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Creation of a Department of Sustainability and Climate Change in New York City

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1. EXECUTIVE SUMMARY

Int No. 1399-2019 is a New York City local bill that repeals the existing Office of Sustainability housed within the mayor's office and replaces it with a new Department of Sustainability and Climate Change. Under a Commissioner, this department will look into all matters relating to resiliency of critical infrastructure, coastal protection, citywide sustainability and climate change. Since this is primarily an organizational bill, this report focuses on climate change and adaptation actions that can be undertaken by this new department.

As a coastal metropolis with over 8 million inhabitants and more than 578 miles of waterfront, New York City is extremely vulnerable to climate change impacts such as rising temperatures, rising sea level, and increasing precipitation. By the 2050s, average temperature is projected to rise up to 5.7°F, with frequent heat waves. Particularly in an extensively built infrastructure like New York City, a third of the temperature rise can be driven by the urban heat island effect. By the 2050s, average sea level is expected to rise by up to 30 inches, and precipitation can increase by up to 11%. This can increase risk of extreme conditions such as coastal and inland flooding, and hurricanes.

Accordingly, climate change adaptation solutions are needed to contend with these challenges. We approached the solutions through the lens of grey and green solutions. Grey solutions refer to the typical greyness of industrial materials such as concrete and metal whereas green solutions refers to integrating natural and built ecosystems (biomorphism) and seeking technological inspiration from nature for building resilient urban solutions (biomimicry). One solution under each category was explored for the three problems we identified. Retrofitting buildings with white roofs and green roofs is one option of adapting to rising heat. Erecting sea walls or living shorelines are viable options to adapt to rising sea levels. And expanding non-combined sewer systems and installing bio-swales can help adapt to increased precipitation.

The bill text recommends a framework for sustainability indicators, including monitoring and reporting progress on short term and long-term goals. The indicators proposed by us, for example, improvement of public health outcomes as a result of adaptation to heat, reduced wave intensity as adaptation to rising sea level, and decrease in combined sewer overflow events can be adopted by this framework.

2. INTRODUCTION

2.1 Bill Overview

The Office of Sustainability is currently part of the Mayor's Office, as described in Section 20, Ch. 1 of the NYC Charter. Local bill Int. 1399-2019, introduced in February 2019 and currently under discussion, would establish a new Department of Sustainability and Climate Change, incorporating the functions of the Office of Sustainability; as well as, foreseeably, some of the functions of the Office of Resiliency, and of the Office of Environmental Coordination. Creating an autonomous department would insulate its functions from volatility in mayoral policies and enshrine climate change adaptation and mitigation as a top priority for the city.

The department would be headed by a Commissioner, who would oversee matters relating to: resiliency of critical infrastructure, the built environment, coastal protection and coastal communities, citywide sustainability and climate change. The Commissioner would have the power to develop and coordinate the implementation of policies, programs and actions to meet the long-term needs of the city, to develop measurable sustainability indicators, and to take actions to increase public awareness and education regarding sustainability and climate change.

The bill creates a sustainability advisory board with representatives appointed by the Mayor from the environmental, environmental justice, planning, architecture, engineering, oceanography, coastal protection, construction, critical infrastructure, labor, business and academic sectors. The board will meet twice per year to advise the Commissioner. An interagency green team will also be established within the department to facilitate the use and piloting of innovative technologies in city construction. The department will develop and implement a long-term sustainability plan and include projections made by the New York City panel on climate change as well as 20-year population projections. These population projections are to be released by the Department of City Planning at least every two years. There shall be an updated long-term sustainability plan every four years and a yearly report on the city's performance.

2.2 Our Focus

The following brief addresses the climate change adaptation efforts that would be overseen by the newly established Department of Sustainability and Climate Change. The bill is primarily an organizational bill, the aspects of which will be explored in detail in the next semester. For the purpose of this semester, we chose to focus on the climate change adaptation actions that can be managed by this department. New York City is a coastal metropolis and will be vulnerable to climate change impacts, including sea level rise, increase in average temperatures, and extreme precipitation. Since adjusting to and avoiding harm from climate change impacts can be achieved at a local scale, as opposed to mitigation which requires global solidarity in decarbonization efforts, it is important that New York City focuses on adaptation to climate change.

3. ENVIRONMENTAL PROBLEM BEING ADDRESSED

Climate change is the long-term increase in the average temperature of Earth and the resulting change in weather conditions. [1] Overwhelming evidence shows that, since 1910, Earth's temperature has increased at an unprecedented rate in human history, as the result of anthropogenic activities - mainly driven by the burning of fossil fuels and the consequent generation of carbon dioxide (CO_2), a greenhouse gas (GHG). Given the inertia of the climate system, changes in equilibrium might be very difficult to reverse and might even reach tipping points, after which change is irreversible. The 2019 New York City Panel on Climate Change (NPCC) report[2] states that, as a result of climate change, New York City will "experience extreme flooding, precipitation, and heat events". The sustained increase in average temperatures has effects on ecosystems and on a wide range of natural cycles, including air and water currents; the average temperature of oceans; and the melting of ice in Polar Regions. Consequences might include extreme weather events, increased sea-level, and disruption of precipitation patterns.

As a coastal metropolis with over 8 million inhabitants and more than 578 miles of waterfront, New York City is extremely vulnerable to climate change. Although most of the damage is expected to occur in the medium-long term, the effects of climate change can already be observed in the city. For the most part, the problem of climate change adaptation in New York City is defined in terms of the visible and perceived impacts that the city will have to face in the future. The city government has responded to the challenge by enacting multiple sustainability policies.

3.1 Increased Temperature

Average temperatures are expected to rise steadily, and more pronouncedly than in the past (observed summer maximum temperatures at NYC airports have increased by 0.5-0.7°F per decade);[3] daily temperatures are also expected to behave more unpredictably; extreme heat (heat waves[4]) and cold snaps might become more frequent and last longer.[5] By the 2050s, average temperature is expected to rise up to 5.7°F driven by heat waves and urban heat island effect.

Heat waves are defined as "periods when heat index is 100°F or higher for one or more days, or when the heat index is 95°F or higher for two or more consecutive days."[6] The factors causing extreme heat waves can be both global and local. In New York City, one-third of this temperature increase is caused by the local urban heat island effect which is a phenomenon in which industrialized areas retain more energy from UV radiation, disrupting the average heat distribution of the area. This is because industrial processes produce ozone which absorbs UV radiation very well. The absorption of solar radiation traps the heat during the day and night.[7] Other factors could be the broad use of air conditioning and automobiles.[8]

Temperatures in New York City have risen by 1.5°C between 1901 and 2011, which is higher than the global rate. Rising temperature can cause more evaporation in soil which cause scarcity of moisture for plants. Rising temperature impacts fetal health and affects later-life outcomes like educational attainment and household income. Also, temperature increases would result in higher energy use – for example, because of air conditioning - and further promote the greenhouse effect.

Heat waves cause more fatalities in the United States than all the other extreme weather events combined. With high humidity, the evaporation rate is lower and therefore the human body loses its capacity to cool down. In these cases, heat can be dangerous causing dehydration, heat stroke and in extreme cases death, especially in more vulnerable segments of the population. Heat exposure can also be responsible for exacerbating chronicle circulatory and respiratory diseases.
Heat waves also affect the efficiency of energy use since they promote higher use of air conditioning and more use of electricity. When the capacity is overloaded, electricity supply might blackout. Air conditioning, electric pumps, refrigerators and freezers, and life-sustaining medical equipment may shut down. Healthcare facilities, food supply systems and wastewater treatment may also be affected. Finally, transportation infrastructure is also affected by heat as high temperatures can cause damage on roads, bridges and railroads.

3.2 Sea-Level Rise and Increased Precipitation

The global average sea level has risen 7-8 inches since 1900[9] and 2.6 inches since 1993.[10] Sea level rise is driven by two distinct factors; the thermal expansion of warmer water and the melting of glaciers and ice caps. When the temperature rises in the ocean, the volume of the water body will expand which causes a rise in water level. The ice will also melt due to high temperature and turn into water which will add water to the ocean.

Climate change has caused increased amounts of precipitation. As the Earth gets warmer, evaporation intensifies causing more water to be stored in clouds and thus, higher levels of rainfall. Extreme weather, hurricanes and storms also increase both in frequency and intensity as a result. Hurricanes draw energy from heat currents deep in the ocean, and as more energy is pushed down into these currents, "rapid intensification" occurs which means wind speed increases and tropical cyclones intensify rapidly.

The sea level in New York City has risen at least 12 inches since 1900, with impacts on coastal lowland safety as well as inland infrastructure. By the 2050s, average sea level is expected to rise by up to 30 inches. Coastal erosion and flooding due to rising sea level and storm surges threaten the coastline and millions of people in New York City. The majority of New York City's sewer system is combined, which means that sewage and storm water is collected by the city drainage system which is treated before entering the river. During heavy rain and snow storms, combined sewers are unable to handle overload capacity, thus excess overflow meaning untreated water is discharged directly into the city's rivers, estuaries, ocean waters and bays. The failure of the combined sewer overflow system is a major concern because in such a densely populated city, water quality will impact aquatic ecosystems, although due to New York's sources of clean upstate water, it does not impact the quality of local drinking water.

Mean annual precipitation might increase by 4-11% by 2050[11] along with the frequency of extreme conditions, such as heavy downpours (resulting in inland flooding) and droughts. The frequency of extreme winds and intense hurricanes is projected to increase in the North Atlantic Basin, which would affect the city greatly. An illustration could be seen in superstorm Sandy. In the aftermath of Hurricane Sandy, the largest Atlantic hurricane that took place in 2012, it was recorded that 43 New Yorkers died and 88,000 buildings were inundated since New York City is highly condensed. Rapid wind speed and intensified hurricanes make evacuation difficult which cause loss of life and property.[12] Massive flooding also poses infrastructural and public transport problems for cities like New York City. Two major power plants, located directly on the East River, were not designed to withstand superstorms; the subway was also shut down because of severe flooding. Millions of people were left without transportation services after the storm and electricity, water and food supply was also disrupted.[13]

4. APPROACH TO SOLUTIONS

We are choosing to analyze climate change adaptation options through two different lenses – 'grey' solutions and 'green' solutions, so as to best assess what ideas would be most effective for the city of New York. It is important to note that adaptation refers to planning strategies that can be implemented to reduce the impacts of climate change.

4.1 Grey Solutions

The first and more conventional type of solution can be regarded as a *grey* solution. This refers to the typical greyness of industrial materials such as concrete and metal which are used in industrial engineering technologies. They are designed to address specific adaptation needs, without necessarily considering the impacts on the environment and ecosystems. However, grey solutions also offer distinct benefits: they are usually quicker to implement and they can be designed to handle peak conditions (given the necessary financial means). The grey solutions analyzed are seawalls, expansion of dual rather than combined sewer systems, and white roofs. In this sense, grey solutions work to maximize industrial engineering technologies so as to help cities adapt to changing weather and climatological patterns.

4.2 Green Solutions

The second category of adaptation solutions can be referred to as *green* solutions.[14] Green urban design and problem solving can manifest in practices of *biomimicry*- incorporating the expansive technologies that nature has to offer into sustainable and resilient solutions; and *biomorphism*- integrating vegetation and ecosystems amidst built infrastructure, to reap benefits such as clean air and green urban spaces. They are also beneficial to the environment, as they help to improve air and water quality, absorb pollutants and increase biodiversity. However, green infrastructure often takes a long time to implement, and might not offer effective resistance against extreme events or peak conditions. The green solutions analyzed in this memo are living shorelines, bioswales, and green roofs.

Both green and grey solutions present different advantages and shortcomings in addressing climate change impacts, and therefore have supporters and critics in the scientific community and among the public. Specific features make individual solutions useful to solve issues on a different time or geographic scale; often, the combination of grey and green technologies is the most effective in a holistic approach to climate change adaptation, especially given the uncertainty in future conditions.

5. PROPOSED SOLUTIONS FOR ADAPTATION

5.1 Sea Walls

Sea walls are erected parallel to the coast to create a "hard shoreline". The structure deflects daily tides from keeping the shore from eroding away and protect human activities and properties. If a natural disaster were to strike, such a fortification would likely deflect the water from destroying property.[15] It is important to note that this structure is not technically a "wall", but a system composed of interconnected levees, berms and sea walls.[16] The Staten Island Multi-Use Elevated Promenade (also known as the Staten Island seawall) recently received $400 million worth of funding from the federal government. The 5.3 miles of seawall will connect Fort Wadsworth to Oakwood Beach, which was one of the neighborhoods that had been struck hardest by Hurricane Sandy. The structure is designed to withstand and adapt to the major flooding events and projected sea level rising. Seawall could deflect up to 80% of the wave energy. Simultaneously, the city sees this fortification functioning as a common area for recreation with a boardwalk, bike path and beach access.

In the short term, seawalls are likely the most effective way to protect shores from energy released by waves. Although seawalls are designed to reduce erosion and protect the coast, some studies show that they can actually have the opposite effect, for example, the bottom part of vertical shaped seawall might be significantly eroded because of the deflected energy.

Due to the continuous force of waves, sediments in front of the seawall can migrate landward in the long term. This can result in erosion at the toe of the seawall, potentially creating hazardous conditions. Seawalls may also impede the trading of sand since they block in between the shoreline and ocean. In fact, seawalls need to be monitored and maintained annually, and replaced every 30-50 years to guarantee performance. Under certain conditions, wave reflection and intensification by the seawall can also accelerate the erosion of adjacent shore lands (so-called "flanking effect").[17] The modification of preexisting hydrodynamic conditions and shorelines morphology has direct impacts on coastal processes and ecosystems, and could lead to loss of habitat and biodiversity.[18]

5.2 Living Shorelines

Marshes and wetlands have an immense potential to protect coastal communities from severe storms. Observed in nature, wetlands have proven relatively unharmed when faced with the wrath of hurricanes. Such a structure can work as a shock absorbing system in the wake of a storm.[19] In the case of New York City, models have been designed that extended the southern parts of Manhattan outward as an artificial marshland (this biomimetic construction can also be implemented with coral, mangroves, etc.). To ensure the maximum reduction of force from incoming waves, structural engineers have also started designing what is known as *living shoreline* or *living breakwaters*, which act as massive, artificially created barriers to incoming storms.[20]

Mangroves are an example of living shoreline that play a critical role in protecting the coast from wave erosion by absorbing wave energy through drag and inertial force.[21] Salt marsh is another coastal ecosystem zone between land and open saltwater which is regularly flooded by tides. Salt marshes facilitate sediment accretion by decreasing current velocity and encouraging suspended sediment to settle. In specific terms, a 15 ft marsh would absorb 50% of incoming wave energy.[22]

Breakwaters are built-in nearshore waters, usually parallel to the shoreline as the first-line of defense from storms and flooding, while marshes and oyster reefs act as natural barriers to wave.[23]

A successful example of living shorelines can be found in Maryland, which implemented over 250 hybrid living shore by planting wetland vegetation and constructed breakwaters. In the past 20 years, these projects reduced sediment inputs 49,877 tons/year due to decreased wave action, increased wetland area by 34%[24] and reduced about 41,835 pounds of nitrogen and 27,508 pounds of phosphorus per year.[25]

Living shorelines provide wildlife habitat, as well as protection for coastal communities and infrastructure. The resiliency of living shorelines against storms depends on how they are built (plant types and coverage, shore morphology, etc.) and on the strength of waves. Some plants provide protection against erosion, but are highly affected by strong winds and waves. Others are naturally absorbent to the energy of waves; however, during storms a certain percentage will be uprooted.[26] As a reference, mangrove cover can decrease between 25-40% due to a single storm. In contrast to seawalls, living shorelines are less likely to fail abruptly; their failure after a storm is usually only partial, and allows time to undertake corrective coastal protection actions. Another issue with artificially-created living shorelines is that they modify the natural conditions of existing shores. Indigenous species and their habitats could be affected; careful studies of existing ecosystems are needed to balance between shoreline protection and biodiversity.

5.3 Expansion of Sewer Treatment Capacity

The City currently has two types of sewer systems - Combined Sewer System (60%) and Separate Storm Sewer System (40%) that manage excess rainwater/ storm water. During very high precipitation events, storm water in a separate system is directly discharged to the waterways without any treatment whereas in a combined sewer system the storm water is mixed with household sewage which is then discharged untreated into the waterways due to limitation in the capacity of the sewer treatment facilities. The excess storm water may carry with it either untreated sewage (in the case of combined sewer systems) or pollutants (in case of separate sewer system) directly into the city's waterways.[27] The current water pump management systems of New York City are already overly burdened today with only 14 water treatment facilities, many of which may need an upgrade, if not outright expansion. Any upgrade or new infrastructure built must also build in resilience to extreme events like Hurricane Sandy which caused substantial damage to communities (such as those living on Staten Island).[28] Additionally, system expansion will also need to take into account projections of a 12% increase in precipitation by the year 2050 in New York City. The Department of Environmental Protection (DEP) may look into enforcing new design standards that take the above into consideration, as it did in the preparation of the NYC Wastewater Resiliency Plan.[29]

The main concern with the Combined Sewer Overflow (CSO) is related to water quality where sewage is discharged, and its local environmental impact. Untreated sewage in surface water bodies is not only unpleasant; it poses a significant biological and chemical health hazards.[30] A recent study adds that CSO can increase greenhouse gases such as carbon dioxide and methane released by wetlands.[31] Discharged waters are also rich in nutrients, and often generate excessive algae production in rivers. Low oxygen concentration leads to eutrophication conditions, jeopardizing aquatic life and biodiversity.

New York City is currently building a storage system that reduces overflow episodes.[32] The expansion of these systems has great value for the growing needs of the city. However, these systems may still be overburdened during increased precipitation and extreme storm events due to climate change. The main uncertainty to address is how large the new capacity would need to be, and if the solution can be physically implemented.

5.4 Bioswales

A bioswale, also known as a "rain garden", is an enclosed natural area that is used to capture excess water from large amounts of precipitation. The center point of the small, green zone is a concave where water flows down into a basin that is typically built of gravel or crushed rock. Beneath this layer is a pipe that allows the rain water to move to a desired destination. They filter out pollutants and debris from storm water and transport them to watershed or storm sewer through a perforated pipe. Bioswales are composed of several layers. The first layer is designed as bio-intensive swale by selecting vegetation that can withstand heavy watering and drought conditions, use nutrients efficiently, prevent erosion, and absorb pollutants. The following layer is designed to handle large amounts of water by using strong absorptive soil containing higher amounts of nitrogen and phosphorus, to increase water retention.[33] Ultimately, the use of this garden system slows the speed at which water travels, resulting in a 1-2-day period of water dispersion. An essential application of bioswales is in the case of a parking lot or larger scale roadway, where the runoff has higher entropy. Having a system designed to slow these danger zones can be prove helpful to alleviating the stress that a storm would have on normal sewage drains.[34]

Project Street Edge Alternatives (SEA) in Pilot, Seattle was completed in 2001. In this project, the city planted 100 evergreen trees and 1,100 shrubs to capture and filter excess storm water. The bioswales were equipped with a 0.5-inch orifice at the outlet, to reduce maintenance concerns. All installed bioswales included a sump pump to reduce the potential for clogging of the orifice, and some included an impermeable liner to prevent seepage into neighboring residences. The project reduced the volume of storm water runoff by 99% and attenuated over 0.75 inches of rain.[35]

Bioswales are normally accepted, and even welcomed, by the urban community; however, some citizens in NYC have expressed concerns, voiced by Democratic Senator Tony Avella (Queens). He claims that the City has not conducted sufficient testing on their safety and sanitary performance (i.e. insect proliferation and liquid and pollutants leakage to adjacent properties),[36] and that a “grey bioswale” solution (i.e. permeable asphalt with no trees) would be preferable. Some studies show that, when regular tree pits are properly protected to avoid soil compaction by pedestrians, they can actually be as effective as bioswales in retaining water. Regular tree pits also have the advantage of being more attractive and more resilient to drought.[37] Another point of controversy is related to the uncertainty of future rainfall. The capacity of bioswales depends on underground geological and infrastructural conditions, which may not respond well to large amounts of water and pollutants. Creating more bioswales would increase total filtration capacity; however, the necessary area might be larger than available surface.

5.5 White Roof

The grey solutions under the Cool Neighborhoods Plan include painting surfaces white to increase albedo to reduce heat retention and repurposing of public spaces as cooling centers during heat wave events. However, the use of air conditioning in these centers will also contribute to intensifying the urban heat island effect. Many of these antiquated building energy systems in New York City rely on gas boilers which make up around 67% of the city’s carbon emissions.[38] To combat the urban heat island effect, New York City will have to transition to less polluting and more renewable energy sources. As recently illustrated in the City Council’s enactment of the Climate Mobilization Act, making buildings more energy efficient can play a major role in mitigating drastic heat waves.

White roofs represent a relatively easy and cost-effective solution to increase rooftop albedo and reduce solar absorption. However, the effects of large-scale solar reflection in cities are uncertain, as pollutants in the atmosphere can absorb reflected radiation, increasing atmospheric temperature in the city[39] or in adjacent regions.[40]

5.6 Green Roof

A Green roof is made of vegetative layer grown on a rooftop which provide shade and reduce temperatures of the roof surface and the surrounding air. Vegetation absorbs solar radiation, converting it into organic matter and water vapor through photosynthesis; through shading and evapotranspiration, vegetation is able to cool and humidify the surrounding environment.[41] Other benefits of green roofs include combating the urban heat island effect; reducing carbon emissions associated with energy consumption; absorbing precipitation and reducing runoff; and promoting biodiversity.

Chicago is a leading city in green roof technology, implementing more than 530,000 ft^2 of green roofs in 2008. Around half of Chicago City Hall is covered by a green roof, with an average year-round temperature reduction of around 4°C.[42] If New York City implemented green roofs, studies[43] indicate that a 50% green roof coverage could reduce as much as 0.8°C in average surface temperatures.

Feasibility depends on whether the green roof is intensive or extensive, as the former requires more depth of soil than the latter, posing greater structural load on the building. The production of low-density polymers used as waterproof membranes also produces toxic substances.[44] Depending on the choice of plants, green roofs can have large maintenance needs, such as irrigation, pruning and weeding. For example, 'sedum' (stonecrop) is a hardy succulent that can withstand seasons and soil conditions (including extensive drought) and is easy to maintain.[45]

6. INDICATORS OF SUCCESS

The bill text recommends a framework for sustainability indicators, including monitoring and reporting progress, here we refer to our recommended solutions and related success indicators.

Summary of success indicators:

Threat	Remediation options considered	How will we measure success?
Increased precipitation	Create bioswales Expand water management system	• Reduction in Combined Sewer Overflow days • Improvement in water quality
Sea-level Rise	Create living shoreline & breakwaters Erect sea walls	• Reduction of wave strength • Reduction in coastal erosion • Reduction of flooding events
Increased Temperatures	Invest in biomorphic urban design – Green Roofs Retrofit buildings with white roofs	• Temperature rise deceleration • Decrease in public health impacts • Decrease in energy consumption

Environmental Problem # 1: Increased Precipitation

- Decrease in CSO days: The NYC Department of Environmental Protection reports the number of days when the sewer system experiences overflow, a reduction in CSO days would indicate success of the adaptation measures.
- Improvement in water quality: The amount of pollutants discharged into the waterways currently increase as a result of storms and CSO. Water samples collected from selected waterways can be assessed for physio-chemical parameters; a reduction in their concentrations would be a scientific indicator of success.

Environmental Problem # 2: Rise in Sea-Level

- Decrease in the intensity of waves hitting the shoreline: Barriers built offshore (such as living shorelines) are intended to reduce the impact of storms on the coast. Wave intensity on the shoreline can be calculated as the height of a wave, per meter that the wave traveled. Reduction in average wave intensity in specific locations behind where barriers were built would indicate success.
- Decrease in the rate of shoreline loss: Shoreline loss is the primary determinant of coastal erosion. This indicator can be analyzed by examining satellite photos of New York City and by performing on-site measurements. A decrease in shoreline loss would be an indicator of success.
- Reduction of flooding events: New York City records the number of flooding events in each neighborhood, a reduction in the number of flooding events would indicate success of adaptation measures.

Environmental Problem#3: Heat waves

- Deceleration in urban temperatures increase: Measuring temperatures and the number of "heat waves" (defined by NOAA as 3 or more days over 90 degrees) would indicate the effectiveness of these programs. A reduction, or deceleration, in urban temperatures increase and in heat waves, would indicate success (relative to modelled temperatures without the adjustments)
- Reduction in heat-related deaths and hospitalizations: By quantifying the public health impact, we can see how urban planning solutions are directly affecting constituents. To compare data, we would adjust these measures to take into account the size, age, and general health of the population. A reduction in the rates of heat-related deaths and hospitalization (relative to the temperature increase) is a success in adaptation.
- Decreased energy consumption during peak heat events: Energy consumption is typically correlated to increase in average temperatures, and demand can surge during extreme heat events. Lower energy consumption, compared to similar heat events in the past, would indicate success. We would need to hold energy measures like appliance, apartment, and even grid energy efficiency constant to make a true comparison.

7. CONCLUSION

Climate change is one of the most formidable challenges the New York City faces. Proposed grey and green infrastructure adaptation will help limit the effects that the environment and New Yorkers will experience.

In general, green solutions are dependent on local existing conditions and need to be adapted to each scenario (i.e. shorelines design depending on existing shore configuration). Integration is even more important when incorporating the green solutions under biomorphic urban planning. While green solutions create a more resilient ecosystem, it takes a longer time to implement and become effective. Grey solutions are normally designed to solve a specific issue. They can be fast implemented, however they tend to be rigid and do consider holistic concerns (such as biodiversity conservation). Given their targeted and non-adaptive nature, a failure of the technology normally leads to enormous risk, and can cause substantial loss of life and capital. The combination of green and grey solutions will bring synergies that enhance the quality and effectiveness of adaptation, diminish risks through diversification and bring more flexibility to face future and changing climate challenges.

While sea walls do provide a short-term sense of security, their long-term upkeep will prove expensive and taxing as erosion is inevitable. In order to preserve the longevity and effectiveness of seawalls, living shorelines and breakwaters would work well by calming the harbor's waters and mitigating the storm surges. On the other hand, living shorelines by themselves may not provide sufficient protection under adverse conditions. In order to ensure that New York City can absorb future precipitation, we are recommending that the city prioritize the further implementation of bioswales. In this instance, rain gardens are not only more cost effective, but also deliver more immediate results than relying on the long-term construction of more grey water management facilities.

As New York is going forward with its plan to retrofit major buildings and decarbonize its energy systems, we are advocating that the city to explore a significant expansion of its greenery and vegetation alongside the (already in place) Climate Mobilization Act and Green Roof Bill. Not only would this type of policy reduce the effects of heat waves, expand urban ecology, drawdown carbon, and mitigate the urban heat island effect - biomorphism adds aesthetic and cultural capital to the city and its stakeholders.

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