Sarah Followill

PLAN 372 – Bhagat-Conway

1 May, 2023

Green Infrastructure in New York City Boroughs

1. **Introduction and Motivation**

I am primarily interested in green architecture and infrastructure and plan to pursue a future in designing such sustainable infrastructure. Additionally, I am currently studying for the LEED Green Associate Exam, and have been learning about various ways to make both buildings and surrounding dense urban area more sustainable. I knew that I wanted to incorporate these interests into my final project, and eventually found a dataset of green infrastructure locations in New York City, New York. The points from this dataset are the locations from the NYC Green Infrastructure Program, piloted in 2011 by the New York City Department of Environmental Protection (DEP) (Enoch and Balci, 2019), and are where sustainability initiatives such as green roofs, rain gardens, or stormwater swales exist. These initiatives are primarily focused on reducing the amount of paved area that contributes to the urban heat island effect, reducing impermeable surfaces, and diverting potentially-polluted stormwater runoff from sewers to avoid Combined Sewer Overflow (CSO) events.

Due to my interest in sustainable urban developments such as this one, I decided to explore this dataset of green infrastructure locations in one of the largest and most well-known urban environments in the United States: New York City. Alongside this exploration, I also wanted to examine the density of green infrastructure in the five main neighborhoods, or boroughs, of New York in comparison to the population of those boroughs, and also use a future population projection to recommend how and where green infrastructure will need to expand in order to account for the projected population increase in New York City.

1. **Literature Review**

According to the NYC Department of Environmental Protection’s 2019 Green Infrastructure Annual Report by Drs. Enoch and Balci, by 2019 the NYC Green Infrastructure Program was responsible for greening 1,230 acres of urban land within city limits. These acres came from initiatives including vegetation between streets and sidewalks, adding green roofs to public and private buildings, installing permeable pavement, installing subsurface water retention systems, and installing bioretention systems among other initiatives (Enoch and Balci, 2020). Additionally, Drs. Enoch and Balch explain that this is the largest green stormwater infrastructure program in the United States (Enoch and Balci, 2019).

I continued to research the New York City Green Infrastructure Program and found their most recent progress report from 2021. As of this report, the group’s initiative totaled a 507 million-gallon CSO reduction in 2021 through their collection of over 9,100 infrastructure assets (now over 15,000). Listed project goals for 2022 included advancement of porous pavement design, a new Community Stormwater Resiliency Grant Program, continuing to promote incentives for green infrastructure on private property (DEP has already committed $14 million to private property owners for constructing new green infrastructure projects), and new research and development partnerships. Finally, NYC Green Infrastructure is on its way to a 2030 goal of reducing 1.67 billion gallons of CSO water per year (NYC Green Infrastructure, 2021).

The New York City Green Infrastructure Program is primarily seeking to reduce Combined Sewer Overflow events and the Urban Heat Island Effect. According to the NYC DEP, about 60% of NYC operates on a combined sewer system, where one pipe is responsible for carrying both stormwater runoff and sewage waste from buildings to a wastewater treatment plant. However, when heavy rainfall events occur, the single pipe can experience higher-than-normal volumes of stormwater, which, combined with sewage, cannot be handled in such a quantity by the treatment facility. Therefore, excess sewage and stormwater must flow out through an overflow drain, which discharges directly into local water bodies, as exemplified in *Fig. 1*. These overflow events negatively impact water quality, damage biodiversity, and hinder recreational use of water bodies (NYC DEP, 2023). This phenomenon can be combatted through minimizing impervious surfaces that rainwater cannot naturally seep into such as asphalt and concrete, increasing vegetated area in urban environments, and capturing and storing rainwater for reuse at a later time. The NYC Green Infrastructure Program is seeking to increase use of these types of infrastructure and more in New York in order to minimize environmental damage from CSO.

While the NYC Green Infrastructure Program is primarily focused on CSO reduction, its efforts also help to combat the urban heat island effect. The urban heat island effect is characterized by increased urban temperatures due to the sun’s heat being absorbed by non-vegetated surfaces like concrete and asphalt that are concentrated in cities, and that heat being re-emitted into the local atmosphere, leading to increased temperatures (EPA, 2023). Urban areas’ daytime temperatures can range from being 1 – 7ºF higher than surrounding, less-infrastructure-dense areas, and urban temperatures at night can be anywhere from 2 – 5ºF higher (EPA, 2023). This phenomenon can be reduced by decreasing non-vegetated surface area in cities and by installing infrastructure like green roofs on buildings and building greenspaces in cities. Both of these solutions minimize the urban heat island effect also help to reduce stormwater runoff as vegetation is much better at absorbing rainfall than asphalt, so the NYC Green Infrastructure Program can simultaneously combat both CSOs and the urban heat island effect by installing such green infrastructure.

1. **Data Review**

My primary dataset of New York Green Infrastructure Project point locations is from the New York City OpenData website, which hosts thousands of free public datasets published by established NYC agencies and governmental partners. This dataset is currently up to date as of 2023, includes over 15,000 features of green infrastructure and 33 variables. Variables of interest to this project include the site area of each asset and the borough in which it is located. I was confident on the completeness of this dataset as none of the features had null values for asset area or borough name. I downloaded this point locations dataset as a shapefile. I also accessed another spatial dataset from NYC OpenData that includes five features of borough boundaries for the five boroughs of NYC: Bronx, Brooklyn, Manhattan, Queens, and Staten Island. I downloaded this dataset as a shapefile as well. My third dataset was tabular data in a CSV file that included the 2020 population of each New York borough as well as a 2040 population projection for each borough based on current and predicted population trends.

1. **Methodology**
2. **QGIS Methods**

I began my investigation by creating a map in QGIS of New York City borough boundaries and green infrastructure asset points layered on top as seen in *Fig. 2* to visualize the distribution of assets across the city. I made each borough a different color in order to easily visualize the borough boundaries. In addition to just examining number of assets alone, I also wanted to evaluate the total area of assets in each borough. Some assets might have a greater surface area and therefore create more benefit as there is more surface that is both capturing and diverting rainfall and reducing the effects of urban heat island, so it is important to evaluate the size of each asset in addition to asset count alone. I therefore joined my green infrastructure data to my borough boundaries layer by borough name in order to find total asset area for each borough in NYC, and created a choropleth map of total infrastructure area by borough, as seen in *Fig. 3*.

Next, I wanted to use the buffer tool in QGIS to identify areas in New York that are not near green infrastructure, and therefore areas where new infrastructure could be built by the NYC Green Infrastructure Project in the future. I started by creating 1-mile buffers around each green infrastructure location point and dissolving the result to create a zone of area that is within 1-mile of a green infrastructure point from all points within the zone. I clipped this buffer to the borough boundaries layer to limit the zone area to just within the borough boundaries, and was left with a resultant map of the 1-mile buffer zone shown in black, and areas of each borough that were not within 1-mile of green infrastructure, shown in *Fig. 4* in full color depending on borough. I also created a second map using 0.5-mile buffer in order to more narrowly highlight areas in New York City that could benefit from the installation of green infrastructure as well as areas that already have a denser concentration of assets, shown in *Fig. 5*, that was created using the same method as the 1-mile buffer and displayed in similar fashion.

I also added population data for New York City boroughs in 2020 and 2040 (projected) from the population dataset to my infrastructure dataset by using expressions, shown in *Figs. 8-9*, to create two new columns of population data.

1. **R Methods**

I then transitioned to working with my data in R. First, I exported my NYC Green Infrastructure dataset from QGIS as a CSV file in order to read it into R. I then created a frequency table to calculate the counts of infrastructure assets per borough. Next, to that table I added an average area column in which I calculated the average asset area per borough for all assets in each borough using the `group\_by( )` and `summarize( )` functions. I also added two more columns to the table for 2020 and 2040 (projected) populations by borough. Next, I wrote an equation for how I wanted to estimate green infrastructure density by borough in both 2020 and 2040, accounting for average asset area by borough and population by borough in both years. The equation is as shown in *Fig. 10* and estimates the density of green infrastructure surface area by population. I then stored each year’s density results by borough into two new columns, one for each year’s density.

My current equation calculated density for 2040 as if no additional green infrastructure assets were added to each borough between 2020 and 2040, which is highly unlikely. Therefore, I wanted to write a new equation to evaluate how many new assets would need to be added to each New York City borough between 2020 and 2040 to make the density equal to what it is in 2020 considering projected population increase in each borough and assuming that average asset area remains the same in each borough throughout the twenty-year period. This equation is shown in *Fig. 11* and I stored the results of each borough’s required infrastructure change in a new column. Additionally, I then plotted that column’s contents on a bar chart, shown in *Fig. 7*, to visualize the distribution of necessary infrastructure additions by borough to maintain the 2020 area density.

Next, I added a population change by borough column by subtracting the 2020 population from the 2040 population in order to visualize the magnitude of each borough’s projected population increase during the 20-year span. I then made a bar chart of the population change distribution between the boroughs, seen in *Fig. 6*. My final table is shown in *Fig. 12*.

1. **Analysis and Results**

According to *Fig. 12* as well as *Fig. 2*, Queens has the highest count of green infrastructure assets with a total of 7,428 assets, and Staten Island has the lowest count of assets with a total of 65 assets. However, infrastructure area must be taken into account in addition to asset count alone, as some assets cover more surface area than others, making them typically more valuable than smaller assets as they have a larger impact on reduction of CSOs and reduction of impermeable surfaces. When evaluating total asset area, seen in *Fig. 3*, Queens, which had the highest asset count, is actually only the third highest in total asset area and lowest in average asset area. The borough with the greatest total asset area is Brooklyn, with an area of almost 2 million ft^2. Staten Island still has the lowest total asset area at 655,792 ft^2, which is a little over 25% of Brooklyn’s total asset area. However, it is worth noting that Staten Island does indeed have the largest average asset area, at a little over 10,000 ft^2, demonstrating that though Staten Island does not have many assets, the ones that they do have are quite large.

According to my two buffer maps, *Figs. 4-5*, Southeastern Queens and central Staten Island seem to be the two main areas where increased green infrastructure is needed. However, these maps are limited in that they do not account for asset area, such as how Staten Island average asset area is a little over 10,000 ft^2, so it is difficult to determine exactly where infrastructure is needed without being able to account for area. Despite this limitation, these two identified areas of Queens and Staten Island would likely be a good place to start when determining where more infrastructure is needed. Additionally, while I did not explore this in the scope of this project, it would be interesting to study flooding patterns in New York City as well to determine where new stormwater-diverting infrastructure would be most beneficial.

My first density equation in *Fig. 10* calculates an estimated total square feet of green infrastructure area per person in each borough. The density in each borough is over 1, meaning that there is more than 1 ft^2 of infrastructure per inhabitant of the borough. In 2020, Brooklyn is the most infrastructure dense at 1.58 ft^2 per person, and Queens and Bronx are tied for the least dense at 1.19 ft^2 per person, despite Queens having the highest count of infrastructure points. This trend is likely due to Queens’ high population and low average infrastructure area. Staten Island’s 2020 density is also worth noting, as it is actually the second most dense at 1.36 ft^2 per person. This is likely due to the borough’s relatively low population, but high average infrastructure area.

My second density equation, *Fig. 11*, addresses the issue of my *Fig. 10* 2040 density equation not accounting for increase in green infrastructure between 2020 and 2040. It uses 2020 density, 2020 average asset area, 2020 asset count and 2040 population to determine the required increase in green infrastructure area in each borough to account for rising populations and maintain at least 2020-level density while keeping average asset area consistent with that of the 2020 calculation. This is, of course, an estimation, as average infrastructure area will likely also change from 2020 to 2040, but for the purposes of this analysis, I will assume that the average area remains constant. I found that Brooklyn will require the greatest number of green infrastructure additions in order to account for its projected population change, which is also greater than all other boroughs as seen in *Fig. 6*. Brooklyn’s required additions total to 465 assets, which, as can be seen in *Fig. 7*, is marginally higher than all other borough’s required additions, with the second highest requirement being Queens with 263 assets. Staten Island is projected to have the smallest population change, and will only require an addition of 2 assets between 2020 and 2040. It is important to note that these sums of calculated infrastructure need are only what will bring the borough to the 2020 density, and if the city wants to do better and become more sustainable, it will need to implement more infrastructure than is required to meet 2020 density levels.

1. **Policy Recommendations**

Based on my findings, my first policy recommendation would be for New York City to require that all new builds and remodels of urban infrastructure like buildings, sidewalks, roads, and parking lots, both public and private projects, must include at least one green infrastructure asset of a certain minimum asset area that is logged through the New York City Green Infrastructure Program. I might even recommend that new builds and remodels in the boroughs of Brooklyn and Queens be required to include two or three new green infrastructure assets of a minimum area since these two boroughs will require the greatest number of new green infrastructure assets in the next two decades to account for population increase. These assets can be something as small as a rain garden, costing anywhere from $3 – 12 per square foot in the State of New York (DCSWCD, 2023), but each required asset would likely have to be of a certain average square footage in order to have an impact and provide enough area to meet density needs. The NYC Green Infrastructure Program does also offer some financial incentives to mitigate costs for private green infrastructure assets, so this would likely offset costs at least for private projects.

My second recommendation would be for New York City to require that all new building projects must occur on already developed land to avoid depleting any remaining vegetation in the city. This could potentially be a difficult policy to pass, but since New York City’s Central Business District (only includes Midtown, Lower Manhattan, Downtown Brooklyn, and Long Island City) has only 16.49 acres of vacant land as of 2018 (Property Shark, 2018), I believe that it would be possible to require this for new builds. Hopefully this would preserve what vegetation is left in the city and at least avoid paving over the small amount of surface area that is uncovered and still able to absorb water and soak up the sun’s heat.

Current policy in New York City is that all new builds that will cost at least $2.6 million have to achieve a LEED Gold Certification (NYC Office of Environmental Coordination, 2023). LEED certifications can include infrastructure such as green roofs and rainwater capture and reuse systems, so requiring a certification such as this is beneficial to the NYC Green Infrastructure Project. Another recommendation to help improve green infrastructure would be to reduce the minimum project cost that requires LEED Gold Certification to $2 million, and perhaps require that buildings costing over $1.5 million must achieve LEED Silver Certification. Another option would be to require buildings over a certain square footage to achieve some level of LEED certification depending on its size, as cities such as San Francisco currently practice (DataSF, 2023). These policies would then require more buildings to incorporate sustainable infrastructure and would aid NYC’s current initiatives to hopefully meet future infrastructure density goals.

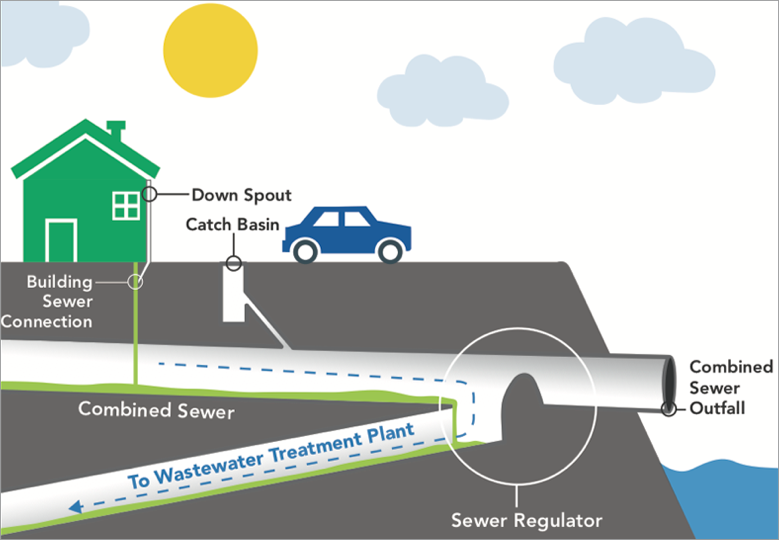
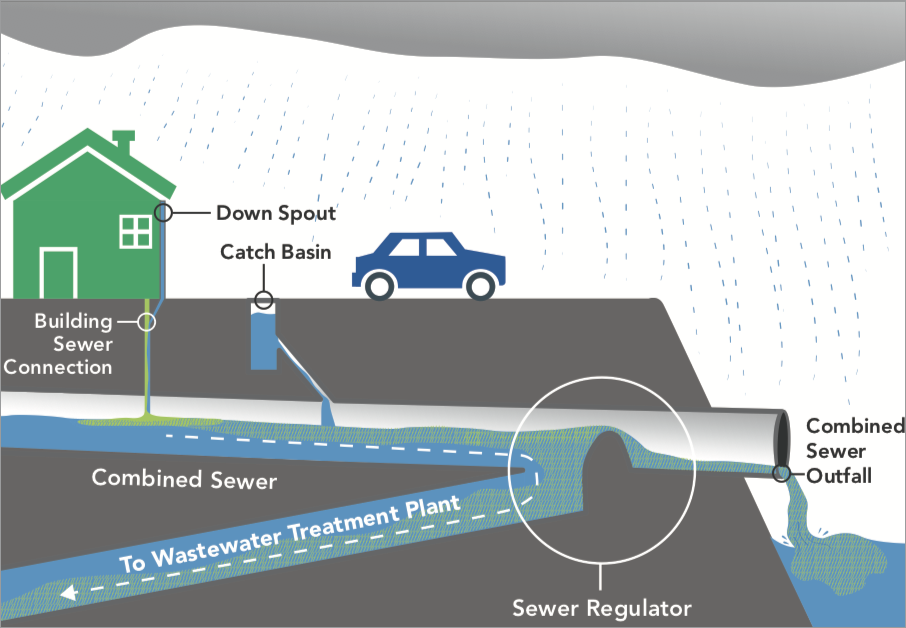
One final recommendation I would make is to pursue beginning the process of switching New York City to a Sanitary Sewer Overflow (SSO) system versus the current CSO that 60% of the city still uses (NYC DEP, 2023). An SSO uses two separate pipes for sewage and stormwater, and during heavy rain events, only stormwater is deposited into local waterways instead of stormwater combined with raw sewage (Stuart, 2022). This system would be much better for water quality of local waterways, reduce biodiversity loss from contaminated waterways, and make recreational use of NYC water bodies safer and more enjoyable. The problem with this recommendation is that there is a predicted cost of over $36.2 billion dollars for repairs and updates to the current sewer system in NYC over the next 20 years (New York State Dept. of Environmental Conservation, 2023). Therefore, switching sewer systems would likely be a lengthy and extremely expensive project, making it the most difficult to implement of my policy recommendations.

Overall, the NYC Green Infrastructure Initiative is already creating an impact on improved water quality in the city and decreasing the urban heat island effect through their 507 million-gallon CSO reduction in 2021 and over 15,000 green infrastructure assets to date. However, due to increasing projected population counts in all five boroughs of NYC, green infrastructure will need to continue to expand to account for the influx of population that will mean the creation of more sewage and the use of more water in the city. Immediate action is necessary, especially in Brooklyn and Queens where the most added infrastructure will be required based on current trends of average green infrastructure asset area and rising populations.

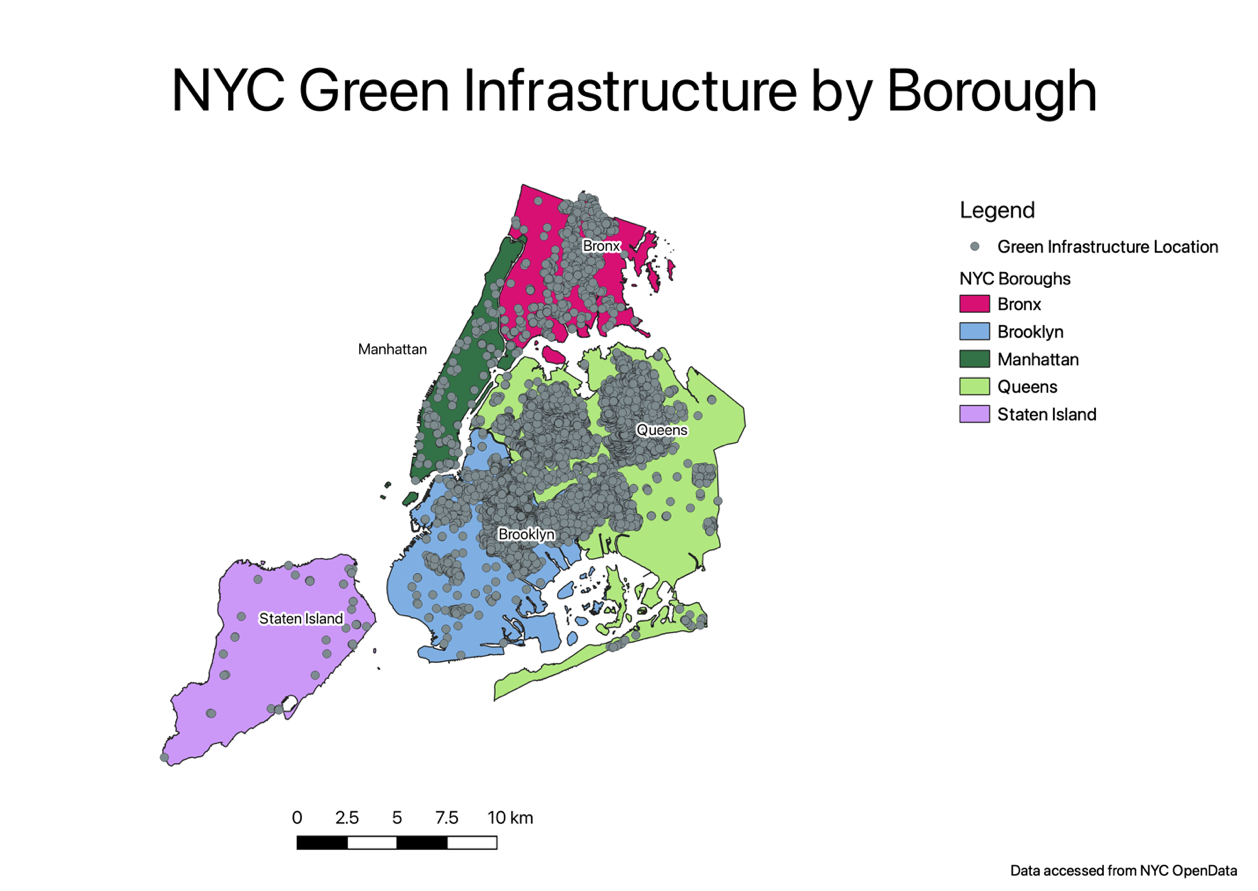
From my proposed policy changes, I would recommend that the first action to be taken should be to require all new builds and remodels of urban infrastructure to incorporate sustainable infrastructure into their projects, which is an initiative that does not necessarily have to add exorbitant extra costs to the project, depending on the type and size of the green infrastructure initiative. I believe that this would be the fastest and easiest way to facilitate real sustainable change and work towards the NYC Green Infrastructure Project’s 2030 goal of reducing 1.67 billion gallons of CSO water per year, and that it is a recommendation that is currently attainable. Of course, no policy change is typically quick to be enacted, but this is one that should hopefully not be met with too much pushback based on its feasibility and relatively low additional costs. Following the success of that recommendation’s implementation, I would return to my other recommendations, but they might be a bit more involved and it would be difficult to create positive change in New York City as quickly as through my primary recommendation.

Repository

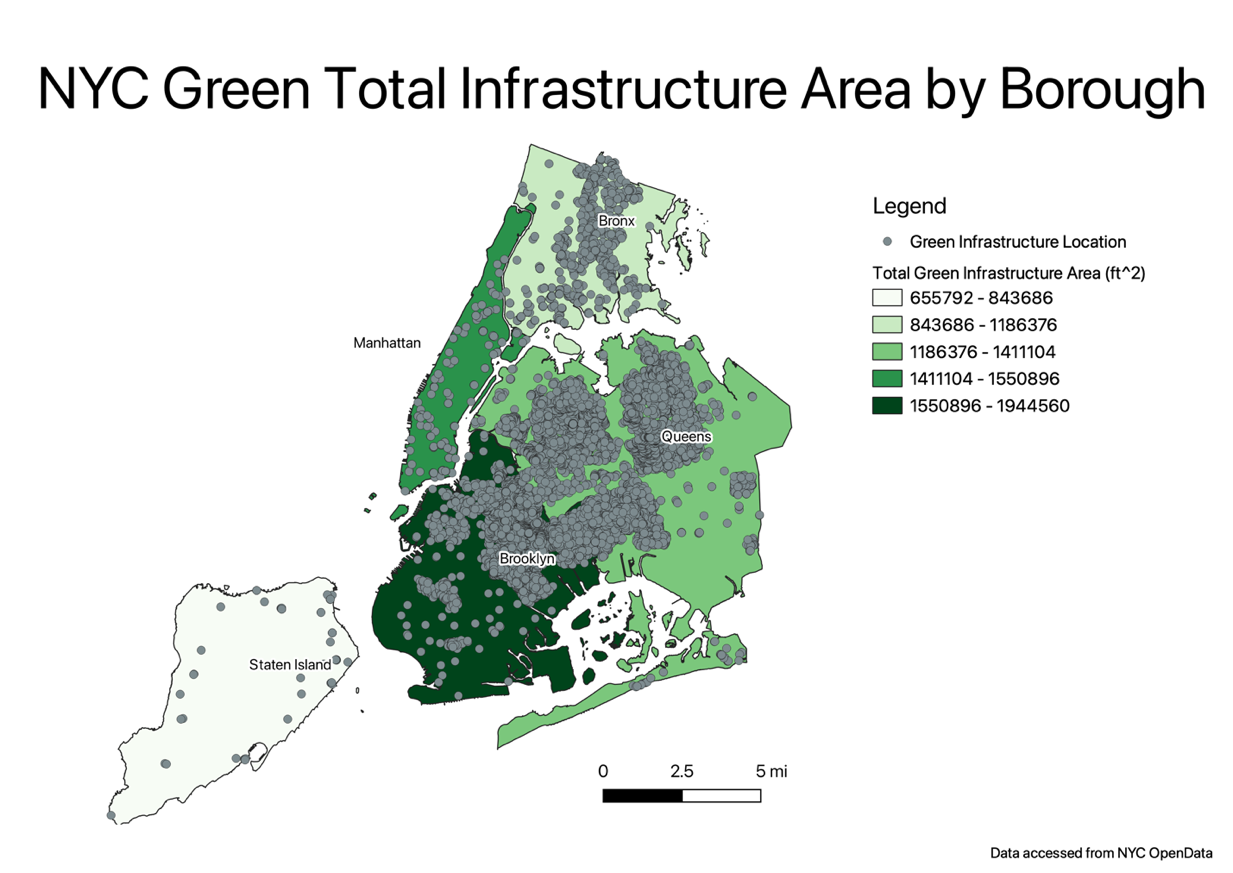
<https://github.com/sarahfollowill/PLAN372-finalproject>

 Appendix

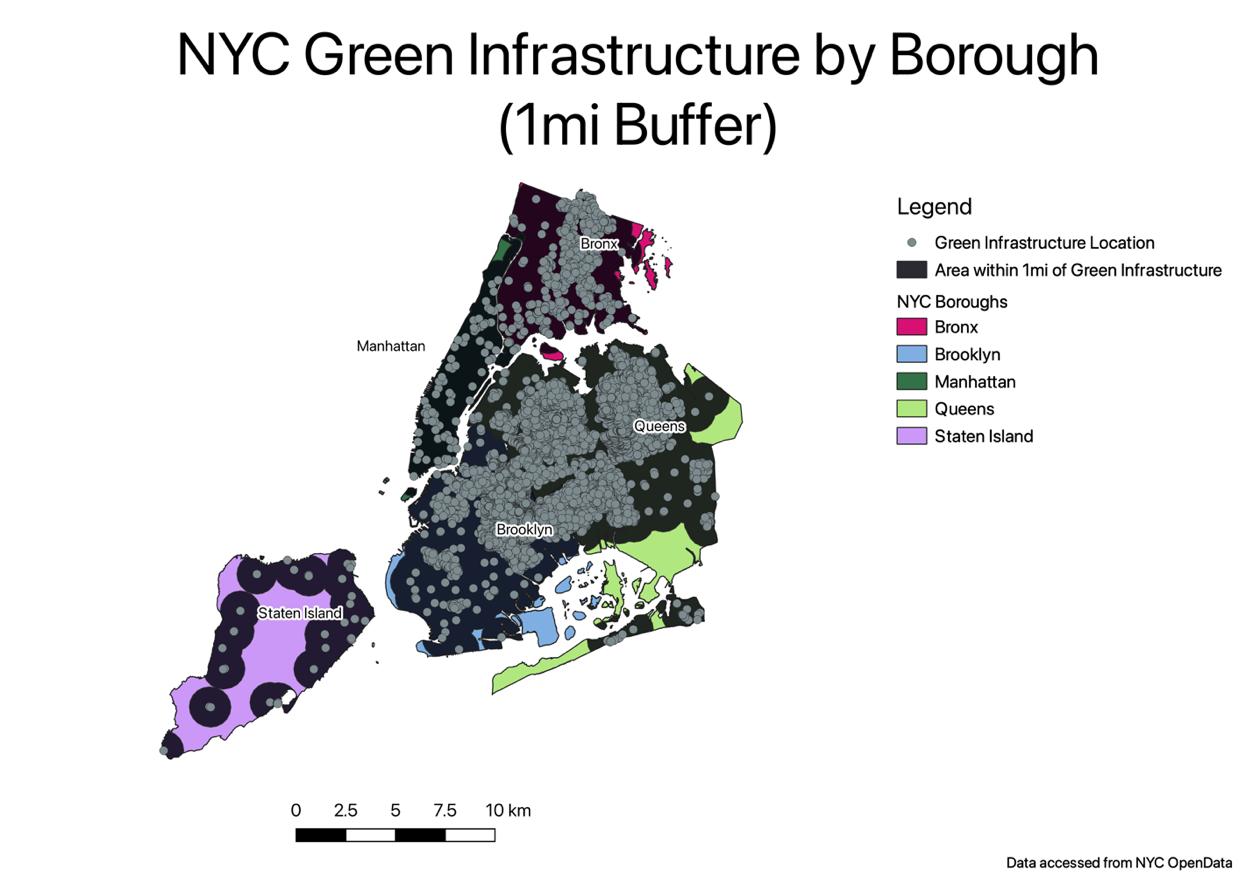
*Fig. 1 –* (NYC DEP, 2023)



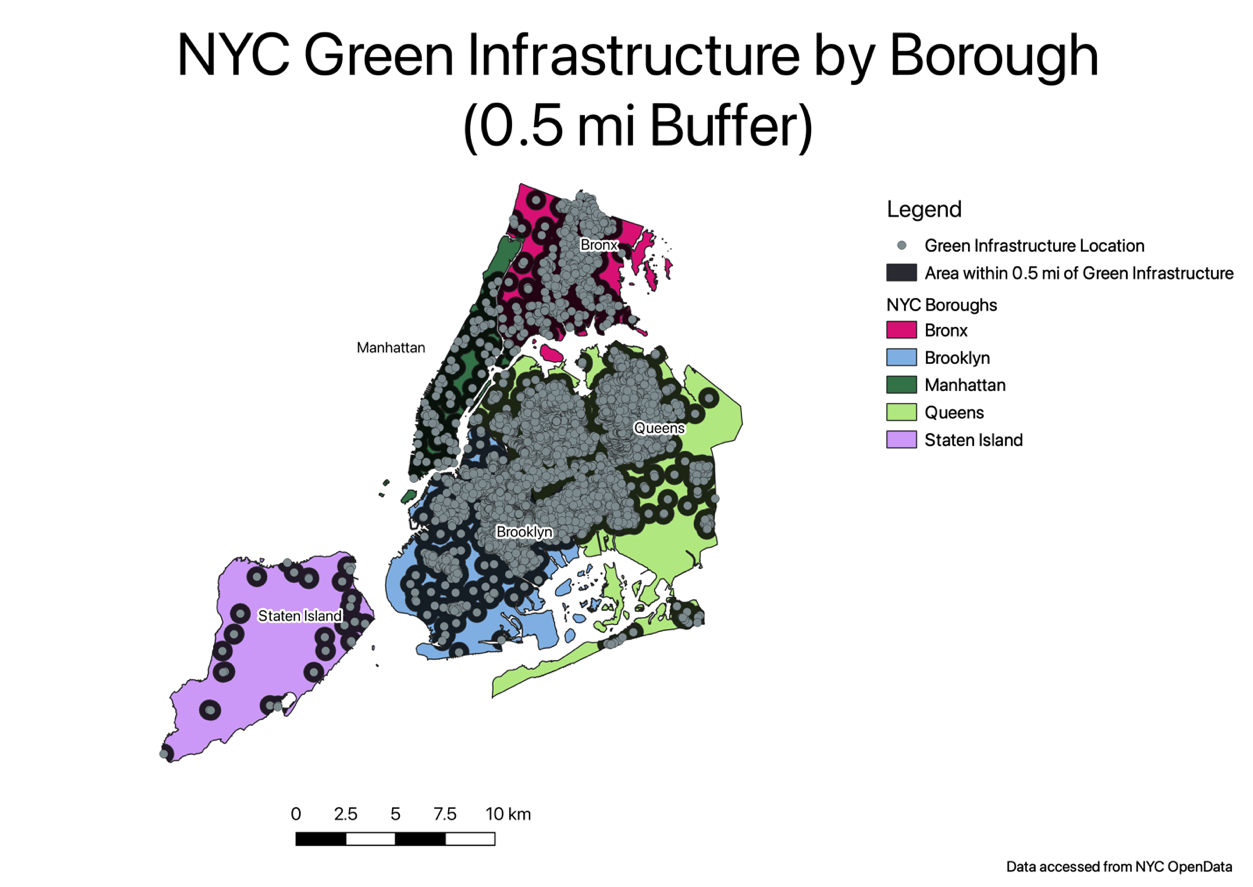
*Fig. 2*



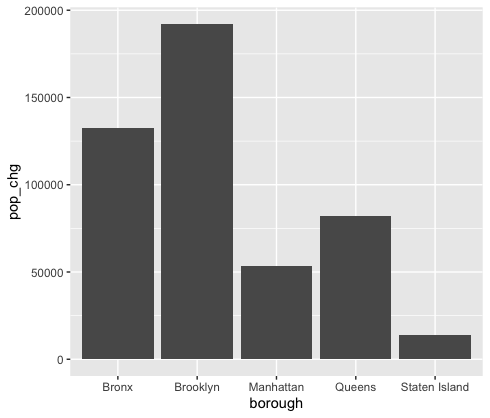
*Fig. 3*

**

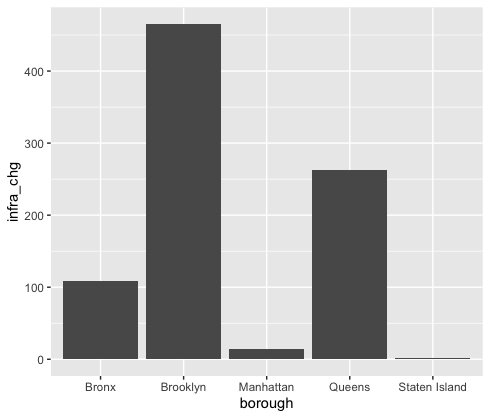
*Fig. 4*

**

*Fig. 5*

**

*Fig. 6*

**

*Fig. 7*

CASE

WHEN borough = 'Bronx' THEN 1446788

WHEN borough = 'Brooklyn' THEN 2648452

WHEN borough = 'Manhattan' THEN 1638281

WHEN borough = 'Queens' THEN 2330295

WHEN borough = 'Staten Island' THEN 487155

ELSE 0

END

*Fig. 8*

CASE

WHEN borough = 'Bronx' THEN 1579245

WHEN borough = 'Brooklyn' THEN 2840525

WHEN borough = 'Manhattan' THEN 1691617

WHEN borough = 'Queens' THEN 2412649

WHEN borough = 'Staten Island' THEN 501109

ELSE 0

END

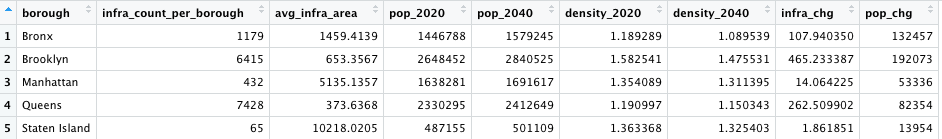
*Fig. 9*

Density = (average area \* infrastructure count) / population

*Fig. 10*

Density 2020 = (average area \* (infrastructure count 2020 + x)) / population 2040

*Fig. 11*

**

*Fig. 12*

References

Data SF. (2023, February 7). *SF Municipal Green Building Inventory: DataSF: City and county of San Francisco*. SF Municipal Green Building Inventory | DataSF | City and County of San Francisco. Retrieved May 1, 2023, from https://data.sfgov.org/Housing-and-Buildings/SF-Municipal-Green-Building-Inventory/yuvm-3ujh

DCSWCD. (2023). *Rain Garden Brochure*. New York, NY; DCSWCD. Retrieved 2023, from http://dutchessswcd.org/wp-content/uploads/rain\_gardens.pdf.

Enoch, M., & Balci, P. (2019). New York City Green Infrastructure Program Implementation Status and Adaptive Management. *Water Environment Federation*. https://doi.org/10.2175/193864718825157494

Enoch, M., & Balci, P. (2020). 2019 Green Infrastructure Annual Report. New York; NYC DEP.

New York State Dept. of Environmental Conservation. (2023). *Wastewater infrastructure needs of New York State Report*. Wastewater Infrastructure Needs of New York State Report - NYS Dept. of Environmental Conservation. Retrieved May 1, 2023, from https://www.dec.ny.gov/chemical/42383.html

NYC DEP. (2021). (rep.). *NYC GREEN INFRASTRUCTURE 2021 Annual Report*. NYC DEP. Retrieved May 1, 2023, from https://www.nyc.gov/assets/dep/downloads/pdf/water/stormwater/green-infrastructure/gi-annual-report-2021.pdf.

NYC DEP. (2023). *Combined sewer overflows*. Combined Sewer Overflows - DEP. Retrieved May 1, 2023, from https://www.nyc.gov/site/dep/water/combined-sewer-overflows.page

NYC Office of Environmental Coordination. (2023). *Green Building Requirements*. Green building requirements - OEC. Retrieved May 1, 2023, from https://www.nyc.gov/site/oec/green-building/green-building-requirements.page

NYC OpenData, & NYC Green Infrastructure Progam. (2023, April 26). DEP Green Infrastructure. New York; New York.

NYC OpenData. (2022, May 9). New York City Population by Borough, 1950 - 2040. New York; New York.

NYC OpenData. (2023, March 3). Borough Boundaries. New York; New York.

Sabau, D. (2018, June 21). *Does NYC still have room for growth? A study on undeveloped land in major US CBDS*. PropertyShark Real Estate Blog. Retrieved May 1, 2023, from https://www.propertyshark.com/Real-Estate-Reports/2018/06/21/does-nyc-still-have-room-for-growth-a-study-on-undeveloped-land-in-major-us-cbds/#:~:text=New%20York%20City%20has%20only,here%20between%202013%20and%202017

Stuart, A. (2022, October 21). *Sanitary vs combined sewer systems*. Sewer Equipment. Retrieved May 1, 2023, from https://sewerequipment.com/sanitary-vs-combined-sewer-systems/

US EPA. (2023). *Heat Island Effect*. EPA. Retrieved May 1, 2023, from https://www.epa.gov/heatislands#:~:text=Structures%20such%20as%20buildings%2C%20roads,temperatures%20relative%20to%20outlying%20areas