Fall 12-23-2020

A Sea of Trouble: The Threat of Rising Sea Level in New York City

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Environmental Studies Thesis

Abstract

Sea levels have been rising steadily due to earth's increasing surface temperature, and they are becoming extremely detrimental to coastal areas, such as New York City. This paper addresses the negative impacts that sea level rise will have on coastal communities and psychological damage it may cause. Additionally, it will discuss sustainable design that will allow these communities to adapt to and mitigate the issue of sea level rise, as well as other policy recommendations to further combat this issue. The introduction illustrates the reality of the citizens of these coastal communities and how their homes and jobs are at risk of disappearance. Chapter one further addresses the causes of rising sea levels and temperature increases, as well as provides a synopsis of the levels and projections at our current rate of environmental change, based on data regarding ice melt, sea level rise, and superstorms. Chapter two provides an analysis of history of sea level rise in New York City and the policies already in place. Chapter three focuses on the sociological and psychological impacts on the communities and how detrimental climate change can be to their mental health Chapter four includes aspects of sustainable design that will allow coastal communities to combine adaptation and mitigation tactics to both protect against sea level rise and reduce their impact. Chapter five discusses policy recommendations that I believe could help prevent the loss of these coastal communities.
Keywords: sea level, environmental psychology, environmental design, history, policy, climate change, New York, adaptation, mitigation

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Introduction: When the Water Comes

At 3:30 p.m. on October 29th, 2012 Kim Joyce's power went out. Hurricane Sandy approached, but unlike the year prior when Hurricane Irene hit, no one came to her neighborhood to ensure their evacuation. Kim packed her bag, prepared to hunker down at her mother's house with her boyfriend, Billy, and her cats. Piling into the car, Kim and Billy decided to take one last spin around the neighborhood and see if anyone else had decided to evacuate. After just one lap, Kim noticed something odd. The water was higher than ever before, rapidly approaching her house. Billy and Kim rushed to put the cats in their travel crates, quickly realizing that this hurricane was far deadlier than either of them had anticipated. At 5:45 p.m. Kim texted her mother, scared. As she warned her mother of potential trouble, a wave crashed through the back wall of the house. Water poured into her home and the couple rushed to the front door. The water pressure was too strong, the door would not open. The boarded-up windows, one of the precautions Kim made sure to take before leaving, prevented any easy means of escape. Two small, roughly 18 inches, windows remained unobstructed. Kim slipped through, but Billy wouldn't fit. Kim hurried to the door, water swirling around her waist, but the water was too strong, and the door would not open. Kim could no longer touch the ground and as she treaded water Billy handed two of her cats through the small window. "Swim", he told her as she was forced to leave her boyfriend trapped in a house rapidly filling with water.

As the storm surge flooded in, Kim was at the mercy of the current. The force of the waves took one of her cats, debris bloodied her face, split her lip, and blackened her eye. Eventually, Kim managed to swim into another home on her street, the family pulling her up to safety and lending her a phone to call her mother. As far as she knew her pets were dead, Billy was dead, and everything she owned was gone. After a couple hours the storm had passed, and Kim had made it to her mothers. Kim thought she was dreaming when Billy walked in. He, too,

had thought her dead. Kim and Billy, ten hours later, bloodied and beaten, were reunited. Kim Joyce lost all nine of her cats, all of her possessions, her home, everything except her life.[1] Her story is not the only one like this. These horrific events are becoming increasingly common as climate change alters the natural world. A culmination of factors relating to climate change have caused the sea level on Earth to begin a disastrous ascent as ice caps melt.

In this thesis I will analyze sea level rise and how it is impacting New York City. I will explore sea level rise on a global scale before analyzing the relative sea level rise in New York City and its implications. Chapter 1 will provide the reader with quantitative information about sea level rise across the globe, including the causes and the predictions for the future. Chapter 2 will elaborate on historical sea level rise in New York City, further analyzing the impacts already felt by the residents of New York City and the existing policies regarding the issue. Chapter 3 discusses the sociological and psychological implications of sea level rise. Chapter 4 supplies the reader with a detailed analysis of various elements of sustainable design that are applicable to an urban setting, specifically New York City. Chapter 5 concludes the thesis with an examination of urban resiliency plans at the forefront of the fight against sea level rise as well as an overview of my policy recommendations designed to increase New York City's adaptation and mitigation of sea level rise.

Chapter 1: Sea Level Rise

Global warming is defined as the "persistent increase in the earth's mean surface temperature relative to long-term average conditions".[2] While there are many factors that contribute to this increased rate of warming, the primary source is said to be greenhouse gases. For the past 10,000 years or so the levels of these gases in our atmosphere have been relatively

[1] Joyce and Wolff, "I Survived Hurricane Sandy."
[2] Dawson and Spannagle, *The Complete Guide to Climate Change*.

stable. However, in the past 250 years they have increased by 40%. The main cause of these gases is human activity such as agriculture, deforestation, and the consumption of fossil fuels.[3] There has been an average warming of 0.8 degrees Celsius since the late 1800s.[4] While there is natural fluctuation in mean surface temperature, it is with high confidence that the scientific community attributes the warming to anthropogenic contributions.[5]

Numerous scientists agree that a consequence of global warming is extreme weather events. These events can manifest in many different forms. For example, destructive storms, floods and droughts, and temperature extremes.[6] The number of people affected by weather-related disasters tripled between 1970 and the 1990s, reaching up to 2 billion. Additionally, as the earth's surface temperature increases, so does the ocean temperature. There is a "high statistical correlation between ocean surface temperatures and tropical storm intensity".[7] Tropical storms typically require surface temperature of 26.5 degrees Celsius or greater to form. The storms are fueled by the heat energy given off by the ocean. As temperatures increase, as does the prevalence of tropical storms.[8] Another damaging weather event caused by global warming is flooding. Flooding is responsible for 40% of all extreme weather events. The occurrence of floods has been increasing in the last two decades. Floods can cause damage to infrastructure of communities as well as lead to loss of agriculture, livestock, and even human life.[9]

Rising sea levels are a pressing threat to the world, specifically coastal communities and islands. Approximately half of the world's cities with 500,000 people or more are 50 kilometers from the coast. Additionally, coastal population is about 2.6 times larger than that of inland

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[3] Dawson and Spannagle.
[4] Archer and Rahmstorf, *The Climate Crisis*.
[5] Dawson and Spannagle, *The Complete Guide to Climate Change*.
[6] Dawson and Spannagle.
[7] Dawson and Spannagle.
[8] Dawson and Spannagle.
[9] Dawson and Spannagle.

areas.[10] Though this thesis focuses on coastal communities in New York City, April Reese states in *Sea Level Rise*, "Sea levels are expected to rise across 95% of the ocean".[11] This statistic illustrates the breadth of the issue at hand. A large portion of the world's population live by the ocean, and a large portion of the ocean will be encroaching inland.

These rising sea levels are a result of ice melt, caused by the increasing surface temperature of Earth. The polar regions of the world contain the majority of ice and snow. Through a process called the albedo effect, this light-colored ice and snow reflect solar energy back into space. This provides a cooling effect that will be lost as these continue to melt.[12] As this temperature rises approximately 90 percent of is released into the ocean.[13] Like many compounds, when water increases in temperature it expands, according to R. Steven Nerem, a professor of aerospace engineering sciences at the University of Colorado Boulder. However, this phenomenon accounts for only one third of sea level rise.[14] The remaining two thirds can be attributed to melting mountain glaciers and ice sheets in Greenland and Antarctica.[15] The majority of ice comes from the poles of our Earth, the Antarctic and the Arctic, where Greenland is located.[16] Additionally, these areas are experiencing the effects of soot deposits from industries in Asia, Europe, and North America. The soot darkens the ice, inhibiting the aforementioned albedo effect, the reflection of solar energy back into space, and contributing to global warming.[17] As temperatures rise, this ice is melting. The temperature is rising at an alarming rate. For example, "In the past twenty years, the Arctic has warmed by more than three

[10] Dawson and Spannagle.
[11] Reese, "Sea Level Rise."
[12] Miller, Miller, and Spoolman, *Living in the Environment*.
[13] Reese, "Sea Level Rise."
[14] Reese.
[15] Reese.
[16] Goodell, *The Water Will Come*.
[17] Miller, Miller, and Spoolman, *Living in the Environment*.

degrees Fahrenheit, roughly twice as fast as the global average".[18] This data was extrapolated from the satellite, Jason-3 (part of the Joint Altimetry Satellite Oceanography Network) and its predecessors. Jason-3 is used to track changes in sea level across the planet.[19] Since the poles are where the ice is located, this is extremely problematic. We are seeing the repercussions of this, "According to NASA, Greenland is losing three times as much ice each year as it did in the 1990s".[20] To put this into perspective, in 2016 climate scientist William Colgan estimated that approximately 8,000 tons of the land-based ice in Greenland melts per second.[21] This increase in the rate of ice loss is detrimental to coastal cities. If this rate continues it could be catastrophic. Already, "Between 2012 and 2016 alone, a trillion tons of ice vanished—enough to make a giant ice cube that is six miles on each side (that's taller than Mount Everest)".[22] The ice did not, as Goodell phrases it, "vanish". It melted, raising the level of water in our oceans. In the last 25 years "the climate-change–driven acceleration of global mean sea level" was 0.084 ± 0.025 mm/y2.[23] By 2100 global sea level could rise anywhere from one foot to over eight feet.[24]

The Antarctic is another area of concern, with the rate of ice shed tripling in the last decade. West Antarctica in particular is vulnerable to climate change. If West Antarctica were to collapse it would add over 10 feet of sea-level rise alone. Interestingly enough, this would not cause sea level to rise predominantly in the Antarctic, but rather across the world. These ice sheets are so massive they actually exert a gravitational pull on the surrounding water. This pull is weakened as the ice sheets melt, and sea levels drop. The land also rises slightly, freed of the weight of the ice. These effects diminish further away from the ice sheets, which is why those

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[18] Goodell, *The Water Will Come*.
[19] Reese, "Sea Level Rise."
[20] Goodell, *The Water Will Come*.
[21] Miller, Miller, and Spoolman, *Living in the Environment*.
[22] Goodell, *The Water Will Come*.
[23] Nerem et al., "Climate-Change–Driven Accelerated Sea-Level Rise Detected in the Altimeter Era."
[24] Goodell, *The Water Will Come*.

places experience rising sea levels.[25] The 2014 Intergovernmental Panel on Climate Change report outlined a series of potential consequences of a 3-foot rise in sea level. These effects include; the destruction or degradation of roughly, "least one-third of the world's coastal estuaries, wetlands, coral reefs, and deltas"[26] intensive damage to fisheries around the world, flooding and erosion in countless communities. Some of the areas the report claimed were most at risk were low-lying, highly dense countries, such as Bangladesh. Bangladesh demonstrates increased risk, as it is one of the world's poorest nations. Another area the IPCC report drew attention to was low-lying islands and gently sloping coastlines, that can be found along the coast of the United States, as well as in the islands of the Pacific Ocean and Caribbean Sea. The latter area contains roughly 5 percent of the world's population. Finally, the IPCC report emphasizes the risk that rising sea levels present to coastal cities throughout the world, including New York City.[27] Changing shorelines are not the only risk of rising sea levels. Ice melt, along with higher sea levels, can have other consequences, such as "ice melt cooling of the North Atlantic and Southern oceans increases atmospheric temperature gradients, eddy kinetic energy and baroclinicity, thus driving more powerful storms".[28] These powerful storms pose risks to coastal cities as well as places more inland. The disruption of weather patterns is a potentially deadly side effect. Storm surges have the potential to become even more devastating when combined with higher sea levels. A storm surge is the rise in sea level above the predicted level during a storm. The further inland the coastline is and the more water there is, the more damaging the storm surges could be. Not only could this cause loss of buildings, it could cause loss of life.

[25] Schwartz, "Underwater."
[26] Miller, Miller, and Spoolman, *Living in the Environment*.
[27] Miller, Miller, and Spoolman.
[28] Hansen et al., "Ice Melt, Sea Level Rise and Superstorms."

Sea level rise is not an issue that can be immediately resolved. For instance, even if greenhouse gas emission disappeared completely, sea level rise has already been set in motion from the warming that has already taken place. An estimated 200 million people, as well as hundreds of trillions of dollars in infrastructure are at risk of coastal flooding. Research suggests that these estimates might be conservative. Without adaptation, at the world's current economic trending, these risks will continue to rise.[29] The ocean responds slowly to increases in temperature, meaning the warming that has already occurred will cause sea level rise for centuries to come.[30]

By 2050 the majority of the world's population will live in cities near deltas or other coastal areas.[31] New York City, as a coastal urban setting, is at significant risk from rising sea levels. The East Coast of the United States faces sea level rise projections that exceed the global average. This can be attributed to multiple factors, including "glacial rebound, changes in ocean currents, and groundwater extraction".[32] Compared to levels in 1950 the sea level off of New York's coast is nine inches higher, with a rapid acceleration in the last 10 years, and since 1900 it has risen nearly one foot.[33] This is largely due to the expansion of the water. Levels are now rising at a rate of one inch per year. This increase in sea level is predicted to continue to rise. Scientists predict another six inches of rise in the next 14 years.[34] Scientists have also predicted that, by the end of the century, levels could range from 18 inches to 50 inches higher. There are multiple risks attached to sea level rise, perhaps the largest of which is flooding. New York state as a whole is suffering from this. Since 2000 flooding is 247% worse in some areas of the state.

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[29] Church et al., *Understanding Sea-Level Rise and Variability*.
[30] Reese, "Sea Level Rise."
[31] Aerts et al., *Climate Adaptation and Flood Risk in Coastal Cities*.
[32] Schedel and Schedel, "Analysis of Variance of Flood Events on the U.S. East Coast."
[33] SeaLevelRise.org, "Sea Level Rise Causes."
[34] SeaLevelRise.org.

This is due to storm surges. During a hurricane, even one that remains off the coast, a couple extra inches of sea level can rise and cause destructive flooding.[35] In 2012 Hurricane Sandy hit New York. This storm was incredibly destructive, causing approximately $19 billion worth of damage and 43 deaths.[36] However, the damage was intensified by the increased sea levels. Without the rising levels, the 9.5-foot surge would have been much lower.[37] Residents in New York City are projected to suffer due to this sea level rise. Currently there are "5,592 residential properties already at risk from repeated tidal flooding, by 2033 that number will increase to 8,194 as sea levels rise".[38] New York City released a Lower Manhattan Resilience Study in 2019 that illustrated the future risk areas for the borough. 37% of buildings in Lower Manhattan are vulnerable to storm surges. If the levels rise the predicted 6 feet by the end of the century then nearly half of Manhattan properties will be at risk, with 20% of streets exposed to daily tides.[39] Additionally, sea level rise can cause destabilization in buildings and destroy underground utilities and subway lines.

The United Nations "Millennium Ecosystem Assessment" discusses the services provided by the Earth's ecosystems, humanity's reliance on the ecosystems, and the transformation of the ecosystems due to human involvement. The four types of ecosystem services are; provisioning services (i.e. water, food, timber), regulating services (i.e. water quality and climate health), cultural services (i.e. spiritual and recreational benefits), and supporting services (i.e. nutrient cycling and photosynthesis)[40]. Humanity is dependent on these four ecosystem services to fulfill what are known as the constituents of well-being. These

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[35] SeaLevelRise.org.
[36] Afeworki et al., *Flood Management Infrastructure in a Changing Climate*.
[37] SeaLevelRise.org, "Sea Level Rise Causes."
[38] SeaLevelRise.org.
[39] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[40] Millennium Ecosystem Assessment (Program), *Ecosystems and Human Well-Being*.

include; material for a good life (i.e. food, water, shelter, goods, etc.), health (i.e. clean air and water), good social relations (i.e. social cohesion and community), security (i.e. access to resources and safety), and freedom of choice (i.e. means to achieve goals).[41] In conjunction with detailing the influence ecosystems have on the human experience, the assessment emphasizes the importance of recognizing human involvement in the ecosystems. Humans play a role in these systems and that human behavior can act as a driving force for the natural world. Conditions separate from the environment, such as social, economic, and cultural aspects of human life can impact humanity's ability to achieve the five constituents of wellbeing.[42] The assessment also illustrates the idea that the natural world possesses intrinsic value. Intrinsic value is value that exists separate from anything else. Put more simply, intrinsic value is the value that ecosystems and species exists outside the benefit they can serve to humanity.[43] It is imperative to keep this intrinsic value in mind when making decisions regarding ecosystems. Both the ecosystem services that humankind relies on, as well as the intrinsic value of species and ecosystems, are necessary to consider when addressing sea level rise. Comprehension of the issue would be incomplete if these aspects were not present in one's mind.

Chapter 2: New York City's History with Sea Level Rise

Sea level rise in New York City is not a new phenomenon. In the past, New York City has experienced extreme storms and the flooding that accompanies them. To date, the city has managed the damage. However, sea levels are projected to continue rising, and current measures will no longer be sufficient. New adaptation and mitigation tactics are necessary for New York City to continue to thrive. The citizens of this region are known for being tough, and the city is

[41] Millennium Ecosystem Assessment (Program).
[42] Millennium Ecosystem Assessment (Program).
[43] Millennium Ecosystem Assessment (Program).

no different. NYC has withstood many disasters thus far and will remain one of the most resilient cities.

In a study conducted by the National Academy of Sciences, scientists studied the changes in coastal flooding in New York City. Since the observational record only dates back to 1821, which does not provide very comprehensive data, the scientists estimated the effect of Relative Sea Level Records (RSLR) since the year 850. To do so, they measured foraminifera and bulk sediment levels in salt marsh sediment samples from two locations, the Cape May Courthouse in New Jersey and Leeds Point.[44] They combined the data from these two locations to create a reconstruction of regional relative sea level records. They also utilized thermodynamic and kinematic state variables from 850-2005 to create synthetic tropical cyclone data sets[45]. With this data the study examined the peak storm surge height for each synthetic storm.[46] The results show that flood heights have increased in the New York City region from the pre-anthropogenic era to current times. This is due to changes in the RSLR as well as an increase in the extremity of the tropical cyclones.[47] This combination of factors shows a higher risk of coastal inundation in New York City. Based on the RSLR from the proxy sea level record developed in the study, the storm surges shown in the surge models illustrates that flood heights at the Battery in NYC are significantly greater in the anthropogenic era (current times).[48] The scientists identified an approximate 1.24-meter increase in mean flood heights, with a 99% confidence level.[49]

New York City is no stranger to large storms. Hurricanes and nor'easters frequently batter the city leaving varied forms devastation behind. These two types of storms are

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[44] Reed et al., "Increased Threat of Tropical Cyclones and Coastal Flooding to New York City during the Anthropogenic Era."
[45] Reed et al.
[46] Reed et al.
[47] Reed et al.
[48] Reed et al.
[49] Reed et al.

historically responsible for the most damage in the New York City region.[50] This is for a number of reasons. Areas of New York City, as well as coastal Long Island, lie within 5 meters of the mean sea level. This increases the vulnerability of these areas to storm surges, which occur as a result of both hurricanes and nor'easters.[51] A storm surge is defined as the, "anomalous rise of water above predicted astronomical tides".[52] Storm surges are created and exacerbated by the wind patterns of a storm, as well as the path of the storm and the geomorphology of the coast. To a smaller extent, reduced atmospheric pressure from the storm causes a small rise in the ocean surface. The combination of these factors determines the force of a storm surge.[53] The damages caused by the surge are also dependent on a number of factors. These include the intensity, frequency, size, and duration of the storms that hit the area and the base water level, also referred to as the rate of relative sea level rise (RSLR). As sea level rises, the intensity of storm surges does as well, and thus the risk they pose to coastal communities.[54] This region also is home to a shallow section of the continental shelf. This, along with the southward bend from Long Island to New Jersey, creates a funneling effect towards the water of New York City. This is especially prevalent when low-lying winds from the east occur. This specific combination of factors exacerbates storm surges in the area. The coastal marsh environment of areas of the region can also worsen the effects of flooding.[55] This, in conjuncture with the rising sea levels, will cause many issues for the NYC area. The American Metrological Society published a journal article analyzing storm surges in the NYC region from 1959 to 2007. The authors discuss "minor-surge events" and "moderate-surge events". These are classified as 0.6-1.0 m and >1.0 m, respectively,

[50] Aerts et al., *Climate Adaptation and Flood Risk in Coastal Cities*.
[51] Colle, Rojowsky, and Buonaito, "New York City Storm Surges."
[52] Reed et al., "Increased Threat of Tropical Cyclones and Coastal Flooding to New York City during the Anthropogenic Era."
[53] Reed et al.
[54] Reed et al.
[55] Colle, Rojowsky, and Buonaito, "New York City Storm Surges."

above the mean high water at the Battery, on the southern tip of New York City.[56] If sea levels are to rise, the threshold for flood events decreases, leading to an increase in the number of damaging events. For example, "If one increases sea level at the Battery by 13, 25, and 50 cm, the number of moderate-flooding events during the 1997–2007 period increases to 4, 16, and 136 events, respectively.".[57] This data illustrates the potential risks New York City faces from sea level rise. Regardless of the frequency of storms, a rise in sea level will create the opportunity for destruction, even from milder storms. Hurricanes can cause higher storm surges than nor'easters, but they typically are much shorter storms. With the increase in sea level, nor'easters could produce flooding comparable to a weak hurricane. Nor'easters typically span over several days, which means storm surges at high tide will be unavoidable. New York City is on track to have increased flooding in their communities.[58]

Flooding, as explained by the Intergovernmental Panel on Climate Change's (IPCC's) Fourth Assessment Report, will continue to grow as a problem for coastal settings. The IPCC states that it is imperative that governments implement adaptation strategies that parallel mitigation efforts if these risks are to be adequately addressed.[59] Floods are a complex and destructive issue, with many characteristics that can change the impact of the flood. Flood risk specifically is, "the probability of flooding multiplied by the potential consequences, such as economic damage or loss of lives".[60] This is a basic definition, with other characteristics such as depth, extent, duration, and flow velocity of the flood playing into the level of destruction. Additionally, exposure characteristics can increase a flood's impact. If areas prone to flooding

[56] Colle, Rojowsky, and Buonaito.
[57] Colle, Rojowsky, and Buonaito.
[58] Aerts et al., *Climate Adaptation and Flood Risk in Coastal Cities*.
[59] Aerts et al.
[60] Aerts et al.

are densely populated or contain land or assets of value, then the economic and social impact is higher. Additionally, the communities in flood-prone areas can be at increased risk in areas with higher levels of vulnerability, such as lower income neighborhoods where evacuation may not be an option and economic impacts hit harder.[61]

Past weather events, such as Hurricane Sandy, have pounded New York City, and the flood effects will continue to worsen. Sandy, "caused an estimated $50billion of damage and destroyed at least 650,000 houses in 2012, largely because of flooding from a 3- to 4-meter storm surge and large waves"[62] The storm also flooded parts of the subway system in 2012, as did a nor'easter in December 1992. At the Battery water levels peaked at 2.5 m (8 ft) above mean sea level. Even though the sea level was only above the city's seawalls for a matter of hours, it resulted in flooding of, "the NYC subway and Port Authority Trans-Hudson (PATH) train systems at Hoboken, New Jersey, thus precipitating a shutdown of these transportation systems for several days.".[63] The transport systems in New York City are incredibly vulnerable to flood events. The majority of tunnels and rail point of entry are within 10 feet of sea level. This is also true of all three major airports in the NYC metropolitan area. If flood levels were 1 to 2 feet greater than the levels in the 1992 nor'easter, the damages to these areas may have resulted in loss of life, as well as an even longer shutdown of systems.[64] In the 1995 Metro New York Hurricane Transportation Study the U.S. Army Corps of Engineers reported that a Category 3 hurricane, worst case scenario, could cause "a surge of up to 25 feet at JFK Airport, 21 feet at the Lincoln Tunnel entrance, 24 feet at the Battery, and 16 feet at La Guardia Airport.".[65]

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[61] Aerts et al.
[62] Reed et al., "Increased Threat of Tropical Cyclones and Coastal Flooding to New York City during the Anthropogenic Era."
[63] Colle, Rojowsky, and Buonaito, "New York City Storm Surges."
[64] Gornitz and Rosenzweig, "Severe Storms and Sea Level Rise in New York City."
[65] Gornitz and Rosenzweig.

New York City has found issues in managing stormwater during heavy rains. The city primarily uses a combined sewer overflow system (CSO). This system has limited capacity, leading to an overflow and discharge of tens of millions of gallons of contaminated water. This contaminated water is dumped into rivers and streams, leading to eutrophication.[66] During storms with heavy precipitation the storm sewers overflow. This stormwater enters the sanitary sewers, and this combined sewage and storm water is released into local waterways. This is a major problem for New York City, as this causes hazardous waste such as coliform bacteria, heavy metals, and organic matter to enter their water systems. The Environmental Protection Agency urges green infrastructure in cities to help alleviate the quantity of water that enters the CSO systems. This could be achieved through permeable surfaces or other design elements that help prevent runoff.[67]

New York City's government has begun to address the issue of sea level rise and its implications. There have been numerous policy initiatives taken in recent years to combat climate change and sea level rise. In 2011 New York assembled the New York State Sea Level Risk Task Force. In their report the task force assessed the impacts of sea level rise and highlighted the most pressing consequences. These included, "increased frequency and intensity of severe flooding and storm surge damage, not only to communities and infrastructure, but also to critical ecosystems that buffer against floods, protect drinking water and provide habitat for important species; increased erosion of beaches and bluffs; inundation of low-lying areas; saltwater infiltration of surface waters and aquifers; and possible compromise of low-lying sewage, wastewater, transportation, communication, and energy infrastructure and systems.".[68]

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[66] McPhearson, Hamstead, and Kremer, Peleg, "Urban Ecosystem Services for Resilience Planning and Management in New York City."
[67] McPhearson, Hamstead, and Kremer, Peleg.
[68] "Sea Level Rise."

New York City Mayor de Blasio released a resiliency plan in 2019 with a number of initiatives to combat rising sea level in New York City. He outlined a range of options, one of which the potential extension of the Lower Manhattan coastline. It would extend about 500 feet, which is approximately two blocks. This new extension would be elevated, with the highest points at least 20 feet above sea level.[69] Not only would this help to protect against sea level rise, it would also provide a barrier against flooding and storm surges. The Office of Recovery and Resiliency as well as the New York City Economic Development Corporation are in the process of creating a Financial District and Seaport Climate Resilience Master Plan. The design for this extension will be included.[70] If all goes according to plan, the process will begin in 2021 and the first phase project will be released. Though this idea has not been approved yet, it is only one of numerous ways the NYC local government plans to combat this issue.

Mayor de Blasio and NYC will be allocating $500 million towards four projects to reinforce against sea level rise in Manhattan. The focus areas are "the Seaport, parts of the Financial District and Two Bridges neighborhoods".[71] These projects will begin construction between 2019 and 2021. The first project, in the South Seaport area, extending to parts of the Financial District as well as the Two Bridges Neighborhood, includes the $3.5 million creation of dams and pre-deployed HESCO barriers. These were constructed prior to the 2019 hurricane season, though they are not a permanent solution. These are temporary solutions until a more permanent solution is available.[72]

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[69] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[70] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[71] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[72] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."

Battery Park City is the next focus, with the Battery Park City Authority implementing $134 million worth of coastal protection projects. These aim to adapt to the sea level rise as well as attempt to mitigate the effects. Planning began in 2018 and construction was scheduled to begin in 2020. The Battery is another focus of climate resilience initiatives. $165 million is being invested in elevating the wharf to allow the integration of a protective barrier. This may consist of a berm on the back of the park. NYC is dedicated to both retaining the nature of the park while also protecting the shoreline. Construction is scheduled to begin in 2021.[73] The final leg of the sea level rise projects takes place in the Two Bridges Neighborhood, where the New York City Economic Development Corporation has designed an "integrated flood protection system composed of permanent barriers and deployable or 'flip up' protections that will protect view corridors and public access".[74] This system will cost nearly $200 million and will begin in 2021.

The state government of New York City has been forced to address the issue of climate change, and its implications such as sea level rise. In 2011 New York released ClimAID, a report that outlined the projections of sea level rise along New York's coastlines. It was supplemented in 2014. In the updated ClimAID the known components of sea level rise were taken into account. These additional details were calculated with climate modeling and computing and reflecting observational data. Both Hurricane Irene and Hurricane Sandy were included in this data, in order to understand how extreme weather events impact the coastline with increased sea levels. New York's Department of Environmental Conservation (DEC) claims that these projections are the most accurate predictions at this time.[75] Additionally, in 2014 Governor

[73] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[74] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."
[75] "Sea Level Rise."

Cuomo signed the Community Risk and Resiliency Act (CRRA). This act has five main parts, first of which is sea level projections. Second, the consideration of sea level rise, storm surge, and flooding in facility siting, permitting, and funding. The third amends the Smart Growth Public Infrastructure Policy Act to include mitigation. Fourth, model local laws to include risk analysis of sea level rise hazards. And, fifth is the development of natural resources and natural process use to enhance resiliency.[76]

Sea level rise in New York City poses a number of threats. Flood risk and storm surges are projected to worsen as the sea level rises. The impacts this will have on NYC communities ranges across numerous disciplines. Not only will vulnerable communities experience mental consequences surrounding the lack of security they feel for their homes and livelihood, but the economic impacts could seriously damage the robust economy of New York City. Updates to infrastructure and design across the city are needed in order to adapt to and mitigate these rising water levels. As climate change worsens and sea level rise, New York City finds itself in a progressively worsening precarious position.

Chapter 3: Social and Psychological Effects

Vulnerability in disaster-prone areas is not evenly distributed. Through a myriad of factors, including human and nonhuman influences, flood events can become even more traumatic for certain communities.[77] Hurricane Sandy, for example, battered the coastline of New York City in October of 2012. While the windspeed of Sandy was less than historically catastrophic storms, such as Hurricane Katrina that devastated the Mississippi Gulf Coast in 2005, other factors fueled the destruction of Sandy. The primary cause of Sandy's force was its massive diameter, over 800 miles wide. When combined with northern winter weather systems,

[76] "Sea Level Rise."
[77] Gould and Lewis, *Twenty Lessons in Environmental Sociology*.

it created an incredibly destructive storm.[78] The flooding along the coast of New York City and parts of New Jersey was unprecedented.[79] Sandy wreaked havoc upon New York City's transportation and electrical infrastructure. The physical implications of the storm, however, were felt most by the vulnerable communities.

Vulnerability is typically categorized by disaster sociologists into physical vulnerability or social vulnerability. Physical vulnerability is based on location, on varying scales. Residents of coastal cities have increased vulnerability to floods than those of inland cities. Within cities, those who live in low-lying areas or directly on the shoreline have increased physical vulnerability. In "Understanding Disaster Vulnerability" Nicole Youngman explains that sometimes physical vulnerability is referred to as "unsafe conditions".[80] Social vulnerability, conversely, is, "rooted in social inequalities, that affect potential disaster victims' ability to escape, survive, and/or 'bounce back' from a disaster,".[81] These include; race, gender, socioeconomic status, age, disability, etc. Youngman refers to these as "preexisting conditions".[82] New York City has a complex combination of the two types throughout its neighborhoods. For example, Staten Island neighborhoods of working and middle-class families have increased social vulnerability. This area also experiences physical vulnerability, due to a development boom that destroyed most of its natural wetlands, increasing storm surge potential.[83] After Sandy hit the media focused primarily on damage to transportation and infrastructure in wealthy neighborhoods, while lower-income communities struggled for help. Youngman explains that, "public housing residents were hit especially hard, with 402 buildings

[78] Gould and Lewis.
[79] Gould and Lewis.
[80] Gould and Lewis.
[81] Gould and Lewis.
[82] Gould and Lewis.
[83] Gould and Lewis.

comprising 35,000 housing units damaged by the storm.".[84] Social and physical vulnerability often go hand in hand, because low-income residents typically do not have the means to move out of more physically vulnerable areas.[85] Youngman introduces the concept of "hurricane amnesia" as a factor that might increase vulnerability in coastal communities. This is when the memories of devastation due to physical disasters fade and, combined with the push for economic growth that typically follows disasters, increases the population density of an area and thus, its vulnerability.[86]

Climate change has well known physical dangers to humanity, natural disasters can be deadly and effects damaging to communities. However, physical health is not the only risk of climate change. Since 2000, there has been a 46% increase in climate-change caused disasters.[87] According to the International Journal of Mental Health Systems, as these disasters are growing in "frequency, intensity, duration, and complexity of climate change effects is on the rise and thus climate-related mental health outcomes are also increasing".[88] The blanket term "mental health" includes not only mental illness, mental problems, and mental disorders, but also refers to mental and psychological wellbeing and resilience.[89] This is essentially one's mental state and their ability to handle climate change related issues. This increased prevalence of natural disasters is leading to stress and anxiety, as well as others. The American Psychological Association and the nonprofit group, ecoAmerica released a report claiming that along with stress and anxiety, climate change is linked to other issues such as post-traumatic stress disorder and depression.[90] While climate change in general is causing increased mental health issues,

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[84] Gould and Lewis.
[85] Gould and Lewis.
[86] Gould and Lewis.
[87] Hayes et al., "Climate Change and Mental Health."
[88] Hayes et al.
[89] Hayes et al.
[90] "Climate Trauma."

certain natural disasters can yield specific outcomes. Large climate-change related events may cause, "heightened anxiety levels, feelings of impending doom, hopelessness, and fatalism that can be triggered by approaching extreme events or associated weather warnings; and which may also be amplified due to the perceived risk of subacute, environmental changes like rising temperatures and episodic droughts".[91] These highly traumatic events are hard to prepare for and cause lasting damage, both physical and mental. Additionally, slower occurring issues, like sea level rise, are creating a prevailing sense of dread and hopelessness.[92]

The Giddens Paradox states, "since the dangers posed by global warming aren't tangible, immediate or visible in the course of day-to-day life, many will sit on their hands and do nothing of a concrete nature about them. Yet waiting until such dangers become visible and acute—in the shape of catastrophes that are irrefutably the result of climate change—before being stirred to serious action will be too late".[93] Not only is this way of thought damaging to the environment, because climate change is very real, it can exacerbate mental wellness issues. There are three categories into which climate change events fall into. These are "acute (flooding, hurricanes, etc.), sub-acute (pervasive drought), and chronic (rising sea-level, increasing temperatures.[94] This thesis focuses on a chronic issue, rising sea-level, but all of the issues can be detrimental to psychological health. For each climate hazard there are both direct and indirect psychological consequences. Direct consequences include the trauma related to extreme events, such as floods, hurricanes, fires, droughts, etc. These consequences affect the individual and correlate directly to the event. Indirect psychological consequences still affect the individual, but stem directly from consequences of the event. The social, economic, and environmental disruptions caused by a

[91] Hayes et al., "Climate Change and Mental Health."
[92] Hayes et al.
[93] Hayes et al.
[94] Hayes et al.

changing climate can be just a mentally damaging. These are a result of a direct consequence of a climate change, such as famine, civil conflict, displacement, and migration.[95] Initially, after a traumatic event one experiences terror, anger, shock, among other extreme emotions. As these feelings begin to lessen, they can be replaced by post-traumatic stress disorder, due to, "personal injuries, loss of a loved one, damage to or loss of personal property, or the loss of livelihood.[96] A prime example of this is found in survivors of Hurricane Katrina, in which "suicide and thoughts of suicide more than doubled after the storm. Additionally, one in six people met the diagnostic criteria for PTSD, and 49 percent developed an anxiety or mood disorder such as depression".[97] These statistics are staggering as are becoming more common as climate change worsens. New York City, with the rising sea levels, is becoming more vulnerable to flooding and storm surges, thus becoming more vulnerable to the mental risks that accompany these events.

Deteriorations in mental health do not stem solely from extreme events. These issues can also develop as gradually as some other types of climate change issues. For example, in the span of a couple decades, these incremental climate changes, such as rising temperature and sea level rise, can alter landscapes, damage food and water resources, shift the conditions for agriculture, destabilize infrastructure, increase rates of violence and aggression, and cause significant financial and social stress by displacing entire communities.[98] This affects occupations and quality of life, as well. New York City, facing rising sea levels, is vulnerable to this. As sea levels rise, flooding and storm surges also increase. This causes a type of domino effect, as coastal areas face submergence due to hurricanes and floods, there occurs a "migration of

[95] Hayes et al.
[96] "Climate Trauma."
[97] "Climate Trauma."
[98] Hayes et al., "Climate Change and Mental Health."

population, regionally and internationally".[99] These consequences, while less immediate, are no less damaging to one's psychological well-being. Displacement of entire communities can rupture social ties and make citizens feel lost. This environment can be very mentally damaging. People run the risk of losing social support structures. They may feel a loss of control and autonomy. Additionally, this loss of their homes can create "feelings of helplessness, fear, and fatalism".[100] This hopelessness and despair are for a number of reasons. Firstly, these people are losing their homes and their sense of community. Additionally, the actual root cause of these feelings, climate change, can seem incredibly daunting. Such a big issue appears to be intangible and as an individual one may feel insignificant. These types of feelings can crush any hope these people may have.[101] The threat of potentially losing their home, loved ones, communities, and possessions looms over the heads of many residents in a high-risk area. This can lead to the development of bereavement, which is a grief reaction, or depression. Along with depression, citizens forced to migrate can experience acculturation stress, due to an unfamiliar environment. This can create psychiatric disorders.[102] These disorders can range from anxiety to depression. Additionally, "migrants are more likely to suffer from schizophrenia than the host population or the population of their origin".[103] A significant factor as to why climate related migration is so psychologically damaging is the fact it is forced by strife. Individuals forced to migrate due to these types of reasons are more likely to develop mental diseases than voluntary migrants. Being stripped of their home and all the memories associated takes a toll on a person. For many, home is a safe space that they feel extremely connected to. The loss of this place of comfort and safety

[99] Padhy et al., "Mental Health Effects of Climate Change."
[100] "Climate Trauma."
[101] Hayes et al., "Climate Change and Mental Health."
[102] Padhy et al., "Mental Health Effects of Climate Change."
[103] Padhy et al.

is referred to as “Solastalgia”.[104] Solastalgia can describe the consequences and hardships one facets after a loss of this personal environment. Not only does this affect the individual, but the community as a whole. There comes a decrease in the cohesion of communities as people are forced to move away. This loss of the community contributes to a loss of sense of belonging. Not only is a general sense of identity lost, but cultural integrity is at risk as well. The importance of a place of solace is crucial to people, and the lack of this environment undermines their livelihoods.[105]

Physically, socially, and mentally vulnerable communities will continue to be at risk as climate change and sea level rise worsen. It is important to focus on adaptation and mitigation strategies, but also governments must be aware of the skewed distribution of risk in their communities. Additionally, while many of these types of mental health issues can be caused directly by climate aggravators, it is important to remember that some psychological problems can predate the changes in climate. While these may not have formed due to climate issues, they can certainly be worsened by the environmental changes.[106] However, it is not a hopeless cause to combat these psychological impacts. Researchers use the term “resilience”. By this they mean increasing awareness regarding these issues. This is both for the citizens experiencing the issues and the first responders who attempt to help in the wake of disasters. Along with combatting the unequal distribution of risk, communities can expand mental health programs to better accommodate citizens[107]. Later chapters will outline potential sustainable design features as well as other policy recommendations, which will allow communities and governments to protect themselves and future generations from sea level rise.

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[104] Padhy et al.
[105] Hayes et al., “Climate Change and Mental Health.”
[106] Hayes et al.
[107] “Climate Trauma.”

Chapter 4: Sustainable Design

Sea level rise, even if all environmentally detrimental practices were halted today, will continue to be an issue for global communities for many years to come. Thus, coastal cities must develop strategies throughout various scales of design. These strategies can target a single site and aspects of a structure or focus on a larger scale reach strategy, involving many different sites and land uses. The approach can be "gray", "green", or a hybrid of the two. Gray infrastructure is typically permanent; however, the structures need maintenance and have high installation costs. Another detriment to gray solutions is the disruption of ecological systems they typically cause. Green solutions, on the other hand, combine ecological principles and flood protection tactics to stabilize shorelines, protect against floods, and enhance habitats. The downside to green solutions is their temporary nature and extensive upkeep, as they are vulnerable to erosion.[108] A combination of the two strategies may be utilized as well. The most appropriate design strategy depends on a number of factors, one of which is the geomorphology of the site. New York City is made up of many different types of land, however this chapter identifies nine different types of geomorphology in the New York City limits and will explore the possible structures that could maximize adaptation and mitigation in these areas.[109] Another factor to consider is the current land use of a site, whether it be industrial, residential, or something else. Land use in New York City can be divided into eight different categories, and some design features integrate much more appropriately in certain zones.[110] This chapter will identify and analyze the various combinations of sustainable design tactics that are possible to implement in New York City.

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[108] Al, *Adapting Cities to Sea Level Rise*.
[109] The Department of City Planning of New York, "Urban Waterfront Adaptative Strategies."
[110] The Department of City Planning of New York.

New York City boasts approximately 520 miles of coastline that is home to numerous businesses, homes, and ecosystems. The shoreline was analyzed in a study done by the New York City Department of City Planning. The study explains that coastal geomorphology is a composite of geologic landforms, such as the glacial history, slope, and elevation of an area, shoreline condition and wave exposure.[111] Put simply, geomorphology is an analysis of coastal landform; how they have changed over time and by what processes they have undergone these changes. These factors all impact how a site will be affected by sea level rise and the associated hazards, such as storm surge, wave forces, and erosion from weather events as well as more gradual erosion and flooding from sea level rise. New York City was home to a massive glacier approximately 20,500 years ago. The Wisconsin Ice Sheet spanned Canada and parts of the United States. As it began to melt, about 18,000 years ago, the glacier deposited rocks and sediment at its southern end. This area, which is now Staten Island and parts of Brooklyn and Queens, is known as "outwash plains".[112] These outwash plains are low-lying and vulnerable to flooding and erosion. Other areas of the city, including Northern Manhattan and the Bronx, are safer. This is due to the higher elevation and increased presence of bedrock. The study breaks the geologic landforms into; Low Elevation/Gradual Slopes (like the outwash plains), Medium Elevation/Medium Slopes (areas the glacier ground up the rock), and High Elevation/Steep Slopes (bedrock-controlled areas). Shoreline condition is essentially hard or soft edges. Hardened edges are those that are human-constructed and reinforced, such as bulkhead or riprap. Soft edges, also referred to as natural edges, are made up of sand, mud, vegetation, and naturally occurring rock.[113] Exposure to wave force is integral in selecting design strategies. When an area

[111] The Department of City Planning of New York.
[112] The Department of City Planning of New York.
[113] The Department of City Planning of New York.

is exposed to open ocean there is nothing to lessen the energy of the waves before they reach the shore. This is referred to as high "fetch"[114]. In areas with low fetch, which are more sheltered, the waves generally carry less force as they have dispelled some of their energy before reaching the shores. Parts of New York City are classified by the Federal Emergency Management Agency as V zones, in which wave hazards are very high. Other parts are classified as Coastal A zones, in which waves typically only reach 1.5-3 feet.[115] The NYC Department of City Planning identified nine types, which are a combination of these three factors. They are (with examples); Oceanfront Beaches (Seagate, Brooklyn), Hardened Oceanfront Plains (Gravesend Bay, Brooklyn), Coastal Marshes (Broad Channel, Queens), Hardened Sheltered Bay Plains (Newton Creek, Brooklyn), Oceanfront Slopes (South Shore, Staten Island), Sheltered Bay Slopes (Hutchinson River, The Bronx), Hardened Sheltered Bay Slopes (Whitestone, Queens), Sheltered Bluffs (Northern Manhattan), Hardened Sheltered Bluffs (Riverside Park, Manhattan).[116]

The NYC Department of City Planning also classified New York's land use into eight types. Land use is just as important as the geology of an area, as it will impact the realistic implementation of design strategies. The study also included an analysis of the density of each area. The eight types are; open space (i.e. parks), industrial (i.e. utilities, manufacturing), low-density residential/industrial, medium-density residential/industrial, low-density residential, medium-density residential, high-density residential/commercial, and very high-density commercial.[117] The density of an area and the use of it can create specific risks for the area, which influences vulnerability and the applicability of design strategies.

[114] The Department of City Planning of New York.
[115] The Department of City Planning of New York.
[116] The Department of City Planning of New York.
[117] The Department of City Planning of New York.

The design tactics explored in this chapter are categorized in a couple different ways. The first differentiation is between site strategies and reach strategies. Site strategies entail preventing damage to pre-existing buildings and design features for new buildings that enable floodproofing and minimization of damages.[118] These site strategies focus on single developmental sites or single aspects of buildings. Conversely, there are also reach strategies. These focus on achieving resilience on a larger scale, which can be more realistic in high density areas. These types of strategies are often more complex to achieve, as they require more cooperation from various sources.[119]

Within these two overarching types, there are four subsets of flood management. The first of which are hard protect strategies.[120] This approach emphasizes the demarcation between water and land. It is the most common flood management strategy, with organizations such as the U.S. Army Corps of Engineers preferring this method. Hard protect strategies include, "seawalls, revetments, breakwaters, floodwalls, dikes (or levees), and surge barriers.".[121] The second strategy is similar to the first, in that they both aim to "defend" the land from the water. Soft protect strategies utilize ecological approaches. These nature-based systems implement flood protection solutions that do not create a hard barrier between land and water. Rather, these strategies, including living shorelines, dunes, and floating islands, can act as habitats for species and become part of local ecosystems. While these are better for the environment of the coasts, they are less permanent than hard protect solutions and thus require more maintenance.[122]

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[118] The Department of City Planning of New York.
[119] The Department of City Planning of New York.
[120] Al, *Adapting Cities to Sea Level Rise*.
[121] Al.
[122] Al.

While hard and soft protect strategies are focused on defense or attack solutions, the following two focus on accommodating the water, rather than separating it from the land. The third type of strategy is known as store strategies. Examples include floodable plains, stormwater infiltration areas, and polders. This type of solution is incredibly important as sea level continues to rise. Urban areas often have impervious surfaces, which exacerbate runoff and flooding. By utilizing permeable designs water can be stored and controlled.[123] The final type of strategy is retreat. This is essentially moving away from the risk. This can be either unplanned, in response to an event or disaster, or it can fall into the category of "strategic" retreat. This can be done by raising grounds or flood proofing.[124]

New York City, with 520 miles of coastline, needs a mix of sustainable design strategies to properly adapt to sea level rise and its implications. Additionally, coastal cities must develop mitigation strategies in order to combat climate change and slow its progression. This mix of design solutions pulls from each subset of strategies. These design recommendations will be analyzed based on the types of hazards they address, the applicability to the geomorphology of New York City, the estimate of costs, the additional benefits they may offer, and any other considerations.

On the site level, most strategies that are applicable to areas in New York City are designated as "retreat" strategies. Through strategic retreat tactics individual owners can improve pre-existing structures or build new structures that are better prepared to adapt to flooding. Flooding proofing is an example of strategic retreat and can be achieved in multiple ways, one of which is dry floodproofing. This method entails preventing the infiltration of a building by targeting the exterior. Through "waterproof coatings, impermeable membranes, aquarium glass,

[123] Al.
[124] Al.

or additional layers of exterior concrete or masonry.".[125] Additional considerations are required to ensure the buildings can resist the forces of storm surges. Dry floodproofing protects against low storm surges, three to four feet above grade, is relatively successful against high storm surges, but does not hold up well against wave forces. FEMA standards prevent dry floodproofing on residential structures, though it may be implemented on commercial structures.[126] Wet Floodproofing, also known as elevating on enclosure, does not protect the interior of buildings, but can prevent structural damage. Wet floodproofing involves elevating a structure on an enclosed space that is constructed with materials meant to withstand flood forces. The structure utilizes flood vents to allow water to enter and exit without compromising the integrity of the structure. Unlike dry floodproofing, it is approved for residential buildings, however there are strict regulations on what can be done with the enclosed space.[127] This method is also not ideal for protection against wave forces. Site strategies, while helpful to home and business owners, are hard to deploy in high density settings.

Reach strategies are more applicable in the high-density setting of New York City. It is more efficient to focus on larger stretches of coastline, even if it does require involvement and cooperation from multiple sources. Reach strategies differ from site strategies in a number of other ways. For example, in conjunction with requiring cooperation from multiple levels of organizations, they often require public funding to implement. The U.S. Army Corps of Engineers plays a large role in this implementation[128]. Additionally, the geomorphology of an area is an important factor in determining which reach strategy is best suited for a certain region. Reach strategies, which aim to stabilize the land, typically include three types; upland, shoreline,

[125] The Department of City Planning of New York, "Urban Waterfront Adaptative Strategies."
[126] The Department of City Planning of New York.
[127] The Department of City Planning of New York.
[128] The Department of City Planning of New York.

and in-water. Upland strategies are very aptly named, they do not directly impact the water, but rather focus on inland areas. Shoreline strategies are protective, they aim "to protect from erosion, block storm surge, or attenuate waves.".[129] Finally, in-water strategies act as the first line of defense. Positions seaward of the coast, they reduce the force of waves and storm surge. This helps prevent flooding and erosion in upland areas.

Hard protect strategies, which focus on the differentiation between the land and the water, are already being implemented in New York City. Hard protect strategies outlined in this chapter include; bulkheads, floodwalls, revetments, seawalls, surge barriers, breakwaters, and multipurpose dikes (also known as levees). While many of these options are successful in preventing devastating flood effects, they exhibit negative impacts on shorelines stability and local ecosystems. Through incorporation of sustainable features, such as living aspects (i.e. vegetation) or nonliving updates (i.e. permeable surfaces), these hard protect strategies can develop sustainably.

Bulkheads, while already deployed in many areas in New York City, are not a very sustainable option. These vertical walls are intended to create a stable shoreline to protect against moderate surge and wave events. Unfortunately, these structures often cause erosion and loss of intertidal ecosystems. However, through incorporating sustainable design elements, such as permeable surfaces, this strategy can become more environmentally conscience while promoting resiliency. Bulkheads are best suited for hardened sheltered bay plains, hardened sheltered bluffs, and hardened oceanfront plains.[130]

Floodwalls can be either permanent or deployable. These walls are a shorelines design feature that aims to prevent flooding. Permanent walls, while better suited to handle higher surge

[129] The Department of City Planning of New York.
[130] The Department of City Planning of New York.

events and wave forces, are less preferred because they may subtract from aesthetic value or disrupt aquatic ecosystems of an area. Deployable flood walls, which are implemented prior to a predicted flood event, are effective in protecting against low to moderate wave action. This strategy is more aptly suited for sheltered areas, although some permanent structures can be implemented on oceanfront sites. In New York City floodwalls can be deployed in coastal marshes, bay plains, bay slopes, and sheltered bluffs.[131]

Revetments are already present throughout New York City and are a more environmentally sensitive option than bulkheads. Also referred to as ripraps, these structures are placed on the shoreline and are stone blocks that slope downwards towards the water. They increase accessibility to the water and can be incorporated into green space. While they act to stabilize the shore and protect against storm surge, they can cause the destruction of intertidal habitats. Revetments need stable soil in order to be effective in dispelling wave forces, so they are more applicable in areas with hardened shorelines, otherwise erosion can occur. Though a better alternative to bulkheads, both for the environment, aesthetic value, and cost, these structures require further development to be a sustainably responsible solution. They are most effective in hardened oceanfront plains, hardened sheltered bay plains, oceanfront slopes, sheltered bay slopes, and hardened sheltered bluffs.[132]

Seawalls are structures built parallel to the shore, typically made of cement or stone, that are designed to withstand the force of waves and storm surges. Typically placed in high wave environments, they function to resist wave forces and protect from flooding. They are very applicable to areas with high flooding and storm surge potential, while also lacking in natural shorelines. Though these protect against upland erosion, they can cause shoreline erosion. Wave

[131] The Department of City Planning of New York.
[132] The Department of City Planning of New York.

forces hit the seawall and are reflected back, drawing the sand away from the shore.[133] It is difficult to place these along beaches, as they may disrupt the natural sediment transport. Seawalls present higher upfront costs of installation but have minimal maintenance costs. They have many benefits, such as offering strong protection, being less space intensive, and can be designed to allow public access. However, they tend to be less visually pleasing, can cause sediment disruption, and if implemented in areas with natural shorelines they can destroy the intertidal zone, thus causing the loss of species and ecosystem services. Seawalls are applicable in oceanfront beaches, hardened oceanfront plains, coastal marches, bay slopes, and oceanfront slopes.[134]

Surge barriers are dam structures with gates that, when closed, prevent water from entering. This structure aims to prevents coastal flooding due to storm surges. Surge barriers can withstand low and high storm surges, wave action, and erosion. This strategy can only be applied in specific places, as it needs to connect adjacent shorelines. Surge barriers possess multiple environmental co-benefits, such as the protection of water quality by dispersing pollutant. However, surge barriers must be constructed carefully, as flood elevation exceeding the dam heigh can be potentially disastrous. Surge barriers are applicable in all nine geomorphology types of New York City, as long as there is the proper adjacent shoreline for connection.[135]

Breakwaters, which can either be fixed or floating, are constructed offshore and act to absorb wave forces or, as the name suggest, break the water. Fixed breakwaters are better suited for shallow waters, as they are most effective when barely or partially submerged. Floating breakwaters can adapt to higher fluctuations in water level, as they are not attached to the ocean

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[133] Al, *Adapting Cities to Sea Level Rise*.
[134] The Department of City Planning of New York, "Urban Waterfront Adaptative Strategies."
[135] The Department of City Planning of New York.

floor and can change elevation.[136] Breakwaters are typically made of stone, wood, reinforced concrete, and other materials, depending on what is available to the community. Later in the chapter floating breakwater islands, comprised of vegetation, are discussed as a more environmentally sensitive choice. Breakwaters protect against erosion as well, by reducing wave force. They can assist in reducing flood and storm surge heights. Breakwaters, especially fixed breakwaters, require strong soil in order to remain anchored. This strategy is most effective in oceanfront beaches, oceanfront plains, coastal marches, oceanfront slopes, and bay slopes.[137]

Dikes or levees are constructed "earthen embankments" deployed on shorelines.[138] Multipurpose levees provide benefits in addition to the protection from flooding. For example, many multipurpose levees are integrated into other uses, such as parks buildings, highways, etc. These levees are suited to withstand low to high surge events, but do not protect against erosion, unless used in conjunction with other strategies, such as revetments. By utilizing these structures for multiple purposes, cities can create additional green space or expand transportation infrastructure. The co-benefits to multipurpose levees can increase the quality of life for the surrounding communities. They are suitable for low-lying areas and have large land requirements. In New York City multipurpose levees may be applicable to coastal marches, bay plains, and bay slopes.[139]

Soft Protect strategies also emphasize a demarcation between land and water, but incorporate more natural elements than hard protect strategies, creating a more sustainable and integrated approach to combatting sea level rise. The following design strategies are analyzed in this chapter: living shorelines, dunes and beaches, constructed wetlands, artificial reefs, and

[136] The Department of City Planning of New York.
[137] The Department of City Planning of New York.
[138] The Department of City Planning of New York.
[139] The Department of City Planning of New York.

constructed breakwater islands. These structures provide additional benefits to ecosystems, such as habitat creation and shorelines stabilization, as well as increase aesthetic value and access to green space in coastal communities.

Living shorelines are a green alternative to bulkheads or revetments. Made up of plants, sand, and occasionally some hard landscape aspects, they act to stabilize the shoreline, while also creating and maintaining habitats for local ecosystems. They are often very unique, though there are a few defining qualities. For example, they all incorporate the local environment and utilize ecological functions. They can include some grey structures, such as breakwaters, which help to stabilize the zone for vegetation to grow. Living shorelines are capable of addressing most coastal hazards; wave force, sudden erosion, and low storm surge. However, they are not very successful at combating high storm surges. They do take up more space than bulkheads, however their co-benefits might make up for this. These co-benefits include; maintain natural shore shape and dynamics, creating habitats and breeding grounds, improving water quality, and improving aesthetic quality in urban areas.[140] They are typically low cost, though they do require permitting through the New York State Department of Environmental Conservation and the U.S. Army Corps of Engineers. There is some maintenance associated with living shorelines, as they do alter the ecology of the shoreline. Another benefit of this type of strategy is that living shorelines can double as parks, increasing accessible green space in urban settings.[141] Living shorelines can be constructed in coastal marshes, hardened sheltered bay plains, sheltered bay slopes, hardened sheltered bay slopes, sheltered bluffs, and hardened sheltered bluffs.[142]

Case Study: Brooklyn Bridge Park

[140] The Department of City Planning of New York.
[141] Al, *Adapting Cities to Sea Level Rise*.
[142] The Department of City Planning of New York, "Urban Waterfront Adaptative Strategies."

New York City is already home to a living shoreline. During the design stage of the park Michael Van Valkenburgh Associates, the landscape architects designing the park, worked to integrate a living shoreline in order to adapt to flooding in the area[143]. The living shorelines features a rip-rap shoreline, which is essentially a flexible revetment. They are typically made up of stone or other hard materials and aid in flood protection and help prevent erosion. They also are more durable at withstanding wave forces compared to vertical walls favored in the past. The landscape architects also ensured that salt-tolerant plants were chosen in order to increase the resiliency of the park. A salt marsh, found on the southern end of Pier 1, acts to disperse wave forces and as a natural cleaning system for storm runoff. Another resilience aspect of the park is the elevation of portions above the 100-year storm level. In 2012, when Hurricane Sandy hit, the living shoreline proved its effectiveness in action. The elevated sections of the park deterred flooding and the plant species remained healthy, even with the inundation of saltwater.[144]

Dunes and beaches can be utilized as a more natural approach to shorelines protection. While vulnerable to erosion, reinforced beaches and dunes can act as a buffer to inland communities from waves and flooding. These are suitable for lower-lying areas and need regular maintenance, as they will erode with time. This natural option is very sustainable and refrains from introducing gray infrastructure to shorelines ecosystems. It also increases recreational space and aesthetic value. Implementation of beaches and dunes is very flexible, as it can be redesigned with ease. This strategy is applicable to oceanfront beaches, hardened oceanfront plains, and oceanfront slopes.

Constructed Wetlands utilize natural features, (i.e. plants and soil) to increase shoreline stability and provide a buffer for coastal communities, while also benefitting local ecosystems.

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[143] The Department of City Planning of New York.
[144] The Department of City Planning of New York.

Wetlands are able to withstand wave forces and storm surges, and if they are large enough these impacts of sea level rise will not reach coastal communities. By mitigating the wave forces, erosion is minimized. This strategy is best suited in low-lying areas that contain, or once contained, wetlands. When combined with offshore strategies, like breakwaters, wetlands do very well. Constructed wetlands also increase aesthetic value and green space in communities. This strategy does not do well when implemented in areas with steep sloping, so in New York City is would be best featured in costal marshes, hardened sheltered bay plains, sheltered bay slopes, and hardened sheltered bay slopes.[145]

Artificial reefs are structures submerged, partially or fully, composed of stone and other materials. They demonstrate a duality of functions; to provide a marine habitat to aquatic and avian species as well as dispelling wave forces. These structures can be deployed in a way that benefits the local ecosystems, by providing a habitat and increasing breeding grounds.[146] The reefs also benefit resiliency by absorbing wave forces. While most effective in shallow water, these can be used for oceanfront sites with large waves.[147] If properly placed, they can also reduce sediment erosion and stabilize the shoreline, preventing marsh retreat and beach destruction. Through dispelling wave forces, these structures reduce storm surge and flooding. This strategy is relatively new, however it's co-benefits and easy integration into natural systems make it a very attractive option. Artificial reefs are most applicable in oceanfront beaches, hardened oceanfront plains, oceanfront slopes, sheltered bay slopes, hardened sheltered bay slopes, hardened sheltered bay plains, and coastal marshes.[148]

[145] The Department of City Planning of New York.
[146] The Department of City Planning of New York.
[147] The Department of City Planning of New York.
[148] The Department of City Planning of New York.

Constructed breakwater islands are essentially identical to floating breakwaters, which were discussed as a hard protect strategy[149]. However, this specific strategy can be constructed using vegetated islands. These enhance aquatic environments by creating more space for habitats. Additionally, the recreational and aesthetic value of a site increases with the implementation of these structures. While they mitigate the same effects that traditional breakwaters do, they have additional co-benefits and greater environmental sensitivity, making them the more environmentally responsible strategy to achieve resiliency. One downside of living breakwaters is the research necessary to successfully incorporate them into an ecosystem. Since they are directly integrated into ecosystems, they require carful planning. Like traditional breakwaters, these are best suited to oceanfront beaches, hardened oceanfront plains, coastal marshes, hardened sheltered bay plains, oceanfront slopes, hardened sheltered bay slopes, and sheltered bay slopes.[150]

Unlike hard and soft protect strategies, store strategies do not place an emphasis on the separation of land and water. Rather, these strategies aim to more seamlessly incorporate the two while increasing resiliency. Two strategies that would be applicable to New York City that will be further analyzed are floodable squares and stormwater infiltration.

Floodable squares are urban areas that lie below sea level. These plazas are designed to collect water, becoming pools when inundated with either rainfall or flooding. When not filled with water, these spaces can be used for recreational purposes. Through the implementation of permeable surfaces, these spaces can aide stormwater management and provide flood protection.[151] While they may not be suitable protection against storm surges, these can increase

[149] The Department of City Planning of New York.
[150] The Department of City Planning of New York.
[151] Al, *Adapting Cities to Sea Level Rise*.

the aesthetic value and quality of life, by providing areas for the public to utilize. They can be playgrounds, sunken plazas, basketball courts, or any number of things when not flooded. The downside of floodable squares is the high installation and continued need for maintenance. This type of design strategy is suitable for New York City. While a highly dense area, there are many green spaces or recreational spaces that can be adapted and updated to create a floodable square.

Case Study: Benthemplein Water Square – Rotterdam

The Benthemplein Water Square, located in Rotterdam, the Netherlands, is an urban plaza that is floodable but retains usage even when not flooded.[152] When dry the square features a basketball court and when flooded becomes a water basin. Along with holding floodwater or stormwater that could otherwise collect in less manageable places, it provides space for citizens to relax. As water collects in the square, it fills basins. The basins then funnel the water through steel gutters under the square, before draining into a water filtrations system outside the city. The square is particularly beautiful, with blue spherical patterns accenting the plaza. It not only provides water management value, but recreational and aesthetic value as well.[153]

Stormwater Infiltration, which has been referred to as "green infrastructure" by some, filters stormwater through structures (natural and human-made) to alleviate flooding on the surface. The difference between green and gray infrastructure in this case, is green infrastructure utilizes natural systems, such as bioswales or rain gardens, to collect the floodwater or stormwater, as opposed to the pipe drainage systems favored in gray infrastructure.[154] This design strategy is also very applicable in the urban setting of New York City. All urban areas must be conscious of water treatment and runoff, and implementing permeable features is a sustainable way to do so.

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[152] Al.
[153] Al.
[154] Al.

Sustainable design features require extensive research, planning, funding, and maintenance. However, with sea level rise as a perpetuating issue, it is worthwhile for cities to invest in sustainable urban planning, both to increase resiliency and adapt to climate change, but also to attempt to mitigate climate change. For the sake of current citizens and future generations, New York City needs to implement environmentally responsible green infrastructure.

Chapter 5: Policy Recommendations

Cities must adopt adaptation and mitigation strategies in order to thrive on a planet experiencing drastic climate change. Creating a sustainable city through policy and infrastructure implementation is imperative. New York City has already begun to develop policies regarding climate change and, specifically, sea level rise. The local government of NYC understands that climate change is a pressing issue and is prepared to take measures to ensure the city is resilient against these threats. I would argue, though, that many of the existing policies focus almost entirely on adaptation and very little on mitigation.

New York City can derive inspiration from other cities with extensive resiliency plans. Rotterdam, the Netherlands, for example, is incredibly advanced in their resilience planning. As a low-lying delta city, it is flood-prone and thus has a long history of water inundation. 90% of the city is below sea level and has a history of flooding. In 1953 nearly two thousand people drowned in a flood, jumpstarting a resilience plan that is now one of the best on the planet. After this disaster the city established a system of dams, dikes, and barriers, known as the Dutch Delta Works.[155] The Delta Works system works in conjunction with dunes, and city-wide water management systems. The city plans to be completely climate-proof by the year 2025 and is an excellent guide for integration of green architecture and sustainable design, as well as policy

[155] Al.

implementation. Rotterdam divides its city into sectors, based on age of the architecture, population density, and location to the existing inner ring of dikes. Each district has a detailed and specific plan for updating structures and increasing resilience.

Rotterdam's resilience plan stands apart from others because it does not view climate change as a threat, but rather as "an opportunity to make Rotterdam a more attractive city to live, work, and play in, as well as to invest in."[156]. Rotterdam exemplifies the connection between strategies that fight and protect against climate change with updates to the city that increase quality of life, aesthetic value, and general livelihood. Water plazas and green roofing offset the impacts of stormwater runoff and increase energy efficiency, while also increasing green space and aesthetic value in the city. Rotterdam boasts floating and amphibious structures, which are home to entire communities. The city has designed a network of parks that absorb rain and floodwater. This network not only disperses the impacts of flooding but aids underground water sources in replenishment. Rotterdam's extensive sustainable planning has put it on the forefront of urban sustainability, making it a perfect example for the government of New York City to reference in regard to developing its own policies.

General Recommendations for Policy Makers:

Before outlining more specific policy recommendations, it is important to include general guidelines when developing policies to increase resilience in coastal communities. In order for government policies to be effective, they need to be developed and implemented in ways that directly respond to the issue at hand. Additionally, community involvement is imperative. Members of the community need to understand the risks and hazards they are facing. It will also increase public attention to the issue and involvement in the development and continuation of

[156] Al.

policies. When the community is involved in the discussion of policies, it benefits both the governing force and the residents. Governments also must identify vulnerable communities, which was touched on in Chapter 3. The socioeconomic barrier that vulnerable communities often face needs to be recognized when developing policies and aptly addressed. For example, when developing regulations and mandates for green infrastructure and sustainable design features it is important to ensure that these are affordable and available to all who need them, especially those most at risk. Free maintenance trainings may be pursued in order to educate citizens and property owners on the green infrastructure updates.

Other general policy advancements can include the expansion of public transportation, standards and regulations for new buildings to optimize energy conversation, required evaluation to increase equal distribution of benefits of city-wide green architecture. Emergency management and early warning systems can be implemented in order to increase evacuation time for at risk communities.

Additions to Current Policy:

Chapter 2 outlines a summary of New York City's plans to reinforce four areas of Manhattan against sea level rise. Mayor de Blasio allocated approximately $500 million towards these projects, with construction set to begin by 2021.[157] However, these projects focus on affluent areas. While these projects are a good start, I believe focus should be placed on communities who may not have the personal wealth necessary to implement strategic retreat strategies on their homes or the ability to retreat from the coast if need be. Additionally, many of Mayor de Blasio's proposed solutions are gray structures that allow for adaptation but provide little mitigation. For example, the integrated flood protection system planned for the Two

[157] "Mayor de Blasio Announces Resiliency Plan to Protect Lower Manhattan From Climate Change | City of New York."

Bridges Neighborhood could be replaced with green architecture such as a living shoreline or living breakwaters.

Pollution Tax:

Implementation of green architecture is not a cheap endeavor; however, New York City can generate the revenue needed while also combating sea level rise at its source; climate change. The local government should utilize a carbon tax and carbon markets to limit carbon emissions in the New York City region. In Article IX of the New York state constitution it is stated that localities have the power to make laws. More specifically, New York City is allowed to make laws in order to protect the "'health and well-being of persons' within its jurisdiction".[158] The New York City Air Pollution Control Code allows for the Commissioner of Environmental Protection to take action to control air contaminants. While the city may not have the power to tax carbon emissions, only the state government has that power, the city may levy a "fee" instead of a "tax".[159] In order to be considered a fee instead of a tax it must undergo careful scrutiny, however the purpose of a fee is typically to regulate behavior.[160] I propose New York City should institute a carbon fee, to regulate carbon emissions. The proceeds of this fee would go into a special fund that must go back to the impacted areas (i.e. the coastal communities). In Chapter 3 an overview of the sustainable design features is provided, which New York City could benefit from implementing. Chapter 3 analyzed the applicability of these features based on the hazards they address and the suitability of New York City's geomorphology in conjuncture with these design strategies. These examples of green architecture could be implemented using the money in the special fund, from the carbon fee.

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[158] Vaida, "The New York City Carbon Charge ('NY3C'): Unlocking Localities' Power to Fight Climate Change." 281
[159] Vaida. 286
[160] Vaida. 287

Education Programs and Mental Health Outreach:

Community involvement is paramount in the fight against climate change; however, this will not happen unless the community is educated on the issue. Using money generated from the carbon fee community outreach program could be created. This would not only increase the desire and opportunity for involvement, it could help to combat the psychological repercussions of sea level rise addressed in Chapter 4. Along with these educational programs mental health counseling could be offered as well. The government is responsible for supporting their communities through any crisis, even one as gradual as sea level rise seems to many.

The previous four chapters have analyzed sea level rise on a global scale and specific to New York City. The history of rising sea levels as well as the social and mental repercussions were outlined and explained. Sustainable design features were introduced and each strategy's applicability was discussed. Finally, cities at the forefront of sea level rise resilience were examined and policy recommendations were developed. Sea level rise is a pressing issue and New York City must make the necessary changes to ensure the city can adapt to our ever-changing world. Though a complex problem which requires an intricate series of systems to form a solution, the future of New York City's coastline, rich communities, and historic neighborhoods can be transformed through sustainable design. One of the most influential cities in the world can become a resilient and sustainable urban environment the world will see as a leader and a beacon of hope. Climate change will not cease to exist if ignored, the time has come, the water has come, and New York City must adapt to this new world.

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