



HURRICANE GLORIA'S POTENTIAL STORM SURGE

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Scientific Services Division Eastern Region Headquarters July 1986

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Introduction

Hurricane Gloria threatened residents of the New York City metropolitan area on Friday, September 27, 1985. Gloria was one of the strongest north atlantic hurricanes of the century, yet the area never received the full fury of the storm due to the following reasons:

1) The upper right hand quadrant (in this case the northeast quadrant) of a hurricane usually contains the strongest winds and most damaging storm surges. Gloria made landfall near Babylon, Long Island; therefore, the brunt of Gloria's force was felt by residents of Suffolk County.

2) The storm gained a rapid forward speed as it approached our area. This meant that hurricane-force winds were experienced for only a short period of time.

3) Gloria weakened tremendously before making landfall. A contributing factor may have been the colder water temperatures along the New Jersey and Long Island shores.

4) The hurricane struck close to low-tide.

Storm Surges

The greatest losses of life and destruction from hurricanes result from the coastal flooding associated with the storm surge rather than storm winds. A storm surge (or tidal wave) is an abnormal rise of sea level along the shore which accompanies the hurricane at landfall. The storm surge is generated by the combination of strong winds and reduced air pressure. Storm surges were responsible for 6000 deaths in Galveston, Texas in 1900. A 25-foot storm surge accompanied hurricane Camille, making it one of the costliest storms of this century.

The actual storm surges which accompanied Gloria were seven feet at Bergen Point, New York; Sandy Hook, New Jersey; and the Battery, New York City; and 4.5 feet at Willets Point, New York. Figures one through four indicate that most of the coastal waters were close to low-tide at the time of Gloria's arrival, with the exception of western Long Island Sound. The actual storm tide (the combination of the astronomical tide and storm surge) for Gloria was similar to that resulting from a strong wintertime coastal storm.

Hypothetical High Tide Flooding Damages

Flooding due to Gloria cost the metropolitan area well over ten million dollars. Water levels were only around five feet above sea level because the rise in storm surge was offset by falling tidal heights. The damage due to coastal flooding and beach erosion would have been significantly greater if Gloria traveled more slowly and arrived at high-tide on Friday night. This would apply even if Gloria made landfall at the same location. Figures five through eight show the hypothetical situation of what storm tides would have been if Gloria struck at high-tide. The combination of high tide with the actual observed storm surge from Gloria would have generated storm tides around ten feet above sea level. This does not include the wave heights

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produced by gale-force winds which would have made the actual water level even higher.

Had Gloria come in at high-tide, the water at the Battery would have been 9.8 feet above sea level, setting a new all-time record for this location. The current record, set during Hurricane Donna in 1960, is 8.2 feet. Water levels at Willets Point, Bergen Point and Sandy Hook would have crested at 8.4 feet, 10.0 feet and 10.5 feet above sea level, respectively.

Ten feet may not sound impressive, but many parts of the area that are not protected by dams, seawalls, levees or other protective structures would have been vulnerable if Gloria struck at high-tide. Using National Oceanographic and Atmospheric Administration (NOAA) flood evacuation maps which show topographic heights, each borough would have experienced flooding on an average of 200 feet inland from shore. For example, the three major airports would have sufficient flooding to close them down. All piers and railroad depots on both sides of the Hudson River would be flooded.

Based on NOAA evacuation maps, the following is a listing of what additional areas would have been innundated if Gloria struck at high-tide in the City, northern and central New Jersey, and Long Island:*

<u>Queens</u>: Most of the Rockaways; most of Rosedale south of Sunrise Highway and east of Rockaway Boulevard; parts of South Ozone Park and Howard Beach; all of the islands in Jamaica Bay; most of Alley Pond and Flushing Meadow Park and the Cross Island Parkway along Little Neck Bay; the Long Island Railroad and the Transit

*For locations mentioned in this publication, the reader should refer to Maps 1, 2 and 3 following the Figures.

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Authority Rock-away Divisions.

Brooklyn: All of Coney Island, half of the borough southeast of the area outlined by Flatbush, Flatland, Pennsylvania Avenues and Linden Boulevard; all of the Belt Parkway from the Bay Parkway exit to the Owls Head Park; Newton Creek would have doubled in size.

Manhattan: Ellis, Liberty, most of Governor's and Roosevelt Islands; about 1/6 of Randall and Wards Islands; all of the unelevated portion of the West Side Highway -- Henry Hudson Parkway, and the Harlem River-FDR Drive; 96th Street West to 2nd Avenue; 125th Street East to Broadway; up to 1/5 of a mile inland in lower Manhattan south of 34th Street; all of the subway systems which serve lower Manhattan; all of Battery Park City.

Staten Island: Most of the borough to the southeast of Hyland Boulevard; about 2/3 of the island west of the area bounded by Arthur Kill Road; Richmond Avenue and Morningstar Road; all of the Staten Island Expressway west of Richmond Avenue.

Bronx: Both of the Brother Islands; 1/4 of City Island; about half of Hart Island; half of Co-op City; the Bronx River up to the Cross Bronx Expressway; Westchester Creek up to Westchester Square; 1/3 of Pelham Bay Park; parts of the Hudson Division Metro-North line from the city line southward to near Yankee Stadium; part of the Hunts Point Market; and the Hutchinson River northward into lower Westchester.

The western part of Newark Bay would have tripled in size, according to northern New Jersey NOAA flood evacuation maps, causing waters to surge more than two miles inland and placing most of Newark International Airport under more than three feet of water; the Arthur Kill Waterway would quadruple in size, causing the Rahway River to back up well inland. The increased size of the Arthur Kill and Newark Bay would threaten to place a third of Bayonne and the extreme eastern sections of Carteret

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between Washington and Roosevelt Avenues under water. Sections of Rahway near the Rahway River and the extreme eastern sections of Linden and Elizabeth would be threatened as well. The Passaic and Hackensack Rivers would flood their banks. Parts of Newark along Market Street and most of the towns east of Route 17 could go under water, including the towns of Kearny, Arlington, East Rutherford (including Giant Stadium), Lindhurst, Moonachie, a fourth of Secaucus, sections of Little Ferry (including Teterboro Airport), and sections of Hackensack within 300 feet of the Hackensack River.

According to NOAA evacuation maps, the following is a listing of major roads and railways that might have been effected by Gloria's storm surge if she had come during high-tide:

<u>Major Roads:</u> 3/4 of the entire length of the New Jersey Turnpike between Exit 12 in Carteret and Exit 18 in Palisades Park; most of Belleville Turnpike east of Route 17 in Belleville; Route 3 between Lindhurst and Union City; Route 20 from Carlstadt to Union City; Route 46 between Lodi and Ridgefield Park; a small section of Route 80 between Lodi and Ridgefield Park; a small section of Essex Street along the Hackensack River; Routes 22, 24, 78 and 1-9 near Newark International Airport; most of Schuyler Avenue in Kearny; Hoboken Road near Giant Stadium, Washington Avenue, Moonachie Avenue, Red Neck Avenue, and Moonachie Road in Moonachie.

Railways: 3/4 of the Central Railroad of New Jersey between the Rahway River and the Hudson River; 1/3 of the Lehigh Valley Railroad between Route 22 and the intersection with the Central Railroad of New Jersey; most of the Delaware-Lackawanna, Western, Erie, Erie-Lackawanna, Susquehanna-Western, and New York Central Railroads east of Route 17.

Looking further to the south into central New Jersey, the

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lower branch of the Raritan River would increase to nearly five times its width, making it nearly two miles wide in places. The United States Military Reservation located on the northern banks of the Raritan River could incur serious flooding. Most of the coastal 'towns between South Amboy and Point Pleasant Beach would have been vulnerable to flooding as tidal waters rose. Towns such as Keyport Harbor, Union Beach, Port Monmouth, Sea Bright, Monmouth Beach, Long Branch, Bradley Beach, and Avon-by-the-Sea would have been exceptionally vulnerable to flooding since they are close to the water. Some of these areas are so low in elevation that the storm surge would possibly have penetrated several miles inland. Sandy Hook would be reduced by 25 percent in size and would become an island as the southern portion between Sea Bright disappeared into the sea. Most of the break-waters, docks, and condominiums would have been subjected to the destructive power of the storm surge. Extensive beach erosion would surely have resulted.

Although no tide information was available for Nassau and Suffolk Counties of Long Island, the SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model indicates that a similar storm surge of between five and ten feet would have been experienced over most of Long Island. Based on NOAA evacuation maps, the following is a listing of what areas could have been flooded in Nassau and Suffolk Counties:

Almost all of Long Beach, including the major roadways; parts of the Long Island Railroad Long Beach Division;

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sections of the Loop; Meadowbrook and Wantagh State Parkways south of Merrick Road; most of the beaches from Jones Beach eastward to and including Captree State Park; half of the area south of Merrick Road-Montauk Highway between Grand Avenue in Baldwin and Islip Avenue, including the towns of Oceanside, Freeport, Seaford and Amityville; most of Fire Island; half of Heckscher State Park; small sections of Oakdale, Sayville, Bayport, Bluepoint and Patchogue south of Montauk Highway and Middle Road; all of the beaches between Moriches and Shinneckock Inlet along Dune Road; William Floyd Parkway south of Kommack Road; 1/4 of Mastic Beach, including Whitter and Wavecrest Drives; small sections of Center Moriches; 1/2 of the area south of Montauk Highway between Riverhead road and Ponqueque Avenue, including the Hampton communities of Hampton Bays, Tianas, the Quogues and Westhampton, and parts of Quogue Street and Beach Lane; most of Southampton Beach between Shinnecock Inlet and Halsey Lanes; limited sections along the shores of the Twin Forks east of Shinnecock and Little Peconic Bays.

Maximum Damage Possibilities

However, the worst conditions would have occured in the New York City and New Jersey metropolitan areas had Hurricane Gloria moved <u>along the New Jersey coastal waters during high-tide</u>.^{*} The SLOSH model indicates that a storm surge of up to 15 feet would have occured throughout northeastern New Jersey and New York City. The Delaware Bay Evacuation Study suggests storm surges over 20 feet in the Raritan Bay of New Jersey.

If this scenario had materialized, Gloria could have been the worst storm to hit the area this century. The extent of flooding and damage incurred by the storm would have been catastrophic, and the resultant beach erosion could have significantly altered the coastline of New Jersey and western Long Island. Flooding would have occured over most of Brooklyn

*Assume that the hurricane eye moved 40 miles west of its actual path.

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and Queens south of Kings Highway, Linden Boulevard and Conduit Boulevard, as well as over 1/4 of Manhattan south of 34th Street, and parts of the Bronx south and east of the Bruckner Expressway and New England Thruway. There would have been enough flooding in parts of the upper east side to reach Central Park, and, in Staten Island, about 1/6 of the land would have been under water. Most of the heavily populated areas of northeastern New Jersey would have been severely flooded, and in Central New Jersey, almost all of Sandy Hook and the land between the ocean and the Intercoastal Waterway would have disappeared under water. Since Nassau and Suffolk Counties on Long Island would have been further away from Gloria in this scenario, they would not receive the full fury of the storm. With the exception of moderate flooding along the outer bank beaches from Southampton westward to and including Fire Island, most of Suffolk County would have experienced only minimal flooding.

Conclusion

The New York/New Jersey metropolitan area missed the brunt of the storm. Some might feel that, based on the actual outcome, warnings were not necessary and we must realize that forcasting a hurricane's track is still an inexact science. Specifying the actual points of landfall 24 hours in advance is still subject to large errors and will be for some time into the future. We must remember also that hurricanes are nature's most devastating

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storm. Given their magnitude and our limitation in forecasting the exact track, it seems only prudent to take the course of least regret. The purpose of this paper was to illustrate just what might have happened if Gloria had changed speed and altered course only slightly.

The New York/New Jersey metropolitan area was fortunate with Gloria. Flooding causes nine out of every ten deaths associated with hurricanes as well as causing most of the destruction. Will we be as fortunate next time?

Figure 1. Storm Tide at Bergen Point, N.Y. during Gloria











Figure 4. Storm Tide at Willets Point, w.Y. during Gloria



Figure 5. Storm Tide at the Battery, NYC if the Passage

of Gloria Had Coincided with High Tide







· Figure 7. Storm Tide at Bergen Point, N.Y. if the Passage

of Gloria Had Coincided with High Tide



Figure 8. Storm Tide at Sandy H_{∞} /N.J. if the Passage

of Gloria Had Coincided with High Tide



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