Forensic Analysis of the 1893 “New York City” Hurricane: Implications for the Future

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LETTERS TO THE EDITOR

Forensic Analysis of the 1893 "New York City" Hurricane: Implications for the Future

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ABSTRACT

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Examination of an offshore-replenished beach in New York City in 1995 revealed that it contained anthropogenic debris from the distant past. Dating of the debris determined that the archeological items were deposited from a category 1 hurricane that made landfall in New York City on the nights of 23–24 August 1893. This "midnight storm" caused great damage in spite of its relatively low category on the Saffir-Simpson scale. A detailed study of the storm was conducted because it was the first hurricane to hit a major metropolitan area with many high-rise buildings. Subsequent discovery of the original weather records from New York City allowed for the re-creation of meteorological conditions in 1893, and they account for the great destruction it caused. The meteorological data were also used to conduct a SLOSH analysis that provided additional information on the storm. These analyses helped to determine why the damage was so high. The results of this study have provided valuable information for damage mitigation in future northern hurricanes.

ADDITIONAL INDEX WORDS: *New York City hurricane, storm surge amplification, urban hurricane winds, hurricane debris dating, SLOSH analysis*.

INTRODUCTION

In 1995, Rockaway Beach, in New York City (Figure 1), was replenished by the U.S. Army Corps of Engineers. Sand was pumped from offshore to restore the beach after years of storm erosion. A subsequent excavation of the replenished beach showed that the offshore fill was unusual in that it was rich in anthropogenic debris. The fill included bricks, serving utensils, children's toys, liquor and beer bottles, hurricane lamp wick holders, and grooming tools, among other domestic items (Figure 2).

The colors and designs on the dinnerware indicated an origin at least in the early twentieth century. The assortment of artifacts was not typical of domestic debris. The variety of artifacts suggested that it came from a recreational area that had experienced great violence. Over 500 different items were collected and separated by category (Figure 3).

DATING THE EVENT

An attempt to date the materials was made in order to determine the conditions under which this debris was originally deposited offshore. The artifacts were dated using published catalogs that showed production schedules of pottery and glasses, as well as a U.S. Custom Law that specifies the country of origin must be shown on any imported item produced after 1891. Thus, a piece of pottery with the country of origin shown had to have been produced after 1891. The production span of each item was plotted on a bar plot. The point at which the bars coincided was interpreted as the probable year during which all the debris could have been deposited together. The plot suggests that the date was somewhere in the vicinity of the early to mid-1890s (Figure 4).

A search began of New York City periodicals from that period to determine when such a catastrophic event could have

Figure 1. Index map of southeastern New York showing location of Rockaway Beach and waterways mentioned in the text. (Color for this figure is available in the online version of this paper.)

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Figure 2. Examples of artifacts excavated in the Arverne area of Rockaway Beach. (Color for this figure is available in the online version of this paper.)

occurred. After an extensive search, it was found that all the major New York City newspapers from 25 August 1893 recorded the damage from a category 1 hurricane that made a landfall in New York City on that date. The description of the hurricane's damage took up all six columns of the front page of the *New York Times* on 25 August 1893. In the intervening years, New York City had forgotten what had been a major destructive event. The debris from the coastal destruction by the hurricane was washed offshore and remained there for 102 years, until was returned to the shore by the U.S. Army Corps of Engineers.

The 1893 hurricane is very important because it was the first storm to hit a major metropolitan area with high-rise structures. What could still be learned about the storm today in order to help in the prediction of coastal damage from future storms? Could the meteorological conditions of that storm be reconstructed, even though there were no airplanes or radar? These questions became the goals of this research.

Figure 3. Excavation and collection of artifacts from the replenished beach at Arverne in Rockaway Beach. Note the high percentage of artifacts in the beach fill. (Color for this figure is available in the online version of this paper.)

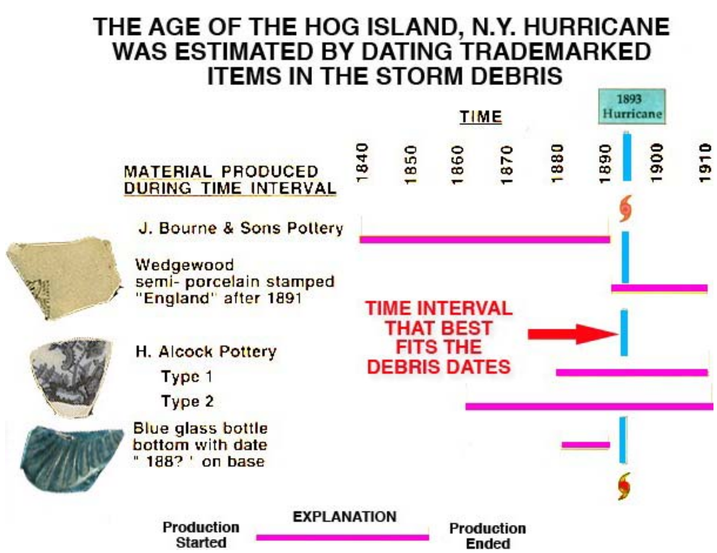

Figure 4. Chart showing the age determination of artifacts in replenished beach fill in the Arverne area of Rockaway Beach. (Color for this figure is available in the online version of this paper.)

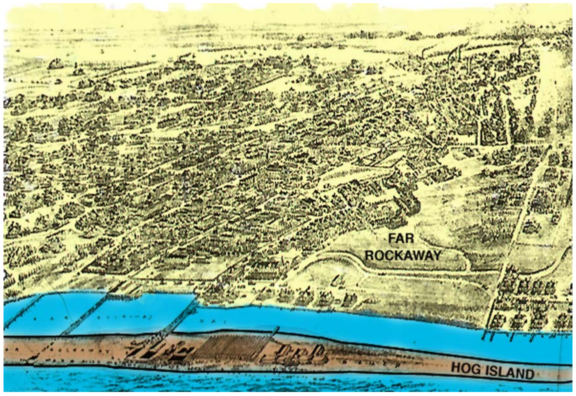

Figure 5. Hog Island as it was before the 1893 hurricane. Source: Bellot (1917). (Color for this figure is available in the online version of this paper.)

HOG ISLAND: THE ISLAND THAT TIME FORGOT

One of the major recreational beaches in New York City in 1893 was Hog Island, known locally as the "The Beach of Far Rockaway" (Figure 5). The island was an eastward-extending barrier island separated from the mainland by a narrow bay (Figure 5). Hog Island was created shortly after the Civil War and "formed gradually by the ocean depositing sand on its westward sweep from Long Beach" (Bellot, 1917). The historic development of Hog Island is illustrated by the series of maps in Figure 6. According to Bellot (1917), the island was well developed for day-trip recreation and had numerous restaurants, bars, and bathing houses (Figure 5). On the night of August 24th, Hog Island was swept clean and heavily eroded in the hurricane. By the twentieth century, it had been reduced to a series of shallow shoals (Figure 6). Hurricanes commonly erode barrier islands, but they rarely *remove* them. How could such extensive damage have been done by what was basically a low-category hurricane? What made the 1893 hurricane so destructive? This research hoped to provide an answer.

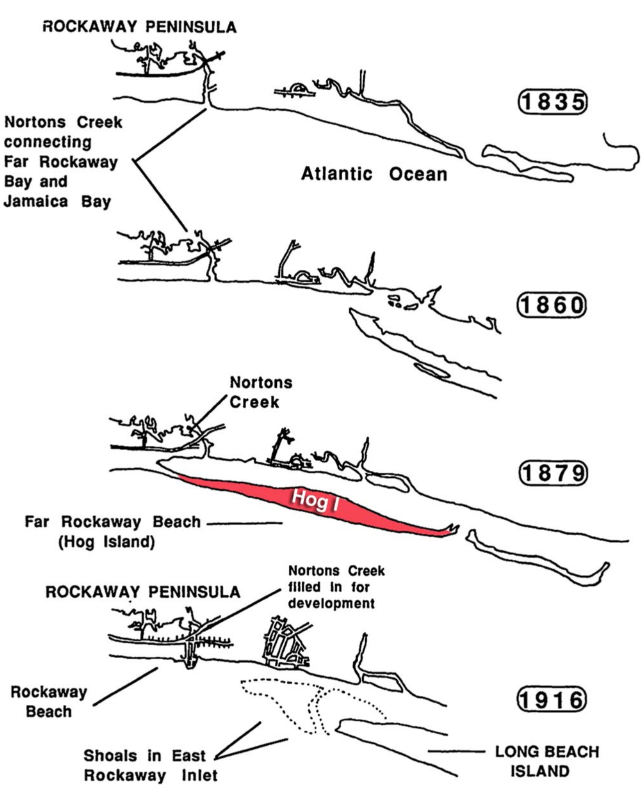

Figure 6. Evolution of Hog Island through time. Based on an undated map in the archives of the New York Public Library. (Color for this figure is available in the online version of this paper.)

DAMAGE REPORTED IN THE 1893 HURRICANE

Newspapers of the time provided details about the interactions of the hurricane with a major metropolitan area. The following quotes are all from the columns of the front page of the *New York Times* for 25 August 1893.

The first interaction between hurricane winds and New York's high-rise structures was recorded from Manhattan:

> *The storm beat with full force on the North and East sides of the (Central) park. Striking the very tall buildings fronting on West Fifty-Ninth street, the wind was reflected back into the park with great violence. Small bushes and trees were snapped from the ground...*

Damage along the coast was extensive:

> *Coney Island came near to blowing out to sea. The cyclone swept the beach almost clean and wrecked many bath houses and other ground...*

Surge heights at Coney Island rose to higher levels than would be expected in a category 1 hurricane:

> *The waves swept in to a distance of 600 feet [183 m] back of the beach, and rose up to a height of thirty feet [9.1 m]. They swept over the elevated (subway) station to such a height that they carried away a twenty-five foot [7.6 m] electric light, which stood near the end of the structure.*

The storm was accompanied by heavy precipitation across New York State (Figure 7). According to the N.Y. State Monthly Weather Report (1894), rainfall was the greatest in southernmost New York:

> *The storm broke the record in the matter of rainfall. From 8 o'clock Wednesday to 8 o'clock yesterday there fell 3.82 inches [9.70 cm] of rain. So much rain never fell in New York State in the same length of time.*

The storm had a significant economic effect as well when Wall Street firms were cut off from the rest of the country:

> *The telegraph wires went down in every direction, like cotton strings, and New York was for a time almost completely cut off from communications with everywhere. For a time the Western Union sent its dispatches to Boston by a personal messenger.*

The storm also went on to destroy areas in southern New England. The question was then postulated: How could a low-

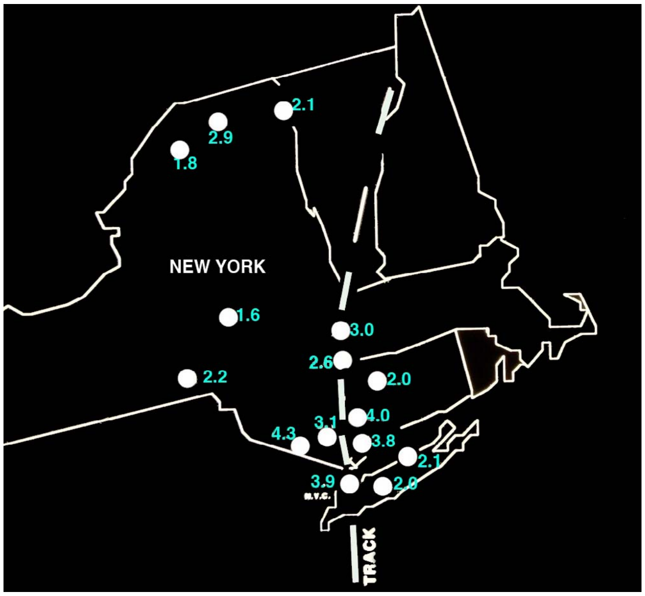

Figure 7. Rainfall values for the 1893 hurricane in New York State. Based on the N.Y. State Monthly Weather Report (1894). (Color for this figure is available in the online version of this paper.)

category hurricane create such high wind, surge, and precipitation destruction?

METEOROLOGY OF THE 1893 HURRICANE

The discovery of the original weather records of the hurricane in the archives of the Library of Congress presented us with a great opportunity. It was now possible to reconstruct the chronology and effects of the hurricane. The New York City Parks Department Weather Observatory in Central Park recorded the barometric pressure and wind direction as well as the wind strength in 1893. At that time, the mechanism for measuring wind speed was a pressure plate reading in pounds per square foot. Efforts were made to obtain a conversion value from plate pressure to wind speed, but they were unsuccessful. Even though it has not been possible to get actual wind speeds, the *relative* wind speeds were plotted from the pressure plate values. The chronology of the storm is shown in Figure 8.

The barometric pressure plot (in inches) shows the arrival of the front eye wall, eye, and rear eye wall of the storm. Storm intensity increased rapidly from 2200 hours onward on August 23rd. This resulted in newspapers referring to it as "The Midnight Storm." The wind force plot (Figure 9) shows the wind increased rapidly until the passage of the rear eye wall. The lowest wind force was at 2000 hours on August 24th, when the eye of the storm was over Central Park in New York City.

SLOSH ANALYSIS OF THE 1893 HURRICANE

Brian Jarvinen (retired) was the surge specialist at the National Hurricane Center in 2000. He used these data to make a SLOSH analysis of the 1893 hurricane in a joint research project. The results were presented at a meeting of the American Meteorological Association (Coch and Jarvinen, 2000).

The SLOSH wind analysis showed that the 1893 hurricane had a very large wind field, with the eye in westernmost Long Island and the radius of maximum winds (Rmax) at Fire Island (Figure 10). The SLOSH storm surge analysis indicated that the surge increased westward from Rmax and reached a maximum value of over 3 m in Raritan Bay, west of New York City (Figure 11). The plot of coastal destruction presented here (Figure 12), based on reports in newspapers, suggests the same pattern.

Normally, storm surge increases on the right side of a landfalling hurricane. This pattern was shown in Hurricane Hugo in 1989 (Coch and Wolff, 1991, Figure 10) and in Hurricane Andrew in 1992 (Coch, 1994, Figure 14). In 1893, the picture was quite different. On the left side, the easterly winds at the front of the hurricane drove coastal waters westward down the coast. It is now known that when a hurricane makes a landfall on Long Island, there is also a major surge increase westward on the left side of the storm (Coch, 2019; Gofseyeff and Pannuzio, 1962). The resulting surge amplification is a function of the right-angle geometry in the New York Bight. The mechanism for this increase in surge is shown in Figure 13. The easterly winds at the front of the hurricane drive coastal waters westward into the right angle made by New York and New Jersey. The trapped waters markedly increase storm-surge levels. In addition, the continental shelf south of Long Island becomes gentler eastward (Coch, 2015, Figure 6). The gentler slope of the western shelf favors the development of higher surge levels. Hours later, the same winds drive Long Island Sound waters westward into New York City.

DAMAGE AMPLIFICATION IN THE 1893 HURRICANE

The wind, surge, and precipitation damage in the 1893 hurricane was significantly greater than would be expected in a low-category hurricane. This was the result of the unique demographic, geographic, and geologic characteristics of the greater New York–New Jersey Metropolitan Area (NYNJMA).

Winds and Urban Structure Damage

According to the Hurricane Research Division (2018), the 1893 hurricane had maximum winds of 86 mi/h (138 km/h), a central pressure of 986 mbar, a radius of maximum winds of 30 mi (48 km) and affected both New York and Connecticut. According to the Saffir Simpson scale (National Hurricane Center, 2018), this makes it a high category 1 storm. The damage description for a category 1 hurricane is as follows (National Hurricane Center, 2018):

> *Very dangerous winds will produce some damage. Well-constructed frame homes could have damage to roof, shingles, vinyl siding, and gutters. Large branches of trees will snap and shallowly-rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.*

A review of damage reports in newspapers of the period showed that wind damage significantly exceeded the descrip-

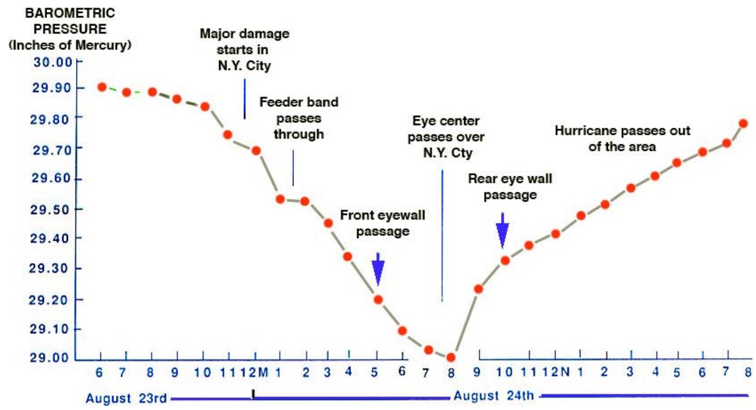

Figure 8. Changes in barometric pressure during the passage of the 1893 hurricane over New York City, plotted and interpreted by the author from records of the Central Park Observatory of the New York City Department of Parks. (Color for this figure is available in the online version of this paper.)

tion above. It was a category 1 hurricane based on maximum winds, but the wind damage significantly exceeded category 1 classification. What could have caused this damage amplification?

The 1893 hurricane was the first recorded interaction between storm winds and high-rise commercial structures. The *New York Times* (1893) reported the reflection of hurricane winds by high-rise buildings. This is only one of the urban wind effects that have been noted in hurricanes since 1893. The complex forces acting on a high-rise building are shown in Coch (2015, Figure 11). Recent gas dispersion studies (Wood *et al*., 2009) have shown that the wind field in an urban area is highly complex. A wind dispersion model for Manhattan (Hanna *et al*., 2006) is most relevant to understanding wind interaction between skyscrapers and hurricane winds in 1893. The figures in Hanna *et al*. (2006) show that the wind flow over an urban skyscraper field is both irregular and unpredictable. There are marked changes in wind strength and direction between adjacent streets. These effects have been seen in several recent hurricanes in Florida and Texas. In addition, the winds in southern New York were blowing across bedrock hills and valleys as well as a glacial moraine. This irregular topography created a more intensive and irregular wind field.

Storm Surge

Storm-surge damage in the 1893 hurricane significantly exceeded that expected in a category 1 hurricane. This was largely the result of the geography of the area (Figure 1). It is important to reiterate that the hurricane surge response in the NYNJMA is distinctly different from most other coastal segments in the United States. Any hurricane that makes a landfall on Long Island will result in abnormally high surge levels in New York City. This storm-surge amplification in the apex of the New York Bight is the result of the right-angle

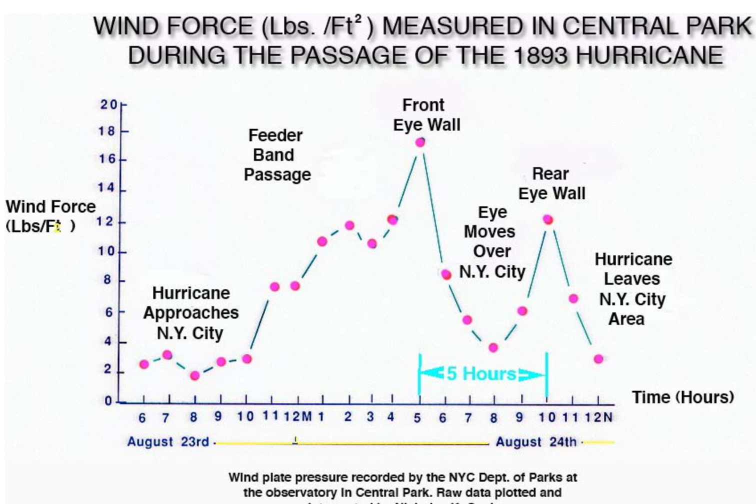

Figure 9. Changes in wind force during the passage of the 1893 hurricane over New York City, plotted and interpreted by the author from records of the Central Park Observatory of the New York City Department of Parks. (Color for this figure is available in the online version of this paper.)

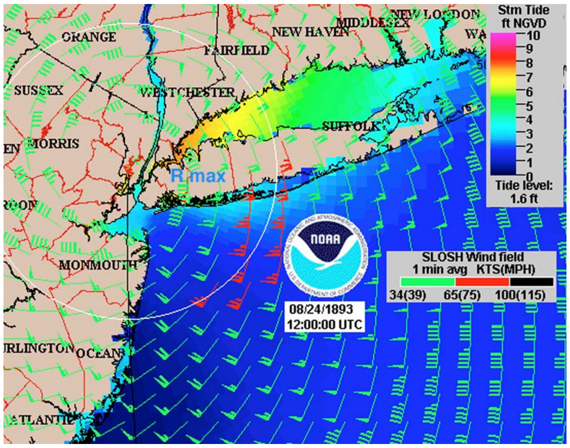

Figure 10. SLOSH model of the wind field of the 1893 hurricane (Coch and Jarvinen, 2000). The hurricane had an immense wind field. The radius of maximum winds (Rmax) was near Fire Island in the central part of the South Shore of Long Island. (Color for this figure is available in the online version of this paper.)

junction of New York and New Jersey, as well as the gentler western shelf slope that was discussed previously.

The mechanism for storm-surge magnification in the NYNJMA is shown in Figure 13. The easterly winds of an approaching hurricane drive coastal waters westward into the junction of New York and New Jersey. Typically, coastal waters are dispersed down the coast in most hurricanes. However in the NYNJMA, they pile up and greatly increase storm-surge

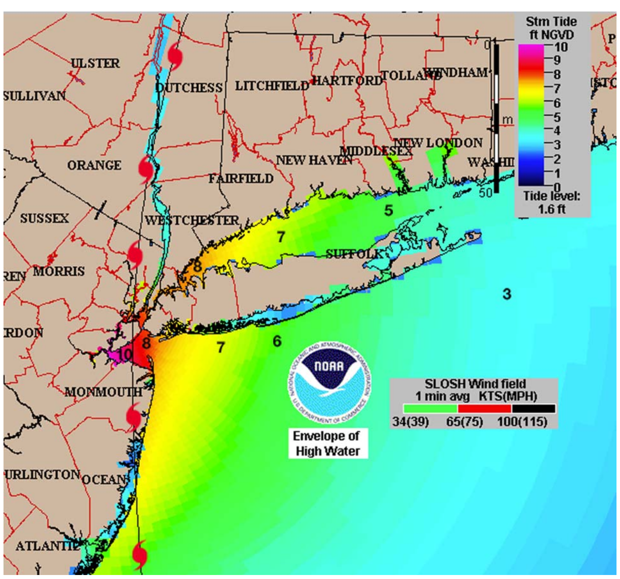

Figure 11. SLOSH model of the storm surge in the 1893 hurricane (Coch and Jarvinen, 2000). The figure shows the anomalous increase in storm surge on the left side of the storm track. The maximum surge was in Raritan Bay, New Jersey. (Color for this figure is available in the online version of this paper.)

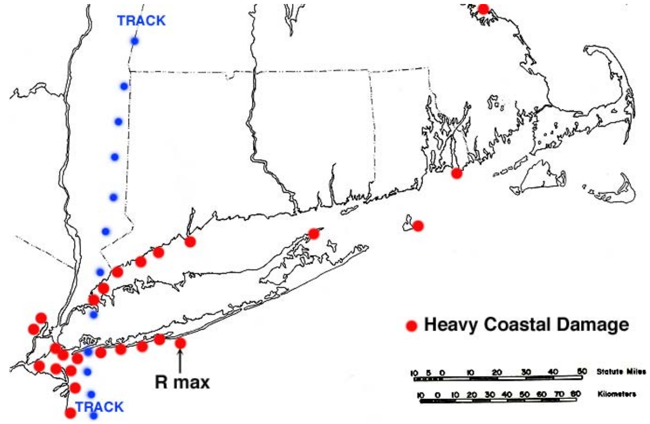

Figure 12. Plot of the areas of highest coastal damage in the 1893 Hurricane. Areas of high destruction are based on newspaper reports. The pattern is in keeping with the SLOSH storm surge prediction results (Figure 11). (Color for this figure is available in the online version of this paper.)

levels. This phenomenon accounts for how a low Saffir-Simpson category hurricane in 1893 could have caused such massive coastal devastation. Hog Island was very close to the right angle defined by New York City and New Jersey. The extreme surge amplification here resulted in the removal of Hog Island.

Hurricane Gloria (1985) made landfall just to the east of Rockaway Beach (Figure 1). Gigi and Wert (1986) pointed out that if Hurricane Gloria (1985) had made landfall further west, the surge damage in New Jersey would have been far greater.

The surge damage reported at the western end of Long Island Sound in New York City (New York Times, 1893) represents another unusual pattern of storm-surge response in southern New York. Several hours after a hurricane passes over the south shore, storm surge rises at the eastern end of Long Island Sound. The easterly winds at the front of the hurricane then drive the waters of Long Island Sound westward, through a decreasing cross section (Coch, 2015, Figure 7).

An example of this second surge event was given by Pore and Barrientos (1976) for the 1938 hurricane. Surge in the eastern part of Long Island Sound was about 2.3 m when the eye of the storm cleared Long Island. The easterly winds created a progressive wave that took about 3 hours to move through the decreasing cross section of Long Island Sound (Figure 1). When it reached New York City, the surge had increased to 3.9 m. This accounts for the reported damage at the western end of Long Island Sound in New York City.

Precipitation

Rainfall across New York State was very heavy in the 1893 hurricane (Figure 7). A hurricane that reaches New York City is no longer flowing over low-lying sandy coastal plains like in the south. Within a few miles of the coast, it encounters hills and valleys of relatively impermeable bedrock or glacial moraine deposits. The inland increase in altitude increases precipitation from moisture-laden hurricane winds. The increase in Hurricane Irene precipitation as it moved inland, over mountainous terrain, was described by Coch (2012). Recent studies have shown that even the modest topography (100 m) of

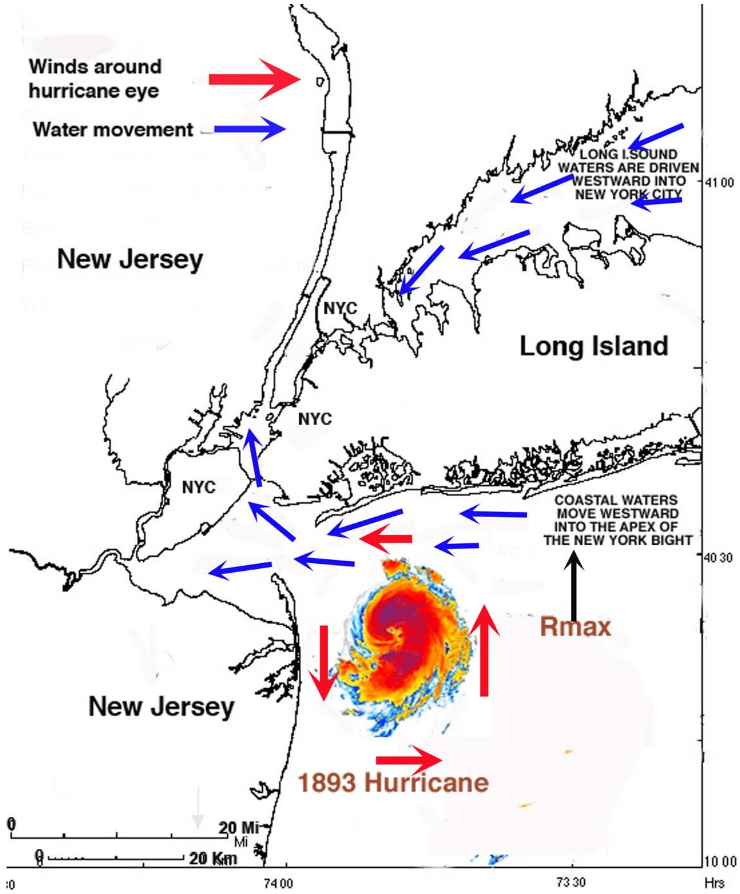

Figure 13. Mechanism for storm surge amplification in the apex of the New York Bight in 1893. The easterly winds at the front of the hurricane move coastal waters westward. The waters are blocked by Staten Island and New Jersey, resulting in higher surge levels in westernmost Long Island and New York City. (Color for this figure is available in the online version of this paper.)

Long Island's glacial moraines can increase rainfall in a hurricane (Cole and Yuter, 2007).

Figure 14. The Hog Island area as it appears today. (Color for this figure is available in the online version of this paper.)

High rainfall also increases water levels in bedrock or concreted areas. Abnormally high water levels in parts of Manhattan in Hurricane Sandy (2012) were attributed by Coch (2014, Figure 10) to a combination of both freshwater and storm-surge waters. Impermeable bedrock (Coch, 2015, Figure 10) and concreted surfaces prevented freshwater infiltration and increased freshwater flow at the same time that saltwater storm surge was moving inland. This effect may have been less in a rather undeveloped New York City in 1893. However, this mechanism must be considered in any future hurricane affecting an urban area in the northeast.

Economic Loss

Little data are available about damage costs in the 1893 hurricane. However, damage to commercial and residential structures, infrastructure, roads, airports, *etc*., could be catastrophic in a future hurricane landfall in New York City. Additional losses will occur as a result of New York City's major role as a service provider and leader in finance, entertainment, fashion, publishing, and other fields. For example, there was considerable financial loss when New York City closed its subways and businesses, entertainment, and other employers in advance of Hurricane Sandy in 2012.

CONCLUSION

The 1893 hurricane showed that New York City is highly vulnerable to hurricane damage because of its unique geologic, geographic, demographic, oceanographic, and topographic characteristics. The phenomenal growth in development since 1893 has greatly increased the potential damage. The 1893 hurricane showed that as a result of these factors, even a low-category hurricane can do more damage than one of similar category that makes landfall to the south. New York City today is a far cry from what it was in 1893. Only imagine what would happen if a hurricane hit the highly developed Rockaway area (Figure 14) today.

ACKNOWLEDGMENTS

Andrew Hagen, of the National Hurricane Center, provided the latest updates on the meteorology of the 1893 hurricane. Brenda Fuqua was of great help in obtaining some of the archive records of the 1893 hurricane. Edgar Diaz dated the excavated items. Tom Liogys supervised field excavations. Numerous other Queens College geology majors participated in our excavations and artifact collections at Rockaway Beach.

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