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Sandy and the City: The Need for Coastal Policy Reform

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ABSTRACT

After tropical storm Sandy battered the East Coast in October 2012, New York City was damaged extensively by flooding, high-intensity winds and the resultant flames. The resultant flooding rendered many underground subway lines unusable along the southern coasts for an extended period of time, as well as damaging buried electrical wiring. These outages were compounded by the hi-strength winds in the upper areas that also brought down above ground wiring. The lack of electricity for use in traffic lights, care facilities, emergency services and mass transit had a staggeringly adverse impact on public health.

In the upcoming effort to rebuild the affected portions of New York City, considerations will have to be taken as to the cost of hardening the infrastructure in preparation for future events, and what types of remediation and preventative actions will be necessary in dealing with the resultant public health issues. The flooding that occurred in the low-lying areas of Manhattan, Brooklyn, Staten Island and Long Island brought ashore water contaminated with heavy metals and disease, which have inundated houses and apartment buildings. Any related policies should then be subject to a set of guidelines which would bring about the most resilient engineering changes at the most economically effective cost.

Tokyo, Miami, Mumbai and many more “mega-cities” currently exist below sea level. With its unique status as one of the wealthiest and most politically powerful cities in the world, New York is perfectly situated to act as a template for other coastal cities in regards to future storm preparation policy implementation.

INTRODUCTION: A WORLDWIDE PROBLEM WITH A DIFFICULT SOLUTION

The so-called “greatest” cities in the world all share many lot of common factors. They’re usually considered to be socio-economic powerhouses, designating art and fashion trends throughout the world. This elite status and wealth is what makes them so alluring to outsiders, and drives people to migrate towards these cultural meccas. At the same time, they all also share another common trait, one that actually led to their rise; many of these mega-cities are located on the waterfront. This proximity to shipping ports allowed these cities to grow into economic powerhouses that were able to ship and receive goods all over the world. However, this same advantage that once allowed them to thrive may very well also be their undoing. In a 2007 OECD study that ranked the most vulnerable coastal cities, from present until 2070, the top twenty cities at risk, all over the world (ranked first by population at risk, and then by assets at risk, in dollars [Figures 1 & 2]):

Rank	Country	Urban Agglomeration	Exposed Population Current	Exposed Population Future
1	INDIA	Kolkata (Calcutta)	1,929,000	14,014,000
2	INDIA	Mumbai (Bombay)	2,787,000	11,418,000
3	BANGLADESH	Dhaka	844,000	11,135,000
4	CHINA	Guangzhou	2,718,000	10,333,000
5	VIETNAM	Ho Chi Minh City	1,931,000	9,216,000
6	CHINA	Shanghai	2,353,000	5,451,000
7	THAILAND	Bangkok	907,000	5,138,000
8	MYANMAR	Rangoon	510,000	4,965,000
9	USA	Miami	2,003,000	4,795,000
10	VIETNAM	Hai Phòng	794,000	4,711,000
11	EGYPT	Alexandria	1,330,000	4,375,000
12	CHINA	Tianjin	956,000	3,790,000
13	BANGLADESH	Khulna	441,000	3,641,000
14	CHINA	Ningbo	299,000	3,305,000
15	NIGERIA	Lagos	357,000	3,229,000
16	CÔTE D'IVOIRE	Abidjan	519,000	3,110,000
17	USA	New York-Newark	1,540,000	2,931,000
18	BANGLADESH	Chittagong	255,000	2,866,000
19	JAPAN	Tokyo	1,110,000	2,521,000
20	INDONESIA	Jakarta	513,000	2,248,000

Rank	Country	Urban Agglomeration	Exposed Assets Current ($Billion)	Exposed Assets Future ($Billion)
1	USA	Miami	416.29	3,513.04
2	CHINA	Guangzhou	84.17	3,357.72
3	USA	New York-Newark	320.20	2,147.35
4	INDIA	Kolkata (Calcutta)	31.99	1,961.44
5	CHINA	Shanghai	72.86	1,771.17
6	INDIA	Mumbai	46.20	1,598.05
7	CHINA	Tianjin	29.62	1,231.48
8	JAPAN	Tokyo	174.29	1,207.07
9	CHINA,	Hong Kong	35.94	1,163.89
10	THAILAND	Bangkok	38.72	1,117.54
11	CHINA	Ningbo	9.26	1,073.93
12	USA	New Orleans	233.69	1,013.45
13	JAPAN	Osaka-Kobe	215.62	968.96
14	NETHERLANDS	Amsterdam	128.33	843.70
15	NETHERLANDS	Rotterdam	114.89	825.68
16	VIETNAM	Ho Chi Minh City	26.86	652.82
17	JAPAN	Nagoya	109.22	623.42
18	CHINA	Qingdao	2.72	601.59
19	USA	Virginia Beach	84.64	581.69
20	EGYPT	Alexandria	28.46	563.28

If for nothing else, our interest in examining and protecting these coastal cities can stem from a sense of economic and public self-preservation. It should be noted that if we combine the value of at-risk assets in the four listed American cities, they're currently valued at 1 trillion, 54 billion dollars collectively. If we add together the projected values of these four cities for the

2070 estimates, than the collective total is well over seven billion dollars. These estimates only take the value of the exposed infrastructure into consideration; they discount the loss of productivity that would follow any kind of catastrophe. After hurricane Sandy made landfall along the eastern coast of the United States, the projected economic loss due to lost productivity alone was 20 billion dollars (according to a CNN Money news report released a month after cleanup operations had begun). If this is the case, then don't policy makers owe it to their electorate to take preventative measures? If there are currently lawmakers occupying every position along the political spectrum arguing over how to best manage the economy and reduce our deficit, then why have they overlooked the havoc that such storms could bring? Such an economic drain would hurt Americans across every rung of the ladder, from those living below the poverty line to the super-wealthy.

Obviously there are more than just the economic factors to consider as well. As previously noted, these cities harbor an immense amount of people; all of them at risk if a major storm system were to flood their respective homes. The study cites that in the US alone, there are currently 3 and a half million people who collectively stand to risk displacement, injury or even death in the event of a serious storm surge; this number will rise to over 7 and a half million by the 2070 estimate. Such numbers are definitely not inconsequential. It should also be noted that while these are simply the people who are the *most* at risk, every person living along a coastal area will potentially be in harm's way in the event of a storm surge.

Using a post-Sandy New York City as a case study, we can begin to examine how and why the storm so brutally affected a city that had been prepared up until then. The lapses in judgment policy-wise have rekindled a debate over how New York should best defend itself against storms; some are advocating a technological solution that will allow residents to remain where they are (despite the exponentially increasing chance of major storms and storm surges), some are advocating changes in public health policies that will bolster the city's preparedness for future events, and some are advocating a withdrawal back to the mainland, maintaining that the rise in sea level will inevitably overwhelm any attempt at resistance. I maintain, and will try to prove, that a measured combination of all three approaches is the "best" one, in that it makes the most sense on an ecological and economical level. New York City is in a unique position of re-evaluating for the future at a critical junction in its history. If their policy is laid out in such a way that it can save the greatest amount of money as well as lives, then it should be emulated in these other coastal cities as a sort of framework for creating, evaluating and implementing climate change-related policy all over the world.

1. Social and Scientific Analysis of the Problem

1A. The IPCC Climate Change Assessment Report and Rising Sea Levels

This sudden increase in vulnerability can be attributed to climate change caused sea level rise, as well as a shift in air current patterns that can intensify or even redirect storms that normally would have passed harmlessly by. These two events have worked to drastically increase the frequency, as well as intensity, of storms. In the 2007 Intergovernmental Panel for Climate Change: Physical Science Report on the impacts of climate change, the report comes to a conclusion that sea level rise is the result of anthropogenic climate change. In the projections section of the report, several models of estimated global heat increases and their respective rises in ocean level were given (on a decade-by-decade basis [figure 3]):

Case	Temperature Change (°C at 2090-2099 relative to 1980-1999)[a] Best estimate	*Likely* range	Sea Level Rise) (m at 2090-2099 relative to 1980-1999) Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations[b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1FI scenario	4.0	2.4 – 6.4	0.26 – 0.59

The models given in this chart range from their least severe projections (b and B1) to their most severe (A2 and A1F1). Charts b and B1 assume that manmade emission levels remain at their 2000 constants or increase minimally, that forest cover doesn't reduce drastically, and that oceanic heat and acidity doesn't increase to the point of being unable to mitigate the temperature increases (or to act as a carbon sink for the increasing levels of CO2 in the atmosphere). The A2 and A1F1 scenarios conversely take into account an increase in both the output of anthropogenic CO2 as well as an increase in warming, and a change in global air current changes as a result. Either way, we face an average increase of 0.9 meters to 3 meters in the next 50 years.

What does this mean for our coastal cities then? According to a report by the journal Climate Change (Rosenzweig 2012), this type of change could be absolutely catastrophic. They note that New York City is especially at risk due to the fact that the infrastructure is already located along the waterfront, that much of the food and water come from outside the city (creating a potentially deadly situation if supply-lines were disrupted), that much of the transportation infrastructure was located below ground and that it was particularly vulnerable to flooding disruptions (and which proved true during Sandy). The report states that "The NPCC climate projections focus on changes in both means and extremes in temperature, precipitation

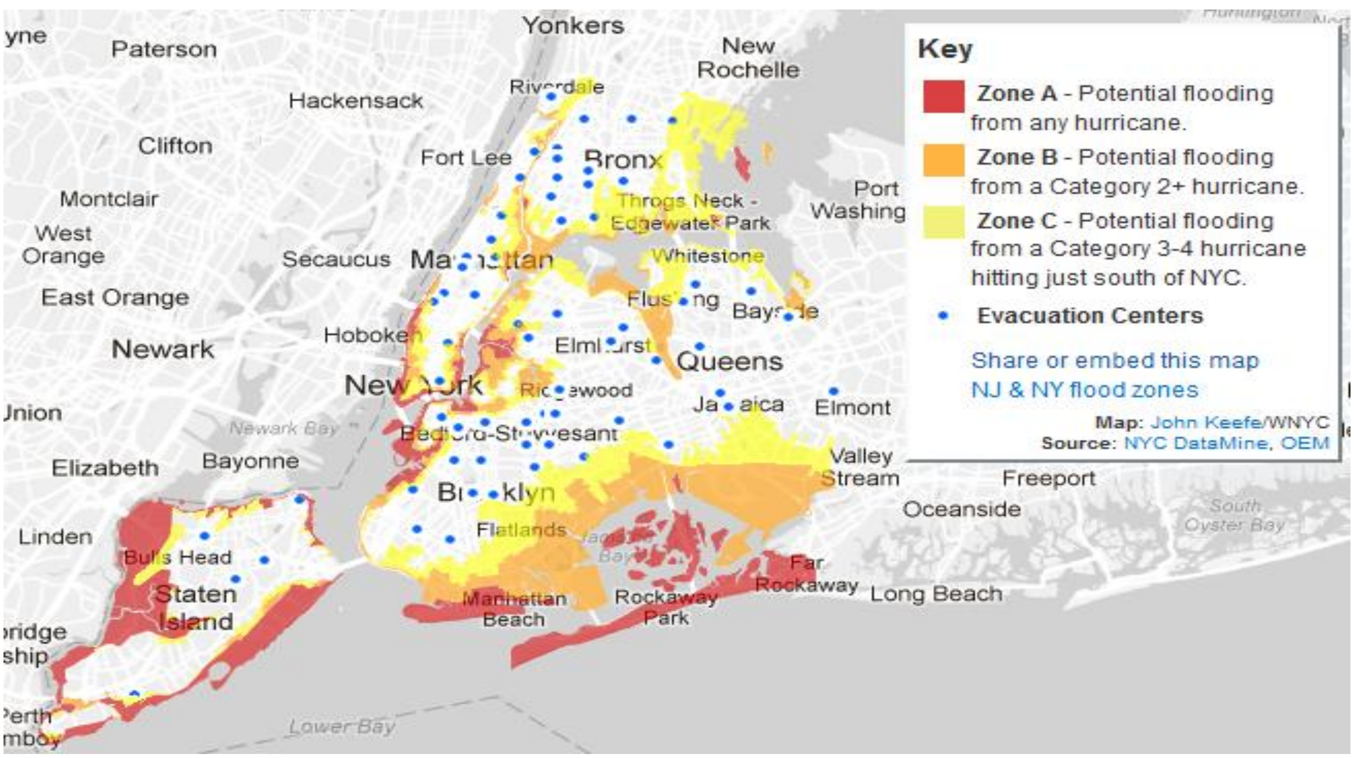
and sea level rise (for full description of methods of sea level rise projection development see Horton and Rosenzweig 2010; Horton et al.
2010). The NPCC used two different sea level rise methods, both incorporating observed rates of local land subsidence, as well as global and regional projections from global climate models. The first method, referred to as the global climate model (GCM)-based method (adapted from IPCC 2007), projects (using the central range, or middle 67% of the model distribution) mean annual sea level rise in New York City as 2 to 5 in. by the 2020s; 7 to 12 in. by the 2050s; and 12 to 23 in. by the 2080s…

As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity shown here, however, are solely due to changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent future flood occurrences relative to the current 1-in-10 and 1-in-100 year coastal flood events. By the end of the twenty-first century, sea level rise alone suggests that coastal flood levels which currently occur on average once per decade may occur once every 1 to 3 years".

This means that if sea level rise continues to occur along the projected path, by the year 2100, New York and other coastal cities could be beset by storms with the intensity of Sandy every 1 to 3 years. Unless something is done to adapt our infrastructure and policies, then we might see a repeat of that same destruction, but on a global scale. But what policies were responsible for the underwhelming preparation in the first place? It's one thing to physically harden infrastructure, but the policies in place also play a major role in protecting residents from disaster.

1B. Planning for Storms: Taking Public Preventative Measures

Public health policy measures are another important factor when it comes to mitigating storm damage and loss of life. As such, the failure of the Bloomberg administration to adequately plan for a 100 year storm represents a lack of foresight dating back to the initial construction of the waterfront. As Raymond Gastil's book on New York City's waterfront design notes (Gastil, 2002), up until the late 1980s, much of the waterfront was used as a "dumping ground" for undesirables, and the policy involved reflects this. Even while modern zoning and architectural tastes lend towards mixing residential and business along the waterfront, the same archaic policies remain in place. Prior to Sandy, houses were only allowed to be elevated up to 9 feet above sea level according to the 2008 FEMA compliant building code; Sandy's storm surge was over 14 feet in New York City (Svensson, 2012). This unwillingness to take climate change into consideration is also reflected in the evacuation zone maps seen here (Figure 4):



As we can see, the mandatory evacuation zones stretch along the coasts of the city and lower Westchester. However, these maps, while current, are woefully outdated. Due to the unprecedented storm surge, many areas beyond Zone C were flooded to the point of ruin, including in Westchester, up beyond New Rochelle. As such, many residents unexpectedly lost their homes or had their homes damaged by flooding. After the normalized procedures protected much of the infrastructure and minimalized loss of life during Hurricane Irene the year prior, it was assumed by the Bloomberg administration that the current course of action was the correct one (see proposed changes to PLANYC after Sandy).

Flood insurance policies and federal aid have also contributed in creating an unsafe environment. These policies have encouraged people to rebuild in flood-prone areas instead of relocating, while at the same time not affording them enough to harden their businesses against future flooding. As a result of Sandy, there have been several proposals on the state and local levels to buy out these businesses using disaster relief funds, and to repurpose the land as storm barriers (serving the dual purpose of relocating exposed structures and further protecting those inland [New York Matters 2013]).

Clearly something needs to be done, on both the engineering level as well as the policy level. There have a been a multitude of solutions proposed, but any and all feasible solutions should be subject to either an Environmental Impact Assessment, or a Health Impact Assessment. Each assessment consists of the same steps (with the HIA containing an additional step for screening out frivolous proposals), ranging from scoping out any possible problems to actually implementing research and community feedback supported suggestions of improvement. In addition, a cost-benefit analysis of the economic pros and cons, weighted against the potential benefits in protection, should provide the best solutions. But what are these solutions for hardening our infrastructure? Are they feasible? Is it possible to design a protective system in such a way as to make it unobtrusive and sustainable as well as effective?

2. Environmental Engineering

2A.What is Environmental Engineering and how can it be Used?

Cliff Moughtin's *Urban Design: Green Dimensions* opens with a definition of both sustainable development, as well as environmental engineering. For development to be considered sustainable, it has to both respect the area it's serving as well as the culture of the people living there. It has to better the standard of living for the residents while also leaving a minimal environmental impact (or, in keeping with modern architectural developments, contributing through power generation or carbon absorption). Ideally, any sustainable designs should also be aesthetically pleasing. Environmental engineering is the practice of utilizing engineering principles to better improve the environmental quality of life. Projects that would work to help clean the air or water of a community are of equal importance in the field as projects that would help to prevent a communicable disease. Combining the two principles should ideally foster a state of development that would help improve the quality of life for New Yorkers by protecting against future disasters, by hardening the coastlines and transportation infrastructure to prevent flooding. Within the field of environmental engineering, there are two schools of design, each with their own approaches to certain problems.

"Hard" environmental engineers keep the mentality that large scale projects which take advantage of "traditional" techniques are the best ones. For example, projects such as the installation of large seawalls along the coast to keep out storm surges, elevating or creating new streets, or physically cordoning off an area to redirect the flow of water or air would all be considered hard techniques. While some people may view these as brute force answers to delicate problems, they often present cheaper, more effective alternatives.

“Soft” engineering, on the other hand, refers to the school of thought that more natural, organic solutions are the best way to deal with urban design and environmental problems. By installing things such as barrier islands, or through revitalizing an island’s natural coastline and original flora, soft engineers can restore natural ecosystems, but also reduce flooding. In this way, they seek to create organic and natural systems that help to restore natural functionality to an area, as well as making it pleasing to look at.

While these approaches might seem like incompatible views, the tactic that is most likely to succeed is a mixed approach that blends aspects from the two. Several different proposals will be evaluated for their practicality in each category, as well as their theoretical effect on saving lives.

2B. Hard Engineering Approaches

In examining hard approaches, care must be taken to ensure that they’re sustainable. With a project such as a seawall that would extend around lower Manhattan, an environmental impact assessment would almost certainly trigger after the plan specifics were proposed. The building of a sea wall to protect New York City would actually have to be the largest ever constructed; as such it would have a very large impact on the immediate surrounding area. In *The First Wave of Change* (Meyers 2013), Meyers notes that a sea wall would not be effective enough on its own to prevent catastrophe, and a Japanese study on the impact of a smaller sea wall on the local ecosystem compliments his assertion. In a series of 2007 studies, Toshio Yamagishi and co-authors documented the deleterious effects that a series of break-waters and seawalls had on two beaches in Japan. They found that the walls severely disrupted the deposition of sediment along the coast and created a new problem, one that many engineers must already deal with in designing seawalls: the walls alter this deposition so much, that soil and other materials are washed away from the base of the walls and never re-deposited there. Thus, unless made thicker at the base or continually resupplied with materials, a sea wall will become inherently unstable at the bottom and create ecological problems directly behind it.

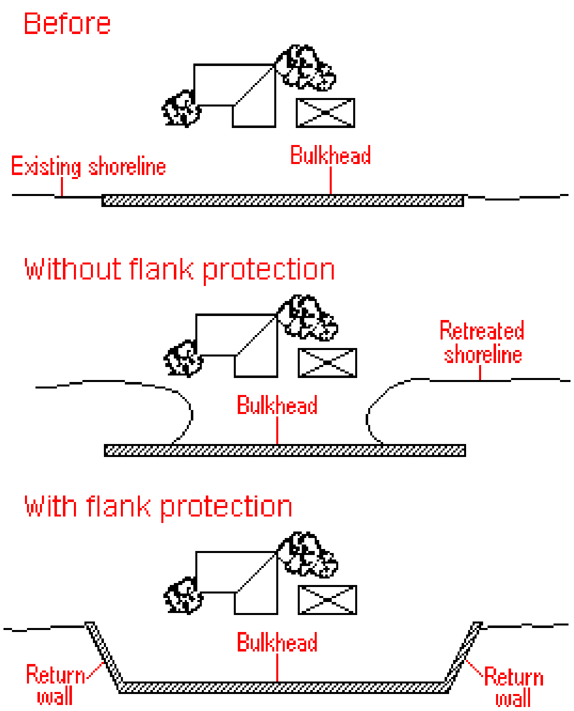
As the seawall seals off an area from flooding, the imbalance in deposition can starve the area behind it of vital nutrients. This disrupts food chains by starving the lower rungs, and would lead to more polluted water in the areas in which they're installed. In addition, this change in flow would fundamentally alter NYC's shoreline in shape as it eroded away and was re-deposited somewhere else. In addition, going back to the Huffington Post article mentioned earlier (Svensson), the author notes that with the zoning issues and these environmental concerns, it might be upward of twenty years before construction even began. Such a mega-scale program would require approval from a multitude of departments as well as in-depth studies as to its impact on residential and environmental health. However, projects such as this are fast-tracked all the time, and are even often rendered "exempt" in the EPA evaluations; but even if a seawall project *was* approved, it would still have a major problem, one that most hard engineering projects face. A seawall, once constructed, is immutable. Subject to modern-day engineering restrictions, any seawall constructed today would likely face an enormous amount of problems fifty to one hundred years from now in light of the increasing storm intensity (coupled with the projected sea level rise). As such, a seawall *could* protect the city, but it would have to be flexible enough to adapt to newer threats, or torn down and rebuilt every few decades.

The Netherlands are a good example of how hard engineering principles can be used to stave off flooding, as well as a cautionary tale of over-reliance. Because the majority of the country lives below sea level (2/3rds), flood protection has played a major part of the Dutch way of life. For hundreds of years, dikes (earthen walls constructed in low-lying areas, similar to levees), dams, and extensive drains and catch-basins that captured the redirected water. While the image of the windmill is intrinsically linked to the Dutch in popular culture, they've served another purpose besides grinding grain. Their secondary, and more important, use are to act as pumps that continually drain the basins in times of heavy rain. While this system had been adequate for centuries, modern storms have begun to show that a lot of new construction will be needed in order to cope with climate change.

After the North Sea flood of 1953, in which 2,000 Dutch residents lost their lives, a major construction re-evaluation began (BBC News, 2009). No longer were the same dikes and sea-walls adequate to protect the mega-cities that had begun springing up along the coastline. While this did lead to a major overhaul 30 years ago, and the installation of larger and more modern sea-walls around these cities, their *current* value is now being called into question. These walls are only 20 feet high, raising the question of what would happen when sea-level rise caused a storm surge to overtake them. In addition, the flooding of rivers on the *opposite* side of the walls during storms presents another problem. Because they were built 30 years ago, they often lack the capability to effectively drain these large amounts of water. As an unintended side-effect, the presence of these massive walls has led to a sort "false confidence" among the Dutch populace. Tineke Huizinga, the Dutch Deputy Minister for Transport and Water, said that "Dutch people are not afraid of water; we live below sea level… Sometimes it would be better if the Dutch people were a little bit more afraid. Now, with climate change, it really is important to take measures and to really do things". Immediately after this quote, the same BBC article noted that in an emergency evacuation drill, 4,000 people would have died due to lack of preparedness. While the government ultimately decided on a several-billion Euro plan to update these coastal walls, the same lessons can be applied to New York City *before* it's too late. The precedent of “building a large system of walls and levees, razing and rebuilding after a major storm and then doing it all again later when the sea-levels rise” is a dangerous one that can be avoided.

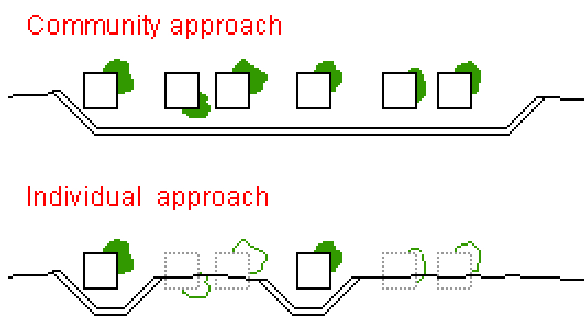
Aside from the obvious protection they provide, seawalls and break waters (off-shore barriers designed to deflect and disperse waves before they have a chance to reach the shore) each come with their own share of deleterious environmental problems. According to studies by UNESCO (The United Nations Educational, Scientific and Cultural Organization) in their coastal management sourcebook, *any* solid defense system near a beach will negatively alter the composition of the beach. Because beaches are formed through the deposition of sediment by wave action along the coast, any change in the way those waves break will also alter that deposition pattern (UNESCO). When erosion occurs, it erases the distance between retaining walls (large walls built to separate property from the water) and incoming waves; and because these walls were only meant to hold back soil and create a barrier, they often collapse when hit by waves. This not only destroys the wall, but can damage the surrounding property and allow the soil and supported structure(s) to collapse.

Of course, there are mitigation measures that can be taken; they involve building supports and other walls along the shore to protect it against erosion, and to bolster the strength of the beaches. Return walls are slanted sections of wall that help disperse waves and naturally replenish sand along the shore that would otherwise be depleted. Figures 5 illustrates the difference in shoreline profile with, and without, these return walls:



It's clear that without any sort of ancillary protection, the property would actually become *more* vulnerable over time. Any proposed barrier construction along the coasts would have to account for this; due to the size of New York City's coastline, full coverage may not be economically feasible. If this proves to be the case, then the affected areas would have to be chosen carefully in order to minimize any ecological damage.

In addition, the same study also shows that this method only provides protection if the entire community chooses to implement these barriers (those who didn't would be subject to the deleterious effects). See figure 6:



While this might not apply on the governmental level due to the larger scale of construction, without a comprehensive plan to police private implementation there may be serious repercussions.

2C. Soft Environmental Engineering Approaches

The risks and rewards of hard environmental techniques have been thus far documented, but what about the alternatives? Whereas hard approaches seek to build barriers, soft approaches focus more on restoring natural marshland and wetlands, creating barrier islands and beaches through off-shore dredging to increase the distance from the waves to the shores and naturally disperse their energy. As previously noted, soft environmental engineering is a school of sustainable design; the major tenents of which include creating "greener" spaces that enrich the developed area ecologically, economically and aesthetically. In order to integrate these principles into a coastal design plan, care must be taken to not only preserve New York City's natural ecosystems, but to bolster them.

Returning to the MoMa's Rising Tides exhibit in 2007, several major architectural teams were tasked with sustainably redesigning New York's waterfront. As a case study that encapsulates the majority of the soft proposals, the Architecture Research Office (ARO) developed a working plan for lower Manhattan that not only extends the coastline, but also redevelops the transportation infrastructure above and below-ground. Figure 7 diagrams their full installation plan:

ARO's new design first and foremost includes the construction of "urban estuaries"; this term refers to the conversion (and creation) of existing streets into runoff channels that would funnel floodwaters into predetermined routes in the event of a flood (water coming into the city) or during times of heavy runoff (water leaving the city). Urban estuaries are designed to work in tandem with the newly installed saltwater marshes that would run along the coasts, using plants with a high tolerance for saltwater, and animals native to New York to help replenish the ecosystem. Saltwater marshes provide a myriad of positive ecological effects, and their implementation in an urban area could also lead to economic and social/cultural benefits.

These marshes, once in place, would act as filters that could naturally trap and sequester saltwater and pollution. The previously mentioned urban estuaries would serve to direct the filtered water through the marshes to stave off the risk of flooding, as well as keep it in the system for longer. Next, the water would flow into “shallows”, pre-cut pools of water that could host their own small biospheres. The ARO team has also proposed elevating other streets and turning them into walkways above the shallows, allowing pedestrians to both cross these areas unhindered as well as observe the shallows without intruding. By converting these areas into natural parks, the city government could charge a small fee and recoup some of their initial investment (as well as educate the public on their environment). Finally, the now purified water would run even further inland and collect in pools, to be harvested for later use in industrial applications (it’s unknown how potable the water would be). To maintain the sustainable design principles that the project was drawing from, and to ensure that new ecosystem maintained uniformity, the marshland and estuaries would be strategically woven into the fabric of those affected city blocks. Elevated recreational walkways designed for use even in high tide, and for submersion during storms, line the outskirts of the coastal neighborhoods and pass over the marshes; as the walkways threaded back inland, they would gradually lower until connecting with the already existing streets. Where the tidal line is drawn (high and low tide) at the coast, there would be a steep embankment into the harbor to accommodate for small boat and ferry travel (with a pier slightly further out). Right behind the high-tide line would be a series of public recreational parks that have been expressly designed to be "submersible", containing plants that can survive submersion and all-concrete benches (similar to the Dutch park system).

Sandwiching the marshes are another two layers of extra protection. On the outer side, a series of breakwaters would help disperse much of the wave-energy in the southern regions (around Battery Park) before the storm surges reached the marshes. Built out of "geotextile" tubes (a special fabric used to contain sediment), the barriers would be filled with dredged soil from the Hudson and East Rivers and seeded with marsh grasses on their tops. Because the tubes would be oriented lengthwise in relation to the shore, they would act more like sandbars in slowing storm surges, and avoid the detrimental effects of a hard barrier. Because the breakwaters gain effectiveness when deployed en-masse, a successful implementation could be considered part of the shoreline extension; the breakwaters would serve to "bleed" the shore into the harbor and delineate any abrupt lines between the shore and water, causing any incoming waves to "drag" along them and slow down.

Lining the land behind the marshes is a strip of "linear" forest (thin and continual), modeled off of Fire Island's sunken forests, that would curve around the interior of the marshes along the coast. Stocked with salt-water tolerant trees, the forests would serve as another tertiary barrier for flood waters, as well as yet another buffer zone. The additional trees would also bring with them a whole host of positive externalities; they would foster bird life in the area, clean the air, and provide NYC residents with new recreational areas (the Parks Department would also be able to implement an entrance fee to help reimburse their construction funding). The soil that the trees require would either need to be transplanted in or uncovered naturally. Either way, the installation of this forest system would considerably cut down on storm water runoff.

Any reduction in runoff would play an effective part in also reducing the likelihood of a combined sewer overflow event (CSO). The New York City Department of Environmental Protection defines CSO as when "Sometimes, during heavy rain and snow storms, combined sewers receive higher than normal flows. Treatment plants are unable to handle flows that are more than twice design capacity and when this occurs, a mix of excess storm water and untreated wastewater discharges directly into the City's waterways at certain outfalls" (NYC DEP 2013). As with any storm-related water management issue, this would also have to be addressed if a comprehensive overhaul plan was put into action. A CSO during a crisis would mean that raw sewage would start flowing onto the streets, further complicating cleanup efforts and endangering public safety. Storm runoff mainly becomes a problem in densely paved areas (mainly urban centers), as asphalt and concrete can't absorb the water and it runs directly into storm drains and local bodies of water. A study published by the United States General Accounting Office in 2001 highlighted all of the negative impacts that runoff imparts in urban areas; besides causing CSO, it also collects contaminants from roads and walkways (such as pesticides, fecal matter and heavy metals) and re-deposits them in ecologically sensitive areas. In the ARO team's proposal, all of the previously touched upon measures also serve to sequester runoff and return it to the water table after being filtered through soil and plant matter. The team also proposed the installation of "blue roofs" throughout the five boroughs, which are designed to capture water during rainfall and then release it gradually into the streets after the storm was over.

The streets themselves are also in need of a major redesign. Whereas New York's current street system provide unmitigated lanes for water to flow along (while also encouraging people to drive and thus raise the amount of pollution and CO2 in the atmosphere), the ARO team has proposed a major overhaul that would place a much greater emphasis on public transportation and walking. Several of the larger downtown streets, such as West Street, would be renamed (in this case Western Parkway) and rezoned to exclude automobile traffic. Instead, these streets would be portioned off into 3 sections: bike lanes, light-rail tracks and pedestrian walkways. Most of the surrounding area would, again, be converted into parkland that would slow any encroaching storm surges. Finally, buried underneath all of this are consolidated infrastructure hubs. Hoping to avoid any loss of services, the ARO team envisioned large waterproof vaults that would be kept in maintenance-accessible areas beneath the sidewalks. Partitioned into public and private service areas, the vaults would contain sewer, gas and water lines in the public half and electricity and communication lines in the private areas. There would also be smaller redundant vaults buried nearby as well, to ensure the availability of backup systems in case of an emergency.

All of these suggestions would, of course, serve as very practical and effective defensive measures, especially when combined with the hard engineering practices touched upon in section **2B**. However, the political endeavors and economic costs (both direct and indirect) in enacting such designs would first need to be evaluated before any plan could be implemented. While PLANYC (the Bloomberg administration's 30 year plan for revamping New York City) has already been revised to add in some of the aforementioned features, they may not be enough to successfully prepare for the future.

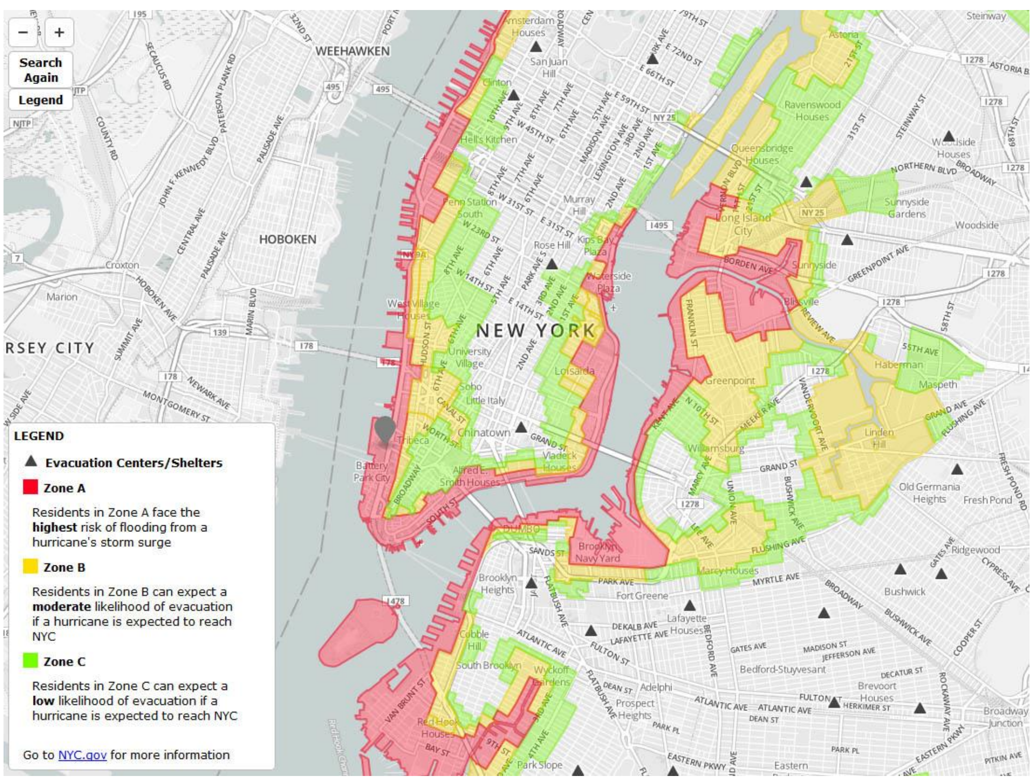
3. The Public Health Policy and Decision Making

3A. Urban Health Policies

Any proposed change to New York City's infrastructure and zoning ordinances would need to first be cleared with the city administration and its appropriate department; and in this case, several departments would need to be involved with the change. In <u>Cities and the Health of the Public</u> (Freudenberg, 2006), public urban health policy is defined as the policy decisions involved with ensuring the safety and health of those living in urban areas; the population of which is projected to rise to 3/4ths of the world's population by the year 2030. In evaluating what must be changed on the policy-side in order to minimalize future deaths and streamline storm cleanup for the future, the problems with the current local administration's efforts must first be understood.

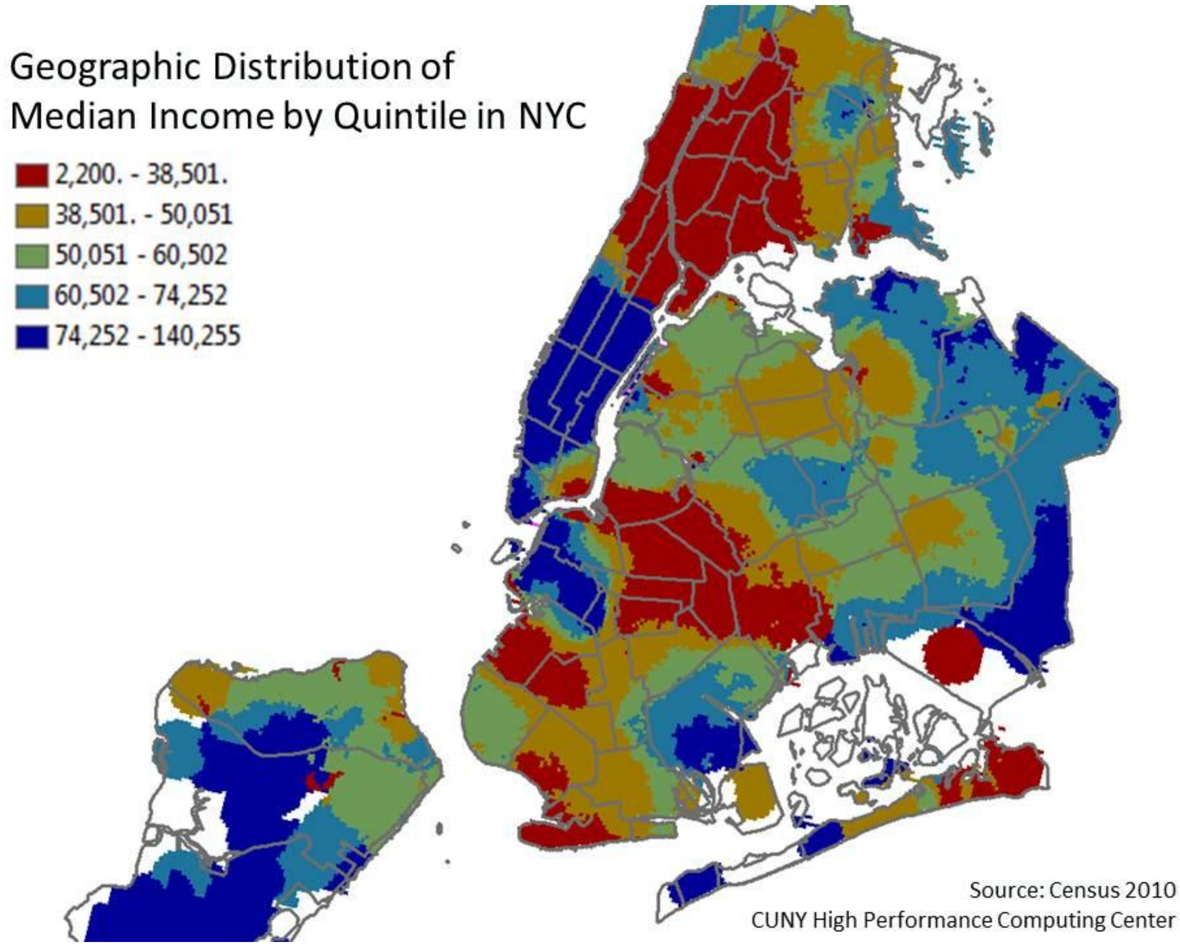
3B. A Troubled Political Past

Hurricane Sandy demonstrated to many that New York was more at-risk than previously thought (at least by policymakers). Whereas Hurricane Irene had left the city relatively unscathed, Sandy proved the measures in place at the time were simply not adequate for dealing with a severe storm. Take, for example, the pre-Sandy flood evacuation map that the administration was using prior to, and during, Sandy (figure 8):



After Sandy hit, it became clear that this map needed serious revisions. Sandy's 14 foot storm surge inundated those living beyond Zone A (although nearly all of New York's 43 fatalities came from those living in Zone A). According to a recent poll by NPR, despite a nearly 100% rate of informance that evacuations were mandatory, only 37% of Zone A residents actually left their homes during Sandy (Associated Press, 2013). "More than 2.3 million people live in the city's three evacuation zones now. The roughly 375,000 residents of the most vulnerable area, called Zone A, were ordered to leave a day before Sandy walloped New York on Oct. 29. Mayor Michael Bloomberg gave several televised briefings urging them to go, and the city sent out text-message alerts and dispatched police cars with bullhorns to some neighborhoods. And yet a city-commissioned survey of 509 Zone A residents found 63 percent stayed home, according to the report released Friday". This was due to a combination of factors, mainly the security residents felt after having weathered previous storms and their suspicions that Sandy would not be as powerful as it was predicted to be. This was a byproduct of the administration's handling of Hurricane Irene, wherein the city's transportation infrastructure was shut down, and evacuation orders were issued, but where the storm's impact was much milder than what had been predicted. This falls in line with what had been shown earlier in sections **1A** and **1B**, where although the intensity and frequency of such storms is increasing, public preventative policies are not keeping pace. Because many of the lower Manhattan, Staten Island and coastal Brooklyn neighborhoods affected were of lower income, having arisen from a long history of minorities being pushed out to the coastal areas (such as in Redhook), the issue can also be framed as one of environmental justice and the lack of services being provided to those who are most vulnerable.

See figure 9:



In the same vein, building codes and zoning ordinances in those same areas also contributed to much of the damage caused. As noted by the NYC Building Department in a memo acknowledging FEMA's new coastal elevation recommendations, before Sandy there was a conflict between what New York's zoning code allowed in regards to elevation height and what FEMA had recommended. Even if home or business owners had wanted to elevate their buildings to above what the federal government had recommended, the state and local laws would not allow them to. This is another gross oversight by the city government that is now only being fixed after such a powerful storm actually occurred. Compounding the issue even further is that of flood insurance and how the city has been doling out recovery funds for reconstruction.

Flood insurance for at-risk individuals living in vulnerable coastal areas is a contentious issue. Long cited as subsidizing the risk of building in these places (where some people, such as Columbia University's research director of environmental studies, Klaus Jacobs, say that homes should never have been built to begin with), flood insurance can instill a sense of false confidence into those residents who build there. In addition, the process of actually receiving any compensation after a storm can be an arduous journey; the New York Times covered this process in an article from March 1st of 2013. As of 6 months after Hurricane Sandy, many affected families and businesses have still failed to receive any compensation from their insurance companies. In addition, the compensation that has been offered only covers (or partially covers) the initial cost of construction; if a reimbursed resident wanted to raise their building to comply with the new FEMA standards, there would currently be no way for them to do so outside of personal or private funding. This ensures that the same buildings will continuously be hit by storm surges and flooding over and over again. The total amount awarded to New York State by the federal government's disaster relief fund only amounted to 1.7 billion dollars, whereas New York City incurred 50 billion dollars' worth of combined damages; that amounts to 3.4% of the needed funding. With so little public funding going back into even repairing necessary infrastructure, there's next to nothing available for public reconstruction. However, all of these mistakes in preparing for the future can be rectified, and the Bloomberg administration immediately sprang into action after the storm in an attempt to correct their course; but the city is currently at a crossroads, and any policy change now should be geared towards long-term planning.

3C. Planning for the Future

If Sandy had not occurred, then much of the same measures and plans for the future would still be in place. In a January talk hosted by the New York Academy of Sciences entitled "Adapting Cities to Climate Change in a Post-Sandy World", a host of climate scientists and policy makers were called upon to give their vision of what life in a future affected by climate-change might require. The answers ranged from the practical all the way up to grand, sweeping changes in the political landscape and the eventual abandonment of New York City; while PLANYC has changed to account for, and mitigate the effects of climate change, and while FEMA has increased elevation recommendations, the general consensus was that what is currently being enacted isn't thinking far enough ahead into the future.

As the previously referred to NPR article in section **3B** explained, recent plans to widen the scope of services offered include doubling the evacuation areas in size to include 640,000 new residents and expanding educational outreach about how and when to leave. As the article states, "Some governments have tried dire warnings about the dangers of staying behind, moral appeals not to endanger rescuers, and laws that threaten fines or jail time. In New York — where a little more than half the survey respondents said they thought the city could have done more to encourage evacuation — Friday's report calls for seeking to use digital billboards and making sure orders emphasize what's at stake". In a city as wealthy and technologically savvy as New York, many more options exist for effectively warning people. According to Freudenberg, education has always existed as one of the most powerful public health policy tools available, and that raising awareness of any problem is vital in reducing its damage to the populace.

In Mayor Bloomberg's December 6th speech, and the subsequent talk by Seth Pinsky, he outlined the administration's plan for dealing with future storms. Bloomberg spoke on how climate change was not the only problem facing the city, but how it might prove utterly overwhelming if no long-term action was taken. Praising the first responders and medical personnel responsible for overseeing the evacuations of critical zones and those residents in long-term care, he also laid out the need for a more comprehensive system for evacuating the infirm and making sure that they would have access to any necessary medications while away from their care facilities. The storied resiliency of the city, and how it's often viewed as a world policy template also came up, as he detailed that a reduction in greenhouse gasses would need to begin in the world's most vulnerable areas; because New York has this type of clout, any emissions initiative would draw a great deal of attention. A particularly effective example can be drawn from the city's "cool roof" initiative, which encouraged residents to paint their roofs white in order to combat the urban heat island effect. The project became a runaway success, and a vast majority of the formerly black roofs throughout the city have been repainted. A fund was also established to help maintain mass transit systems in case of an emergency, via ferries, buses and other systems that don't rely on the electricity grid. Again, although he did not admit that the previous guidelines could have been amended, Bloomberg also recognized the need for reconfiguring the zoning practices for elevation guidelines: "For instance: even though the City has already revised the building code to strengthen standards for flood protection, we will now do it again. The fact is: two-thirds of all the homes damaged by Sandy are outside of FEMA's existing 100-year flood maps. Here's the existing 100-year FEMA and 500-year FEMA flood maps – last updated in 1983. You can see the 100-year flood zone in yellow, and the 500-year flood zone extending out of it in orange. Now, here is where Hurricane Sandy actually flooded, in red".

This direct acknowledgement that many engineering changes will have to be undertaken can be seen as tacit approval for some of the soft engineering approaches mentioned previous; Bloomberg even goes on to stress the importance of creating more distance between the shore and harbor using some of the more “natural” techniques touched upon earlier. PLANYC was soon amended accordingly to include more green building initiatives to further cut down on emissions and increase the number of green spaces, and plans to harden infrastructure were also soon put in place. In his speech, Bloomberg stated that “every one of the city's major infrastructure networks failed” during Sandy, and that drastic action would be needed to successfully adapt to this new reality. He went on to say that although many of the city’s buildings are under the control of private contractors; the administration would from then on work very closely with them, and with the utility companies. In fact, he also announced that “Con Ed has committed to a $250-million project to harden its gas, electric and steam systems”, all in line with his vision of reconfiguring the city so that it would be able to withstand a strong category 2 hurricane (Sandy was only a category 1 storm). Even the information infrastructure proved to be extremely vulnerable, as “Verizon I think learnt that lesson during Sandy, which took out an astonishing 95 percent of its copper network in downtown Manhattan. They are now rebuilding better and smarter with fiber, but full restoration will take months”. With the full backing of the city government, Verizon and other cable companies will soon begin laying buried fiber optic cables throughout the city, ensuring that communication would be uninterrupted in the event of another natural disaster.

All of these initiatives seem promising, and may certainly succeed in lessening the damage from a near-future natural disaster; however, when Bloomberg spoke about hardening the city in preparation for a category 2 hurricane, it underlined the lack of foresight in any of the proposed policy plans. As he himself noted, FEMA’s maps from 30 years ago were now so out of date that a category 1 hurricane flooded into their 500 year flood projection zones. If this was the case, then in another 30 years yet another mild storm may flood past what our current predictions are, given the rise in sea level height. Because of this potential for disaster, a few scientists, especially Klaus Jacob, have advocated for a policy of "planned withdrawal". What this means is that over the next 100 years, the proposed engineering and policy changes will still go ahead as planned. However, they will be put in place with the express purpose of only providing temporary protection to allow for the population to slowly relocate to the mainland. The main proponents of this idea believe that no amount of barriers will be able to fully shield New York, and a withdrawal is the only viable long-term strategy. Relocating 18 million people would be an enormous undertaking, and any such plan would have to begin along the shores in the most vulnerable areas where the damage is most evident. Because many of the residents in New York have deep cultural and social connections there, even convincing them to move in the first place would prove to be a challenge; this is why a comprehensive educational program would also need to be put in place. Even Governor Cuomo's plans for a buyout of currently ruined land has faced logistical problems and opposition (Kaplan, 2013). As the New York Times notes, Cuomo is seeking 400 million dollars in aid from the state government to buyout ruined properties at their original costs. "The land would never be built on again. Some properties could be turned into dunes, wetlands or other natural buffers that would help protect coastal communities from ferocious storms; other parcels could be combined and turned into public parkland". This has met with active resistance from the residents there, even though their homes were completely destroyed by the storm. Implementing such a program on a city-wide scale would then need to be undertaken even more gradually, within 100 years.

4. Environmental Economics; It's the Math

4A. Defining How Environmental Worth is Calculated

All of the previously examined plans may seem like ideal solutions to a looming problem, but any and all proposals would have to be priced out before being put into effect; and because many of them involve changing the environment in some way as to alter the ecosystem, there needs to be an examination along environmentally economic lines. The study of environmental economics holds then preservation of "natural capital", or resources only found in nature, at its core. As such, not only would the monetary costs need to be looked at (and weighed versus the benefits), but the impact that a particular plan would have on any natural systems would also have to factor in. This includes the unintended costs that humans and members of the biosphere would have to experience, or externalities. Externalities can be either positive or negative, but in either case they are usually considered "afterthoughts" in the decision making process.

4B. Weighing the Costs and Benefits

Cost benefit analysis is a core tenet of environmental economics, as well as of any rational policy making model. Before construction can begin on any large project, or before a new regulation can be passed, the potential impacts, detriments and who will share each of them needs to be accounted for. As such, a few of the major proposals that this paper mentions will need to be evaluated as such.

The large seawalls that would surround the lower coastal regions of the city would cost billions of dollars, and take years to complete if they were started today, as mentioned in section **2B**. In addition, Klaus Jacobs, in his defense of withdrawal, also explained that such seawalls only have an effective lifespan of 20-30 years. Besides the repeated impacts from waves, which would already necessitate constant upkeep, once sea levels had risen high enough there would be a disparity between the water in front of and behind of the wall. After a certain point, water would no longer be able to flow back out, causing flooding on the city side even if the storm surge had not breached the wall. In addition, because sea levels are rising, this also presents the secondary problem; after a certain period of time, depending on the rate of seal level rise, storm surges may simply begin to pass over the top of the wall. If the increased erosion factor is added in to our estimates, then there will come a point where such a wall (or series of walls) would simply start causing more harm than good. While their initial installation might cause a smaller amount of ecological damage, if it's seen as being relative to the initial benefit, then seawalls are an attractive option. However, if the timescale is increased then their flaws become obvious. As with any of these proposals, both the long and short-term costs must be considered.

When evaluating the soft engineering approaches seen in **2C**, the same sort of approach must be taken. Although the expansion of New York's shoreline in this way would provide a marginal amount of protection during a current storm and help to reduce the number of CSO occurrences, its long-term protection value isn't precisely known (if it were to be enacted alone). However, the positive externalities that could be produced by such an initiative would include more recreational space for New Yorkers, cleaner air and water, educational opportunities, the reintroduction of a lost ecosystem and a cheaper system of mass transportation. The parks themselves might also charge for entry, potentially making back some of their initial investment later down the line. While this option might also prove to be expensive due to the high cost of dredging the soil needed, installing the marshes and converting the streets, the preservation of the more expensive infrastructure further inland as a result might prove valuable enough to pursue this option. If both of these approaches were implemented simultaneously, then they would largely act to balance out each other's drawbacks. However, the life of this system would still be restrained by the limitations of the seawall and the financial costs would be double that of a single project.

On the policy side, the proposed measures under PLANYC are already being paid for via taxpayer money or through private initiatives, and serve to streamline operations and reduce greenhouse gas emissions to the point where a cost benefit analysis isn't required. However, the plan for any sort of withdrawal would need to be examined very closely before considering it viable. On the economic side, it would prove to be very, very expensive. Even Cuomo's relatively small relocation will cost 400 million dollars, as it involves buying out the homeowners, razing their wrecked houses and installing some kind of storm barriers in their stead. If this sort of program was expanded to a city-wide level, the monetary costs would likely be staggering. The federal government also hasn't given the Cuomo administration an approval for this yet either, as the scope is unprecedented. Under eminent domain the government can simply seize an individual's land under extenuating circumstances, but in allowing this deal to go through, critics argue that it can be seen as a slippery slope. If one state government is suddenly given the power to simply buy out its residents, then the precedent exists for other states as well. While an expansion of state and federal power might seem like a bit of a stretch, the fact that it exists as an externality makes it worth mentioning. Ultimately, again the timespan factors in heavily to this decision. In calculating whether such a withdrawal would be necessary, the potential costs of the loss of a majority of New York's infrastructure, the costs of maintaining and periodically rebuilding storm defense systems and the potential loss of life over the next 100 years and beyond should all weigh in to the decision of whether or not to pursue this strategy.

5. Conclusion

New York City, along with much of the world, currently stands at a crossroads. Anthropogenic climate change is a very real risk that is currently endangering our way of life, and will continue to do so for the foreseeable future. As the UN IPCC's thorough reports have shown, mankind faces a large set of upcoming challenges that will need to be dealt with. Sea level rise alone will necessitate an overhaul in coastal infrastructure and how policy makers deal with issues such as zoning, regulating emissions and determining reimbursement and liability after a storm does occur.

As with other disasters in our history, either manmade or natural, the public's awareness of this particular problem has only begun to hit home after a direct impact on their daily lives. Hurricane Sandy proved 3 things to the populace: that climate change can have a tangible effect, that previous storm preparation plans and defenses are woefully inadequate in light of climate change, and that future preparations would need to be designed in such a way as to account for future rises in sea level. Simply engineering our way out of such a problem isn't enough, despite claims to the contrary. On a scale of 10-50 years, then such projects seem feasible, even recommended; but when the timetable increases to 100 years it becomes much clearer that additional measures must also be taken. While a seawall and a natural extension of the shorelines might provide some relief, eventually any such measures would be overtaken. That isn't to say that they shouldn't be built; if the positive ecological and cultural benefits of expanding New York City's green spaces can be met in doing so, and if the amount of infrastructure being protected exceeds the cost of the project, then it makes economic sense to do so.

Ultimately, the best course of action for New York may be to simply withdraw, over a long period of time, back to mainland. While this process would be costly, exhausting and difficult to implement at first, the earlier the process begins the easier it will be. Allowing the same cycle of building and destruction to simply repeat is a waste of resources as well as human life. In establishing these guidelines on how to adapt, and when *not* to adapt, New York City can serve as a guide for the rest of the world in dealing with climate change issues.

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