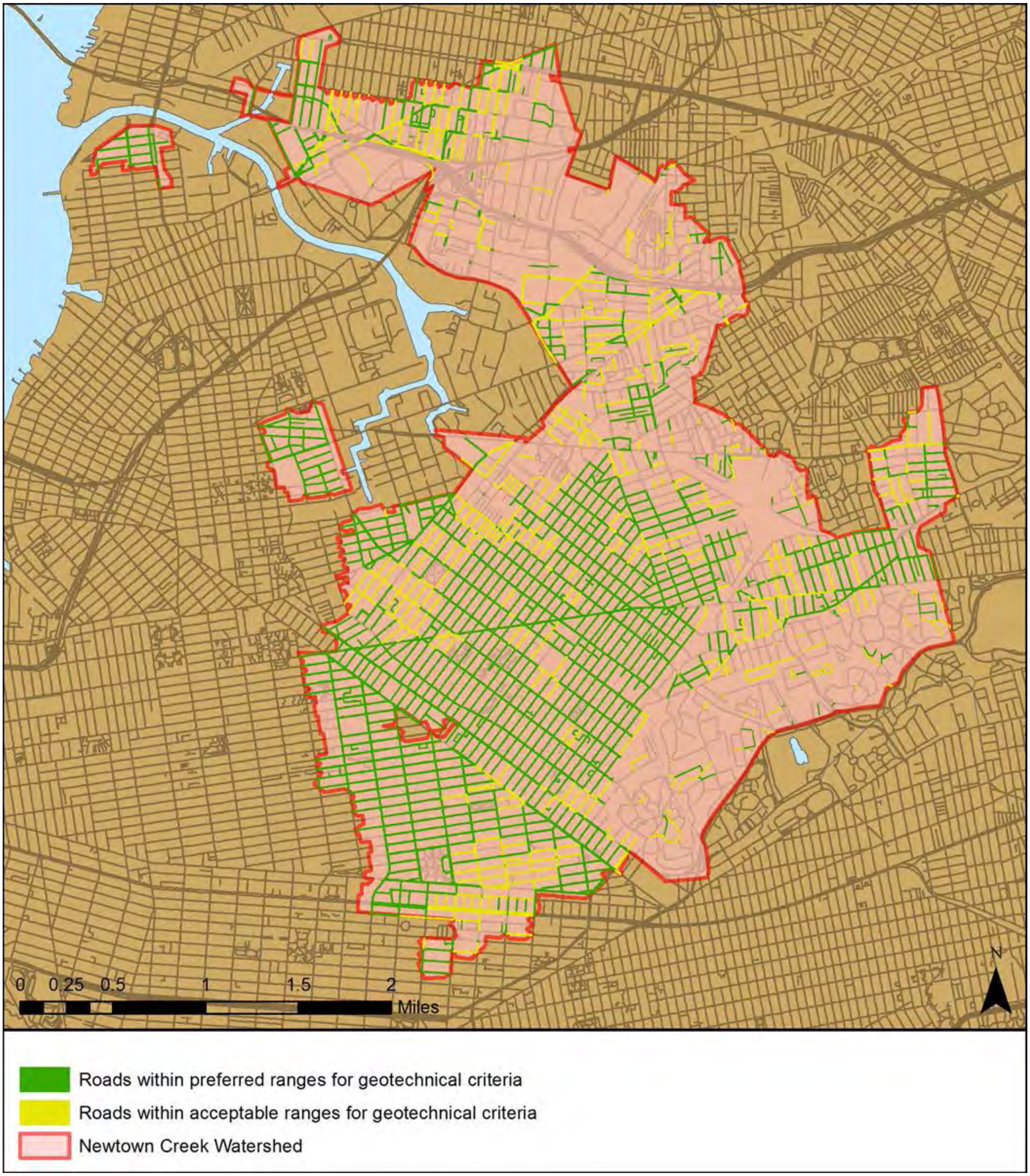


Figure 4.34: Newtown Creek Watershed Built Environment Criteria: Residential Zoning Districts with Building Setbacks of 10′ or Greater

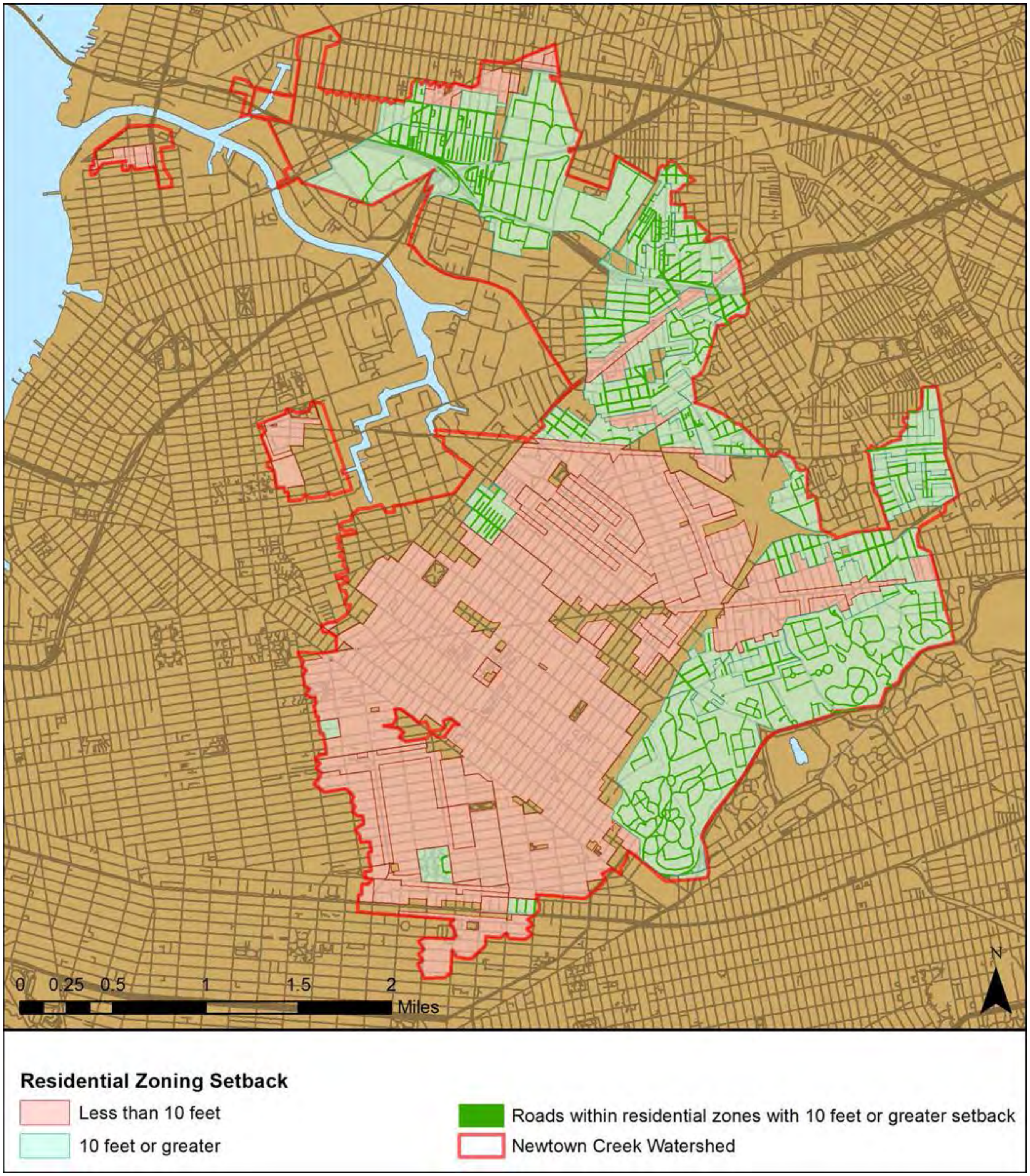


Figure 4.35: Newtown Creek Watershed Built Environment Criteria: Commercial Overlay Districts

Figure 4.36: Newtown Creek Watershed Built Environment Criteria: Street Tree Density

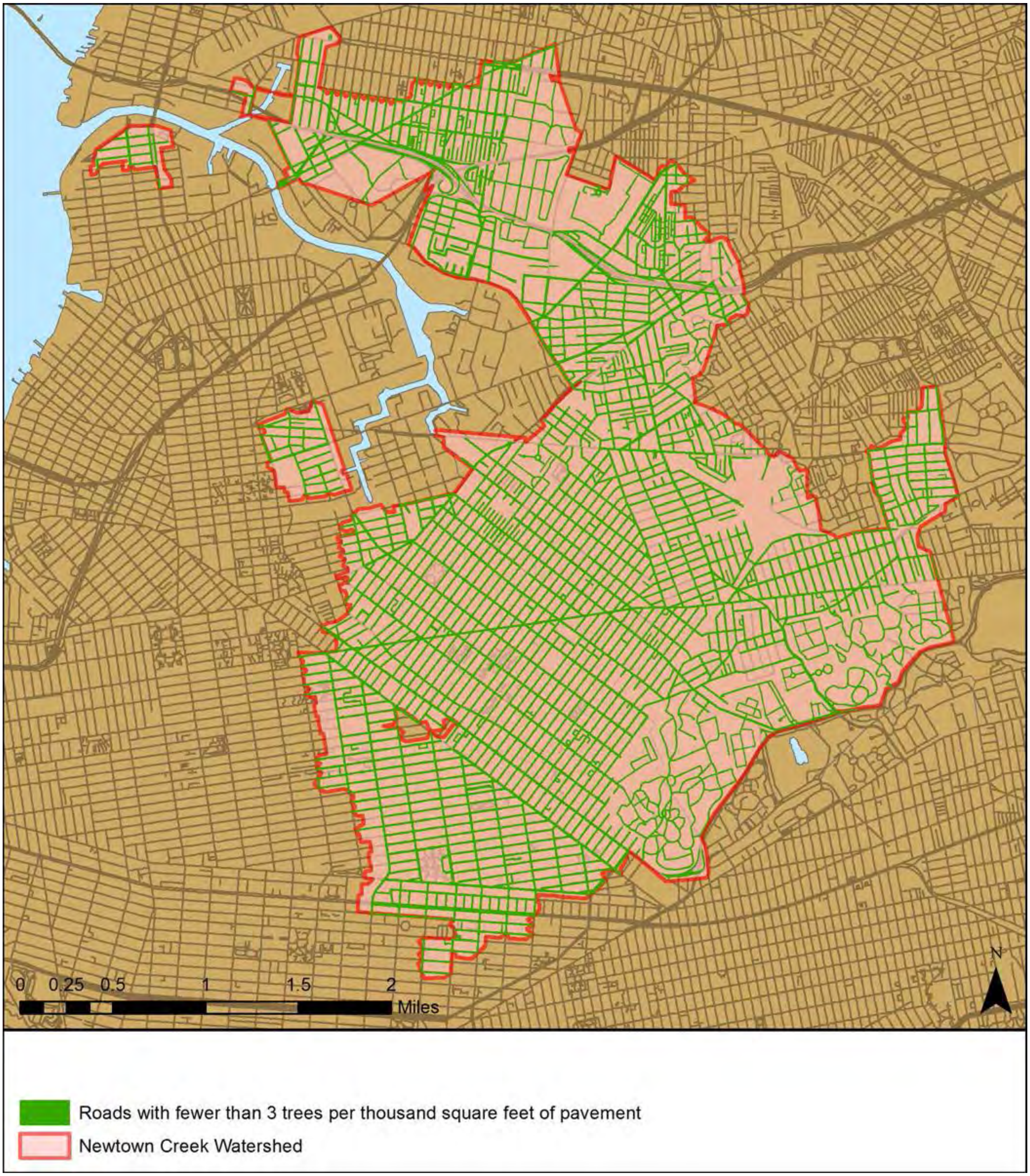


Figure 4.37: Newtown Creek Watershed Built Environment Criteria: Pavement Condition

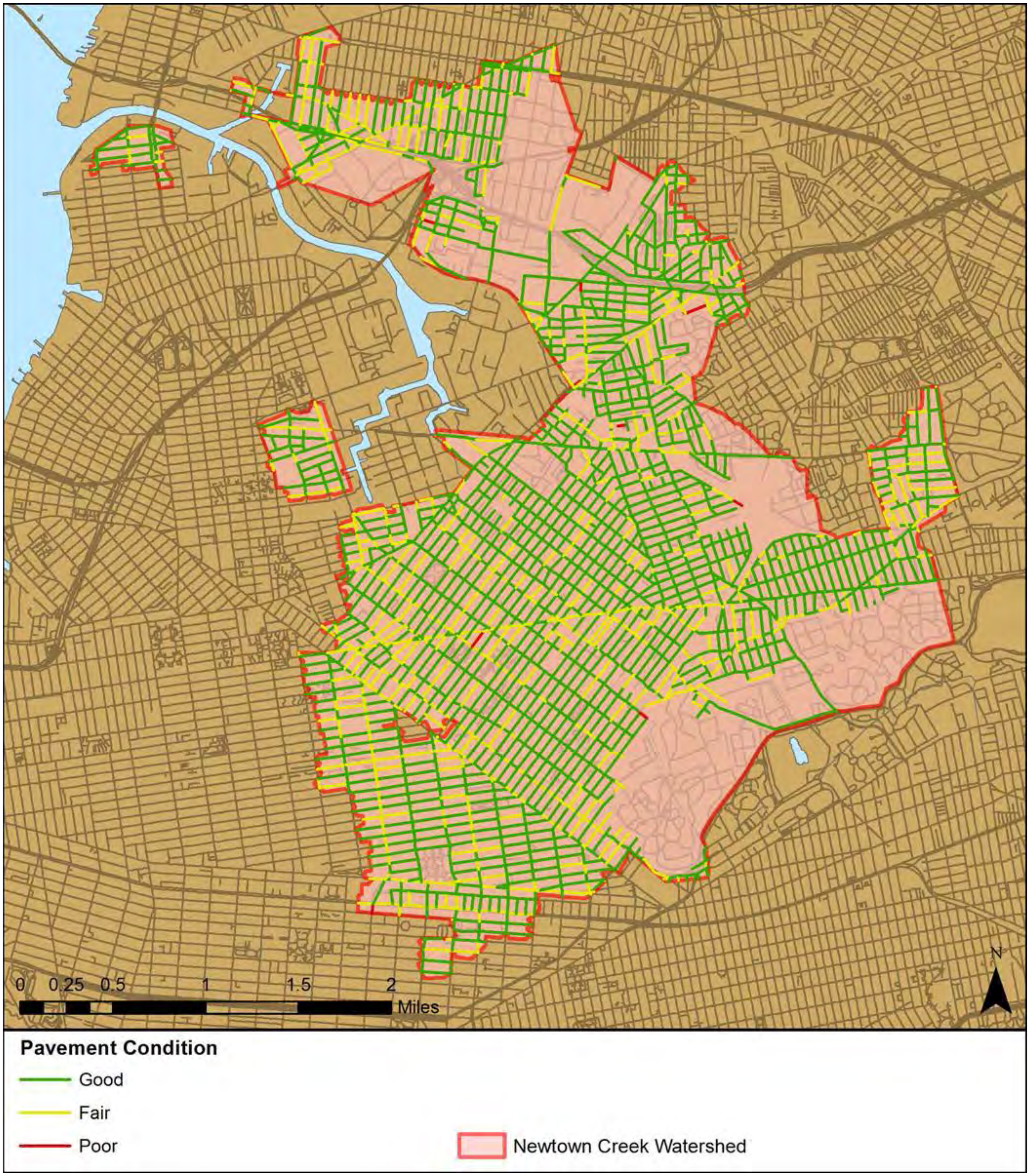


Figure 4.38: Newtown Creek Watershed Built Environment Criteria: Combined Criteria Excluding Pavement Condition

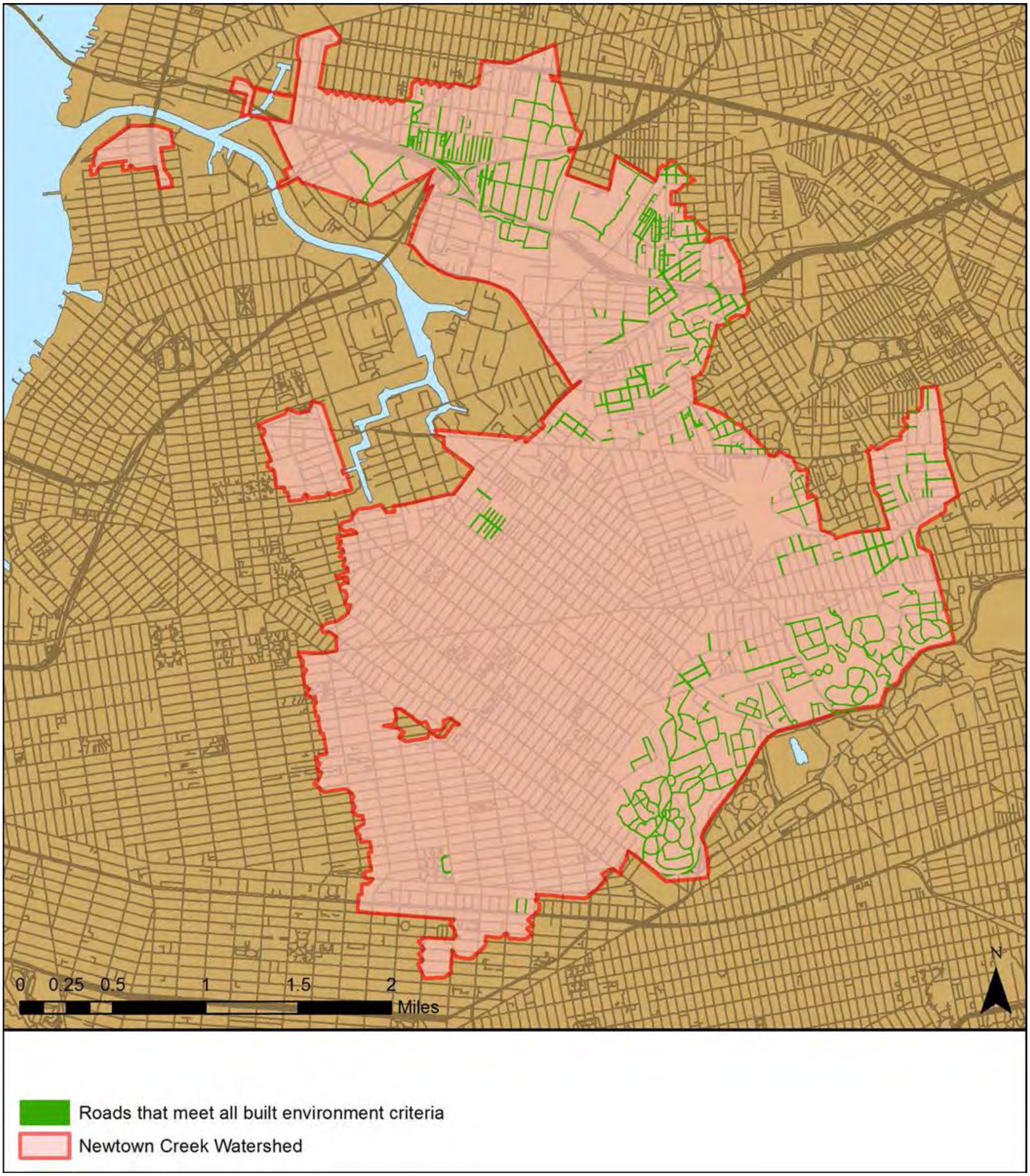


Figure 4.39: Newtown Creek Watershed Preliminary Pervious Pavement Site Recommendations

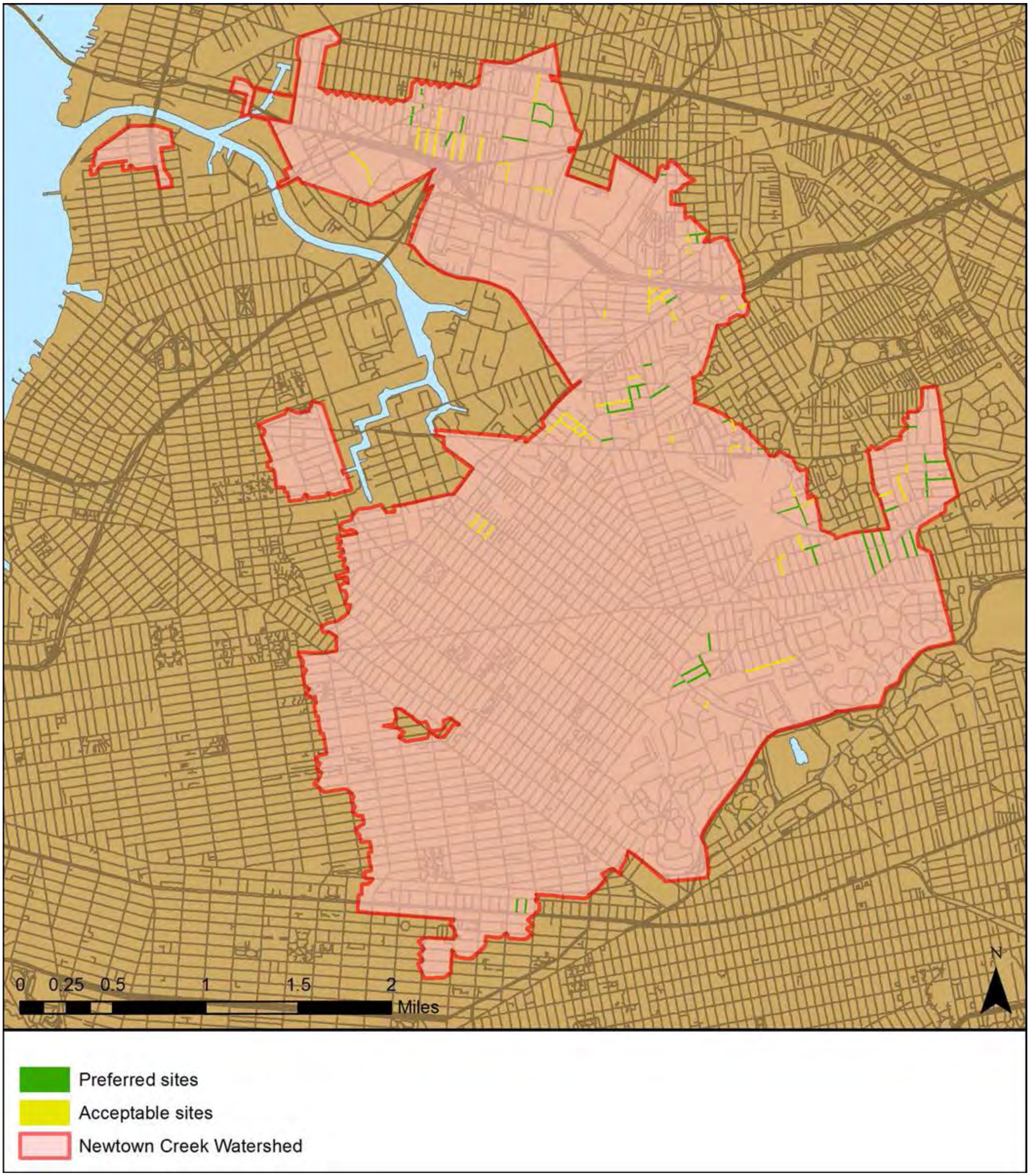


Figure 4.40: Newtown Creek Watershed Final Pervious Pavement Site Recommendations

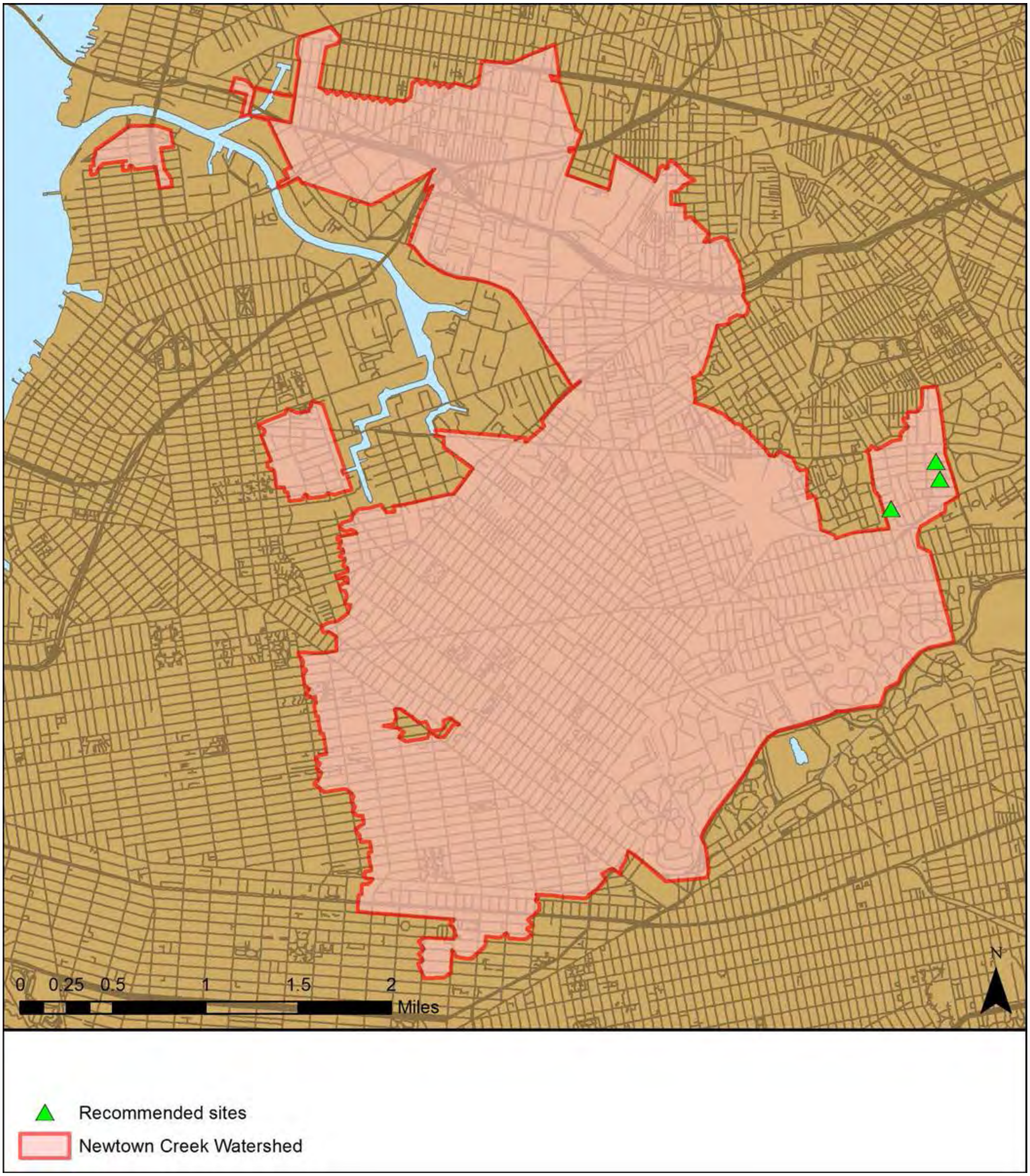


Figure 4.41: Jamaica Bay Watershed Transport Network Criteria: NYC DOT Road Designations

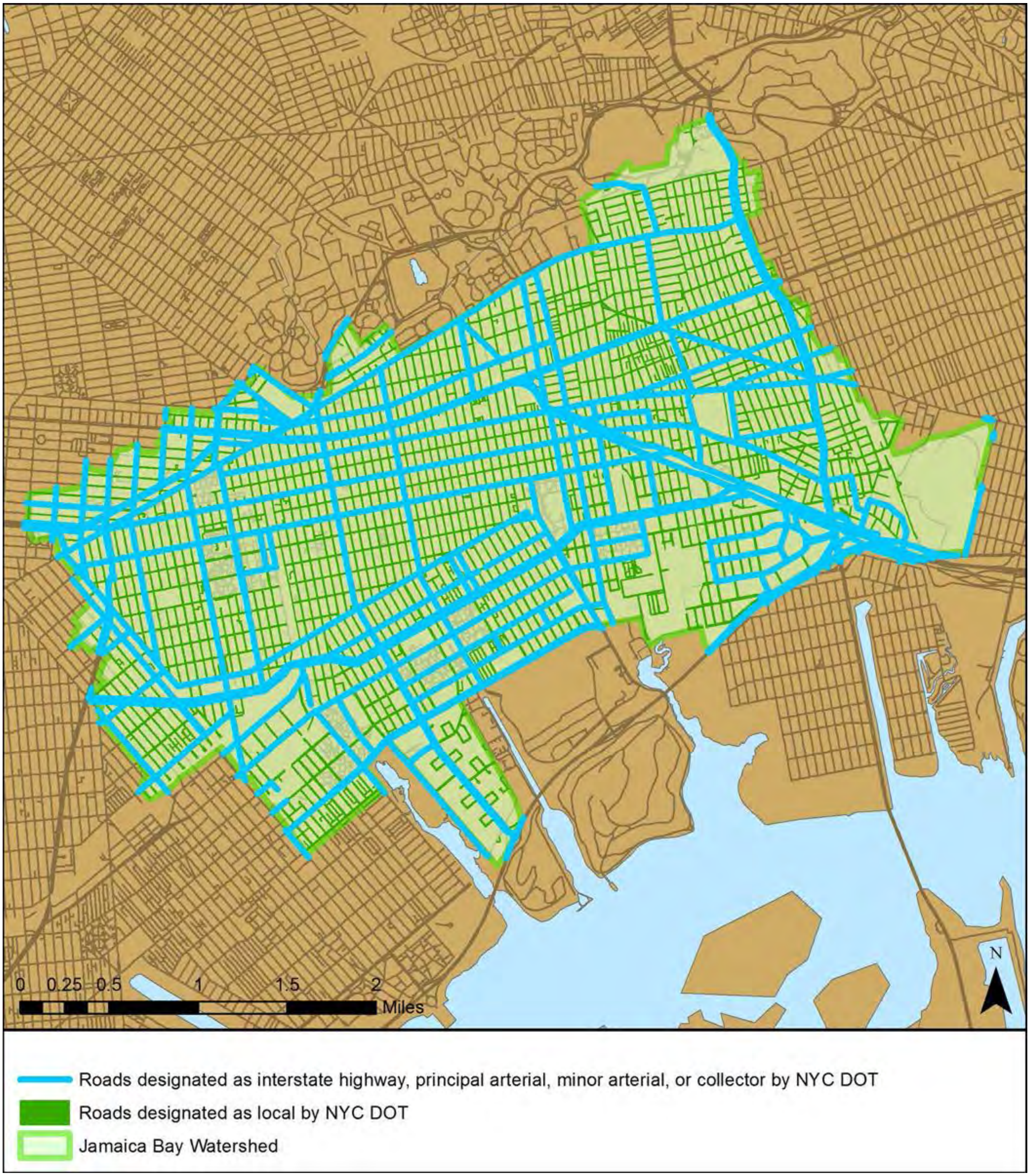


Figure 4.42: Jamaica Bay Watershed Transport Network Criteria: Major Roads

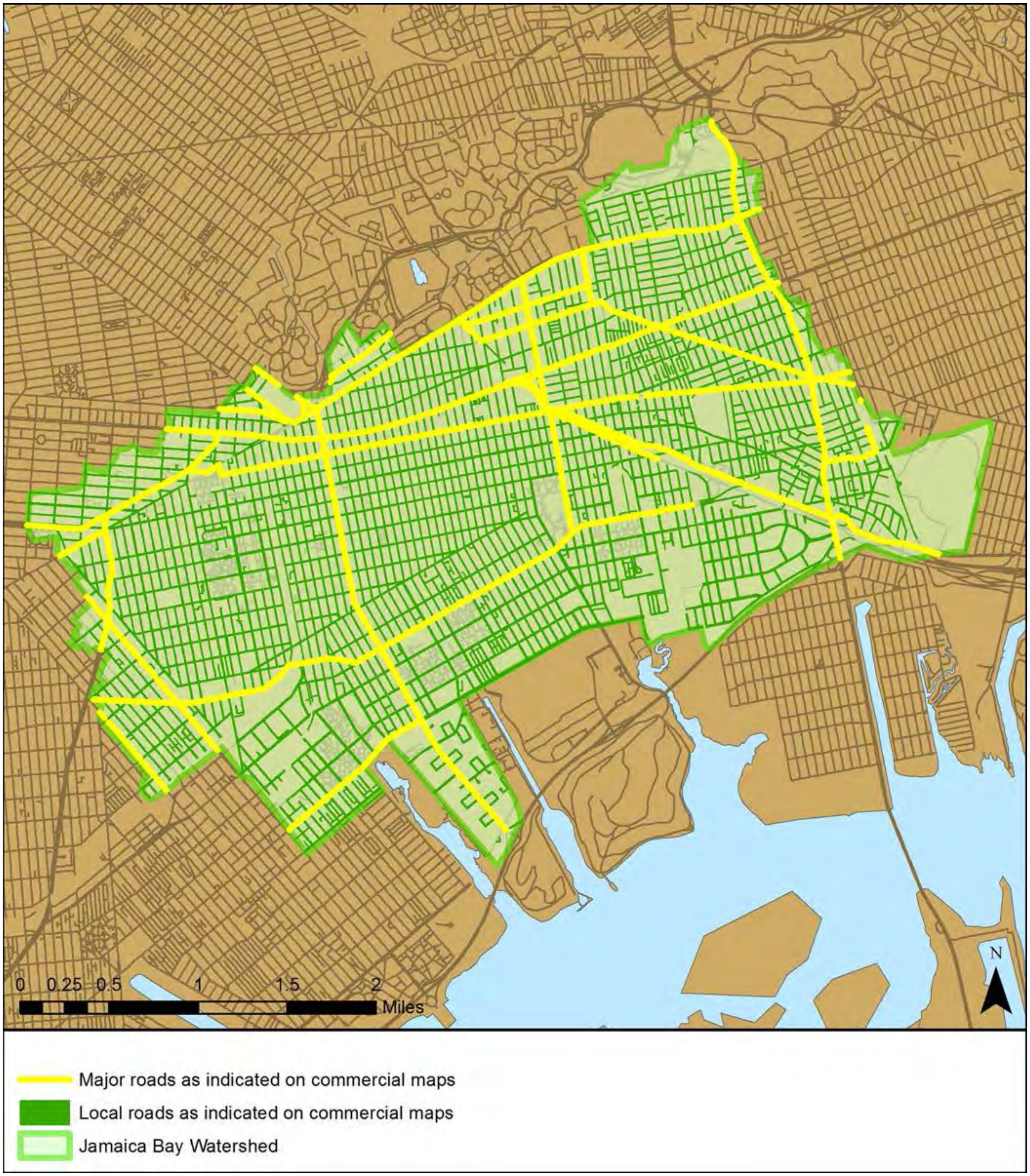


Figure 4.43: Jamaica Bay Watershed Transport Network Criteria: Truck Routes

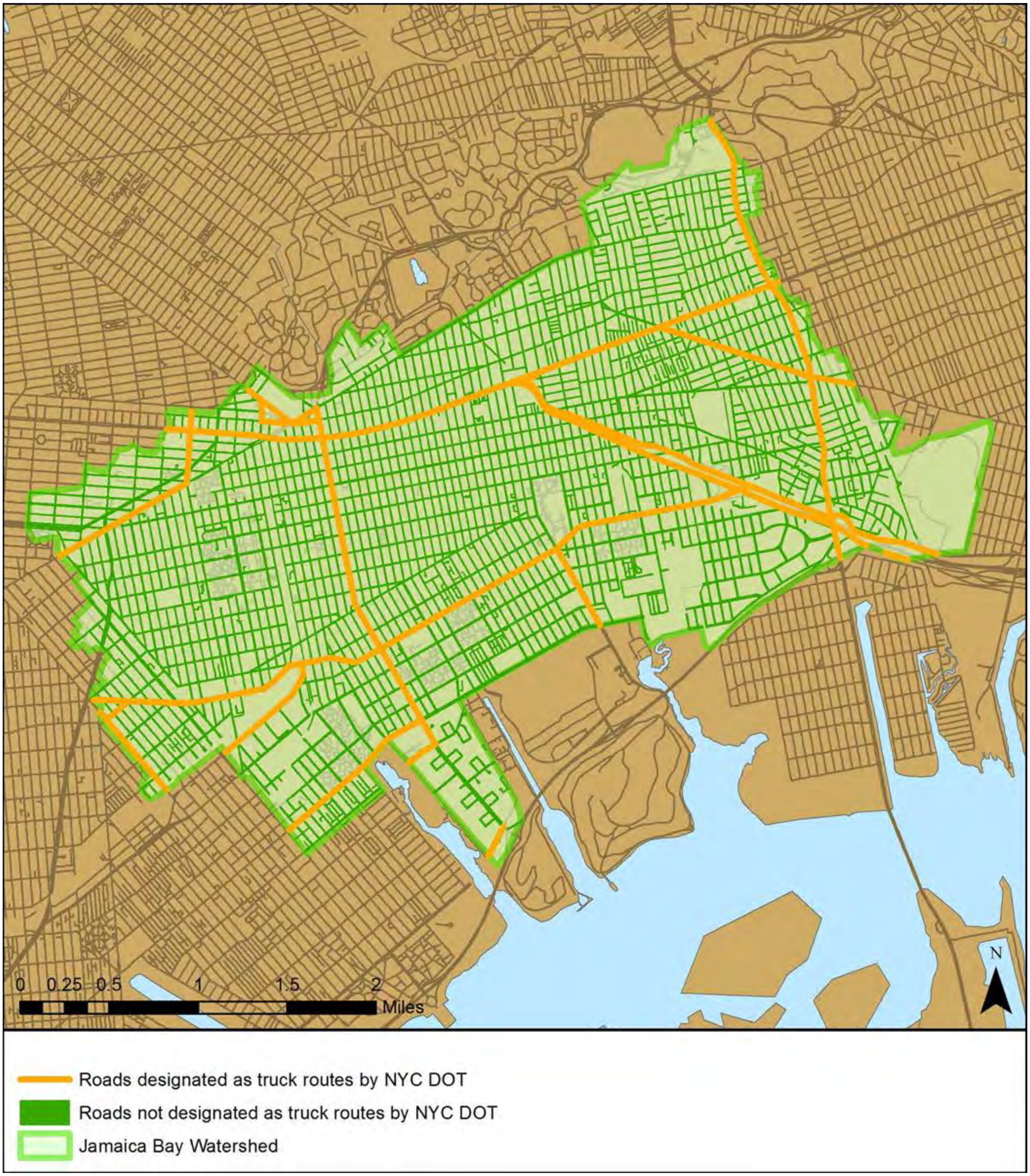


Figure 4.44: Jamaica Bay Watershed Transport Network Criteria: Bus Routes

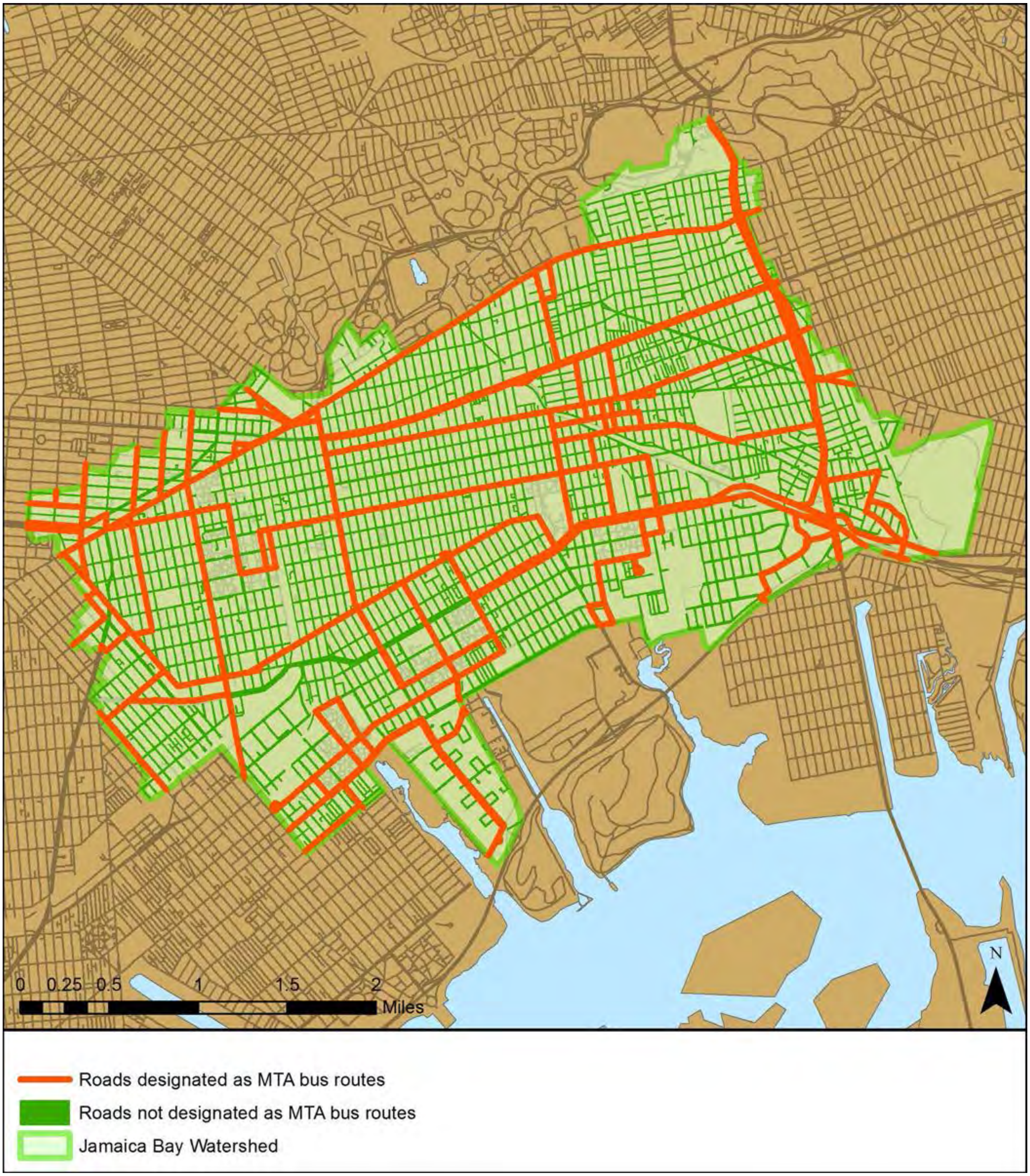


Figure 4.45: Jamaica Bay Watershed Transport Network Criteria: Subway Lines

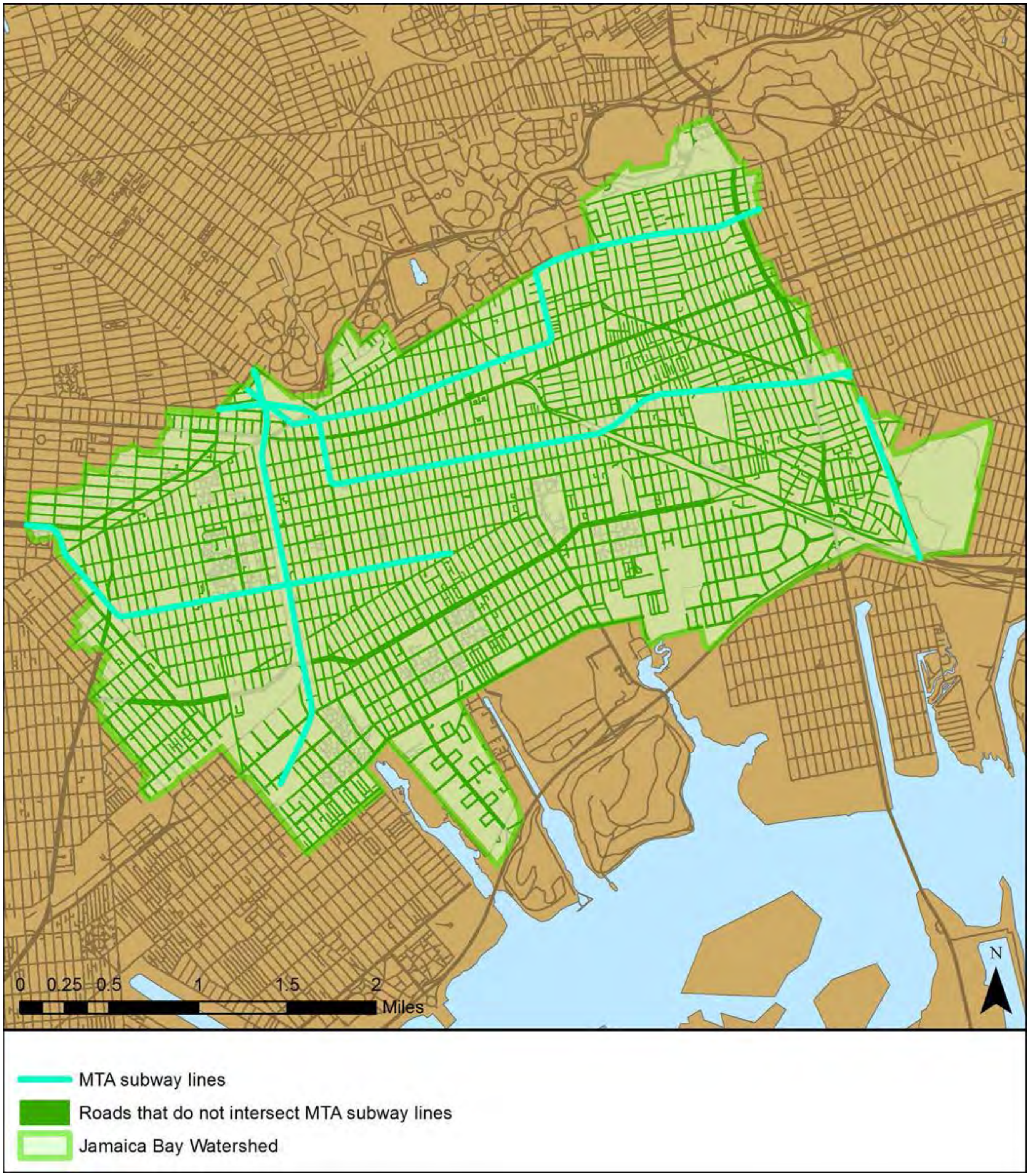


Figure 4.46: Jamaica Bay Watershed Transport Network Criteria: Railroad Lines

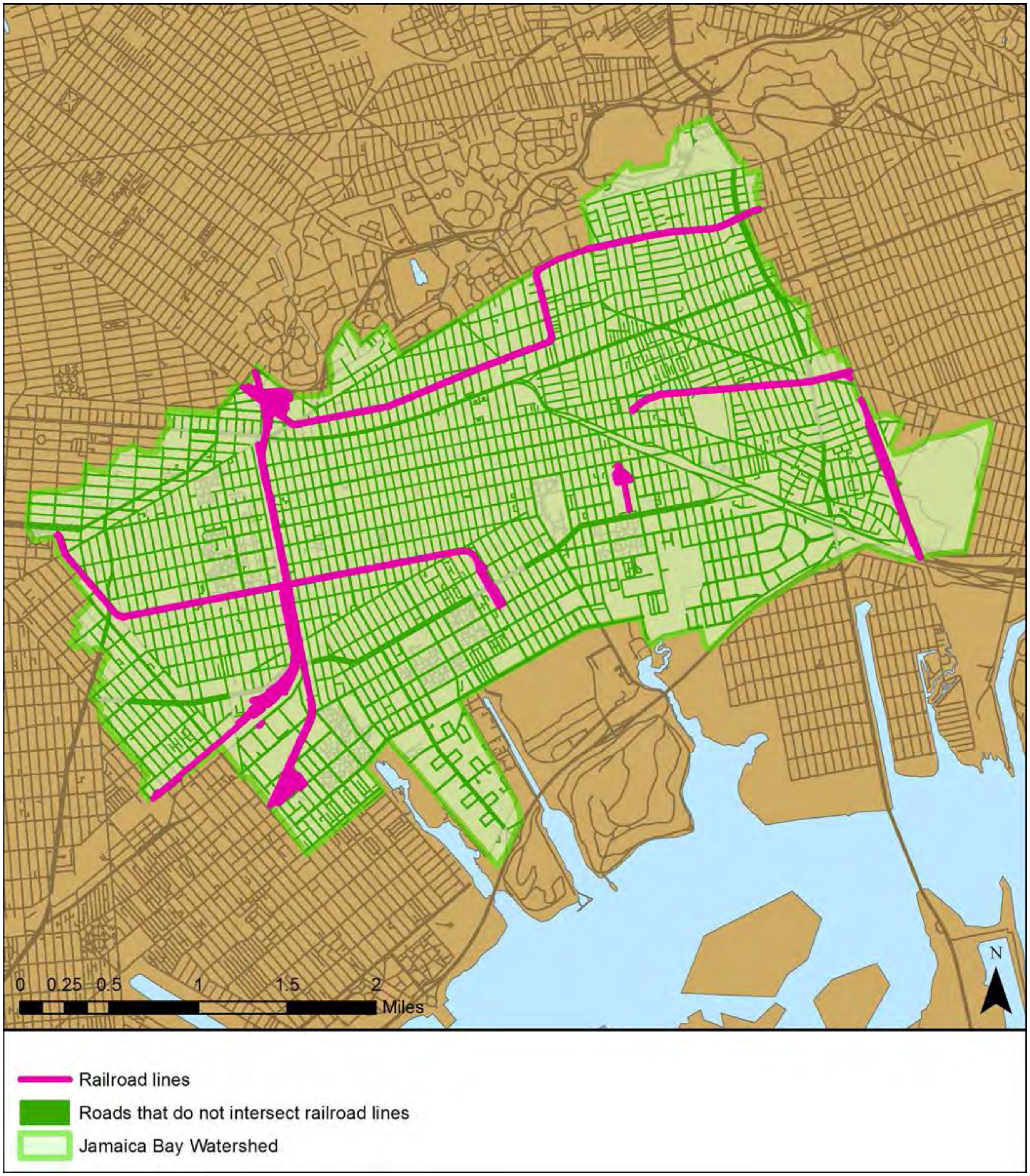


Figure 4.47: Jamaica Bay Watershed Transport Network Criteria: Combined Criteria

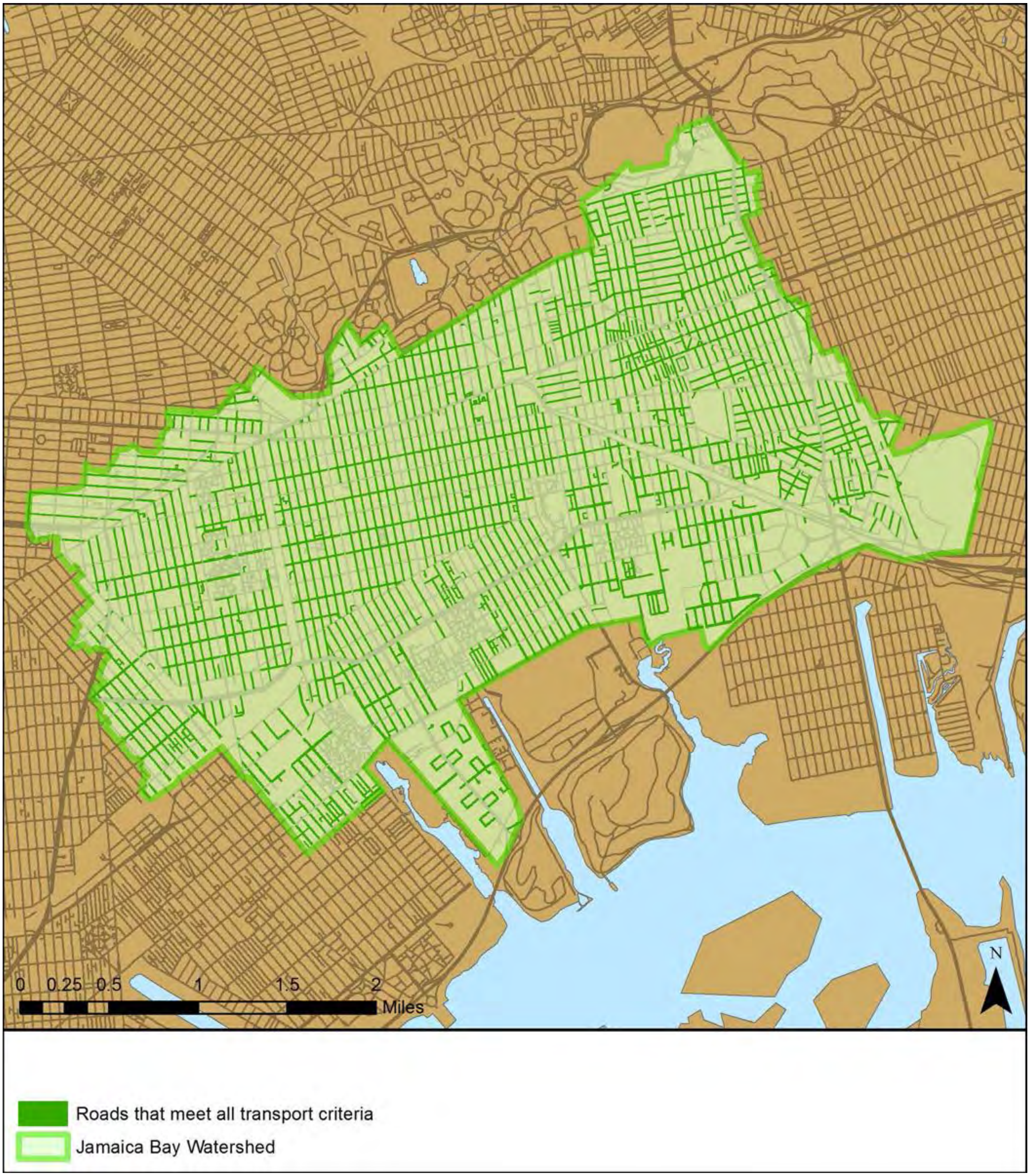


Figure 4.48: Jamaica Bay Watershed Geotechnical Criteria: Slope

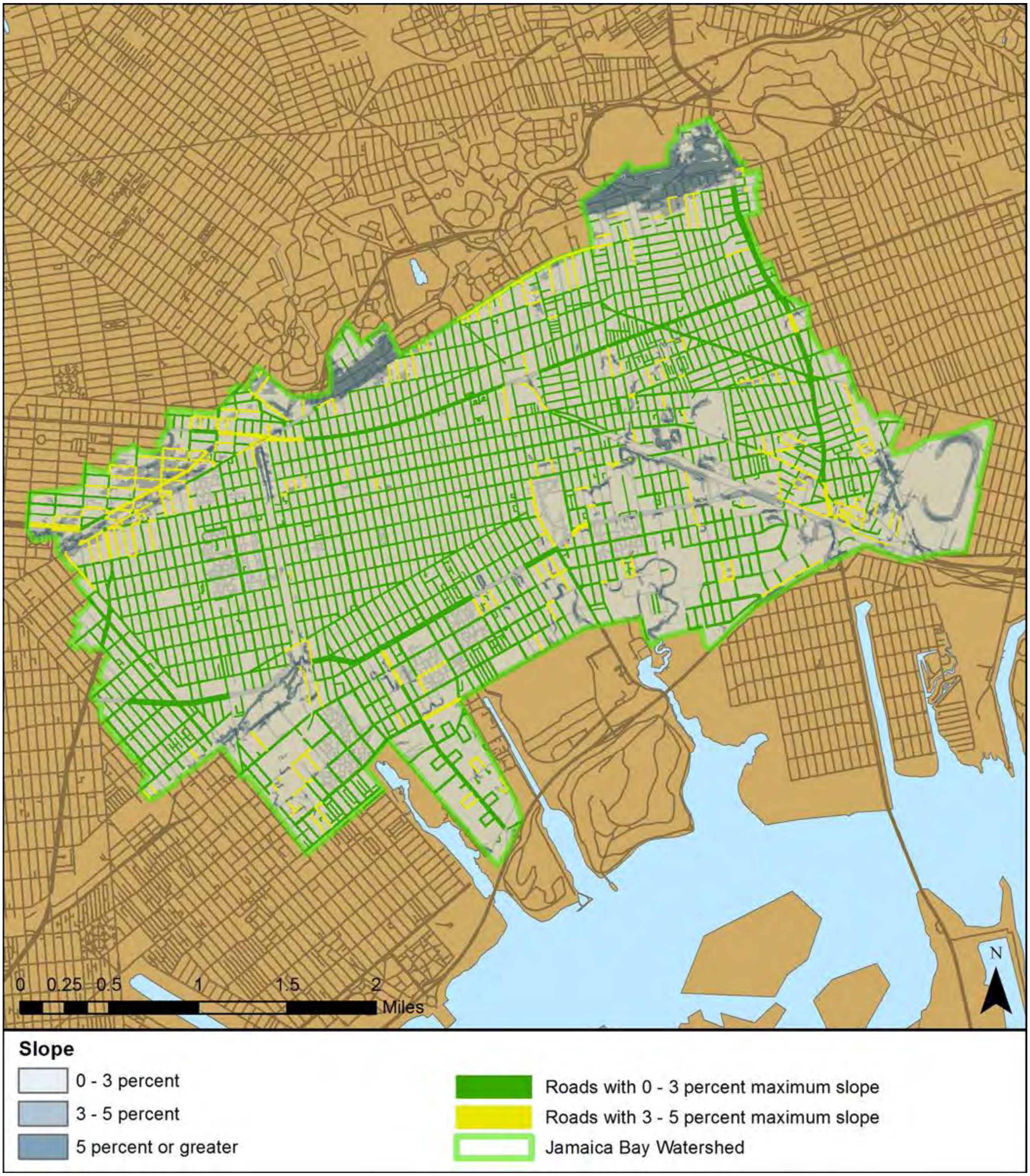


Figure 4.49: Jamaica Bay Watershed Geotechnical Criteria: Depth to Bedrock

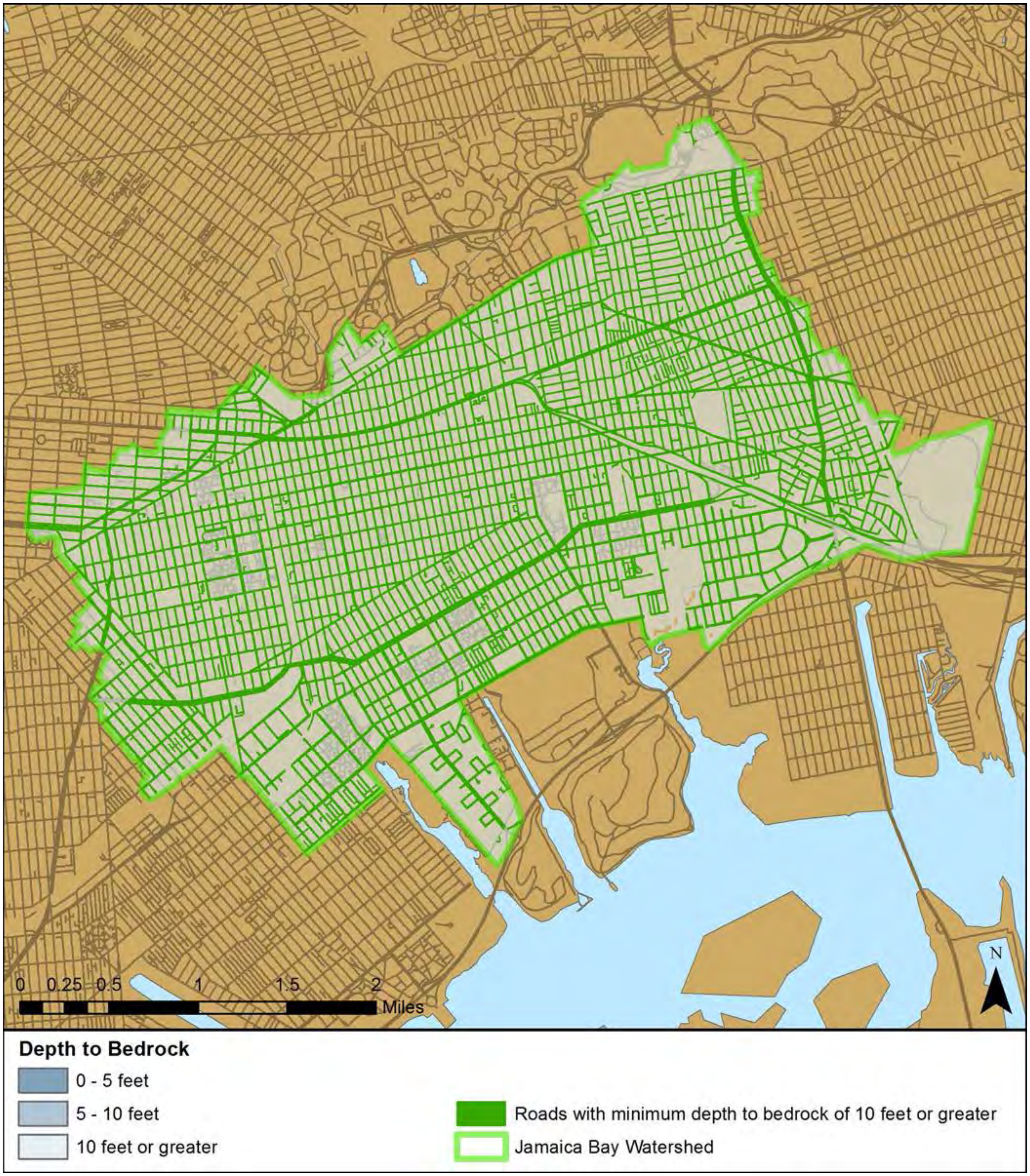


Figure 4.50: Jamaica Bay Watershed Geotechnical Criteria: Depth to Watertable

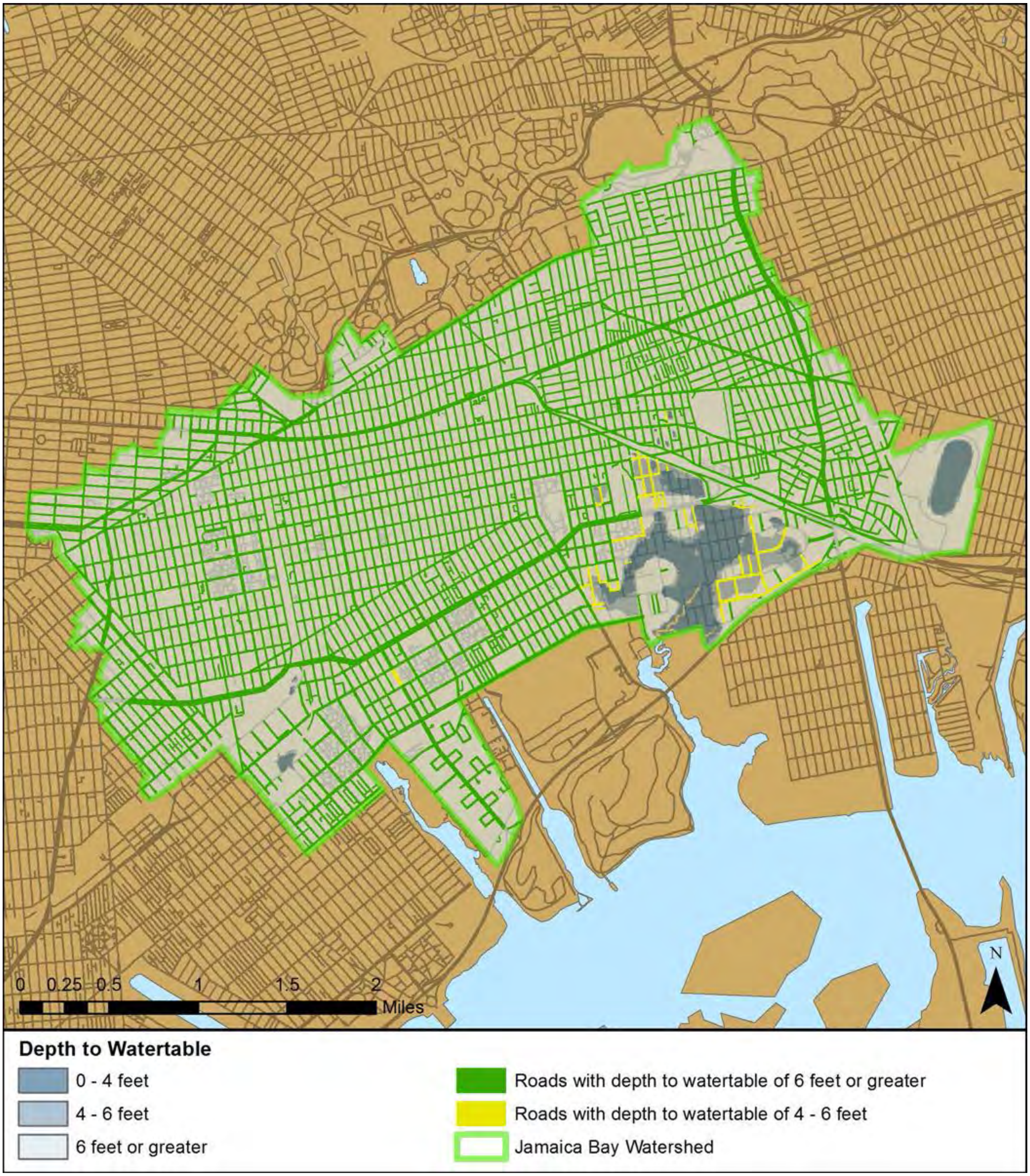


Figure 4.51: Jamaica Bay Watershed Geotechnical Criteria: Soil Permeability

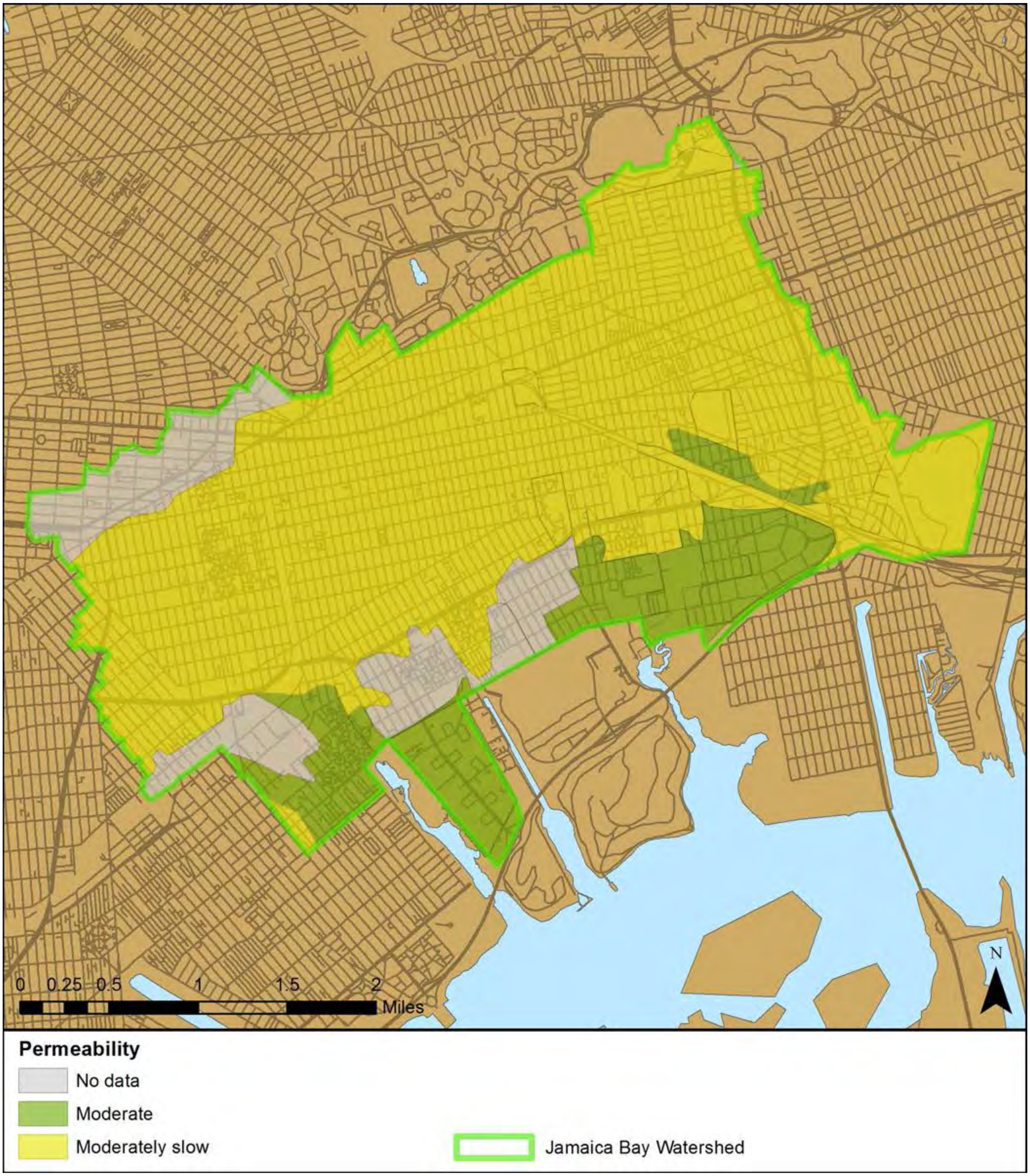


Figure 4.52: Jamaica Bay Watershed Geotechnical Criteria: Hydrologic Soil Group

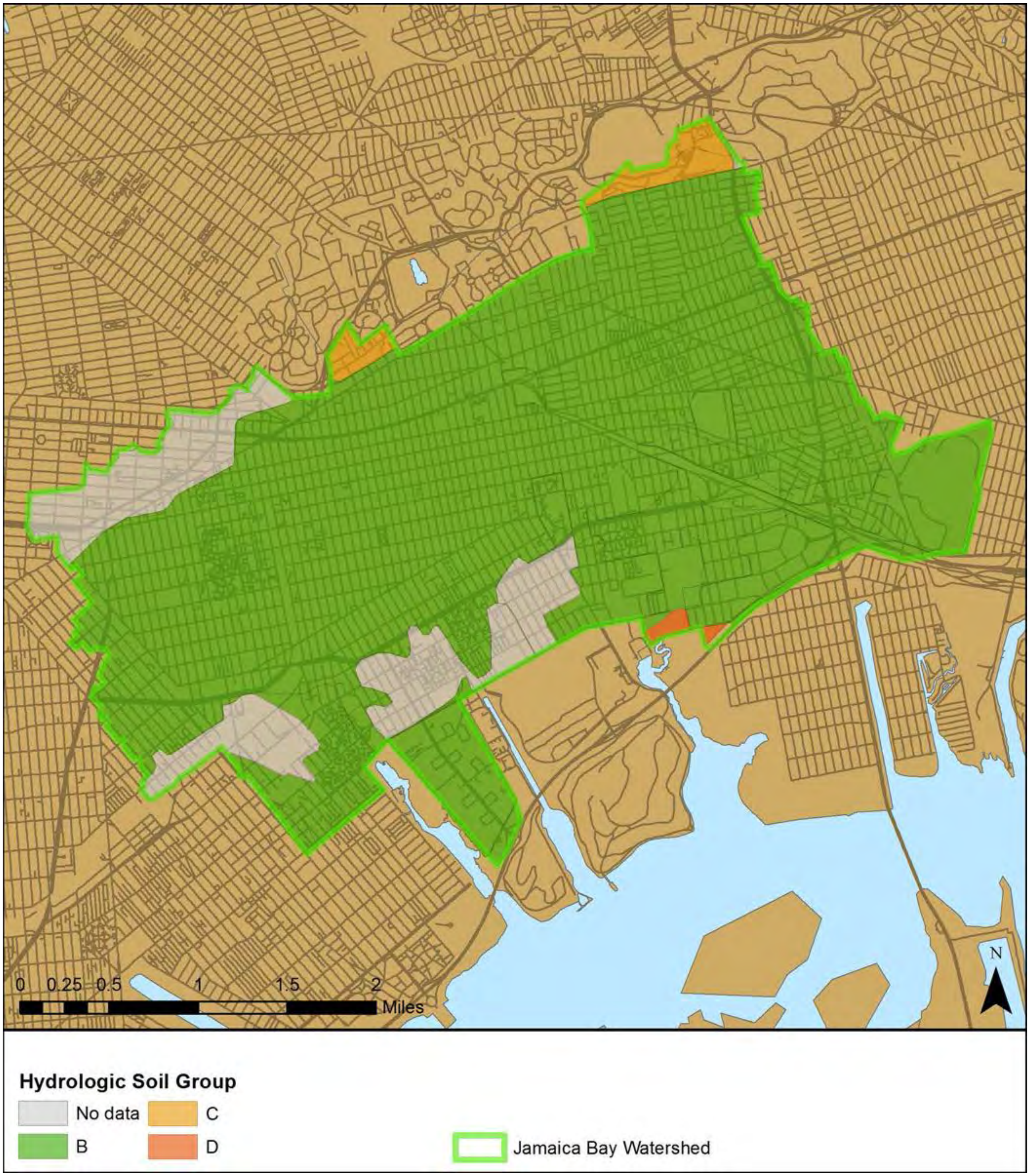


Figure 4.53: Jamaica Bay Watershed Geotechnical Criteria: Combined Criteria Excluding Soils

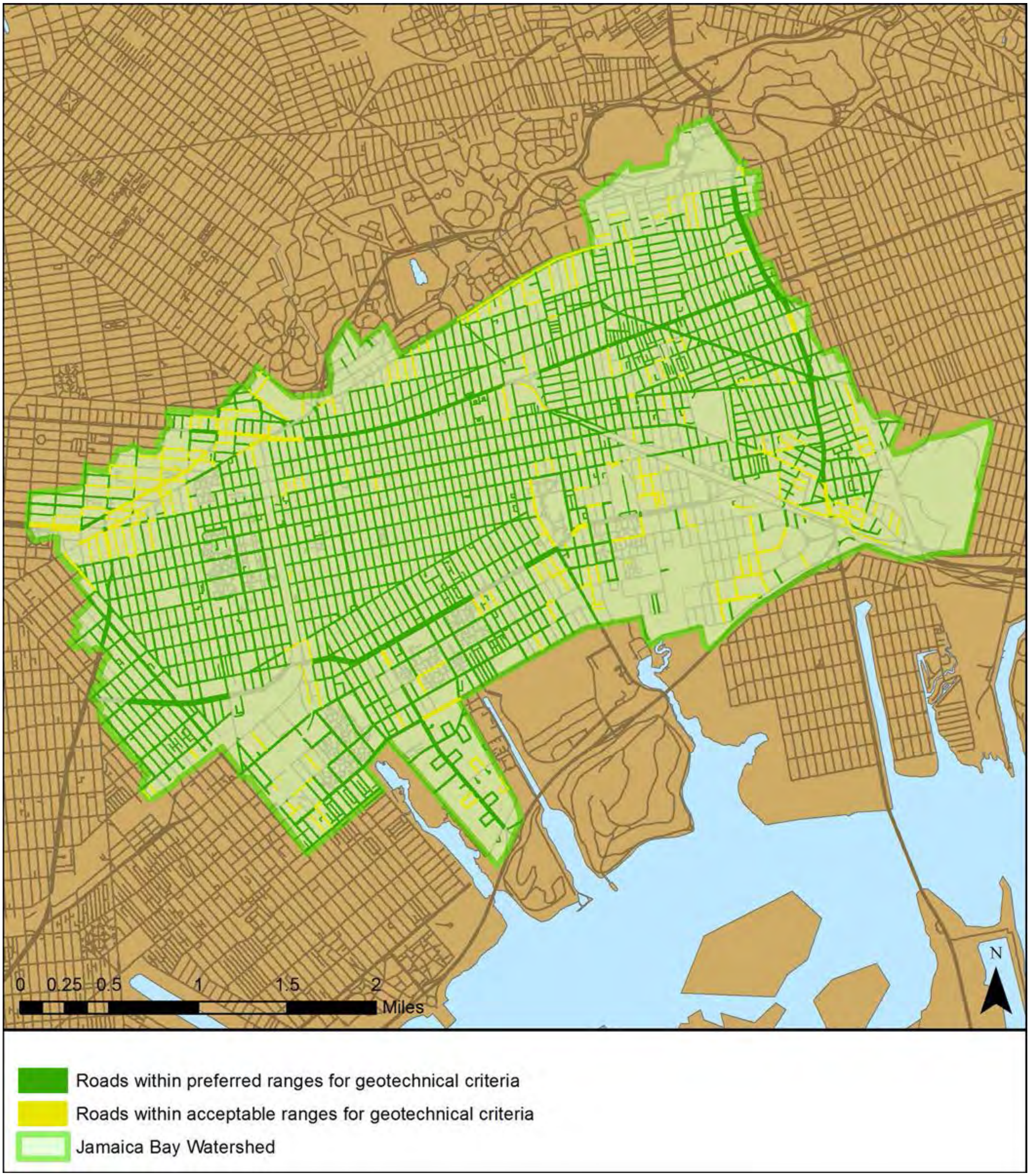


Figure 4.54: Jamaica Bay Watershed Built Environment Criteria: Residential Zoning Districts with Building Setbacks of 10′ or Greater

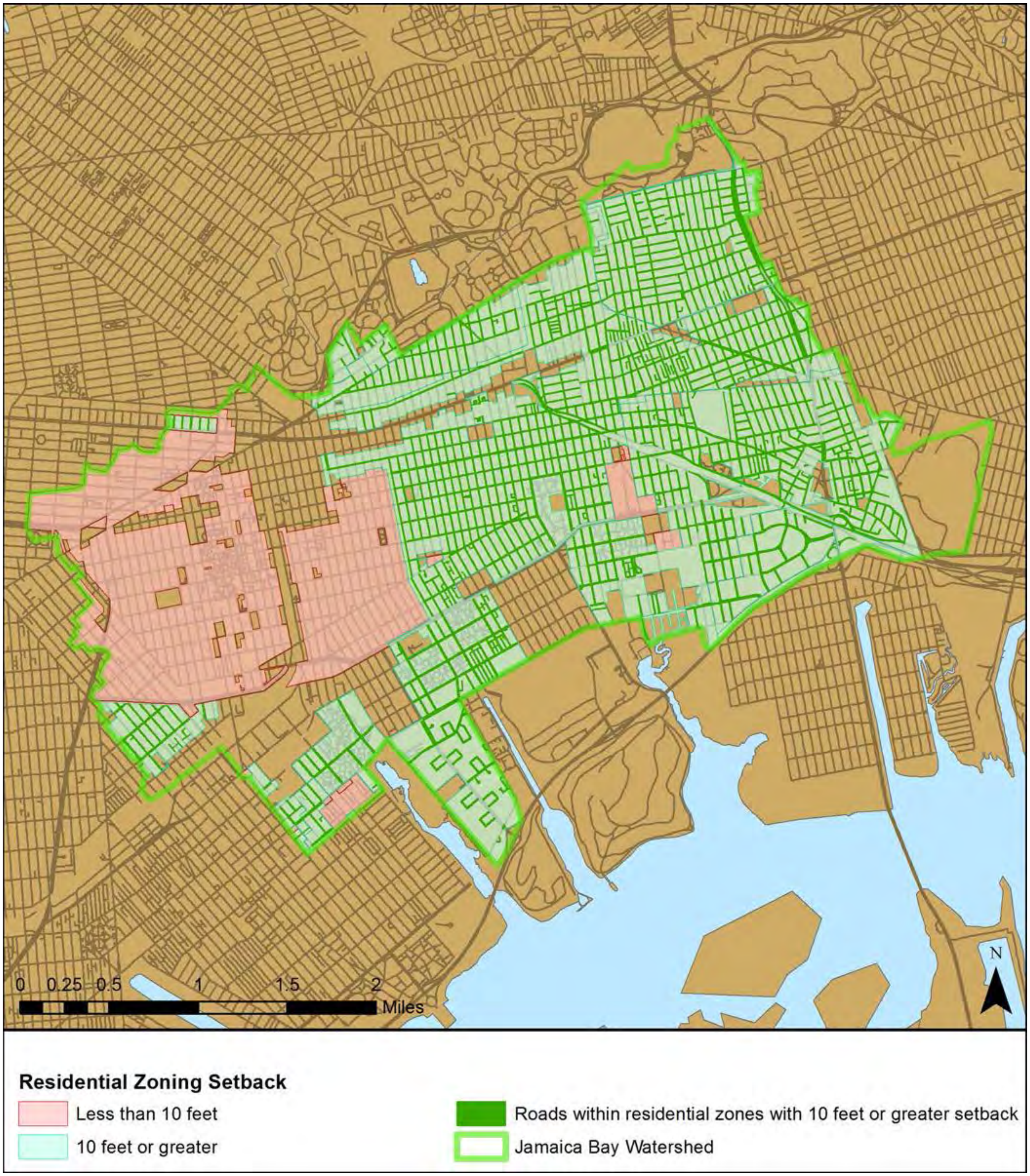


Figure 4.55: Jamaica Bay Watershed Built Environment Criteria: Commercial Overlay Districts

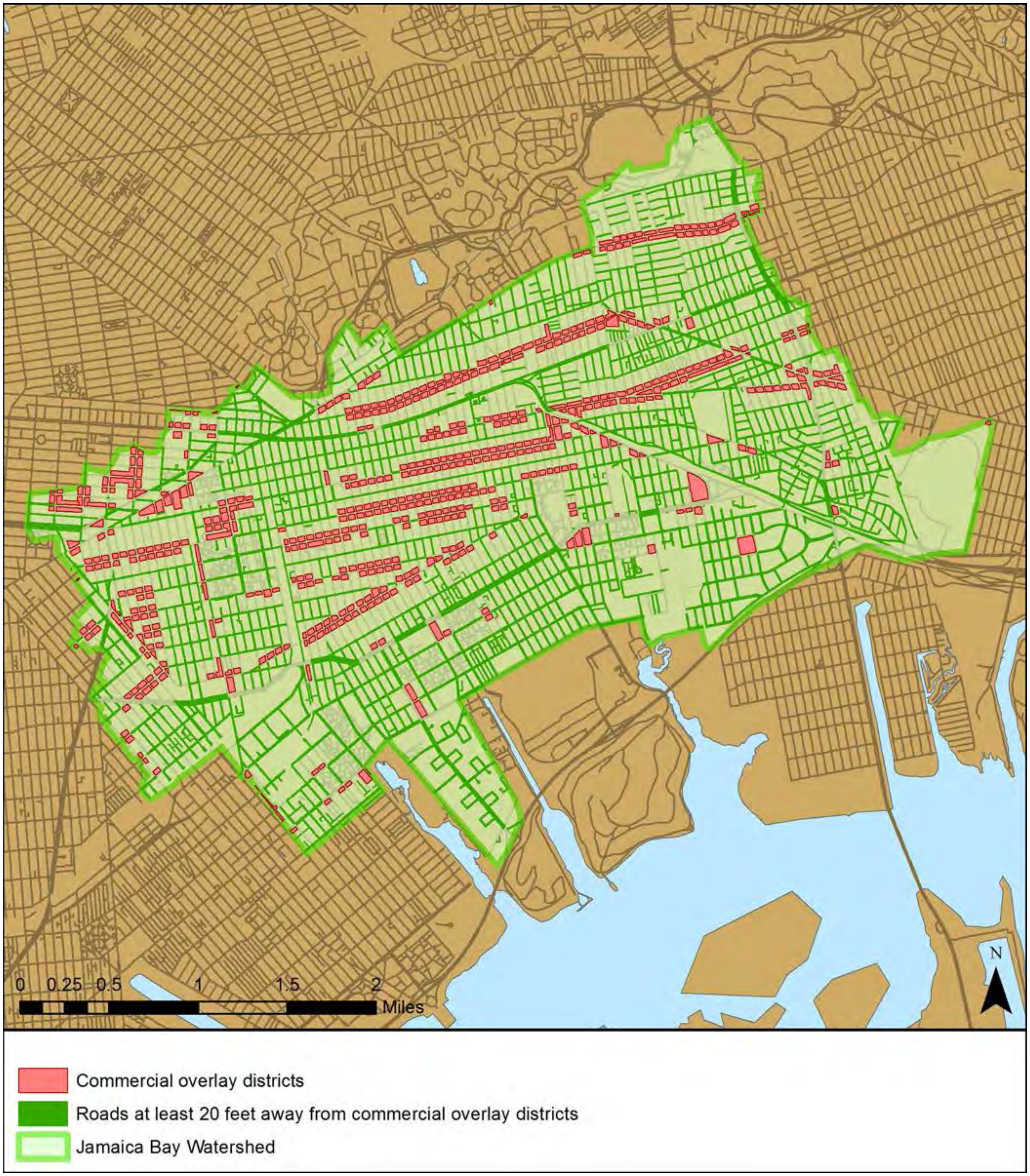


Figure 4.56: Jamaica Bay Watershed Built Environment Criteria: Street Tree Density

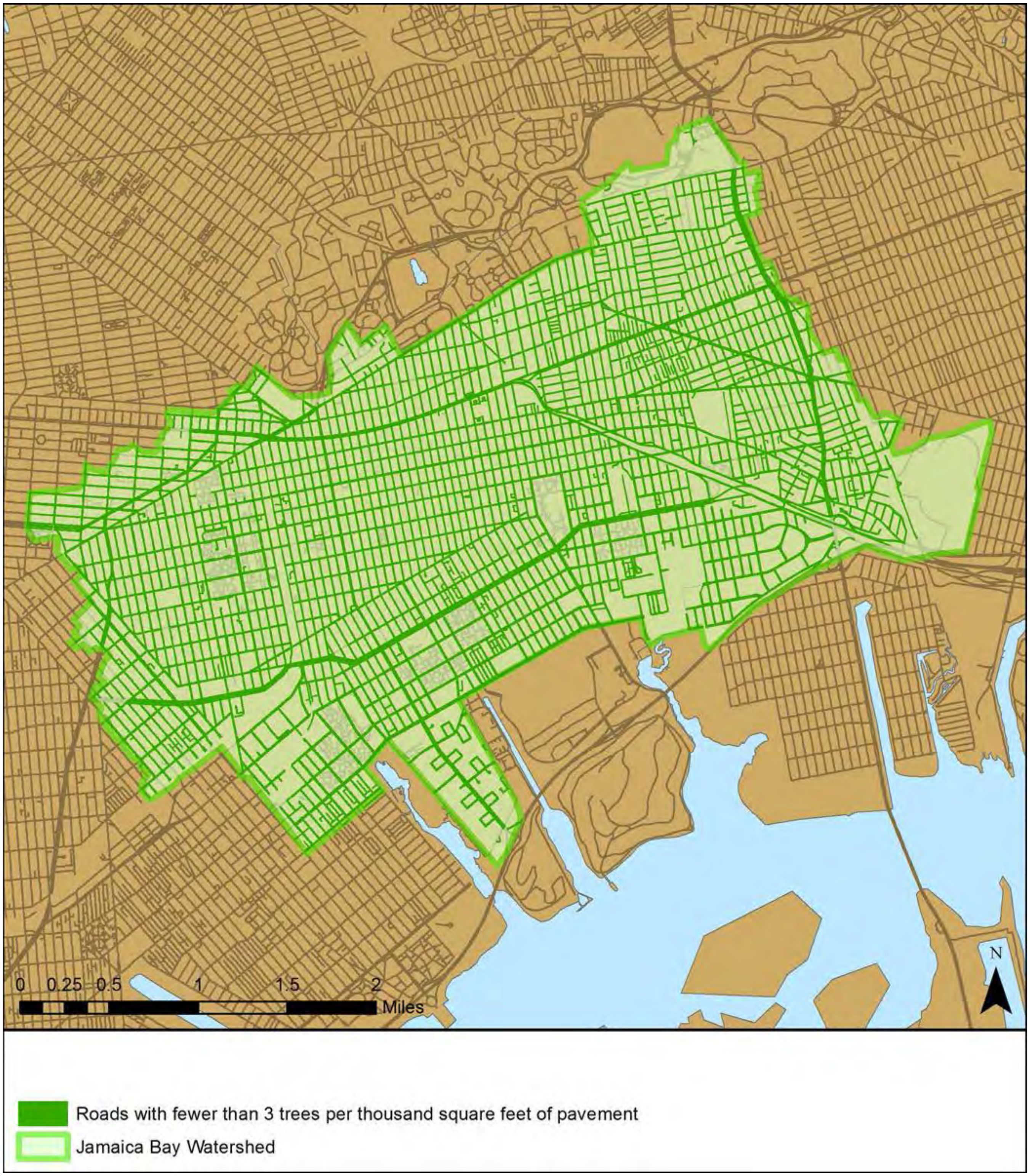


Figure 4.57: Jamaica Bay Watershed Built Environment Criteria: Pavement Condition

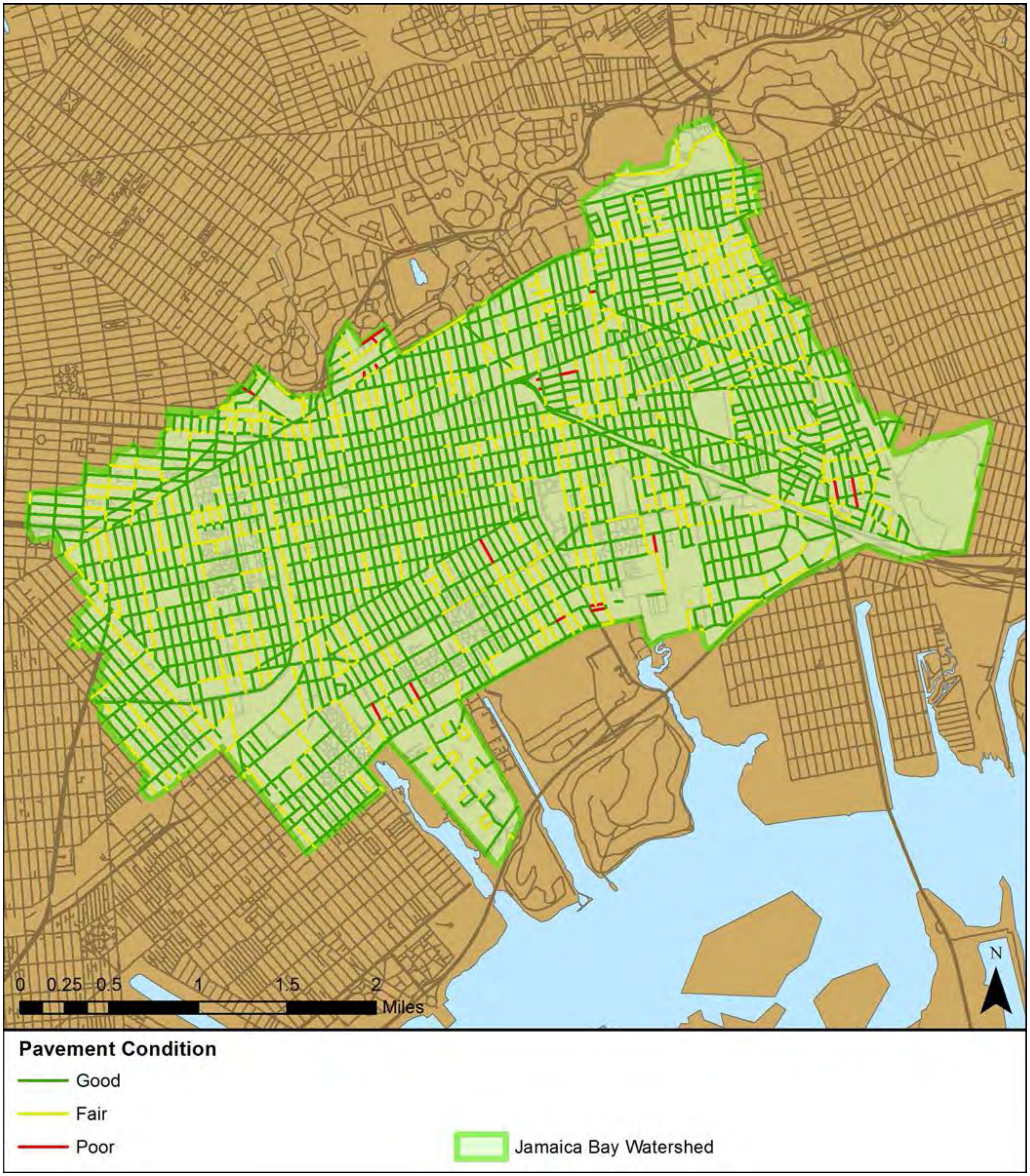


Figure 4.58: Jamaica Bay Watershed Built Environment Criteria: Combined Criteria Excluding Pavement Condition

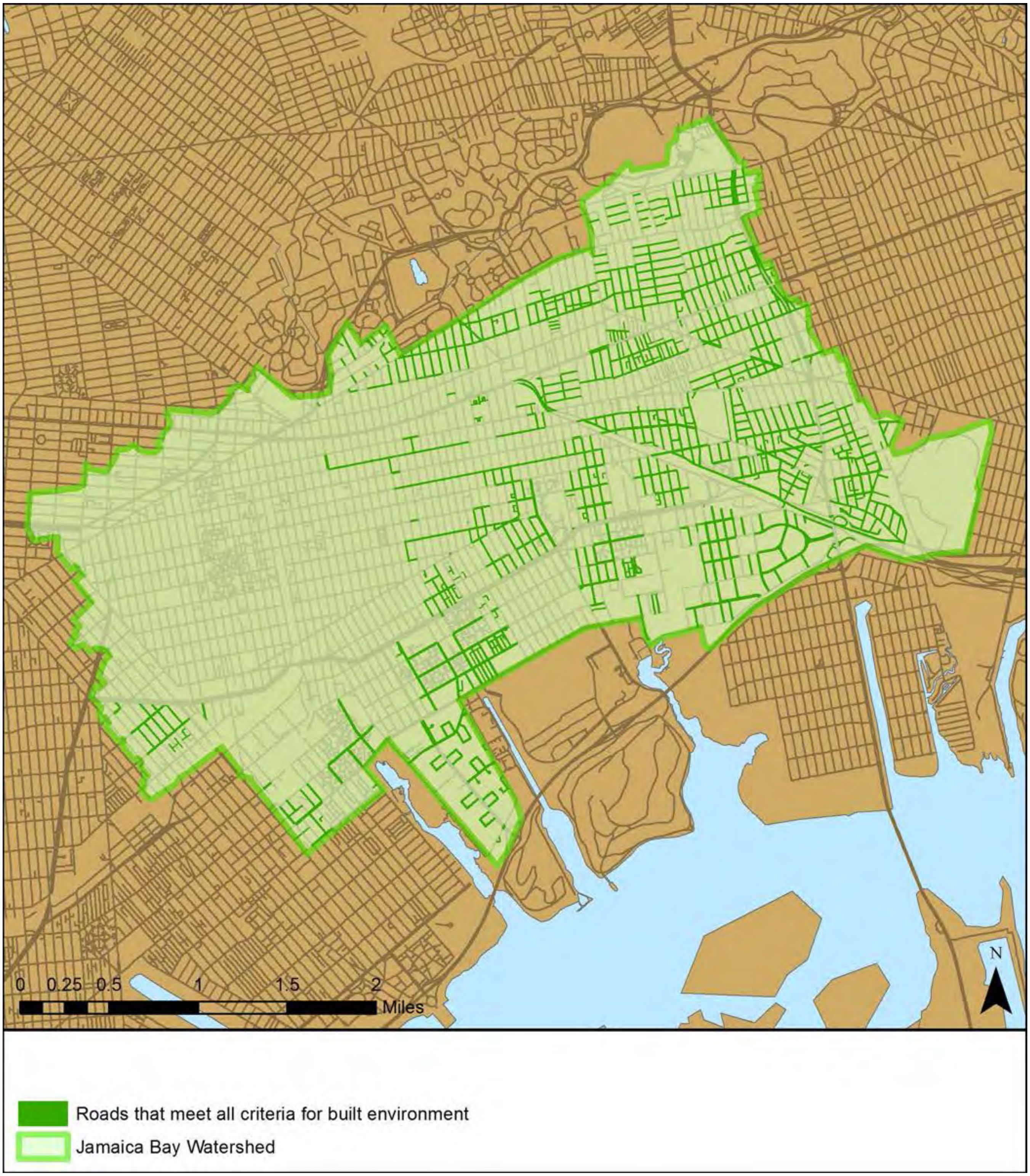


Figure 4.59: Jamaica Bay Watershed Preliminary Pervious Pavement Site Recommendations

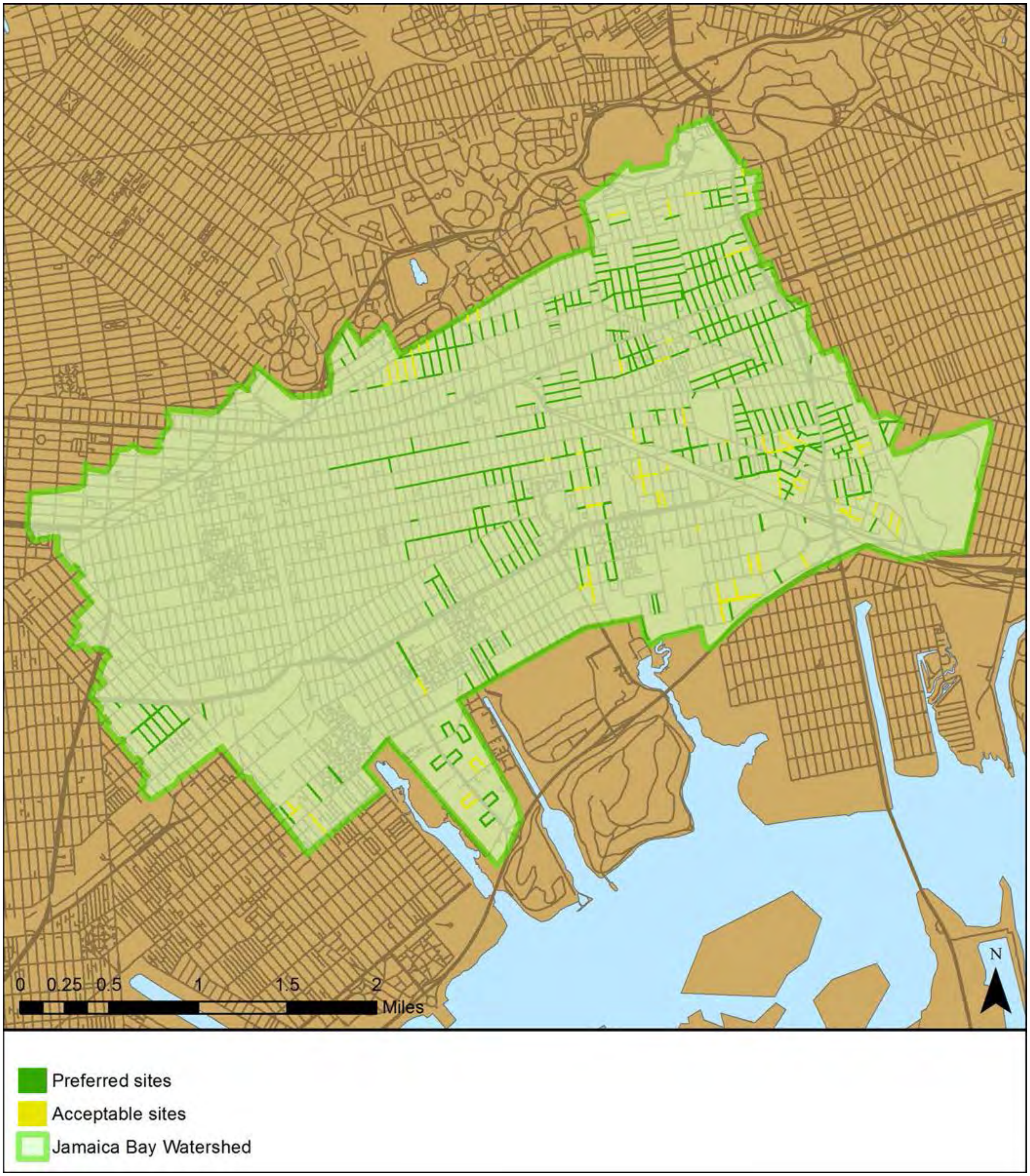


Figure 4.60: Jamaica Bay Watershed Final Pervious Pavement Site Recommendations

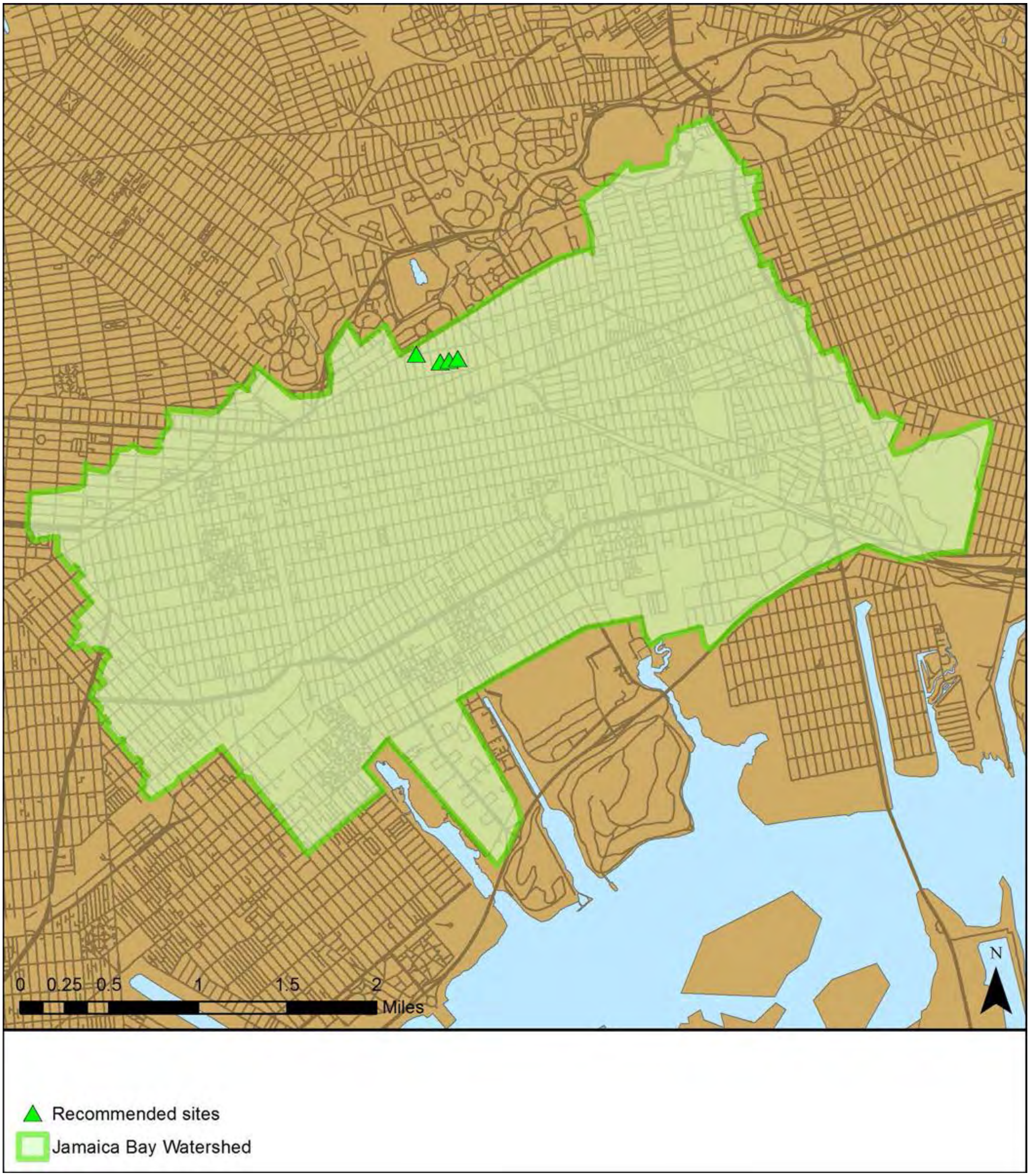


Figure 4.61: Gowanus Canal Watershed Transport Network Criteria: NYC DOT Road Designations

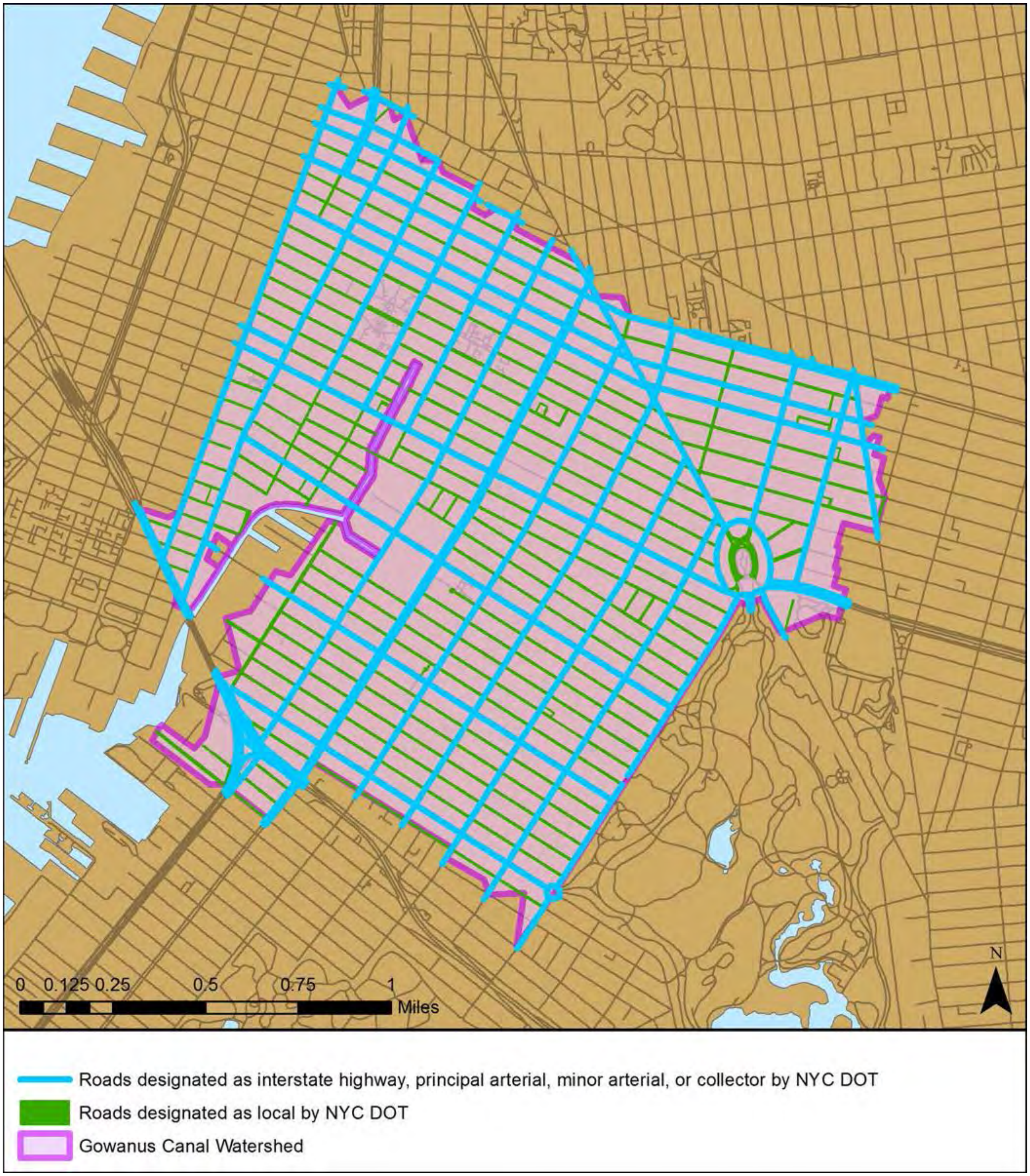


Figure 4.62: Gowanus Canal Watershed Transport Network Criteria: Major Roads

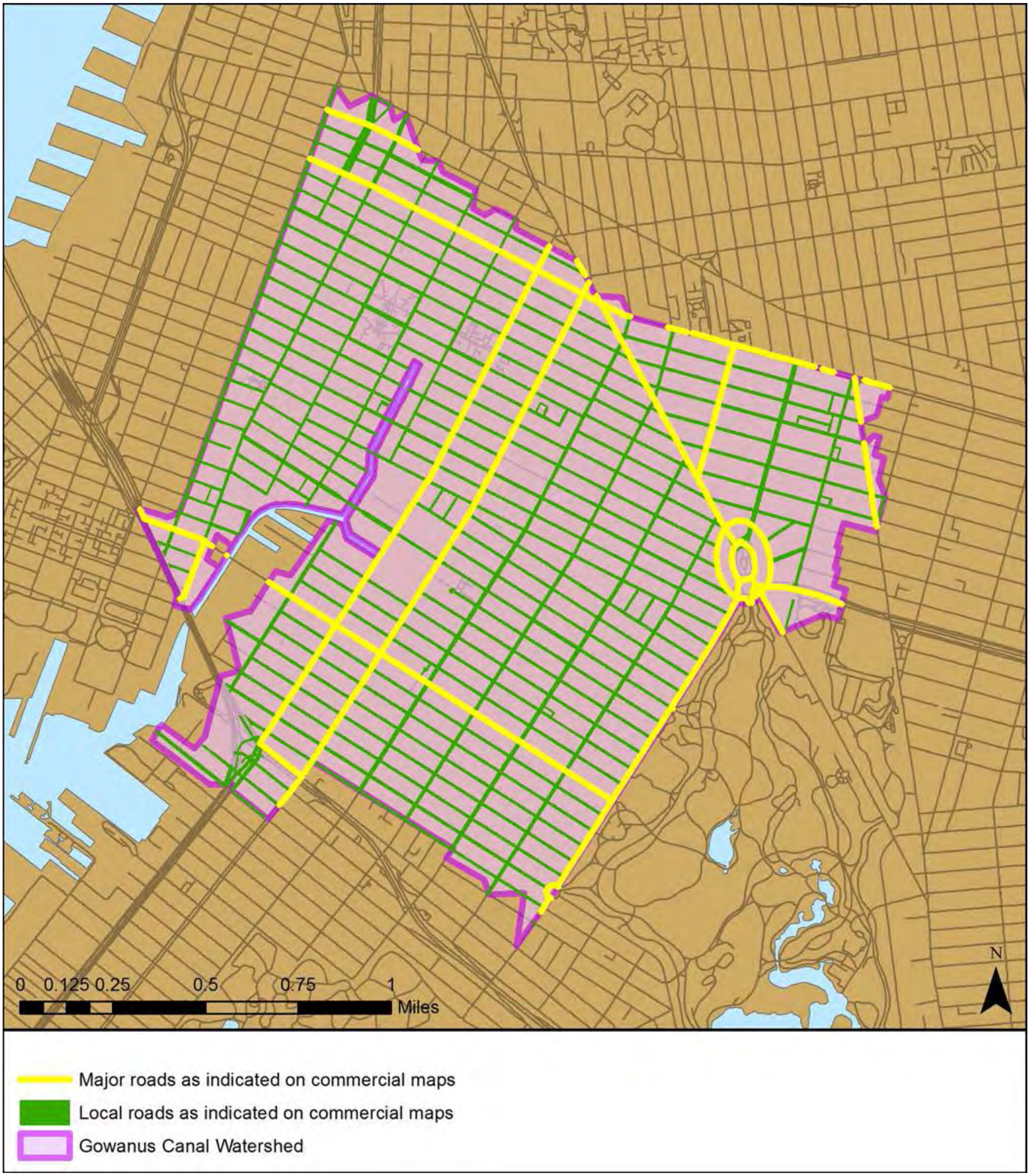


Figure 4.63: Gowanus Canal Watershed Transport Network Criteria: Truck Routes

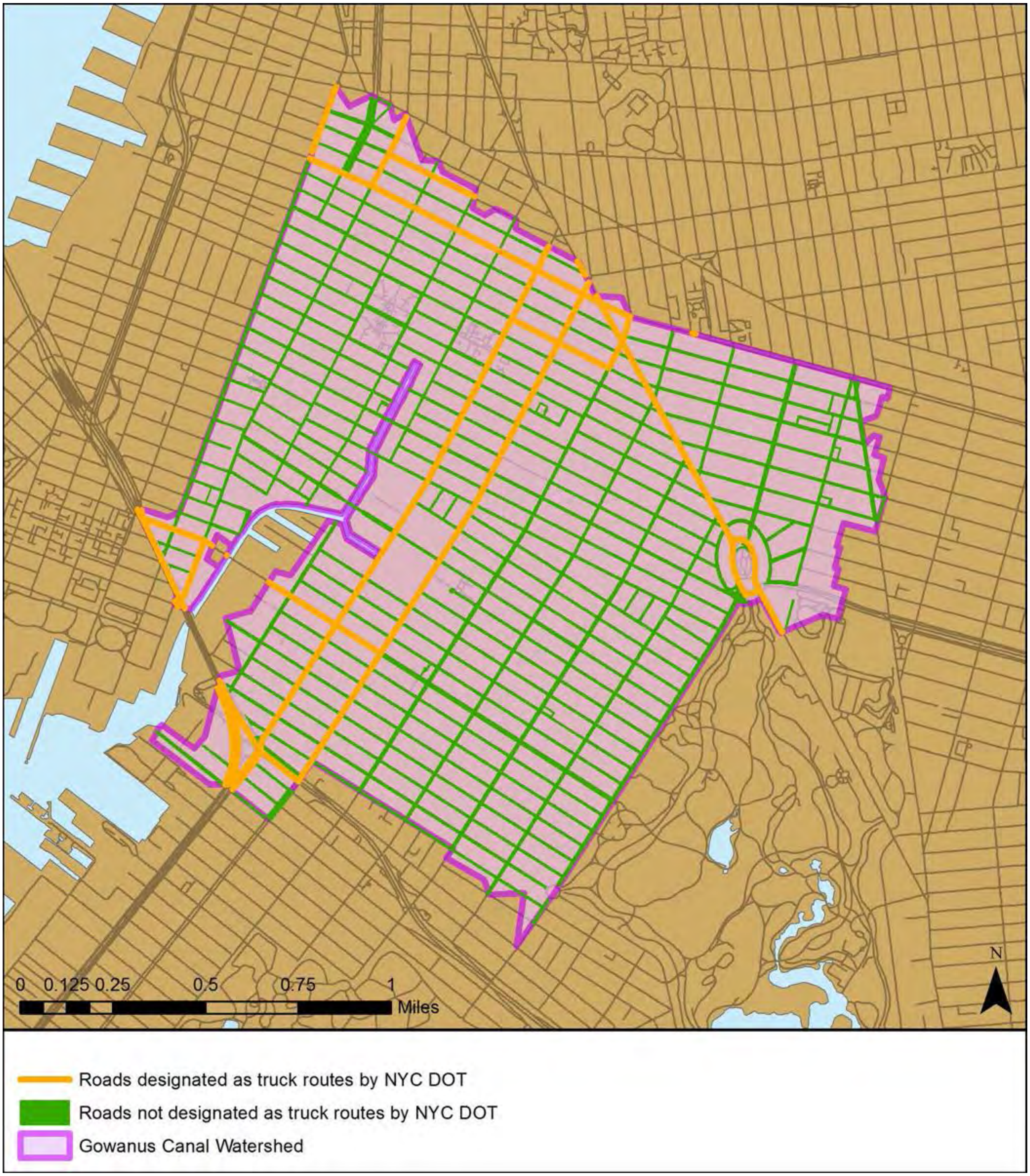


Figure 4.64: Gowanus Canal Watershed Transport Network Criteria: Bus Routes

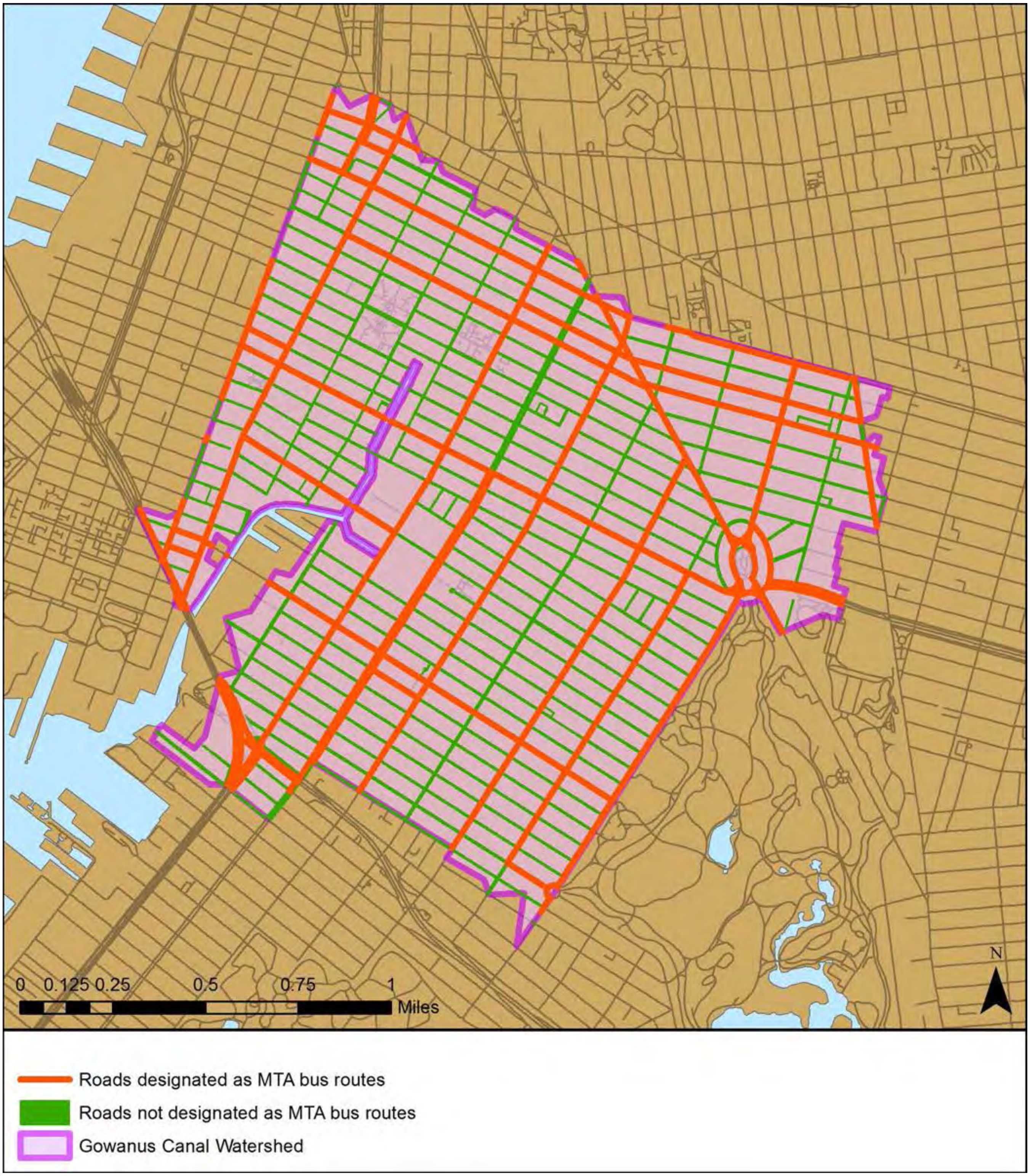


Figure 4.65: Gowanus Canal Watershed Transport Network Criteria: Subway Lines

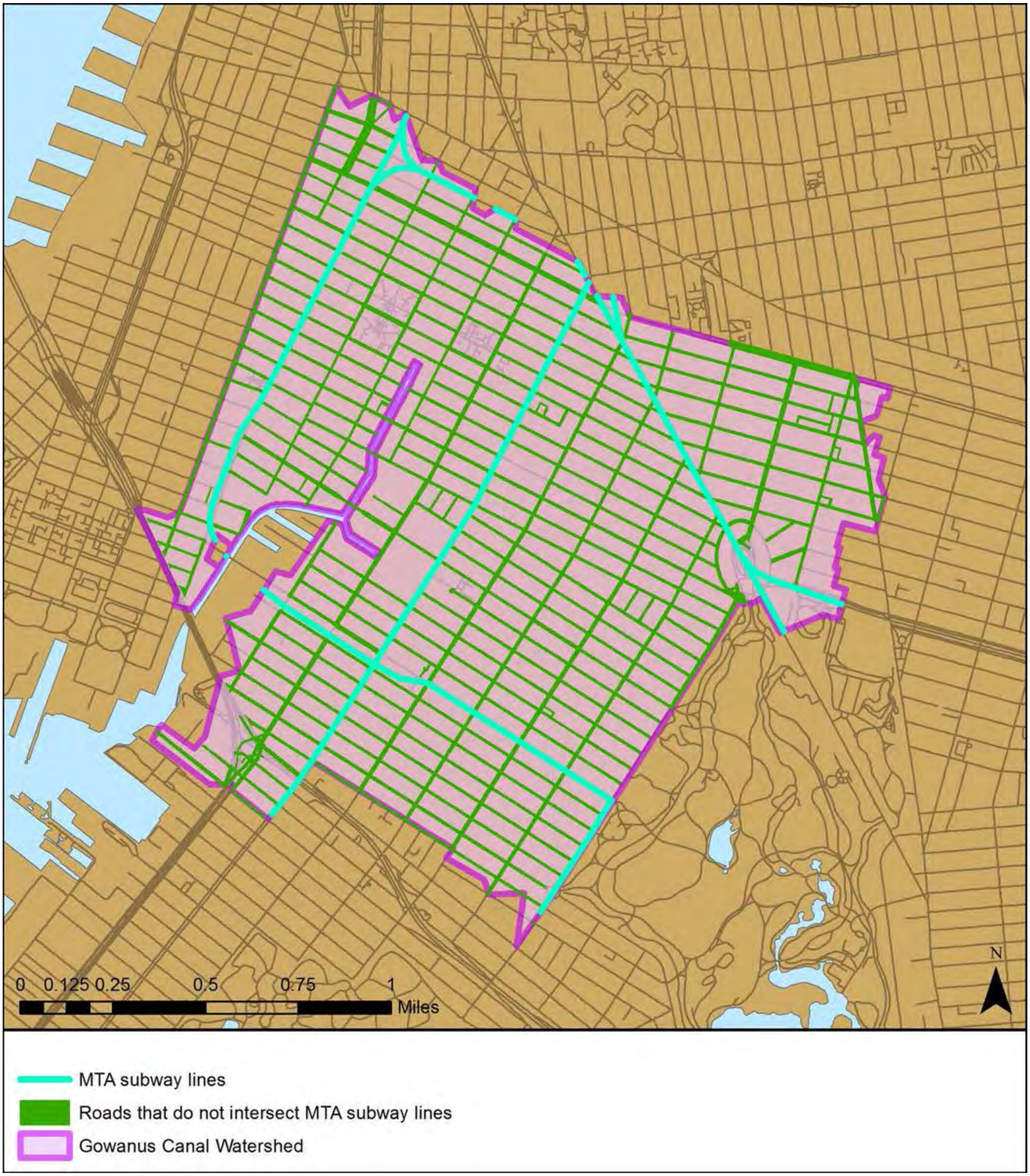


Figure 4.66: Gowanus Canal Watershed Transport Network Criteria: Railroad Lines

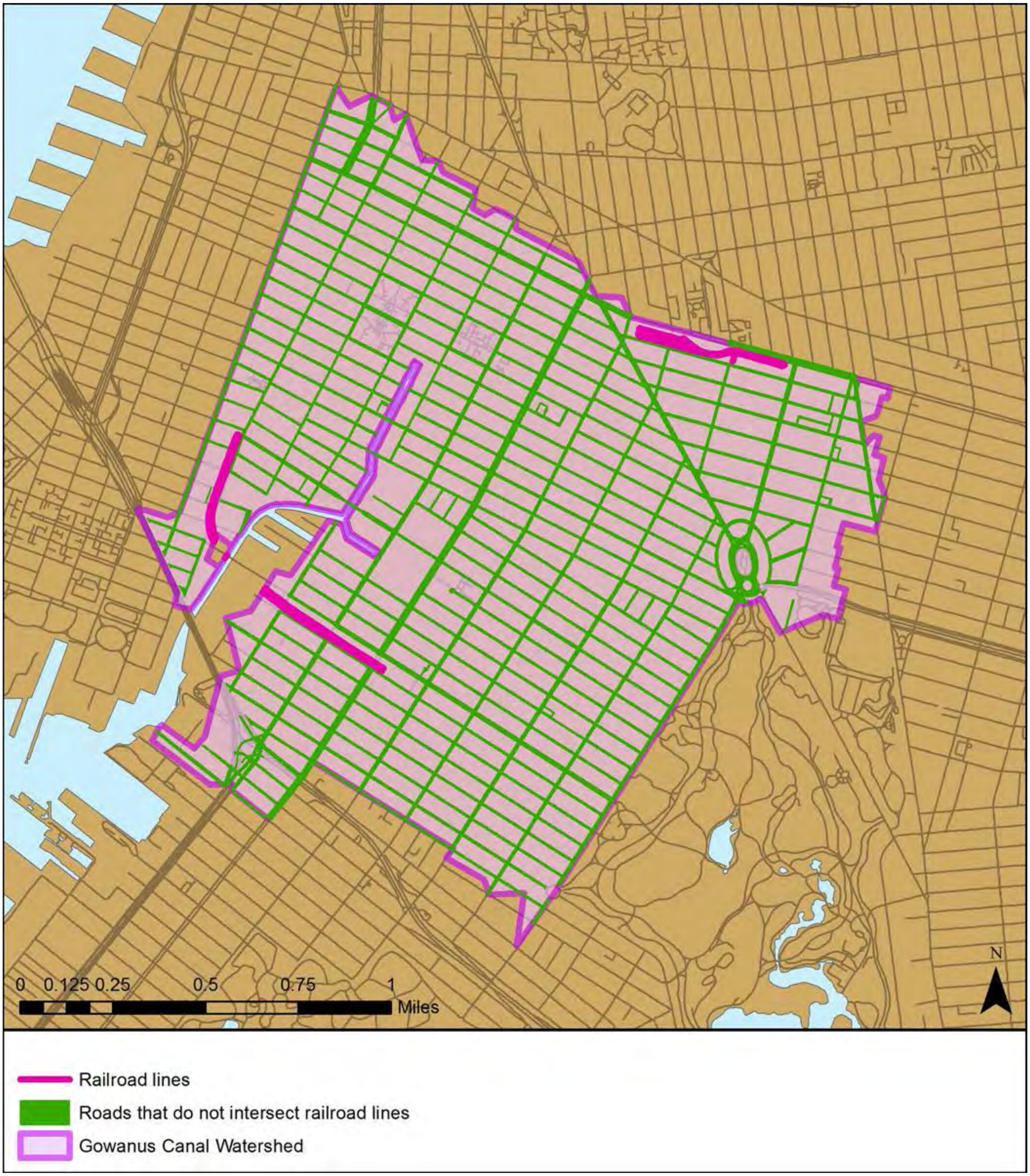


Figure 4.67: Gowanus Canal Watershed Transport Network Criteria: Combined Criteria

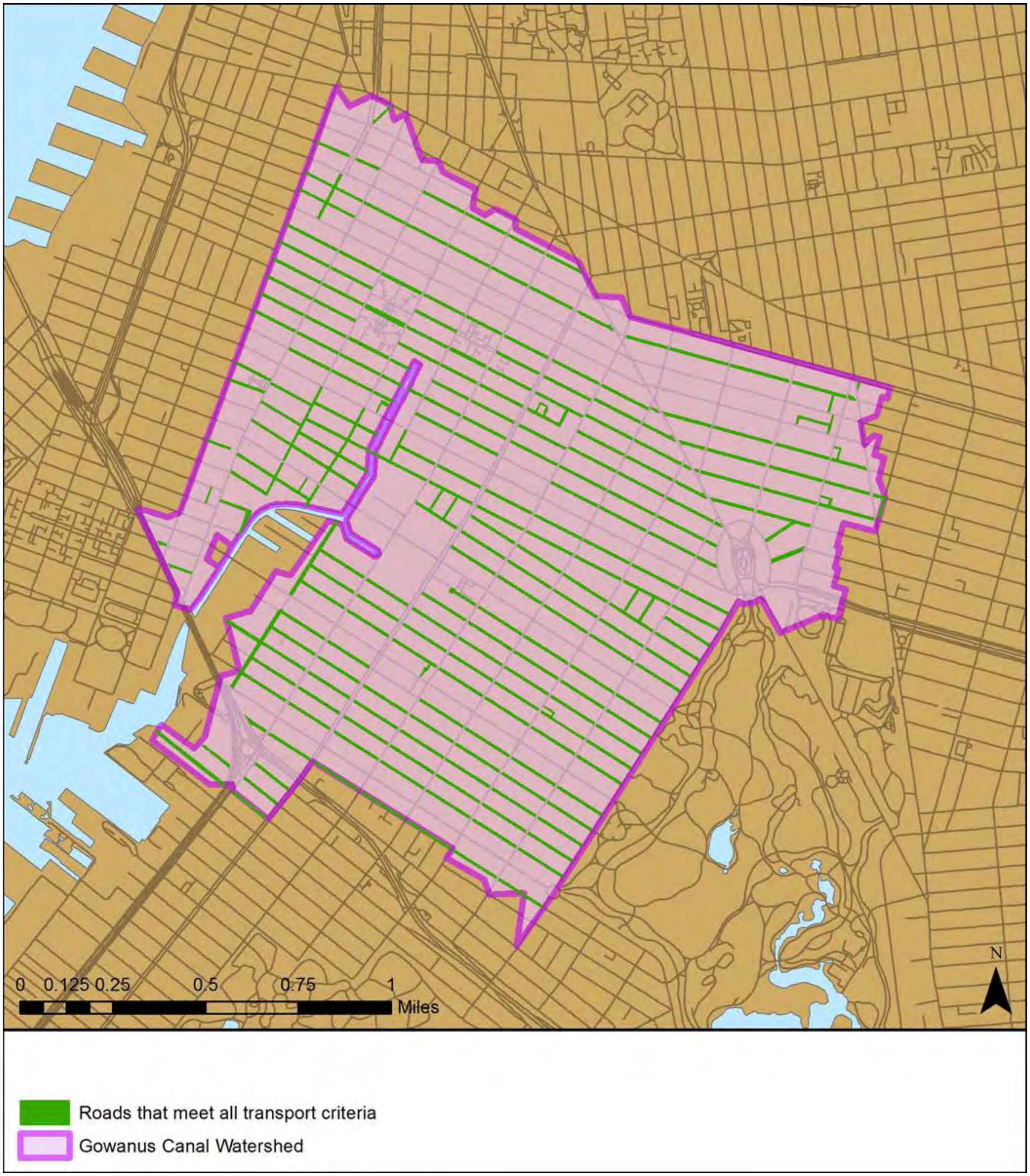


Figure 4.68: Gowanus Canal Watershed Geotechnical Criteria: Slope

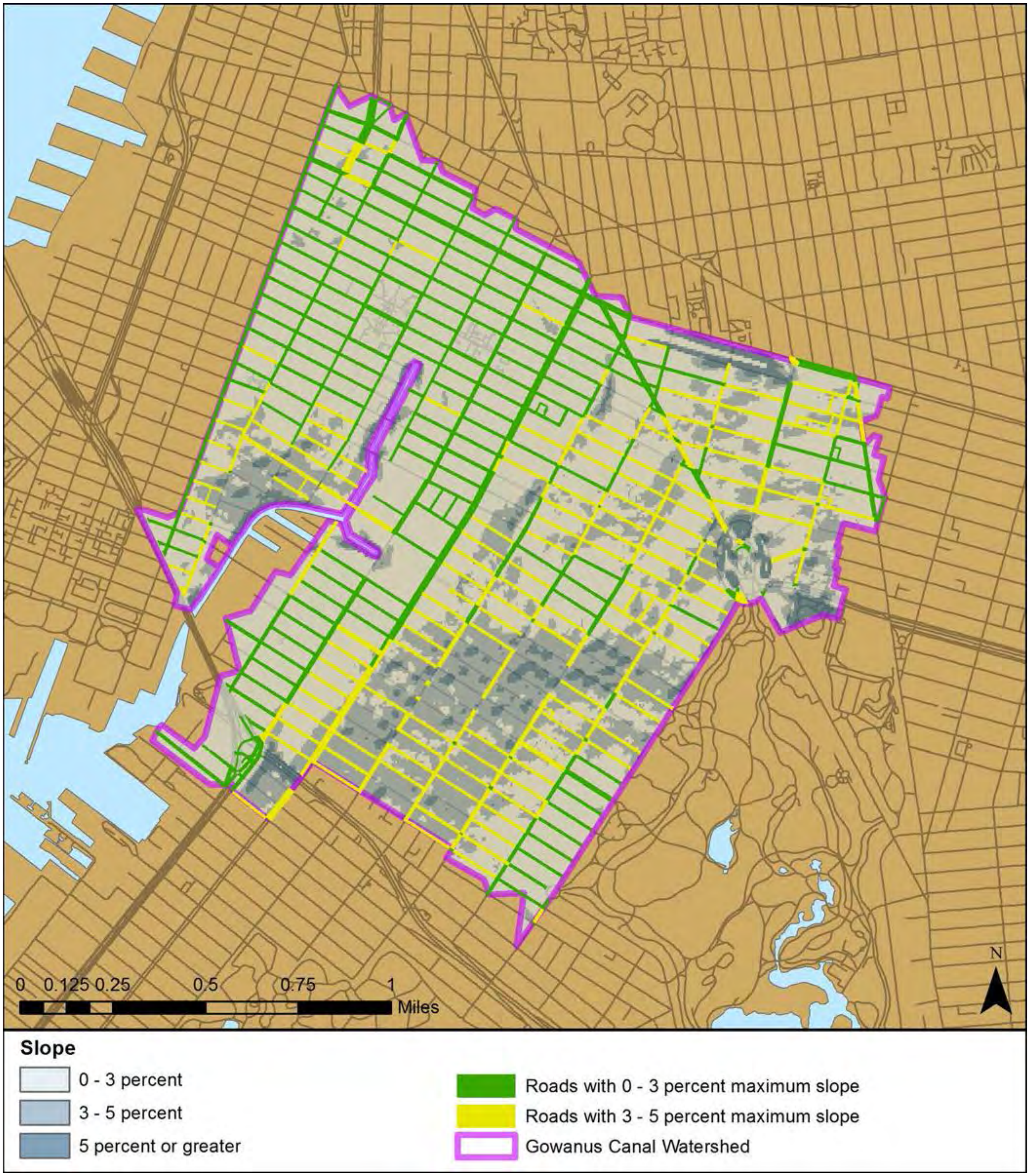


Figure 4.69: Gowanus Canal Watershed Geotechnical Criteria: Depth to Bedrock

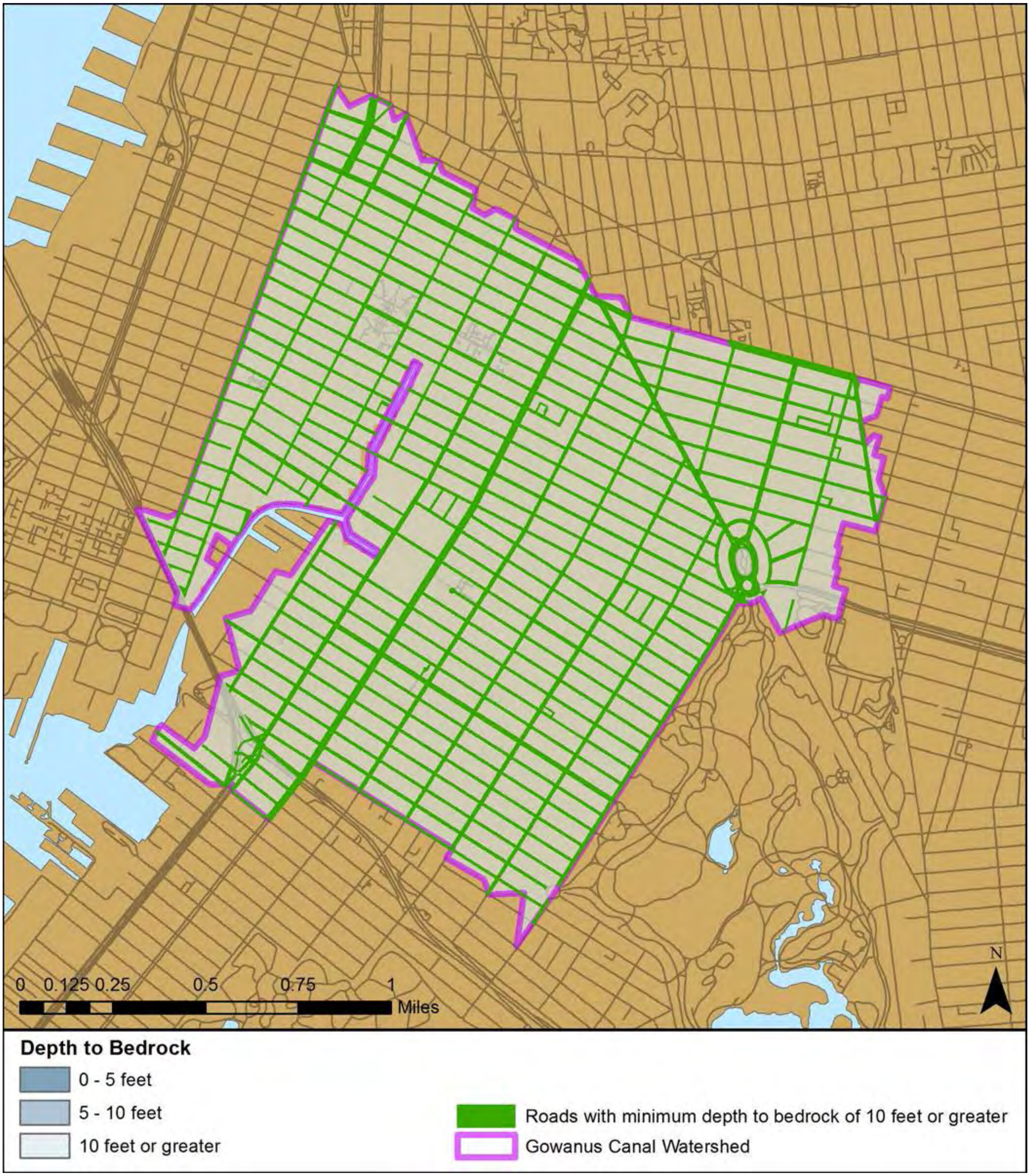


Figure 4.70: Gowanus Canal Watershed Geotechnical Criteria: Depth to Watertable

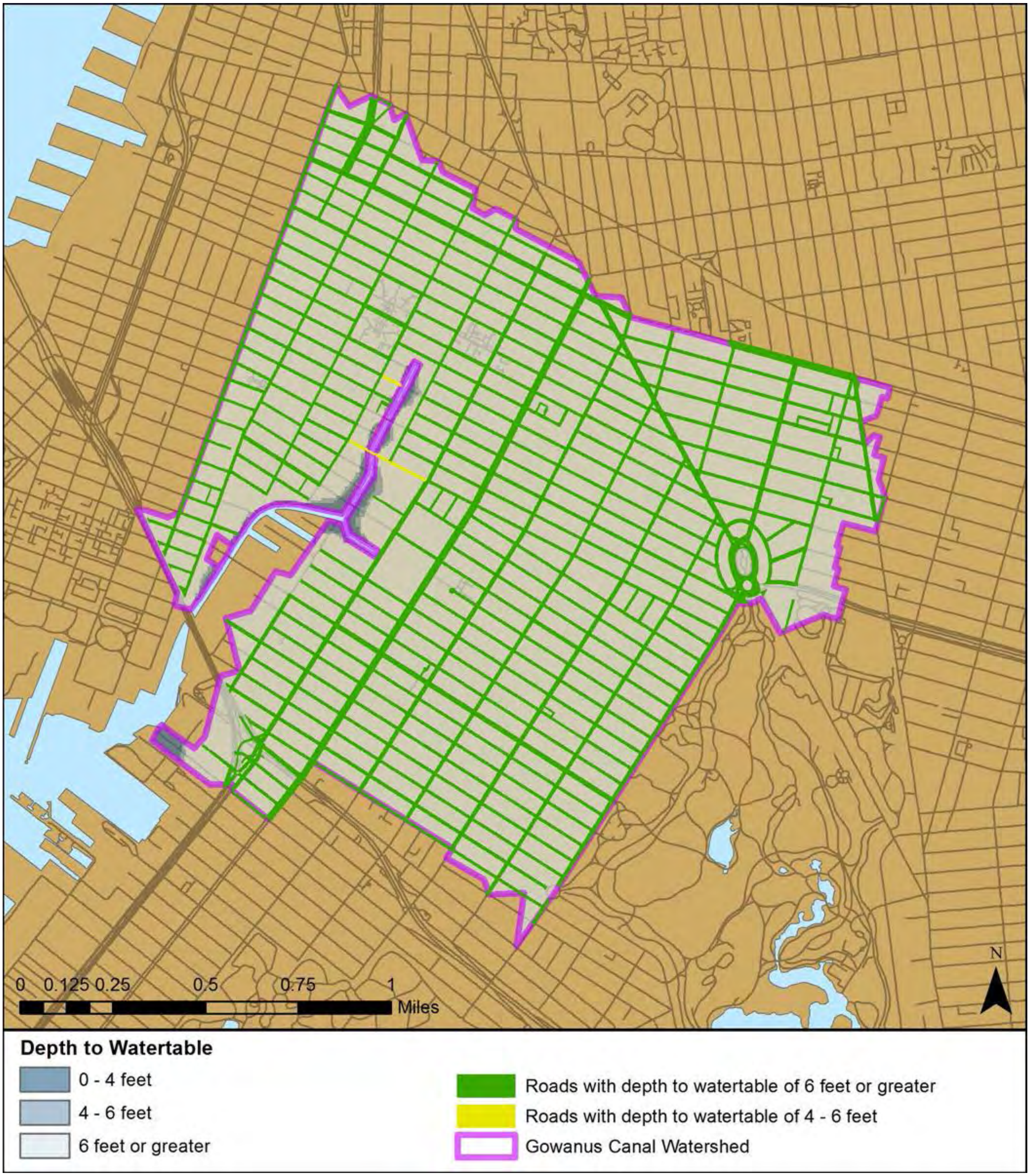


Figure 4.71: Gowanus Canal Watershed Geotechnical Criteria: Soil Permeability

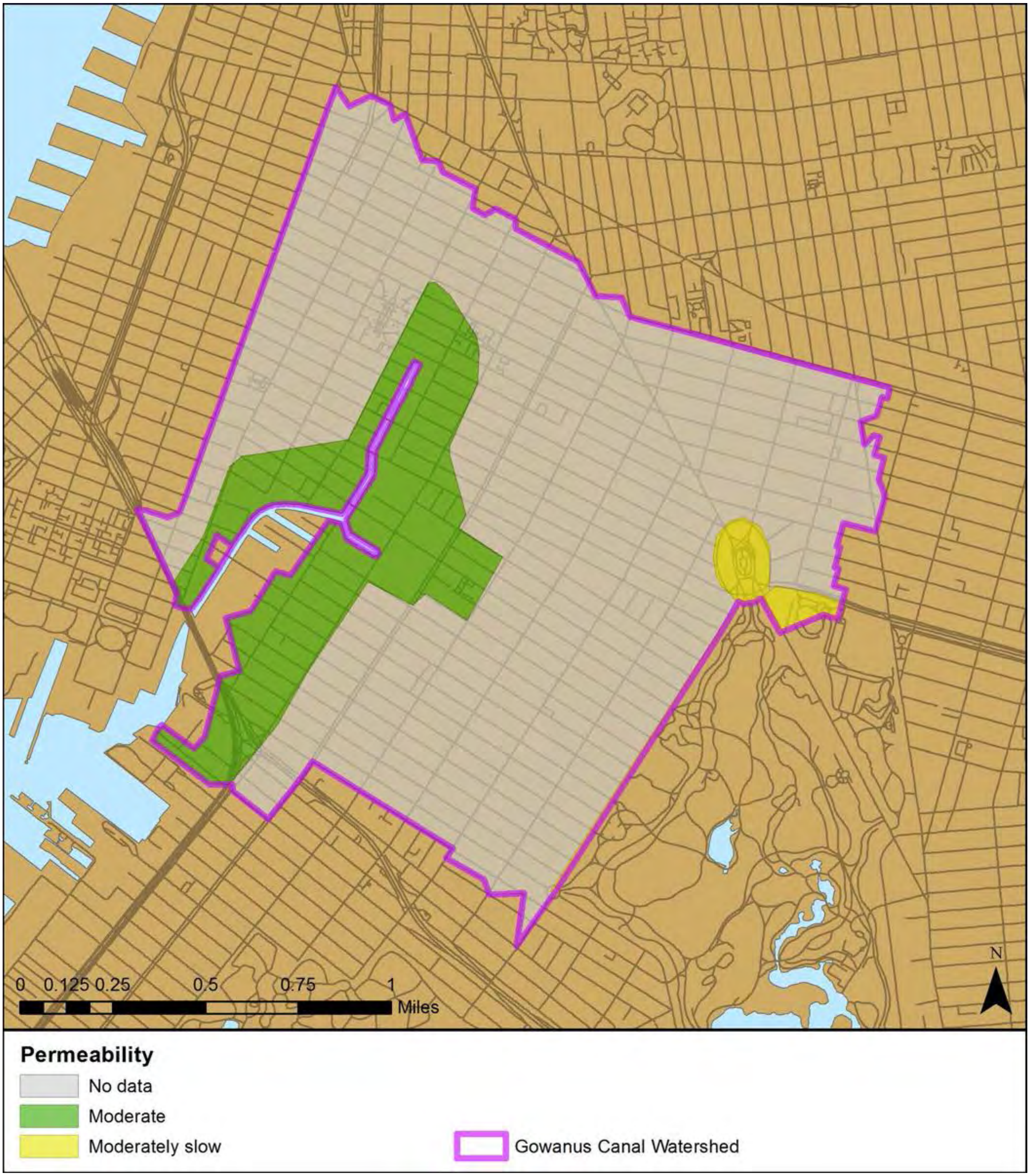


Figure 4.72: Gowanus Canal Watershed Geotechnical Criteria: Hydrologic Soil Group

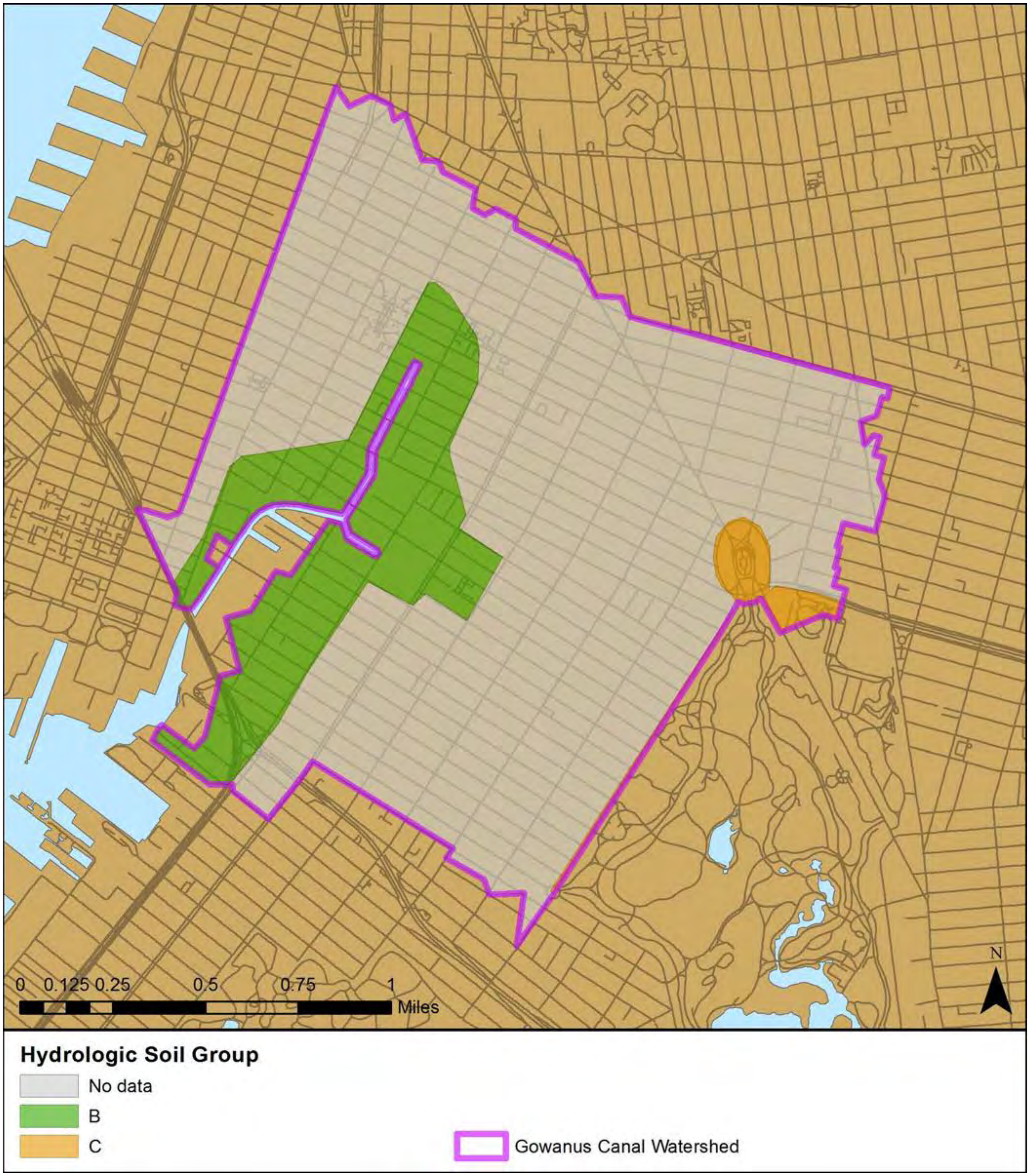


Figure 4.73: Gowanus Canal Watershed Geotechnical Criteria: Combined Criteria Excluding Soils

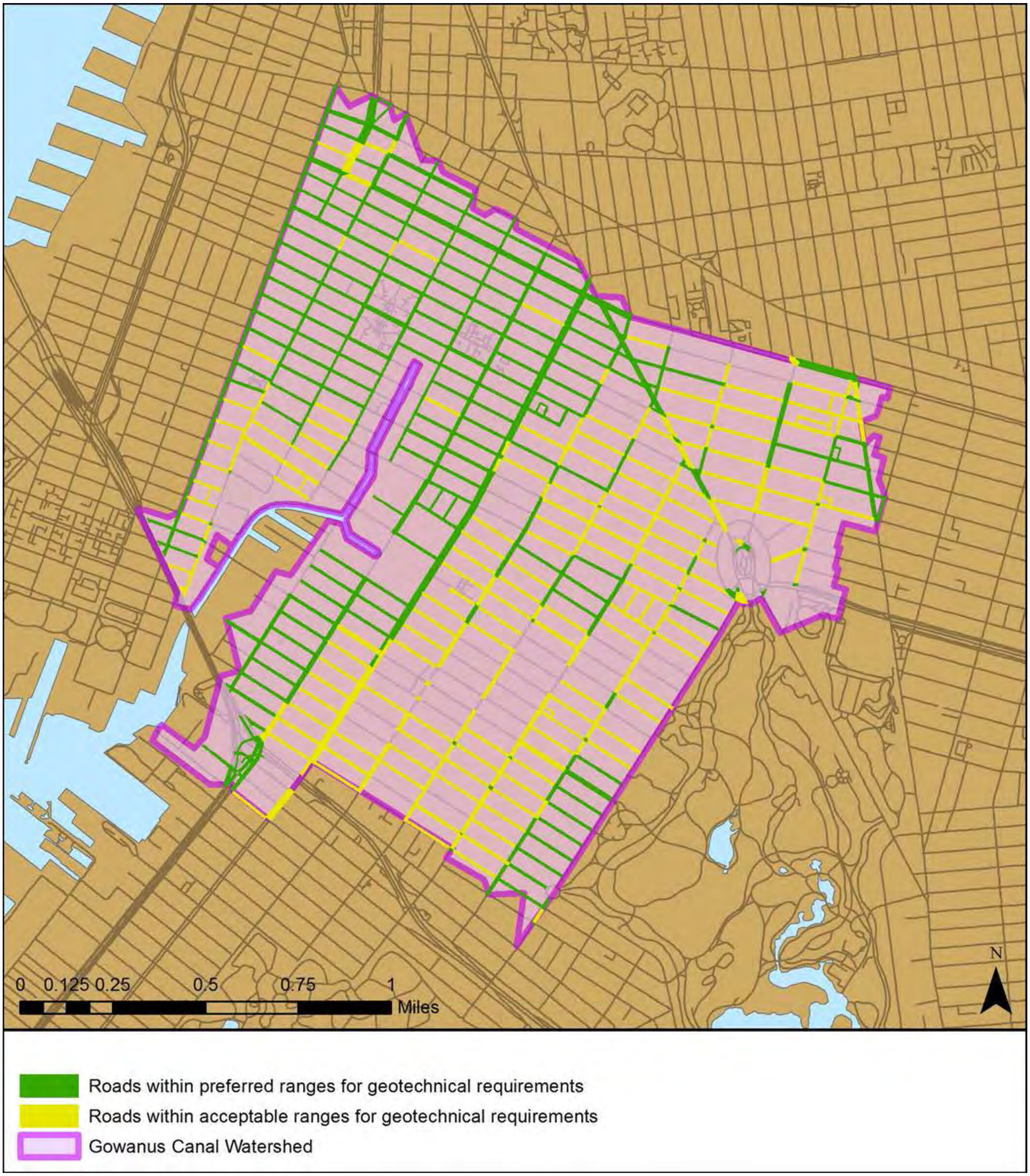


Figure 4.74: Gowanus Canal Watershed Built Environment Criteria: Residential Zoning Districts with Building Setbacks of 10′ or Greater

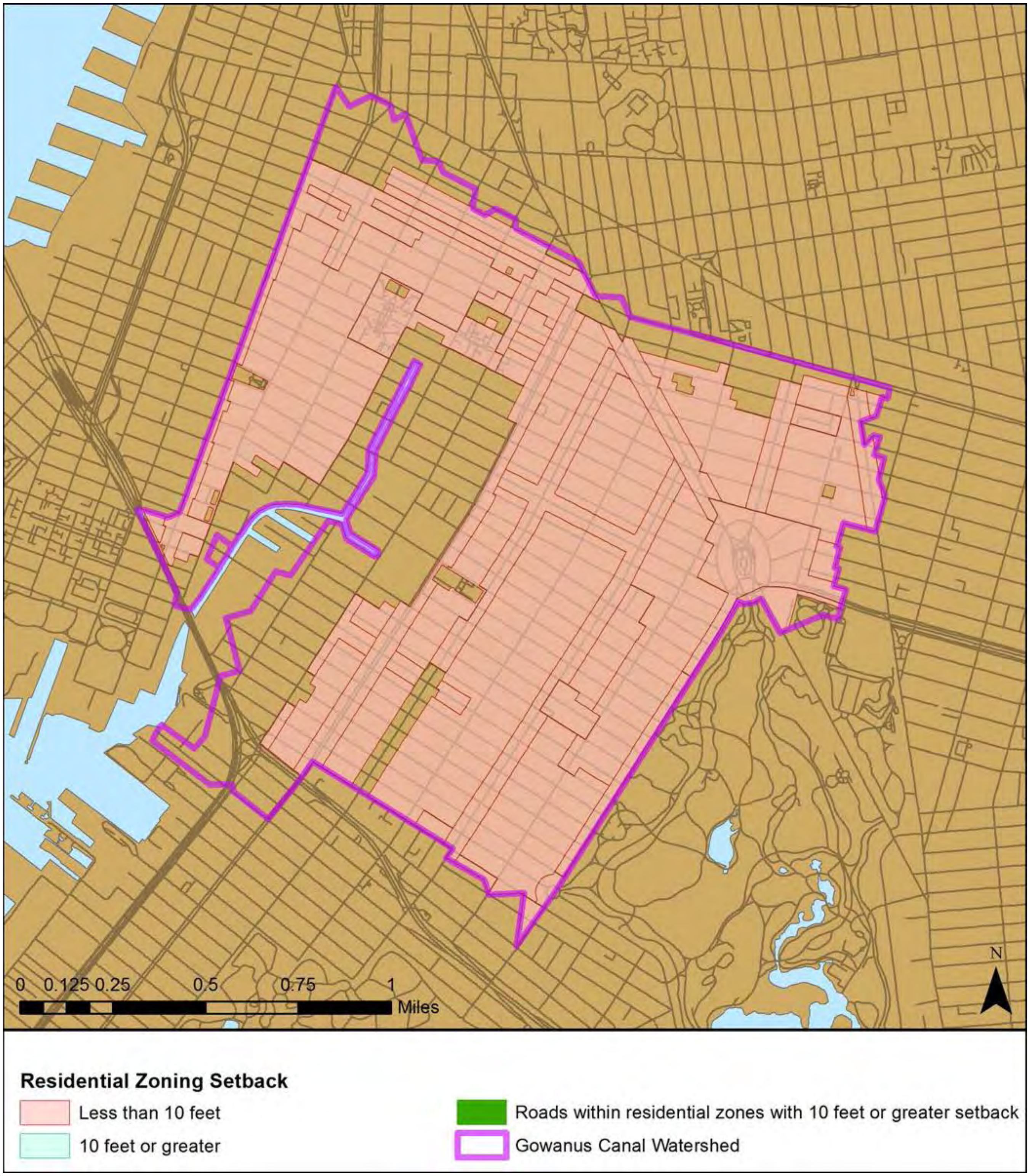


Figure 4.75: Gowanus Canal Watershed Built Environment Criteria: Commercial Overlay Districts

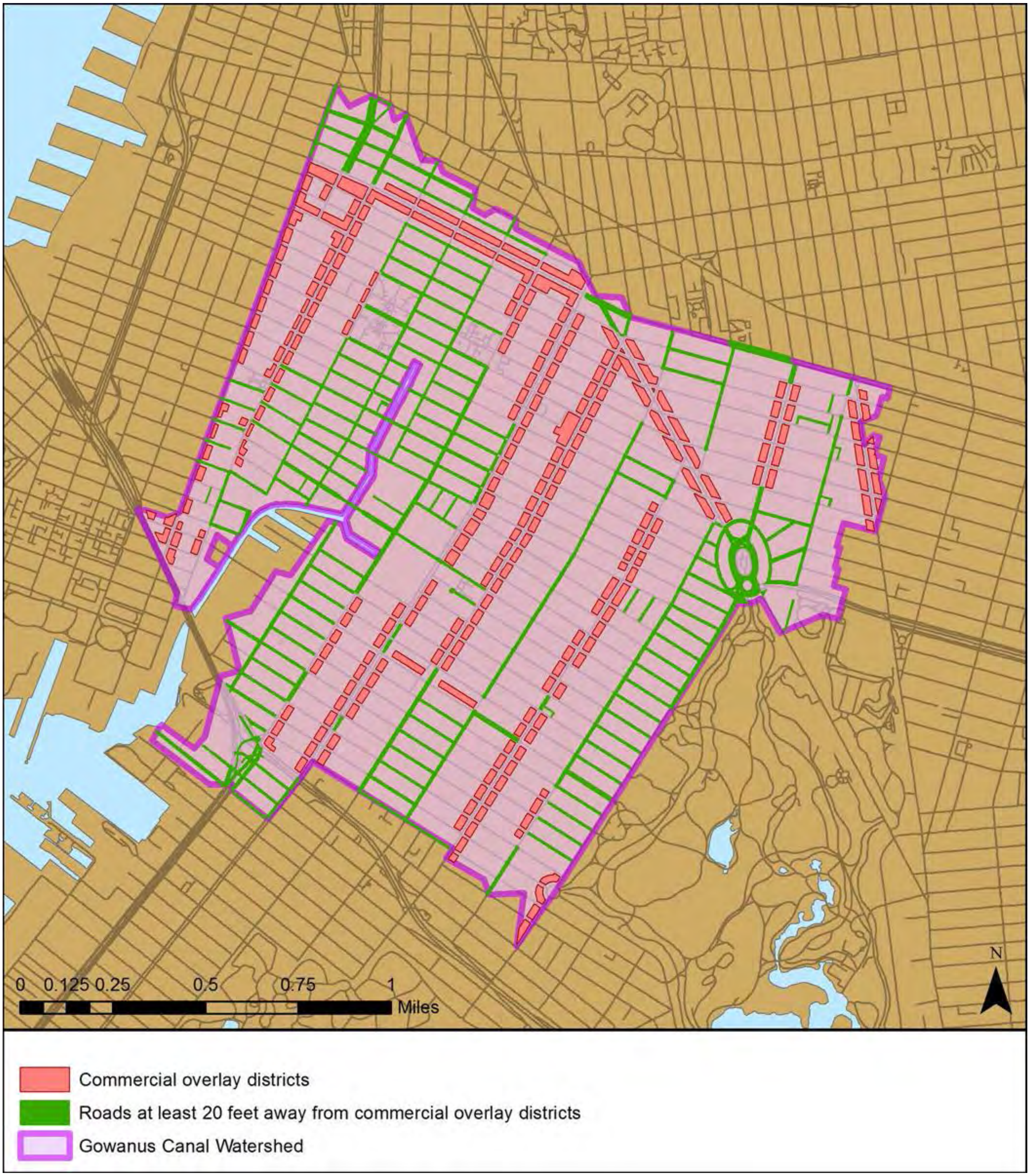


Figure 4.76: Gowanus Canal Watershed Built Environment Criteria: Street Tree Density

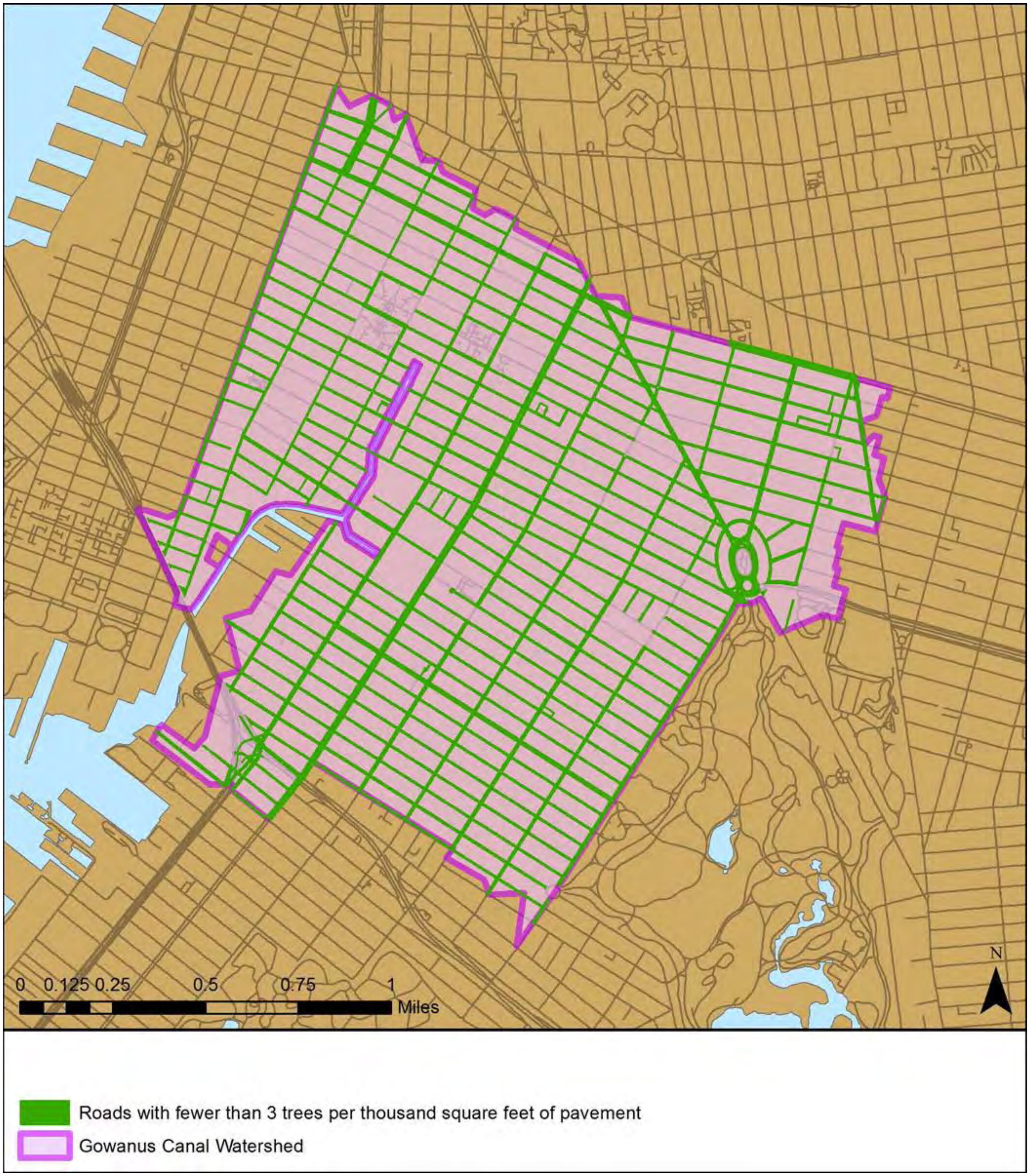


Figure 4.77: Gowanus Canal Watershed Built Environment Criteria: Pavement Condition

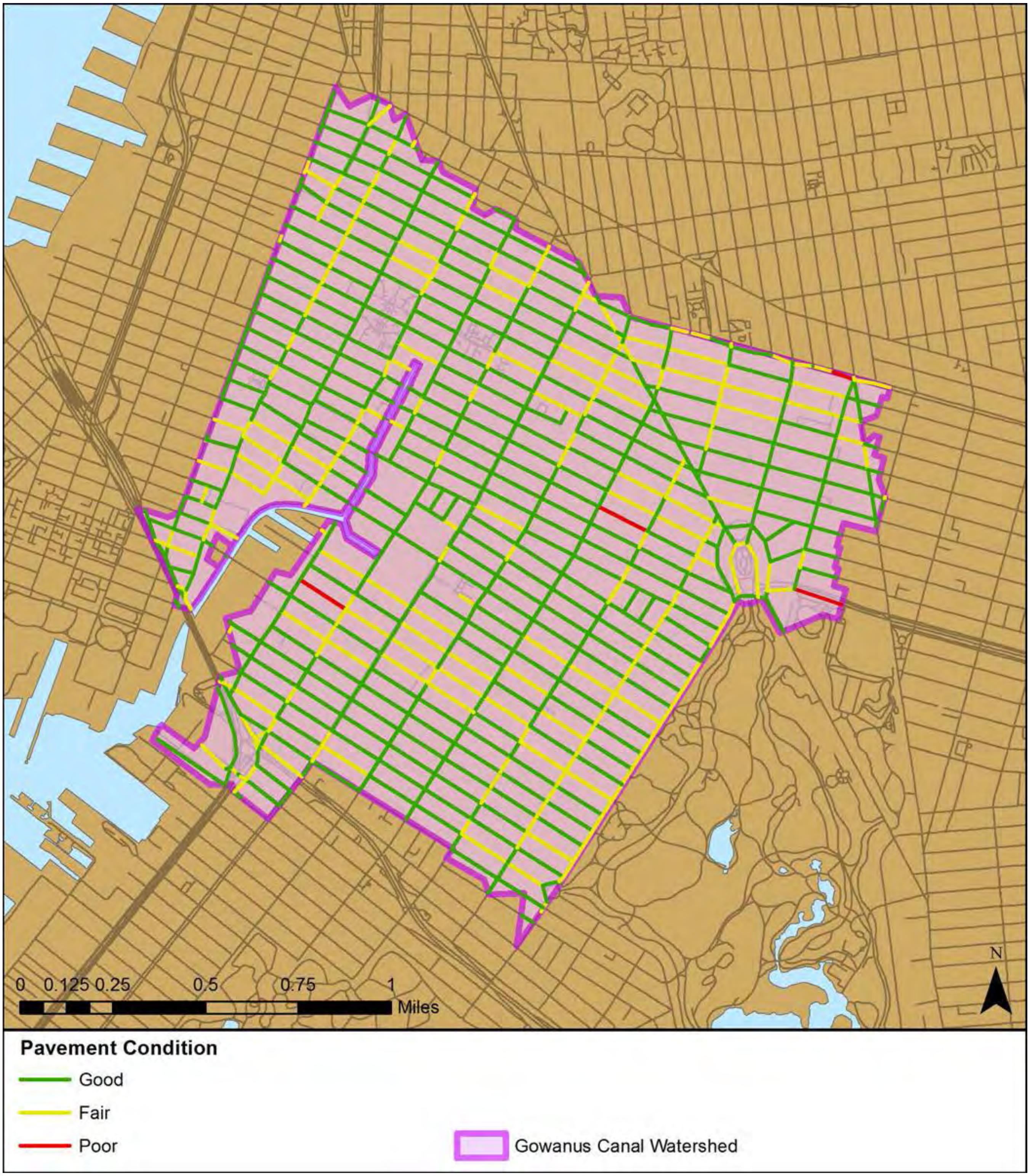
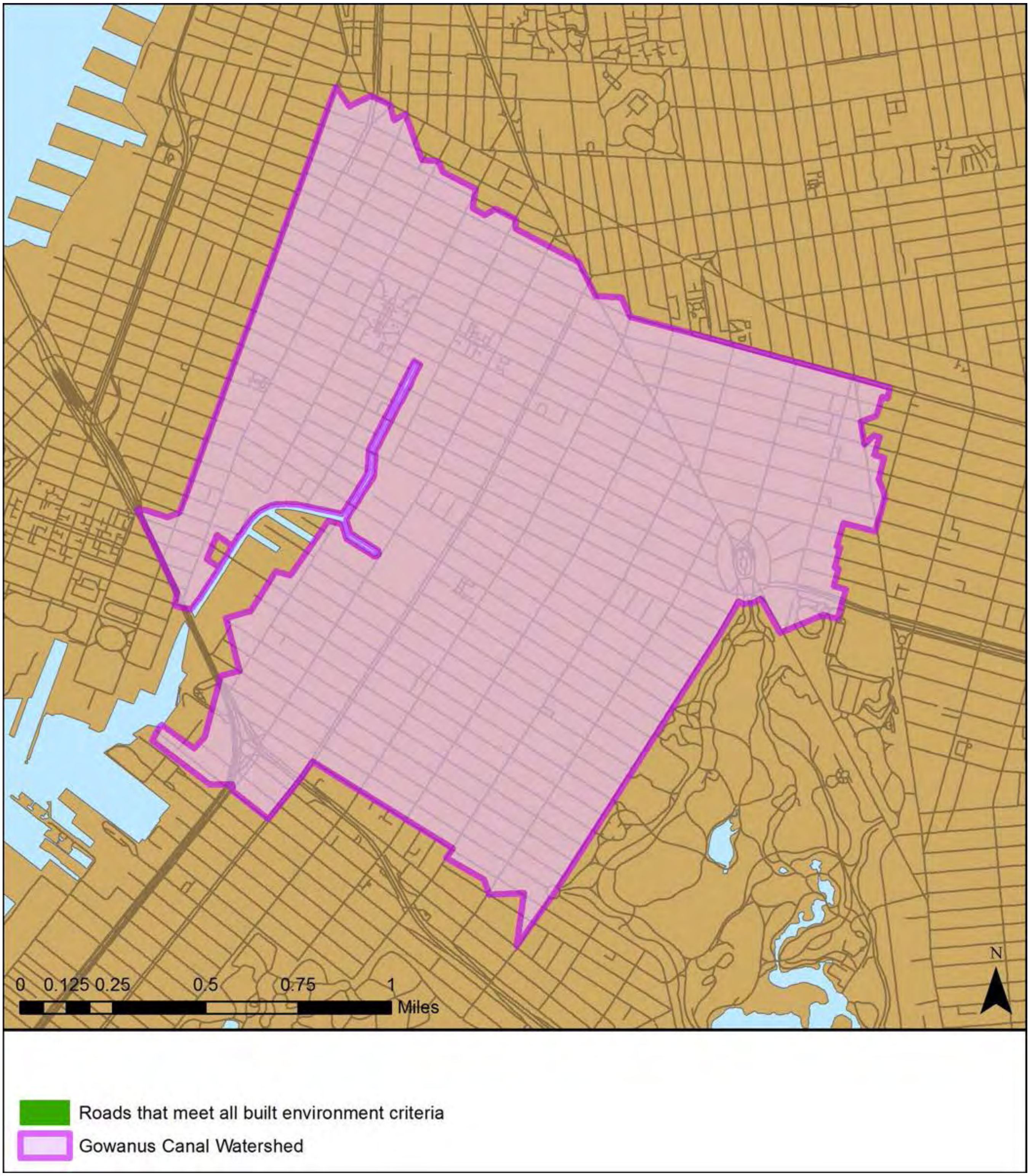


Figure 4.78: Gowanus Canal Watershed Built Environment Criteria: Combined Criteria Excluding Pavement Condition



APPENDIX 5: DESIGN SPECIFICATIONS

Appropriate siting and design of pervious pavement installations is required to realize the full potential benefits while avoiding complications. This section is a guide to recommend design characteristics of pervious asphalt and concrete installations. Information in this section is based on our research and is untested in the NYC environment—a licensed engineer would be required to develop proper specifications and mixes appropriate for NYC.

Asphalt Mix

A permeable asphalt application requires the design and installation of up to six layers of roadbed material. The pervious asphalt mix is the top layer of the roadbed. The asphalt layer should be 2-4" thick depending on expected traffic loads.[207] The pervious asphalt mix consists of "modified performance grade asphalt binder (PGAB), coarse and fine aggregates, and optional additives such as silicone, fibers, mineral fillers, fatty amines, and hydrated lime."[208] The exact mix of material will vary based on the application requirements. The following mix recommendations have been modified from the "University of New Hampshire Stormwater Center Design Specifications for Porous Asphalt Pavement and Infiltration Bed:"[209]

1. LOW-MODERATE DURABILITY: PG 64-28* with 5 pounds of fibers per ton of asphalt mix. This mix is recommended for smaller projects with lower traffic counts or loading potential. This mix is manageable at common batch plants.
2. MODERATE DURABILITY: Pre-Blended PG 64-28 SBS/SBR with 5 pounds of fibers per ton of asphalt mix. This mix is recommended for large projects > 1acre where high durability pavements are needed.
3. HIGH DURABILITY: Pre-Blended PG 76-22 modified with SBS/SBR and 5 pounds of fibers per ton of asphalt mix. This mix is recommended for large sites anticipating high wheel load (H-20) and traffic counts for maximum durability.

Concrete Mix

"Pervious concrete comprises the surface layer of the permeable pavement structure and consists of Portland cement, open-graded coarse aggregate (typically 3/8 to 5/8 inch), and water. Admixtures can be added to the concrete mixture to enhance strength, increase setting time, or add other properties. The thickness of pervious concrete ranges from 4 to 8 inches depending on the expected traffic loads."[210] Pervious concrete follows the same subsurface design as pervious asphalt, with a lower base/sub-base thickness requirement.

Sub-Street Layers

Choke Course

This layer is typically 1-2'' thick but can be up to 8'' thick when there are concerns about compaction. [211,212] The choke course layer serves as a permeable, level, and stabilized surface for the asphalt layer.[213] It is typically composed of course stone (AASGTO No.57).[214]

Open-Graded Base Reservoir

"This aggregate layer is immediately beneath the choke layer. The base is typically 3-4' thick and consists of crushed stones typically 3/16" to 3/4". Besides storing water, this high infiltration rate layer provides a transition between the bedding and subbase layers."[215]

Open-Graded Subbase Resevoir

The stone aggregate in this layer is typically .75 to 2.5".[216] Thickness depends on application, and this layer may not be required for non-roadway applications. The purpose of this layer is to provide excess capacity for water storage and support.

Subgrade

"The layer of soil immediately beneath the aggregate base or subbase. The infiltration capacity of the subgrade determines how much water can exfiltrate from the aggregate into the surrounding soils. The subgrade soil is generally not compacted."[217]

Optional Layers

The underdrain and geotextile layers are not required for pervious asphalt installations but they may be used depending on the site characteristics.

Underdrain (Optional)

An underdrain can be used to mitigate low infiltration rate subgrade soils. "The underdrain is perforated pipe that ties into an outlet structure. Supplemental storage can be achieved by using a system of pipes in the aggregate layers. The pipes are typically perforated and provide additional storage volume beyond the stone base."[218]

Geotextile (optional)

"This can be used to separate the subbase from the subgrade and prevent the migration of soil into the aggregate subbase or base."[219] Filter fabric geotextiles can be effective for removing pollutants from water however they are not recommended when the application is designed with infiltration as the top priority (use graded stone filter blankets instead if soil clogging is a concern).[220]

Bibliography

City of New York, The. "The Mayor's Management Report: Fiscal 2011." (September 2011). <http://www.nyc.gov/html/ops/downloads/pdf/mmr/0911_mmr.pdf> (20 April 2012).

City of New York, The, Office of the Comptroller. "Internal Control and Accountability Directives." (31 May 2011). <http://www.comptroller.nyc.gov/bureaus/acc/directives/Dir10-CapitalProjectsFund.pdf> (28 April 2012).

City of New York, The. "The Plan." <http://www.nyc.gov/html/planyc2030/html/theplan/the-plan.shtml> (13 March 2012).

City of New York, The. "PlaNYC: A Greener, Greater New York. Update April 2011." <http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_2011_planyc_full_report.pdf> (13 March 2012).

City of New York, The. "PlaNYC: Sustainable Stormwater Management Plan 2008." <http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/nyc_sustainable_stormwater_management_plan_final.pdf> (13 March 2012).

City of New York, The. "Waterways." <http://www.nyc.gov/html/planyc2030/html/theplan/waterways.shtml> (13 March 2012).

City of Olympia, Washington, The. "North Street Reconstruction Project: Summary of Porous Concrete Sidewalk." <http://olympiawa.gov/city-utilities/storm-and-surface-water/science-and-innovations/~/media/Files/PublicWorks/Water-Resources/North_Street_Reconstruction_Project_Porous_Concrete_Summar.ashx> (4 April 2012).

City of Vancouver Engineering Services. "Country Lanes." (2002). <http://www3.telus.net/public/a6a47567/CounrtyLaneFlyer.PDF>

Cohen, Steven. "Everyone's Backyard: Parks in New York City." *The Huffington Post*. (12 April 2010). <http://www.huffingtonpost.com/steven-cohen/everyones-backyard-parks_b_533815.html> (4 April 2012).

Copeland, Claudia. "CRS Report for Congress: Water Quality: Implementing the Clean Water Act." Prepared for Members and Committees of Congress. (12

December 2006). <http://www.nationalaglawcenter.org/assets/crs/RL33466.pdf> (27 April 2012).

CRC Press. "Porous Pavements: Porous Asphalt." (2005). <http://www.crcnetbase.com/doi/pdfplus/10.1201/9781420038439.ch12> (4 April 2012).

Danish Road Institute. "Noise Reducing Pavements in Japan – Study Tour Report." DRI-DWW Noise Abatement Program. (December 2005). <http://www.ipl-airquality.nl/data/actie-asfalt-geluidsvermindering-japan.pdf> (4 April 2012).

Dierkes, Carste and Lothar Kuhlmann, Jaya Kandasamy, and George Angelis. "Pollution Retention Capability and Maintenance of Permeable Pavements." <http://www.psparchives.com/publications/our_work/stormwater/lid/paving_docs/Permeable%20Paving%20Pollution%20Processing-Dierkes.pdf > (10 April 2012).

East Baton Rouge Parish. "Stormwater BMPS." <http://brgov.com/dept/planning/pdf/bmp6.pdf> (4 April 2012).

Elert, Glenn. Ed. "Volume of New York City's Annual Precipitation." The Physics Factbook. (2005). <http://hypertextbook.com/facts/2005/LauraDePalma.shtml> (10 April 2012).

Fujita, Shoichi. Nagaoka University of Technology. "Stormwater Management for Urban Sustainable Water Use." <http://www.recwet.t.u-tokyo.ac.jp/furumailab/crest/workshop05/june9pm_2_ppt.pdf> (13 March 2012).

Fujita, Shoichi. Japan Institute of Wastewater Engineering and Technology. "Infiltration Structures in Tokyo." Water Science and Technology, IAWQ, Vol. 30, No. 1, pp 33-41, 1994. <http://members.jcom.home.ne.jp/0710034301/031i10IAWQHUNGARYpaper.htm> (10 March 2012).

Gonwa, Willie, PE, PhD. "Installing Porous Pavement: Waukesha County Dept. of Parks and Land Use Stormwater BMP Design and Installation Workshop. (11 March 2009). <http://www.waukeshacounty.gov/uploadedFiles/Media/PDF/Parks_and_Land_Use/Land_Conservation/Stormwater/2009_Workshop/2_-_Gonwa_-_Porous_Ravement.pdf> (10 March 2012).

Gwilym, Kathryn, PE, LEED AP. SvR Design Company. "WSU & Puget Sound Partnership Permeable Pavement Workshop. Operations and Maintenance for Porous Pavements. (May 2011).

<http://conferences.wsu.edu/conferences/lidworkshops/presentations/permeable_paving/Gwilym_Presentation1.pdf> (4 April 2012).

Hoyer, Jacqueline, Wolfgang Dickhaut, Lukas Kronawitter, Bjorn Weber. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). <http://www.switchurbanwater.eu/outputs/pdfs/W51_GEN_MAN_D5.1.5_Manual__on_WSUD.pdf> (4 April 2012).

Hsu, Tung-Wen, Shyue-Chein Chen and Kuo-Nang Hung. "Performance Evaluation of Asphalt Rubber in Porous Asphalt-Concrete Mixtures."*Journal of Materials in Civil Engineering*. (2011) Vol. 23, Issue 3, 342-349.

Liandi, He. "Water Percolation on Road Surfaces to Absorb Pollution." *Wenhui Daily*. (29 October 2009). In Chinese. <http://news.sohu.com/20091029/n267826766.shtml> (4 April 2012).

Living City Block LLC. "Brooklyn Gowanus: About Us." <http://www.livingcityblock.org/living-city-brooklyn/1782-2/> (15 April 2012).

Meir, W.R. Jr. PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. "Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report." (July 1988). <http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ227-first.pdf> (12 March 2012).

Milar, Brandon. "Porous Asphalt Pavements with Stone Recharge Beds." California Asphalt Pavement Association. < http://www.coastal.ca.gov/nps/lid/Milar-PorousAsphaltPavements.pdf> (10 March 2012).

National Resources Defense Council. "New York City to Clean Up Waterways by Greening Roadways and Roofs: City Council Adopts New Measures for Sustainable Stormwater Management Plan." (30 January 2008). <http://www.nrdc.org/media/2008/080130.asp> (22 March 2012).

New York City Department of Environmental Conservation. "Wastewater Infrastructure Needs of New York State." (March 2008). <http://www.dec.ny.gov/docs/water_pdf/infrastructurerpt.pdf> (18 March 2012).

New York City Department of Environmental Protection. "Green Infrastructure Grant Program." (2012).

<http://www.nyc.gov/html/dep/pdf/green_infrastructure/2012_gi_grant_workshop_presentation.pdf > (20 March 2012).

New York City Department of Environmental Conservation. "Combined Sewer Overflow (CSO): Impact on Receiving Water and Recreational Activities." <http://www.dec.ny.gov/chemical/48595.html> (20 March 2012).

New York City Department of Environmental Conservation. "New York City CSO: Consent Order, Long-term Control Plans, and Green Infrastructure." <http://www.dec.ny.gov/chemical/77733.html> (20 March 2012).

New York City Department of Environmental Conservation. "Wastewater Infrastructure Needs of New York State Report." < http://www.dec.ny.gov/chemical/42383.html> (15 April 2012).

New York City Department of Environmental Protection. "NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways. <http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml> (13 March 2012).

New York City Department of Environmental Conservation. "NYSDEC & NYCDEP Reach Innovative Draft Agreement to Improve New York Harbor Water Quality." (19 October 2011). < http://www.dec.ny.gov/press/77894.html> (13 March 2012).

New York City Department of Transportation. "Street Design Manual." (2009). <http://www.nyc.gov/html/dot/downloads/pdf/sdm_lores.pdf> (13 March 2012).

New York City Department of Transportation. "Duties and Obligation of Property Owners." < http://www.nyc.gov/html/dot/html/sidewalks/19-152.shtml> (4 April 2012).

New York City Department of City Planning (DCP). "About Us: Our Mission." <http://www.nyc.gov/html/dcp/html/subcats/about.shtml> (5 April, 2012).

New York City Department of Parks and Recreation. "Greenstreets: Stormwater Management Portfolio." (2010). <http://www.nycgovparks.org/sub_your_park/trees_greenstreets/images/NYC_Greenstreets-Green_Infrastructure_for_Stormwater_Management.pdf > (5 April, 2012).

New York City Department of Transportation. "Street Works Manual." (2011). <http://www.nyc.gov/html/dot/streetworks/downloads/pdf/street-works-manual.pdf> (13 March 2012).

New York City Office of Emergency Management. "Natural Hazard Mitigation Plan." (2009). <http://www.nyc.gov/html/oem/downloads/pdf/hazard_mitigation/section_3j_flooding_hazard_analysis.pdf> (10 April 2012).

New York City Panel on Climate Change. "Climate Risk Information: Climate Change Scenarios & Implications for NYC Infrastructure." (17 February 2009). <http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf> (13 March 2012).

New York City Rent Guidelines Board. "Explanation of the Rent Guidelines: Process By which the Rent Guidelines Board Determines the Guidelines." <http://www.housingnyc.com/html/guidelines/guidelines.html> (10 April 2012)

Nielsen, Carsten B. "Do Japanese Cars Come with a Japanese Pavement." NORDIC. <http://www.nordicroads.com/website/index_print.asp?pageID=88> (4 April 2012).

Portland Bureau of Environmental Services. "Sustainable Infrastructure: Alternative Paving Materials Subcommittee Report." (3 October 2003). <http://www.portlandonline.com/bes/index.cfm?a=53556&c=45382> (4 April 2012).

Portland Bureau of Environmental Services. "North Gay Avenue: Portland, Oregon." <http://www.portlandonline.com/bes/index.cfm?a=196785&c=44953> (4 April 2012).

Portland Bureau of Environmental Services. "Pervious Pavement Projects: A New Approach to Stormwater Management." <http://www.portlandonline.com/bes/index.cfm?c=45435&a=77074> (4 April 2012).

Roseen, Robert PE, PhD and Thomas Ballestero, PE, PhD, PH, GGWP, PG, and James Houle. "Porous Pavements in Cold Climates: Part 1 – Design, Installation, and Maintenance." University of new Hampshire Stormwater Center, Department of Civil Engineering. (March 2011). <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/presentations/Porous%20Pavements%20in%20Cold%20Climates%20Part%201.pdf> (4 April 2012).

Stormwater Solutions. "Case Study: Pringle Creek Green Streets." <http://www.lcog.org/documents/sub_action/LID_CaseStudy_PringleCreekGreenStr.pdf > (20 April 2012).

United States Department of Transportation, Federal Highway Administration. "Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring." <http://environment.fhwa.dot.gov/ecosystems/ultraurb/uubmp2.asp#s22> (13 March 2012).

United States Environmental Protection Agency. "Reducing Urban Heat Islands: Compendium of Strategies." (2005). <http://www.epa.gov/heatisld/mitigation/pavements.htm > (10 April 2012).

United States Environmental Protection Agency. "National Pollutant Discharge Elimination System. Combined Sewer Overflows: CSO Control Policy." <http://cfpub2.epa.gov/npdes/cso/cpolicy.cfm> (20 March 2012).

United States Environmental Protection Agency. "National Pollutant Discharge Elimination System. Porous Asphalt Pavement." <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=135&minmeasure=5> (4 April 2012).

United States Environmental Protection Agency. "National Pollutant Discharge Elimination System. Pervious Concrete Pavement." <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=137&minmeasure=5> (4 April 2012).

United States Environmental Protection Agency, Regional Pollution Prevention Program Offices. "Funding Opportunity Announcement: Request for Proposals." <http://www.epa.gov/p2/pubs/grants/srap/srap12.pdf> (20 March 2012).

University of New Hampshire Stormwater Center, The. "Porous Pavement for Stormwater Management." <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/porous_ashpalt_fact_sheet.pdf> (4 April 2012).

University of Rhode Island Cooperative Extension in Partnership with the Rhode Island Department of Health Source Water Protection Program. "The University of Rhode Island's Permeable Parking Lots: A Case Study of Alternative Pavement Materials." <http://www.uri.edu/ce/wq/NEMO/Publications/PDFs/PP.URICaseStudy.pdf> (20 March 2012).

Van Diemen, Nick. "Permeable Paving Systems." ISS Institute/TAFE Fellowship. (March 2009). <http://issinstitute.org.au/wp-content/media/2011/04/ISS-FEL-REPORT-van-Diemen-Low-Res.pdf>. (4 April 2012)

Virginia Department of Conservation and Recreation. "Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement." (1 March 2011). <http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_7_PERMEABLE_PAVEMENT_Final_Draft_v1-7_03082010.htm> (4 April 2012).

Wanielista, Marty and Manoj Chopra. "Performance Assessment of Portland Cement Pervious Pavement: Report 4 of 4, Performance Assessment of a Pervious Concrete Pavement Used as a Shoulder for an Interstate Rest Area Parking Lot." A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection." (June 2007). < http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BD521_02_rpt4.pdf> (10 April 2012).

---

[1] The City of New York. "The Plan." <http://www.nyc.gov/html/planyc2030/html/theplan/the-plan.shtml> (13 March 2012). This site provides an overview of PlaNYC objectives and links to PlaNYC and related policy documents.

[2] The City of New York. "The Plan."

[3] The City of New York. "Waterways." <http://www.nyc.gov/html/planyc2030/html/theplan/waterways.shtml> (13 March 2012). Here you can find an overview of PlaNYC waterways objectives and a link to the relevant chapter of PlaNYC.

[4] The City of New York. "Waterways."

[5] City of New York, The. "PlaNYC: Sustainable Stormwater Management Plan 2008." <http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/nyc_sustainable_stormwater_management_plan_final.pdf> (13 March 2012).

[6] New York City Department of Transportation. "Street Design Manual." (2009). <http://www.nyc.gov/html/dot/downloads/pdf/sdm_lores.pdf> (13 March 2012).

[7] New York City Department of Environmental Protection. "NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways." <http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml> (13 March 2012): 46.

[8] New York City Department of Transportation. "Street Design Manual." (2009). <http://www.nyc.gov/html/dot/downloads/pdf/sdm_lores.pdf> (13 March 2012). Updates and addenda to the Street Design Manual are periodically posted to the Street Design Manual Web site at www.nyc.gov/streetdesignmanual.com, where readers may also register to receive updates via e-mail.

[9] New York City Department of Environmental Protection. "NYC Green Infrastructure Plan." (20 March 2012): 47. Calculation: Estimated area of NYC = 469 square miles. 26.6% of total area in NYC is roads/sidewalks, hence 469*0.266= 124.75 square miles.

[10] New York City Department of Environmental Protection. "NYC Green Infrastructure Plan." (20 March 2012): 47. See the calculation under note 8.

[11] The City of New York. "Waterways."

[12] New York City Department of Environmental Protection. "NYC Green Infrastructure Plan." (18 March 2012): 13.

[13] New York City Department of Environmental Protection. "NYC Green Infrastructure Plan." (18 March 2012): 15.

---

[14] New York City Department of Envrionmental Conservation. “Wastewater Infrastructure Needs of New York State.” (March 2008). <http://www.dec.ny.gov/docs/water_pdf/infrastructurerpt.pdf> (18 March 2012): 13. Olympic swimming pools measure 50m long, 25m wide and are at least 2m deep. 25m x 50m x 2m = 2,500m^3 = 2.5 million L = 660,430 gallons. (27 billion gal)/(660,430 gal per pool) = 40,882 pools.
[15] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 15.
[16] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 15.
[17] The City of New York. “The Plan.”
[18] The City of New York. “Waterways."
[19] The City of New York. “Waterways."
[20] New York City Department of Transportation. “Street Design Manual.” (2009). (20 March 2012): 111.
[21] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (20 March 2012): 46.
[22] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (20 March 2012): 4.
[23] New York City Department of Environmental Protection. “Combined Sewer Overflow (CSO): Impact on Receiving Water and Recreational Activities.” <http://www.dec.ny.gov/chemical/48595.html> (20 March 2012).
[24] Copeland, Claudia. “CRS Report for Congress: Water Quality: Implementing the Clean Water Act.” Prepared for Members and Committees of Congress. (12 December 2006). <http://www.nationalaglawcenter.org/assets/crs/RL33466.pdf> (27 April 2012): 2-3.
[25] New York City Department of Environmental Protection. “Combined Sewer Overflow (CSO): Impact on Receiving Water and Recreational Activities.” (20 March 2012).
[26] New York City Department of Environmental Protection. “Combined Sewer Overflow (CSO): Impact on Receiving Water and Recreational Activities.” (20 March 2012).
[27] New York City Department of Environmental Protection. “New York City CSO: Consent Order, Long-term Control Plans, and Green Infrastructure.” <http://www.dec.ny.gov/chemical/77733.html> (20 March 2012).
[28] New York City Department of Environmental Protection. “New York City CSO: Consent Order, Long-term Control Plans, and Green Infrastructure.” (20 March 2012).
[29] United States Environmental Protection Agency. “National Pollution Discharge Elimination System. Combined Sewer Overflows: CSO Control Policy.” <http://cfpub2.epa.gov/npdes/cso/cpolicy.cfm> (20 March 2012).
[30] National Resources Defense Council. “New York City to Clean Up Waterways by Greening Roadways and Roofs: City Council Adopts New Measures for Sustainable Stormwater Management Plan.” (30 January 2008). <http://www.nrdc.org/media/2008/080130.asp> (22 March 2012).
[31] New York City Department of Environmental Conservation. “NYSDEC & NYCDEP Reach Innovative Draft Agreement to Improve New York Harbor Water Quality.” (19 October 2011). <http://www.dec.ny.gov/press/77894.html> (13 March 2012).
[32] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 10.
[33] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 31.
[34] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 23.
[35] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 47.
[36] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 4.
[37] The City of New York. “PlaNYC: A Greener, Greater New York. Update April 2011.” (13 March 2012): 67.
[38] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 31.
[39] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 31.
[40] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 47. See Calculation in Note 8.
[41] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=135&minmeasure=5> (4 April 2012).
[42] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).
[43] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).
[44] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

---

[45] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[46] Virginia Department of Conservation and Recreation. “Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement.” (1 March 2011). <http://vwrrc.vt.edu/swc/april_22_2010_update/DCR_BMP_Spec_No_7_PERMEABLE_PAVEMENT_Final_Draft_v1-7_03082010.htm> (4 April 2012).

[47] Portland Bureau of Environmental Services. “Pervious Pavement Projects: A New Approach to Stormwater Management.” <http://www.portlandonline.com/bes/index.cfm?c=45435&a=77074> (4 April 2012).

[48] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/pubs_specs_info/porous_ashpalt_fact_sheet.pdf> (4 April 2012).

[49] Virginia Department of Conservation and Recreation. “Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement.” (4 April 2012): 5

[50] Virginia Department of Conservation and Recreation. “Virginia DCR Stormwater Design Specification No. 7. Permeable Pavement.” (4 April 2012): 5

[51] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).

[52] East Baton Rouge Parish. “Stormwater BMPS.” <http://brgov.com/dept/planning/pdf/bmp6.pdf> (4 April 2012): 128.

[53] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).

[54] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[55] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Pervious Concrete Pavement.” <http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm?action=browse&Rbutton=detail&bmp=137&minmeasure=5> (4 April 2012).

[56] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).

[57] Karthryn Gwilym, PE, LEED AP. SvR Design Company. “WSU & Puget Sound Partnership Permeable Pavement Workshop. Operations and Maintenance for Porous Pavements. (May 2011). <http://conferences.wsu.edu/conferences/lidworkshops/presentations/permeable_paving/Gwilym_Presentation1.pdf> (4 April 2012): 7.

[58] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Pervious Concrete Pavement.”

[59] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Pervious Concrete Pavement.”

[60] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Pervious Concrete Pavement.”

[61] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 46.

[62] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” <http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/nyc_sustainable_stormwater_management_plan_final.pdf> (13 March 2012): 33.

[63] United States Department of Transportation, Federal Highway Administration. “Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring.” <http://environment.fhwa.dot.gov/ecosystems/ultraurb/uubmp2.asp#s22> (13 March 2012).

[64] New York City Department of Transportation. “Street Works Manual.” (2011). <http://www.nyc.gov/html/dot/streetworks/downloads/pdf/street-works-manual.pdf> (13 March 2012): ix. Print copies can be purchased at www.nyc.gov/dot, where addenda and updates are also posted.

[65] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): 56-57.

[66] New York City Panel on Climate Change. “Climate Risk Information.” (17 February 2009). <http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf> (13 March 2012): 17.

---

[67] New York City Panel on Climate Change. “Climate Risk Information.” (17 February 2009). (13 March 2012): 41.

[68] New York City Panel on Climate Change. “Climate Risk Information.” (17 February 2009). (13 March 2012): 49.

[69] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” (13 March 2012): 57.

[70] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” (13 March 2012): 57.

[71] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” (13 March 2012): 56-57.

[72] New York City Department of Transportation. “Duties and Obligation of Property Owners.” <http://www.nyc.gov/html/dot/html/sidewalks/19-152.shtml> (4 April 2012)

[73] New York City Department of Transportation. “Duties and Obligation of Property Owners.” <http://www.nyc.gov/html/dot/html/sidewalks/19-152.shtml> (4 April 2012)

[74] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” (13 March 2012): 57.

[75] City of New York, The. “PlaNYC: Sustainable Stormwater Management Plan 2008.” (4 April 2012): 76.

[76] Shoichi Fujita. Nagaoka University of Technology. “Stormwater Management for Urban Sustainable Water Use.” <http://www.recwet.t.u-tokyo.ac.jp/furumailab/crest/workshop05/june9pm_2_ppt.pdf> (13 March 2012).

[77] Fujita, Shoichi. Japan Institute of Wastewater Engineering and Technology. “Infiltration Structures in Tokyo.” Water Science and Technology, IAWQ, Vol. 30, No. 1, pp 33-41, 1994. <http://members.jcom.home.ne.jp/0710034301/031i10IAWQHUNGARYpaper.htm> (10 March 2012).

[78] Tung-Wen Hsu and others. “Performance Evaluation of Asphalt Rubber in Porous Asphalt-Concrete Mixtures,” *Jounral of Materials in Civil Engineering,* (2011) Vol. 23, Issue 3, 342-349.

[79] He Liandi. “Water Percolation on Road Surfaces to Absorb Pollution.” *Wenhui Daily.* (29 October 2009). In Chinese. <http://news.sohu.com/20091029/n267826766.shtml> (4 April 2012).

[80] Nick van Diemen. “Permeable Paving Systems.” ISS Institute/TAFE Fellowship. (March 2009). <http://issinstitute.org.au/wp-content/media/2011/04/ISS-FEL-REPORT-van-Diemen-Low-Res.pdf>. (4 April 2012)

[81] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). <http://www.ipl-airquality.nl/data/actie-asfalt-geluidsvermindering-japan.pdf> (4 April 2012): 21.

[82] Nick van Diemen. “Permeable Paving Systems.” ISS Institute/TAFE Fellowship. (4 April 2012): 3.

[83] *City of Vancouver Engineering Services. “Country Lanes.” (2002).* (4 April 2012).

[84] Jacqueline Hoyer et al. “Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future.” Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). <http://www.switchurbanwater.eu/outputs/pdfs/W51_GEN_MAN_D5.1.5_Manual_on_WSUD.pdf> (4 April 2012).

[85] *City of Vancouver Engineering Services. “Country Lanes.” (2002)* <*http://www3.telus.net/public/a6a47567/CounrtyLaneFlyer.PDF*> (4 April 2012).

[86] Carsten B. Nielsen. “Do Japanese Cars Come with a Japanese Pavement.” NORDIC. <http://www.nordicroads.com/website/index_print.asp?pageID=88> (4 April 2012).

[87] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012): 12.

[88] Hsu et al., 342-349.

[89] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012): 12.

[90] City of New York, The, Office of the Comptroller. “Internal Control and Accountability Directives.” (31 May 2011). <http://www.comptroller.nyc.gov/bureaus/acc/directives/Dir10-CapitalProjectsFund.pdf> (28 April 2012): 6-8.

[91] Information obtained in an April 5, 2012, interview with Peter Reilly, Civil Engineer at the Philadelphia Water Department.

[92] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012): 11.

[93] Hsu et al., 342-349.

[94] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (28 April 2012).

[95] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (28 April 2012).

[96] Milar, Brandon. “Porous Asphalt Pavements with Stone Recharge Beds.” California Asphalt Pavement Association. (10 March 2012): 53.

---

[97] Milar, Brandon. “Porous Asphalt Pavements with Stone Recharge Beds.” California Asphalt Pavement Association. (10 March 2012): 53.

[98] Milar, Brandon. “Porous Asphalt Pavements with Stone Recharge Beds.” California Asphalt Pavement Association. (10 March 2012): 52.

[99] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[100] Milar, Brandon. “Porous Asphalt Pavements with Stone Recharge Beds.” California Asphalt Pavement Association. (10 March 2012): 52.

[101] Willie Gonwa, PE, PhD. “Installing Porous Pavement: Waukesha County Dept. of Parks and Land Use Stormwater BMP Design and Installation Workshop. (11 March 2009). <http://www.waukeshacounty.gov/uploadedFiles/Media/PDF/Parks_and_Land_Use/Land_Conservation/Stormwater/2009_Workshop/2_-_Gonwa_-_Porous_Ravement.pdf> (10 March 2012): 12.

[102] Willie Gonwa, PE, PhD. “Installing Porous Pavement: Waukesha County Dept. of Parks and Land Use Stormwater BMP Design and Installation Workshop. (11 March 2009). (10 March 2012): 29.

[103] He Liandi. “Water Percolation on Road Surfaces to Absorb Pollution.” *Wenhui Daily.* (29 October 2009). In Chinese. (4 April 2012).

[104] He Liandi. “Water Percolation on Road Surfaces to Absorb Pollution.” *Wenhui Daily.* (29 October 2009). In Chinese. (4 April 2012).

[105] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012): 26.

[106] Jacqueline Hoyer et al. “Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future.” Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[107] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[108] City of Vancouver Engineering Services. *“Country Lanes.”* (2002). (4 April 2012*).*

[109] University of Rhode Island Cooperative Extension in Partnership with the Rhode Island Department of Health Source Water Protection Program. “The University of Rhode Island’s Permeable Parking Lots: A Case Study of Alternative Pavement Materials.” <http://www.uri.edu/ce/wq/NEMO/Publications/PDFs/PP.URICaseStudy.pdf> (20 March 2012): 5-6.

[110] Lebens, M. Minnesota DOT Test Facility - "Porous Asphalt Pavement Performance in Cold Regions" Unpublished Report, December 2010, Office of Materials and Road Research, Minnesota Department of Transportation

[111] Glenn Elert, Ed. “Volume of New York City’s Annual Precipitation.” The Physics Factbook. (2005). <http://hypertextbook.com/facts/2005/LauraDePalma.shtml> (10 April 2012). Derived from 1961-1990 NOAA Climate Data.

[112] New York City Office of Emergency Management. “Natural Hazard Mitigation Plan.” (2009). <http://www.nyc.gov/html/oem/downloads/pdf/hazard_mitigation/section_3j_flooding_hazard_analysis.pdf> (10 April 2012): 142-143. Storm events were modeled on the year 2000 storm data from this plan.

[113] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (20 March 2012): 41.

[114] New York City Department of Environmental Protection. “NYC Green Infrastructure Plan.” (18 March 2012): i.

[115] United States Environmental Protection Agency. “Reducing Urban Heat Islands: Compendium of Strategies.” (2005). <http://www.epa.gov/heatisld/itigation/pavements.htm> (10 April 2012).

[116] United States Environmental Protection Agency. “Reducing Urban Heat Islands: Compendium of Strategies.” (2005). (10 April 2012).

[117] New York City Rent Guidelines Board. “Explanation of the Rent Guidelines: Process By which the Rent Guidelines Board Determines the Guidelines.” <http://www.housingnyc.com/html/guidelines/guidelines.html> (10 April 2012)

[118] Per Conversations with NYC DOT. (24 April 2012)

[119] New York City Department of City Planning (NYC DCP). “About Us: Our Mission.” <http://www.nyc.gov/html/dcp/html/subcats/about.shtml> (5 April, 2012).

[120] Details in this paragraph obtained directly from NYC DOT. (24 April 2012).

[121] City of New York, The. “The Mayor’s Management Report: Fiscal 2011.” (September 2011). <http://www.nyc.gov/html/ops/downloads/pdf/mmr/0911_mmr.pdf> (20 April 2012).

---

[122] Details in this paragraph obtained directly from NYC DOT. (24 April 2012).
[123] Steven Cohen. "Everyone's Backyard: Parks in New York City." *The Huffington Post*. (12 April 2010). <http://www.huffingtonpost.com/steven-cohen/everyones-backyard-parks_b_533815.html> (4 April 2012).
[124] Living City Block LLC. "Brooklyn Gowanus: About Us." <http://www.livingcityblock.org/living-city-brooklyn/1782-2/> (15 April 2012).
[125] New York City Department of Environmental Conservation. "Wastewater Infrastructure Needs of New York State Report." <http://www.dec.ny.gov/chemical/42383.html> (15 April 2012).
[126] New York City Department of Environmental Protection. "Green Infrastructure Grant Program." (2012). <http://www.nyc.gov/html/dep/pdf/green_infrastructure/2012_gi_grant_workshop_presentation.pdf> (20 March 2012).
[127] New York City Department of Environmental Protection. "Green Infrastructure Grant Program." (2012). (20 March 2012).
[128] This is a recommendation of the study team and is not externally cited.
[129] New York City Department of Environmental Protection. "Green Infrastructure Grant Program." (2012). (20 March 2012).
[130] United States Environmental Protection Agency, Regional Pollution Prevention Program Offices. "Funding Opportunity Announcement: Request for Proposals." <http://www.epa.gov/p2/pubs/grants/srap/srap12.pdf> (20 March 2012): 1.
[131] United States Environmental Protection Agency, Regional Pollution Prevention Program Offices. "Funding Opportunity Announcement: Request for Proposals." <http://www.epa.gov/p2/pubs/grants/srap/srap12.pdf> (20 March 2012): 1.
[132] United States Environmental Protection Agency, Regional Pollution Prevention Program Offices. "Funding Opportunity Announcement: Request for Proposals." (20 March 2012).
[133] United States Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics, Regional Pollution Prevention Program offices. "Fiscal Year 2012 Pollution Prevention Grant Program: Request for Proposals." <http://www.epa.gov/p2/pubs/grants/ppis/2012rfpp2grant.pdf> (20 April 2012).
[134] United States Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics, Regional Pollution Prevention Program offices. "Fiscal Year 2012 Pollution Prevention Grant Program: Request for Proposals." <http://www.epa.gov/p2/pubs/grants/ppis/2012rfpp2grant.pdf> (20 April 2012).
[135] United States Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention, Office of Pollution Prevention and Toxics, Regional Pollution Prevention Program offices. "Fiscal Year 2012 Pollution Prevention Grant Program: Request for Proposals." (20 April 2012).
[136] United States Environmental Protection Agency. Office of Children's Health Protection. "Building Capacity to Implement EPA Voluntary Guidelines for K-12 State, Tribal and Territorial School Environmental Health Programs." <http://www.epa.gov/schools/ehguidelines/downloads/RFA%20Schools%20EH%20Guidelines.pdf> (27 April 2012).
[137] United States Environmental Protection Agency. Office of Children's Health Protection. "Building Capacity to Implement EPA Voluntary Guidelines for K-12 State, Tribal and Territorial School Environmental Health Programs." (27 April 2012).
[138] New York City Municipal Finance Authority. "Welcome to the New York City Municipal Water Finance Authority." <http://www.nyc.gov/html/nyw/home.html> (27 April 2012)
[139] New York City Municipal Finance Authority. "Welcome to the New York City Municipal Water Finance Authority." (27 April 2012)
[140] CRC Press. "Porous Pavements: Porous Asphalt." (2005). <http://www.crcnetbase.com/doi/pdfplus/10.1201/9781420038439.ch12> (4 April 2012).
[141] The Weather Channel. "Average Weather for Chandler, AZ." <http://www.weather.com/outlook/health/allergies/wxclimatology/monthly/graph/USAZ0034> (10 April 2012).
[142] The Weather Channel. "Average Weather for Chandler, AZ." (10 April 2012).
[143] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. "Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report." (July 1988). <http://www.azdot.gov/TPD/ATRC/publications/project_reports/PDF/AZ227-first.pdf> (12 March 2012).

---

[144] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012).

[145] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012).

[146] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012).

[147] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012): 30.

[148] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012): 28.

[149] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012).

[150] Portland Bureau of Environmental Services. “North Gay Avenue: Portland, Oregon.” <http://www.portlandonline.com/bes/index.cfm?a=196785&c=44953> (4 April 2012).

[151] W.R. Jr., Meir, PhD and Edward Elnicky, PE. Western Technologies Inc. Arizona Department of Transportation. “Porous Pavement for Control of Highway Runoff: First Annual Monitoring Report.” (July 1988). (12 March 2012).

[152] The Weather Channel. “Average Weather for Salem, OR.” <http://www.weather.com/weather/wxclimatology/monthly/graph/97301> (10 April 2012).

[153] Portland Bureau of Environmental Services. “Pervious Pavement Projects: A New Approach to Stormwater Management.” <http://www.portlandonline.com/bes/index.cfm?c=45435&a=77074> (4 April 2012).

[154] Portland Bureau of Environmental Services. “Pervious Pavement Projects: A New Approach to Stormwater Management.” <http://www.portlandonline.com/bes/index.cfm?c=45435&a=77074> (4 April 2012).

[155] Portland Bureau of Environmental Services. “North Gay Avenue: Portland, Oregon.” <http://www.portlandonline.com/bes/index.cfm?a=196785&c=44953> (4 April 2012).

[156] Portland Bureau of Environmental Services. “North Gay Avenue: Portland, Oregon.” (4 April 2012).

[157] Portland Bureau of Environmental Services. “Sustainable Infrastructure: Alternative Paving Materials Subcommittee Report.” (3 October 2003). <http://www.portlandonline.com/bes/index.cfm?a=53556&c=45382> (4 April 2012).

[158] Portland Bureau of Environmental Services. “Sustainable Infrastructure: Alternative Paving Materials Subcommittee Report.” (3 October 2003). (4 April 2012).

[159] Portland Bureau of Environmental Services. “Sustainable Infrastructure: Alternative Paving Materials Subcommittee Report.” (3 October 2003). (4 April 2012).

[160] Portland Bureau of Environmental Services. “Sustainable Infrastructure: Alternative Paving Materials Subcommittee Report.” (3 October 2003). (4 April 2012).

[161] Marty Wanielista and Manoj Chopra. “Performance Assessment of Portland Cement Pervious Pavement: Report 4 of 4, Performance Assessment of a Pervious Concrete Pavement Used as a Shoulder for an Interstate Rest Area Parking Lot.” A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection.” (June 2007). <http://www.dot.state.fl.us/research-center/Completed_Proj/Summary_RD/FDOT_BD521_02_rpt4.pdf> (10 April 2012).

[162] Climate Zone. “Climate Information for Philadelphia, Pennsylvania.” <http://www.climate-zone.com/climate/united-states/pennsylvania/philadelphia/> (13 April 2012).

[163] Climate Zone. “Climate Information for Philadelphia, Pennsylvania.” (13 April 2012).

[164] Marty Wanielista and Manoj Chopra. “Performance Assessment of Portland Cement Pervious Pavement.” A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection.” (June 2007). (10 April 2012).

---

[165] Marty Wanielista and Manoj Chopra. “Performance Assessment of Portland Cement Pervious Pavement.” A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection.” (June 2007). (10 April 2012).

[166] Marty Wanielista and Manoj Chopra. “Performance Assessment of Portland Cement Pervious Pavement.” A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection.” (June 2007). (10 April 2012).

[167] Marty Wanielista and Manoj Chopra. “Performance Assessment of Portland Cement Pervious Pavement.” A Joint Research Program of the State of Florida Department of Transportation, Rinker Materials, and the Florida Department of Environmental Protection.” (June 2007). (10 April 2012).

[168] Information in this case study was obtained in an April 5, 2012, interview with Peter Reilly, Civil Engineer at the Philadelphia Water Department.

[169] Climate Zone. “Climate Information for Philadelphia, Pennsylvania.” (13 April 2012).

[170] Climate Zone. “Climate Information for Philadelphia, Pennsylvania.” (13 April 2012).

[171] Stormwater Solutions. “Case Study: Pringle Creek Green Streets.” <http://www.lcog.org/documents/sub_action/LID_CaseStudy_PringleCreekGreenStr.pdf> (20 April 2012).

[172] The Weather Channel. “Average Weather for Salem, OR.” (10 April 2012).

[173] The Weather Channel. “Average Weather for Salem, OR.” (10 April 2012).

[174] Climate Zone. “Climate Information for Olympia, Washington.” <http://www.climate-zone.com/climate/united-states/washington/olympia/> (13 April 2012).

[175] Climate Zone. “Climate Information for Olympia, Washington.” <(13 April 2012).

[176] City of Olympia, Washington, The. “North Street Reconstruction Project: Summary of Porous Concrete Sidewalk.” <http://olympiawa.gov/city-utilities/storm-and-surface-water/science-and-innovations/~/media/Files/PublicWorks/Water-Resources/North_Street_Reconstruction_Project_Porous_Concrete_Summar.ashx> (4 April 2012).

[177] City of Olympia, Washington, The. “North Street Reconstruction Project: Summary of Porous Concrete Sidewalk.” (4 April 2012).

[178] City of Olympia, Washington, The. “North Street Reconstruction Project: Summary of Porous Concrete Sidewalk.” (4 April 2012).

[179] City of Olympia, Washington, The. “North Street Reconstruction Project: Summary of Porous Concrete Sidewalk.” (4 April 2012).

[180] Tosomeen, P.E. City of Olympia Public Works Water Resources. “Pervious Concrete Bicycle Lanes.” <http://olympiawa.gov/city-utilities/storm-and-surface-water/science-and innovations/~/media/Files/PublicWorks/Water-Resources/RWJohnsonASCEPresentation_PerviousConcreteBicycleLanes.ashx> (29 April 2012).

[181] *City of Vancouver Engineering Services. “Country Lanes.” (2002).* (4 April 2012).

[182] Environment Canada. “National Climate Data and Information Archive: Canadian Climate Normals 1971-2000.” (9 March 2012). <http://www.climate.weatheroffice.gc.ca/climate_normals/results_e.html?stnID=888&lang=e&dCode=0&StationName=VANCOUVER&SearchType=Contains&province=ALL&provBut=&month1=0&month2=12> (1 April 2012).

[183] Environment Canada. “National Climate Data and Information Archive: Canadian Climate Normals 1971-2000.” (9 March 2012). (1 April 2012).

[184] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[185] Japan Meteorological Agency. In Japanese. <http://www.data.jma.go.jp/obd/stats/etrn/view/nml_sfc_ym.php?prec_no=44&prec_ch=東京都&block_no=47662&block_ch=東京&year=&month=&day=&view=p1> (1 April 2012).

[186] The Weather Network. “Statistics: Tokyo, Japan.” <http://www.theweathernetwork.com/statistics/c01022> (1 April 2012).

[187] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[188] Danish Road Institute. “Noise Reducing Pavements in Japan – Study Tour Report.” DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[189] http://members.jcom.home.ne.jp/0710034301/031i10IAWQHUNGARYpaper.htm

---

[190] Danish Road Institute. "Noise Reducing Pavements in Japan – Study Tour Report." DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[191] Danish Road Institute. "Noise Reducing Pavements in Japan – Study Tour Report." DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[192] CRC Press. "Porous Pavements: Porous Asphalt." (2005). (4 April 2012).

[193] CRC Press. "Porous Pavements: Porous Asphalt." (2005). (4 April 2012).

[194] Danish Road Institute. "Noise Reducing Pavements in Japan – Study Tour Report." DRI-DWW Noise Abatement Program. (December 2005). (4 April 2012).

[195] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[196] Weatherbase. "Historical Weather for Stuttgart, Germany." (2009). <http://www.weatherbase.com/weather/weather.php3?s=083701&refer> (1 April 2012)

[197] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[198] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[199] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[200] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[201] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[202] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012). Exchange rate drawn from <http://xxw3441.blog.163.com/blog/static/7538362420110372249589/> based on the data published by the European Union.

[203] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[204] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[205] Jacqueline Hoyer et al. "Water Sensitive Urban Design: Principles and Inspiration for Sustainable Stormwater Management in the City of the Future." Jovis Jovis Verlag GmbH, Kufurstenstrabe 15/16, D-10785 Berlin. (March 2011). (4 April 2012).

[206] Dierkes, Carste and Lothar Kuhlmann, Jaya Kandasamy, and George Angelis. "Pollution Retention Capability and Maintenance of Permeable Pavements." <http://www.psparchives.com/publications/our_work/stormwater/lid/paving_docs/Permeable%20Paving%20Pollution%20Processing-Dierkes.pdf> (10 April 2012).

[207] United States Environmental Protection Agency. "National Pollutant Discharge Elimination System. Porous Asphalt Pavement." (4 April 2012).

[208] University of New Hampshire Stormwater Center, The. "Porous Pavement for Stormwater Management." (4 April 2012).

[209] Robert Roseen et al. "Porous Pavements in Cold Climates: Part 1 – Design, Installation, and Maintenance." University of new Hampshire Stormwater Center, Department of Civil Engineering. (March 2011). <http://www.unh.edu/unhsc/sites/unh.edu.unhsc/files/presentations/Porous%20Pavements%20in%20Cold%20Climates%20Part%201.pdf> (4 April 2012).

---

[210] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[211] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[212] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).

[213] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[214] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).

[215] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[216] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[217] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[218] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[219] United States Environmental Protection Agency. “National Pollutant Discharge Elimination System. Porous Asphalt Pavement.” (4 April 2012).

[220] University of New Hampshire Stormwater Center, The. “Porous Pavement for Stormwater Management.” (4 April 2012).