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## Preparing for Climate Change in New York City - Geographic Information Systems as a Valuable Tool for Natural Hazard Management

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# **Preparing for Climate Change in New York City**

Geographic Information Systems as a Valuable Tool for Natural Hazard  
Management

Amy Carrillo

## Abstract

This paper addresses the impact of climate change in New York City. Chapter 1 focuses on details found in the United Nations Intergovernmental Panel on Climate Change Report on the impact of climate change worldwide. At the city level, this paper analyzes New York City's Risk Landscape: A Guide to Hazard Mitigation and New York City Panel on Climate Change 2019 Report, which provides data on how climate change will impact NYC, specifically. Chapter 2 explores the history of Geographic Information Systems (GIS) and its use in mitigation and conservation practices over time. Chapter 3 studies how GIS has been used for environmental matters pertaining to NYC specifically, especially when addressing natural hazards. Chapter 4 looks at how GIS has been useful in analyzing economic aspects and social matters in terms of resiliency. After drawing conclusions and information from the previous chapters, Chapter 5 lists policy recommendations on how to use GIS proactively in resiliency efforts. It is based on grassroots action and modernizing NYC government data processes and information.

**Keywords:** Geographic Information Systems (GIS), climate change, New York City, GIS history, sea-level rise, flooding, rising temperatures, grassroots action, NYC Mayor's Office of Recovery and Resiliency

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## **Introduction**

Along the Pacific Ocean, sits a small island country in Melanesia named Fiji. It is home of about 900,000 residents, many of whom have ancestral roots deeply embedded within the island. Despite the islanders' simple lifestyle and being far removed from major emission producing countries, Fiji is experiencing the brunt of climate change's effects. For instance, it has become one of the first countries to deal with catastrophic rising sea levels, weather changes, etc. A young man from a small village called Vunisavisavi, named Aisake Lovobalavu, is coming to terms with the impacts of saltwater intrusion. Seawater has made its way into the community's septic tanks, streams used for drinking water, and the land used for harvesting crops (Lutunatabua n.d.). At the same time, climate change is impacting how islanders connect to their ancestral land. For example, Filipino Bukadrokadroka refuses to leave for higher land because the first paramount Chief of Cakaudrove asked his ancestors to "remain here and watch over the land for him" (Lutunatabua n.d.). It is difficult to leave a home when it contains cultural significance and is the basis of one's indigenous identity. However, many of Fiji's villages have been forced to leave due to the increasingly devastating impacts of sea-level rise and intense storms. The impacts are eerily similar to what is occurring and are expected to occur on the island of Manhattan. Fiji's current situation may become New York City's future. However, unlike Fiji, we have the time to both prevent and adapt to these changes. Fiji has looked to technological solutions, such as GIS, to help in mitigation practices and inform the public of what to expect in the future. Ambassador Nazhat Shameem Khan highlights the use of GIS for its predictive ability and its ability to assess future situations (Carmelle, Deusen 2019). This is also a technique that NYC has taken advantage of, yet not nearly enough as it should.

## **CHAPTER 1: Climate Change Impacts in NYC**

### **Climate Change - World Wide**

Climate can be defined as a compilation of averages and variations of weather patterns over several decades (Walsh 2014, 22). Land surface, the ocean, atmosphere, and ice all connect with Earth's climate system. This complex and delicate system is changing quickly due to human-related drivers. For instance, the majority of global warming occurred in the past 50 years in response to the emissions produced by burning fossil fuels and deforestation. Actions that involve the release of emissions impact climate negatively due to their release of heat-trapping gasses such as carbon dioxide, methane, nitrous oxide, along with others (Walsh 2014, 23). Meanwhile, humans are also removing trees that convert these harmful emissions into oxygen. Human activities are estimated to have already impacted approximately 1.0°C of global warming above preindustrial levels. It is expected to reach 1.5°C between 2030 and 2052 if humans continue at the same rate (Bongaarts 2018, 6). Once temperatures hit 1.5°C, climate change is predicted to unleash a domino effect of catastrophic events worldwide (IPCC 2019, 6). In New York City, climate change is expected to impact and disrupt a variety of important urban ecosystem services.

### **Regulating Services**

#### *Erosion and Flood Control*

The natural erosion and flood control provided by ecosystems in and around NYC are expected to diminish in resiliency as sea-level rises. NYC will see the results of sea-level rise very soon, especially in the upcoming decades, due to its location. For instance, Manhattan is an island surrounded by water and requires coastal protection. It is situated between the Hudson

River and the East River. The New York Bay touches lower Manhattan, Staten Island, and Brooklyn. Meanwhile, northern Queens is bordered by Long Island Sound. New York City, like many islands across the world, is expected to be negatively impacted by sea-level rise. However, NYC will experience higher than average sea-level rise, compared to other parts of the world. For instance, the net effect from enhanced thermal expansion, ice melting from the Antarctic Ice Sheet, and glacial isostatic adjustment (GIA) will contribute to NYC's sea-level rise. (Gornitz 2019, 72-73). In fact, NYC is already experiencing the premature effects of rising sea levels due to its lateral position on Earth. According to NOAA in 2017, the local or relative sea-level rise in New York City has averaged 0.11 in./year from 1850 to 2017. This is nearly double the 1900–1990 mean global rate (Gornitz 2019, 73). Overall, the New York City area is extremely susceptible to the impacts of upcoming sea-level rise due to its position on Earth.

Due to sea-level rise, the extra available water is expected to boost storm surges. Since 1900, NYC's sea-level has risen over 1 foot. Because of this, Hurricane Sandy flooded locations that would have remained untouched otherwise (Damiano 2014, 57). Meanwhile, NYC is projected to reach a 2.5 foot sea-level rise by the middle of this century. In the event of a future Hurricane Sandy, this means a higher possibility of storm surge and destructive flooding throughout coastal areas in NYC (Damiano 2014, 57). The fact that NYC is encountering and will continue to encounter intense and frequent impacts of sea-level rise, threatens the city's erosion and flood control.

Weakened erosion and flood control will come from intenser storm impact from sea-level rise and negative human activity on the environment. For example, depending on how intense a coastal storm is, it can remove significant amounts of sand and land. During Hurricane Sandy, 3.5 million cubic yards of sand in the Rockaway Peninsula and 679,000 cubic yards of sand in

Coney Island were washed away (Damiano 2014, 61). As storms become more frequent and intense, they have the power to erode entire beaches and create instability in the shoreline's bluffs. This sand and land area is vital and provides a regulating service for creating storm barriers between the ocean and communities on land. Additionally, human activity can exacerbate erosion in vulnerable areas because of poor land management practices (Damiano 2014, 59). For example, trees that once absorbed rainwater are being replaced with pavement roads that prevent rainwater from soaking into the ground and vegetation. Less available trees mean a lesser capacity to regulate stormwater. On another point, ill-conceived, man-made erosion controls meant to prevent erosion in certain areas are blocking sand movement and deflecting wave energy to other areas, thus disrupting the entire shoreline (Damiano 2014, 59). Due to previous human activity and increasingly destructive storm activity, NYC faces weaker natural flood and erosion control. This will only get worse if nothing is done, thus leaving the future of NYC in an even more vulnerable and susceptible position.

### *Waste Management*

The method in which the city manages waste currently, will soon not be enough in the face of future rising sea levels. For instance, the waste of millions of NYC residents is flowing underneath in the sewer systems. Rising sea levels are expected to increase that sewer surcharge, thus leading to more sewage and rainwater flooding on to the streets. Sewer surcharge occurs when the water sanitation and supply is unable to properly distribute or sanitize, due to strains on the system. The strains are due to an increased probability of blocked outfalls, poor drainage, and high backflow when storm surges occur on top of rising sea levels (Gornitz 2019, 75). Meanwhile, city waste management also fails when wastewater systems become overloaded by

frequent and intense storm surges, thus releasing their untreated wastewater into the nearby harbors (Bloomberg 2013, 211). Depending on the location and supply of waste-water, the facilities of waste management facilities can be impacted and release hazardous waste material into the NYC waterways. Climate change will have an increasingly negative impact on man-made structures made for waste management.

Waste management is also expected to suffer more due to the lack of natural drainage corridors and vegetation around NYC. For instance, natural drainage corridors and vegetation help absorb and slow the flow of water during a storm. Furthermore, the pollutants from the wastewater can be readily absorbed through vegetation. Therefore, overwhelmed and strained water systems can be treated from, quite literally, the ground up. Thankfully, the city's "Bluebelt Movement" has aided in engineering more natural drainage corridors and planting vegetation. However, more work needs to be done because storm/wastewater overflow remains an issue. Trees and natural drainage corridors provide a natural and regulating service of treating waste, it is important NYC use that to its advantage.

### *Climate Air Quality*

Air quality can be impacted by rising temperatures. The average temperature in the United States has increased by 1.3°F to 1.9°F since 1895 (Walsh 2014, 20). Meanwhile, there has also been an increase in annual average maximum summer temperatures across the city. For example, Central Park's temperatures, between 1900 to 2013, has been increasing by 0.2°F per decade (González 2019, 34). Meanwhile, between 1970 to 2013, JFK Airport and LaGuardia Airport have had rising rates of 0.5°F and 0.7°F per decade, respectively. As a side note, JFK and LaGuardia have much higher numbers due to the sea breeze effect on temperatures

(González 2019, 34). As of now, temperatures are not going to stop increasing. By the 2080s, temperatures above 90°F are expected to occur as often as 24 to 75 days a year. In comparison, between 1971 - 2000, temperatures above 90°F occurred for 10 days on average (González 2018, 37). However, it is not only the frequency of heatwaves that are increasing but also the mean intensity. By the end of the century, the current 93°F average will soon reach 95°F-98°F (González 2018, 37). Overall, extreme temperatures are becoming the norm in NYC.

High temperatures can contribute to negative air quality, especially in urban environments that release emissions consistently. First, heatwaves cause poor air quality because stagnant atmospheric conditions trap pollutants (Damiano 2014, 104). Urban areas, such as New York City have a high number of buildings and cars that release carbon dioxide, methane, and other hazardous heat-trapping gasses. During a heatwave, the emissions released further exacerbate the negative impact they have on air quality. Meanwhile, the ozone is created in the presence of sunlight by reactions of chemicals from motor vehicles and other emission sources (Damiano 2014, 104). Therefore, sunlight, stagnant air quality, and emissions can all lead to worsening ozone conditions. Overall, the climate's ability to regulate clean air is expected to suffer, while emissions are still being produced and temperatures continue to rise.

Aside from emissions, the lack of climate regulation in reducing the urban heat index will instigate poor air quality. For instance, the city landscape consists of heat-absorbing material and minimal green space. New York City is called the concrete jungle for a reason. It is surrounded by black pavement roads and sidewalks, concrete buildings, and a lack of green areas. These traits exacerbate and contribute to the Urban Heat Island (UHI) effect, thus creating warmer temperatures. The UHI effect is when incoming radiation from the sun is absorbed by the high concentration of pavement and buildings in a city, then later re-radiated at night (Damiano 2014,

100). Therefore, temperatures are typically drastically warmer in cities than in surrounding county areas. In fact, the UHI effect can cause a city to become more than seven degrees warmer than neighboring areas (Damiano 2014, 100). All of this, once again, leads to poor air quality because of the impact high temperatures can have on the ozone. The New York City environment is unable to regulate clean air quality due to improper city planning, continual emissions release, and already world-wide rising temperatures.

### **Provisioning Services:**

#### *Freshwater Supply*

How nearby reservoirs respond to sea-level rise will impact NYC's freshwater supply. For instance, saltwater intrusion from rising sea levels in New York City can affect the city's emergency water supply and water infrastructure. For example, the combination of sea-level rise and climate change alter the flow of seawater, circulation of tides, and storm surge upstream. Therefore, the salt front is pushed further upstream. This can majorly affect estuaries like the Hudson River. This is extremely troublesome for New York City because if the salt front migrates up the Hudson River, NYC can no longer turn to the emergency NYC drinking water supply from the Hudson during times of droughts (Gornitz 2019, 76). Besides from sea-level rise permeating a NYC water supply, saltwater intrusions can impact the NYC drainage systems. The current drainage structures put in place are not equipped for constant saltwater exposure and may face frequent damage (Gornitz 2019, 76). Repairing the equipment damaged by saltwater intrusions can be economically costly while also troublesome for future water supply needs. For instance, if the structure to transport water is damaged, it would be difficult to transport NYC's water supply needs. Overall, NYC's water supply depends heavily on clean water quality in our

reservoirs and reliable water infrastructure, which are both in danger due to the impacts of rising sea levels.

### *Food Supply*

Manhattan is an island that must provide food to about 9 million people. NYC is not self-sustaining in terms of food production, therefore it looks beyond its borders. About 95% of food transported comes primarily via truck; the remaining 5% is transported by ship, air, and rail. To put this in relative terms, three out of ten trucks that cross the George Washington Bridge are bound for the Hunts Point Food Distribution Center in South Bronx (Damiano 2017, 33).

Therefore, the food supply of NYC relies on roads, bridges, and tunnels to work properly at all times so citizens can be fed. However, transportation infrastructures and access to liquid fuels are usually the first to collapse during hazardous events, such as hurricanes and snowstorms. As climate change is expected to cause worsening impacts from major weather events, this can heavily impact NYC's food supply. Access to food supply is also threatened due to the fact that the epicenter of NYC's food network, Hunts Point Food Distribution Center, lies on a portion of the 1 percent annual chance flood plain (Damiano 2017, 33). This means flooding, especially from rising sea levels, can impact and hit the center in catastrophic ways. Moreover, energy production can become unavailable from storm activity and extreme temperatures, disrupting food availability. For instance, 70 percent of food needs refrigeration or freezing at each stage (Damiano 2017, 35). Without energy to supply refrigeration, it can cost millions of dollars in damaged food. Overall, the impacts of climate change can majorly impede food supply, thus the standard of living for every New Yorker.

## **Cultural Services**

### *Aesthetic Appreciation*

Parks across the city serve as a way for humans to aesthetically appreciate nature. For example, trees and other aspects of nature found in parks are able to provide people the simple enjoyment of nature. Although parks are all around NYC, some of the public amenities can be difficult to access, depending on the neighborhood. About 81.7 percent of New Yorkers live within walking distance of a park, but there is 18.3 percent that do not (De Blasio 2019, 18). If there would be more investment in parks and recreation spaces in areas of highest need, more New Yorkers would be able to appreciate these spaces. Furthermore, it would bring more communities together, contribute to better health, and foster cohesion and community development (De Blasio 2019, 18). On the other hand, parks can also act as an instrument for climate change management. In Brooklyn, parks have been used as flood and storm barriers. More trees can also provide shading, absorb greenhouse gasses, and provide habitats for animals. However, the aesthetic appreciation that humans are provided from a park is also highly valuable.

## **Supporting Services**

### *Coastal Habitats*

Salt marches provide important coastal habitats for wetland bird species and marine life. For instance, these wetlands are vital for sustaining populations of clapper rail, sharp-tailed sparrow, marsh wren, and the northern harrier. Meanwhile, many clam species, bay scallop, and blue mussel also use the tidal flats as a habitat. However, with rising sea levels, warmer ocean

temperatures, frequent flooding events, and an advancing shoreline, the wetland ecosystem may soon crash.

For instance, New York City's salt marshes are being impacted by sea-level rise related flooding. Specifically, salt marshes at the shoreline edge, such as Jamaica Bay, are turning into tidal mudflats. This is due to the fact that salt marshes are receding and submerged for longer periods of time resulting in them becoming ponded (Gornitz 2019, 76). High tides and high sea levels are the major factors that lead to longer periods of submergence. Wetlands are predicted to drown if the rates of accretion cannot keep up with the sea-level rise and/or do not have enough sediment supplies (Gornitz 2019, 76). This can ultimately destroy vital ecosystems that many species need to survive. The areas that are expected to be impacted are along the Atlantic Ocean and adjacent estuaries, such as the Long Island Sound and the Hudson River (EPA).

Climate change is also expected to cause warmer ocean temperatures. For one, this will disrupt coastal ecosystems that rely on certain ocean temperatures for migrating, mating, or simply to survive in. Meanwhile, warming temperatures can also cause more intense and frequent tropical cyclones due to changes in water temperature circulation. Frequent coastal storms can erode beaches and dunes, cause barrier islands to narrow and break apart, and submerge wetlands (Damiano 2014). Not only does this disrupt the existing natural environment, but it also leaves surrounding habitats exposed to impacts of wind and storm surges.

Climate change impacts, such as frequent flooding, can also disrupt the storage of toxic material. If toxic material is released to the environment, it can destroy the coastal habitats of many species. For instance, brownfield sites may contaminate waterways during moments of heavy downpours or flooding from storms. Or, the contaminated soil from the site can disperse to other nearby clean sites (Damiano 2017, 37). Moreover, sewage facilities can also take a hit in

the event of severe storms and damage nearby ecosystems. For example, during Hurricane Sandy, 10 of the DEP's 14 wastewater treatment plants released untreated and partially treated wastewater into waterways due to hefty damages (Bloomberg 2013, 209). With effluents released from brownfield sites or wastewater facilities, in the event of frequent and more intense storms, it can have an environmental impact of higher pathogen and containment levels in coastal areas or other clean waterways (Bloomberg 2013, 211)

## **CHAPTER 2: GIS – Hazard and Disaster Management Tool**

### **What is GIS?**

Geographic Information Systems (GIS) hold sets of data and makes it readable – a map. For example, GIS technology can hold information of individuals in a given area, then map it into categorical terms based population, income, education level, etc. It can also incorporate data on the landscape, types of vegetation, soil variety, and/or sites. After inputting all or a few of these categories, one can analyze how different information layers relate to one and other. Different forms of information can be layered on a single map because GIS uses location as a key index variable. If layers of information vary in scale, GIS then aligns the various maps and sources into one common projection (National Geographic Society 2012). In terms of data formats, GIS can come in various file formats. The two major file formats are vector and raster. Raster format is in the form of pixels or grids of cells. This is useful in depicting and storing data for elevation or satellite information. Vector format is in the form of polygons that uses lines and points. Borders for streets, state boundaries, or community districts use vector format (National Geographic Society 2012). GIS makes it easy to compute and visually create maps using a variety of different types of attributes.

GIS can be useful as a visual representation to inform people of future, upcoming catastrophic events. The use of GIS also allows for a different caliber of qualitative and quantitative data analysis. In other words, GIS has the capacity to identify problems. It can reveal geographic patterns once difficult to interpret but now made visible when an area is properly mapped (Harder 2017, 3). Overall, GIS provides the necessary background information and variables to make important decisions based on development, climate change factors, and upcoming catastrophic events.

## **History of GIS**

The field of GIS began in the 1960s. This was the time when computers and emerging concepts in quantitative and computational geography were first being conceptualized. Soon, spatial concepts also began to be formularized. The first developer of GIS was Roger Tomlinson. He developed the Canada Geographic System in 1963. The goal behind the automated computing processing he developed was to create an inventory of Canada's natural resources. When gathering data of the resources needed to plot for plantation location, he found it was extremely difficult to display. He had to show and overlay layers of topographic information, rainfall patterns, soil quality, animal migration routes, atmospheric conditions, and demographic information onto a map (Aguirre 2014). A little later, in 1964, Howard Fisher created the first computer mapping software (SYMAP) to synthesize map data. All of these moving parts led up to Jack and Laura Dangermond into founding the Environmental Systems Research Institute (ESRI), Inc. They applied both computer mapping and spatial analysis to create maps that allow geographic experts to make important land use or land resource decisions. In 1981, after much

improvement and building of software tools, Esri commercialized the GIS product into something anyone can use. (History of GIS n.d.)

## **Natural Hazard Management**

There is one thing that remains consistent throughout human history - natural disasters. Disasters of all shapes and sizes have impacted populations worldwide. It is believed that great civilizations, such as the Mayans, the Norse, and the Egyptian Empire were not wiped out due to enemies, but from the effects of floods, famines, earthquakes, and tsunamis (Coppola 2011, 1). For example, the fourteenth-century bubonic plague reduced Europe's to about 50%. Meanwhile, very recently, the 2004 Indian Ocean Earthquake and Tsunami left about 23,000 people dead (Coppola 2011, 1). However, as time progresses, the way in which different countries deal with upcoming hazards has evolved.

### *Non-GIS Mapping – Natural Hazard Management*

In ancient history, computer software was not available for planning or analyzing data. Nonetheless, people around the world used different techniques and regular mapping to develop disaster management plans. For example, archeologists found that floods were a major problem in Egypt during the time of 18<sup>th</sup> century BC. Pharaoh Amenemhat III (1817-1722 BC) developed the first substantial river control project using 200 water wheels. The system aided in diverting the annual floodwaters from the Nile River into Lake Moeris. The result was 153,000 acres of reclaimed fertile land (Coppola 2011, 3). In the 13<sup>th</sup> and 15<sup>th</sup> centuries, the Incas practiced complex urban planning. This resulted in Machu Pichu. This fortress facilitated a life of

protection against enemies due to its extreme, mountainous terrain. The Incas also planned land terracing in order to conserve water and protect crops from landslides (Coppola 2011, 3).

In more recent times, mapping has been used to prevent further outbreaks of major epidemics. For instance, in 1854, there was a cholera outbreak in London. A man named John Snow plotted the location of deaths, water pumps, and streets in London. Ultimately, the map helped Snow find that a water pump in Broad Street, not air quality, was to blame for the outbreak (Aguirre 2014).

Mapping has also been used to reduce the annual starvation in India that occurred during regular drought patterns. There was enough food for the population of India, but an insufficient distribution capacity got in the way of addressing location-based needs. A railways system framework based on mapping was created. The framework identified areas of emerging needs and was logged into the central repository. By mapping this information, a sufficient means to transport food was created and helped reduce the impacts of drought-related famine (Coppola 2011, 4).

The major problem with maps is its lack of complex dimensionality. Maps are trying to portray a 3D experience in a 2dimensional space. This means that important topographical features are not available on a map. This is a similar dilemma to what the founder of GIS faced. When too many layers of information are displayed on a 2D map, it becomes unreadable and useless. Information can be lost or hidden under layers, even with Mylar sheets. Although these former disaster management plans were brilliant, if the GIS computer software was available, it could have greatly aided the technological and planning process. It could have even yielded greater results. GIS can be beneficial as a tool for natural hazard management or resiliency plans.

## *GIS Mapping – Disaster Management*

In the last few decades, the world has seen a rise in natural disasters and this has enabled the GIS community to manage the after-effects of natural disasters. Although hazards are premature to natural disasters, it is important to discuss the impact of GIS in managing recovery. Because of pre-GIS cartographic and table data, GIS became instrumental in understanding a community's risk and potential response rate in real-time. As a result, ESRI developed a Disaster Response Program for critical disasters worldwide. The program offers software, data, and technical support for emergencies that may need GIS operations. In 1994, the ESRI Disaster Response Program (DRP) was first activated to aid in the 6.7 magnitude Northridge Earthquake in Southern California. GIS was used for damage assessments and impact modeling on the area's buildings and freeway overpasses.

The DRP was also activated for Hurricane Katrina in 2005. Direct aid in map production, search and rescue operations, and a regional database was developed through the program in before and after the hurricane. For instance, digital elevation models with ArcGIS 3D Analyst software was used for modeling storm surge flooding. Additionally, ArcMap's street-level mapping helped prepare search and rescue grids for first responders (ArcNews Fall 2005 Issue 2005). After the devastation, GIS volunteer staff translated addressees and landmarks into GPS coordinates for U.S. Coast Guard helicopters to use during rescue and evacuation operations. Maps were created for missing people detailing their last known location. This helped direct emergency response. Briefing maps were created to visualize and prioritize areas of power outages, road closures, communication networks, and aid stations. Meanwhile, maps also helped visualize areas with critical infrastructures, like water treatment plants, that were previously hidden by flooding and debris (ArcNews Fall 2005 Issue).

In 2010, ESRI's DRP offered their assistance in the BP oil spill that occurred in the Gulf of Mexico. GIS was used to monitor the oil spill and assess its impact on surrounding natural resources. The information from these maps, or common operating picture (COP), were then used by other agencies for management efforts. The information was also relayed rapidly in response to changes. For instance, layers of information were updated and re-released to agencies due to changes after relief efforts (Users Respond to Oil Spill Disaster 2010).

### ***GIS Mapping - Hazard Management Case Studies***

Disaster management is an important area in which GIS can be used. However, GIS can also be used to assess and mitigate the fallouts of a natural disaster. This is called hazard management. There are cases world-wide in which GIS is used to prevent disastrous impacts, whether it be from climate change, natural hazards, natural hazards influenced by climate change, or biodiversity that is threatened. No matter the hazard, GIS remains a useful tool for collecting, analyzing, and presenting information.

#### *Arctic Sea – Ice Extent*

ESRI partnered with the “National Snow and Ice Data Center” to map the monthly average ice extent in the Northern Hemisphere. The sea ice observed can vary in the form of slush to ice sheets (a width of several meters). The concentration of sea ice has been monitored by satellites since the 1970s. Using the information gathered from the microwave satellite data sources, the National Snow and Ice Data Center sends out daily reports of analyses. The new data is then applied to the GIS map's shapefiles. The map consists of two layers: sea ice extent for the Arctic in polar projection and sea ice extent for the Antarctic.[1]

Data collected shows ice coverage to be about 9.33 million square kilometers. This concludes that ice coverage is 670,000 square kilometers (259,000 square miles) above the 2016 record low for the month. However, it also 1.37 million square kilometers (529,000 square miles) below the 1981 to 2010 average.[2] Using GIS helps visualize the changes in sea ice coverage in the Arctic and Antarctic. Figure 1, is the arctic sea ice extent for November 2019 for data reference. The figure also helps compare the difference in average ice coverage extent between 1981 and 2010. The information on the map is vital for understanding how much of the sea ice is melting, thus impacting sea level rise. It is important to understand and analyze the rate at which it is going, in order to prepare for future possible impacts across the world.



Figure 1 GIS map of the Arctic Sea's Ice Sheet in November 2019. The magenta line shows 1981 to 2010 average extent for the month

### *Vietnam - Assessment of Coastal Vulnerability*

Vietnam is one of many islands on the planet that has become more and more susceptible to climate change. So far, Vietnam encountered significant damage from floods, erosion, and typhoons. The intensity and frequency have only increased due to rising sea levels. What makes rising sea levels so hazardous to Vietnam is that the country's development sits predominately on the coastlines (Boateng 2011). Therefore, Vietnam's development and population are increasingly vulnerable to rising sea levels.

To mitigate the future harmful effects of climate change, GIS is used in assessing coastal vulnerability. GIS contributes to finding high-risk areas that are extremely vulnerable to major climatic events or changes in sea level. It did so by using Geo-Reference Shuttle Radar Topography Mission (SRTM) data, which generates satellite images with ground elevation (Boateng 2011, 27). Based on the satellite images, one can find communities, development, and land areas that are vulnerable to flooding. After assessing elevation and populated areas, the analysis found that a significant portion of Vietnam was under flood risk. For instance, the areas around the Red River Delta (north) and Mekong River Delta (south) had an elevation below 1 meter. This low-lying coastal area serves as one of the country's main economic centers and is one of the more developed areas (Boateng 2011, 28). These low-lying developed coastal areas must adapt quickly to the new upcoming changes brought by climate change.

Using the information from GIS mapping, future appraisals and planning policy measures on coastal adaptation were created. For instance, first risk management policies identified possible climate change impact areas. Spots included areas of inundation near the Red River and Mekong River deltas, settlements in low-lying coastal areas, areas impacted by increased erosions, areas of loss of farmland, mangrove, and wetlands. (Boateng 2011, 26). Next, using this information, an integrated shoreline management planning approach was put forward. A non-structural approach was voted for areas that are low-elevated but highly developed. This involved building coastal buffer zones, houses on stilts, growing flood-resistant crops, and creating elevated storm shelters (Boateng 2011, 34). Secondly, a structural approach was voted for in the areas that are highly elevated and have hard bedrock. This included creating dykes, breakwaters, sea defense and groynes (Boateng 2011, 34). The use of GIS was extremely

influential and beneficial for Vietnam to find areas of high risk and then act upon the results. Most importantly, GIS was key to helping offset future climate change effects on Vietnam.

### *Costa Rica - Method for Conservation Decision Making*

GIS helped in the interpretation of data when identifying areas of Costa Rica that needed conservation. Specifically, GIS used a gap analysis tool to make an assessment on the distribution of wildlife sightings in Costa Rica's protected areas, thus forming linkages. Ultimately, GIS aided in the creation of the "Habitat Decision Cube." This cube consisted of three GIS layers used for the gap analysis – species distributions, habitat type, and protected areas. The gap analysis focused on one combo: wildlife present (w), unprotected areas (p), and habitat available (h) to find additional wildlife protection areas. After assessing possible combination, categories were created: wildlife protected category (w+ h+ p+), conservation gap category (w+ h+ p-), potential habitat restoration category (w+ h- p+), further wildlife category (w+ h- p-), protected area data gap category (w- h+ p+), unprotected area data gap category (w- h+ p-), negation area (w- h- p+), developed area (w- h- p-) (Savitsky and Lacher 1998, 180-185).

Overall, the analysis tool helped conservation biologists and politicians in Costa Rica decide what areas can be effectively conserved. For example, the maps helped show if areas need new buffer zones to existing reserves. Meanwhile, other spots needed to strengthen genetic diversity by supporting the continued survival of an isolated ecosystem. "Having a visual geographic platform from which to build a framework to evaluate such issues is the type of contribution that can be expected from a national or landscape-level gap analysis" (Savitsky and Lacher 1998, 188).

## *Abu Dhabi - Urban Planning*

In Abu Dhabi, there is a city being planned that will be zero net waste, sustainable living, and carbon neutral. The name of this future urban environment is Masdar City. To achieve these ambitious goals, strategies were made in a photovoltaic power plant, waste to energy technology, greywater use and wastewater conversions (GIS for Climate Change 2017, 17). GIS was used to design this future sustainable city. Derek Gibbon, the GIS manager of Masdar City, stated: “GIS is imperative in managing the overall spatial information necessary for designing, building and operating Masdar City” (GIS for Climate Change 2017, 20). GIS helped prevent the hazard of poor city planning.

First, GIS was used for green buildings practices. For example, GIS was instrumental for visualizing and finding the orientation of buildings in a diagonal grid that would maximize natural shading. It was also critical to have data layers in the geodatabase that had information on vegetation, transportation, elevation, buildings, utilities, etc. Meanwhile, GIS also allowed for tabular databases inside map layers (GIS for Climate Change 2017, 21-22). This means geopoints on the map included information on cost, schedule, carbon tracking, etc.

To run Masdar City, it meant looking deeply into aspects such as utilities and transportation. GIS aided in modeling water and power over a period of 10 years. Monthly resource demands per section of the city were plotted to form a geographic histogram (GIS for Climate Change 2017, 21-22). Through this exercise, possible future problems of energy distribution were able to be resolved. As for transportation, GIS was needed for visualizing routes for the Personal Rapid Transit System (PRT) system. Furthermore, optimal locations were created based on the information of real estate plots (GIS for Climate Change 2017, 21-22).

Lastly, the main objective of Masdar City was to develop an innovative and sustainable city that runs on no emissions. GIS would aid in tracking and ensuring no net emissions. It would do this by using a computerized maintenance management system that included the location of infrastructure assets. Assets would be closely monitored are gas pipes, smart grid infrastructure, clean, gray and black water networks, and the transportation network (GIS for Climate Change 2017, 22-23). GIS will make it easy to track changes in resource use and carbon balance once the project is complete.

### **CHAPTER 3: How GIS Can Help NYC – Environmentally**

#### **GIS Resources Available in NYC**

The NYC government has created, with the help of many organizations, an assortment of maps pertaining to the city. The maps are meant to provide New Yorkers with information and the means necessary for engaging with civic life. On the official website of the City of New York, anyone can access the city's wide ray of maps on NYC's services, environmental programs, resiliency outreach, etc.

There are maps available that help keep track of services provided by NYC or navigate where services are available in NYC. For instance, the "NYCityMap" locates cultural institutions, education, health facilities, municipal boundaries, etc. There is also a "Discover NYC Landmarks" map developed by NYC Landmarks Preservation Commission. The "Crime Map" analyzes crime by precinct and aggregated location. The "NYC Health Map" includes information on facilities that provide vaccinations, HIV Testing, and Quit Smoking Programs. For children's education services, there is a "Pre-K Finder" map and "Child Care Provider Search" map. The "Street Closures" map is updated daily for communicating closed streets due to events, parades, filming, etc.

Asides from services, there are maps of information on infrastructure development. For example, there is a map on “Zoning and Land Use.” The “NYC Street Map” has information available on the width, name, and status of streets around NYC. The map also contains layers of information of tax lots, commercial overlays, preliminary flood insurance maps, etc. The “Green Infrastructure” map displays a compilation of green infrastructure assets from the NYC Department of Environmental Protection. Furthermore, there is a map on “NYCHA Developments” and a “Sidewalk Café” map. Meanwhile, the “Business Atlas” map can be useful for discovering business conditions in each neighborhood.

Lastly, maps dedicated to the natural environment are available. However, some maps are not solely dedicated to environmental resources but have layers of information within the map addressing the environment. For instance, the “Resilience and Recovery Map” displays mitigation actions from the 2019 NYC Hazard Mitigation Plan and the total number of projects located in community districts. If one looks further, there is a layer of information on previous or current projects including environmental restoration. Other maps exist, such as the “SPEED” map that provides an in-depth overview of connections between environmental hazards and properties in NYC. Meanwhile, the “New York City Street Map” offers information on the care, maintenance, and ecological benefits of each tree across the city. The “NYC Then & Now” map also displays differences in the urban landscape between 1924 to contemporary ages.

### **Environmental GIS Resources – NYC**

GIS functions as a means of analyzing and presenting data in the form of a map. These maps are essential for the development of NYC planning and policies to push forward.

Information is vital in the city's policymaking and development strategies, therefore a lot of public GIS information available has been cultivated and synthesized for NYC planning policies. The NYC Mayor's Office of Resiliency has created reports that include GIS mapping information to visualize and assess upcoming climate change impacts. These reports are OneNYC 2050 (2019), Climate Resiliency Design Guideline (2017), A Stronger, More Resilient New York (2013), PlaNYC Progress Report (2014), PlaNYC Full Report (2011). The specific map resources used for these resiliency programs are NYC Flood Maps, NYC Resiliency Maps, Resilient Neighborhoods Study, SPEED, NYC Hazard Mitigation Map, Sandy Funding Tracker, and Heat Vulnerability Index.

#### *Searchable Property Environmental Electronic Database (SPEED)*

The Mayor's Office of Environmental Remediation (OER) developed a GIS-based map for the purpose of facilitating property environmental research (Bloomberg 2013, 202). Along the waterfront, from South Bronx to Sunset Park in Brooklyn and Staten Island North Shore to the edges of Queens, there are many companies that made a home there. A large portion of these businesses rely on hazardous chemicals to produce their services and/or goods. Therefore, when or if flooding takes place, the chemicals from industrial sites, recycling centers, print shops, and others may leak and lead to harmful environmental effects (Bloomberg 2013, 201). Although there isn't substantial information on whether hazardous material were safely secured or simply diluted by the high volume of water from Hurricane Sandy, it is important to create maps of areas of vulnerable sites (Bloomberg 2013, 201). It is also important to have a map that provides information on brownfield sites. For instance, brownfields present a major risk to a community because the land still has remnants of hazardous chemicals. During major flooding events, the

chemicals from these sites can leak out to surrounding areas. Thus, it can disrupt ecosystem services we depend on, such as a freshwater supply and coastal habitats. It is important to have a map on local business properties and brownfield sites in order to assess a location's possible hazards to the surrounding environment.

Asides from providing public information, the database has allowed for the Brownfield Cleanup Program to approve of over 95 projects. These projects include a large percentage in historically disadvantaged communities. The advantages to the projects include a cleaner environment and a spur in economic activity. For example, the approval of projects is expected to generate 3,100 permanent jobs, 8,000 construction jobs, and \$600 million in tax revenue. Meanwhile, there are also brownfield sites across the city that are being remediated and redeveloped in a resilient fashion.

### *NYC Hazard Mitigation Projects*

The "NYC Hazard Mitigation Map" can be found on the NYC Mayor's Office of Resiliency. Its existence is part of the OneNYC 2050 initiative. The legend includes areas of emergency services, coastal/natural resources protection, infrastructure project, prevention and policy, property protections, and public education and awareness. It can then be filtered down by hazard, managing agency, and mitigation action category. The map is able to display current projects on how the city is using local ecosystem services to enhance the moderation of extreme events and coastal habitat protection. For instance, the coastal/natural resources group in the mitigation action category filter helps display specific environmental projects across the NYC area. A lot of the projects target services like flood control and wastewater management.

It is important to understand what local environmental projects are taking place in one's community or the communities surround them. Without this information, the public would not know is resiliency measures are taking place or which locations need focus. For example, it can be beneficial to learn about where the "Bluebelt drainage program" is taking place. By looking at the map, the public now knows the location of new drainage systems that help preserve nearby natural areas, such as streams, ponds, and wetlands. The public can also see that the lead agency for the program is the Environmental Protection Agency (EPA) (NYC Gov, n.d.). The EPA is also leading the green infrastructure program. The program involves constructing infrastructure that will help reduce 10% of impervious surface's runoff water into the sewer system by 2030. On Staten Island, the public can also see where areas of "Complete Short-term Beach Nourishment, Dune Construction, and Protection" are located (NYC Gov, n.d.). In 2014, the Department of Parks and Recreation finished creating a continuous line of emergency protection by reinforcing dunes between South Beach and Conference Park. In addition, in Queens, the Economic Development Corporation led a project called "Hunters Point South" in 2018. The project included the restoration of the Hunter's Point South Park and enforce the park with flood-resistant material (NYC Gov, n.d.). On the map, the public can get a closer look at the many more projects on coastal/natural resources protection, information on the program's budget, completion date, the lead agency, etc.

## **CHAPTER 4: How GIS has helped NYC – Socially/Economically**

### **Economic GIS Resources – NYC**

When you look at New York City for the first time, the first thing you notice are the skyscrapers. The home of many corporations, financial firms, small businesses, and New Yorkers are in these buildings. Therefore, it is not only costly to rebuild damaged buildings but also to

stop all the work that is happening inside. A coastal storm that is expected to hit once every 100 years can damage about 40,000 buildings and cost \$3.5 billion in damage (Damiano 2017, 55). Meanwhile, winds from a storm occurring every 1,000 years can destroy half of the city's building stock, 450,000 buildings, and it would cost \$53.6 billion in damage (Damiano 2017, 55). Therefore, NYC has put programs in place to prevent such social and economic disasters in the event of natural hazards, such as the Flood Hazard Mapper. Meanwhile, NYC has also created a map to calculate the economic benefits of preventing maximum natural disaster impact, in the form of street tree mitigation efforts.

#### *New York City Street Tree Map*

The NYC Parks has found a way to translate the value of NYC trees into economic terms. The NYC Street Tree Map began with the initiative of the NYC Parks to create a map with information on every street tree in New York City. The map would allow the public to search addresses and find the species of trees living within the area. The map also works by filtering species of trees and finding where they are located in the five boroughs. One can also narrow down and click on individual trees to find out more about its ecological benefits.

The ecosystem service provided by each tree in NYC is mapped and calculated into economic terms. For instance, each tree has statistics on the stormwater it intercepted in the current year. Stormwater interception is valuable because reduces the urban runoff that pollutes local water sources, and regulates water flow in sewer systems by lessening the burden of rainfall (NYC Parks, n.d). Besides from stormwater interception, how well a tree is able to regulate temperature can also be calculated. Trees serve the ecosystem service of regulating climate by providing shade and reducing wind speeds. Therefore, this service is translated as energy

conserved each year for NYC (NYC Parks, n.d). Meanwhile, carbon sequestration and storage is also provided by the neighborhood trees and urban forests. As trees grow, they are able to absorb greenhouse gasses. A tree's ability to store carbon is computed as carbon dioxide reduced each year. Meanwhile, a tree's ability to remove pollutants (asides from Carbon) is calculated as air pollutants removed each year (NYC Parks, n.d). All these ecosystem services provided by the tree are then able to be valued at how much money it saved the NYC government.

The map is a helpful economic analysis tool that allows ecosystem services to be valued. Typically, environmental benefits are difficult to compare in a cost-benefit analysis, because how does one quantify the benefit of breathing fresh air, a clean drink drinking supply, etc. However, the NYC street TreeMap offers the individual and collective monetary annual benefits of trees located across the five boroughs.

### *NYC Flood Hazard Mapper*

The NYC Flood Hazard consists of three sets of information: base flood elevation, high tide in the 2020s, 2050s, 2080s, and 2100, and future floodplains in 2020s, 2050s, 2080s, and 2100. For base flood elevation, New York City partnered with the Federal Emergency Management Agency (FEMA) to create Flood Insurance Rate Maps (FIRMS) that depict base flood elevation levels. However, the estimates made for future high tide and future floodplains are based on NPCC's projections for sea-level rise. Overall, the layers on the maps help identify and assess different flooding risks on a 100-year floodplain. In other words, the NYC Flood Hazard Mapper provides the public with access to information on which areas in NYC likely have high impact destructive wave action and which areas need flood based protection.

Flooding can jeopardize systems that drive NYC's economy, such as energy, telecommunications, and transportation. If these systems are hit, it puts the NYC economy in a vulnerable and costly position. For example, a sizable portion of the workforce in New York City depends on transportation. Meanwhile, tourists also depend on trains, ferries, taxis to move around. As for world travel, the two major airports in NYC (LaGuardia and JFK) contribute around \$37.3 billion to the regional economy and provide 256,000 jobs (Damiano 2017, 31). However, the transportation system remains vulnerable to flooding, even more so with climate change causing more intense and frequent events. For example, during Hurricane Sandy, many of the city's tunnels were forced to shut down due to flooding. In addition, much of the transportation infrastructure lies in the 1 percent annual chance floodplain (Damiano 2017, 76). Another critical infrastructure that can be vulnerable is energy systems. High winds and storms can disrupt power lines, thus threaten the use of necessary electricity. Flooding can be detrimental to the power generation plants because some plants also lie in the 1 percent annual chance floodplain (Damiano 2017, 31). Similar to energy systems, telecommunications are highly vulnerable to storms, winds, and flooding. About 13 percent of telecom facilities that are located in floodplains are at risk of flooding damage (Damiano 2017, 30). As seen, the economy is highly dependent on areas that are susceptible to flooding, thus proving to be a hazardous impact on the future economy.

Flooding maps point out to residents, business owners, and the NYC government on which areas need the most help and resiliency planning. For instance, to ensure economic costs are not as high in the next flood event, the Flood Hazard Mapper is a valuable tool in mitigation practices. The map can distinguish with subway entrances that need to be remodeled in preparation for future flooding. For instance, which stations need elevated air vent gratings or

improved pumping capacity (Damiano 2017, 82). Meanwhile, property owners that live in high-risk areas can also become better informed on how to be properly prepared for the next flooding event and become insured. Overall, it is important for the public to understand the future economic costs of an area due to flooding. However, these maps must be re-evaluated consistently because flood hazards can be dynamic and change due to changes in weather patterns, erosion, and new coastal development (FEMA 2016).

### **Social GIS Resources – NYC**

New York City is the most populated metropolitan area in the United States. There are 8.4 million residents living in the city, while commuters and tourists increase that number to an average of 9 million people on the island every day (Damiano 2017, 17). The population is expected to grow. When critical systems, such as water distribution, food supply, and health, are not operational then the standard of life also plummets. It is important that factors of community cohesion and health care are addressed in the face of future climate change impacts. The NYC government has used GIS to help create maps that can foster community engagement and inform on health risks in vulnerable communities.

### **NYC Planning - Community District Profiles**

NYC has 59 community boards. The Department of City Planning's Community District Profiles created detailed maps and data to demonstrate information on the environment, socio-economic conditions, and planning activities. The interactive map is meant to aid the public in engaging in city planning and self-activation. All this information is vital in planning for future climate change impacts on one's community board, as well.

In the indicators section, it provides users with a snapshot of the key socio-economic, demographic, and services available. For example, socio-economic statistics included are ages under 18, ages 65 and over, rent burden percentage, percent residents with access to parks, street cleanliness, crime, English proficiency, unemployment, NYCgov poverty measure, etc.

The built environment section includes information on the different types of land use in the area, zoning, and public facilities available. The map of land use includes categories in public facilities and institutions, industrial and manufacturing, open space and recreation, commercial and office, transportation and utility, etc. Meanwhile, there are four different categories of zoning color categorized on the map: residence, manufacturing, commercial, and park. Different type of facilities has also been plotted on the map. Facilities included on the map are the administration of government, health and human services, libraries and cultural programs, parks and historic sites, public safety and emergency services, education and child welfare, and transportation (NYC Planning, n.d.).

There is another section that integrates NYC's floodplain in regards to the age of buildings, basements and building proximity. The age of buildings is critical for evaluating which buildings are within present floodplain regulations. It is also important to include basement information because basements are extremely vulnerable to flooding. Meanwhile, building proximity information is important for assessing if certain buildings are easily retrofitted or elevated. This information tells the user whether it would be costly or difficult to elevate a building. All this information on building, basements and building proximity is available for both the 1% and 2% annual chance floodplain. (NYC Planning, n.d.).

This map is important for community cohesion and health factors. Access to information about one's community and the possible hazard it faces is important for enacting social change.

For example, it is important to know where vulnerable populations, such as the elderly and handicapped, are prevalent in relation to the floodplain. With this information on hand, policies in mitigation planning can be created in regards to which areas are most vulnerable and susceptible to damage.

As for physical health, it can be life-saving to know exactly which and where local hospitals are on a map. As stated, climate change is expected to cause sea-level rise, intense and frequent storm activity, flooding, etc. This can all put a strain on the health care system of NYC. For example, during Hurricane Sandy, hospitals next to the East River had to evacuate (Damiano 2017, 35). Transportation issues can also cause fewer healthcare workers to show up for work. If energy systems are down due to high winds or other climate-related problems, it also means consumers cannot have the necessary basic heating, cooling, ventilation, lighting and life support machines they may need. In addition, if intense storm weather events are expected to occur more often, there will be more opportunities for floodwater, debris on roads, or malfunctioning transportation to prevent people who need medical care from receiving it. In light of all these consequences of upcoming natural hazards, it is important to have a map of locations of health centers and emergency services that are available around NYC.

Furthermore, the addition of a park/gardens/historical sites layer on the map adds to the possibility of improving the mental health of the community. It is known that parks or other forms of green space provide the culture service of improvements in mental health and aesthetic appreciation in a community.

NYC Health – Heat Vulnerability Index Map

Unlike the Community District Map, it does not map vulnerability. However, the Heat Vulnerability Index Map is able to in regards to rising temperature. The NYC Health Department and Columbia University developed the NYC Heat Vulnerability Index (HVI) using a statistical model. After analyzing mortality rate data from 2000 – 2011, a model was created that identified vulnerability and risk of mortality rate. The model is based on the socio-environmental factors of a community to determine the community's risk for heart-related events (NycDOHMH 2015). Environmental factors include daytime summer surface temperature and greens space (tree, grass, shrubs). For instance, green space and/or low surface temperature can decrease the risk of impact from heatwaves. Meanwhile, a major social factor is poverty (NycDOHMH 2015). For instance, people in poverty are unable to or less willing to use air conditioning due to cost concerns. By integrating both environmental and social factors, a vulnerability index was able to be calculated for each community. The purpose of the map is to identify currently high-risk areas so efforts to certain communities are properly distributed (NycDOHMH 2015). However, the major issue of the map is that it only identifies current heat vulnerability index issues. It does not predict future changes in vulnerability and a rise in heatwave activity due to climate change.

## **Chapter 5 - Policy Recommendations**

### **Introduction**

If not adequately addressed, the effects of climate change are only going to grow more destructive and frequent in the upcoming years. However, NYC has the capability to respond to this threat. For one, it should continue developing sustainable adaptation plans to mitigate the current and future impacts of climate change. The IPCC (2007) states that to improve adaptive capacity the city, country, or world must move towards sustainable development planning. By looking into land-use planning and infrastructure design, it can reduce risks in hazardous zones.

Geographic Information Systems can be a key tool in the improvement of New York City's adaptive capacity environmentally and economically.

### **New York City – Current Resilience Plan**

The information provided by the New York City Panel on Climate Change (NPCC) has assisted New York City policymakers in planning for climate change risks. The NPCC projects categorize climate hazards into chronic hazards and extreme events. Chronic hazards in New York City are extreme changes in average temperatures, precipitation levels, and sea-level rises. Meanwhile, extreme events are heatwaves and cold events, intense precipitation, and coastal floods at the battery. Actions have been put in place to mitigate these upcoming hazards. The NYC Mayor's Office of Recovery and Resiliency developed a program and was renewed in March 2019 as the "Climate Resiliency Design Guidelines." The program focuses on mitigating future extreme events with resilient design planning.

For example, part of the resiliency plan is addressing increasing heat temperatures. As stated, public health is expected to diminish as the number of days over 90°F increase. The Guideline offers two key recommendations for city developers to consider: reduce the urban heat island effect and minimize the impact of increasing heat temperatures. To (1) reduce the urban heat island effect, there is a plan for new capital construction to increase the solar reflectance of surfaces. This includes using light-colored pavements, coatings, and other materials when building. Furthermore, new development must increase the shading of surfaces by planting trees, comply with Climate Zone 6 measures for insulation to ensure improvements in energy efficiency, and use green/blue roofs or other landscape elements to maximize cooling (NYC Mayor's Office of Recovery and Resiliency 2019, 12-14). In order to (2) minimize the impact of

rising heat temperatures is to design an urban landscape based on forward-looking climate data. This means looking at data projections for temperatures from now to the 2020s, 2050s, and 2080s. This will be useful in developing infrastructure that is built to last well into the future rather than just for a few years. Evaluation measures on current infrastructure include looking at material change or structural integrity caused by excessive heat, the health and safety impacts of occupants, failure or reduced efficiency in electrical or mechanical systems, etc. Lastly, the strategies for minimizing impact will focus on areas of electric grid outages, failure in facility ventilation, and passive solar cooling and ventilation (NYC Mayor's Office of Recovery and Resiliency 2019, 14-16).

Asides from the rise in temperatures, increasing precipitation is also a call for concern for New York City. The "Climate Resiliency Design Guidelines" has developed measures for facing future challenges of stormwater management and impacts on the built environment from increased precipitation. Part of the resiliency plan is a (1) precipitation design adjustment for on-site stormwater systems. This means undergoing a plan of identifying the duration of the design event required using a 50-year intensity-frequency curve, conducting a sensitivity analysis, identifying design intervention to manage increased precipitation levels, and using appropriate DEP guidelines when designing. Possible design interventions include installing stormwater infiltration, protection of underwater utility, less impervious surfaces, etc (NYC Mayor's Office of Recovery and Resiliency 2019, 18-19). Similar to increasing temperatures, the other step for resiliency planning in increasing precipitation levels is (2) incorporating climate change projection into DEP drainage planning. It is important to build off the climate change projections or else any random upsizing of wastewater infrastructure can lead to a diminished level of service (NYC Mayor's Office of Recovery and Resiliency 2019, 20).

Lastly, sea-level rise consists of four parts when it comes to resiliency planning. The first step is (1) assess tidal inundation due to sea-level rise. This includes determining tidal inundation risk from sea level using the Flood Hazard Mapper. The map should then allow one to address the area's tidal inundation risk. If the site is not expected to be regularly inundated, the next step is to (2) address risk in the current flood plain. This includes determining the flood inundation risk from current coastal storms on the map. Then, a sea-level rise adjusted design flood elevation must be applied to the site. Step (3) is addressing risks in the future floodplain. To do so, using the Flood Hazard Mapper, determine if the site will be in a future floodplain in the 2080s or in 2100. Then, apply the sea-level rise adjusted design flood elevation. Lastly, (4) identify appropriate design interventions to site. Designs include permanent barriers, flood barriers, natural systems-based approaches, dry floodproofing, design redundant telecommunications conduit entrances, etc. (NYC Mayor's Office of Recovery and Resiliency 2019, 22-28).

### *Possible Improvements*

In order for the "Climate Resiliency Design Guidelines" to mitigate rising temperatures, increasing precipitation, and rising sea-levels, they need to be assessed with future data projections on climate change. For one, the plan should enforce the collection of reliable data to guide climate change prevention efforts. For example, to assess the impacts of rising temperatures city officials need to understand what the expected temperatures are in the next 20, 50 or 100 years. This provides the city with time to prepare for possible safety measures, thus creating a system that is resilient to such future impacts. This is true for rising sea levels and increasing precipitation. Despite how important it is to collect accurate climate change projections, a

finalized plan is not in place to ensure maps are up to date. For instance, sea-level rise is being analyzed against a flood map from 2015. Obtaining accurate and timely data is an important step that must be implemented and enforced within the guidelines of climate resiliency, in regards to preventing a future natural hazard. Furthermore, a city that changes environmentally like NYC in response to coastal development and sustainable practices, it is important to have fresh update information because it can make all the difference.

Between rising temperatures, increasing precipitation, and rising sea levels, the precipitation resiliency design is the only one that does not use GIS. The sea level resiliency design assesses tidal inundation and addresses risk in the current floodplain using the Flood Hazard Mapper. Meanwhile, the Heat Vulnerability Index Map is used for understanding the hazard of rising temperatures. The use of GIS is used properly and effectively for the two hazards. However, increasing precipitation can also benefit off the use of GIS. For instance, a map can be created using the information on the available stormwater systems, stormwater systems that need repair, and areas that need stormwater systems. This can be beneficial for resiliency planning by understanding which areas are highly vulnerable.

### **The Importance of GIS in NYC**

James D. Baker, President of ESRI, states “Climate change is a geographic problem, and we believe it takes a geographic solution.” GIS has the capability to teach the public in visual terms complex earth systems. More importantly, provides the necessary information to assess, plan, and implement tangible sustainable solutions. For example, around the world, GIS has fostered critical analyses on the environment thus spurring reforestation programs, engineering projects, and other sustainable management initiatives.

GIS can help communicate information in ways that words can't. ESRI states, "If a picture tells a thousand words, a map tells thousands of pictures" (Harder 2017, 4). Simply showing a map of flood zones and glacial retreat can inform people of upcoming climate change impacts, thus creating change. Maps are a second form of communication that can help one reach to people of different communities and transcend language barriers. This is especially important in NYC where each community has a plethora of different races and ethnicities. GIS is also an extremely helpful tool in spatial analysis. For instance, it can perform geo-referencing, or in other words, associate certain layers of information with geographic space (Harder 2017, 9). The integration of different data sets allows for an analysis of evaluating suitability and capability, estimating and predicting, interpreting and understanding (Harder 2017, 13). In a complex environment, such as NYC, it is important to have a platform that is able to integrate so much information and understand how they dynamically coalesce.

It is no secret that NYC is extremely rich in information, especially in comparison to other cities in the United States. However, after reviewing the information in recent policy plans, it is still not enough. There can certainly be more room for the use of GIS. I see three categories for improvement in NYC Government Maps – update information, organization, and public communication. A risk management strategy dedicated to the support and development of GIS can be extremely helpful for mitigating future climate change impacts. Furthermore, doing so can be a cost-effective strategy because a map is useful in strategizing, informing and managing risks. For every \$1 invested in hazard mitigation is \$4 saved (Damiano 2017, 14).

### **Risk Management Strategies:**

As stated, the “Climate Resiliency Design Guidelines” is limited in its use of GIS, but it has the capability to be extremely beneficial with updated and accurate data. The same goes for many of the other policies created by the NYC Mayor’s Office of Recovery and Resiliency. For instance, policies, such as OneNYC 2050, are also limited by outdated data. Meanwhile, organization management and leadership are other problems with GIS in NYC. There are too many maps and layers of city attributes that exist separately rather than on one map, thus making comparisons difficult. An effort to support public communication and education on GIS can also be beneficial for NYC. For instance, the public should have access to map-making tools when developing climate change resiliency plans for their homes, businesses, parks, and buildings.

#### *Updated Information*

Revision is necessary, especially with climate change creating both predictable and unpredictable impacts. For instance, flood maps in the United States, not only in NYC, need to be continually revised. FEMA is responsible for creating accurate maps so government officials, developers, and builders understand which areas are safe to build or need protection (NRDC 2017). If information is inaccurate or not up to date, communities will be at risk of flood exposure due to being misinformed. The first time FEMA truly mapped New York City was in 1983. Since then, only minor changes have been made. This can be seen by the 2007 and 2015 preliminary flood maps by FEMA. If a map is not properly assessed every 5 years, under FEMA guidelines, the flood risk is considered “unknown” (NRDC 2017). It is important to reassess maps because flood risk is not static due to changing land-use patterns and climate change impacts. For instance, rising sea levels and intense rainstorms each year change the intensity

and/or rate of impact on the current environment. Therefore, the environment we are looking at right now is not the same, in terms of resiliency, as it was 30 years ago.

Currently, there are FEMA map layers that predict flood zones based on previous storms and on future conditions based on climate change. For instance, currently, FEMA maps operate using a 1% annual chance flood (100-year flood) and 2% annual chance flood (500-year). This means maps are assessed by looking back in time on previous storm events to determine the size of the 100-year and 500-year floodplain. Meanwhile, there are also prediction maps of what NYC will look like in 2020, 2050, 2080, and 2100. However, funding must continue in GIS mapping in order to assess if current predictions of future NYC have merit. NYC is currently an example for the rest of the nation, especially in terms of flood mapping, therefore it is extremely important NYC continues to forge the path.

It is not only flood maps that not to be updated, but the NYC Department of Health and Mental Hygiene's Heat Vulnerability Index (HVI) does, as well. The latest update of the map was in 2015. A map for a hazard that is extremely fatal must be renewed or redone. New York City has been changing in green space, environmental protection, development in the last five years. Therefore, a map should reflect those changes. On another point, the HVI map also assesses a community's vulnerability based on local socio-economic conditions. Since the socio-economic condition of neighborhoods is also always changing, it is important to update a map using that current information, too. It is very valuable to assess a hazard on new information, especially when developing fair regulations and programs for specific vulnerable areas.

*Organization and Leadership*

NYC lacks a map template that contains multiple layers of information related to natural hazards. It also does not have a map that is automatically updated with relevant information as map layers. Unlike NYC government maps, the Open Accessible Space Information System (OASIS) is run by a nonprofit and is an open-source for data maps on the NYC environment and urban infrastructure. Unlike for-profit mapping sites, OASIS is available to anyone, including architects, students, community boards, non-profit companies, etc. Its mission is to grant the public access to information about the city. This type of GIS information is instrumental to organizations involved in the city's greening and planning communities.

Different from many NYC maps, the OASIS map integrates many different types of information and is updated frequently with new sets of information. It has partnered with the Wildlife Conservation Society to incorporate information from "The Manhattan Project," which includes information on ecosystems, soil types, etc. It also uses the City Planning Department's information on land use and ownership in NYC (Urban Omnibus 2018). The specific layers developed are land-use patterns, NYC park properties, state and federal open space, wetlands, recreational sites, community gardens, street tree locations, natural resource areas, waterfront access locations, living memorial projects, community resources, transit resources, aerial photos (1996-2010), infrared photography, and cemeteries. OASIS is also flexible enough to adapt and integrate new layers of mapping information into the data set. Therefore, OASIS is consistently evolving to the new changes the city has undergone.

If NYC can create a map similar to this, the map would be far more organized and reachable by the public. The public would no longer have to switch between maps in the NYC Map Gallery to analyze different sets of data. Although there are maps available with a lot of different layers of information, there is no overarching map that houses all this information. It

can be beneficial to create a map like this, especially for climate change risk management, because it would allow multiple layers of information to exist in one spot and be compared on a map for the public to see and use. It would also standardize which NYC maps are being used for mitigation practices since there are a series of maps used throughout the years that address climate-related information.

### *Community Involvement and Education*

A study was done in 2001 that researched the effects of GIS on an inner-city neighborhood in Milwaukee. The residents in the Metcalfe Park Residents Association were given GIS training and access to public information. Later, it was explored how GIS impacted the residents in community empowerment when equitable access to GIS was provided at the grassroots level. Results include success in introducing a community to the information and technology necessary for participatory empowerment in the civic process. For instance, the community was able to map residential land use and vacant lots (a sign of neighborhood deterioration). They also created a sanitation survey map and soon planned to create a crime map (Ghose 2001, 154-155). Overall, GIS was used as an influential and powerful to voice the community's concerns on current climate issues.

As seen, GIS can be instrumental in public communication in urban city areas, such as NYC. If GIS could be implemented at the grassroots level, especially in low-income areas, it could lead to meaningful participation from groups of people who are usually excluded from the planning process. This could lead to creative solutions and more available information. On assessing natural hazard impacts and analyzing possible solutions for local communities, the

NYC government can look at community planning groups for answers, too. Meanwhile, GIS can serve as an effective tool for demonstrating these neighborhood strategies.

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