Columbia University

Leveraging the Multiple Benefits of Green Infrastructure

Sustainability Management Capstone Project for
New York City's Department of Environmental Protection

Fall 2013

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COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

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Dear Reader,

This report was prepared by a team of graduate students from Columbia University's Masters of Science in Sustainability Management, co-sponsored by the Earth Institute and the School of Continuing Education.

The capstone workshop is a client-based consulting project that students undertake to address real life sustainability issues. The workshop is designed to integrate the program's distinct curriculum areas, including: integrative sustainability management, economics and quantitative analysis, environmental sciences, engineering, planning and public policy.

Sincerely,

Abigail Santner
Capstone Manager

Andrea Moore
Capstone Manager

LIST OF FIGURES & TABLES

LIST OF ACRONYMS

Community: New York City Community District
CSO: Combined Sewer Overflow
DEC: New York State Department of Environmental Conservation
DEP: New York City Department of Environmental Protection
DOH: New York City Department of Health and Mental Hygiene
DOT: New York City Department of Transportation
EPA: U.S. Environmental Protection Agency
GI: Green Infrastructure
GIS: Geographic Information Systems
Grant Program: DEP Green Infrastructure Grant Program
NYC: New York City
OLTPS: Office of Long Term Planning and Sustainability
PlaNYC: New York City's long-term sustainability plan
PM 2.5: Particulate Matter 2.5 (micrometers in diameter)
The Team: Columbia University M.S. in Sustainability Management Capstone Group

EXECUTIVE SUMMARY

Like many iconic cities, New York is defined by its waterways, but during even minor rainstorms those scenic waters are quickly degraded. The problem lies in a combined sewer system that delivers wastewater from buildings, and stormwater from city streets, to wastewater treatment plants that lack the capacity to keep up. Overwhelmed treatment plants are often forced to send a mix of raw sewage and stormwater directly into city waters.

In a new approach to improving water quality in greater New York Harbor, the NYC Department of Environmental Protection (DEP) plans to invest $1.5 billion in a mix of grey and green infrastructure by 2030. Green infrastructure absorbs rain where it falls, providing a natural, cost-effective alternative to "grey" solutions like holding tanks. Most of the green infrastructure money will be spent on rain gardens, bioswales and other installations along public sidewalks and roads, but a portion will be spent on projects on private land. To incentivize property owners, DEP offers grants of $35,000 or more under its Green Infrastructure Grant Program. Applicants in priority watersheds, where combined sewer overflows are heaviest, receive preference.

Beyond stormwater capture, green infrastructure provides additional benefits--cleaning and cooling the air, reducing energy use and creating jobs, among other community improvements. We were asked by the DEP to consider the ways that the multiple benefits of green infrastructure might be incorporated into its Grant Program and larger green infrastructure planning process.

To approach the problem, we identified a list of scientifically-based community vulnerability indicators that could be addressed by green infrastructure's main benefits:

- Urban Heat Island Reduction
- Energy Reduction
- Improved Air Quality
- Improved Quality of Life

Using Geographic Information System (GIS) mapping and Excel to analyze data we gathered, we developed an optimization tool that can help the DEP begin to create profiles of NYC communities where green infrastructure can be most effective in reducing combined sewer overflows while addressing additional public health and environmental needs.

The results of our analysis indicate that DEP could maximize the benefits of green infrastructure in the Bronx's East Tremont-Belmont neighborhoods, where the effects of poor air quality take an unacceptably high toll on children and the elderly. We identified two private institutions that own large amounts of land in these

neighborhoods—Fordham University and St. Barnabas Hospital—that the DEP might consider approaching to apply for grants. With a mission in education and public health both Fordham and St. Barnabas are well positioned to win a grant.

While these serve as examples of a starting place for additional green infrastructure on private land, we suggest that DEP focus on public installations, as well as private, in NYC's most vulnerable neighborhoods such as East Tremont-Belmont. Initial research shows that while some green infrastructure, such as green roofs, can have small-scale impact by reducing energy use at the building level, in most cases a critical mass of green infrastructure installations are needed to broadly improve air quality or reduce urban heat islands.

Benchmarking cities outside NYC brought us to Birmingham, England, which created a similar tool for optimizing green infrastructure that has led to greater transparency in the city's planning process. By highlighting the multiple benefits of green infrastructure, the tool may improve public support for green investments and incentivize stakeholders to share in the cost. We believe that the tool we developed for DEP can be a starting point in taking a more scientific approach to siting green infrastructure in NYC to make the City a healthier, more livable place.

INTRODUCTION

Problem Statement

Like many older municipalities, New York City has a combined sewer system that treats sewage, industrial waste, and stormwater runoff from city streets and buildings. Living up to its nickname, the Big Apple, NYC processes 1.3 billion gallons of wastewater each day[1] while Philadelphia, the next largest combined sewer system in the U.S., processes only 310 million gallons a day.[2]

Impervious roads, buildings and sidewalks cover nearly three-quarters of New York City. When it rains, stormwater rushes off these impermeable surfaces into the City's combined sewer system and eventually in to NYC's wastewater treatment plants for processing. But even during minor rain events, treatment plants become overwhelmed and are forced to open their floodgates, releasing a mix of raw sewage and contaminated wastewater directly into NYC waterways. As little as one tenth of one inch of rain is enough to generate a combined sewer overflow (CSO).

CSOs deliver pathogens, toxic pollutants, nitrogen and phosphorus into greater New York Harbor, producing algal blooms and forcing the closure of public beaches and shellfish beds.[3] Nearly half of New York State's 937 permitted CSO outfall pipes are in and around NYC,[4,5] releasing approximately 30 billion gallons of stormwater pollution each year, or nearly 82 million gallons each day.[6]

The New York City Department of Environmental Protection (DEP), which oversees the city water supply and sewer system, has been under a longstanding mandate by the U.S. Environmental Protection Agency (EPA) to reduce CSOs under the federal Clean Water Act. In a historic agreement in 2012, the New York State Department of Environmental Conservation (DEC) agreed to allow DEP to use a mix of green and grey infrastructure to address its CSO problem.[7]

A Sustainable NYC

In 2007, the City's first sustainability report, PlaNYC, argued for reducing CSOs to restore the health of New York Harbor and increase recreational opportunities.[8] The Sustainable Stormwater Management Plan was released by the City in 2008 and outlined how PlaNYC goals for water quality could be met. In 2010, DEP published its Green Infrastructure (GI) Plan, which pledged to spend $5.3 billion to eliminate 12 billion gallons of CSOs by 2030 through a cost-effective mix of grey and green infrastructure.[9] While grey infrastructure is necessary in areas unable to meet water quality goals through green infrastructure alone, it provides few additional benefits.

Green Infrastructure

Green infrastructure captures stormwater where it falls, harnessing soil, trees, and other plants to naturally absorb and filter excess water. Under its GI Plan, the DEP

proposed using green infrastructure to capture the first inch of rain on 10 percent of impervious surfaces in combined sewer areas to eliminate an estimated 1.5 billion gallons of CSOs by 2030. By incorporating green infrastructure into its CSO reduction plans and building fewer grey infrastructure pipes and tunnels, DEP estimates that New Yorkers will save $2.4 billion by 2030. Moreover, green infrastructure may boost property values, reduce energy costs, and improve community health, providing between $139 million and $418 million in additional benefits.[10] While some green infrastructure, such as green roofs, can have small-scale impact by reducing energy use at the building level, in most cases a critical mass of green infrastructure installations are needed to broadly improve air quality or reduce urban heat islands.

DEP's Green Infrastructure Grant Program

DEP has developed a grant program to incentivize green infrastructure on private land to complement the GI Plan, which is focused on building green infrastructure on public land, including roads and sidewalks. More than half the land in New York City is privately owned, dotted with rooftops and other impervious surfaces that represent enormous greening opportunities for the DEP.[11] DEP's Green Infrastructure Grant Program awards grants to property owners who can demonstrate that their proposed project will capture and treat the first inch of rainfall on site, with preference given to projects in "priority watersheds," or areas with high CSO rates.[12] Of the 13 designated watersheds in NYC, seven are considered priority areas, where DEP would like to avoid building additional grey infrastructure.[13] Since 2011, the DEP's Grant Program has committed $11.5 million to 29 green infrastructure projects.[14]

DEP's Long Term Control Plan

One of DEP's focuses on public land is with their Long Term Control Plan sites. DEP is monitoring 11 long-term projects as part of its agreement with DEC. Measurements from these pilot projects will ensure that the green infrastructure installed across the city is reducing CSOs by the targeted amount. The pilot projects began in late 2012 and will be developed through 2018.[15]

Project Scope

This project was commissioned by DEP's Climate & Water Quality program to explore ways that the additional benefits of green infrastructure could be identified and maximized. To understand how the benefits of green infrastructure could be maximized, we identified through research and spatial-relationship mapping the most vulnerable communities in NYC where green infrastructure could do the most good.

We developed a tool that provides a scientific framework for matching the additional benefits of green infrastructure with NYC's most vulnerable communities according to a set of leading public health and environmental indicators. The tool can help DEP target the most vulnerable communities within its priority

watersheds, allowing the agency to meet both its water-quality goals and PlaNYC sustainability goals.

We researched green infrastructure plans in the U.S. and abroad to look for best practices in funding and implementing projects on private land. We combined this information with results from our analysis of NYC communities that could benefit most from additional green infrastructure to develop a series of recommendations for the strategic implementation of green infrastructure.

Project Deliverables

In consideration with the client, we produced the following project deliverables:

- Analysis of the additional benefits of green infrastructure with recommendations for optimizing those benefits
- Analysis of green infrastructure case studies for the U.S. and abroad
- Geographic Information Systems maps (GIS) including raster maps and vector map files
- Optimization tool to identify New York City's most vulnerable communities
- Presentation of findings to NYC DEP staff

METHODOLOGY

Key Questions

In collaboration with the client, we identified the following key questions:

- What are the scientifically proven additional benefits of green infrastructure?
- How could DEP maximize each dollar spent by returning the largest number of benefits to communities in priority watersheds?
- How are other cities effectively implementing their green infrastructure grant programs?
- What community-based resources are available in NYC to help expand installations of green infrastructure?

Approach

We decided to address the client's research questions by:

I. Benchmarking Best Practices Used by Other Cities in Administering Their Grant Programs

II. Analyzing DEP's Grant Recipients to Date Using GIS Mapping

III. Analyzing Research to Select 14 Leading Indicators of Community Vulnerability

IV. Developing GIS Maps to Identify Vulnerable Communities

V. Developing an Optimization Tool That Provides a Scientific Framework for Locating Green Infrastructure in Places Where its Benefits can be Optimized

VI. Identifying Local NYC Resources and Organizations That Could be Leveraged in Implementing Green Infrastructure Installations

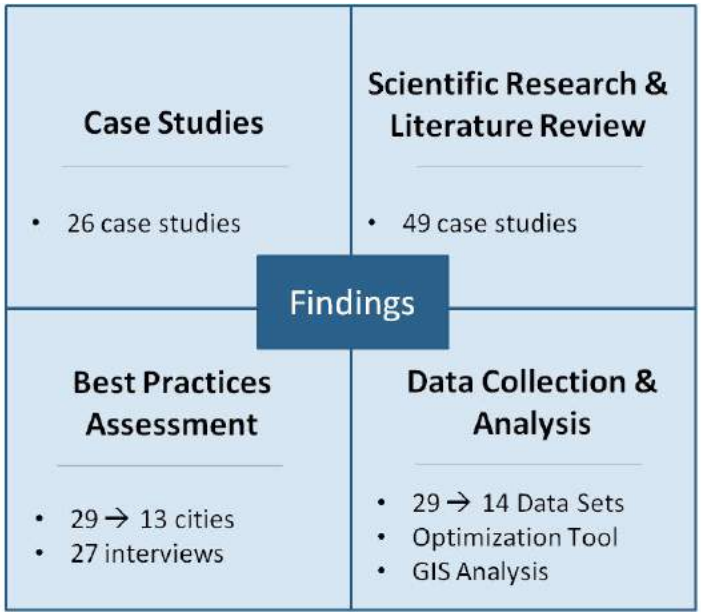


Figure 1: Overview of Methodology

I. Benchmarking Best Practices Used by Other Cities in Administering Their Grant Programs

In reviewing case studies by the U.S. EPA, Natural Resources Defense Council, and University of Manchester, among others, we identified 29 cities in the U.S. and abroad that are leaders in green infrastructure implementation.

For the purpose of this project, we focused on cities that excelled in three main areas:

1. Innovative funding strategies
2. Collaborations with local partners
3. Effective public outreach

From these criteria, the Team selected 13 cities and interviewed 16 key officials in these cities to learn more about the outcome of their grant programs, leveraging of outside funding, and public outreach.

Best Practice Cities Selected	Interviewees
Basel, Switzerland	Dr. Stephan Brenneisen
Birmingham, UK	Nick Grayson
Chicago, Illinois	Sarita Upadhyay
Los Angeles, California	--
Malmo, Sweden	--
Milwaukee, Wisconsin	Breanne L. McDonald
Nagoya, Japan	--
Philadelphia, Pennsylvania	Erin Williams
Portland, Oregon	Matt Burlin
	Amber Clayton
	Alice Coker
	Alisa Kane
	Clark Yokom
Seattle, Washington	Bob Spencer
	Tracey Tackett
Stuttgart, Germany	Ulrich Reuter
Syracuse, New York	Madison Quinn
Washington, D.C.	Leah Lemoine
	Evan Branosky

Table 1: Cities Selected and Administrators Associated Interviewed

II. Analyzing DEP's Grant Recipients to Date Using GIS Mapping

We mapped the 29 GI grant recipients to date and discovered that 72 percent of the approved projects are in the East River watershed, an area eligible for green infrastructure but not a DEP-designated "priority watershed." In discussions with DEP, we learned that the agency has not received enough qualified applications in its priority watersheds to award more grants there. In its award criteria, DEP gives preference to installations in priority watersheds that can reduce energy use, improve air quality and meet other sustainability goals. But so far, applicants have mostly stressed education and job training in their applications, according to DEP press releases.[16]

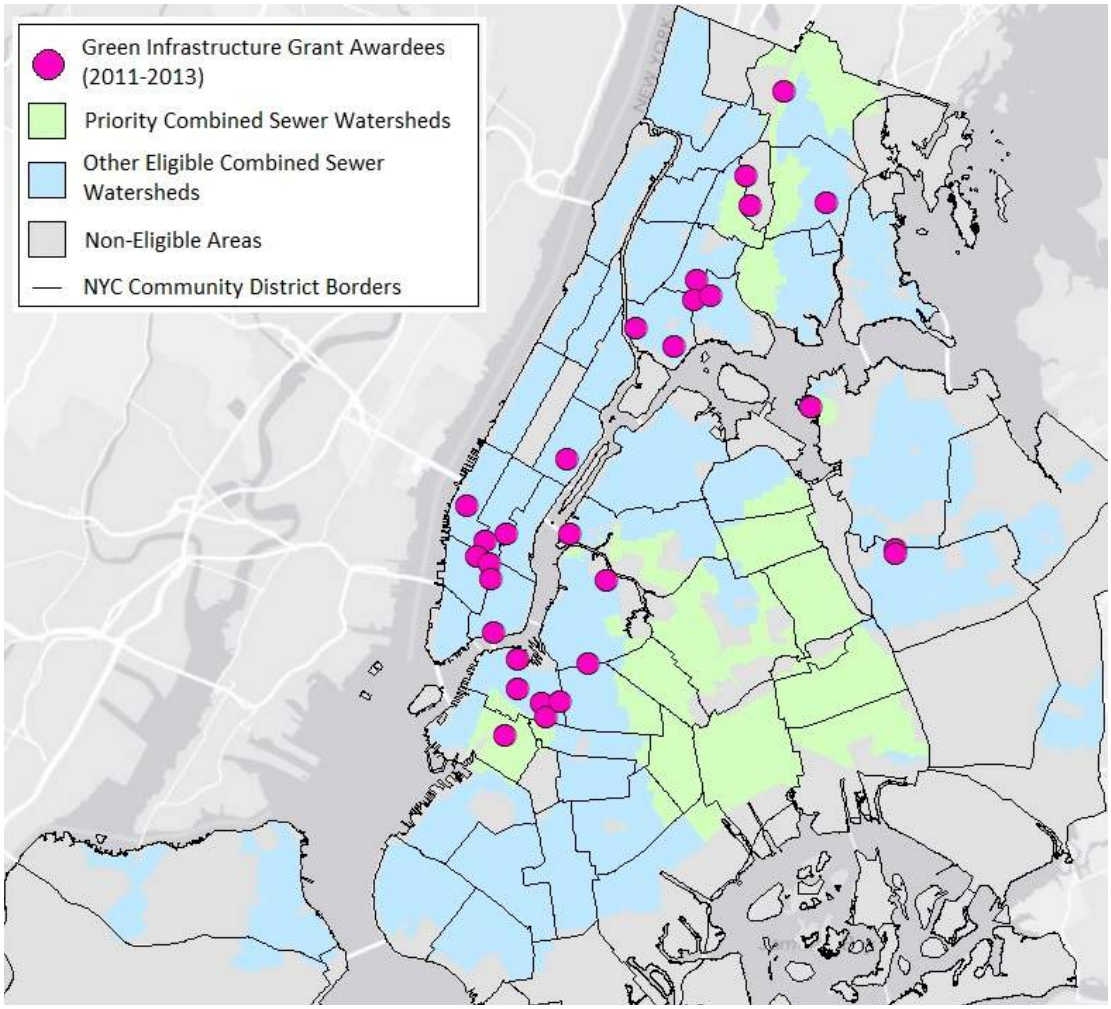


Figure 2: Map of Green Infrastructure Grant Awardees from 2011 to 2013

III. Analyzing Research to Select 14 Leading Indicators of Community Vulnerability

We developed a set of criteria that would allow DEP to match additional benefits of green infrastructure with important indicators of community vulnerability. In a review of scientific literature and public policy reports, we developed a list of

widely-accepted vulnerability indicators that green infrastructure can address. We focused datasets available through the DEP, U.S. Census Bureau, and NYC OpenData, among others, to retrieve community-specific data in NYC. Ultimately, we narrowed down a list of vulnerability indicators from 29 to 14, to populate the optimization tool.

We identified four broad benefit categories of green infrastructure based on scientific evidence:

- Urban Heat Island Reduction
- Air Quality Improvement
- Energy Use Reduction
- Community Factors

Urban Heat Island Reduction

Covered in concrete and asphalt, the urban landscape traps the sun's heat by day and prevents cities from cooling off at night. The resulting urban heat island effect makes cities hotter than the surrounding countryside by 18° to 27° Fahrenheit (F).[17] Urban heat islands not only make it hard to sleep at night, they increase energy use, impact air quality, and can raise the chance of heat stroke or even death.

Though urban heat islands can be measured directly, we did not have access to instrumental data in Excel format and therefore selected an indirect measure, *heat stress hospitalizations*, to find out where in the city people are most at risk of heat-related illness. Because age is also a risk factor for heat stress, we added an additional vulnerability multiplier for *people under 15* and *over the age of 65*. Studies show that the elderly are at greater risk for heat stroke because of their age, greater use of prescription drugs, and underlying medical conditions. Poverty is also an issue for heat stress vulnerability since the poor often lack access to air-conditioning, therefore we added *households below the poverty line* as an additional vulnerability multiplier.

Green infrastructure vegetation combats urban heat islands by reflecting the sun's energy and by cooling the air through evapotranspiration, reducing temperatures by as much as 5°F. A 2010 study led by Columbia University scientist Stuart Gaffin, found that a green roof in Queens was up to 6°F cooler than its asphalt counterpart.[18]

Energy Reduction

When it gets hot, New Yorkers use more air conditioning, forcing power plants to increase output to meet peak demand. The added energy use increases air pollution and strains the electric grid, putting NYC at risk of blackouts. The Team pulled electricity-use data from across NYC to gauge where usage is greatest, and where the trees and plants used in green infrastructure could help reduce demand.

Green infrastructure has proven air-cooling benefits. The U.S. Department of Energy estimates that vegetated surfaces can reduce city air temperatures by 5.4°F, creating up to $6 billion per year in energy savings nationally.[19] A 2007 study by the NYC Department of Design & Construction finds that for each degree Fahrenheit reduced, NYC could save $82 million per year in reduced energy costs.[20] Cities can achieve even greater savings when green infrastructure replaces mechanical systems for processing stormwater. DEP estimates that its "Green Strategy," on average will cost 27 percent less per gallon of CSO reduction than a traditional engineering approach.[21]

Improved Air Quality

Emissions from cars and trucks, as well as from power plants that supply city buildings with heat and electricity, significantly affect NYC's air quality. At peak demand, power plants emit greater amounts of carbon dioxide and air pollutants such as sulfur dioxide, nitrogen oxide, and fine particulates. Particulates also react with heat to form ground-level ozone, or smog, putting people at added risk for asthma. [22]

We selected *asthma hospitalization rates* as an indicator for poor air quality.[23] The World Health Organization (WHO) estimates that breathing more than 10 micrograms of Particulate Matter (PM) 2.5 per cubic meter of air (ug/m3) increases the risk of respiratory and cardiovascular disease, particularly in children and other vulnerable populations.[24] We also selected *levels of ozone* and *particulate matter 2.5*, and *deaths due to respiratory disease*, as vulnerability indicators, further using the *percentage of children under the age of 15* and *adults older than 65* as vulnerability multipliers. Children are at greater risk for respiratory illness when their lungs are developing,[25] while people over 65 are more sensitive to air pollution as inhaled pollutants further diminish lung capacity.

Green infrastructure has proven air-cleaning benefits. Vegetation absorbs carbon dioxide from the air and traps ozone, small particles and other pollutants. A 2013 study by the EPA found that a green roof as small as 1,000 square feet could remove 40 pounds of particulates per year.[26] A 2013 study by the U.S. Forest Service and Davey Institute found that NYC trees, by filtering fine particulates, save eight lives each year, worth an estimated $60 million.[27]

Community Factors

Cities often face a range of social and environmental ills, including higher rates of poverty, unemployment, crime, obesity and mental illness. Poorer neighborhoods may have less space for walking and recreation, and fewer stores to shop for healthy food. A 2006 study by the American Journal of Preventive Medicine found that people in poor neighborhoods are more likely to develop learning disabilities as children, and to become mentally ill, unemployed, abuse drugs, and commit crimes using drugs as adults.[28]

We selected several indicators for communities that face severe social and environmental challenges: *obesity* and *unemployment* rates, and amount of *open space* for recreation.

By improving the aesthetics of a community, green infrastructure may encourage people to walk more, alleviating obesity. Evidence also shows that green infrastructure provides employment. American Rivers estimates that greening 49 billion square feet of rooftop would create 190,000 jobs.[29] An Alliance for Water Efficiency study found that a $10 billion investment in water efficiency programs could grow the U.S.'s Gross Domestic Product by up to $15 billion while creating 150,000 to 220,000 jobs.[30]

Benefit Type	GIS Mapping Metric	Optimization Tool Metrics	Sources	Data Normalization
Stormwater Management	Priority Watershed Areas	Priority Watershed Areas	DEP data set	
	311 Complaints: Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged	311 Complaints: Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged	NYC Open Data 2010 - 2012	# of Complaints per 100,000 residents; 2010-2012
Air Quality Improvement	Fine Particulate Matter 2.5	Fine Particulate Matter 2.5	Department of Health (DOH) portal, annual average from 2009-2010	Annual Average
	Asthma Hospitalizations	Asthma Rates (2008-2010)	DOH portal, total ER visits from 2008-2010	Per 100,000 residents
	Respiratory Deaths	Respiratory Deaths	DOH portal, Chronic lower respiratory deaths per 100,000 residents; 2010	Per 100,000 residents
	Ozone	Ozone	DOH portal, 2-Year Annual Average 2009-2010	Annual Average
Urban Heat Island Reduction	Heat Stress Hospitalizations	Heat Stress Hospitalizations	Heat Illness: Bureau of Vital Statistics, NYC DOH 2010 vital statistics	Per 100,000 residents
	Reflection data - Vector maps only		USGS, Landsat 2010 data	
Energy Reduction	Electricty Usage	Electricty Usage	NYC Open Data, 2010	Per 100,000 residents; kWh used in millions
Community Factors	% Local Unemployment	% Local Unemployment	U.S. Census Bureau, 2009-2011 American Community	# Unemployed / # in Labor Force
	City Gardens	City Gardens	Department of Environmental Portection park land dataset	Percentage of local community
	Obesity Rates	Obesity Rates	New York Community Health Survey 2011, self-selecting obesity	Adult Obesity rate
Demographic Vulnerability Indicators	% Population <15	Land area	Department of City Planning, 2010	Percentage
	% Population 65+	% Population 65+	Department of City Planning, 2010	Percentage
	% Households with Income <$25k	% Households with Income <$25k	Department of City Planning, 2010	Percentage

Table 2: Benefit type and proxies used to measure benefit type as well as data sources and normalization used

IV. Developing GIS Maps to Identify Vulnerable Communities

To understand which communities in NYC are most vulnerable, we mapped our vulnerability indicators using GIS to identify the most at-risk communities across the benefit types. As Table 2 indicates, we sourced data sets from online portals, such as NYC Open Data, as well as from DEP. Mapping proved particularly important as GIS is able to integrate data from three geographic types and formats: community district, zip code and United Hospital Fund neighborhoods (UHFs). GIS translated zip codes and UHFs into community districts for the optimization tool while underlying data in both the GIS and the tool is identical.

GIS can be used to quickly identify the most vulnerable communities across NYC by combining all the indicators into one composite map. The maps that we created also visualize each benefit area and again combine these benefit areas into one composite map. These can be found in Appendix A. The optimization tool is able to rank communities according to 14 vulnerability areas. Each community receives a score based on its potential to benefit from green infrastructure.

V. Developing an Optimization Tool That Provides a Scientific Framework for Locating Green Infrastructure in Places Where Its Benefits Can be Maximized

To evaluate the multiple needs of NYC communities that might be addressed in part by green infrastructure, we developed a tool that could synthesize a wide range of community data. We built an optimization tool in Microsoft Excel, normalized the data by population (per 100,000 residents), and organized the data to show a range of indicators by community district. For example, *heat stress hospitalizations* can be compared against *unemployment*. We also converted all 14 vulnerability indicators into percentiles for each community district, allowing us to compare indicators across all 59 districts. Each community district receives a standardized score based on the sum of all 14 vulnerability indicators; communities with more vulnerable sub-populations receive a higher score.

VI. Identifying NYC Resources That Could be Leveraged to Implement Green Infrastructure

Our analysis of the Grant Program underscored the need for DEP to recruit more qualified applicants to optimize the health and environmental benefits of green infrastructure. We spoke with government officials in NYC and other cities to learn how they collaborate with outside groups. We also spoke with NYC community groups to understand the barriers they face in applying for grants and what opportunities may exist for organizations to collaborate in applying for grants. Lastly, we spoke with Grant Program recipients in priority watersheds to understand how much assistance they received and if they would be willing to guide future applicants. This information informed our recommendations for DEP.

Government Sustainability Professionals	Community-based Organizations
Lacey Shelby, NYC Department of Transportation	Yakima Peña, Cypress Hills Local Development
Howard Slatkin, City Planning	Gwen Schantz, Brooklyn Grange
Daynan Crull, Office of Long Term Planning	Angela Tovar, Sustainable South Bronx
Nette Compton, Parks Department	Rachel Crawford, DesigNYC
Lauren Sicilian, Economic Development Corporation	Rob Crauderueff, Storm Infrastructure Matters (S.W.I.M.) Coalition
Mikelle Adgate, DEP GI Grant Team	Jamie Stein, Pratt Institute
Sarah Bloom, DEP GI Grant Team	
Carolina Griggs, DEP	
Kate Shackleford, Bronx Economic Development Corporation	

Table 3: Interviews Conducted with NYC-based Resources

FINDING I

The multiple benefits of green infrastructure can be maximized in NYC's Bronx Community District 6, which our tool identified as the most vulnerable community in a priority watershed.

The GIS map in Figure 3 below highlights the community districts that can most benefit from green infrastructure based on our four benefit areas: urban heat island, energy, air quality and additional community factors, as well as additional vulnerability multipliers for age and income. The South Bronx, in dark red, faces some of the greatest public health and environmental challenges in NYC.

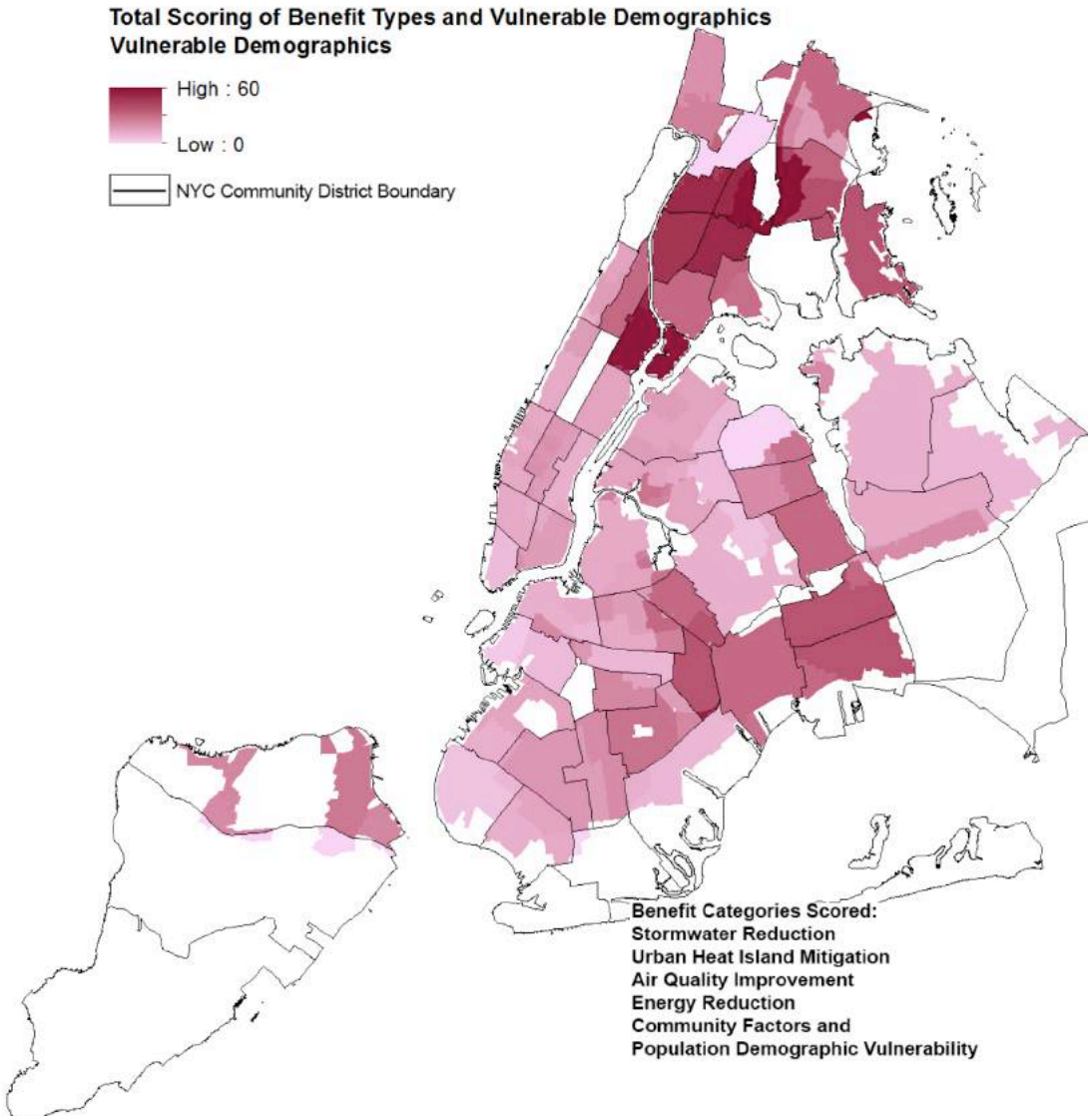


Figure 3: Composite Map Reflecting Community Districts Opportunity to Benefit from Green Infrastructure

Our optimization tool found that the South Bronx is home to NYC's five most vulnerable community districts scoring between 4.25 and 4.75 out of 5.0.

Ranking #	Borough	Community District #	Corresponding Neighborhood	Vulnerability Score
1	Bronx	3	Morrisania, Crotona Park East	4.75
2	Bronx	6	East Tremont, Belmont	4.57
3	Bronx	1	Melrose, Mott Haven, Port Morris	4.56
4	Bronx	5	University Heights, Fordham, Mt. Hope	4.41
5	Bronx	4	Highbridge, Concourse Village	4.27

Table 4: Ranking of Community Districts Based on Optimization Tool

All five communities are vulnerable to urban heat islands as indicated by heat stress hospitalizations, higher than average air pollution as measured by fine PM 2.5, ozone and asthma hospitalizations, and community risk factors such as high levels of unemployment and obesity, and low levels of open space. Making matters worse, the Bronx has higher than average percentages of children and people living in poverty, who are both more vulnerable to heat stress and air pollution.

Bronx Community District 6

Figure 4: Community District in the Bronx
Source: New York City Department of City Planning

With a score of 4.75, the East Tremont-Belmont neighborhood in Community District 6 (Bronx CD 6), highlighted in Figure 4, is the most vulnerable NYC community in a priority watershed.

The factors that led to Bronx CD 6's score of 4.75:

- Heat stress hospitalizations more than twice the NYC average
- Asthma hospitalizations more than three times the NYC average
- Half as much open space as the NYC average
- Unemployment 50 percent higher than the NYC average

Demographics weigh heavily as well. In CD 6, 54 percent of households live below the poverty line making less than $25,000 a year. Compared to NYC's average of 30 percent of households living below the poverty line, this makes CD 6 one of the poorest community districts in the Bronx, which is already one of the poorest urban counties in the country. Furthermore, 25 percent of the population is below the age of 15, compared to the NYC average of 18 percent, and eight percent of its population is over the age of 65. Therefore, poor air quality affects more people in CD 6, resulting in a more heavily-weighted score.

Table 4 below, compares Bronx CD 6 and NYC averages for stormwater management and additional benefits of green infrastructure.

Benefit Type	Indicator	NYC Average	BX-6 East Tremont, Belmont
Stormwater Management	CSO Priority Watershed	Eligible	Priority
Urban Heat Island Mitigation	Heat Stress Hospitalizations	3	8
Air Quality Improvement	Fine Particulate Matter 2.5	10.7	11.7
	Ozone [O3]	26.9	27.1
	Asthma Hospitalizations	2,971	9,397
Community Factors	% Unemployment	11%	17%
	% of Land Area Open Space	14%	6%
	% Obesity	24%	33%
Demographic Factors	% Population <15	18%	25%
	% Households Below Poverty Level	30%	54%

Table 5: Bronx CD6 Vulnerabilities Compared to NYC Averages

Crisscrossed by Highways

As illustrated in Figure 6, Bronx CD 6 is bordered to the west by Webster Avenue and Metro North tracks, Fordham University to the north, Bronx Parkway and NY Botanical Gardens to the east and one of NYC's busiest highways, the Cross Bronx Expressway, to the south.

Intersected by highways carrying large numbers of trucks and cars, the Bronx is challenged, not surprisingly, by poor air quality. A 2009 study by N.Y.U. researchers found that students in the South Bronx were twice as likely to attend school near a highway as children elsewhere in the city and more likely to have higher asthma rates.

Figure 5: Detailed Image of CD 6 in the Bronx
Source: Google

Two Potential Grant Applicants: Fordham and St. Barnabas

Fordham University and St. Barnabas Hospital own 25.3 percent of the land in East-Tremont-Belmont, representing a tremendous opportunity for the GI Grant program.

Occupying 85 acres in the northern part of CD 6, Fordham University has shown commitment to sustainability by building all new construction to LEED Silver certification standards. Fordham joined Mayor Bloomberg's 2017 challenge for universities to reduce greenhouse emissions by 30 percent by 2017 and is almost there with a 22 percent reduction so far.

St. Barnabas Hospital is the 15th largest hospital in New York State, and occupies ten acres in the heart of CD 6.[31] St. Barnabas is currently replacing its oil-fired boiler plant with a new combined heat and power plant, which will provide all of the hospital's heating and cooling and a large part of its electrical needs, indicating its commitment to improving public health.[32]

FINDING II

Taking into account the additional benefits of green infrastructure may increase sources of funding on private land.

One barrier facing many green infrastructure programs is incentivizing private property owners. We found that the cities that best publicize green infrastructure's additional benefits are more likely to persuade stakeholders to share in the cost, further improving the cost-effectiveness of retrofits on private land. Of the 13 cities we reviewed, five – Basel, Switzerland, Chicago, Portland, Nagoya, Japan, and Washington D.C. – have created model incentives for property owners to share in the cost.

Basel, Switzerland

Basel, home of the Swiss banking industry, financed a two-phase expansion of green roofs across the city by placing a 5 percent tax on electricity bills that helped to subsidize green roof construction costs for property owners.[33] The city justified the subsidies by emphasizing the potential of green roofs to cut heating and cooling costs as well as cut carbon emissions through reduced energy use. Basel has also publicized the biodiversity benefits of green roofs. Basel consultant Stephan Brenneisen, a scientist at the University of Zurich Applied Sciences, has documented an increase in insect, birds and other wildlife on green roofs. In 2002, Basel made green roofs mandatory on all new buildings. Nearly one third of Basel's flat roofs are now planted, making Basel the world leader in per capita green roof coverage.[34]

Portland, Oregon

Portland has used energy taxes to subsidize green infrastructure on private land by highlighting green infrastructure's ability to reduce urban heat islands and conserve energy. For example, between 1995 and 1999, in a partnership with the nonprofit group, Energy Trust Oregon, Portland raised $750,000 in financing for its Green Investment Fund (GIF) from fees on consumers' electricity and gas bills. (The fees are ongoing though they no longer support the GIF.) Through this collaboration, Portland built $2.5 million of green infrastructure on private land. One project, Shizen Condominiums, features a basement cistern that captures stormwater and reuses it for toilets and landscaping. The cistern also doubles as a heat sink to keep the building cooler in summer and warmer in winter. The reduced energy use saves residents money and allows utilities to meet peak-load requirements without having to build new power plants.

Chicago, Illinois

Chicago focused on energy-savings in pushing to radically green the city skyline under Mayor Richard M. Daley. In 1995, the city suffered a crippling heat wave that killed more than 750 people, most of them poor and elderly. Impressed by how Germany was addressing the twin problems of urban heat islands and climate change with green roofs, Mayor Daley in 2001 symbolically planted the roof of City

Hall with prairie grass and other vegetation.[35] Chicago no longer subsidizes green roofs directly but does offer fast-track permitting and building-fee waivers to developers that incorporate them into their plans. Chicago, along with Portland and Washington D.C., allow developers to build higher or add more square footage, if they include a vegetated roof.

Milwaukee, Wisconsin

In Milwaukee, homeowners and businesses have more than doubled the $11.4 million that the Milwaukee Municipal Sewer District (MMSD) has spent installing green infrastructure on private land since 2003 under its Green Infrastructure Partnership Program and Regional Green Roof Initiative.[36] One notable success has been the redevelopment of the former Pabst Brewery into a LEED platinum housing and retail complex in downtown Milwaukee. Covering six square blocks, the factory was once entirely impervious but through MMSD's program, bioswales, porous pavement and underground water storage tanks have been built. Seventy-five percent of rainfall is now filtered on site, diverting 2 million gallons of stormwater from city sewers each year. The best part for the MMSD is that the developer contributed more than 50 percent of the $944,000 in drainage improvements.[37]

Nagoya, Japan

The port city of Nagoya, in Japan, has taken a related approach in a country that in 2001 declared urban heat islands a form of air pollution. Nagoya is working to reduce air temperatures by increasing the amount of land that is vegetated, from the current 25 percent to 40 percent by 2050, by planting more trees, green roofs, and installing recreational greenways.[38] Under the city's voluntary NICE GREEN Nagoya Program, residents are eligible to borrow money from participating regional banks at a .2 percent discount if their property is deemed to have enough plants growing on building walls, in yards and on rooftops.[39]

Leveraging Stormwater Fees and Other Innovative Financing Strategies

One way that cities are funding green infrastructure is by charging property owners a fee based on the percentage of impervious surface on their property. Under this approach, properties that send more stormwater into city sewers pay more, creating an incentive for property owners to install porous pavement or replace hard surfaces with soil and vegetation to manage flows and lower their bills.

The Philadelphia Water Department (PWD) now uses the pro-rated billing approach with commercial and industrial property owners, and uses some of that revenue to fund retrofits on private land under its Stormwater Management Improvement Program (SMIP). To qualify, a proposed project must cost $100,000 or less per acre and applicants get an advantage if they can provide matching funds.

In the program's first year, applicants pledged 20 percent in matching funds, but by 2013 that number had doubled, said Erin Williams, who runs the program for PWD.

Among the projects funded so far: a stormwater wetland and two bioswales at the Pennypack Woods Homeowners' Association. The total project cost is $761,000 but thanks to contributions from the EPA and the homeowners themselves, PWD will contribute just $135,000. The combination of matching funds and the lower costs associated with private retrofits (as much as 60 percent less than Philadelphia's $250,000 per-acre cost in the public right of way), makes SMIP a bargain for the city. "We're getting much more cost-efficient green infrastructure than we could build on our own," said Williams.

Like Philadelphia and Portland, among others, Washington D.C uses its stormwater fee as leverage to incentivize green infrastructure retrofits on private land. The fee funds several retrofit grant programs run by the District Department of the Environment (DDOE), supplemented by a unique funding source: a five-cent tax on plastic bags paid by supermarkets, bodegas, and other food and beverage sellers, that in 2010 raised at least $1.9 million.[40,41] The District is also pioneering a new incentive, Stormwater Retention Credits, which allow businesses that exceed their stormwater-absorption requirements to sell their excess allowances to those unable to meet their goal.[42]

FINDING III

Cities that develop a comprehensive set of criteria for awarding their grants are more likely to optimize the benefits of green infrastructure.

Birmingham, England

Birmingham, England, has developed an interactive planning tool that includes climate projections through 2100 and public health data that can be matched against the multiple benefits of green infrastructure. Birmingham's tool, BUCCANEER, is comparable to the one we created, allowing city planners, public health advocates, and developers to identify vulnerable neighborhoods and prioritize green infrastructure in the places that need it most. "From here on, public health outcomes are going to be one of the most significant factors in determining future development in the city," said Nick Grayson, Climate Change and Sustainability Manager for Birmingham City Council.[43]

To complement BUCCANEER, Birmingham has developed a companion Natural Capital City Tool that applies ecosystem services data to prospective development, with an emphasis on human well-being. In one application, Birmingham worked with a private water company to model the effects of a mixed-use development project in the city center on a 40-year time frame. Exposing waterways currently buried under concrete, adding bioswales, and fronting the new development on a green corridor, Grayson said the project will reduce heat islands and flooding while improving filtration and water quality. Combined with increased property values, these factors will add an estimated £1.4 billion of value to the project, he said, increasing the chances that water or insurance companies may be willing to share in the cost.

In another application, residents in Birmingham's Erdington neighborhood were able to use the Natural Capital City Tool to pinpoint areas most challenged according to a range of factors.[44] On the basis of the tool's findings they applied for and received £1.5 million in grants to plant trees and wildflower meadows, build bioswales and cycling-walking routes, and provide flooding-relief, said Grayson. The funding came from government grants aimed at reducing flooding and revitalizing communities, as well as a fund established by landfill companies to compensate the public for their environmental impact.

Syracuse, New York

In 2009, Syracuse became the first city in the U.S. to use green infrastructure to satisfy a court mandate to reduce sewage overflows. To track its progress in reducing CSOs, Syracuse has developed a real-time stormwater modeling system; the results help the city prioritize the location of future green infrastructure so that projects are built where they are needed most. Under the city's Green Improvement Fund, which provides green infrastructure grants on private land, property owners

in flood-prone areas are given greater incentive to build: 30 cents for each gallon of water captured, versus 10 cents per gallon in a low-priority area. Two projects that have been funded under the grant program are the replacement of Skiddy Park basketball courts with porous pavement, and a system to collect and filter rain from the roof of the city's hockey arena for reuse in making ice for the rink and heating and cooling the building.[45] While these efforts are small in the context of NYC's $13.1 million Grant Program, the use of economic incentives to prioritize green infrastructure on private land is an approach NYC could consider in meeting its own targets.

FINDING IV

Cities that reduce upfront costs for property owners to install green infrastructure are more likely to disperse the benefits evenly across the city.

Chicago

In collaboration with the non-profit group, Center for Neighborhood Technology, Chicago has installed shrubs and trees across the city under its Sustainable Backyards Program. Chicago's Department of Transportation provides up to $100 for each tree that residents buy and up to $60 for each shrub, in a 50 percent matching rebate offered through participating garden centers across the city. The instant rebates have made the program more accessible to low-income residents, while improving the bottom line of local businesses, said Sarita Upadhyay, water program coordinator at the Center for Neighborhood Technology.[46]

Philadelphia

Philadelphia tried offering low-interest loans to incentivize businesses to build green infrastructure but the savings were not enough to justify the costs and few commercial property owners applied, said Erin Williams. The city launched its SMIP grant program to create additional incentives, and to date has successfully funded a range of geographically dispersed projects by advertising through community groups, its website, and by working closely with applicants to come up proposals that meet all grant criteria. As of November, 2013, SMIP had funded more than $9 million of green infrastructure and is offering $5 million in grant funding for 2014.[47]

Washington D.C.

Washington D.C. has managed to recruit a diverse range of grant applicants with help from graduates of the Anacostia Watershed Society's 13-week training program in environmental issues. The program includes a capstone project that allows students already involved in their communities to recruit property owners to apply for green infrastructure grants, said Leah Lemoine, an environmental protection specialist at the DDOE. [48] As a result, non-profit organizations like churches have been able to take advantage of the grants, along with businesses and housing co-ops with large capital budgets.

RECOMMENDATIONS

Optimization Tool Recommendations

Complementing our GIS analysis, we created an optimization tool to identify which communities in NYC would most benefit from green infrastructure based on an expanded set of criteria. Though we used current data to describe NYC's public health and environmental landscape, climate projections and other forward-looking data could allow city planners to look ahead on a longer time horizon. We have designed the tool to make it flexible and responsive to the user's priorities.

I. Target Community District Bronx 6- East-Tremont-Belmont neighborhoods

Following our analysis of the city's most vulnerable neighborhoods based on a set of expanded criteria, we suggest that DEP focus additional green infrastructure in a community such as Bronx CD 6. Research suggests that the benefits of green infrastructure may only start to take effect when a critical number of projects have been installed, [49] underscoring the need for DEP to focus projects in one or two communities. Based on our analysis of past applicants, which tend to be mission-driven organizations, we suggest that Fordham University and St. Barnabas Hospitals would be good candidates for installing green infrastructure on private land. We also suggest prioritizing more public-right-of-way projects and Long Term Control studies in this community district.

II. Use the Optimization Tool for Planning and Outreach

To maximize the benefits of the Grant Program, we recommend that DEP further use the optimization tool for planning as well as outreach to communities and potential collaborators.

Planning: The tool can help DEP evaluate GI Grant applications as well as green infrastructure projects on public land.

Public outreach to communities: The tool can help DEP recruit better applicants by publicizing benefits that may be most attractive to particular communities.

Public outreach to potential funders: The tool can highlight the multiple benefits of GI Grants to leverage funds from outside organizations.

III. Add Climate Projections and GI Performance Data into Tool

By 2080, temperatures in NYC are expected to rise by an average of 4 – 8° F,[50] and sea level by up to two feet,[51] putting New Yorkers at added risk for heat related illness, health problems linked to poor air quality, and increased flooding, especially during storms. Following Birmingham's example, DEP could make our optimization tool more robust by adding future climate projection data to identify communities that will be most affected. Armed with future climate projections, the city would be able to strategically plan where the additional benefits of green infrastructure, such as urban heat island mitigation, might be most beneficial. DEP might also

incorporate the results of its ongoing research to quantify the additional benefits of green infrastructure into this tool.

Findings Based Recommendations

I. Create Mutually-Beneficial Partnerships

Landscape designers can be an effective resource for would-be applicants. DesigNYC is an organization of designers, including landscape designers, which provides pro-bono design work for non-profits to affect social change. While engineers are essential to the design process, landscape architects take into account the unique location and a project's end-users. The landscape designs for Central Harlem Senior Citizens Center's community garden with an edible garden component do just that. The final plans lay out comfortable seating, easy to reach vegetative elements and shade canopies for an elderly end-user in a designated "food desert."[52] DesigNYC Executive Director Rachel Crawford, expressed her interest in the Grant Program and the potential to collaborate.

Past grant recipients can also be a useful resource. Through the Grant Program, Brooklyn Grange built a two-and-a-half acre farm on the Brooklyn Navy Yard's roof and has designed other green roofs, including one for Cypress Hills Local Development Corporation in Brooklyn and another for the South Bronx Overall Economic Development Corporation. Brooklyn Grange provides a range of services to other grant applicants from grant writing and design, to project management and construction.[53] "Many green roof companies in NYC are providing similar services these days," said Gwen Schantz**,** chief operating officer at Brooklyn Grange.[54]

Providing further evidence that successful projects in the past can spark ongoing collaborations, Portland, Oregon, is tapping a large network of homeowners to build more ambitious green infrastructure projects. Over two decades, the city disconnected downspouts from 26,000 homes and is now building on those positive experiences with homeowners to build rain gardens, stormwater planters and porous pavement on private land to reduce sewer backups and street flooding. "We're working in some of the same areas as the Downspout Disconnection program so we're able to build upon that trust with property owners," said Amber Clayton, Stormwater Retrofits Program Manager.[55]

Leveraging such community partnerships can lead to identifying potential applicants. Universities and environmental nonprofits are examples of successful past applicants. These organizations are more likely to have in-house expertise, or the available capital to hire consultants to write grant applications and prepare architectural designs in the hope that they win a grant and be reimbursed for their upfront costs.

Going forward, we recommend that DEP continue to reach out to other like-minded organizations that could benefit from the additional benefits of green infrastructure.

Organizations whose focus is energy reduction or urban heat island abatement may embrace green roofs projects if they can be convinced that green infrastructure can address these.

Figure 6: Syracuse's Detailed Awardee Information Available Online
Source: Syracuse 'Save the Rain' Green Improvement Fund

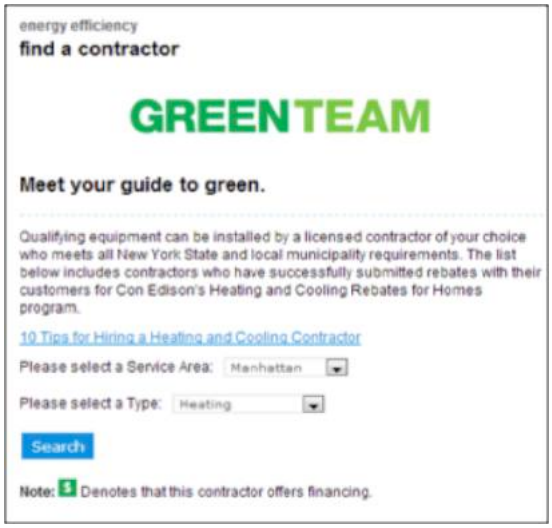


Figure 7: Con Edison Energy Efficiency Contractor List
Source: Con Edison website

II. Provide Grant-Related Resources Online

Syracuse and Philadelphia include green infrastructure grant awardees on their websites as well as helpful resources for applicants. Syracuse publishes the technical specifications of all installed projects,[56] allowing applicants to see what constitutes a successful project, as shown in Figure 6.

Con Edison, which also offers reimbursement programs to private property owners in NYC, lists the names of contractors on its website to encourage customer involvement in the program. The portal to this program is shown in Figure 7.

We recommend that DEP include user-friendly information online for future Grant Program applicants as well as the names of past recipients, project costs, gallons of stormwater captured, collaborators and the additional benefits that the Grant recipient will also capture. We also recommend that DEP provide a list of pre-approved consultants, engineers, and landscape architects on its website so applicants can easily contact professional contractors to help them apply for the grant.[57]

III. Make Cost-Effective Designs Available to the Public

We recommend that DEP make the grant program more cost-effective by providing a "tool-kit" to applicants, as suggested by Jaime Stein, coordinator for Pratt

Institute's environmental systems management program. The tool-kit might include pre-approved green infrastructure designs, their estimated costs and a list of contractors.

One barrier for Grant Program applicants currently is the high upfront costs. Pratt has spent $70,000 so far on engineering tests and design work to build a green roof and a permeable parking lot on its Brooklyn campus. DEP awarded two grants to cover most of the $650,000 cost, but the grants will not cover the significant time Stein says she has spent serving as project manager. As more projects are built, she says she expects the costs and time involved will go down, making it easier to scale future green infrastructure installations.

"As an academic institution we're adding to the toolkit of what green infrastructure can do in the city," she said. "With a tool kit, these design ideas can get honed over time eventually making projects more cost-efficient. Think about Brownstone Brooklyn. There's a building typology that's repeated ad infinitum. Block by block they've created energy retrofits, why not do that for green infrastructure?"

In Washington D.C., the Anacostia Watershed Society has a landscape architect on staff that has developed standardized designs for different green infrastructure projects funded by the DDOE. The designs have allowed low-income property owners to win lower-cost grants through the DDOE's RiverSmart Communities Grant Program. By reducing design costs, the strategy has allowed more property owners in vulnerable neighborhoods to take advantage of green infrastructure.

IV. Enhance Communication Strategy to Target Potential Applicants

The DEP can best take advantage of the tool we developed if property owners in vulnerable neighborhoods have improved access to capital and technical expertise in order to submit competitive grant applications. We identified effective outreach strategies used by other NYC government agencies as well as non-profit community groups in educating people about funding opportunities.

Cypress Hills Local Development Corporation is a longtime non-profit in Brooklyn that has participated in such green initiatives as Million Trees New York and NYC °Cool Roofs. To promote its programs, Cypress Hills reaches out to its own clients as well as local churches, said Yakima Pena, coordinator at Cypress Hills Verde.[58]

NYC Economic Development Corporation (EDC) works with elected officials to reach community members. After Hurricane Sandy, EDC launched a $90 million "Neighborhood Game-Changers Competition", that offered grants to private investors and local businesses in the top five neighborhoods most impacted by the storm. To share information about eligibility and answer questions, EDC set up conference calls with city, state, and local leaders who passed on the information to their constituents.[59]

Lastly, although there is limited outreach for Syracuse, New York's Green Improvement Fund, they rely on officials in the city's Economic Development Office to recruit potential applicants. A large number of Syracuse's 120 green infrastructure grant recipients learned of the program through the Economic Development Office, said Madison Quinn, the Fund's Program Coordinator.[60]

CONCLUSION

Based on case studies, scientific research and data collection, data analysis and an investigation into local NYC resources, we identified ways DEP could add value to its existing green infrastructure planning. Although DEP's main objective is to reduce CSOs and improve water quality, we believe that incorporating the additional benefits of green infrastructure into DEP's criteria for siting green infrastructure can help the agency maximize benefits. The optimization tool we developed rates community districts by their relative vulnerability, advising DEP on where the benefits of green infrastructure might be optimized, on both private and public land. In most cases, a critical mass of green infrastructure installations is needed to broadly improve air quality or reduce urban heat islands.

Our discussions with other cities provide examples of how DEP might recruit more applicants and identify new sources of funding to spread the benefits of green infrastructure more evenly across the city. Building green infrastructure on private land can be more cost-effective and provides unique opportunities for cost-sharing with property owners. Our research into best practices in other cities shows that public-private partnerships and collaborations with community groups and others can help cities scale up their green infrastructure programs.

NYC has numerous resources that DEP can utilize. Political leaders, community organizations and landscape designers could significantly help to advertise the Grant Program and increase the pool of qualified applicants. With an optimization tool to guide the expansion of green infrastructure on not only private land but cross the city as a whole, we believe DEP can meet its water-quality goals while addressing the needs of New York City's most vulnerable communities.

APPENDIX

A. GIS Maps
B. Sample Maps Generated from BUCCANEER Tool
C. Optimization Tool “How To” Guide
D. GIS Map with Optimization Tool Generated Scores
E. Optimization Tool Scores Across NYC

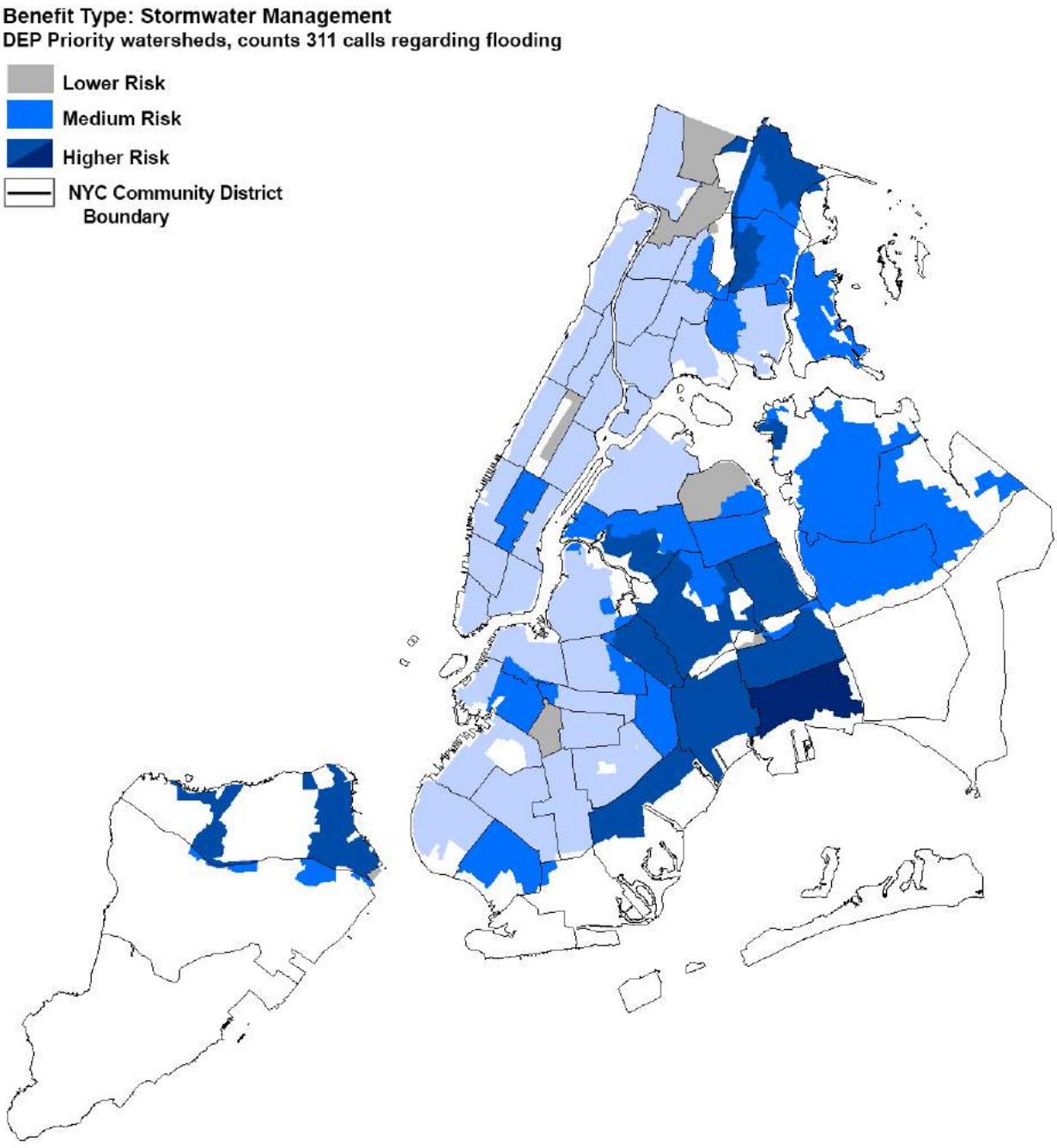
Appendix A. GIS Maps

We used GIS mapping visualize trends across NYC neighborhoods. This tool also helped synthesize information given in three different geographic types – United Health Funds (UHFs), zipcodes, and community districts. We used vector maps to quickly change classifications in each of the 14 indicators, and raster maps to sum the benefits across the different areas. The composite map was found by the following formula: [(Energy Reduction + Community Factors + 311 calls) + Demographic Vulnerability * (Air Quality Improvement + Urban Heat island)] * Priority Watersheds. By multiplying the entire sum by Priority Watersheds, areas in DEP-termed "ineligible" watersheds drop out of the possible results.

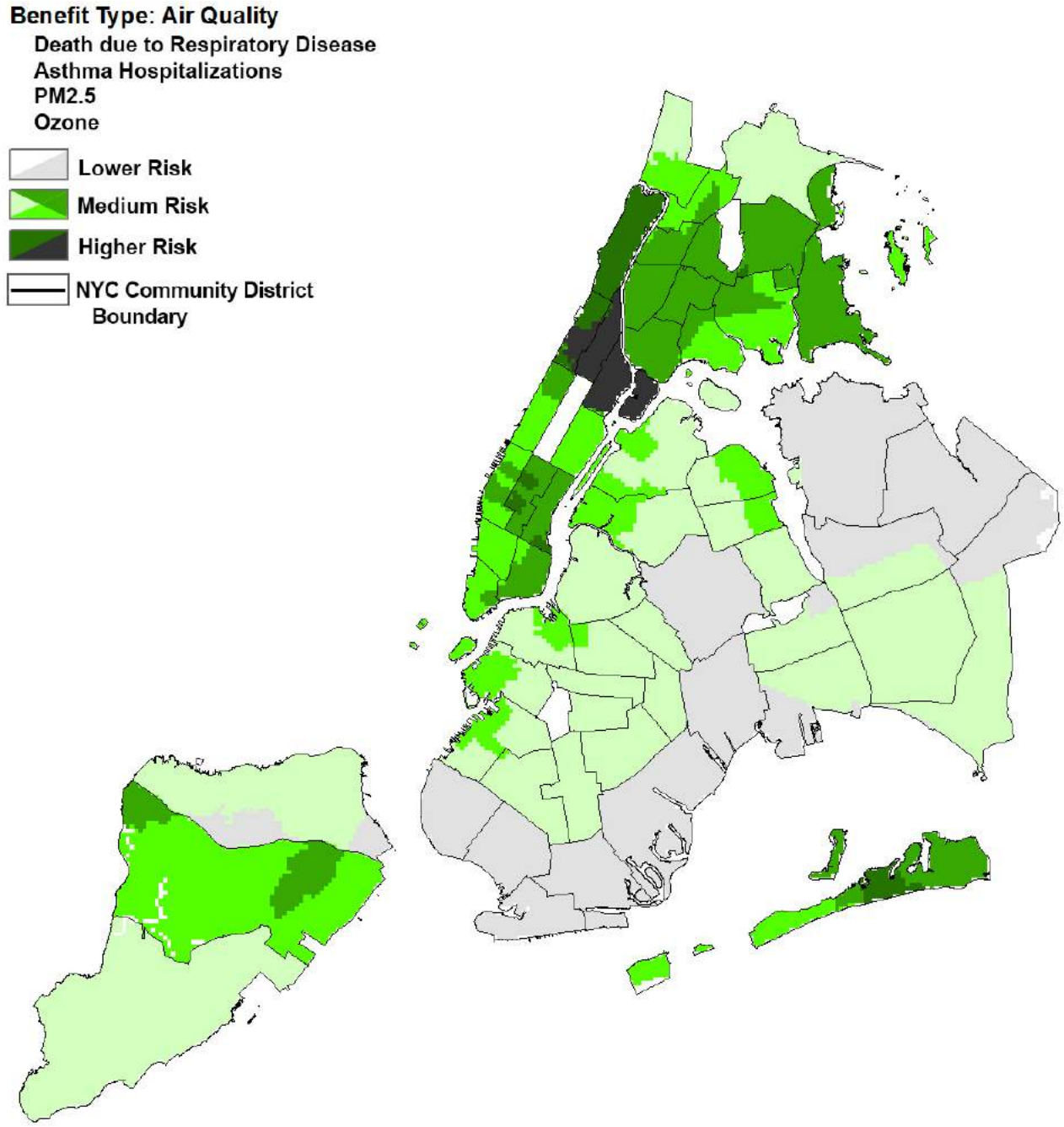
While these maps are not a 1:1 representation of the optimization tool, the underlying data and approach was the same. This means that the indicators such as demographic vulnerability was a factor in UHI and in Air Quality, as it was in the optimization tool. Below are the classifications for the raster maps followed by the raster maps generated in this analysis. Vector and raster maps were given to DEP.

Benefit Types	Indicators	Data Normalization	Values Assigned to Raster Map Classes	Notes
Stormwater Management	CSO Priority Watershed	NA	0 = Not Eligible; 1 = Eligible; 2 = Priority Watershed	Based on DEP Grant Values
	311 Reports of Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged	# of Complaints per 100,000 residents; 2010-2012	0-525 calls = 0 (Low Risk); 525-1058 calls = 1 (Medium Risk); 1058-2416 calls = 2 (High Risk)	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
Urban Heat Island	Heat Stress Hospitalizations	Per 100,000 residents; 2010	0 - 2 visits = 0 (Low Risk); 2 - 4 = 1 (Medium Risk); 4 - 8.6 = 2(High Risk)	Used age adjusted column; Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
Air Quality Improvement	Fine Particulate Matter 2.5	2 year annual average; 2009-2010	PM<10 = 0 (Low Risk); PM10-15 = 1 (Medium Risk); 15-16 =2 (High Risk)	Used WHO level of 10 mg/m3 and EPA level of 15 mg/m3
	Ozone [O3]	2 year annual average; 2009-2010	0-25 = 0 (Low Risk); 25-29=1 (Medium Risk); 29-31=2 (High Risk)	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
	Deaths Due to Respiratory Disease	Chronic lower respiratory deaths per 100,000 residents; 2010	0-34=0 (Low Risk); 34-74=1 (Medium Risk); 74-230 = 2 (High Risk)	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
	Asthma Hospitalizations	Asthma hospitalizations per 100,000 residents; 2008-2010	0-76 = 0; 77-219 = 1; 220-460 = 2	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
Energy Reduction	Electricity Use [kWh]	kWh used in millions per 100,000 residents; 2010	0 - 410 = 0 (Low Risk); 410 - 1290 = 1 (Medium Risk); 1290 - 6030 = 2 (jHigh Risk)	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2
Community Factors	% Unemployment	# Unemployed / # in Labor Force; 2010	0 - .096 = 0 (Low Risk); .096-0.17 = 1 (Medium Risk); .17-.206 =2 (High Risk)	National Average in 2010 was 9.625% unemployment
	% of Land Area Open Space	2010	0 - .1 = 2 (High Risk); .1 -.27 =1 (Medium Risk); .27 - .5=0 (Low Risk)	Urban Area Average open space = 10%; NYC Average is 27%
	% Obesity	Adult Obesity rate; 2011	0-.21=0 (Low Risk); .21-.29=1 (Medium Risk); .29-37=2 (High Risk)	National average = 21%
Demographics Vulnerability	Rate of Residents 65 and older	Percentage based on rate in community district	0 - 12% = 0 (Low Risk); 12% - 15.5% = 1 (Medium Risk); 15.5% - 21/5% = 2 (High Risk)	US Average = 13.7%; NYC Mean = 9.9%;
	Rate of Residents 15 and Younger	Percentage based on rate in community district	0%-18% =0 (Low Risk); 18% - 23% = 1 (Medium Risk); 23%-30% = 2 (High Risk)	NYC Mean = 14.8% ; next Jenk =
	Poverty levels	Percentage based on rate in community district	0 - 20% = 0 (Low Risk); 20% - 42% = 1 (Medium Risk); 42% - 56% = 2 (High Risk	Below Mean = 0; Standard Deviation Plus Mean = 1; Greater than 1 SD from Mean = 2

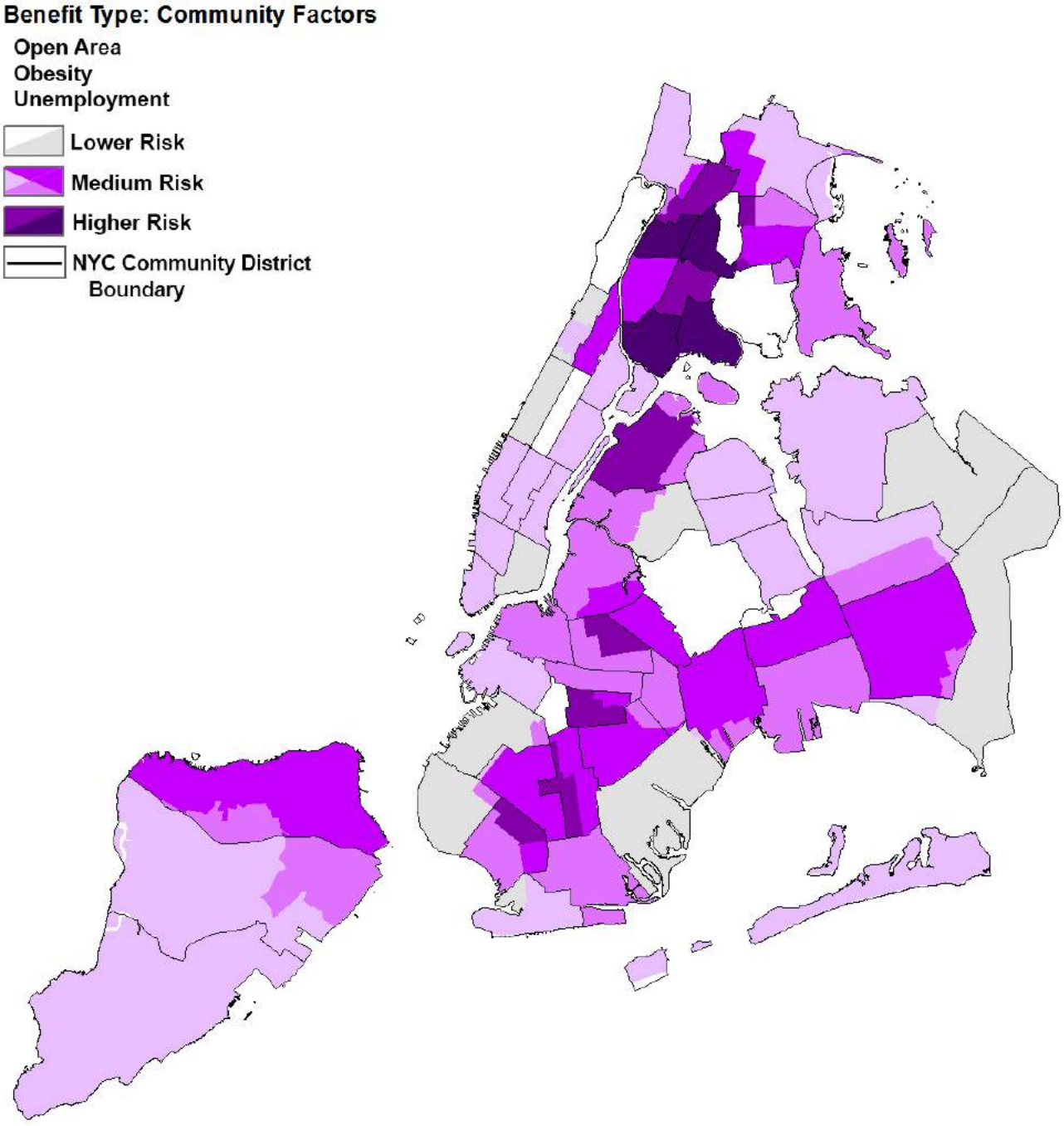
Stormwater Management Map



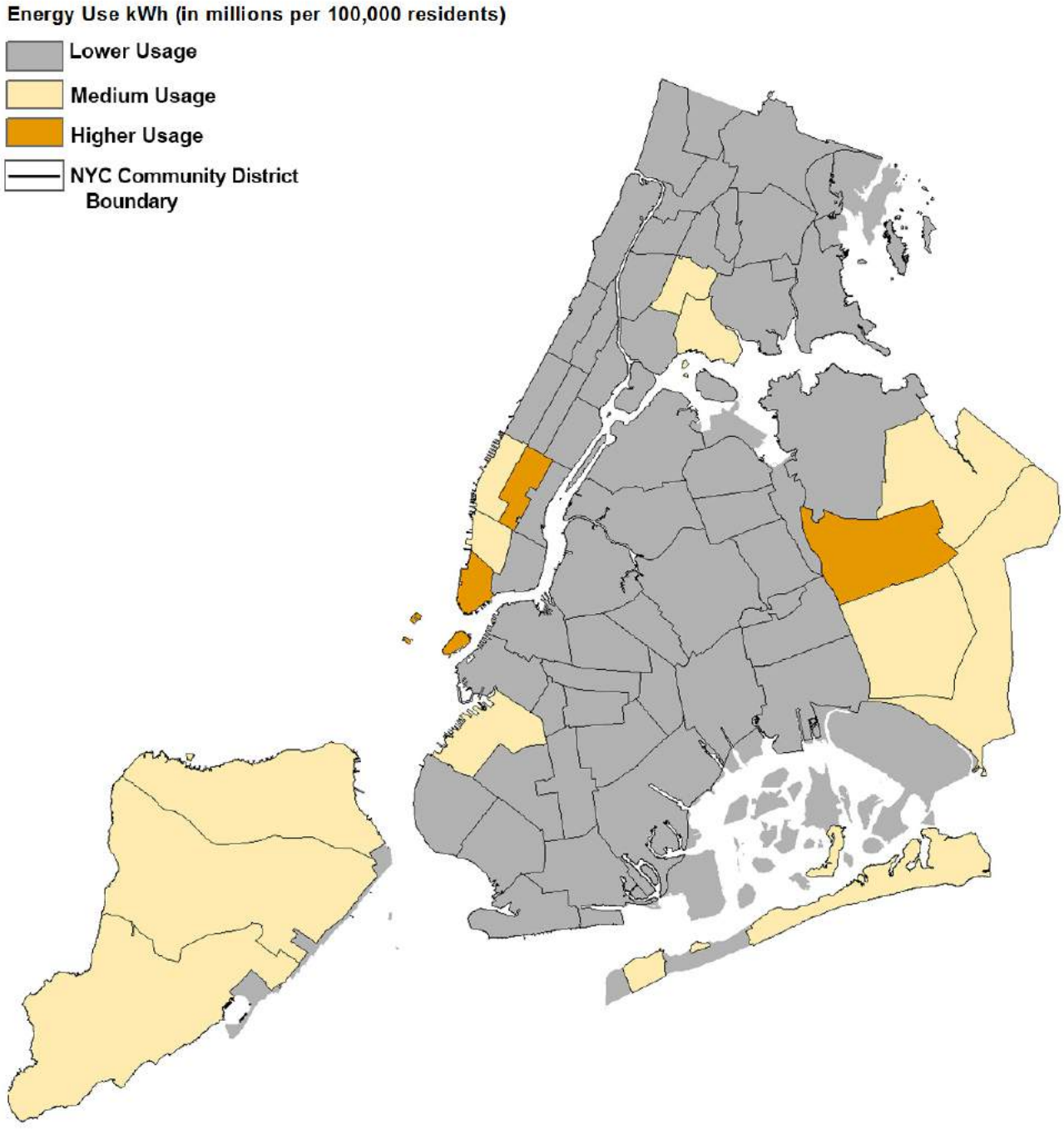
Air Quality Improvement Map



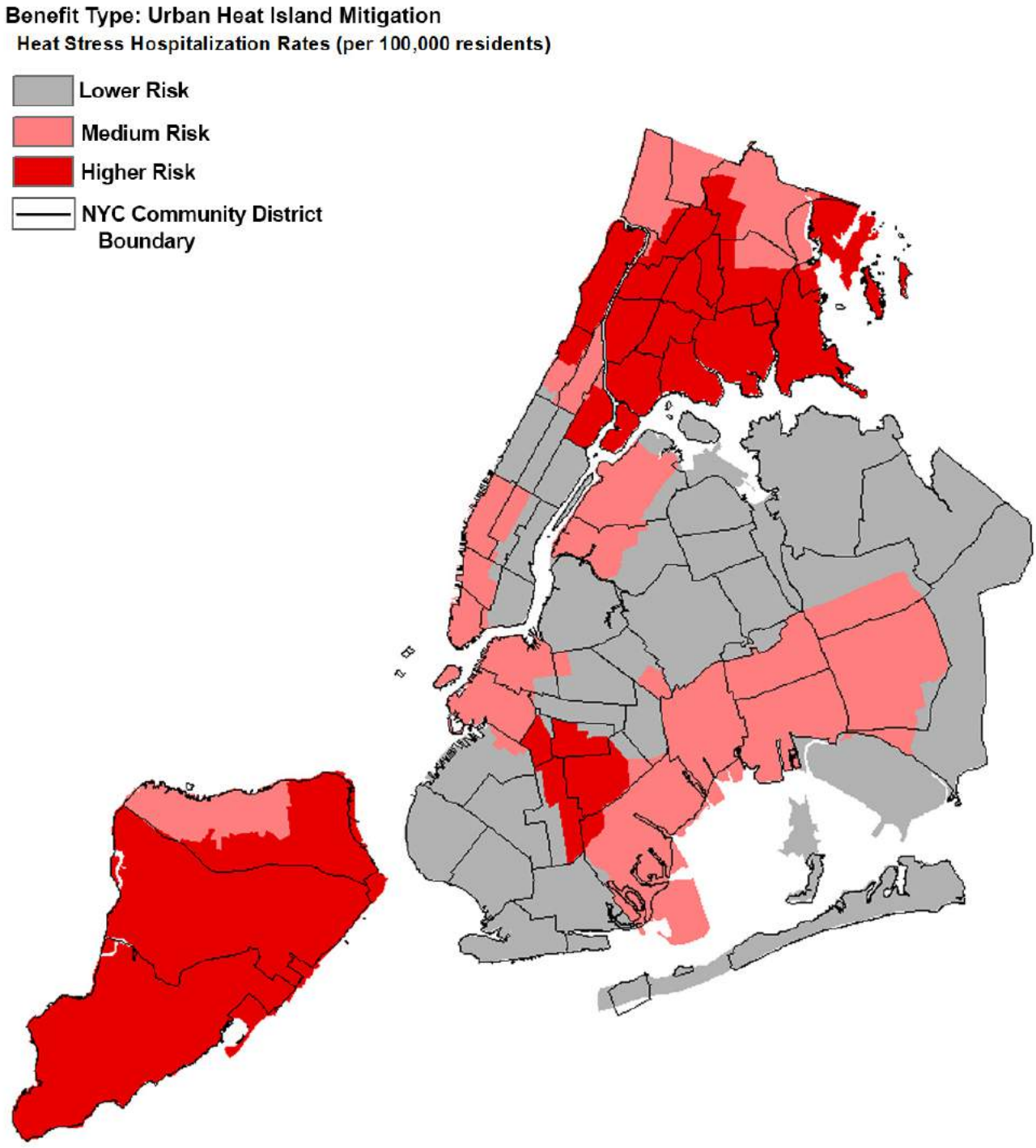
Community Factors Map



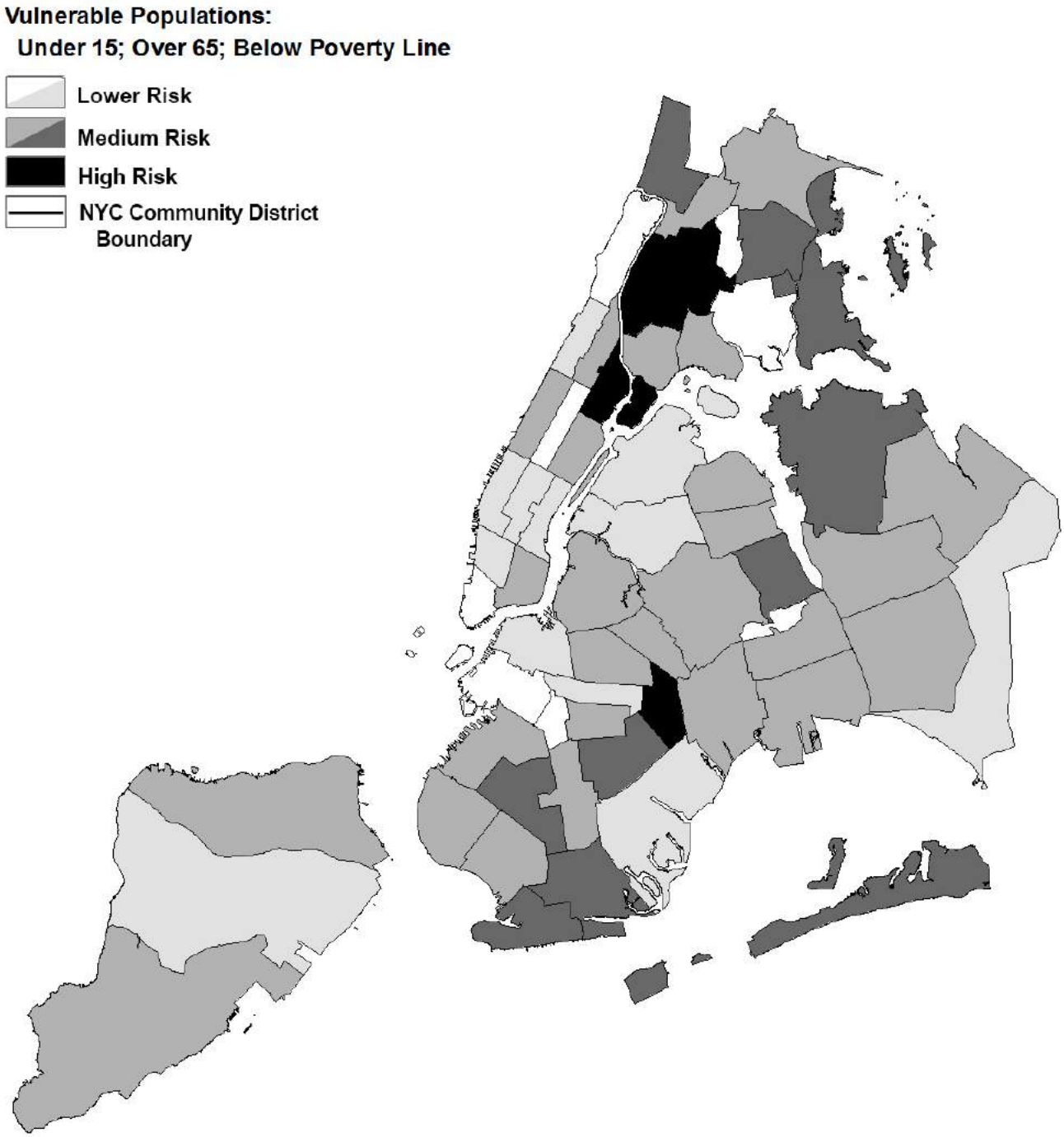
Electricity Reduction Map



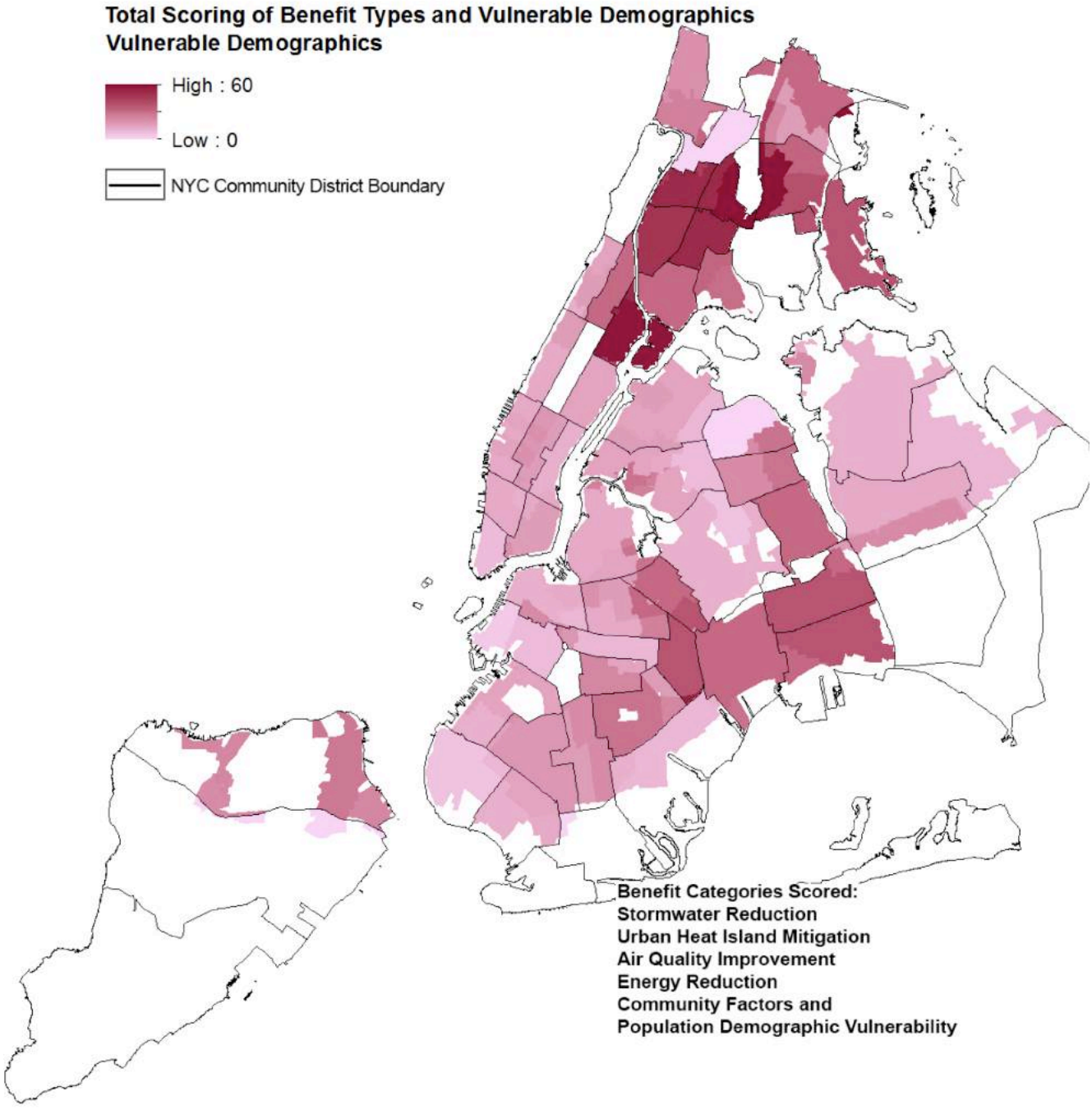
Urban Heat Island Mitigation Map



Demographic Vulnerability Map

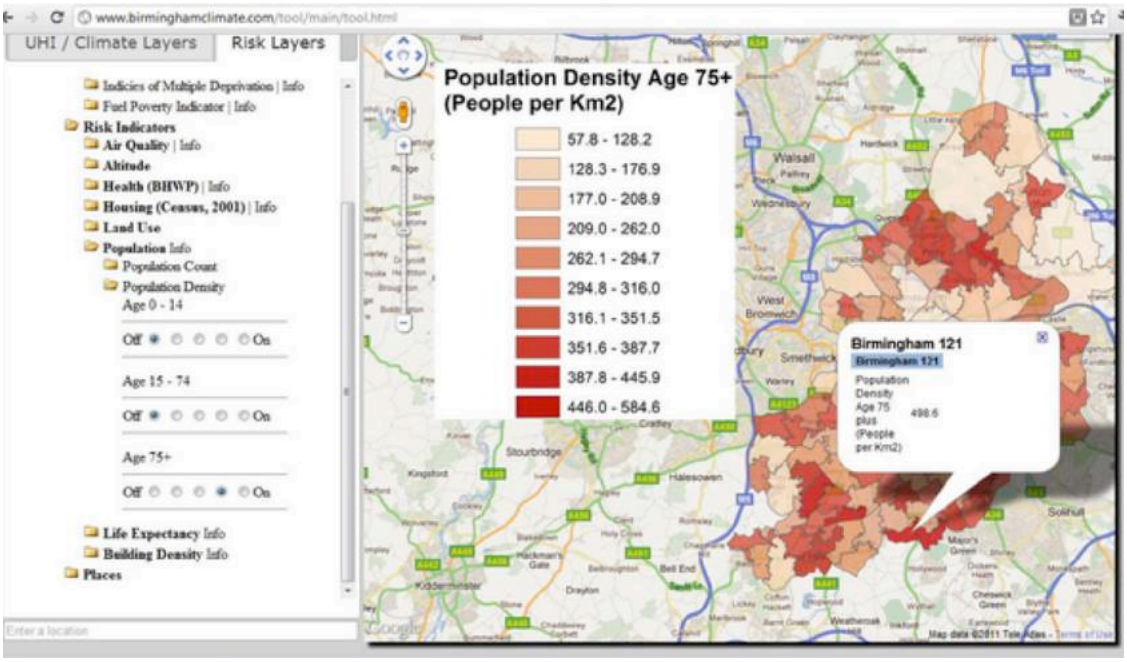


Composite Benefit Map

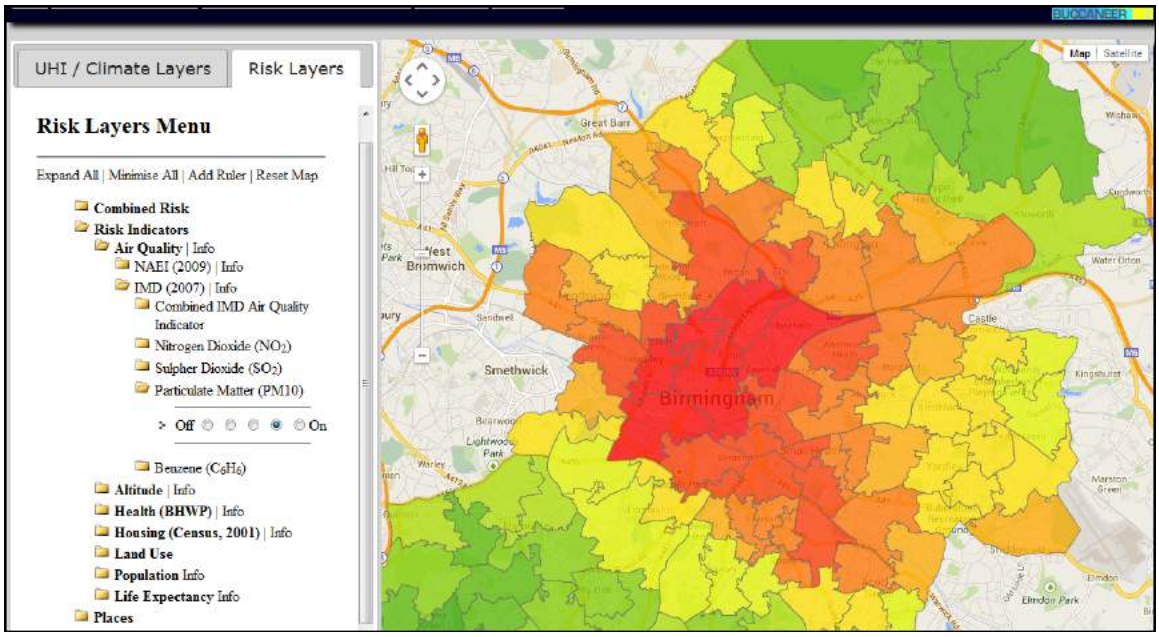


Appendix B: Sample Maps Generated From BUCCANEER Tool

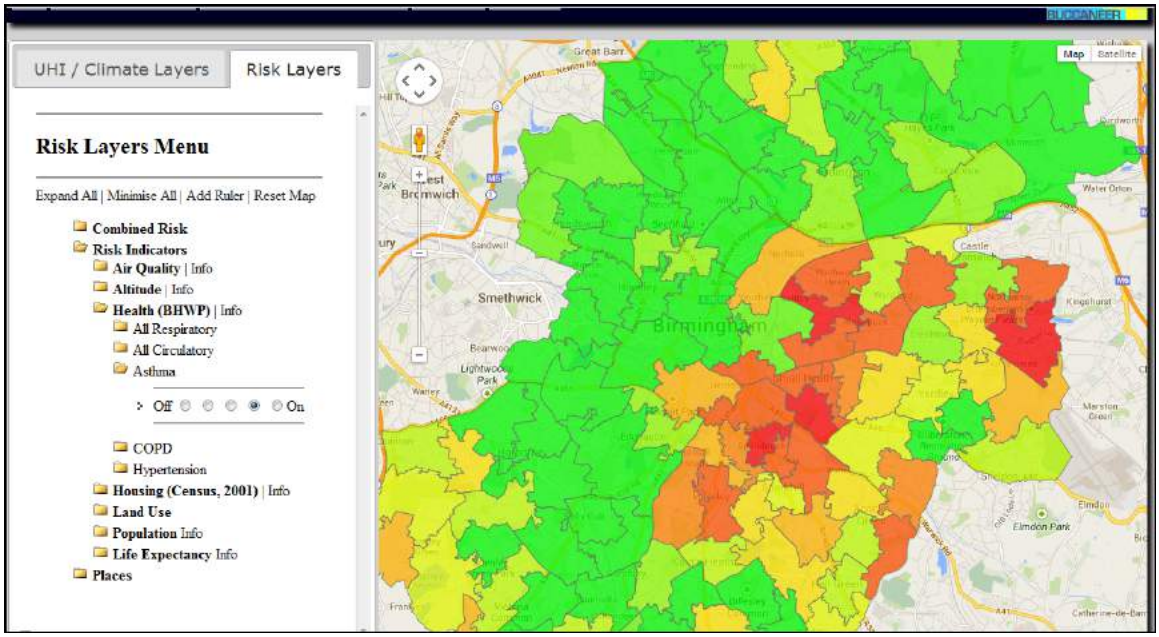
The city of Birmingham in conjunction with Birmingham University developed an online program called BUCCANEER, driven by the city's goal to "balance the pressures of a growing population with its environmental and socioeconomic sustainability." This new tool is to be used by planners, developers, and public health advocates to help prioritize investment in green infrastructure by identifying areas of greatest risk. Birmingham is considered a leader in Europe due to their work linking the co-benefits of green and blue infrastructure to the needs in their communities.



Population density layer of residents older than 75 years.



Risk of Particulate Matter 10



Risk of Asthma

Appendix C: Optimization Tool "How To" User Guide

The following is a user guide for the New York City Environmental Optimization Tool that was developed by a team of graduate students from Columbia University's Masters of Science in Sustainability Management for use by the NYC Department of Environmental Protection in December 2013. The tool is password protected and can be accessed with the password: DEP.

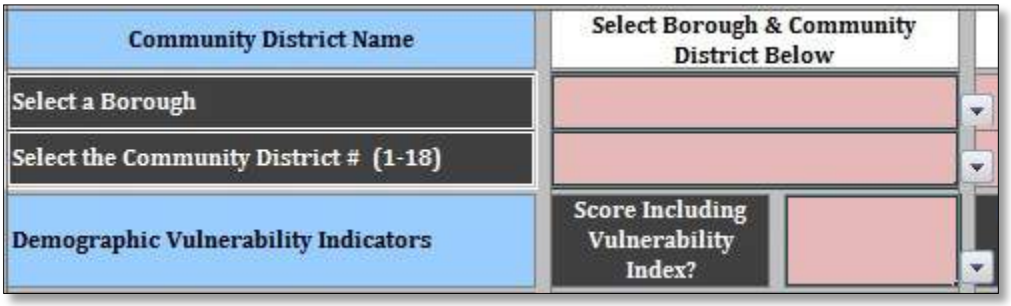
I. Purpose

The purpose of this tool is to enable the NYC Department of Environmental Protection (DEP) to analyze and compare NYC community districts in order to identify communities in NYC that have the most opportunity to benefit from stormwater management and other "co-benefits" provided by green infrastructure.

II. Layout and Formatting

The data is organized by NYC Community District. To populate the tool with data that can be scored, select a borough and community district number. We created three columns to compare and analyze more than one community district at a time.

Cells highlighted in pink indicate a cell that *must* be filled in to accurately evaluate and score the community districts. These cells are prompted by the titles "Select a Borough", "Select the Community District #", *and*, "Score Including Vulnerability Index?," and can be populated by choosing the drop-down arrow in the right corner of the cell.



The "Benefit Weight" column, also highlighted in pink, is currently set at a default value of 1.0 for each benefit. This value can be changed depending on your preference and the amount of weight you would like to give to each benefit category. This is explored further in the **Weighting** section.

All cells in white cannot be adjusted.

All data referenced in the tool is sourced via formulas from the "Master CD Lookup Sheet" tab. The columns in this sheet are sourced from data tabs that are hidden by default to preserve the data. Data tabs can be exposed and explored by right-clicking in the tab section of the sheet, clicking "Unhide" and choosing a data tab to explore.

Sources and links to the sources of the data are included on the bottom of each tab. The columns highlighted in light purple on each data tab are the columns of data that were used in the tool. They are also included in the **Indicators, Data and Sources** section of this document.

III. Weighting

The benefit weight column assigns a weight to each benefit-category defined in the tool to add flexibility and allow users to tailor the results according to their preferences.

Benefit	Benefit Weight	Indicator	Weight Allocation
Stormwater Management	**1.0**	Combined Sewer Priority Watershed	0.50
		311 Reports of Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged	0.50
Urban Heat Island Mitigation	**1.0**	Heat Stress Hospitalizations	1.00
Air Quality Improvement	**1.0**	Fine Particulate Matter 2.5	0.25
		Ozone [O3]	0.25
		Deaths Due to Respiratory Disease	0.25
		Asthma Hospitalizations	0.25
Energy Reduction	**1.0**	Electricity Use [kWh]	1.00
Community Factors	**1.0**	% Unemployment	0.33
		% of Land Area Open Space	0.33
		% Obesity	0.33

Each benefit category has been assigned a default weight of 1.0 that can be raised or lowered depending on user preference. If for instance you wanted to focus primarily on Stormwater Management as well as Energy Reduction you can assign greater weights to those categories, or lower weights to benefits deemed less important. The Weight Allocation column is automatically populated based on the benefit weight and the number of indicators for each benefit using the formula Benefit Weight / # of Indicators for that Benefit. This column is hidden by default. For example, the total weight of the Air Quality Improvement benefit is 1.0, divided among four indicators with a weight of 0.25 each (1.0/4 = 0.25). Air Quality

Improvement is thus weighed equally as Urban Heat Island Mitigation, which has one indicator. This column can be adjusted manually if the user chooses.

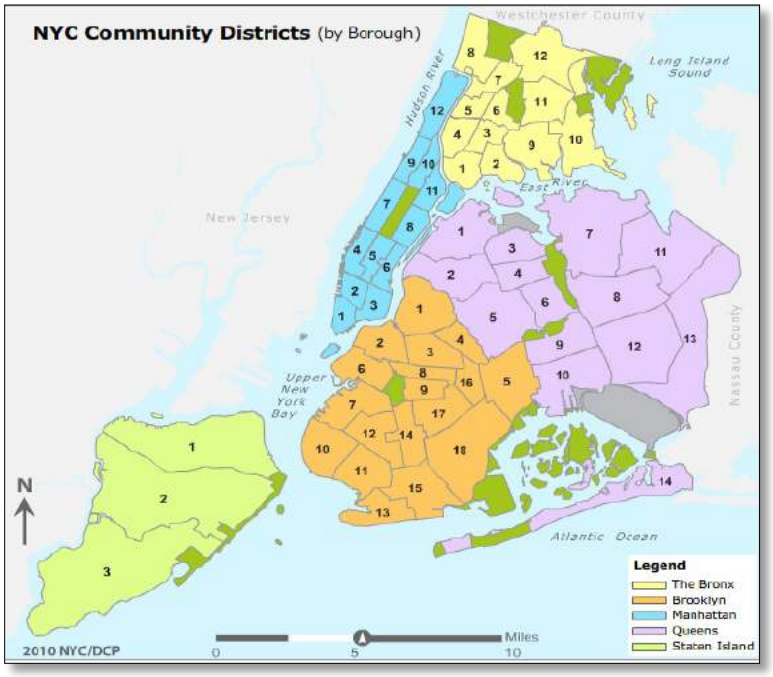
IV. Indicators, Data and Sources

i. General

Note 1: *A brief definition and data source year is provided in the far right column of the tool, but a full definition is provided in this section of the document.*
New York City's 59 community districts were established by local law in 1975. Each borough has up to 18 community districts. We have defined the metrics in this tool based on the organization of these community districts.

- **Community District IDs and Names** (Note 2): NYC Department of City Planning: Community District Profiles.
  http://www.nyc.gov/html/dcp/html/lucds/cdstart.shtml

  Note 2: *Community Districts are zoned to exclude major city parks and areas of green space such as Central Park, Prospect Park and Bronx Zoo, as illustrated below.*



The team referenced scientific research to identify the top benefits provided by green infrastructure, and further researched indicators of community vulnerability that offer opportunities to maximize green infrastructures' benefits.

The benefit categories and associated indicators are shown in the table below.

Benefit	Indicator
Stormwater Management	Combined Sewer Priority Watershed
	311 Reports of Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged
Urban Heat Island	Heat Stress Hospitalizations
Air Quality Improvement	Fine Particulate Matter 2.5
	Ozone [O3]
	Deaths Due to Respiratory Disease
	Asthma Hospitalizations
Energy Reduction	Electricity Use [kWh]
Community Factors	% Unemployment
	% of Land Area Open Space
	% Obesity

ii. Stormwater Management

The indicators that measure the opportunity to reduce stormwater flows are Combined Sewer Priority Watershed and 311 Reports of street and highway flooding, sewer backups, overflowing manholes and clogged catch basins.
The team used GIS to map community districts in relation to watersheds, overlaying watershed shapefiles provided by the DEP with shapefiles of NYC community districts to determine which community districts fell within priority, eligible, and non-eligible watersheds. This is important because the DEP prioritizes green infrastructure grants in community districts within priority watersheds. Non-eligible, eligible and priority watersheds are weighted 0, 1 and 2 respectively.
NYC Open Data provided a list of 311 Reports, which we narrowed down to complaints for street and highway flooding, sewer backups, overflowing manholes and clogged catch basins.

- **Combined Sewer Priority Watershed:** NYC DEP; 2013. NYC Department of City Planning via BYTES; 2013.
  Overlaid shapefile sourced from map link below with NYC Community Districts provided by BYTES of the BIG APPLE link below.
  http://www.nyc.gov/html/dep/pdf/green_infrastructure/2013_gi_grant_reference_map.pdf
  http://www.nyc.gov/html/dcp/html/bytes/dwndistricts.shtml
- **311 Reports:** NYC Open Data: DEP Related Requests: street and highway flooding, sewer backups, overflowing manholes and clogged catch basins; 2010-2012.
  Normalized per 100,000 residents.
  https://data.cityofnewyork.us/Social-Services/311-data/fkh3-qjxr

iii. Urban Heat Island Mitigation

The vulnerability indicator used to measure the opportunity for urban heat island mitigation is heat stress hospitalizations. The data was originally defined by United Health Fund (UHF) code. To use this data in a tool organized by community districts, the Team used GIS to overlay a shapefile of UHF boundaries with community district boundaries to find out how they overlapped and created a mapping of which UHF are within which community districts. To deal with the problem of UHF and community districts not matching up with each other, we averaged UHF values across each community district. The same methodology was used to deal with ZIP code data which also had conflicting boundaries between ZIP codes and community districts. The mapping can be found in this document under **Tables.**

- **Heat Stress Hospitalizations:** NYC Environmental Public Health Tracking Portal: Age-adjusted rate; 2010. Normalized per 100,000 residents.

iv. Air Quality Improvement

The indicators used to measure the opportunity for air quality improvement are fine particulate matter 2.5, ozone, respiratory death, and asthma hospitalizations.

- **Fine Particular Matter 2.5**: NYC Environmental Public Health Tracking Portal: 2-Year Annual Average; 2009-2010.

- **Ozone:** NYC Environmental Public Health Tracking Portal: 2-Year Summer Average; 2009-2010.

- **Respiratory Death:** NYC Department of Health and Mental Hygiene: Crude rate of Death by Chronic Lower Respiratory Diseases; 2010. Normalized per 100,000 residents.
  http://www.nyc.gov/html/doh/downloads/pdf/vs/vs-population-and-mortality-report.pdf
  Page 23-24

- **Asthma Hospitalizations:** NYC Environmental Public Health Tracking Portal: Total ER Visits; 2008-2010. Normalized per 100,000 residents. Data available by ZIP Code and therefore utilized the mapping methodology explained above and shown in the **Tables** section of this document.

v. Energy Reduction

The indicator used to measure the opportunity to obtain the benefit of energy reduction is average electricity use.

- **Electricity Use:** NYC Open Data; 2010. Represented in millions of kilowatt-hours and normalized per 100,000 residents. This data was available by ZIP Code and therefore utilized the mapping methodology explained above and shown in the **Tables** section of this document.
  https://nycopendata.socrata.com/d/dhry-6nsv

vi. Community Factors

The indicators used to measure the opportunity to tackle various urban problems that we have termed "community factors" are percent unemployment, percent of land area devoted to open space, and obesity rates.

- **% Unemployment:** NYC Department of City Planning: Economic Profile; 2010. Count of number of unemployed / Total in labor force
  http://www.nyc.gov/html/dcp/html/census/popacs.shtml

- **% Land Area Open Space:** NYC Department of City Planning: 2013. Open Space / Recreation divided by total area per CD –
  http://www.nyc.gov/html/dcp/html/lucds/cdstart.shtml

- **% Obesity:** Environmental Public Health Tracking and Sustainability Portal: Percent Obesity in Adults; 2011.

vii. Vulnerability Indicators by Age and Income Level

Demographic Vulnerability Indicators
% Population <15
% Population 65+
% Households Below Poverty Level

The team also included vulnerability indicators by age and income (below) that play into the benefit outcomes. These three vulnerability indicators are Percent of Population under the age of 15, Percent of Population over the age of 65, and Percent of Households with Incomes under the poverty level. The very young and very old are especially vulnerable to air pollution and urban heat island effect, while the poor are also more susceptible to heat-related illness because they are less likely to have air-conditioning. All three groups are included in the tool to provide additional public health context.

These vulnerability factors can be added into community district scoring by choosing "Yes" under the option to "Score Including Vulnerability Index?" Specifically, % Population <15 and % Population 65+ will be factored into all four Air Quality Improvement indicators, and % Population <15 and % Population 65+, and % Households Below Poverty Level will be factored into the Urban Heat Island indicator. Scoring methodology is explored further in the **Scoring** section.

- **% Population <15:** NYC Department of City Planning: Total Population by Age Group and Sex; 2010. Sum of Population ages 0-14 / Total Population

http://www.nyc.gov/html/dcp/html/census/demo_tables_2010.shtml

- **% Population 65+:** NYC Department of City Planning: Total Population by Age Group and Sex; 2010. Sum of Population ages 65+ / Total Population http://www.nyc.gov/html/dcp/html/census/demo_tables_2010.shtml

- **% Households below Poverty Level (Notes 3&4):** NYC Department of City Planning: Economic Profile; 2010. Sum of number of households with income ranging from $0-10,000, $10,001-$14,999 and $15,000-24,999 / Total number of households http://www.nyc.gov/html/dcp/html/census/popacs.shtml

Note 3: *The federal poverty level for a household of four is $23,550. Data from the Department of City Planning was divided into three categories of income ranging from $0-$10,000, $10,001-$14,999 and $15,000-$24,999. In the tool, a sum of the number of households within these three thresholds is counted under Percent of Households with Incomes under the poverty level. An additional flaw in this figure is that the federal poverty level depends on the number of people living in each household. However, this figure was unavailable on a community district level.*
Note 4: *Economic Profile Data is categorized by Public Use Microdata Area (PUMA) code. Manhattan Community Districts 1 and 2 are grouped into one PUMA code. Therefore, the value used in the tool utilizes the same percentage for each. This also applies to Manhattan Community Districts 4 and 5, Bronx Community Districts 1 and 2, & 3 and 6.*

viii. Other Indicators

Other Indicators
Total Population
Cost Green Infrastructure < Grey
Land Area
of Prior Grants Awarded
English Fluency

The tool includes additional indicators for reference that do not figure into the scoring: Total Population, Cost of Green Infrastructure vs. Grey Infrastructure, Land Area, Number of Prior Green Infrastructure Grants awarded and English Fluency.

Total population tells you how many residents a project may affect. Some community districts may be better suited for green infrastructure than grey in terms of cost effectiveness and so their comparative costs are also included. This data was obtained from the NYC Green Infrastructure Plan which compares the cost per gallon of combined sewer overflow captured for the green strategy and grey strategy by Watershed. The team created mapping using GIS of community districts to watersheds by overlaying a shapefile of watersheds with a shapefile of NYC

community districts in order to see which community districts were better suited for grey or green infrastructure.
The tool defines Land Area in thousands of square feet.
We counted the number of Green Infrastructure Grants Awarded from DEP press releases and mapped their locations to get geographic coordinates. We uploaded those coordinates into GIS and overlaid them with community district shapefiles to see where the grants have been awarded by community district.
The tool includes the indicator English Fluency to help guide the DEP in community outreach efforts.

- **Total Population:** Department of City Planning: Total Population by Age Group and Sex; 2010.
  http://www.nyc.gov/html/dcp/html/census/demo_tables_2010.shtml

- **Cost Green Infrastructure < Grey**: NYC Green Infrastructure Plan: Page 35; 2010.
  http://www.nyc.gov/html/dep/pdf/green_infrastructure/NYCGreenInfrastructurePlan_LowRes.pdf

- **Land Area:** Department of City Planning: Community District Profiles; 2013.
  http://www.nyc.gov/html/dcp/html/lucds/cdstart.shtml

- **# of Prior Grants Awarded:** NYC Department of Environmental Protection: Grant Program for Private Property Owners; 2011-2013.
  2013: http://www.nyc.gov/html/dep/html/press_releases/13-053pr.shtml
  2012:
  http://www.nyc.gov/portal/site/nycgov/menuitem.c0935b9a57bb4ef3daf2f1c701c789a0/index.jsp?pageID=mayor_press_release&catID=1194&doc_name=http%3A%2F%2Fwww.nyc.gov%2Fhtml%2Fom%2Fhtml%2F2012a%2Fpr145-12.html&cc=unused1978&rc=1194&ndi=1
  2011: http://www.nyc.gov/html/dep/html/press_releases/11-46pr.shtml

- **English Fluency:** NYC Department of Planning: Social Profile **(Note 5)**; 2010.
  Sum of Population age 5 and over that speaks English "less than very well" / Total Population
  http://www.nyc.gov/html/dcp/html/census/popacs.shtml

  Note 5: *Social Profile Data is categorized by Public Use Microdata Area (PUMA) code. Manhattan Community Districts 1 and 2 are grouped into one PUMA code. Therefore, the value used in the tool utilizes the same percentage for each. This also applies to Manhattan Community Districts 4 and 5, Bronx Community Districts 1 and 2, & 3 and 6.*

V. Scoring

The team created a methodology to generate a total standardized score for each community district. These scores help to rank communities in order of greatest to least opportunity to capture the benefits provided by the installation of green infrastructure.

Weighting Indicators Belonging to Benefit Areas

In our analysis, we gave each benefit category an equal weight. For example, stormwater management's two indicators are weighted at 0.5, so that the sum of the scores for the indicators will sum to a value between 0.0 and 1.0. The weight can be changed to place more emphasis on a desired benefit type. This will populate automatically in the tool, adjusting the scores for the weight chosen.

The NYC minimum maximum and average values are calculated and displayed for each indicator. This allows the user to know where this community district falls within the realm of the entire city. These values also play into the scoring. The maximum score that can be attained by any community district is 7.0 (1.0 for each of the five benefit category, plus the possibility to score 2.0 additional points by factoring in demographic vulnerability indicators which are factored into Urban Heat Island Mitigation and Air Quality Improvement).

Scoring Indicators without Weighting for Vulnerable Populations

Each indicator is scored from 0.0 – 1.0, with '1' representing the greatest vulnerability. In order for a community district to score highly for any indicator, the community district value must be closer to the maximum value for all of NYC.
Formula for scoring an indicator:

$$Score = \left(\frac{Community\ District\ Value - Minimum\ Value\ [NYC]}{Maximum\ Value\ [NYC] - Minimum\ Value\ [NYC]} \right) * Weight\ Allocation$$

Example of scoring for electricity use for Manhattan community district #1, a proxy that is the only measurement for potential energy reduction:

Benefit	Indicator	Weight Allocation	Min Value [NYC]	Max Value [NYC]	Community District Value	Standardized Score
Energy Reduction	Electricity Use [kWh]	1.00	1	9,187	4,132	**0.45**

$$0.45 = \left(\frac{4{,}132 - 1}{9{,}187 - 1} \right) * 1$$

Example of scoring Manhattan community district #1's deaths due to respiratory illness; one of four indicators measuring potential Air Quality Improvement:

Benefit	Indicator	Weight Allocation	Min Value [NYC]	Max Value [NYC]	Community District Value	Standardized Score
Air Quality Improvement	Deaths Due to Respiratory Disease	0.25	7	226	82	0.09

$$0.09 = \left(\frac{82 - 7}{226 - 7}\right) * 0.25$$

Scoring Indicators and Weighting for At-Risk Populations

As noted in previous sections, the user has the option to score including vulnerable population indicators by choosing "Yes" in the "Score Including Vulnerability Index" box. Indicators which take into account vulnerable populations receive a score from 0.0 – 2.0.

If the user decides to include "at-risk" population indicators into the score, the scores for all air quality improvement indicators (Fine PM 2.5, Ozone, Deaths due to Respiratory Disease, and Asthma Hospitalizations) and the urban heat island indicator (heat stress hospitalizations), include an additional weight that is calculated based on the percent of population under the age of 15 and over the age of 65 in a community district. For urban heat island, the percentage of households with income less than $25,000 is also factored in.

Age and income vulnerability factors are calculated in the same way that other indicators are scored, namely a percentile is given to each community based on the range of scores across NYC. The factor is calculated using the formula below.

$$\begin{matrix}\text{Vulnerable} \\ \text{Populations Factor}\end{matrix} = 1 + \left(\frac{\begin{matrix}\text{Community} \\ \text{District Value}\end{matrix} - \begin{matrix}\text{Minimum} \\ \text{Value [NYC]}\end{matrix}}{\begin{matrix}\text{Maximum} \\ \text{Value [NYC]}\end{matrix} - \begin{matrix}\text{Minimum} \\ \text{Value [NYC]}\end{matrix}}\right) * \text{Weight}$$

In order to add an additional weight for community districts that have high values of population under the age of 15 or above 65, and a lower but still positive value for those that have lower values of population under 15 or over 65, 1 is added to the factor. In the case of urban heat island, a factor for poverty is also included. In the case of urban heat island, all three vulnerability indicators are included with each carrying a weight of .33. In the case of air quality improvement, the two indicators carry a weight of 0.5 each.

Formula for scoring indicators under air quality improvement or urban heat island mitigation when the three vulnerable population factors:

$Score =$		$\left(\left(\frac{Benefit\ Indicator\ Value - \frac{Minimum}{Value\ [NYC]}}{\frac{Maximum}{Value\ [NYC]} - \frac{Minimum}{Value\ [NYC]}}\right) * \frac{Benefit\ Weight}{Allocation}\right)$
	$Vulnerability\ Indicator\ Values$	$* 1 + \left(\left(\frac{Community\ District\ Value\ \%\ Population{<}15 - \frac{Minimum\ \%}{Population{<}15\ [NYC]}}{\frac{Maximum\ \%}{Population{<}15\ [NYC]} - \frac{Minimum\ \%}{Population{<}15\ [NYC]}}\right) * \frac{1}{3}\right.$ $+ \left(\frac{Community\ District\ Value\ \%\ Population{>}65 - \frac{Minimum\ \%}{Population{>}65\ [NYC]}}{\frac{Maximum\ \%}{Population{>}65\ [NYC]} - \frac{Minimum\ \%}{Population{>}65\ [NYC]}}\right) * \frac{1}{3}$ $\left. + \left(\frac{Community\ District\ Value\ \%\ HHI{<}\$25K - \frac{Minimum\ \%}{\%\ HHI{<}\$25K\ [NYC]}}{\frac{Maximum\ \%}{\%\ HHI{<}\$25K\ [NYC]} - \frac{Minimum\ \%}{P\%\ HHI{<}\$25K\ [NYC]}}\right) * \frac{1}{3}\right)$

VI. Tables

i. New York City Indicator Ranges, Averages and Medians

Benefit	Indicator	Min Value [NYC]	Max Value [NYC]	Average Value [NYC]	Median Value [NYC]
Stormwater Management	Combined Sewer Priority Watershed	0	2	1	1
	311 Reports of Street flooding, Highway Flooding, Sewer Backup, Manhole Overflow & Catch Basin Clogged	140	2,416	632	443
Urban Heat Island Mitigation	Heat Stress Hospitalizations	0	9	3	3
Air Quality Improvement	Fine Particulate Matter 2.5	8.9	15.7	10.7	10.6
	Ozone [O3]	17.8	30.6	26.9	27.1
	Deaths Due to Respiratory Disease	7	226	51	21
	Asthma Hospitalizations	0	14,511	2,971	1,618
Energy Reduction	Electricity Use [kWh]	1	9,187	548	236
Community Factors	% Unemployment	6%	21%	11%	11%
	% of Land Area Open Space	1%	50%	14%	8%
	% Obesity	8%	37%	24%	25%
Demographic Indicators	% Population <15	6%	29%	18%	18%
	% Population 65+	6%	22%	12%	11%
	% Households Below Poverty Level	12%	56%	30%	28%

ii. Mapping of ZIP Codes and United Health Funds to NYC Community Districts

Borough-Community District # (Tool)	Community District ID (GIS)	United Health Fund (UHF) Code	Zip Code
BK-1	301	211	11206
BK-1	301	201	11211
BK-1	301	201	11222
BK-1	301	211	11237
BK-10	310	209	11209
BK-10	310	209	11228
BK-11	311	209	11228
BK-11	311	209	11214
BK-11	311	206	11204
BK-11	311	206	11219
BK-12	312	206	11204
BK-12	312	206	11219
BK-12	312	206	11218
BK-12	312	206	11230
BK-13	313	209	11214
BK-13	313	210	11235
BK-13	313	210	11224
BK-13	313	210	11235
BK-14	314	207	11210
BK-14	314	207	11226
BK-14	314	207	11226
BK-15	315	210	11223
BK-15	315	210	11229
BK-15	315	210	11229
BK-16	316	203	11212
BK-16	316	203	11233
BK-17	317	207	11226
BK-17	317	207	11226
BK-17	317	208	11236
BK-18	318	208	11234
BK-18	318	207	11210
BK-18	318	208	11236
BK-18	318	208	11239
BK-2	302	202	11201
BK-2	302	202	11217
BK-2	302	202	11205
BK-2	302	203	11238
BK-3	303	211	11201
BK-3	303	211	11206
BK-4	304	211	11201
BK-4	304	211	11237
BK-5	305	208	11239
BK-5	305	204	11207
BK-5	305	204	11208
BK-6	306	202	11215
BK-6	306	202	11231
BK-6	306	202	11201
BK-7	307	205	11220
BK-7	307	205	11209
BK-7	307	205	11232
BK-7	307	205	11215
BK-7	307	202	11215
BK-7	307	205	11215
BK-8	308	203	11238
BK-9	309	207	11225
BX-1	201	107	10454
BX-1	201	106	10451
BX-1	201	107	10455

Borough-Community District # (Tool)	Community District ID (GIS)	United Health Fund (UHF) Code	Zip Code
BX-10	210	102	10475
BX-10	210	104	10465
BX-10	210	104	10461
BX-11	211	102	10469
BX-11	211	104	10461
BX-11	211	104	10462
BX-12	212	102	10470
BX-12	212	102	10466
BX-12	212	103	10467
BX-12	212	102	10469
BX-2	202	107	10474
BX-2	202	107	10459
BX-3	203	105	10460
BX-3	203	105	10457
BX-3	203	107	10459
BX-3	203	106	10456
BX-4	204	106	10451
BX-4	204	106	10452
BX-4	204	106	10456
BX-5	205	105	10453
BX-5	205	105	10457
BX-6	206	105	10460
BX-6	206	103	10458
BX-6	206	105	10457
BX-7	207	103	10468
BX-7	207	103	10467
BX-7	207	103	10458
BX-8	208	103	10468
BX-8	208	101	10463
BX-8	208	101	10471
BX-9	209	104	10462
BX-9	209	104	10473
BX-9	209	104	10472
MN-1	101	310	10280
MN-1	101	310	10004
MN-1	101	310	10006
MN-1	101	310	10048
MN-1	101	310	10005
MN-1	101	310	10041
MN-1	101	310	10271
MN-1	101	310	10279
MN-1	101	310	10278
MN-1	101	310	10038
MN-1	101	310	10282
MN-1	101	308	10013
MN-1	101	310	10007
MN-10	110	302	10027
MN-10	110	302	10039
MN-10	110	302	10037
MN-10	110	302	10030
MN-10	110	302	10026
MN-11	111	302	10037
MN-11	111	303	10035
MN-11	111	303	10029
MN-12	112	301	10032
MN-12	112	301	10033
MN-12	112	301	10040
MN-12	112	301	10034

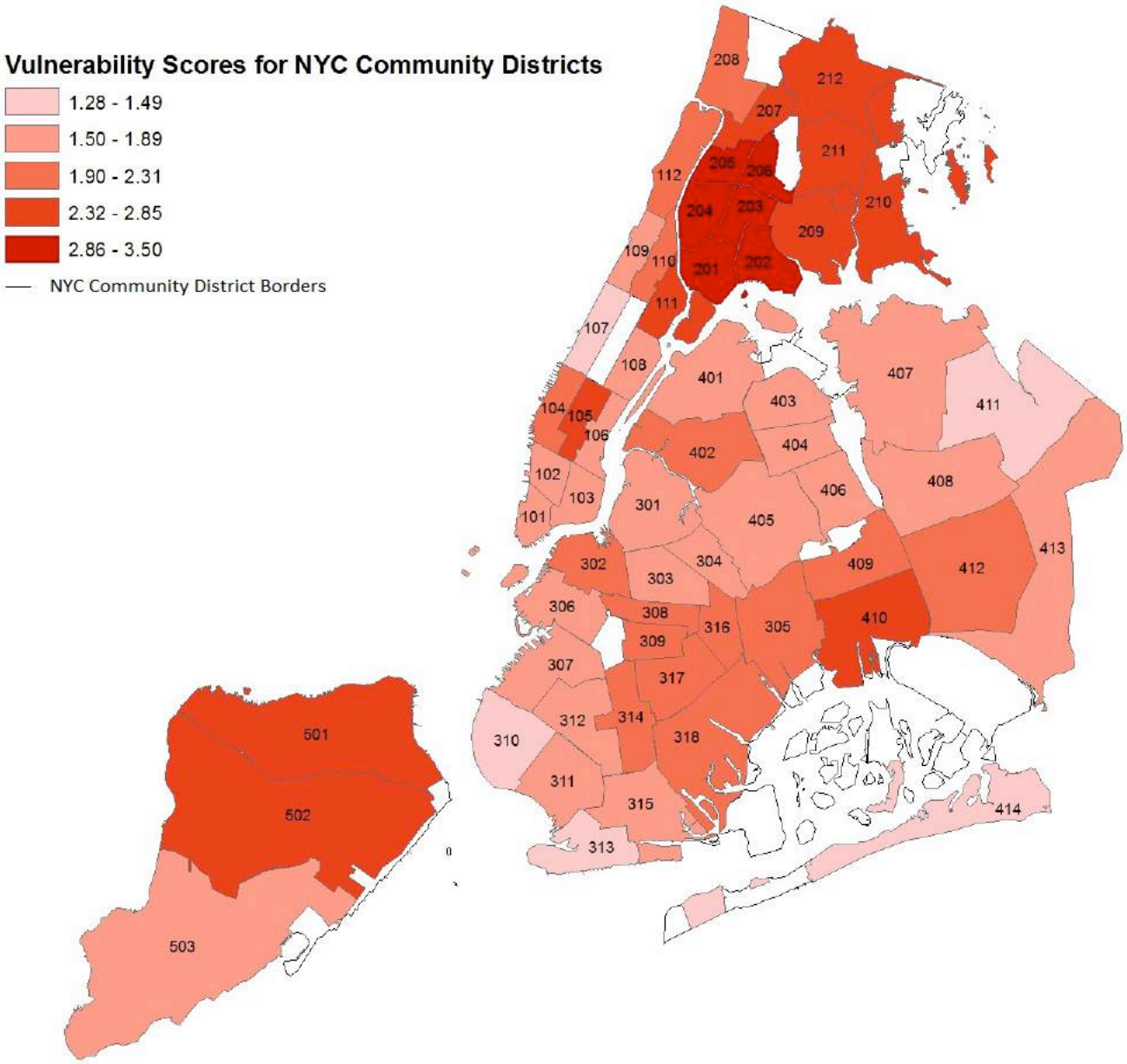
Borough-Community District # (Tool)	Community District ID (GIS)	United Health Fund (UHF) Code	Zip Code
MN-2	102	308	10013
MN-2	102	308	10014
MN-2	102	308	10012
MN-2	102	306	10011
MN-2	102	309	10003
MN-2	102	308	10012
MN-3	103	310	10038
MN-3	103	309	10009
MN-3	103	309	10003
MN-3	103	309	10002
MN-4	104	306	10011
MN-4	104	306	10001
MN-4	104	306	10018
MN-4	104	306	10036
MN-4	104	306	10019
MN-5	105	306	10001
MN-5	105	306	10119
MN-5	105	306	10018
MN-5	105	306	10036
MN-5	105	306	10019
MN-5	105	306	10020
MN-5	105	307	10022
MN-5	105	307	10154
MN-5	105	307	10152
MN-5	105	307	10153
MN-5	105	307	10017
MN-5	105	307	10170
MN-5	105	307	10169
MN-5	105	307	10165
MN-5	105	307	10173
MN-5	105	307	10171
MN-5	105	307	10172
MN-5	105	307	10177
MN-5	105	307	10167
MN-5	105	307	10016
MN-5	105	307	10010
MN-5	105	309	10003
MN-6	106	307	10022
MN-6	106	307	10017
MN-6	106	307	10016
MN-6	106	307	10010
MN-6	106	309	10009
MN-6	106	309	10003
MN-7	107	304	10023
MN-7	107	304	10024
MN-7	107	304	10025
MN-7	107	304	10069
MN-8	108	305	10128
MN-8	108	305	10021
MN-8	108	305	10044
MN-8	108	305	10028
MN-9	109	302	10027
MN-9	109	301	10031
QN-1	401	402	11377
QN-1	401	401	11106
QN-1	401	401	11102
QN-1	401	401	11105
QN-1	401	401	11103
QN-1	401	402	11370

Borough-Community District # (Tool)	Community District ID (GIS)	United Health Fund (UHF) Code	Zip Code
QN-10	410	407	11414
QN-10	410	407	11419
QN-10	410	407	11420
QN-11	411	403	11358
QN-11	411	404	11361
QN-11	411	406	11365
QN-11	411	404	11364
QN-11	411	404	11363
QN-11	411	404	11362
QN-11	411	409	11427
QN-12	412	408	11436
QN-12	412	408	11434
QN-12	412	408	11435
QN-12	412	408	11412
QN-12	412	408	11423
QN-12	412	408	11432
QN-12	412	408	11433
QN-13	413	408	11434
QN-13	413	409	11413
QN-13	413	409	11422
QN-13	413	409	11005
QN-13	413	409	11004
QN-13	413	409	11426
QN-13	413	409	11428
QN-13	413	409	11427
QN-13	413	409	11429
QN-13	413	409	11411
QN-14	414	410	11691
QN-14	414	410	11692
QN-14	414	410	11693
QN-14	414	410	11694
QN-2	402	401	11378
QN-2	402	401	11101
QN-2	402	402	11377
QN-2	402	401	11104
QN-3	403	402	11370
QN-3	403	402	11369
QN-3	403	402	11372
QN-4	404	402	11373
QN-5	405	405	11385
QN-5	405	402	11378
QN-5	405	402	11378
QN-5	405	405	11373
QN-6	406	405	11374
QN-6	406	405	11375
QN-7	407	403	11355
QN-7	407	403	11354
QN-7	407	403	11356
QN-7	407	403	11357
QN-7	407	403	11358
QN-7	407	403	11360
QN-7	407	406	11365
QN-8	408	408	11435
QN-8	408	406	11367
QN-8	408	406	11365
QN-8	408	408	11423
QN-8	408	406	11366
QN-8	408	408	11432

Borough-Community District # (Tool)	Community District ID (GIS)	United Health Fund (UHF) Code	Zip Code
QN-9	409	407	11425
QN-9	409	407	11418
QN-9	409	407	11419
SI-1	501	502	10301
SI-1	501	501	10310
SI-1	501	501	10302
SI-1	501	501	10303
SI-1	501	503	10314
SI-1	501	502	10305
SI-1	501	502	10304
SI-2	502	503	10303
SI-2	502	503	10314
SI-2	502	504	10306
SI-2	502	503	10306
SI-2	502	502	10305
SI-2	502	502	10304
SI-3	503	504	10314
SI-3	503	504	10309
SI-3	503	504	10307
SI-3	503	504	10312
SI-3	503	504	10308
SI-3	503	504	10306
Park Area	356	208	11234
Park Area	355	207	11225
Park Area	356	208	11208
Park Area	480	Null	11371
Park Area	481	406	11375
Park Area	482	405	11418
Park Area	483	Null	11430
Park Area	484	410	11697
Park Area	481	403	11368
Park Area	164	Null	10023
Park Area	164	Null	10019
Park Area	164	164	10024
Park Area	164	Null	10025
Park Area	164	Null	10021
Park Area	226	101	10471
Park Area	226	102	10470
Park Area	227	103	10467
Park Area	226	103	10467
Park Area	228	104	10465
Park Area	228	104	10464
Park Area	227	105	10460

Appendix D. GIS Map with Optimization Tool Generated Scores

After scoring each of the community districts using the optimization tool, we then mapped these to generate a visual representation of where the most vulnerable neighborhoods exist. To generate these scores, the weights per each benefit area were set to "1" and we did include the vulnerability index.



Appendix E: Optimization Tool Scores Across NYC

Borough	Community District #	Community District Name	Vulnerability Score
Bronx	3	Morrisania, Crotona Park East	4.75
Bronx	6	East Tremont, Belmont	4.57
Bronx	1	Melrose, Mott Haven, Port Morris	4.56
Bronx	5	University Hts., Fordham, Mt. Hope	4.41
Bronx	4	Highbridge, Concourse Village	4.27
Bronx	2	Hunts Point, Longwood	4.24
Bronx	9	Soundview, Parkchester	3.76
Manhattan	11	East Harlem	3.75
Bronx	7	Bedford Park, Norwood, Fordham	3.43
Staten Island	2	New Springville, South Beach	3.28
Bronx	11	Pelham Pkwy, Morris Park, Laconia	3.26
Bronx	10	Throgs Nk., Co-op City, Pelham Bay	3.12
Manhattan	12	Washington Heights, Inwood	3.11
Staten Island	1	Stapleton, Port Richmond	3.07
Bronx	12	Wakefield, Williamsbridge	2.84
Queens	10	Ozone Park, Howard Beach	2.72
Bronx	8	Riverdale, Kingsbridge, Marble Hill	2.65
Brooklyn	18	Canarsie, Flatlands	2.64
Manhattan	5	Midtown Business District	2.57
Manhattan	10	Central Harlem	2.55
Brooklyn	17	East Flatbush, Rugby, Farragut	2.53
Brooklyn	9	Crown Heights South, Wingate	2.52
Brooklyn	14	Flatbush, Midwood	2.45
Manhattan	9	Manhattanville, Hamilton Heights	2.44
Staten Island	3	Tottenville, Woodrow, Great Kills	2.36
Brooklyn	5	East New York, Starrett City	2.35
Queens	12	Jamaica, St. Albans, Hollis	2.34
Queens	9	Woodhaven, Richmond Hill	2.30
Brooklyn	16	Brownsville, Ocean Hill	2.26
Queens	2	Sunnyside, Woodside	2.16
Queens	5	Ridgewood, Glendale, Maspeth	2.05
Brooklyn	2	Brooklyn Heights, Fort Greene	1.98
Brooklyn	13	Coney Island, Brighton Beach	1.97
Manhattan	4	Chelsea, Clinton	1.95
Manhattan	3	Lower East Side, Chinatown	1.94
Brooklyn	7	Sunset Park, Windsor Terrace	1.92
Brooklyn	8	Crown Heights North	1.91
Queens	14	The Rockaways, Broad Channel	1.89
Queens	8	Fresh Meadows, Briarwood	1.88
Brooklyn	6	Park Slope, Carroll Gardens	1.87
Queens	1	Astoria, Long Island City	1.82
Queens	13	Queens Village, Rosedale	1.78
Queens	6	Forest Hills, Rego Park	1.74
Manhattan	2	Greenwich Village, Soho	1.74
Brooklyn	15	Sheepshead Bay, Gerritsen Beach	1.68
Manhattan	1	Battery Park City, Tribeca	1.66
Manhattan	8	Upper East Side	1.66
Queens	7	Flushing, Bay Terrace	1.65
Brooklyn	10	Bay Ridge, Dyker Heights	1.64
Manhattan	6	Stuyvesant Town, Turtle Bay	1.63
Brooklyn	1	Williamsburg, Greenpoint	1.63
Brooklyn	12	Borough Park, Ocean Parkway	1.62
Queens	3	Jackson Heights, North Corona	1.61
Brooklyn	4	Bushwick	1.60
Brooklyn	11	Bensonhurst, Bath Beach	1.57
Brooklyn	3	Bedford Stuyvesant	1.56
Queens	11	Bayside, Douglaston, Little Neck	1.55
Queens	4	Elmhurst, South Corona	1.51
Manhattan	7	West Side, Upper West Side	1.47

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