Cost-Benefit Analysis of Storm Surge Barriers vs. Unmitigated Damage due to Costal Flooding in New York City

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Abstract

The threat of coast flooding poses a significant economic hazard to New York City. Several storm surge barriers have been proposed for the main water inlets into the city, however their substantial initial investment makes their cost difficult to immediately justify. In order to determine their economic feasibility, the projected cost of these surge barriers was compared to potential financial losses due to a 15' and 30' floodplain in the absence of any barrier protection. Data provided by FEMA was used with hazard estimation software to calculate the direct economic cost of flooding.

1. Introduction

According to a recent study estimating the exposure of large port cities to flood events, New York City ranked as one of the most financially vulnerable cities to coastal flooding in the world (Hanson, Nicholls, and et al). Much of this financial liability is due to a particularly high concentration of public utilities (such as energy, wasterwater and transportation facilities) along low lying coastline. The problem of coastal flooding is likewise compounded by sea level rise due to climate change which is predicted to accelerate the occurrence and magnitude of flooding. For example, a flood event which currently occurs once a decade is expected to occur three times as frequently by the close of the century (NPCC).

The clear urgency for coastal flooding protection has been met with several proposals, with one of the most promising including the construction of storm surge barriers at various strategic locations across the city. Three barriers presented at the ASCE Infrastructure Group Seminar and which are considered in this report are the:

Verrazano Narrows Barrier – designed by Arcadis to connect Staten Island and Brooklyn at the entrance of the Upper NY-NJ Bay and includes large gates for ship traffic. Estimated cost of $6.5 billion (Jansen and Dircke).

Arthur Kill Barrier – designed by Camp Dresser & McKee to connect Staten Island and New Jersey at Arthur Kill, capable of generating electricity from tidal changes and allows for traffic. Estimated cost of $1.5 billion (Murphy and Schoettle).

East River Barrier – designed by Parson Brinkerhoof to connect the Bronx and Queens between the East River and Long Island Sound and allow for vessels to pass. Estimated cost of $1.5 billion (Abrahams).

These barriers in tandem provide considerable flood protection, although as our previous research shows, there are still portions of New York City which would suffer flooding even with barriers in place. Furthermore, our analysis shows that as is, the location and length of these proposals is not optimal. Our previous research and modified barriers are summarized in Figure 3a. Along with these inadequacies, there is a considerable cost associated with constructing the barriers, both in terms of their initial investment and operating costs. For example, Arcadis estimates an annual O&M cost of $75 million (Jansen and Dircke). These factors, along with the potential cost associated with damage due to a flood event must be considered to determine the feasibility of surge barriers in New York City.

2. Methodology

In order to determine the economic feasibility of implementing these proposals, our purpose in this research was to estimate and compare the *cost of storm surge barrier construction* to the *cost of potential damage* due to an unmitigated flood event. Using these findings, a more educated conclusion could be drawn on whether the potential financial losses due flooding warrant the high initial and reoccurring cost of constructing surge barriers. Our analysis considered two flood scenarios—a floodplain defined by flooding of 15 and 30 feet above sea level.

Several factors were considered when trying to estimate the cost of the surge barriers. Firstly, the barrier proposals presented at the ASCE Infrastructure Group

Seminar included rough estimates which served as our basis. Secondly, our previous research on barrier construction in New York City showed that these proposals were insufficient in length and thus their cost needed to be modified accordingly. Throughout our estimation we kept in mind historical data on barrier costs as well as consulted with surge barrier experts to further refine our cost estimation. Our procedure for determining the cost of barrier construction is outlined in the following section.

To calculate the cost of damage due to flooding, our research used HAZUS-MH, which is a natural hazard loss estimation software distributed by the Federal Emergency Management Agency (FEMA). Using data compiled by federal agencies describing a wide range of parameters such as the location and value of essential facilities, transportation systems and utility infrastrucutre, the damage caused by flooding could be determined. This was done by using HAZUS-MH to define a flood region, determine the intensity of the flood hazard, and finally calculate potential loses. For the purpose of our research, HAZUS-MH was used to calculate the total financial loss due to damage done to buildings in New York City. The types of buildings considered included residential, commercial, utilities, hospitals, schools and others. The estimation of damage took into account several parameters such as losses in building's value, inventory, income, wage, output and the cost of relocation. These total losses were calculated over census tracts, which are regions used for the purpose of taking a census and typically coincide with geographic boundaries such as major streets and other administrative areas.

An important consideration we kept in mind throughout our research was that HAZUS was an estimate tool rather than a precise calculator of economic loses. Our use of HAZUS consisted of a Level 1 Analysis, which is the simplest form of analysis provided by HAZUS and which solely uses data provided by government agencies such as FEMA rather than being user defined. Since the worth of assets in New York City is constantly changing, relying only on recent government data may provide a reasonable but not a completely accurate analysis of economic losses. A more advanced use of HAZUS (Level 2 and 3) would require a more extensive input of information.

2. Storm Surge Barriers

As a basis for our barrier estimation we used the proposals offered at the ASCE Infrastructure Conference. Due to their nature as rough proposals rather than actual competitive bids, we kept in mind that these estimates were undervalued in order to make them attractive proposals for actual construction. To account for this fact, the estimates were marked up by 10%. Considering historic data on the cost of barriers such as the Thames Barrier in the United Kingdom and the St. Petersburg Barrier in Russia, of which the New York City barriers were mainly inspired by, this markup was relatively reasonable.

Our previous research shows that the positioning and length of these proposals is not sufficient to prevent residual flooding around the barriers. The Arthur Kill barrier for example would need to be more than twice its originally proposed length in order to effectively repel a surge. Our estimates for the barriers were therefore adjusted by a percentage relative to the length of our modified barriers and the final estimates are summarized in Table 1.

Surge Barrier	Original Estimate ($B)	% Increase Due to Modification	% Markup	Final Estimate
Verrazano Narrows	6.5	1%	10%	7.2
Arthur Kill	1.5	143%	10%	4
East River	1.5	54%	10%	2.5
	Total Cost of Surge Barrier Construction			**13.7**

Table 1 - Final Barrier Cost Estimation

As can be seen, the total cost of protecting New York City with surge barriers is approximately $14 billion. Although not considered in our analysis, other costs are associated with barrier construction. These include operating, maintenance and insurance costs which over the service life of a surge barrier can amount to a considerable amount. Furthermore, constructing barriers would inevitably interfere with surrounding areas which would incur additional costs. For example, the heavily traveled Belt Parkway in Brooklyn would need to be rerouted in order to accommodate the Verrazano Narrows Barrier.

3. Total Losses due to Flooding

Using HAZUS, the total loss due to a 15’ and 30’ floodplain could be estimated and our findings are respectively summarized in Table 2 and 3. The largest losses come in the form losses to tangible assets, such as buildings and their contents. There are also added losses due to a decrease in productivity which would inevitably follow a large flood event. These losses are more prevalent in commercialized boroughs such as Brooklyn and Manhattan where businesses would experience a drop in sales and output.

Borough	Building Loss ($M)	Contents Loss ($M)	Inventory Loss ($M)	Relocation Cost ($M)	Income Loss ($M)	Rental Income Lost ($M)	Wage Loss ($M)	Direct Output Loss ($M)	Total Loss ($B)
Bronx	518	614	21	1	1	0	2	4	1.15
Staten Island	1,633	1,625	30	2	3	1	4	10	3.29
Queens	5,004	4,744	75	5	6	4	11	27	9.84
Brooklyn	12,724	12,432	244	14	24	12	32	80	25.48
Manhattan	6,455	7,611	76	10	27	9	26	69	14.21
					Total Loss due to 15’ Floodplain				53.97

Table 2- Losses due to 15' Floodplain

Borough	Building Loss ($M)	Contents Loss ($M)	Inventory Loss ($M)	Relocation Cost ($M)	Income Loss ($M)	Rental Income Lost ($M)	Wage Loss ($M)	Direct Output Loss ($M)	Total Loss ($B)
Bronx	10,517	9,009	121	12	30	11	22	64	19.72
Staten Island	5,470	4,029	66	4	6	2	9	25	9.58
Queens	18,801	14,151	247	16	20	11	32	81	33.27
Brooklyn	41,335	31,033	579	33	49	29	80	221	73.13
Manhattan	31,059	28,378	268	31	77	30	107	238	59.94
					Total Loss due to 30’ Floodplain				195.64

Table 3- Losses due to 30' Floodplain

As expected, the highest density of damage occurs in Manhattan, particularly in the area surrounding Battery Park in which there is a concentration of commercial buildings. Another area of concern is southern Brooklyn, where expensive residential buildings are at risk of flooding. An interesting conclusion from our data is that Brooklyn experiences more aggregate loss than Manhattan. There are two possible explanations to this result. Firstly, Brooklyn is a densely populated borough with many residential and commercial buildings. Secondly, Brooklyn's low lying coastline makes it one of the most vulnerable boroughs to flooding. For example, with a 30 ft floodplain nearly four times as much land is flooded in Brooklyn than is in Manhattan.

Although the parts of Queens and the Bronx along the East River and Staten Island would experience significant flooding (the coastline would recede by nearly half a mile in the 15 ft. floodplain scenario), the financial losses are comparatively less than the other boroughs. This can be explained by the fact that flood prone regions in these boroughs consist mostly of park land which is not as commercialized or populated. There are exceptions however, such as local airports and ports which would be at risk.

The total losses were likewise plotted relative to census blocks and are shown in Figures 3c-d and 4c-d. "Aggregate Damage" is the total loss for each census block's general occupancy, as calculated by Hazus. These were plotted over New York in a gradient of eight shades of red, each corresponding to a range of values with heavier shades of red signifying severer damage. Each range of values is ½ standard deviation of Manhattan's damage values, whose census blocks incurred the highest damage value of all boroughs and has a range of \$0B to \$1.3B. Nonetheless, we found that merely plotting "Aggregate Damage" had some visualization difficulty: larger census blocks tend to be heavier in color because they are larger in size and therefore contain more assets. As another perspective, we also plotted damage per feet squared by dividing the total loss per census block by the square footage of that block (as projected on a 2D plane). For a clearer view, the total losses per feet squared for each of the individual boroughs is shown in Figures 5-9.

4. Surge Barriers vs. Total Losses

Having determined the losses due to flooding, the feasibility of the surge barriers could be determined. From our previous research, we used two barrier scenarios which most greatly reduced the area prone to flooding. Scenario A and B are almost identical, other than for a part of the Bronx. Specifically, scenario B protects the Bronx by an additional $8B compared to scenario A for a 30 foot surge; yet, this added protection reduces to a relatively insignificant $40M for a 15 foot surge. Further, scenario B comes at a much higher cost than A, rendering it unnecessary if the system is not designed for a 30 feet foot. In the case of a 30 foot floodplain (Table 5), the total value of assets saved is over $100 billion, which makes constructing the barrier system for a mere $14 billion an obvious choice.

For the 15 foot floodplain (Table 4), the total value of assets saved is about $23 billion dollars, which still surpasses the estimated cost of the barriers however the difference is small enough that additional factors must be considered before determining whether the barriers are economically feasible. For example, one would need to consider the probability of such a flood event and the likelihood of it occurring during the service life of the barrier system.

		Barrier System A		Barrier System B	
Borough	**Total Loss ($B)**	**Total Protected ($B)**	**% Saved**	**Total Protected ($B)**	**% Saved**
Bronx	1.16	0.79	68.25%	0.83	71.91%
Staten Island	3.30	0.95	28.79%	0.95	28.79%
Queens	9.85	1.83	18.61%	1.83	18.61%
Brooklyn	25.48	4.80	18.83%	4.80	18.83
Manhattan	14.21	14.21	100.00%	14.21	100.00%
Total	**54.00**	**22.58**	**41.82%**	**22.63**	**41.90%**

Table 4- Total Losses from 15' Floodplain relative to barrier scenarios

		Barrier System A		Barrier System B	
Borough	Total Loss ($B)	Total Protected ($B)	% Saved	Total Protected ($B)	% Saved
Bronx	19.72	10.33	52.38%	18.27	92.61%
Staten Island	9.59	4.21	43.96%	4.21	43.96%
Queens	33.28	11.82	35.52%	11.82	35.52%
Brooklyn	73.14	16.68	22.81%	16.69	22.82%
Manhattan	59.95	59.95	100.00%	59.95	100.00%
Total	**195.68**	**103.00**	**52.64%**	**110.94**	**56.69%**

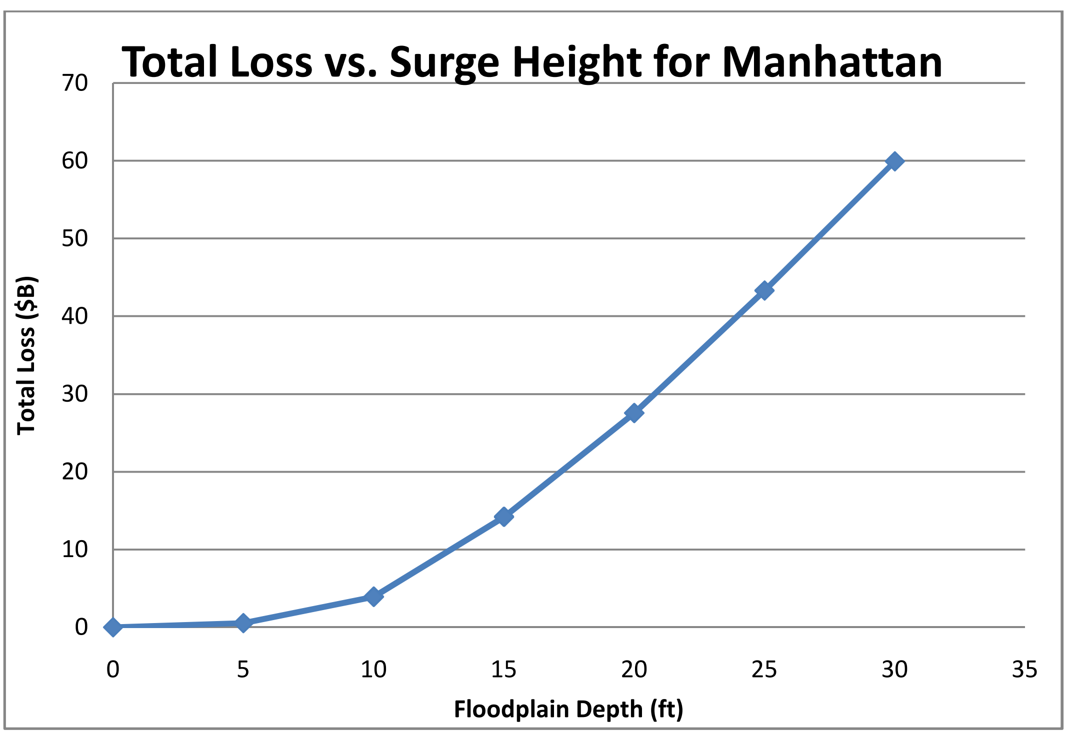
Table 5- Total Losses from 30' Floodplain relative to barrier scenarios

5. Discussion

As noted before, certain areas in New York City will experience more damage during a flood event than others. Rather than the holistic approach to protecting the city from flooding taken by the surge barrier proposals, other “soft” measures can be implemented to reduce and prevent potential losses. Feasible soft measures are (1) setting up temporary small-scale levees to protect underground inventories, and (2) adapting urban planning strategies to projected flood plains. The first measure has already begun to be used to protect New York City’s underground assets such as the subway system. In 2008, the MTA implemented several elevated subway grates to prevent the flooding of selective subways stations. These measures could be similarly applied to subway entrances, as well as any passages to underground assets. Additionally, these levees need not be permanent (as were MTA’s), and can be erected only when anticipating severe storms. Of course, more analysis should be performed to determine how much these measures cost for the entire city, and how much exposed asset could be saved, given various surge heights.

In addition to these almost readily implementable levees, New York City could benefit in the long run from changes in urban planning approaches. In 2011, The New York Academy of Science published a report analyzing how policy changes in flood insurance, building codes, and flooding zoning can stall the future increases in the amount of exposed assets (Aerts). Population growth in urban areas will increase the amount of assets in New York City, and thus, the amount that will be subject to damage by hurricane surges. According to Nicolls et al., although the current estimate of potential damage for the NYC-Newark region is at $320B, this value is expected to increase to $1,739 in 2070, due to population growth (Hanson, Nicholls, and et al). However, changes in flood insurance pricing and in policies regarding developments can discourage or limit the population influx into areas prone to flooding. The mapping of areas prone to flooding itself should be frequently revised, to reflect on the increase in surge likelihood due to climate change. Further, buildings codes could be revised (i.e. to increase the elevation of the lower floors) to decrease the likelihood that lower floor inventories are subject to flooding.

By repeating our analysis for floodplain depths of 10, 20 and 25 feet for economic losses in Manhattan, a conclusion could be drawn as to the relationship between flood levels and damage. As can be seen from Graph 1, the financial loses rise relatively slowly when the floodplain depth is less than 10 feet. However there is a dramatic increase in damage due to flooding once the floodplain passes this threshold with losses rising about $10 billion for every five feet of floodplain depth. Although it is difficult to precisely define the relation, it appears that the relationship between floodplain depth and damage is quadratic.



Graph 1- Total Loss vs. Surge Height for Manhattan

Several conclusions can likewise be drawn from Graph 1. Firstly, Manhattan's natural geography leaves it relatively well protected against floods less than about 5 feet. For losses of less than one billion dollars, it is not economically feasible to construct surge barrier which would cost nearly $15 billion. Secondly, there appears to be a critical floodplain depth around 10 feet after which the potential for loses rises steeply with increases in flooding.

Our choice of analyzing a 15 foot floodplain depth corresponds to about a 1-in-1,000 year event. It is not uncommon for barriers to be constructed for such low likelihoods. For example, the Maeslant Barrier in the Netherlands was designed for a 1-in-10,000 flood event. Furthermore, the frequency of occurrence and magnitude of coastal flooding is expected to increase over the next century due to increases in sea level and climate change. A recent report by the New York City Panel on Climate Change (NPCC) illustrates this trend and is summarized in the Table 6 below.

Flood Event	2020s	2050s	2080s
1-in-10 yrs	~once every 8 to 10 years	~once every 3 to 6 years	~once every 1 to 3 years
6.3 ft	6.5 to 6.8	7.0 to 7.3	7.4 to 8.2
1-in-100 yrs	~once every 65 to 80 years	~once every 35 to 55 years	~once every 15 to 35 years
8.6 ft	8.8 to 9.0	9.2 to 9.6	9.6 to 10.5
1-in-500 yrs	~once every 380 to 450 years	~once every 250 to 330 years	~once every 120 to 250 years
10.7 ft	10.9 to 11.2	11.4 to 11.7	11.8 to 12.6

Table 6- Likelihood and Magnitude of Coastal Flooding

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