NEW YORK CITY SUBWAY: VULNERABILITY TO RISING SEA-LEVELS, FLOODING AND CLIMATE CHANGE

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Introduction

With the onset of climate change, cities are becoming more vulnerable to extreme events, and their densely populated areas increase the amount of people affected by them. Climate change is reshaping the world as we know it today and urban planning requires adaptations for future events.

Climate change is already being experienced in New York City with more intense precipitation, higher temperatures and sea level rise (Rosenzweig and Solecki, 2019). The city's impervious cover counts for 72% of its area, and events like Hurricane Sandy questions the future of its coast line. In neighborhoods like Hamilton Beach that are experiencing daily flooding due to high tides or during rainy days, water has nowhere to go when drainage pipes are blocked by high sea levels (Orton et al., 2019).

The New York City Panel on Climate Change (NPCC) has assessed the question of New York City's resilience to future climate change challenges. Its multiple reports include climate projections and risk management responses to climate change. NPCC3, published in 2019, considers six climate extremes: extreme heat and humidity, heavy downpours, droughts, sea-level rise and coastal flooding, extreme winds, and cold snaps (NPCC, 2019). New York City's long-lived infrastructures, like the subway system, need to be adapted to high-impact scenarios. This research project aims to identify subway infrastructures that will be impacted during the 100-year flooding projections made by NPCC.

The New York City Subway serves 5.6 million rides every weekday. Climate change and mean sea-level rise will ultimately be a threat to the infrastructure for many of the 472 stations that make up its 842 miles of track (Vermeij, 2016). In 2012 Hurricane Sandy gave the city a warning of the vulnerability of coastal-proximate subway stations. Knowledge of the spatial distribution of these threats is important in taking the proper planning measures that will be needed in urban adaptation to climate change.

By using recent data from the New York City Panel on Climate Change 2019 Report, 100-year flood projection shapefiles, and existing subway station entrance points location data and attributes, Python programming will be used to automate geographic analyses, relating to projected impacts on the subway system.

Background and Literature Review

The New York Metropolitan Area encompasses three states - Connecticut, New York, and New Jersey, - 23.7 million people, and 837 km of coastline. It has been the most populous city in the United States since 1790, and the most densely populated since 1804 (Maciag, 2016). Historically, New York rose to its global prominence *as a result* of its waterways, situated at the confluence of the Hudson River and the Atlantic Ocean, sheltered by a large bay accessible by various entry points: the East River, Long Island Sound, Arthur Kill, etc. These natural pathways of transportation allowed the population and economy to grow substantially throughout the 19th century, as millions of immigrants arrived aboard ships treading the waterways. New York's position as the doorstep for the majority of global migration during this period helped to stimulate its global reach, ushering in its status as the newly disputed "Capital of the World" (Burrows and Wallace, 1998). In many ways, New York's coastal position made it the city it is.

Today, New York's proximity to the sea, its high density of people, housing and infrastructure, is demonstrating a vulnerability in the face of a changing climate, rising sea levels and increasingly stronger extreme events (Patrick et al., 2019).

Urban flooding is mainly caused by impervious cover and the lack of vegetation which makes cities unadapted to receive heavy precipitation (Weber, 2019). However, this also depends on the sewage systems' and draining canals' capacity which can differ within a city. Outdated and inadequate infrastructure can also worsen the flooding, especially in socioeconomically isolated urban communities. As sea-levels rise, it increases the chances of a storm and also threatens low lying neighbourhoods with tidal floods. The city was given a rude awakening to this fact in October of 2012, when the Tropical Superstorm Sandy barrelled into the Mid-Atlantic coast.

Hurricane Sandy had major effects on the city's coastal neighborhoods and their infrastructure. In June 2013, the City government provided an extensive report named *A Stronger, More Resilient New York* outlining the storm's impact, which was felt across virtually all sectors and industries (NYC SIRR, 2013, p. 11). Forty-three people lost their lives, two-million were powerless for over a week, schools shut for two weeks in many neighborhoods, and the largest public transportation network in the United States was ground to a halt overnight (NYC SIRR, 2013). The New York City Subway suffered serious damage as a result of the inundation, especially to it's underground stations and tunnels (NYC SIRR, 2013, p. 177).

Before the storm made landfall, makeshift barriers using sandbags and plywood were used to protect many of the coastal proximate stations, yet this did little in the face of such a strong storm surge. Many subway stations were completely flooded, like the South Ferry Station in Manhattan. While most of the subway system was running again six days after the passing of the storm, many repairs to water damages are still being made today on the 116 year-old network (NYC SIRR, 2013, pp. 178-9). The long-term damages stem mostly from the brackish salt-water that can corrode ventilators that allow the system to breathe, and wires that illuminate the over 12,000 train signals along the tracks (MTA, 2020). The train viaduct that runs out from the Howard Beach station near JFK Airport to the Rockaway Peninsula partially collapsed. The South Ferry Station which lies at the tip of Manhattan close to the Battery was closed until 2017.

The New York City Subway System acts as a set of vital arteries for transportation throughout the city. With a daily average of 5.5 million weekday trips it is the busiest system in the United States and the 7th busiest in the world. As was seen during and after Hurricane Sandy, the failure of this system to operate causes huge problems for the flow of city life. The SIRR, catalogued in the wake of Sandy, reported that an estimated 8.5 million public transit riders were affected as a result of Sandy (NYC SIRR, 2013).

Sandy was unprecedented in New York, but it has been cited by climatologists as a sign of what is to become a 'new normal' in the coming decades (Gornitz et al., 2001; Kemp et al., 2017).

Since 2008, the New York Panel On Climate Change (NPCC) has released a series of four reports focussed on "illustrating spatial climate risk information to inform policy makers, stakeholders, and the public of the distribution of climate risk across the landscape of New York City" (Patrick et al., 2019, p. 115). It's mapping components have mostly surrounded issues of flood risk management, while using a variety of methods to quantify and predict future storm surges and floods including climate models, expert knowledge, literature surveys, historic tide gauges, and remote sensing through satellite imagery (Patrick et al., 2019, p. 116). The results of this predictive mapping have produced a multitude of high resolution georeferenced shapefiles, outlining the potential extent of floodplains in 100 and 500-year flood scenarios based on sea-level rise. A 100-year floodplain, as explained by the Panel, "is based on statistical analysis of historical data and encompasses all locations that have a 1% or higher chance of being flooded in any given year" which is an important benchmark in considering "high-risk flooding area and subject to special building codes, insurance requirements, and environmental regulations" (Patrick et al., 2019, p. 122). This data is derived from FEMA's (Federal Emergency Management Agency) sea-level rise projection scenarios at the 90^{th} percentile, taking the highest estimate 'worst-case scenarios'. As a part of their mandate, the NPCC has committed to making their data as accessible as possible, publishing the majority of their shapefiles on New York's OpenData Portal (City of New York, 2020). The portal has been a crucial resource for citizenry participation in municipal affairs, and has ultimately led to greater efficiency of government (New York's OpenData Portal has data on projected floodplain extents developed by the NPCC for the years 2020-2030 and 2050-2060. As this data proliferates to the public, participation among the citizenry can help the city better plan, protect and progress.

Problem Statement

It is not a question of if, but when New York will be struck with another storm that will cause havoc across its cityscape. With higher sea-levels, future flood areas will grow larger and affect more people. FEMA assessed in 2015 that the 100-year floodplain would affect 400,000 residents, about 83% more than their 2007 maps suggested (Dep. City Planning, 2016). The many authorities that govern the collosal network that serves two-thirds of all rail-riders in the US, including the MTA, will need to adapt appropriately to the changing times, for the sake of their passengers' safety, and for this system that drives many sectors of the economy. This project aims to identify which of New York City's almost 1,900 subway station entrances could be affected by future flooding based on the 100-year floodplain predictions made by the NPCC for the years 2020s and 2050s, while visualizing their spatial distribution using a variety of mapping techniques.

Description of Data

To complete this task 8 online, open-source datasets were compiled. The data includes observational, reference and simulation types, retrieved from five different agencies.

Table 1 below outlines the dataset name along with its description, source, format, date of last update and URL.

Table 1: Data used along with metadata

Name	Description
NYC subway entrance and exit data	Coordinates, line, address and corner of subway entrances and exits Data Provided by: MTA Headquarters/New York State Format: .csv file Last updated: June 2019 URL: https://data.ny.gov/Transportation/NYC-Transit-Subway-Entrance-And-Exit-Data/i9wp-a4ja
MTA Subway Station Data (with structure)	Contains the structure of each subway station Data Provided by: MTA Headquarters Format: .csv file Last updated: January 2018 URL: http://web.mta.info/developers/data/nyct/subway/Stations.csv\
Sandy Inundation Zone	Areas of New York City that were flooded as a result of Hurricane Sandy Format: ESRI Shapefile Data Provided by: Department of Small Business Services (BSS) Last updated: September 2018 URL: https://data.cityofnewyork.us/Environment/Sandy-Inundation-Zone/uyj8-7rv5
100-year floodplain for 2020s	Based on New York City Panel on Climate Change's 90th Percentile Projections for Sea-level Rise Data Provided by: Mayor's Office of Sustainability (MOS) Format: ESRI Shapefile Last updated: September 2018 URL:https://data.cityofnewyork.us/Environment/Sea-Level-Rise-Maps-2020s-100-year-Floodplain-/ezfn-5dsb
100-year floodplain for 2050s	Based on New York City Panel on Climate Change's 90th Percentile Projections for Sea-level Rise Data Provided by: Mayor's Office of Sustainability (MOS) Format: ESRI Shapefile Last updated: September 2018 URL:https://data.cityofnewyork.us/Environment/Sea-Level-Rise-Maps-2050s-100-year-Floodplain-/hbw8-2bah

Neighborhood Tabulation Areas (NTA)	Boundaries of Neighbourhood Tabulation Areas (borough subdivisions) Data Provided by: Department of City Planning (DCP) Format: ESRI Shapefile Last updated: February 2020 URL:https://data.cityofnewyork.us/City-Government/Neighborhood-Tabulation-Areas-NTA-/cpf4-rkhq
Subway Lines	Subway Lines along the NYC Subway System Data Provided by: MTA Headquarters, New York City Transit Format: ESRI Shapefile Last updated: September 2018 URL: https://data.cityofnewyork.us/Transportation/Subway-Lines/3qz8-muuu
New York City Coastal Water and Rivers	Polygon shapefile of all waterways around New York Metropolitan Area and Long Island Data Provided by: NYU Spatial Data Repository Format: ESRI Shapefile Last updated: January 2016 URL: https://geo.nyu.edu/catalog/nyu-2451-34507

NYC Subway Entrance and Exit Data

Obtained from the New York State Open Data website as a CSV file, the data fields that were kept for processing were: Line, Station Name, Station Latitude, Station Longitude, 'North South Street, East West Street, Corner, Entrance Latitude, and Entrance Longitude. The dataset contains information on 1868 subway station entrances. The data, however, does not include the entrance and exit of Staten Island's new subway line, nor the ones of the 2nd Avenue Q line.

MTA Subway Station Data

Obtained as an online csv page, the data includes each stations' structure, borough in which they are located and their coordinates. The structure column is used in this project to determine if the station would be impacted. The New York City subway system includes five different types of structure: embankment, open cut, subway, elevated, at grade. Underground stations are the most vulnerable structure to future flooding; they also account for the 60% of the subway system (MTA, 2020).

Sandy Inundation Zone

The Sandy Inundation Zone outlines New York City's areas that were flooded during the 2012 hurricane. This shapefile is used as historical data to compare its extent to the 100-years flood plain projection for 2020s and 2050s by NPCC.

Sea Level Rise Maps (2020s and 2050s 100-year floodplain)

These two shapefiles outline the extent of a 100-year floodplain on the New York City limits and shoreline. It is used to determine which and how many subway station entrances would be affected in such a case.

Neighborhood Tabulation Areas (NTA)

Neighborhood Tabulation Areas are a type of city subdivision in New York. Their size falls between the size of census tracts (smaller) and boroughs (larger). The shapefile defines the boundaries of NTAs based on 2010's census tracts. There are 195 NTAs within the five boroughs of New York City. The file provides a backdrop to plot subway station entrances and lines on, as well as provide spatial reference.

Subway Lines

This shapefile shows all subway routes in the NYC Subway system. It has a line geometry used in the maps as geographical reference for the viewer on our maps.

New York City Coastal Water and Rivers

This is a large shapefile that shows all waterways in the New York/Long Island area. It is used as the contour of New York City. It is specifically used to layer over the floodplain shapefiles since the floodplain extents went beyond the land portions into the water, and were unable to be clipped to the land because of their size and complexity.

Methodology

By taking the data above and using a variety of data management practices through the use of Python libraries, the bigger picture of the extent of flood damage in New York becomes more apparent. Ultimately, this project takes this very specialized and localized data and transforms it so it can be properly visualized. The first part of the programming section, focusses on the georeferencing, merging, joining, clipping, dissolving and filtering of datasets in the context of New York City flooding and the Subway. The second notebook brings along the mapping portion of the analysis. It became apparent that this analysis of flood prediction maps and transportation infrastructure vulnerability can be programmed in the same way for other coastal cities. While the functions used are specific for the data frames that were built in the first processing section, the mapping portion attempts to show the versatility of web-mapping features and that this same technique can be applied to other cities where sea-level rise is a threat and data is available.

Libraries

Geospatial libraries in Python provide users a keyhole to the underlying programming of GIS software and capabilities. By discovering the range of these libraries, one can peel back the curtain which often veils the inner workings of conventional GIS softwares, and design them to compute the same manipulations offered, but with a customizable versatility and the ability to perform multiple analyses at the same time (GISGeography, 2020).

One of the most basic, yet most useful libraries used for this project is GeoPandas. Geopandas is used to read in and out geographic files (shapefiles), merge and join datasets, and perform geoprocessing steps to visualize the spatial and temporal distribution of the impacts. Additionally, for non-geographic data management, the older brother library Pandas was used. Both libraries are free and open source, which allows for easy distribution and widespread documentation of their capabilities and debugging steps.

For all things point, line and polygon based, shapely library provides "a package for manipulation and analysis of planar geometric objects", and the plotting of these geometries was aided by the matplotlib library (Gillies, n.d.).

Experimentation with visualizing the data once it had been manipulated with the libraries mentioned above, was made possible by three different libraries: bokeh, mplleaflet, and folium. Each provides the user with different visualization possibilities and this project explores each of their capabilities in the realm of the extracted data.

Processing

The processing of data began with the reading in of the Subway Entrances csv file (with a length of 1868) and Subway Station csv file (length of 496), which contained information on the Structure of each station (whether it was underground, elevated, at-grade, open-cut etc.) and each station's associated borough. To combine these datasets so that the structure and borough information could be attached to each entrance point, there needed to be a common variable that the two datasets could be merged on. The Entrance dataset has coordinate points for both the entrance and its associated station, of which these coordinates matched perfectly with the coordinates of station location provided in the structure dataset. Therefore, the merge was able to be conducted with the matching station geometry.

40.752689	-73.992742
40.752161	-73.993109
40.752020	-73.993352
40.751996	73.993327
40.751539	-73.994181

Figure 1: Error in the dataframe

A faulty data cell in the Entrance longitude column where the value was incorrectly a positive number caused a fair bit of issues until it was discovered at row 648 (Figure 1). This was fixed by multiplying the cell by -1.

Various column names in the datasets needed to be renamed as a result of spaces in their names, using the rename function. This was necessary in order to assign point geometry and perform other manipulations.

To further streamline geographic processing, a function to change the projection of GeoDataFrames to the official CRS projection for the study area using NAD83 / New York Long Island (ftUS) (which follows Citywide Guidelines for Geographic Information Systems (City of New York, 2015)) was assigned. The function takes one argument of the dataset to change projection using the to_crs function.

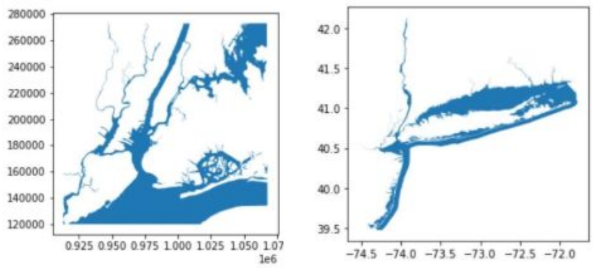


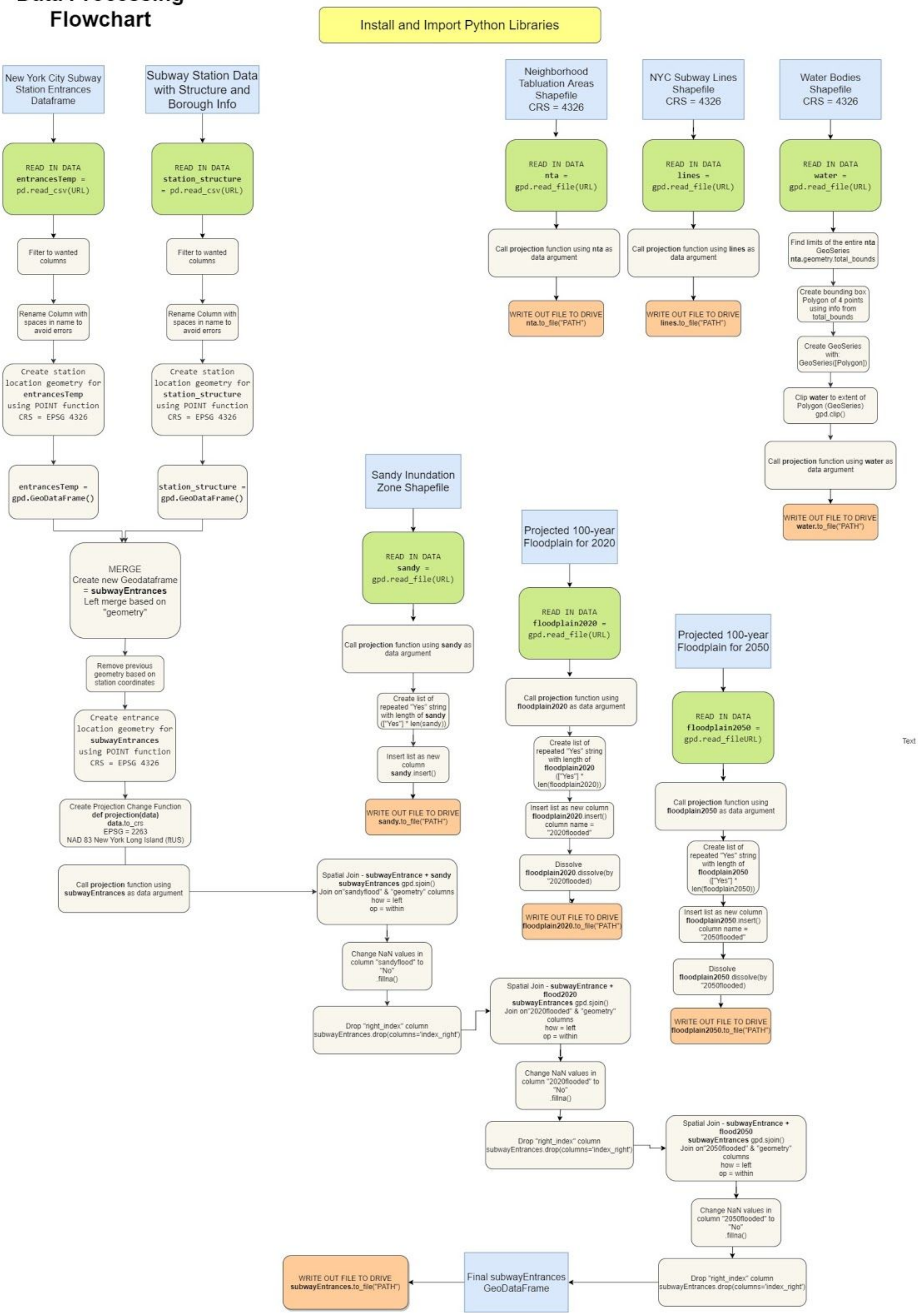
Figure 2: Use of the bbox in the water shapefile

The water shapefile, in its original form (Figure 2), covered a much larger geographic area than was needed. In order to shrink this extent, a bounding box polygon was created to clip the shapefile to. The polygon was made using the total coordinate bounds of the NTA shapefile and then converted to a GeoSeries, which is one of the three data types that can be used in GeoPandas for the clip function (*geopandas.clip*, n.d.).

To analyze which station entrances were in the path of the three flood shapefiles, a spatial join was conducted. Firstly, a new column filled with the string "Yes" was added to each flood shapefile, by creating a list of repeated strings to the length of each shapefile. This common variable column allowed for the geometry of each shapefile to be dissolved, using the GeoPandas dissolve function, so that the file became one single multipolygon, instead of several layers of polygons. The "Yes" column also allows this string to be added to the Station Entrances dataframe upon the completion of the spatial join. After all three joins, each row in the entrance dataframe has a "Yes" if the entrance point falls inside the flood zone and NaN if it does not. This NaN value was changed to the string "No" using the pandas fillna function.

The final product is a series of GeoDataFrames, written out as shapefiles to be used in further analysis and visualization. Using GeoPandas to consistently write out data was very crucial in slowing down the processing time of running the whole program as the flood shapefiles proved to be very large, and manipulations using them often took 20-30 minutes to run. Previous code was then commented out and the shapefile written out was written back in to speed up processing.

Data Processing Flowchart



Mapping

A new, separate Colab notebook was used to perform the data analysis and visualization section of the project. The analysis starts with determining the numbers of station entrances affected by Hurricane Sandy, or possibly affected in future storm surges, using a series of groupby and size functions. Information on the proportions of affected entrances by station structure and by NTA and Boroughs are also computed. This data is then plotted into choropleth maps that identify the NTAs by the number of affected entrances in each flood scenario.

Mapping the subway lines was deemed important for familiarity reasons in visualizing the subway system. By being able to plot the lines in their official colours, the maps resemble the New York City Subway Map, which has become synonymous with the system over the years. The MTA website provides a list of “Line Colors” with the HTML color code associated with each line (MTA, 2020b). By printing out a list of unique names from the Subway Lines dataframe, a dictionary was made in a line of code below, with each unique line and its associated HTML color copied in. To plot this data, a for loop which ran simultaneously through the line color dictionary and a list of lines grouped by name. Iteratively, the loop plotted each of the lines separately with its associated color (Figure 3). This for loop can be then included as a layer in static maps and some interactive ones.

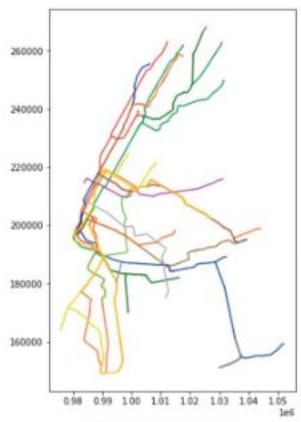


Figure 3: NYC Subway mapped with its official colors on Python

The bokeh interactive map presents the opportunity to plot the data on a graph with the ability to zoom in and out, as well as use it’s Hover Tool to convey information regarding each entrance when the user scrolls over the point (D’Angio, 2019).

The hover tool formatting is able to concatenate variables within the creation of the tool. For example, a unique name for each entrance could be created with a combination of the station name, the directional corner of the intersection where it is located, a string of the word “corner” and the North/South and East/West streets that make up the intersection, are agglomerated into one value for a hover key. The output for the entrance name hover then becomes something like “Bowling Green Station at the NW corner of Broadway and Battery Place”. The hover tool also conveys information on the structure of the entrance, as well as whether or not it is within each of the flood zones (Figure 4).

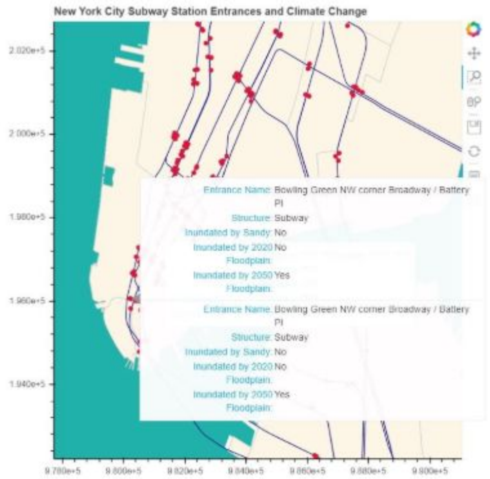


Figure 4: Bokeh’s Hover tool used for subway entrances

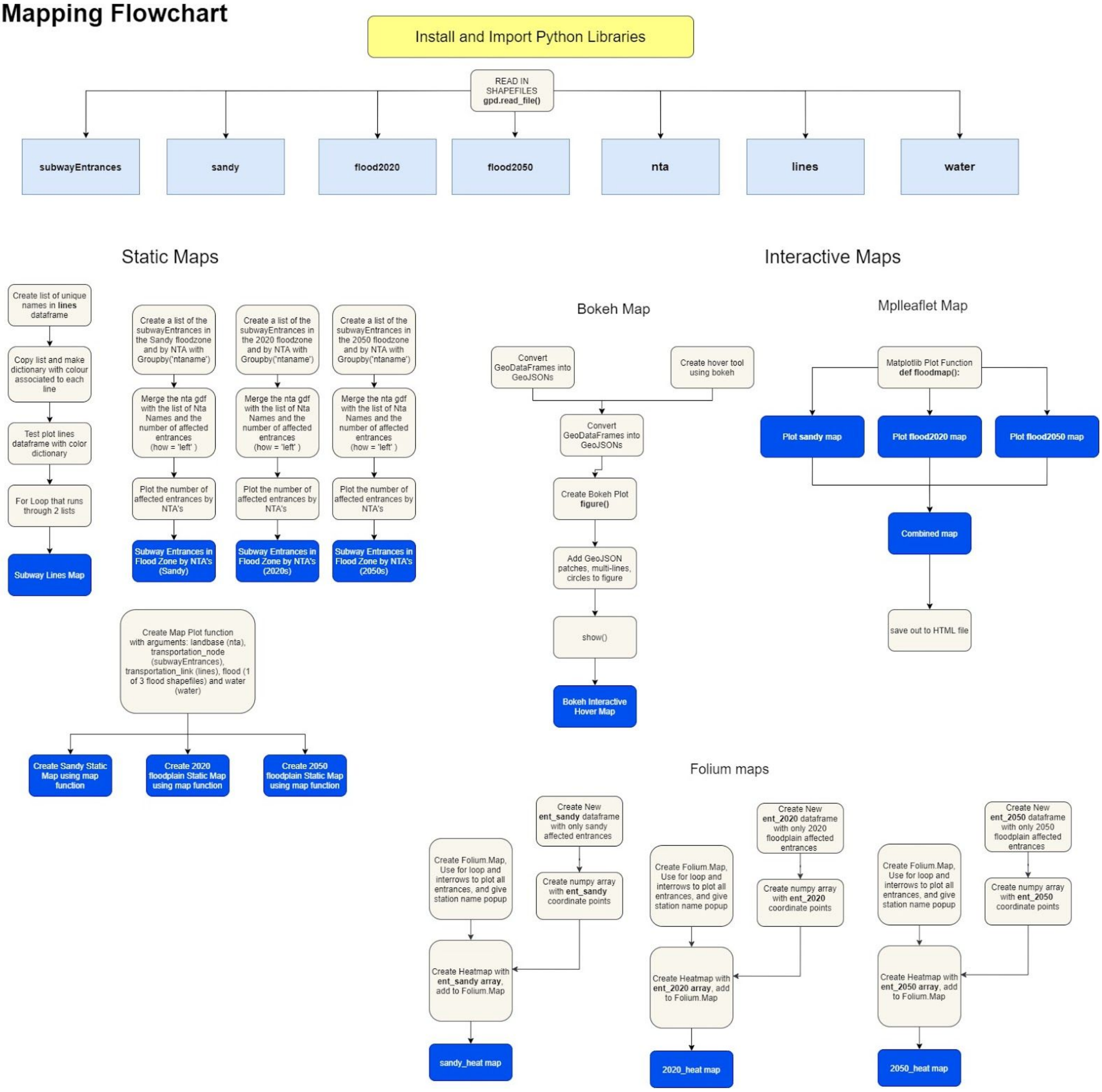
Unfortunately, the conversion of the GeoDataframes into GeoJSONs inhibited the plotting of subway lines with their associated colors. Additionally the flood GeoJSONs were unable to plot into bokeh (because of their size), and attempting to do so would crash the web browser.

As a result of these shortcomings, two alternatives were explored to visualize the data. Mplleaflet is a Python library which can convert Matplotlib plots into Leaflet web-maps (Wasserman, n.d.). Leaflet is an open-sourced JavaScript library that uses OpenStreetMaps and Google Maps API to develop custom web-maps, and mplleaflet gives these capabilities using Python (Leaflet, n.d.). Upon exporting the plot to an html file, polygon files are automatically set to slightly transparent. This allowed to create the effect of layering each of the floodplains on top of each other to visualize the areas that are more likely to be flooded in the near future, with the lightest shade being the 2050 100-year floodplain. It also allows the OpenStreetMaps basemap to still show detailed street and building data through these layers

(Map 10). While Leaflet has the capability of generating popups, mplleaflet does not yet have these same formats of building them, and we did not succeed in finding a way to accomplish this. However documentation on Github shows that the creator of mplleaflet is interested in implementing a function for this (Wasserman, 2016).

Finally, a similar web-mapping library was used in order to create interactive heat maps, detailing concentration of areas where station entrances are affected by each of the flood scenarios. Folium provides an array of tiles as basemaps to plot data onto. This was accomplished for all station entrances by using a for loop to iterate through the dataset using the interrows function and extracting the original E_Lat (latitude) and E_Long (longitude) data from their respective columns to be able to plot in folium. A popup of the station name was also included in the for loop. The heatmap takes a numpy array of coordinate points, in this case converted from a dataframe containing the entrances affected in each of the flood scenarios, and shows the distribution and intensity of areas where the subway system is affected by floods. In zooming in and out, the heat map renders to show appropriate intensity (Tenkanen, 2018).

Mapping Flowchart



Results

By comparing the historical event of Hurricane Sandy to the present and future flood predictions, there can be a greater understanding on how to prepare for extreme weather events. During Sandy, there were about 168 subway entrances in the flooding zone, of which 36 of them were underground subway entrances. With its slightly larger extent, the 100-year floodplain for 2020s has around 49 underground subway entrances in the flooding zone. These two scenarios have similar numbers in each NTA. However, when looking at the 2050s floodplain, this number is about 3 times bigger: there are 146 underground entrances in the flooding zone. Looking into the location of the most touched areas, the greater changes are seen in Battery Park City-Lower Manhattan and SoHo-TriBeCa-Civic Center-Little Italy where the numbers of entrances affected double, going from 18 to 35 and 20 to 44 respectively. On the other hand, Hunters Point-Sunnyside-West Maspeth is the example of a NTA that was not affected by Sandy and is not planned to be greatly affected in 2020s (3 entrances), but that could critically be touched in the prediction for 2050s with 7 times more entrances. The number of infrastructures affected for the 2050s goes beyond the impact experienced during Sandy.

As no library allowed us to communicate the complexity of this problem, we worked with different libraries. The three static maps (Appendix: Maps 1-3) are introductory maps to show a global picture of the floodplain extent. The first one shows the floodplain experienced during Sandy and the two others showing New York City's 100-year floodplain for the 2020s and 2050s. Each map includes the subway lines with its official colors for the viewer to better orient itself and subway stations are marked by a black dot which we can see under the semi-transparent floodplain layer.

The second series of maps (Appendix: Map 4-6) are choropleth maps focussing on the number of subway entrances in flooding zones by Neighbourhood Tabulation Area. Choropleth maps allow an easier visualization of affected entrances' spatial distribution of vulnerability. By comparing the three, the rapid increase in some NTAs' vulnerability can be seen, especially when looking at the 2050s map. In addition, there are a lot more neighbourhoods within the 25-35 affected entrance range. We can also see that Battery Park is another highly touched NTA where multiple subway lines meet at the tip of Manhattan.

Lastly, we experimented with different libraries used in interactive mapping. All interactive maps allow the viewer to zoom in and zoom out where they are most interested. The bokeh map has hoover tools which allows users to click on a subway entrance, and see the information related to that specific station. By integrating the result of the spatial joins made in the processing, the hoover tool would indicate if "Yes " or "No" the subway station was in the flood zone for the three different scenarios. It would also include the name of the station, the subway line and the structure of the subway station. However, we could not get the color of the subway lines with this library and were ultimately replaced by simple black lines. Furthermore, the bokeh map presents more of a reference map for each entrance and must be searched by the user to extract information out of it.

Leaflet and Folium allowed us to integrate the Map 1-3 into quick visualization of the spatial distribution of the issue. For example, the leaflet map shows us the most opaque regions would be those most likely to be affected in all three scenarios while the lighter ones would be those that are only affected in the 2050s scenario. The Folium heat maps are able to show concentrations, hot spots if-you-will, of entrance vulnerability. These phenomenons can be picked up by the eyes quickly and paint a clear picture of the situation.

Ultimately, we would like to explore these options in more detail and succeed in finding ways to add particular elements that are missing (legends, titles etc.) Folium also has a "Heatmap with Time" feature that would be interesting to implement to our design in the future.

Conclusion

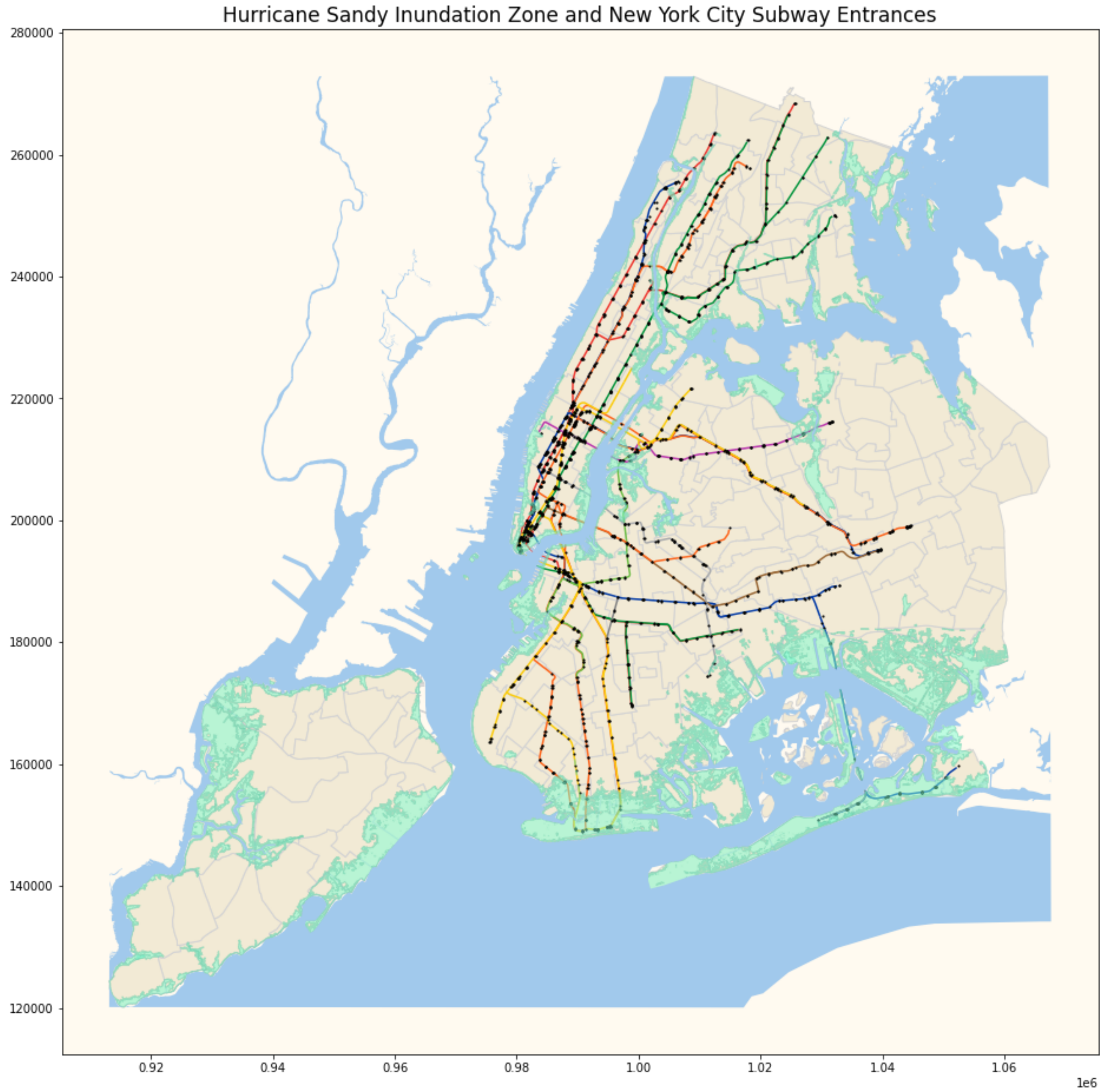
These maps are for informative purposes and are meant to show the possible damage that future extreme weather events will have on coastal cities like New York. However, they could also be used to determine which areas of NYC will need to be more resilient in their functioning. This project allowed us to explore the different options for web mapping and use their strength to communicate the important findings after processing the data. The variety of possible maps were found to be useful to target different audiences. In fact, some maps encapsulated information that other maps could not, which gives them different uses.

The leaflet map is more of an informative map for the population, with which people can easily navigate and not necessarily go into the details of the structure of the station. On the other hand, the Bokeh interactive map clearly provides valuable information for each individual station which can be useful in NYC's plan to make its transportation system more resilient to climate change. This includes the subway entrances that were not in flooding zones in either Sandy or the 100-year floodplain for the 2020s, but are in areas that will be hit in the near future.

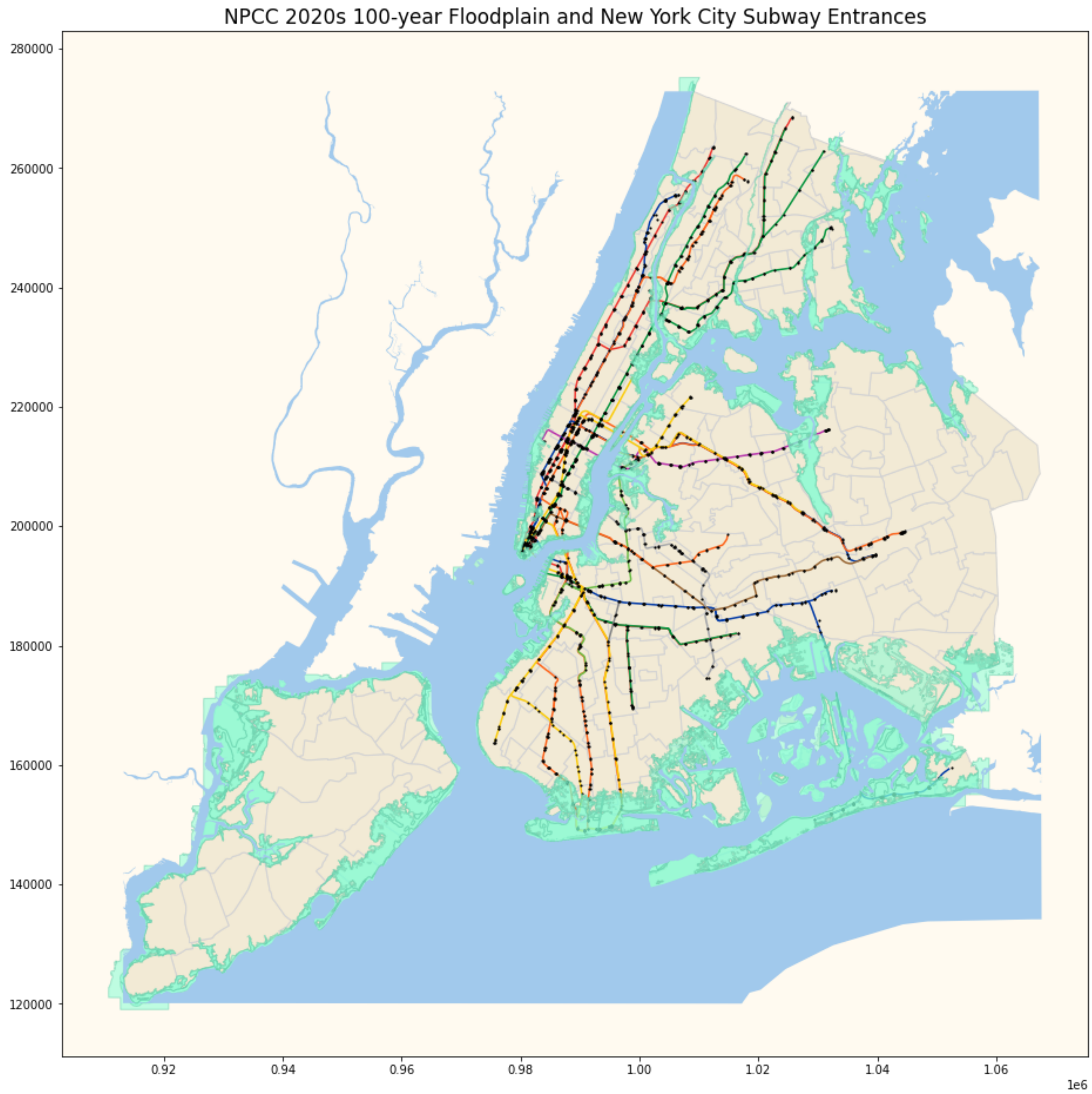
Open source data allows people outside of authority figures to use it for what is important for them. In this case, it provides the tool of planning for the imminent changes impacting New York City. Likewise, with the available data provided by the NPCC, people evaluate the effects of a rising sea level on other valuable services. This might be affecting some people's homes, and other people’s workspaces or favourite restaurants. Environment changes are likely to be perceived differently as it impacts everyone’s life in different ways. The city is looking into spatial patterns of social vulnerability (Foster et al., 2019) to add an equity dimension on their resilience initiative. These initiatives make urban planning more adapted to answer vulnerable communities' needs in times of environmental uncertainty.

Appendix

Map1.



Map 2.


NPCC 2020s 100-year Floodplain and New York City Subway Entrances
280000
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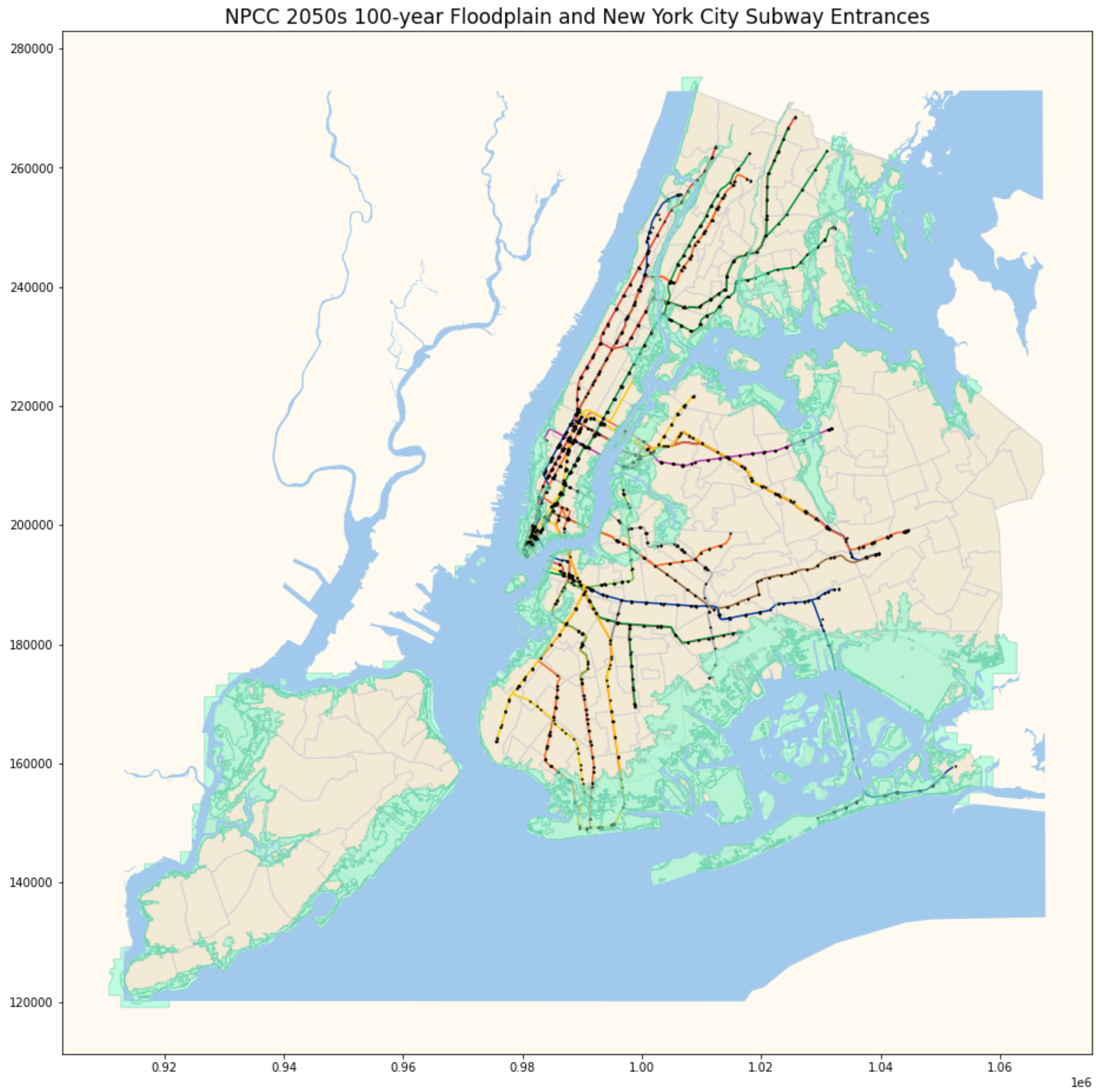
Map 3.


NPCC 2050s 100-year Floodplain and New York City Subway Entrances
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260000
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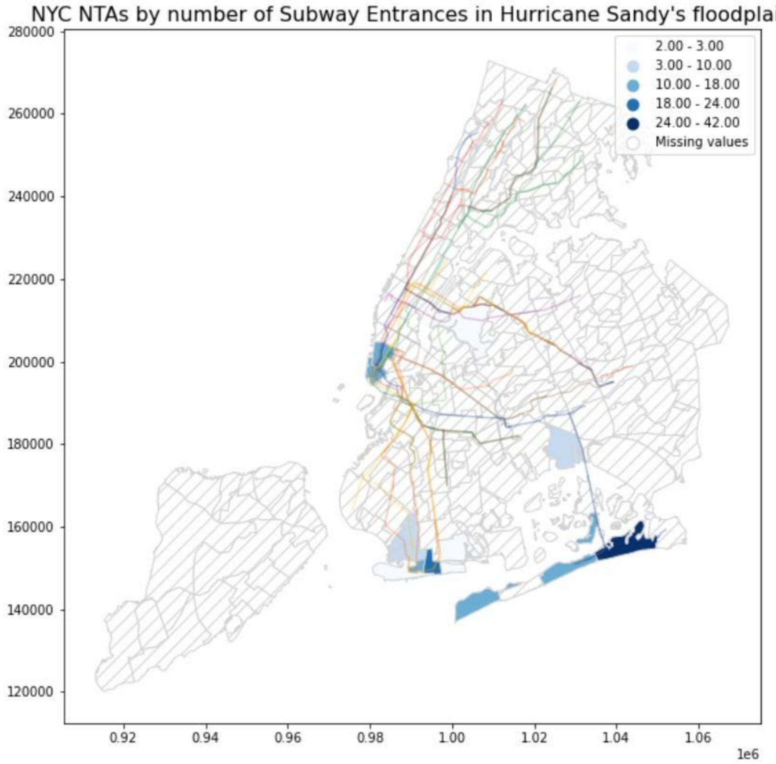
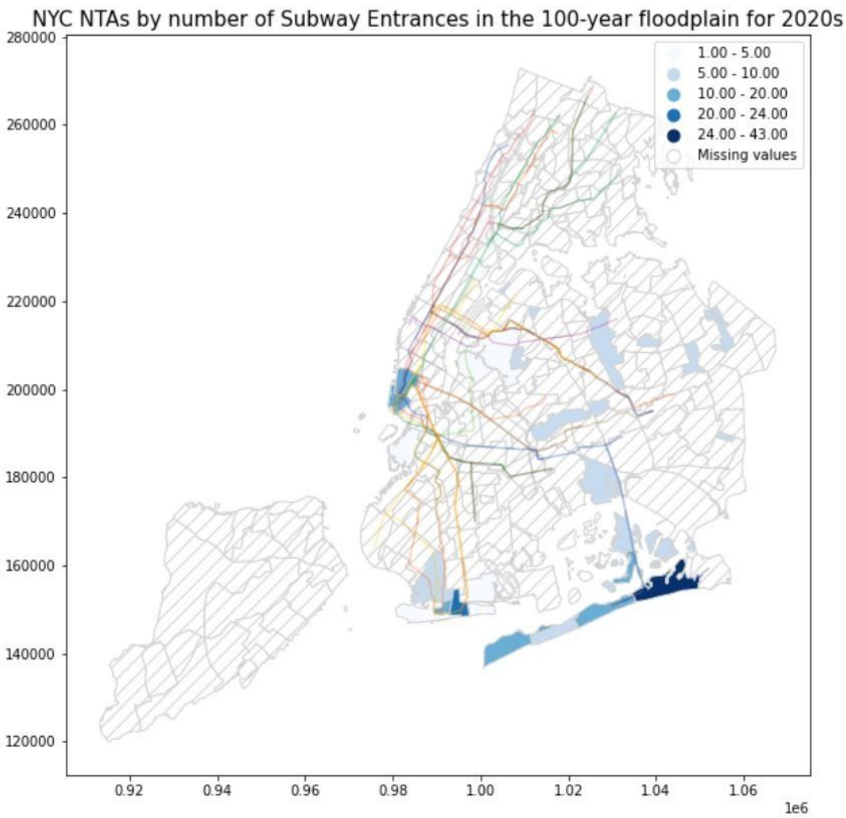
1e6

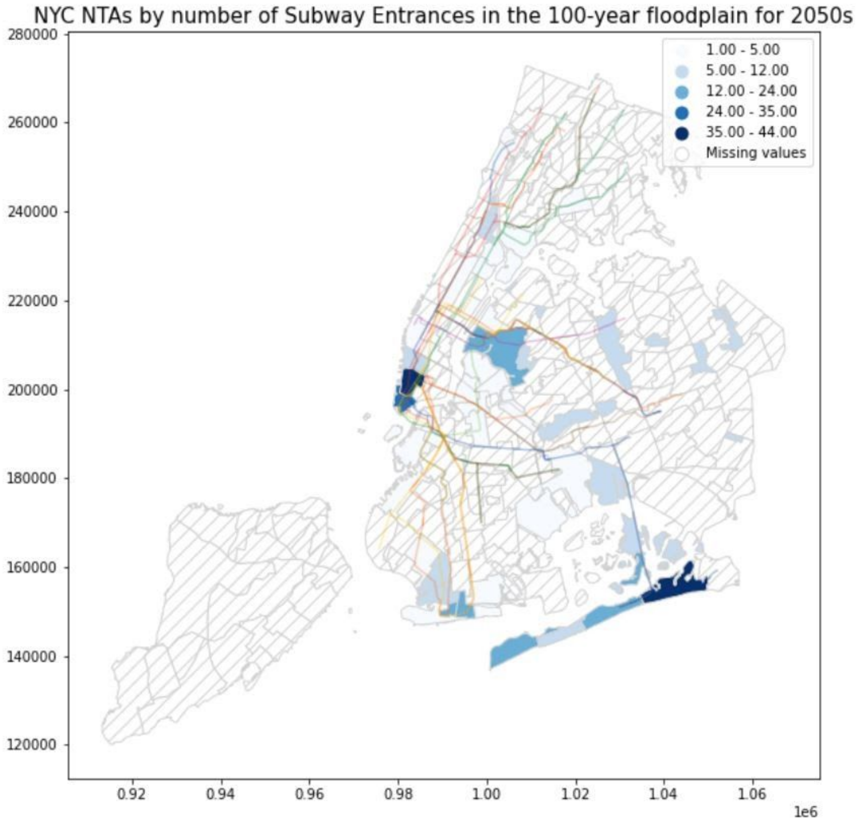
Map 4.


NYC NTAs by number of Subway Entrances in Hurricane Sandy's floodplain
2.00 - 3.00
3.00 - 10.00
10.00 - 18.00
18.00 - 24.00
24.00 - 42.00
Missing values
280000
260000
240000
220000
200000
180000
160000
140000
120000
0.92
0.94
0.96
0.98
1.00
1.02
1.04
1.06
1e6

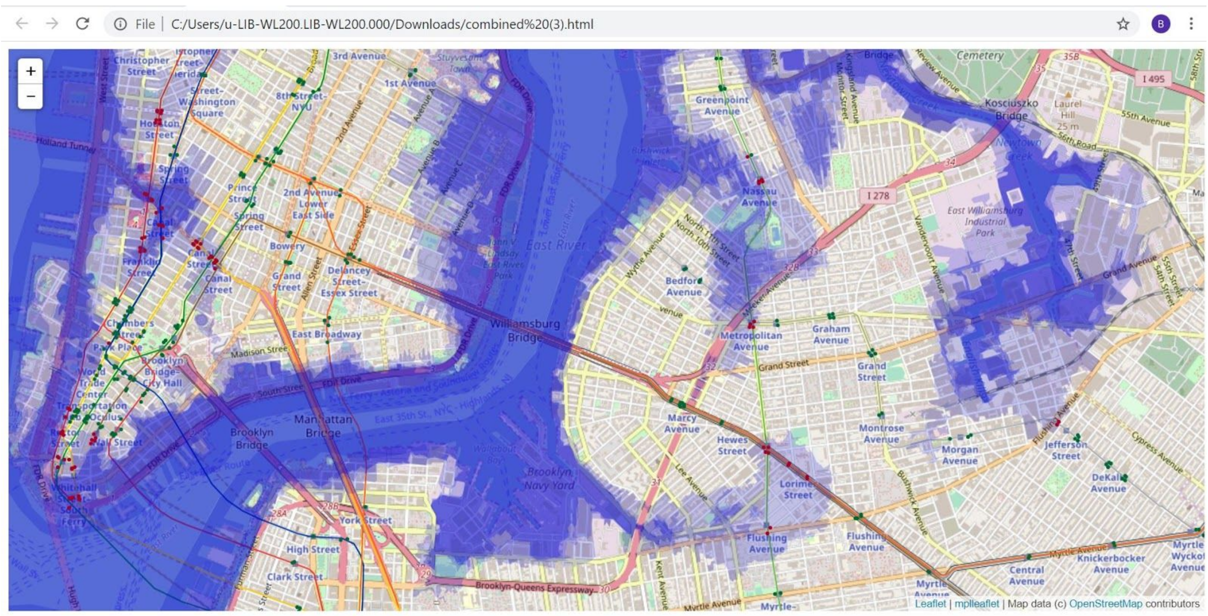
Map 5.


NYC NTAs by number of Subway Entrances in the 100-year floodplain for 2020s
1.00 - 5.00
5.00 - 10.00
10.00 - 20.00
20.00 - 24.00
24.00 - 43.00
Missing values
280000
260000
240000
220000
200000
180000
160000
140000
120000
0.92
0.94
0.96
0.98
1.00
1.02
1.04
1.06
1e6

Map 6.

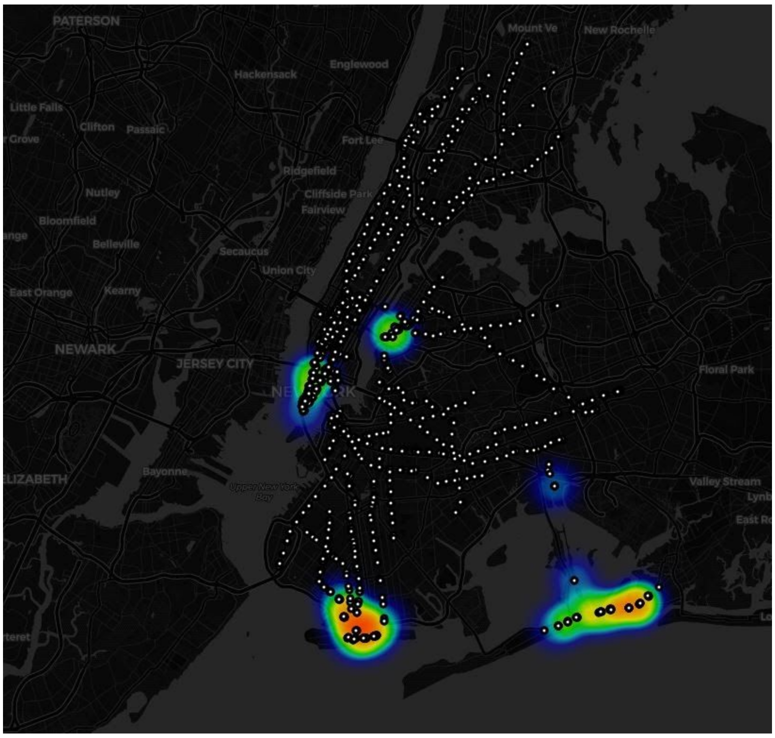


Map 7-10 - Screenshot of Map 10 - HTML download in link below

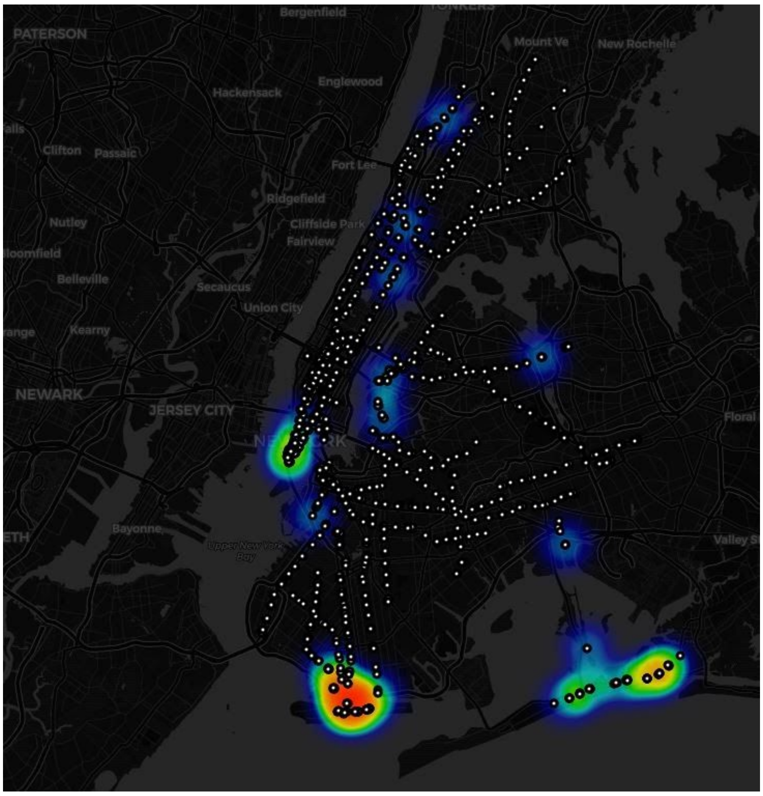


https://drive.google.com/open?id=1-0UURqA29Lx0SEcyFM-tWE1cOgIzSQmy

Map 11. Screenshot of Sandy Heatmap



Map 12. Screenshot of 2020 Heatmap



Map 13. Screenshot of 2050 Heatmap with popup

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