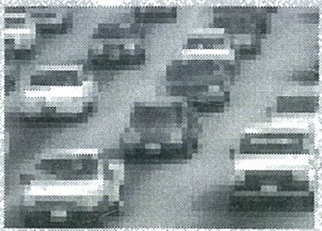
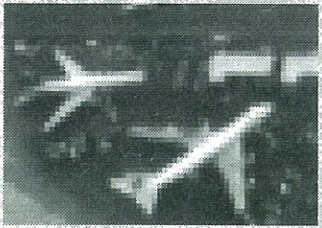
U.S. Army Corps of Engineers • FEMA
National Weather Service
NY/NJ/CT State Emergency Management





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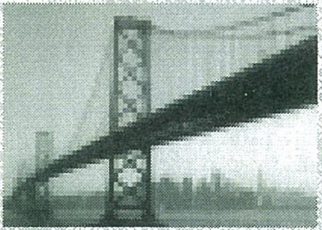
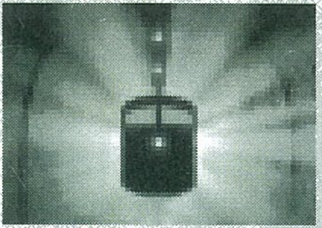
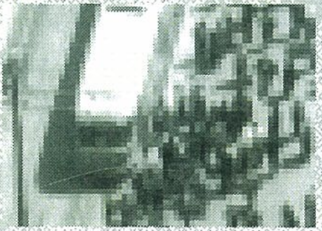
November 1995







METRO NEW YORK HURRICANE TRANSPORTATION STUDY

INTERIM
TECHNICAL DATA REPORT

METRO NEW YORK
HURRICANE TRANSPORTATION STUDY

TABLE OF CONTENTS

ITEM **PAGE NO.**

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS

LIST OF TABLES

TABLE OF CONTENTS

LIST OF FIGURES

TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

Early in 1990, work associated with Hurricane Evacuation Studies for New York, New Jersey, and Connecticut revealed a potential for much higher hurricane surge in the metropolitan New York City (Metro) area than previously believed possible. After researching parameters of hypothetical hurricanes that could affect the Metro area, the National Weather Service used the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) numerical model to compute expected surge heights. **Those computations showed that worst-case surge heights in New York City ranged from about 11 feet for a Category 1 hurricane to over 30 feet for a Category 4 storm.**

Storms that would present low to moderate hazards in other regions of the country could result in heavy loss of life and disastrous disruptions to communication and travel in the Metro area. Although these events have a relatively low frequency of occurrence, emergency management officials are rightly concerned, especially about the obvious consequences of widespread flooding of underground transit systems. **Nearly every rail tunnel system has significant points of entry less than 10 feet above National Geodetic Vertical Datum (NGVD).** When the implications of hurricane strength winds on numerous high-rise structures are also considered, the potential for catastrophe becomes even more disturbing.

The threshold of vulnerability for most Metro transportation systems was exceeded by the surge and winds accompanying the December 1992 extratropical storm. During that event, the still-water level at the Battery tide gage peaked at about 8.5 feet above NGVD and high winds caused traffic accidents that closed several high-rise bridges. Flooding had major impacts in many areas but, with only a few exceptions, stopped just short of being life-threatening. If the storm surge had peaked 2 feet higher, lives could have been lost on the roadways and rail systems.

The dire significance of the December 1992 storm events is revealed by hypothetical time-history data computed by the SLOSH model for Manhattan at the Battery. If the surge associated with that storm had instead resulted from a moderate to severe hurricane, it could have peaked from 16 to 30 feet above normal water levels with a maximum rate-of-rise of 17 feet per hour.

Within the transportation network, high-rise bridges are particularly vulnerable to the hazards of extreme winds. Based on past experience with overturned high profile vehicles, a limiting wind speed should be established for normal bridge operations in the Metro area.

Another consideration is damage to high-rise buildings. During an extreme storm, wind pressures on upper portions of tall structures can be much greater than those at ground level. These pressures can cause significant problems during even a moderate hurricane. Past wind storms in other locations have shown that combinations of wind forces on multi-story buildings can result in window breakage, the destruction of interior partitions, and loss of exterior cladding. In the Metro area, this could create the potential for high numbers of casualties. Not only could building occupants be endangered, but debris falling onto the streets from high above could create an extreme hazard to pedestrians. As high winds begin to damage upper floors of buildings and pedestrians flee street level sidewalks, many will probably turn to subway or PATH stations and their connecting walkways for shelter. **Even if an entrance or surface is above potential flood levels, hurricane surge could quickly fill tunnels below through openings at other locations; they are not safe shelters from severe extratropical storms or hurricanes.**

Riverine flooding in the Passaic River Basin has historically caused extensive property damage and taxed the emergency management resources of New Jersey's State, county, and municipal governments. Several of the passenger rail lines and major highways that link commuters with Manhattan lie in those flood-prone areas. From an emergency management perspective, whether before, during, or after a coastal storm, riverine flooding can disrupt regional rail and highway traffic and operations.

The most effective single action that could be taken to facilitate hurricane response for the Metro area would be a timely decision to curtail or close government and private business prior to the beginning of the work day. This would greatly reduce the number of people using the transportation systems and, potentially, seeking public shelter. In addition, a coordinated program to flood proof vulnerable tunnel openings and raise roadways to a reasonable level should be undertaken.

Each major transportation agency in the Metro area should establish an emergency management office with a designated director responsible for coordinated, unified, interagency planning for coastal storm emergencies. Responsibility for initiating specific emergency actions, including adjusting system operations, should be a function of that office. Communication between all government and private agencies and access to vital information is extremely important. Each emergency management office should have a suitably equipped emergency operations center that, when activated, is responsible for decision making and communication.

Detailed and coordinated coastal storm response and recovery plans are of the utmost importance in protecting the public. Such plans should be developed by each transportation agency for all operating arms as well as the organization as a whole. In addition, a single unified Metro New York plan should be devised that crosses agency lines and establishes clear protocols for facility closure, transportation system operational adjustments, and evacuation decision making. Procedures should be instituted to ensure the coordination of each agency's response efforts with those of other transportation agencies and state and local emergency management offices. Plans must be incorporated into a compatible system among all agencies and governments so that the actions of one can be anticipated and accomplished in concert with others, minimizing hazards and disruptions to the public.

INTERIM
TECHNICAL DATA REPORT

METRO NEW YORK
HURRICANE TRANSPORTATION STUDY

INTRODUCTION

Background

Early in 1990, The Federal Emergency Management Agency (FEMA) and the U.S. Army Corps of Engineers (USACE) were conducting various phases of Hurricane Evacuation Studies for New Jersey, New York, and Connecticut under the FEMA's Hurricane Program. The primary focus of those studies was determining the areas subject to storm surge inundation, the number of residents at risk to hurricane winds and surge, and the time needed to evacuate those people from their homes to safe shelter. For the hazards analysis phase of the studies, the Storm Surge Group at the National Hurricane Center used the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) numerical model to compute worst-case potential hurricane surges in the Metropolitan (Metro) New York area. Previously, projections of hurricane surge heights were based on records of past storms. Work with the SLOSH model revealed that, because of the configuration of the shoreline and the bathymetry of the New York Bight, there is a potential for a much higher hurricane surge in the Metro area than could have been predicted from an analysis of the relatively short historic record. Although the SLOSH model computed potential hurricane surge of over 30 feet above normal tide levels in New York City, a vulnerability analysis by the USACE shows that surge levels of only 10 feet would have dire consequences, including widespread flooding of underground transit systems. When probable severe damage to high-rise structures from hurricane strength winds was also considered, the generally unrecognized potential for catastrophe became especially disturbing. Storms that would present low to moderate hazards in other regions of the country could result in heavy loss of life and disastrous disruptions to communication and travel.

As a result of a May 21, 1990, USACE presentation to transportation officials, the Deputy State Director, New Jersey Office of Emergency Management, expressed concern that the general treatment given transportation-related issues in the hurricane evacuation studies would not provide sufficient support for comprehensive regional emergency transportation plans. In a June 1990 letter to the Commander, North Atlantic Division, USACE, he pointed out perceived shortcomings of the Hurricane Evacuation Studies for the Metro New York area and asked that the USACE and FEMA expand the scope of those studies to address specific transportation vulnerability issues (see Attachment, page 70).

In response to the New Jersey Office of Emergency Management's request, an Executive Study Committee was formed and an initial meeting was held June 20, 1991 (see Exhibit 1, page 72). A significant need was identified beyond the normal scope of the Hurricane Evacuation Studies to educate local government and transportation agency officials about the extraordinary wind and surge hazards, establish the vulnerability of the transportation systems, formulate coordinated emergency transportation plans, and mount an intensive public awareness campaign. The committee decided that a planning effort by Federal, state, and local officials, working in concert with all major transportation agencies, was required to protect the public from the inevitable major hurricane event that will strike the Metro New York area. The Metro New York Hurricane Transportation Study (Metro Study) was conceived as the vehicle through which that goal could best be accomplished. Responsibility for the various tasks was assigned according to areas of expertise among Federal agencies, state emergency management offices, transportation agencies, and consultants.

Although the potential effects of extratropical storms are not specifically addressed in a Hurricane Evacuation Study, the hazards analysis portion of the study provides considerable insight into probable inundation patterns and wind hazards. The analyses in the completed New Jersey, New York, and Connecticut evacuation studies clearly show that, in some areas, a minimal hurricane could produce winds and surge in excess of those experienced with the extratropical storm (nor'easter) of December 11-12, 1992. That storm resulted in a number of major transportation problems in the study area, providing a "wake-up" to the vulnerability of most systems to high winds and/or storm surge that could accompany any severe coastal storm. Virtually every transportation system in the Metro New York area was severely affected. Problems ranged from extended delays on functioning systems to total shut-downs and roadway closures. After that experience, officials began to plan in earnest for a serious hurricane strike.

This year (1995), the New York State Emergency Management Office and the New Jersey Office of Emergency Management are assisting the Port Authority of New York and New Jersey with their Coastal Storm Emergency Planning Project, which is intended to be a guide for other transportation agencies' hurricane preparedness planning. The objectives of this Port Authority project are:

(1) To develop coastal storm emergency response plans which protect life and property.

(2) To prepare an overall coastal storm emergency response plan which ensures a maximum level of coordinated and compatible decision-making, both within the Port Authority and with the city of New York and States of New York and New Jersey.

(3) To develop an overall strategy for coastal storm hazard mitigation for the Port Authority and its facilities, including short-term and long-term initiatives.

The Metro study is not complete, but a large volume of information has been collected and preliminary conclusions on vulnerability have been drawn. This interim report presents the work accomplished to date. Thus far the study effort has concentrated on wind and surge hazards, system operational plans, demands and capacities, and vulnerability. Future work will primarily involve coastal storm emergency planning, mitigation issues, and decision making with the Port Authority and other agencies.

The Technical Data Reports for the completed New Jersey, New York, and Connecticut Hurricane Evacuation Studies contain important relevant information that is not repeated in this report.

Purpose

The purpose of this study is to supplement the New Jersey, New York, and Connecticut Hurricane Evacuation Studies by assessing the potential impact of hurricanes and other severe coastal storms on the users and infrastructure of the Metro New York transportation network and by providing information and assistance toward developing regional plans for those emergencies. The study has the following specific goals:

(1) Identify the potential wind and surge hazards to the facilities and users of each major metropolitan transportation system.

(2) Determine the vulnerability to those hazards and recommend mitigation measures.

(3) Identify offices with decision-making responsibilities related to coastal storm threats.

(4) Recommend decision-making and coordinative procedures.

(5) Formulate specific response actions that should be taken by transportation agencies in coordination with state and local governments.

Authority

This study is being conducted by the Wilmington and Philadelphia Districts and the New England Division, USACE, at the request of the New Jersey Department of Law and Public Safety, Division of State Police, Office of Emergency Management; the State of New York, Division of Military and Naval Affairs, State Emergency Management Office; and the State of Connecticut Office of Emergency Management. The study is supplemental to the New Jersey, New York, and Connecticut Hurricane Evacuation Studies, which are part of a national, co-sponsored effort between the USACE, FEMA, and the National Oceanic and Atmospheric Administration, National Weather Service (NWS). Study authority for FEMA is the Robert T. Stafford Disaster Relief and Emergency Assistance Act, Public Law 93-288, as amended. Through Executive Order 12148, FEMA is delegated primary Federal responsibility; therefore, FEMA is designated program manager. USACE provides study management under the authority of the Flood Plain Management Services program (Section 206 of the 1960 Flood Control Act, Public Law 86-645, as amended).

Funding

USACE and FEMA provided initial study funding in Fiscal Year 1992 and subsequent funding has been shared by those two agencies. The NWS and the states of New York and New Jersey have generously contributed their time, expertise, and coordinative skills.

Study Area

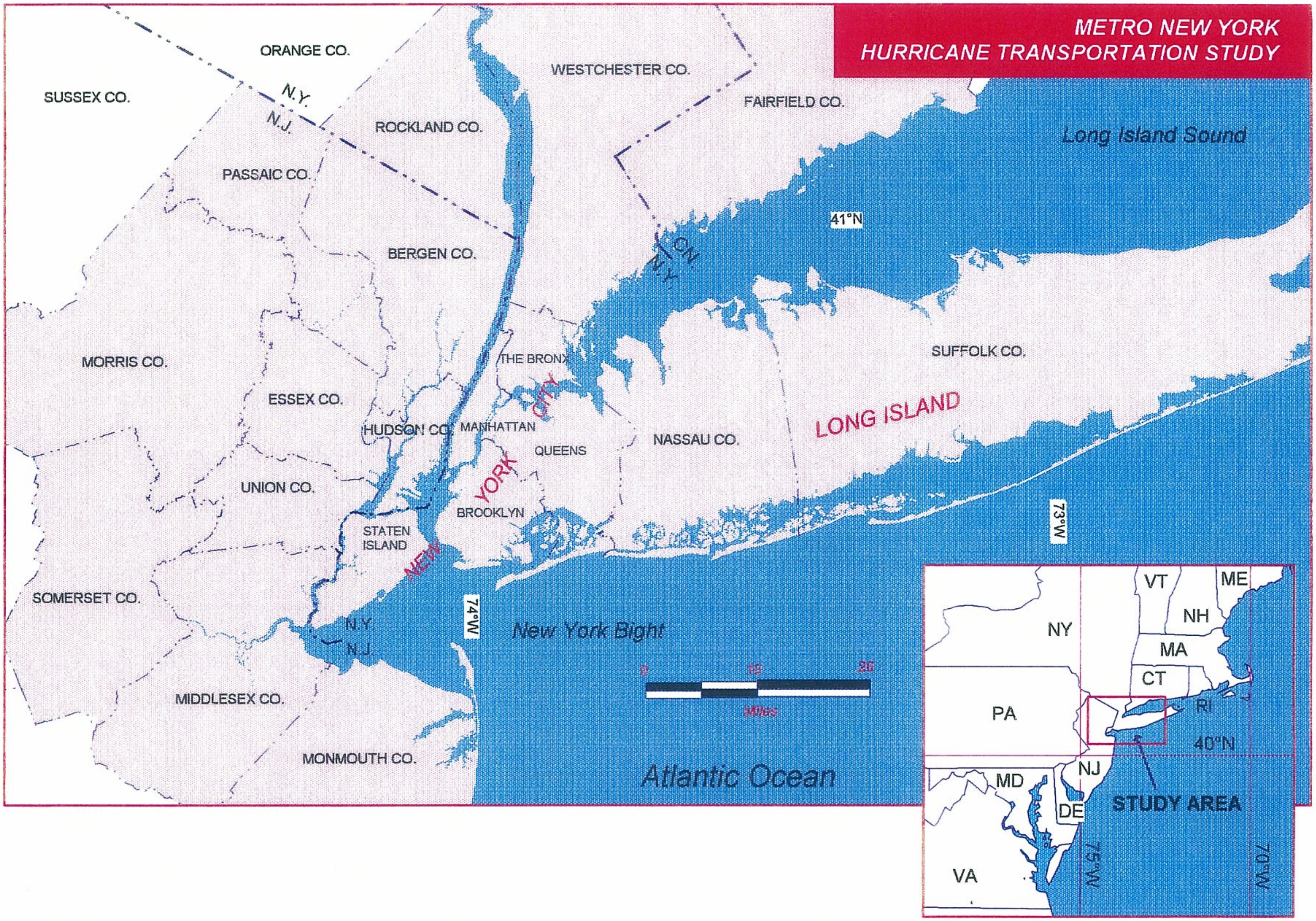
The study area consists of all the boroughs of New York City and the surrounding counties that are considered to be part of Metropolitan New York City. This area includes Morris, Passaic, Somerset, Bergen, Essex, Hudson, Union, Monmouth, and Middlesex Counties in New Jersey; Westchester, Rockland, Nassau, and Suffolk Counties in New York; and Fairfield County in Connecticut. The study area and surrounding region are shown in Figure 1.

Study Management/Coordination

USACE Study Managers for the New Jersey, New York, and Connecticut Hurricane Evacuation Studies share the management of this Metro Study, concentrating on their original areas of responsibility. The Wilmington District, USACE, is furnishing overall study management coordination.

The Executive Study Committee, composed of appropriate USACE, FEMA, NWS, state, and city representatives, provides guidance and coordination for the study. Initially, committee members identified those political jurisdictions, government agencies, and transportation agencies/authorities that should have an active role in preparedness and decision-making related to mass transportation systems. Principal officials of those organizations were asked to appoint appropriate department managers to an Agency Technical Committee.

Agency Technical Committee members (see Exhibit 2, page 73) are serving as the transportation agency/authority points-of-contact for the Study Managers. They are providing the specific technical, operational, and decision-making information that is necessary to conduct the study and are reviewing study products for accuracy and acceptability.



STUDY AREA

FIGURE 1

SYSTEMS ANALYSIS

Agency Systems and Facilities

Several major agencies control most of the mass transit and roadway systems and facilities within the Metro region. Figure 2 shows the Metro New York passenger rail systems while details of the Manhattan rail water crossings are shown on Figure 3. Major highway water crossings within the study area are shown on Figure 4. Appendixes A through I contain hazards and vulnerability data developed for each facility considered in the study. The following is a brief description of agencies and their areas of responsibility.

- The Port Authority of New York and New Jersey is the lead transportation agency in the Metro region in terms of the number of major facilities under its control. Port Authority facilities include the Lincoln and Holland Tunnels and the John F. Kennedy, Newark, LaGuardia, and Teterboro airports. Other Port Authority facilities are the Outerbridge, Goethals, Bayonne, and George Washington Bridges, the World Trade Center, and the following marine facilities: Passenger Ship Terminal, Pier 40, Auto-Marine Terminal, Port Newark & Elizabeth, Red Hook Marine Terminal, and Howland Hook Terminal. The Port Authority Trans-Hudson Corporation rail system connects the World Trade Center and the 33rd Street Terminal on Manhattan with the Hoboken Terminal in Hoboken, New Jersey, the Newark, New Jersey, Pennsylvania Station, and the Journal Square Transportation Center in Jersey City.

- MTA Bridges and Tunnels (formerly Triborough Bridge and Tunnel Authority) also controls several primary facilities within the Metro area. These facilities are the Brooklyn-Battery and Queens Midtown Tunnels and the following bridges: Verrazano-Narrows, Triborough, Bronx-Whitestone, Throgs Neck, Henry Hudson, Marine Parkway-Gil Hodges Memorial, and Cross Bay Veterans Memorial.

- Long Island Rail Road operates rail service from Penn Station in Manhattan to Greenport and Montauk on the north and south forks of eastern Long Island, respectively. Branch lines on Long Island terminate at Port Washington, Long Island City, Flatbush Avenue, Oyster Bay, Port Jefferson, Far Rockaway, Long Beach, Hempstead, and West Hempstead.

- Metro-North Commuter Railroad serves the Metro area with two major lines from Hoboken Terminal in New Jersey and three north from Grand Central Terminal in Manhattan. The New Jersey lines terminate in Port Jervis and Spring Valley, while the lines from Grand Central extend to Poughkeepsie and Dover Plains, New York, and Danbury, Waterbury, and New Haven, Connecticut.

- The New Jersey Transit rail system connects Penn Station, in Manhattan, and Hoboken Station in New Jersey with the Pennsylvania Station in Newark, New Jersey. Branch lines extend to Bay Head, High Bridge, Gladstone, Morristown, and Netcong. New Jersey Transit shares routes to Port Jervis and Spring Valley with Metro-North.

- AMTRAK enters the Metro area from Trenton, New Jersey, passing through the Newark Pennsylvania Station and then into Penn Station, Manhattan. From Penn Station, one branch runs northward, up the Hudson River to Albany, New York, while another runs eastward to New Haven, Connecticut, thence to Hartford and Boston, Massachusetts.

- The New York City Transit Authority controls the NYC subway system, which extends into every city borough except Staten Island.

- The New York City Department of Transportation maintains and controls all highways within the New York City limits. The Garden State Parkway, New Jersey Turnpike, Palisades Interstate Parkway, New York State Thruway, New York State Parks and Recreation parkways, and roadways controlled by the New Jersey and New York State Departments of Transportation carry highway travelers to and from the Metro area.

Daily Peak System Demands

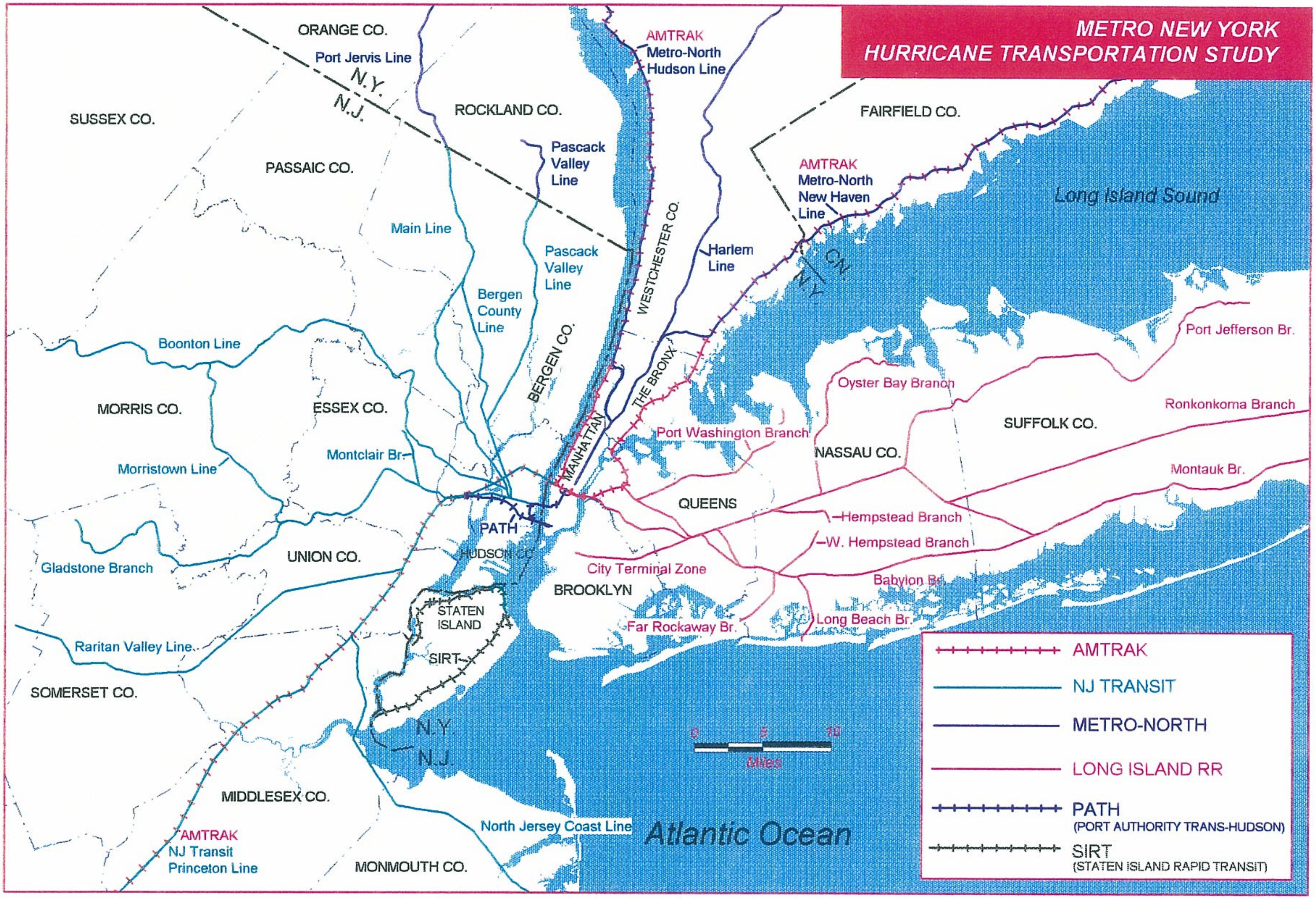
Early in the Metro study, agencies provided statistical summaries of ridership by time of day for each of their system facilities. This data was significant to the study process for four basic reasons:

(1) In a sense, commuters "evacuate" Manhattan every day during the PM peak travel period. Peak system demand data indicates how many people can be transported on an hourly basis by each system and facility. Rather than spend large sums of money trying to model transit evacuation, study participants felt that a close examination of the PM peak period ridership would provide a good approximation of a coastal storm emergency situation.

(2) By comparing ridership exiting the city during the PM peak period, the relative size and role of each system can be ascertained; this could have implications for mitigation priorities in future study phases.

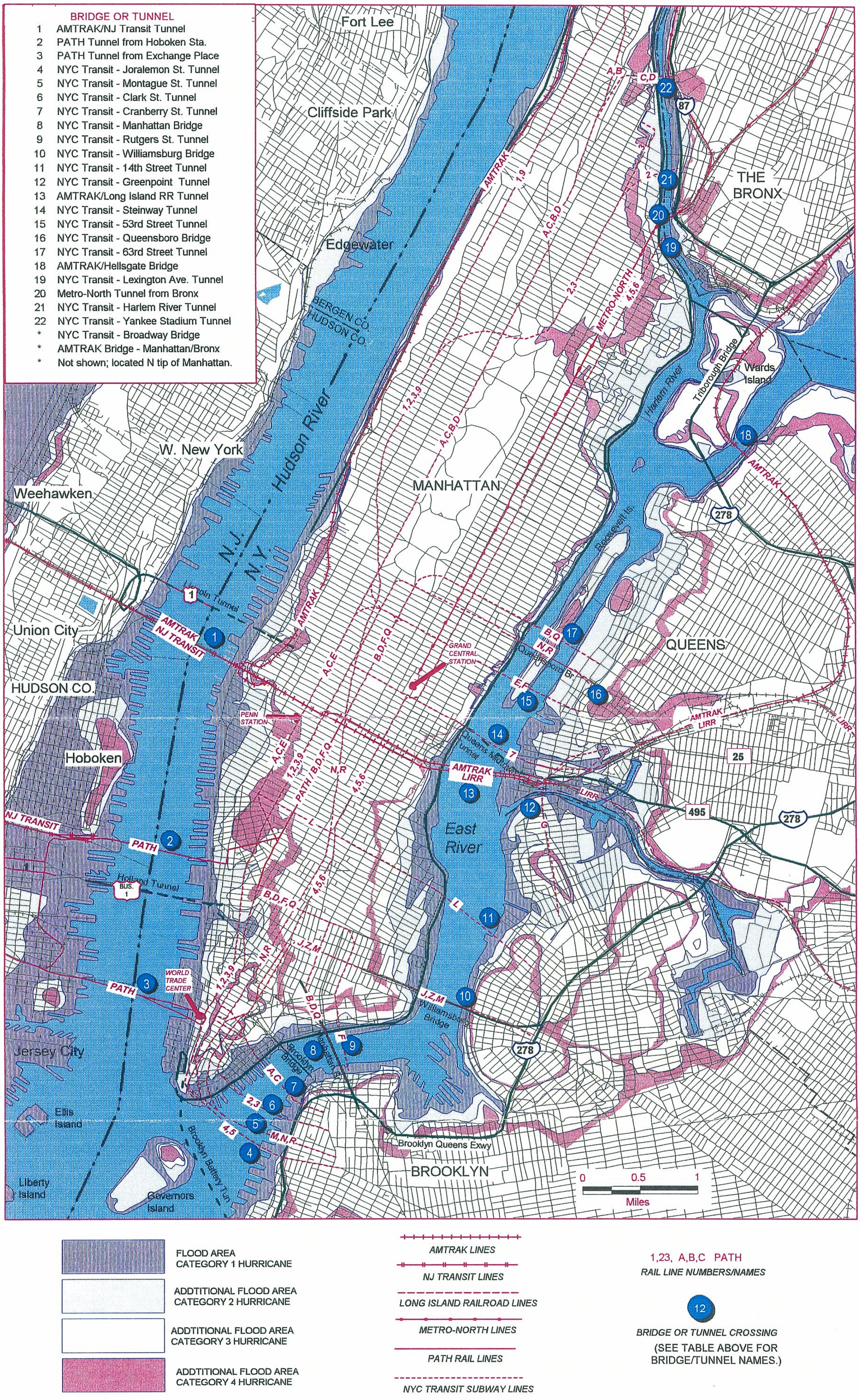
(3) Data on AM peak system demands include the number of commuters that use specific facilities to travel into the city on a normal weekday; the number who could be removed from the burden of Manhattan's evacuation and sheltering efforts if persuaded to stay home.

(4) The time at which AM peak periods occur for various systems indicates when critical decisions regarding emergency "work holidays" or facility closures have to be made.



METRO NEW YORK PASSENGER RAIL SYSTEMS

FIGURE 2



MANHATTAN PASSENGER RAIL WATER CROSSINGS

FIGURE 3

FIG. 4A

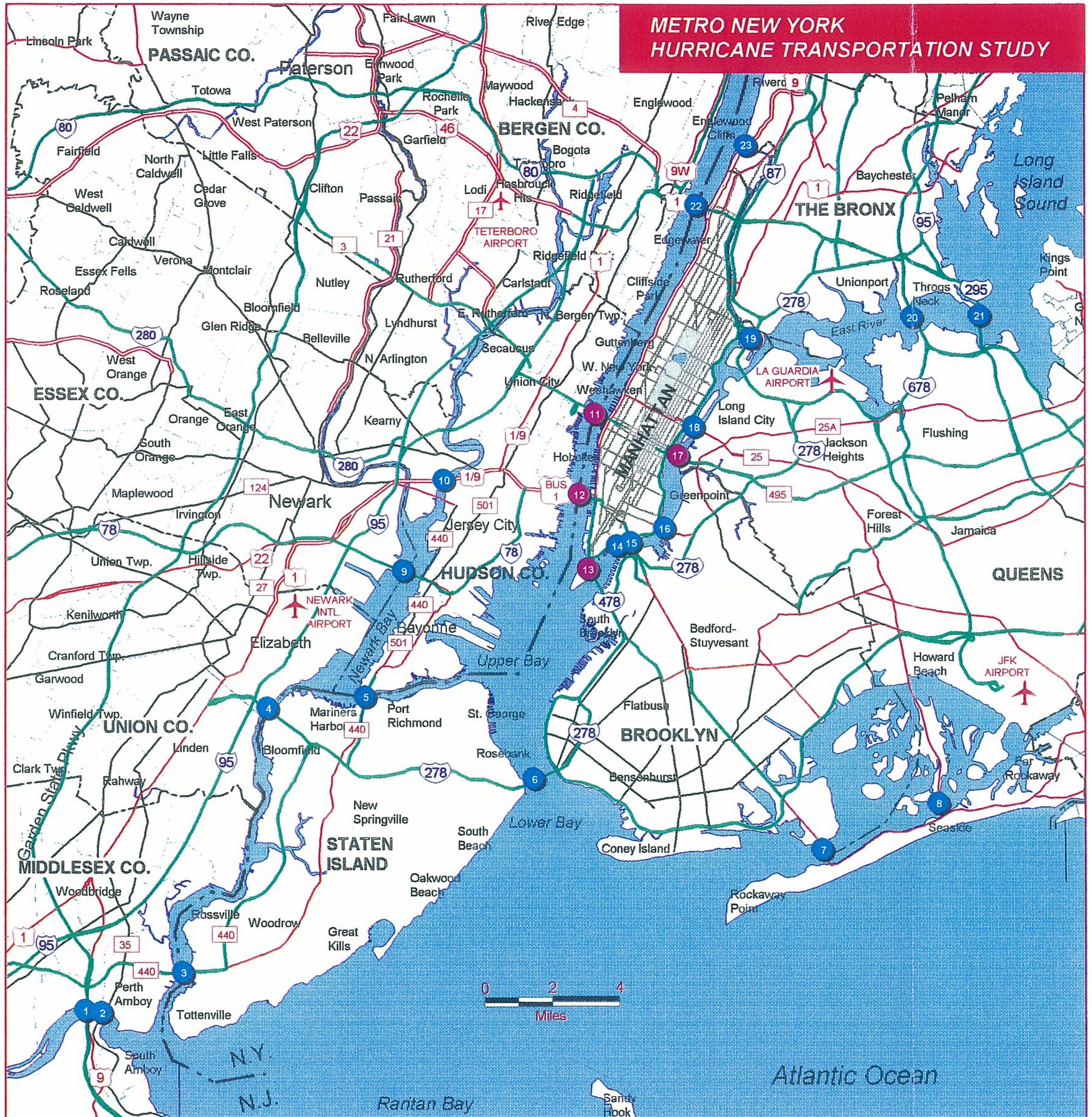
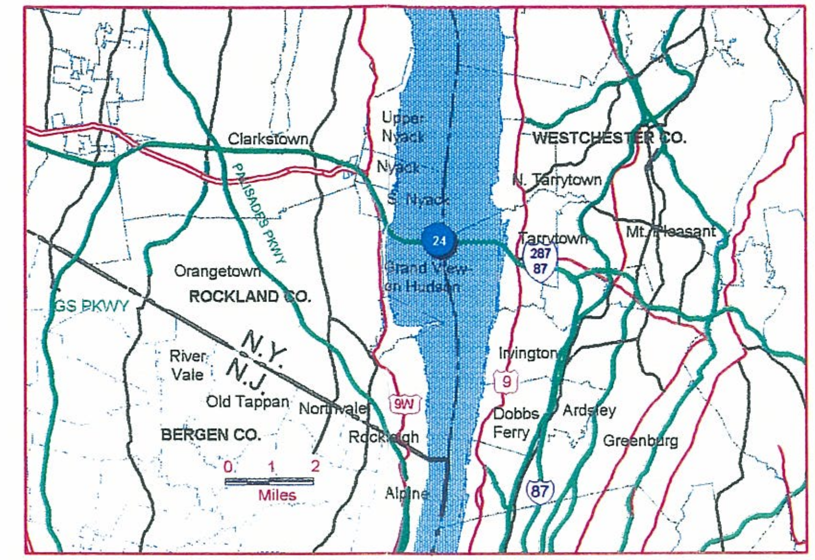


FIG. 4B

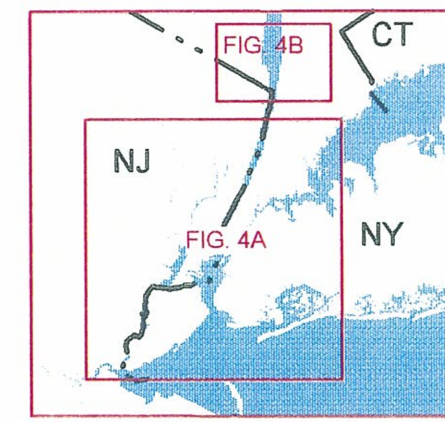


BRIDGE OR TUNNEL

1 Garden State Parkway
2 Victory Bridge - NJ 35
3 Outerbridge Crossing
4 Goethals Bridge
5 Bayonne Bridge
6 Verrazano Bridge
7 Marine Parkway Bridge
8 Cross Bay Bridge
9 New Jersey Turnpike
10 Pulaski Skyway

11 Lincoln Tunnel
12 Holland Tunnel
13 Brooklyn Battery Tunnel
14 Brooklyn Bridge
15 Manhattan Bridge
16 Williamsburg Bridge
17 Queens-Midtown Bridge
18 Queensboro Bridge
19 Triborough Bridge
20 Bronx-Whitestone Bridge

21 Throgs Neck Bridge
22 George Washington Bridge
23 Henry Hudson Bridge
24 Tappan Zee Bridge



MAP LOCATOR

BRIDGE

TUNNEL

(SEE TABLE AT LEFT FOR BRIDGE/TUNNEL NAMES.)

INTERSTATE AND OTHER LIMITED ACCESS HIGHWAYS

MULTI-LANE, DIVIDED HIGHWAYS

FOUR LANE HIGHWAYS

OTHER PRINCIPAL ROADS

NEW YORK CITY AREA

HIGHWAY WATER CROSSINGS

FIGURE 4

Table 1 shows the peak system demand figures for the MTA Bridges and Tunnels facilities. Twenty-four hour, AM peak period, and PM peak period figures are provided for the Brooklyn-Battery Tunnel, Queens-Midtown Tunnel, Triborough Bridge, and Henry Hudson Bridge. These facilities carry their greatest load of vehicular traffic during the AM peak period, carrying about one-third of their total daily to-city volume during the 7 a.m. to 10 a.m. period. The highest hourly to-city volume to pass through each facility occurs from 8 a.m. to 9 a.m. on a typical weekday. Based on travel demand data from the past several years, around 44,000 vehicles come into Manhattan during the AM peak period on a typical workday using these four facilities.

TABLE 1

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

MTA BRIDGES AND TUNNELS AVERAGE DAILY TRAVEL

Facility	24-Hour To-City Volume (Vehicles)	7 a.m.-10 a.m. Peak Per. To-City Volume (Vehicles)	4 p.m.-7 p.m. Peak Per. To-City Volume (Vehicles)	Highest Hourly To-City Volume (Vehicles)
Brooklyn-Battery Tunnel	30,800	10,600	3,700	3,900 (8am-9am)
Queens Midtown Tunnel	37,500	10,600	5,900	3,800 (8am-9am)
Triborough Bridge	53,800	12,700	10,400	4,600 (8am-9am)
Henry Hudson Bridge	31,800	10,200	6,600	3,800 (8am-9am)

Table 2 shows the peak system demand for facilities operated by the Port Authority of New York and New Jersey. Unlike the highway and Port Authority Trans-Hudson (PATH) rail facilities, the peak inbound and outbound demand for the airports generally occurs in the late afternoon/early evening hours. **Depending upon time of closure of airports due to an approaching hurricane, the data show that significant numbers of people could be stranded and need public shelter provisions.** The Lincoln and Holland Tunnels bring 22,700 vehicles into the city during a normal AM peak period, with 5,000 vehicles entering through the Lincoln Tunnel during the 7 a.m. to 8 a.m. peak hour and 2,900 vehicles entering through the Holland Tunnel during the 8 a.m. to 9 a.m. peak hour. As we examine the Port Authority's PATH stations in Manhattan and the number of people exiting the system (to enter the city), we find between one-half to two-thirds of the daily count occurring during the 7 a.m. to 10 a.m. peak period. Approximately 41,700 people come into the World Trade Center during the AM peak period. About 66,700 people enter the city through PATH stations during the AM peak period. The highest single hour occurs from 8 a.m. to 9 a.m. on a normal weekday.

TABLE 2

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY AVERAGE DAILY TRAVEL

AIRPORTS

Airports	24-Hour Eastbound (Passengers)	Highest Hourly Inbound (Passengers)	24-Hour Outbound (Passengers)	Highest Hourly Outbound (Passengers)
Newark	34,500	3,600 (4pm-5pm) 3,100 (8pm-9pm)	33,200	3,300 (8am-9am) 3,100 (6pm-7pm)
JFK	40,000	5,100 (4pm-5pm) 4,300 (5pm-6pm)	60,000	9,300 (7pm-8pm) 6,500 (6pm-7pm)
LaGuardia	32,900	3,100 (8pm-9pm) 2,707 (11pm-12mid)	32,700	2,800 (3pm-4pm) 2,500 (5pm-6pm)

HIGHWAYS

Highways	24-Hour Eastbound (Vehicles)	Eastbound 7am-10am Peak Period (Vehicles)	Eastbound 4pm-7pm Peak Period (Vehicles)	Highest AM Hourly Count (Passengers)
Lincoln Tunnel	56,500	14,200	7,900	5,000 (7am-8am)
Holland Tunnel	41,500	8,500	7,900	2,900 (8am-9am)
George Washington Br.	132,800	32,000	25,200	11,950 (7am-8am)
Bayonne Bridge	7,300	1,000	2,300	400 (8am-9am)
Goethals Bridge	33,000	5,000	8,300	1,700 (7am-8am)
Outerbridge	33,300	6,600	6,700	2,700 (6am-7am)

NEW YORK PATH STATIONS

New York PATH Stations	24-Hour Exit Count (Passengers)	7am-10am Peak Per. Exit Count (Passengers)	4pm-7pm Peak Per. Exit Count (Passengers)	Highest AM Hourly Exit Count (Passengers)
World Trade Center	63,400	41,700	6,600	21,400 (8am-9am)
Christopher Street	2,500	1,300	400	600 (8am-9am)
9th Street	4,500	1,800	800	800 (8am-9am)
14th Street	6,000	3,100	800	1,500 (8am-9am)
23rd Street	7,000	4,800	500	2,400 (8am-9am)
33rd and 30th Streets	22,700	14,000	2,600	7,000 (8am-9am)

Table 3 shows the system demand data for New Jersey Transit lines that bring passengers into the Metro New York area. Those eastbound (to-city) trips occurring during the AM peak period are reported, as well as total daily weekday trips from eastbound and westbound movements. About 48,000 people come into the area between 6:45 a.m. and 9:15 a.m. on a typical weekday using New Jersey Transit lines.

TABLE 3

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

NEW JERSEY TRANSIT
AVERAGE WEEKDAY TRAVEL BY RAIL LINES

Rail Line	Total EB & WB Weekday Trips (Passengers)	AM Peak Period (6:45 am - 9:15 am) Eastbound Trips (Passengers)
Northeast Corridor	57,000	13,800
North Jersey Coastline	36,000	5,500
Morris and Essex	28,000	8,400
Main/Bergen	16,700	6,900
Raritan Valley	11,800	4,100
Pascack Valley	6,300	3,200
Boonton	6,000	3,100
Atlantic City	1,400	400
AMTRAK Cross Honor	5,200	2,400
Totals	168,400	47,800

For the Metro-North Commuter Railroad, Table 4 shows that the heaviest ridership occurs in the AM peak period, with an average of 65,700 people using the system.

TABLE 4

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

METRO-NORTH COMMUTER RAILROAD
AVERAGE WEEKDAY TRAVEL BY LINE

Line	AM Peak Period Ridership	PM Peak Period Ridership	Off-Peak Ridership
Hudson-Lower Hudson Trains	9,900	8,400	3,900
Hudson-Upper Hudson Trains	3,500	3,100	2,800
Harlem-Lower Harlem Trains	14,700	11,500	7,700
Harlem-Upper Harlem Trains	8,600	8,600	5,900
New Haven-Inner New Haven Trains	14,400	10,800	10,300
New Haven-Outer New Haven Trains	14,600	13,700	9,000
Totals	65,700	56,100	39,600

Table 5 shows the peak system demand for the Long Island Rail Road. The AM peak period occurs between 6 a.m. and 10 a.m. and during this period 86,000 of the 102,000 westbound passengers come into Manhattan at Penn Station. The AM peak period represents about 41 percent of the 250,000 total trips made system-wide on a typical weekday.

TABLE 5

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

LONG ISLAND RAIL ROAD
AVERAGE WEEKDAY TRAVEL
(numbers represent passengers)

Westbound AM arriving passengers (6 a.m. - 10 a.m.) (41% of passengers)

Penn Station (Manhattan)	86,000
Flatbush Avenue (Brooklyn)	13,000
Hunterspoint Avenue (Queens)	3,000
Total	102,000

Eastbound PM departing passengers (4 p.m. - 7 p.m.) (32% of passengers)

Penn Station	69,000
Flatbush Avenue	8,000
Hunterspoint Avenue	3,000
Total	80,000

AM peak period westbound trips	102,000	(41%)
PM peak period eastbound trips	80,000	(32%)
Other trips	68,000	(27%)
Total Passengers	250,000	(100%)

One of the most significant systems that brings people into and out of Manhattan is the subway system operated by the New York City Transit Authority. Table 6 shows entrance counts by borough and for each of the ten busiest stations, for a typical 24-hour weekday period and peak periods. As large as these ridership numbers are, these are only the top ten stations in Manhattan. System-wide, over 3 million trips are made daily with 2 million trips having Manhattan as an origin, destination, or both. **Over a million peak period trips are made involving Manhattan.** The station with the highest entrance counts is 42nd Street/Grand Central, with an estimated 69,000 people entering the system through this station in the PM peak period (4 p.m. to 7 p.m.). If we assume that most of these trips are work related, then it follows that a large portion entered the city by exiting the system through these stations in the AM peak period.

TABLE 6

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS
NEW YORK CITY TRANSIT AUTHORITY

AVERAGE WEEKDAY PASSENGER TRAVEL BY BOROUGH

Borough	24-Hour Entrance Count	Estimated* AM and PM Combined Peak Periods Entrance Counts
Manhattan	1,929,000	1,157,400
Bronx	249,000	149,400
Brooklyn	656,000	393,600
Queens	495,000	297,000
Total System	3,329,000	1,997,400

AVERAGE WEEKDAY PASSENGER TRAVEL BY TEN HIGHEST STATIONS

Station	Route	24-Hour Entrance Count	Estimated* PM Peak Period (4 pm - 7 pm) Entrance Counts
42nd Street - Grand Central	6	125,000	68,800
34th Street - Penn Station	1	73,000	40,200
42nd Street	A	61,000	33,600
34th Street	F	54,000	29,700
34th Street - Penn Station	A	54,000	29,700
Chambers St.	A	49,000	26,900
47th - 50th St.	F	47,000	25,800
42nd St. - Times Square	1	47,000	25,800
Lexington Ave.	E	41,000	22,600
Main Street	7	41,000	22,600

*Estimates based on 55-60% of daily entering counts. All reported figures based on 1990 system counts.

The final facilities for which peak system demands are reported are those operated by the New York City Department of Transportation (NYCDOT). Table 7 provides peak period to-city vehicular volumes for the Brooklyn, Manhattan, Queensboro, and Williamsburg Bridges, as well as several key roadway segments. Except for FDR Drive at 100th/101st Streets, the AM peak period (7 a.m. - 10 a.m.) carries the largest volume of to-city vehicles. Over 80,000 vehicles enter the city using these NYCDOT facilities during the AM peak period, with the highest hourly volume occurring between 7 a.m. and 8 a.m. on the bridges and between 8 a.m. and 9 a.m. on the other facilities. Unlike many other Metro New York transportation facilities, the AM and PM peak period to-city volumes combined only account for a third of the daily to-city volume for the NYCDOT facilities. This means that from a traffic demand standpoint, it will be difficult to close these facilities no matter what time of day decisions are made relative to an approaching hurricane.

All system demand data are from the 1990 to 1992 time frame and were provided by members of the various transportation agencies for those years as data were available.

TABLE 7

SELECTED TRANSPORTATION SYSTEM DEMAND STATISTICS

NEW YORK CITY DEPARTMENT OF TRANSPORTATION AVERAGE DAILY TRAVEL

Facility	24 Hour To-City Volume (Vehicles)	7 a.m. - 10 a.m. Peak Period To-City Volume (Vehicles)	4 p.m. - 7 p.m. Peak Period to City Volume (Vehicles)	Highest Hourly To-City Volume (Vehicles)
Brooklyn Bridge	66,100	11,600	10,600 (7 am - 8 am)	4,200
Manhattan Bridge	34,200	7,100	4,400 (7 am - 8 am)	2,500
Queensboro Bridge	66,600	15,000	8,700 (7 am - 8 am)	5,500
Williamsburg Bridge	59,600	13,300	9,300 (8 am - 9 am)	4,700
FDR Drive @ 60th/61st Streets	66,300	13,200	10,800	4,800 (8 am - 9 am)
FDR Drive @ 100th/101st Streets	77,700	11,400	14,200	4,800 (5 pm - 6 pm)
West Street @ 41st Street	30,700	6,300	5,500	2,100 (8 am - 9 am)
Harlem River Drive	9,100	2,700	1,400	1,200 (8 am - 9 am)

Evacuation Clearance Time Considerations

Evacuation clearance time can be estimated by examining PM peak period travel demand and duration for the transit systems. A typical PM peak period lasts from 3 to 4 hours. However, people who customarily exit the city before 4 p.m. or after 7 p.m. will contribute to the peak during an evacuation response, making it necessary to move more people through each system than during a typical PM peak period. Therefore, if a normal number of commuters are in the city, a base clearance time of 6 hours plus time needed for system mobilization, security, and closure should be used for evacuation decision making.

Highway clearance times on Long Island and in coastal New Jersey south of Middlesex County are higher than the assumed commuter clearance times discussed above. Therefore, commuters to Manhattan who travel from those two areas and reside in homes that are highly vulnerable to surge should plan a timely response to evacuation advisories issued for their place of residence. From an evacuation clearance time standpoint, this raises another issue. One of the primary reasons workers should be kept out of the city as a hurricane threatens is that Manhattan-to-home travel eastbound on Long Island will interfere with critical northbound evacuation movements from surge-vulnerable areas to inland Long Island. Residents of northern New Jersey counties whose homes are in surge-vulnerable areas generally will have local evacuation clearance times similar to the aforementioned transit clearance times. Their direction of evacuation travel should not interfere appreciably with commuter movements from Manhattan.

System Emergency Operating Plans

Early in the study process many of the participating agencies in the Metro study submitted their system emergency operating plans for review and evaluation. Although several plans mention potential natural disasters such as snowstorms, wind-storms, floods, earthquakes, and landslides, most focus on snowstorms and rainfall flooding. This is understandable considering the relative infrequency of hurricanes and intense extratropical storms compared to other emergencies and the lack of hazards and vulnerability data prior to this study. Those few plans that directly address hurricanes should be revised to include the wind velocities that could be experienced hours before hurricane eye landfall and the potential surge heights and rates-of-rise of flood waters.

Generally, emergency response plans for the Metro New York area transportation agencies lay out details for reacting to unusual events but do not anticipate hazards such as hurricanes or address the precautions and closures that will be needed to prevent police and other officials from being overwhelmed by events. **Given what is now known about the potential for devastating coastal storm flooding and winds in the Metro New York area, it is imperative to update emergency operating plans, addressing such storms and anticipating their effects.** Some of the content of existing plans could be adapted to hurricanes and other coastal storm events, particularly where procedures for facility closures are discussed.

Several agencies, including the New York City Department of Transportation, have a good start on a hurricane preparedness plans. One agency that has developed an effective hurricane alert and response plan in the Metro New York area is the Port Authority's Marine Terminals. Their emergency plan is good for several key reasons:

a. Separates hurricanes as a unique natural disaster event which warrants special actions and plans.

b. Clearly identifies the source for weather bulletins and advisories.

c. Sets up a series of five hurricane warning conditions based on hours before hurricane landfall, specifying precautionary actions to be taken prior to a possible event and the individuals responsible for those actions.

d. Pre-storm, during the storm, and post-storm actions are delineated.

e. Contains notification and coordination roster.

Emergency response plans for other agencies both within and outside the Port Authority should build on the strong points of the Marine Terminal's plans.

HAZARDS ANALYSIS

Hazards of Coastal Storms

One early task of every Hurricane Evacuation Study is the hazards analysis. The purpose of that analysis is to quantify the wind speeds and still-water surge heights that could be produced by a combination of hurricane intensities, approach speeds, approach directions, and tracks considered to have a reasonable meteorological probability of occurrence within the study area. Valuable information developed in the New Jersey, New York, and Connecticut Hurricane Evacuation Studies provides the basis for the current hazards analysis. Since extratropical storms can also dramatically affect transportation systems with abnormally high winds and resultant high water levels, they are also included in this study.

Storm Surge

Storm surges are higher than usual water levels along coastlines and the shorelines of bays and estuaries that result from large-scale meteorological disturbances. **Along the mid-Atlantic seaboard, extratropical storms called "nor'easters" have produced some of the highest storm surges and accompanying damages in recent history. However, hurricanes, because of their vast energy and relative compactness, have the potential to produce much higher water levels.**

Wind is the primary cause of storm surge. As it blows over the surface of the water, it exerts a horizontal force that induces currents in the same general direction. In the case of a hurricane, the depth affected by this process depends upon the intensity and forward motion of the storm and can reach several hundred feet. As the hurricane approaches the coastline, these horizontal currents are impeded by a sloping continental shelf, thereby causing the water level to rise. The amount of rise increases shoreward to a maximum level that is often inland from the usual coastline. Because of the size and forward speed of hurricanes, the duration of peak surge is normally less than one tide cycle.

Extratropical storms are usually slower moving and considerably larger than hurricanes, but less intense. Because of their relative size and motion, they prevail for longer periods at a particular location than hurricanes. Surge resulting from extratropical storms is not so much a function of extraordinarily high winds and rapid forward motion of the storm as it is the effect of sustained gale force winds blowing landward over an extended period of time, sometimes several tide cycles. The surge tends to build gradually, reaching higher levels with each astronomical high tide, still, with far less potential for catastrophic flooding than an intense hurricane.

Wind Hazards

Although most casualties of hurricanes and extratropical storms are victims of storm surge, wind hazards accompanying these storms are not to be ignored. Hurricanes Hugo (1989) and Andrew (1992) have demonstrated the widespread devastation often caused by violent winds in intense storms.

According to the American Society of Civil Engineers publication ASCE 7-88, July 1990, "Minimum Design Loads for Buildings and Other Structures," at a height of 140 feet, design wind pressures should be increased by 50 percent; at 200 feet, increased by 70 percent; and at 350 feet, increased by 100 percent. The implications for tall buildings and high-rise bridges are quite clear. In the case of tall buildings, not only are wind velocities and pressures usually higher at upper floors, but suction effects at critical points on the structure can be twice as great as the maximum direct force on the windward face (Proceedings of the American Society of Civil Engineers, Journal of the Structural Division, Vol. 102, No. ST1, Jan. 1976, "Window Glass Failures in Windstorms," Minor and Beason). Additionally, sudden failure of windows or doors can momentarily increase internal pressures by as much as 80 percent (Proceedings of the American Society of Civil Engineers, Journal of the Engineering Mechanics Division, Vol. 107, No. EM2, April 1981, "Building Internal Pressure: Sudden Change, "Liu and Saathoff). The vulnerability of tall buildings to extreme winds and the inherent hazards to the population are discussed in the vulnerability analysis section.

A major consideration for high-rise bridges is the fact that they will not only experience considerably higher peak velocities than at the surface, but sustained tropical storm winds (the cutoff point for evacuation) may arrive at those heights prior to occurring at ground level (Table 8). **Hurricane preparedness planning should include the likelihood that high-rise bridges will close before roadway traffic is curtailed at ground level.**

TABLE 8

HYPOTHETICAL (SLOSH) ARRIVAL OF TROPICAL STORM WINDS SURFACE VS. HIGH-RISE BRIDGES

Hurricane Category	Hours Before Peak Wind*	
	Surface	150-200 ft.
1	2	3
2	3	5
3	3.5	6
4	4.5	7

*Assumes 40 mph approach speed.

Forecasting Errors

Hurricane (and extratropical storm) forecasting is not an exact science. An analysis of hurricane forecasts made by the National Hurricane Center indicates the normal magnitude of error. From 1976 to 1990, the average error in the official 24-hour hurricane track forecast was 140 statute miles. The average error in the 12-hour official forecast was 70 miles. During the same time period, the average error in the official 24-hour wind speed forecast was 15 miles per hour (m.p.h.), and the average error in the 12-hour official forecast was 10 m.p.h. **Decision makers should note that an increase of 10 to 15 m.p.h. can easily raise the intensity value of an approaching hurricane one category on the Saffir/Simpson Hurricane Scale (Table 9). For this reason, officials who are faced with an imminent hurricane emergency should consider preparing for a storm one category above the strength forecast for landfall.**

TABLE 9

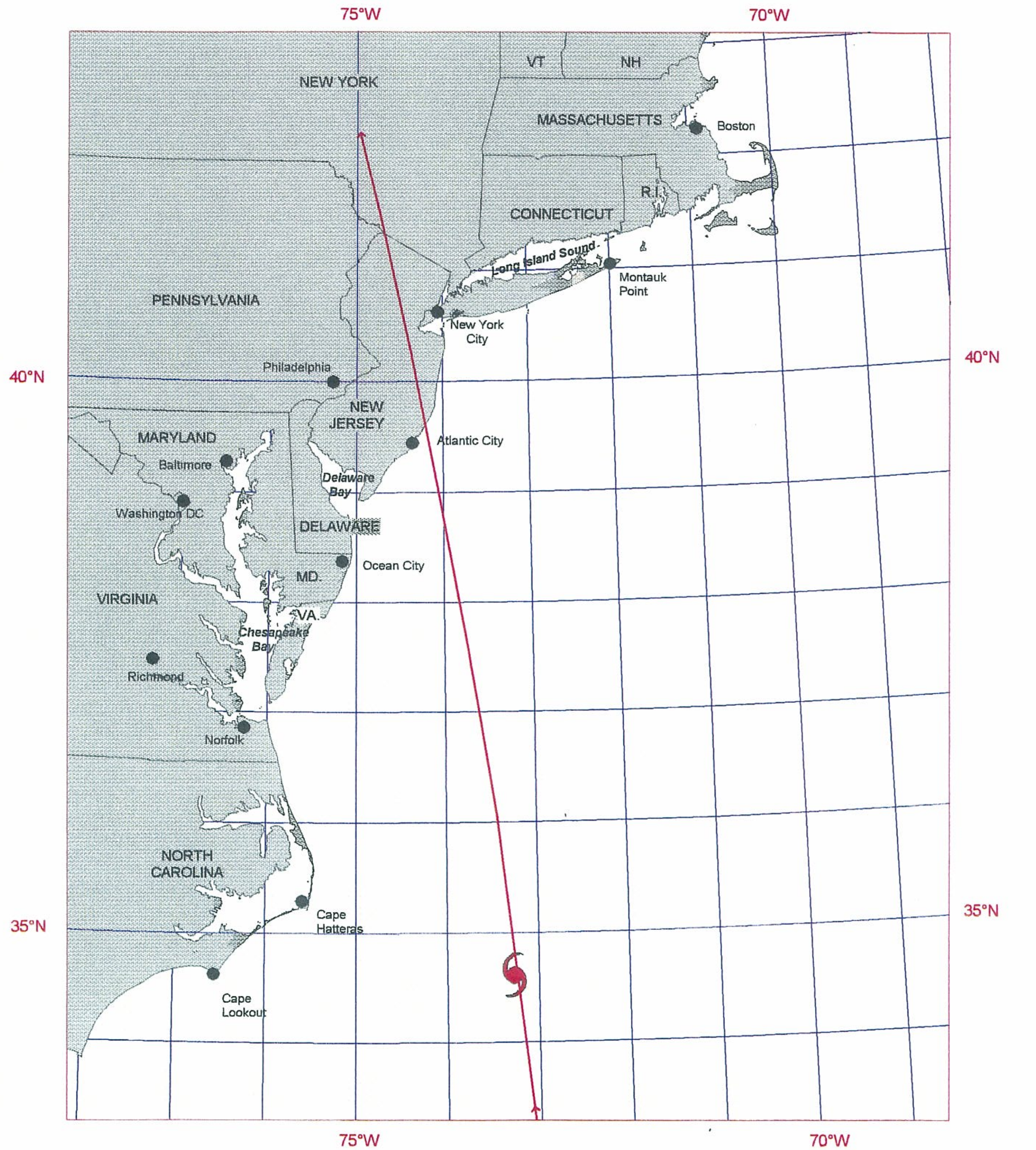
SAFFIR/SIMPSON HURRICANE SCALE RANGES

Category	Central Pressure Millibars	Central Pressure Inches	Winds (Mph)	Winds (Kts)	Damage
1	≥ 980	28.94	74 - 95	64 - 83	Minimal
2	965 - 979	28.50 - 28.91	96 - 110	84 - 96	Moderate
3	945 - 964	27.91 - 28.47	111 - 130	97 - 113	Extensive
4	920 - 944	27.17 - 27.88	131 - 155	114 - 135	Extreme
5	< 920	< 27.17	> 155	> 135	Catastrophic

The SLOSH Model

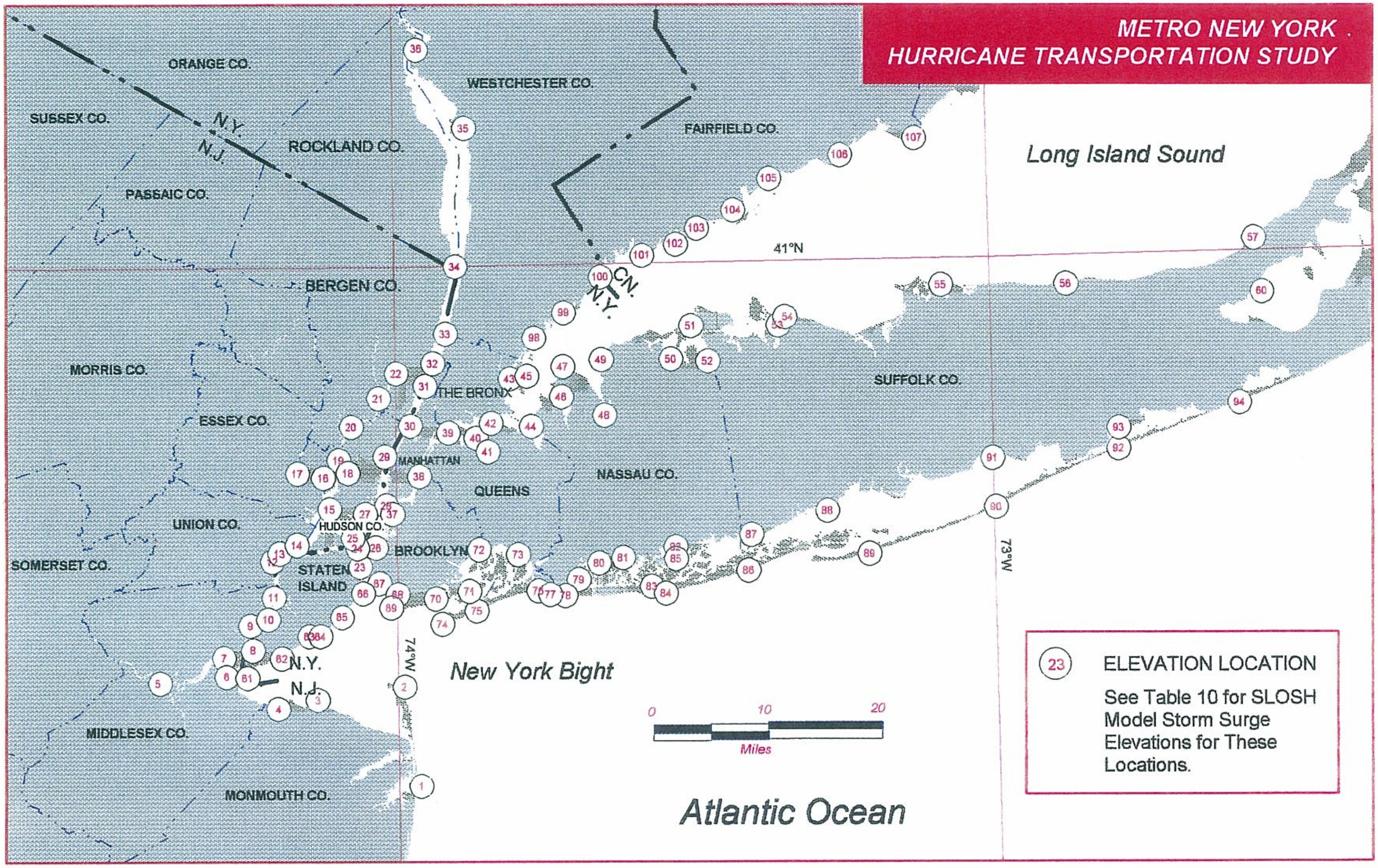
To determine potential hurricane wind speeds and still-water surge heights for the study area, the National Hurricane Center used the SLOSH numerical model to compute the theoretical effects of several hundred hypothetical hurricanes. Computations show that the worst-case for northern New Jersey and New York City would be a Category 4 hurricane moving along the track shown in Figure 5, in a north-northwesterly direction, making landfall near Atlantic City, New Jersey at 40-60 miles per hour forward speed. Such a storm would create a surge of nearly 30 feet at the Battery.

Because of inaccuracies in forecasting the precise tracks and other parameters of approaching hurricanes, a worst-case approach is used for the hazards analysis. Peak surges and wind speeds computed by the SLOSH model are compiled according to hurricane intensity category, without regard to storm forward speed, approach direction, or track. Accordingly, these peak surge values are the highest that can be expected for each category, eliminating other variables that could be bothersome in preparedness planning and decision making. Their frequency of occurrence has not been calculated or considered in this population protection study. Table 10 gives peak surge heights that should be added to normal tide levels at locations shown in Figure 6.



WORST CASE TRACK FOR HURRICANES IMPACTING
THE METRO NEW YORK CITY AREA

FIGURE 5



SLOSH CRITICAL POINTS

FIGURE 6

TABLE 10

SLOSH MODEL SURGE ELEVATIONS

	Location	Maximum Surge Height (ft)* Still-Water Elevation Above Normal Tide			
		Cat 1	Cat 2	Cat 3	Cat 4
1.	Monmouth Beach, N.J.	6.2	10.2	13.8	17.4
2.	Sandy Hook, N.J.	7.7	12.3	16.5	21.7
3.	Keansburg, N.J.	9.7	15.6	20.8	26.2
4.	Keyport Harbor, N.J.	10.3	16.6	22.4	27.4
5.	Sayreville, N.J.	8.2	11.6	17.1	27.8
6.	Amboy, N.J.	10.8	18.7	23.8	26.9
7.	Victory Bridge, Raritan R.	10.7	18.0	19.7	24.9
8.	Tottenville, Staten Island	10.4	20.0	23.2	26.9
9.	Woodbridge, N.J.	10.0	12.5	19.3	21.9
10.	Fresh Kills Landfill, Staten Island	8.6	10.5	12.8	17.3
11.	Travis, Staten Island	9.0	10.5	14.3	17.7
12.	Linden, N.J.	9.0	10.6	14.3	18.0
13.	Goethals Bridge, Arthur Kill	8.9	10.7	14.4	17.8
14.	Elizabeth, N.J.	8.4	10.3	13.6	17.2
15.	Newark Bay Bridge, Bayonne	7.1	9.1	11.8	15.0
16.	US 1 @ Passaic River, Newark	7.4	9.2	11.9	14.0
17.	Passaic River, Harrison, N.J.	8.5	10.0	13.4	15.9
18.	Pulaski Skyway, Hackensack R.	6.8	9.0	11.8	14.4
19.	N.J. Turnpike, Kearny, N.J.	6.9	7.4	8.5	12.2
20.	Route 3, Secaucus, N.J.	5.2	6.3	7.7	11.4
21.	Ridgefield Park, Hackensack R.	Dry	Dry	Dry	9.9
22.	Palisades Park, Overpeck CR.	Dry	Dry	Dry	9.2
23.	Stapleton, Staten Island	9.9	15.4	21.1	26.0
24.	ST. George, Staten Island	10.0	16.0	22.0	26.7
25.	Bayonne, N.J.	9.2	12.5	19.3	27.9
26.	Bush Terminal, Brooklyn	10.4	15.7	22.3	27.6
27.	Liberty Island, N.J.	10.3	15.7	22.8	28.0
28.	Battery, Manhattan	10.5	16.6	23.9	28.7
29.	Lincoln Tunnel	7.5	17.2	20.5	30.8
30.	W 96TH Street, Manhattan	8.2	15.0	17.7	28.1
31.	George Washington Bridge	6.9	14.1	16.8	26.7
32.	Spuyten Duyvil, Manhattan	6.1	13.0	14.8	24.6
33.	City Line, NY/C-Yonkers	5.5	11.6	13.4	22.5
34.	Tappan, Palisades State Park	4.6	9.5	10.5	17.5
35.	Ossining, NY	2.9	7.6	8.7	14.6
36.	Peekskill/Indian Point, NY	2.0	6.6	7.8	13.7
37.	Manhattan Bridge, East R.	10.1	15.8	22.4	25.6
38.	Newtown Creek, Queens/Kings	9.6	14.4	21.0	23.6
39.	Hell Gate, Wards Island	7.9	11.7	14.9	18.1
40.	La Guardia Airport	6.4	11.2	15.7	20.8

TABLE 10--Cont'd

SLOSH MODEL SURGE ELEVATIONS

	Location	Maximum Surge Height (ft)* Still-Water Elevation Above Normal Tide			
		Cat 1	Cat 2	Cat 3	Cat 4
41.	Flushing Bay, Flushing Cr.	6.6	11.6	16.3	20.9
42.	Whitestone (Bronx)	6.5	11.3	16.6	22.2
43.	Pelham Bay, Bronx	6.4	11.6	17.5	22.4
44.	Willets Point, Queens	6.3	11.4	18.3	23.0
45.	City Island, Bronx	6.3	11.5	17.3	22.2
46.	Manorhaven, Manhasset Bay	6.5	11.7	17.8	22.7
47.	Sands Point, Long Is. Sound	6.1	11.1	16.3	21.5
48.	Roslyn, Hempstead Harbor	6.2	11.3	16.5	21.8
49.	Glen Cove, long Is. Sound	6.0	10.9	16.0	21.0
50	Mill Neck, Bayville, Nassau Co.	5.7	10.3	15.2	19.8
51.	Centre Island, Oyster Bay	5.7	10.3	15.2	19.8
52.	Cold Spring Harbor, Oyster Bay	5.7	10.3	15.1	19.8
53 .	Northport Bay, Suffolk Co.	5.4	9.8	13.7	18.1
54.	Asharoken, N. Shore, Suffolk	5.2	9.3	13.6	18.0
55.	Port Jefferson, North Shore	5.0	9.0	13.1	17.3
56.	Shoreham, Long Island Sound	4.6	8.1	11.8	15.5
57.	Mattituck, North Shore	4.3	7.6	11.0	14.6
58.	Orient, North Fork	4.5	7.4	10.4	13.4
59.	Shelter Island, Gardiners Bay	5.1	8.5	12.0	15.5
60.	Jamesport, Great Peconic Bay	3.8	6.8	10.2	13.8
61.	Ward Point, Staten Island	10.7	17.5	23.2	27.6
62.	Huguenot, Staten Island	10.2	16.6	22.1	27.4
63.	Great Kill, Staten Island	10.1	15.9	21.2	27.1
64.	Oakwood Beach, Staten Island	9.7	15.7	21.0	27.0
65.	Midland Beach, Staten Island	9.4	15.3	20.7	26.8
66.	South Beach, Staten Island	9.1	15.0	20.4	26.4
67.	Fort Hamilton, Brooklyn	9.3	15.2	20.9	27.0
68.	Gravesend Bay, Brooklyn	9.2	15.2	20.8	27.2
69.	Seagate, Coney Island	9.1	15.0	20.5	26.4
70.	Sheepshead Bay, Coney Island	7.8	15.1	21.0	27.4
71.	Floyd Bennett Naval Air Station	6.7	14.0	21.7	28.5
72.	Pennsylvania Ave. Jamaica Bay	6.2	15.7	25.0	31.3
73.	Kennedy International Airport	6.6	15.6	24.5	31.2
74.	Breezy Point, Rockaway Inlet	9.1	14.3	20.0	25.9
75.	Rockaway Beach, Queens	9.1	14.0	20.4	26.6
76.	East Rockaway Inlet	9.0	14.8	20.0	25.2
77.	Lawrence, Nassau County	6.7	15.7	20.4	25.4
78.	Long Beach, Nassau County	8.7	15.5	20.1	24.8
79.	Island Park, Long Beach	8.3	16.0	21.0	25.7
80.	East Rockaway, Hewlett Bay	6.1	17.0	22.1	26.9

TABLE 10--Cont'd

SLOSH MODEL SURGE ELEVATIONS

	Location	Maximum Surge Height (ft)* Still-Water Elevation Above Normal Tide			
		Cat 1	Cat 2	Cat 3	Cat 4
81.	Oceanside, Middle Bay	6.1	16.7	23.0	28.3
82.	Freeport, South Shore, Nassau	7.7	14.9	23.2	29.4
83.	Loop Parkway, Jones Inlet	7.7	14.9	21.0	26.3
84.	Jones Beach State Park	8.4	13.8	19.1	24.1
85.	Wantagh Parkway, East Bay	2.3	13.3	20.5	27.0
86.	Gilgo Beach, Suffolk County	8.0	13.6	17.3	23.5
87.	Amityville, Great South Bay	2.5	8.7	19.7	26.8
88.	West Islip, Great South Bay	3.2	8.4	15.9	22.6
89.	Atlantique, Fire Island	6.8	11.4	15.4	19.8
90.	Davis Park, Fire Island	6.5	11.3	15.9	19.6
91.	Patchogue, Great South Bay	2.4	4.8	9.2	15.1
92.	Smith Pt./Moriches, Grt So. Bay	6.2	10.6	14.8	18.2
93.	Center Oriches, Moriches Bay	5.5	9.7	13.2	19.7
94.	West Hampton, Moriches Bay	6.0	10.4	14.1	18.1
95.	Mecox Bay, South Shore	5.7	9.9	14.0	17.9
96.	Napeague Beach, South Shore	5.2	8.9	12.6	16.2
97.	Montauk Point, South Fork	4.9	7.9	10.7	13.5
98.	New Rochelle, Westchester Co.	6.1	11.2	16.4	21.5
99.	Mamaroneck Harbor, L.I. Sound	6.0	11.0	15.9	21.0
100.	Port Chester, N.Y. State Line	5.8	10.6	15.6	20.5
101.	Greenwich Cove, Connecticut	8.4	8.4	11.1	15.1
102.	Shippan Point, Connecticut	8.1	8.1	10.6	14.9
103.	Stamford, Connecticut	8.0	8.0	10.2	14.4
104.	Norwalk, Connecticut	7.1	7.1	10.0	13.3
105.	Westpoint, Connecticut	6.9	6.9	10.0	13.2
106.	Bridgeport, Connecticut	7.2	7.2	11.1	13.9
107.	Stratford, Connecticut	7.6	7.6	11.6	14.3

*Surge heights shown in this table represent the worst-case combination of forward speed, approach direction, and track. Frequency of occurrence has not been determined.
For high tides, see Table 11.

Adjustments to SLOSH Values

The accuracy of the SLOSH model has been evaluated using parameters of historical hurricanes to hindcast the surge heights measured after those storms. In Manhattan, for Hurricane Gloria the SLOSH model computed the same peak surge at the Battery that was recorded on the National Ocean Service (NOS) tide gage. More recently, the SLOSH model computed the peak surge from Hurricane Hugo almost exactly and understated the peak surge from Hurricane Andrew by about two feet. Planners should keep in mind that the SLOSH model is a mathematical model that cannot always replicate nature perfectly. Based on a statistical analysis conducted by the National Hurricane Center, adding 20 percent to the computed SLOSH values would eliminate most of the potential negative errors. However, such an adjustment would also add additional surge height to those values that already contain positive errors, possibly endangering the credibility of the SLOSH results. **Since a general adjustment for SLOSH errors was not made to the computed surge heights for this study, decision makers should remember that some of the values shown could understate the potential surge by as much as 20 percent.**

The SLOSH model does not provide data concerning the additional heights of waves generated on top of the still-water storm surge. Generally, waves do not add significantly to the area flooded. **However, immediately along the coastline or the shorelines of large bodies of water, wave crests can increase the expected water depth above the terrain by one-third, thus greatly increasing the hazard.** Due to the presence of buildings and other barriers, waves usually break and dissipate a tremendous amount of energy within a short distance inland. Structures in that zone are often heavily damaged or destroyed if not specifically designed to withstand the forces of wave action.

Since the datum used in the SLOSH model is National Geodetic Vertical Datum (NGVD), formerly known as mean sea level of 1929 (m.s.l.), an astronomical tide level above NGVD would add additional height to the values computed by the SLOSH model. This would be especially significant, percentage-wise, for less intense storms. New York State opted to make any necessary adjustments for tide on a case-by-case basis during an actual event; therefore, inundation mapping for New York State is based on mean tide level. Consistent with the worst-case planning approach used throughout the New Jersey study, a general adjustment of +3 feet was made in mapping maximum surge values for that state. New Jersey hurricane inundation areas shown in this report reflect this adjustment. In Connecticut, for the inundation mapping, surge height adjustments were varied from east to west according to normal tide range. **If astronomical high tide occurs coincidentally with the peak storm surge, the combination could be considerably higher than the SLOSH surge values shown in Table 10 of this report.**

Table 11 gives the height of the normal high tide above mean tide level for sample locations within the study area. Spring tide situations would add less than 1 foot to these values.

TABLE 11

NORMAL ASTRONOMICAL HIGH TIDES

NEW YORK

Location	Height Above Mean Tide Level (ft.)
New York City	
Coney Island	2.0
St. George	2.0
The Battery	2.0
Spuyten Duyvil	2.0
East 41st Street	2.0
Wards Island	2.5
Bronx River	3.0
Whitestone Bridge	3.5
Westchester County	
Yonkers	2.0
Ossining	1.5
Peekskill	1.0
New Rochelle	3.5
Port Chester	3.5
Nassau County	
Manhasset Bay	3.5
Oyster Bay	3.5
Massapequa	0.5
Freeport	1.5
Long Beach	2.0
Woodmere	2.0
Suffolk County	
Lloyd Harbor	3.5
Port Jefferson	3.0
Mattituck	2.5
Plum Island	1.0
Riverhead	1.0
Threemile Harbor	1.0
Montauk Point	1.0
Shinnecock Inlet	1.5
Moriches Inlet	1.5
Mastic Beach	0.5
Fire Island	2.0
Bellport	0.5
Sayville	0.5
Babylon	0.5
Amityville	0.5

NEW JERSEY

Location	Height Above Mean Tide Level (ft.)
Hudson County	
Port Elizabeth	2.3
Constable Hook	2.1
Shooters Island	2.1
Essex County	
Newark, Passaic River	2.4
Bergen County	
Kearny Point	2.4
Hackensack	2.4
Union County	
Carteret	2.3
Middlesex County (Arthur Kill)	
Perth Amboy	2.8

Storm Surge Rate-of-Rise

The SLOSH model provides a time-history tabulation of surge height, wind speed, and wind direction for critical locations within the study area. The time-history values for the Battery on the southern tip of Manhattan Island were analyzed for hypothetical storm surge rate-of-rise. For other locations, comparisons of similar computed data to actual tide gage records have shown a correlation well within the 20 percent discussed above. The SLOSH time-history analysis shows that the maximum hourly rise could vary from 6 feet for a Category 1 hurricane to 17 feet for a Category 4 storm (see Table 12 and Figures 7-10). Implications of these rates are discussed in the vulnerability analysis.

Rainfall Flooding

Due to the wide variation in amounts and times of occurrence from one storm event to another, potential freshwater flooding from rainfall accompanying hurricanes is usually addressed in general terms in Hurricane Evacuation Studies. For most hurricanes, the heaviest rainfall begins near the time of arrival of sustained tropical storm winds; however, heavy rains exceeding 20 inches can precede an approaching hurricane by as much as 24 hours. Unrelated weather systems can also contribute significant rainfall amounts within a basin in advance of a hurricane. If a severe coastal storm causes riverine and storm surge flooding in a major river basin, the surge flooding usually occurs first, near the height of the storm, while the riverine flooding typically develops later as rainfall runoff accumulates and flows seaward. This sequence can vary, however, depending on storm track and forward speed as well as the pattern of rainfall preceding its arrival. For this study, locations and facilities that have historically flooded during periods of heavy rainfall are assumed to be vulnerable to freshwater flooding from hurricane conditions. Particular rainfall flooding problems are discussed in the Vulnerability Analysis.

TABLE 12

HYPOTHETICAL (SLOSH) HURRICANE SURGE RATE OF RISE AT BATTERY FOR 40 MPH APPROACH SPEED

	Surge Elevation (Feet)	Before Peak Surge (Hrs:Min)
Category 1	8	:10
	11	@ peak

	Surge Elevation (Feet)	Before Peak Surge (Hrs:Min)
Category 2	10	:30
	11	:25
	12	:15
	13	:12
	14	:07
	15	:05
	16	@ peak

Maximum Hourly Rise: 10 Feet

	Surge Elevation (Feet)	Before Peak Surge (Hrs:Min)
Category 3	10	1:05
	11	:55
	12	:50
	13	:40
	14	:35
	15	:30
	16	:25
	17	:22
	18	:18
	19	:15
	20	:12
	21	:10
	22	:07
	23	05
	24	@ peak

Maximum Hourly Rise: 13 Feet

	Surge Elevation (Feet)	Before Peak Surge (Hrs:Min)
Category 4	10	1:20
	11	1:10
	12	1:05
	13	1:00
	14	:55
	15	:45
	16	:40
	17	:35
	18	:30
	19	:25
	20	:20
	21	:17
	22	:12
	23	:10
	24	:08
	25	:07
	26	:06
	27	:05
	28	:04
	29	@ peak

Maximum Hourly Rise: 17 Feet

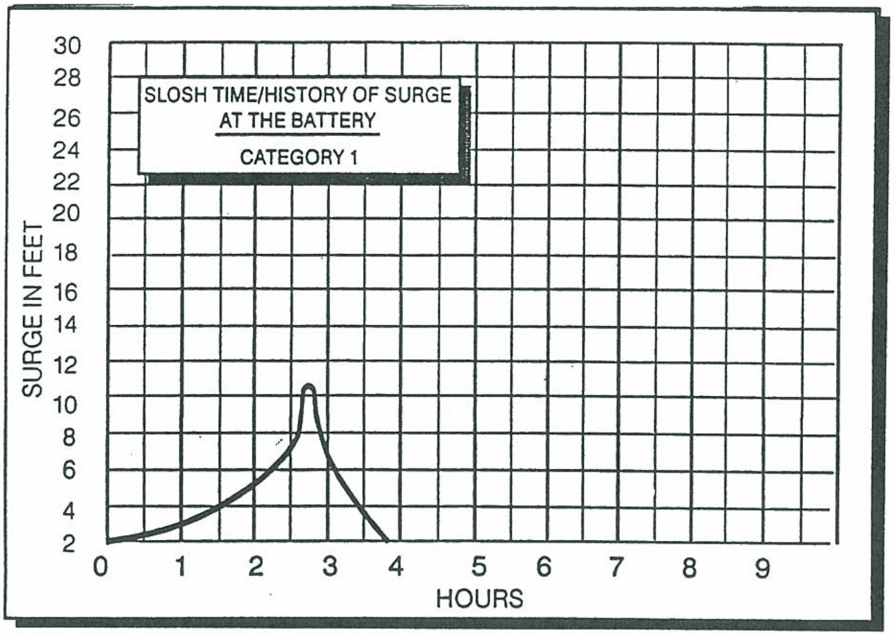


FIGURE 7

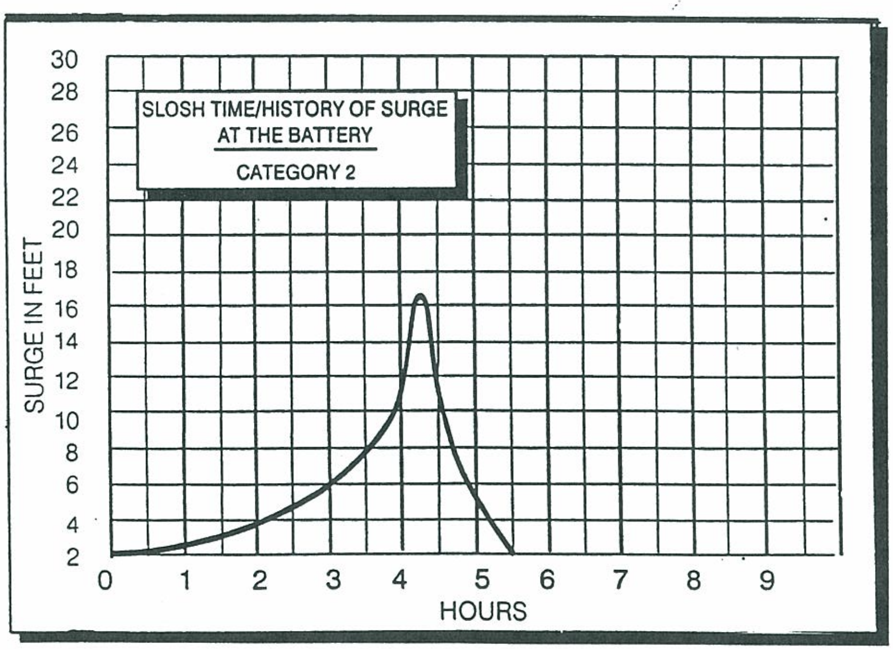


FIGURE 8

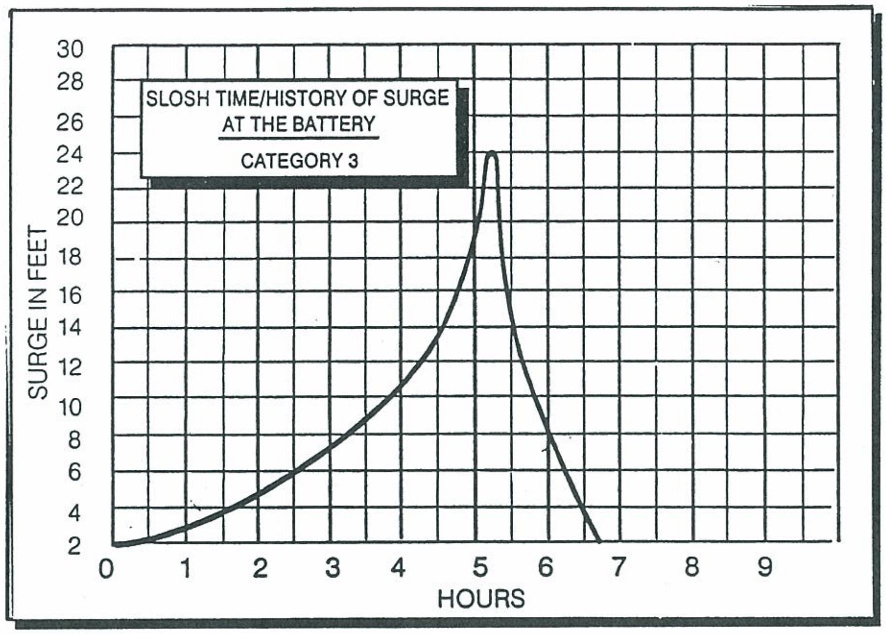


FIGURE 9

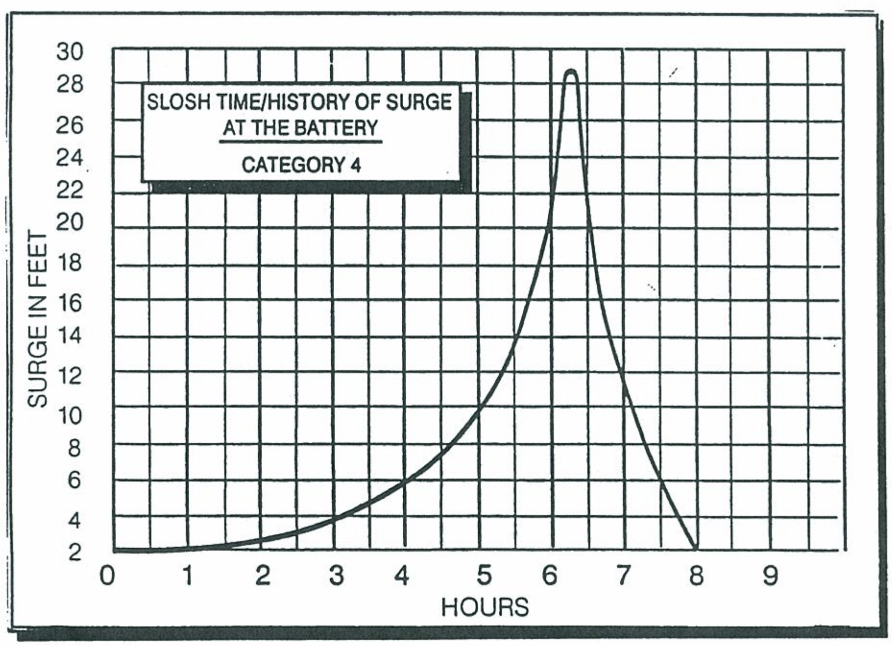


FIGURE 10

VULNERABILITY ANALYSIS

This vulnerability analysis, based on SLOSH model hazards data of proven reliability, greatly heightens the urgency for coordinated coastal storm preparedness planning among Metro transportation and governmental agencies. **Based on hypothetical surge and wind data, as well as actual events, there is an immediate need for comprehensive plans that can be put into motion by timely decisions.**

Hazards Basis

Hazards information developed for the New Jersey, New York, and Connecticut Hurricane Evacuation Studies was used to evaluate the vulnerability of the various transportation systems to coastal storm winds and surge. Riverine flooding data from the USACE Passaic River Basin Study is also included. **This analysis is not intended to be all-inclusive, but rather to provide a representative basis for comprehensive preparedness planning on major systems. It is beyond the scope of this study to determine vulnerability in exact terms. As part of an effective mitigation program, individual agencies should perform a detailed investigation to identify all points of system vulnerability and assess the associated wind and/or flood hazard.**

Storm of December 11-12, 1992

The threshold of vulnerability for most Metro transportation systems was exceeded by the surge and winds accompanying the December 1992 extratropical storm. During that event, the still-water level at the Battery NOS tide gage peaked at about 8.5 feet above NGVD and high winds caused traffic accidents that closed several high-rise bridges. Although critical flood levels (elevation at which flood water will begin entering or covering system facilities) for most systems were surpassed for fairly brief periods, and by only 1 to 2 feet, near paralysis of the Metro area resulted. The flooding had major impacts on important transportation systems but, with only a few exceptions, stopped just short of being life-threatening. If this storm surge had peaked 2 feet higher, lives could have been lost on the roadways and rail systems.

Two of the most vulnerable systems, the underground rail networks belonging to Port Authority Trans-Hudson (PATH) and New York City Transit Authority (subway) were completely shut down. Storm surge entered the PATH system in at least one location, the Erie-Lackawana staircase at the Hoboken Terminal where the critical elevation is 7.4 feet NGVD (see Figure 11). Low points in the rail tunnels were flooded and major damage occurred to the control signals. The Port Authority's *Pathways* newspaper reported that a train with 19 passengers stalled 75 yards from the Hoboken Terminal. Rescuers worked for 1-1/2 hours to move those passengers from the train into the terminal. Portions of the system were out of operation for 10 days. Surge only 1 to 2 feet higher than the December 1992 storm would involve other points of entry and probably cause massive flooding of the PATH tunnels.

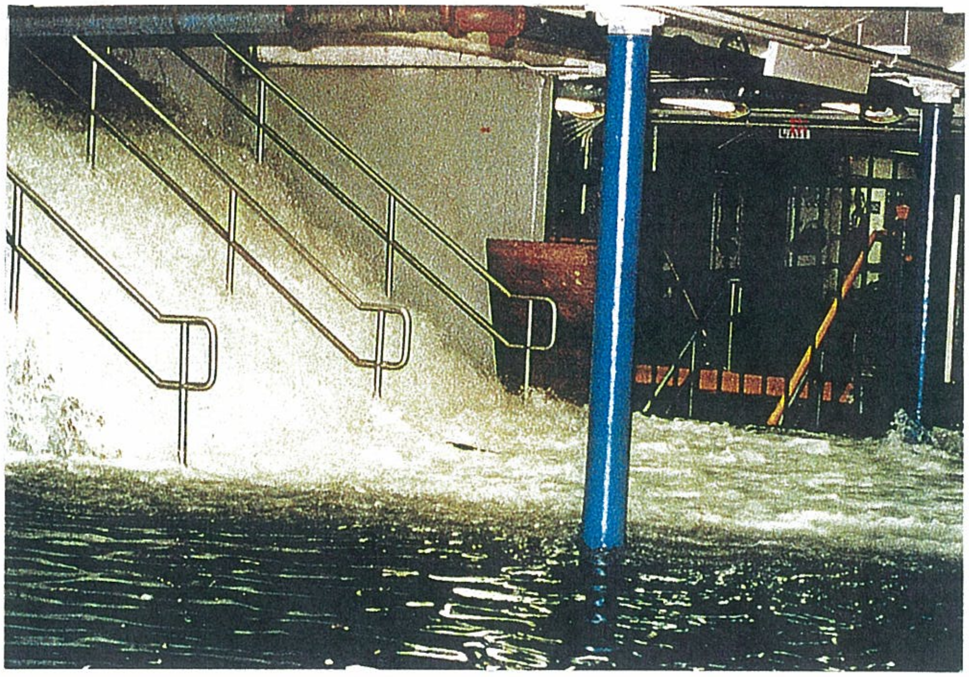


FIGURE 11

Floodwater cascades into the Hoboken PATH Station
December 11, 1992

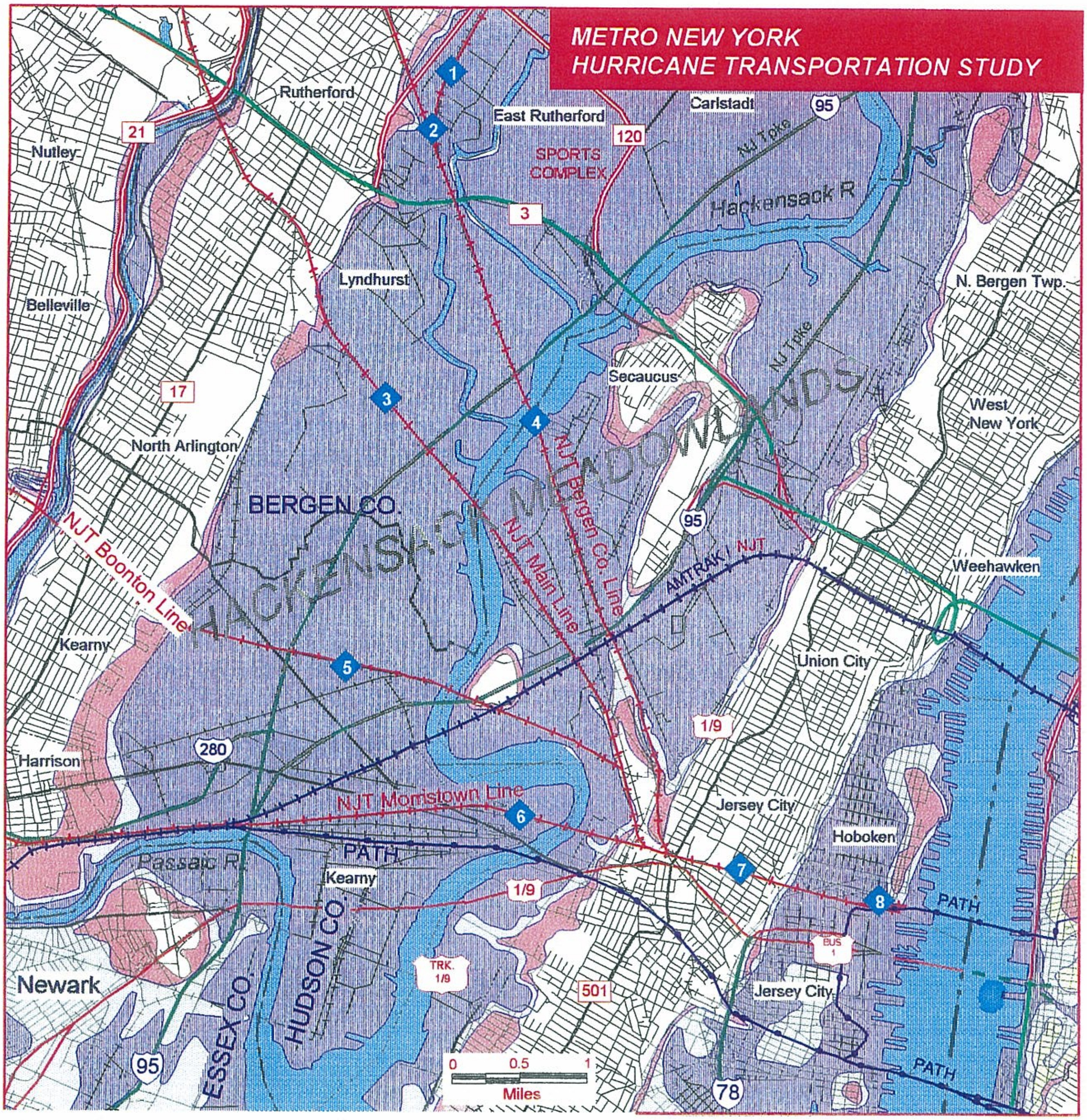
Almost simultaneously, the New York City Transit Authority lost electrical power for subway signalization, crippling the entire system. The *New York Times* reported that an N-Train was stopped for nearly 2 hours between 8th Street and Union Square. An L-Train was backed out of the 14th Street tunnel when it began filling with water. Three hundred passengers had to leave a G-Train and walk 1000 feet out of the flooded Greenpoint tunnel. No required time was reported for that incident. Above ground, 100 passengers were stranded on an A-Train in flood waters at Broad Channel.

Other rail agencies were also severely affected. The same power outage that stalled the subway system stopped Metro-North service into Grand Central Station. In addition, the Metro-North Hudson Line was flooded in Westchester County near the Croton-Harmon station. According to one newspaper report, 300 automobiles were flooded at the Westport, Connecticut station. Long Island Rail Road service was suspended to Long Beach, Far Rockaway, Montauk, Port Washington, and from Hicksville to Farmingdale. New Jersey Transit rail service at Hoboken was closed and tracks were reported flooded or washed out at East Rutherford, Lyndhurst, Harrison, and Kearny. There was also extensive damage to electrical equipment. Figure 12 shows selected locations where New Jersey Transit rail experienced flood problems.

During the same nor'easter, roadway flooding was widespread. In New York City, the Battery Park Tunnel held six feet of water, FDR Drive had major flooding that required rescues by emergency personnel (see Figure 13), and West Street, Belt Parkway, Hutchinson River Parkway and Father Capodanno Boulevard were all closed. In Nassau County, the Meadowbrook, Wantaugh, and Robert Moses Parkways were closed as were Westchester County's Hutchinson River, Bronx River, and Saw Mill River Parkways. New Jersey roadway closures included the Garden State and Meadowlands Parkways, Routes 1 and 9 in Rahway, and Harrison Avenue and Belleville Turnpike in Kearny.

Roadway travel was further complicated by bridge closures. Approaches to the Cross Bay, Marine Parkway, and Bronx-Whitestone Bridges were flooded and traffic accidents caused by high winds closed several other bridges. The Goethals, Outerbridge, Verrazano-Narrows lower level, Throgs Neck, Henry Hudson, and Brooklyn Bridges were closed due to various wind-related problems.

Miscellaneous closures included LaGuardia Airport, because of runway flooding, and the Staten Island Ferry, with wind and wave problems.



1. Pascack Valley Line - Track flooded at Union Ave., East Rutherford
2. Pascack Junction - Signal cases under water.
3. Main Line - Track flooded in Lyndhurst near Valley Brook Road.
4. Bergen Co. Line, Hackenasack R. at Secaucus - Water in signal cse.
5. Boonton Line in Kearny - Track washed out.
6. Morristown and Essex Line - Track washout; damage to equipment
7. Bergen Tunnel - Cable grounded in tunnel.
8. Hoboken Station - Extensive and varied flood damages; tunnel to NYC flooded.

FLOOD AREA CATEGORY 1 HURRICANE

ADDTITIONAL FLOOD AREA CATEGORY 2 HURRICANE

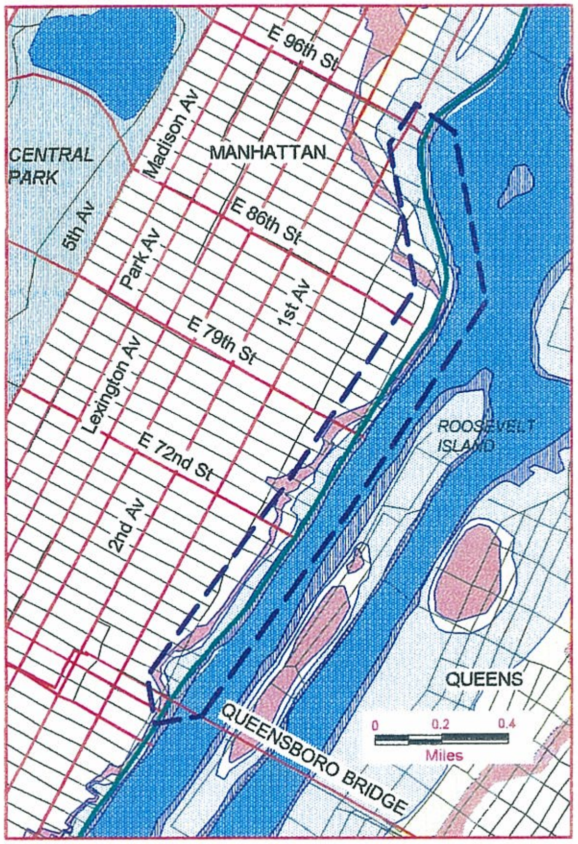
ADDTITIONAL FLOOD AREA CATEGORY 3 HURRICANE

ADDTITIONAL FLOOD AREA CATEGORY 4 HURRICANE

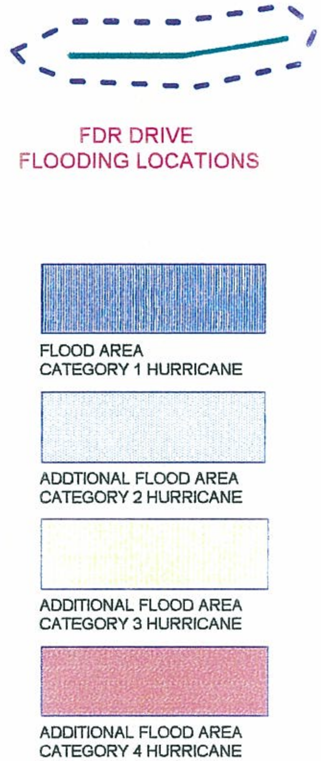
DECEMBER, 1992 NORTHEASTER

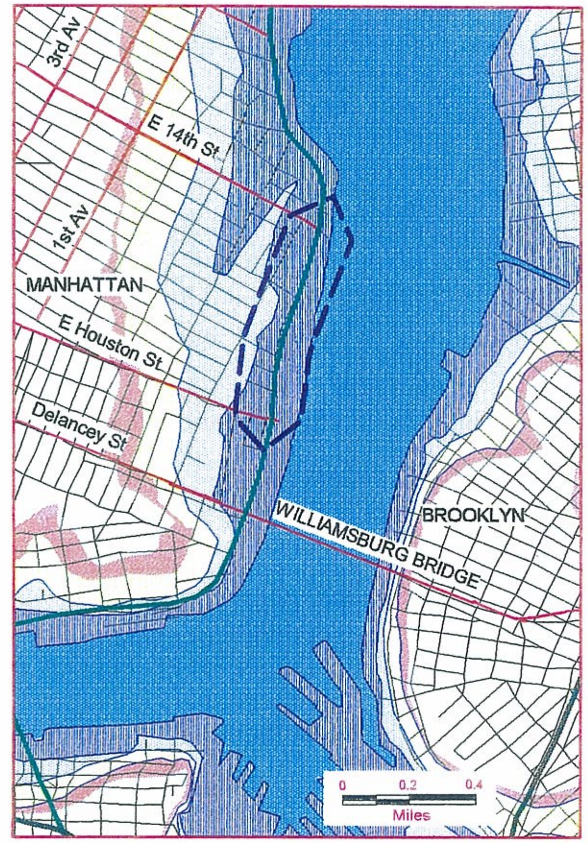
SELECTED NJ TRANSIT FLOODING LOCATIONS

FIGURE 12



Major flooding occurred along these sections of FDR Drive during the December 1992 Northeaster. The storm tide elevation at the Battery was approximately 8.5 feet NGVD.





FDR CRITICAL ELEVATIONS (NGVD)	
Above Queensboro Bridge	6.0 feet
POTENTIAL HURRICANE SURGE	
Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

FDR CRITICAL ELEVATIONS (NGVD)	
Vic. of Williamsburg Bridge	6.0 feet
POTENTIAL HURRICANE SURGE	
Category 1	9.7 feet
Category 2	14.7 feet
Category 3	22.0 feet
Category 4	24.9 feet

DECEMBER, 1992 NORTHEASTER FDR DRIVE FLOODING LOCATIONS

FIGURE 13

Vulnerability to Storm Surge

Physical characteristics of many major transportation system facilities have been evaluated for wind and storm surge vulnerability. The vulnerability of tunnels (rail and roadway) to flooding depends on two primary factors, potential volume of water inflow (a function of opening size, flood depth, and duration), and the significance of that volume to the system in question. The SLOSH model has provided accurate estimates of potential surge heights and duration. Table 13 compares the critical elevations of various facilities to potential surge heights, Table 14 lists all critical tunnel elevations, and Table 15 shows all facility elevations considered during the study. Figures 14 through 18 depict potential surge heights at prominent Metro locations. Appendixes A through I contain hazards and vulnerability data developed for each facility.

In the case of subways and other underground rail systems, the network is complex and points of entry for flood waters are numerous and varied. When examined in isolation, some locations do not appear to be vulnerable but further analysis shows that interconnections at various levels ultimately combine all of the individual systems into one network. Table 16 gives a representative list of these interconnections. **Nearly every rail tunnel system has significant points of entry below 10 feet NGVD.**

The dire significance of the December 1992 storm events is revealed by Table 12 and Figures 7 through 10. If the surge associated with that storm had instead resulted from a moderate to severe hurricane, it could have peaked from 16 to 30 feet above normal water levels with a maximum hourly rise of 17 feet. For example, if the PATH incident had involved a worst-case Category 2 hurricane (not a particularly rare event), flooding would have peaked at a depth of 8 feet in the Hoboken terminal about 1 hour after initially entering the building. As discussed above in the Hazards Analysis, the rapidly rising flood waters probably would have trapped rescuers and passengers alike. **Similar life-threatening situations in the roadway tunnels and throughout the rail tunnel network can be avoided only by making timely decisions to close and evacuate affected facilities prior to the onset of the flood event. Stringent measures must also be used to prevent the public from taking shelter in these facilities.**

The possibility of voluminous flood waters rapidly filling several roadway tunnels and a large percentage of the rail tunnel network raises a specter of catastrophe. In the worst-case scenario, all rail tunnels would first flood to the peak surge level (possibly to an elevation of nearly 30 feet NGVD), then the floodwaters would recede and stabilize at the level of the lowest surface openings, about 7-8 feet NGVD. Trapped floodwaters would fill AMTRAK/Long Island Rail Road tunnels, lower levels of Grand Central and Penn Stations, the PATH system, and the Manhattan subway system from the Battery to at least 14th Street, including the East River tunnels. Flooding of the subway system in other boroughs has not been evaluated, but would also be severe. System managers should consider the potential impacts of major flooding on their facilities and be prepared for long-term consequences. Rehabilitation of the infrastructure after such an event would take many months, in some cases years, causing serious disruptions to normal travel patterns.

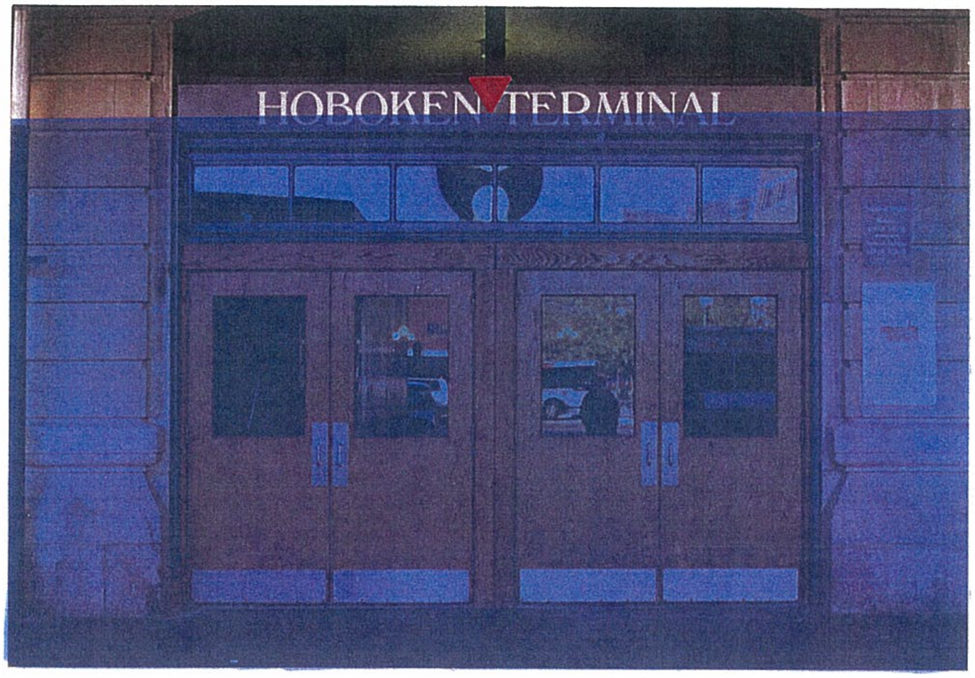


FIGURE 14 - Potential Category 2 hurricane surge at Hoboken Terminal

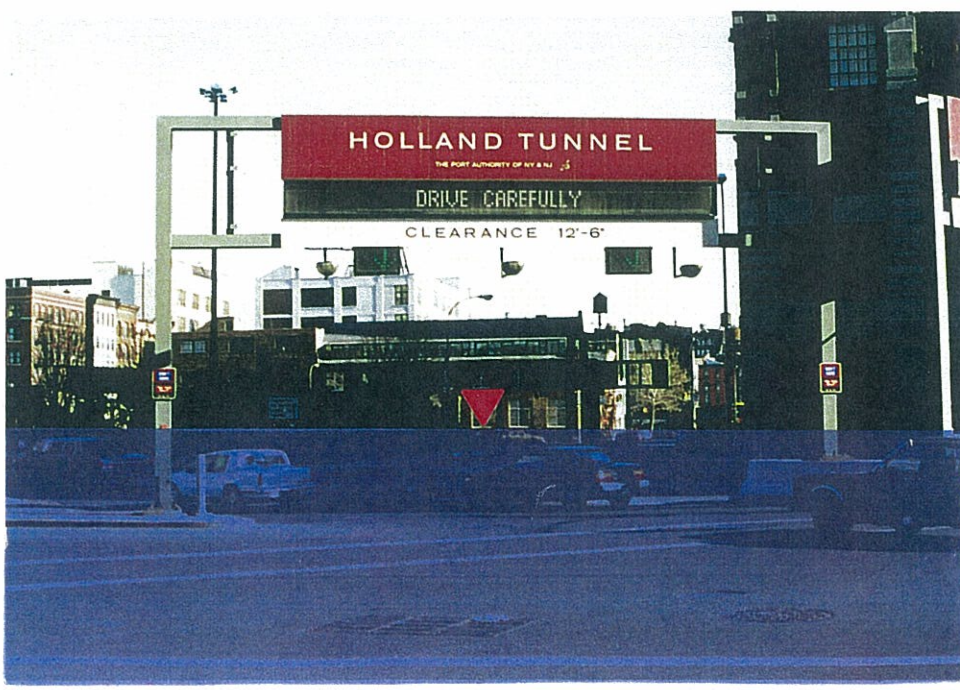


FIGURE 15 - Potential Category 2 hurricane surge at Manhattan Holland Tunnel entrance

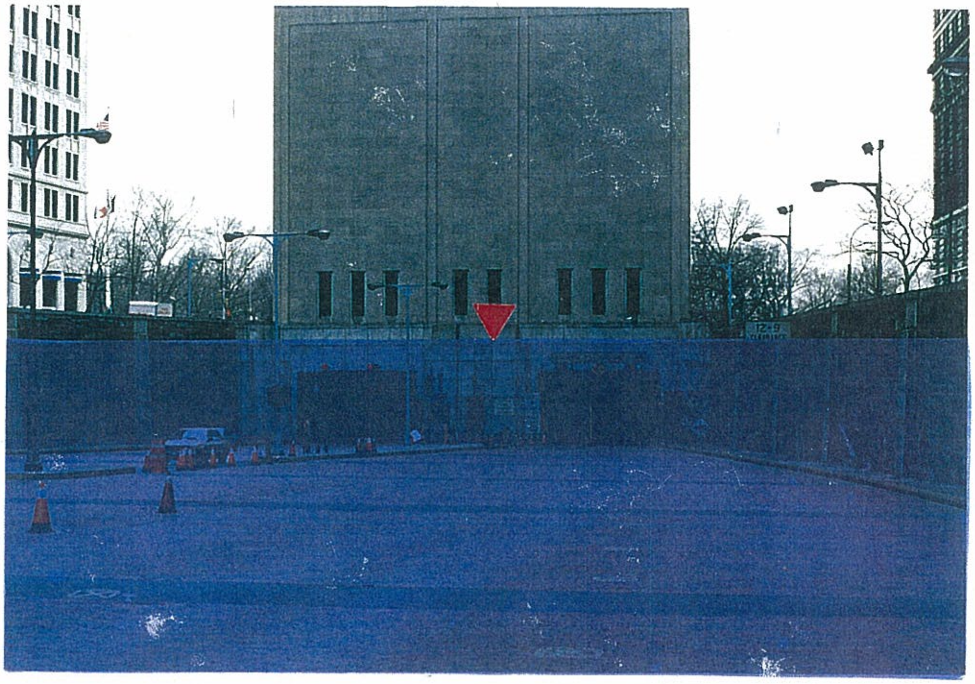


FIGURE 16 - Potential Category 1 hurricane surge at Manhattan Brooklyn-Battery entrance

FIGURE 17 - Potential Category 2 hurricane surge at South Ferry (Battery) Subway Station

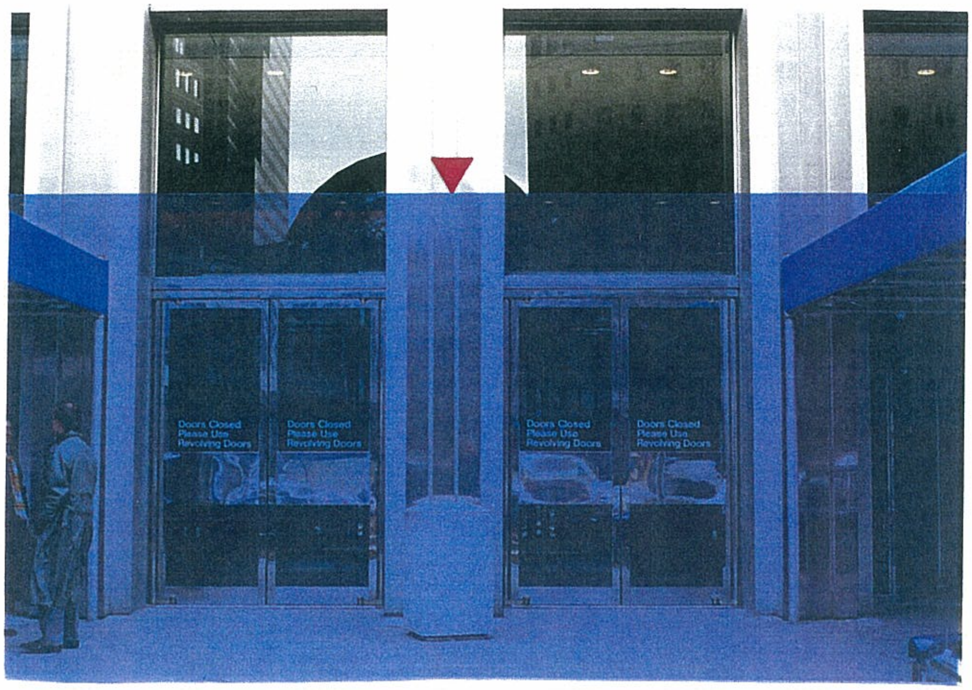


FIGURE 18 - Potential Category 3 hurricane surge at World Trade Center, West Street

TABLE 13
FACILITY VULNERABILITY

FACILITY	CRITICAL [1] ELEVATION (NGVD)	POTENTIAL HURRICANE SURGE (FT)[2] ABOVE NORMAL TIDE				TIME HAZARDS COULD OCCUR [3] SURGE/WIND				BRIDGE CENTER SPAN (NGVD)
		CAT 1	CAT 2	CAT 3	CAT 4	CAT 1	CAT 2	CAT 3	CAT 4	
PORT AUTHORITY OF NY & NJ										
LincoLn Tunnel	10.6	7.5	17.2 [4]	20.5 [4]	30.8 [4]	-/-	0.5/-	1.0/-	1.2/-	
Holland Tunnel	7.6	10.9 [4]	17.7 [4]	23.3 [4]	28.2 [4]	0.2/-	1.0/-	1.6/-	1.9/-	
PATH Tunnels										
Exchange Place Station	7.0	10.9 [4]	17.7 [4]	23.3 [4]	28.2 [4]	0.3/-	1.2/-	1.7/-	2.0/-	
Hoboken Station	7.4	10.9 [4]	17.7 [4]	23.3 [4]	28.2 [4]	0.3/-	1.2/-	1.7/-	2.0/-	
PATH Substations (power)										
#4 @ Exchange Place	6.0	10.6 [4]	16.4 [4]	24.3 [4]	28.6 [4]	0.5/-	1.5/-	2.0/-	2.3/-	
George Washington Bridge	+200.0	No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	213
Bayonne Bridge	20.0	9.8	14.5	19.8	27.5 [4]	-/3.0	-/5.0	-/6.0	-/7.0	150
Outerbridge	+50.0	No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	145
Goethals Bridge	15.0	8.8	10.7	14.4	17.7 [4]	-/3.0	-/5.0	-/6.0	-/7.0	140
JFK International Airport	11.7	6.6	15.6 [4]	24.5 [4]	31.2 [4]	-/2.0	0.3/3.0	0.8/3.5	1.2/4.5	
LaGuardia Airport	6.8	6.4	11.2 [4]	15.7 [4]	20.8 [4]	-/2.0	0.5/3.0	1.3/3.5	2.0/4.5	
Newark International Airport	10.3	8.4	10.3	13.6 [4]	17.2 [4]	-/2.0	0.0/3.0	0.3/3.5	0.5/4.5	
Teterboro Airport	5.0	5.0	6.0 [4]	7.5 [4]	10.5 [4]	-/2.0	0.1/3.0	0.3/3.5	1.0/4.5	
Passenger Ship Terminal	8.9	7.4	17.5 [4]	22.6 [4]	28.9 [4]	-/2.0	0.8/3.0	1.3/3.5	1.5/4.5	
Port Newark and Elizabeth	9.6	8.4	10.3 [4]	13.6 [4]	17.2 [4]	-/2.0	0.1/3.0	0.3/3.5	0.5/4.5	
Howland Hook Marine Terminal	9.9	8.8	10.7 [4]	14.4 [4]	17.7 [4]	-/2.0	0.0/3.0	0.3/3.5	0.5/4.5	
Auto-Marine Terminal	9.5	10.1 [4]	15.6 [4]	21.8 [4]	26.8 [4]	0.1/2.0	0.5/3.0	1.2/3.5	1.4/4.5	
Pier 40	8.9	10.9 [4]	17.7 [4]	23.3 [4]	28.2 [4]	0.1/2.0	0.8/3.0	1.2/3.5	1.5/4.5	
Red Hook Marine Terminal	9.8	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.1/2.0	0.5/3.0	1.2/3.5	1.4/4.5	
MTA BRIDGES AND TUNNELS										
(Triborough Bridge and Tunnel										
Authority)										
Brooklyn-Battery Tunnel	8.6	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.2/-	0.8/-	1.4/-	1.7/-	
Queens Midtown Tunnel	10.6	9.6	14.4 [4]	21.0 [4]	23.6 [4]	-/-	0.5/-	1.0/-	1.2/-	
Triborough Bridge	15.0	8.4	12.7	16.4 [4]	20.4 [4]	-/3.0	-/5.0	0.1/6.0	0.4/7.0	146
Bronx-Whitestone Bridge	12.0	6.5	11.3	16.6 [4]	22.2 [4]	-/3.0	-/5.0	0.3/6.0	0.8/7.0	139
Throgs Neck Bridge	10.0	6.5	11.3 [4]	16.6 [4]	22.2 [4]	-/3.0	0.1/5.0	0.5/6.0	1.1/7.0	146
Verrazano-Narrows Bridge	8.0	7.9	15.4 [4]	21.1 [4]	26.6 [4]	-/3.0	0.9/5.0	1.4/6.0	1.8/7.0	231
Marine Parkway Bridge	8.0	7.0	14.4 [4]	20.6 [4]	27.2 [4]	-/2.0	0.9/3.0	1.4/3.5	1.8/4.5	58
Cross Bay Parkway Bridge	8.0	6.3	13.7 [4]	21.4 [4]	27.5 [4]	-/2.0	0.9/3.0	1.4/3.5	1.8/4.5	58
Henry Hudson Parkway Bridge	+100.0	No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	146

TABLE 13
FACILITY VULNERABILITY

FACILITY	CRITICAL [1] ELEVATION (NGVD)	POTENTIAL HURRICANE SURGE (FT)[2] ABOVE NORMAL TIDE				TIME HAZARDS COULD OCCUR [3] SURGE/WIND				BRIDGE CENTER SPAN (NGVD)
		CAT 1	CAT 2	CAT 3	CAT 4	CAT 1	CAT 2	CAT 3	CAT 4	
NYC TRANSIT AUTHORITY										
STATIONS										
World Trade Center	8.1	10.6 [4]	16.4 [4]	24.3 [4]	28.6 [4]	0.3/-	0.9/-	1.4/-	1.8/-	
South Ferry	9.1	10.5 [4]	16.6	24.0	28.7	0.2/-	0.8/-	1.3/-	1.5/-	
TUNNEL VENTS										
Cranberry Street	7.0	10.2 [4]	16.0 [4]	25.1 [4]	31.3 [4]	0.3/-	1.1/-	1.7/-	2.0/-	
14th Street	7.2	9.7 [4]	14.7 [4]	22.0 [4]	24.9 [4]	0.2/-	1.0/-	1.6/-	1.8/-	
Montague Street	7.5	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.3/-	1.0/-	1.6/-	1.8/-	
Greenpoint (Newtown)	8.1	9.7 [4]	14.7 [4]	22.0 [4]	24.9 [4]	0.2/-	0.8/-	1.2/-	1.5/-	
Clark Street	9.1	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.2/-	0.8/-	1.3/-	1.5/-	
Joralemon Street	9.8	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.0/-	0.5/-	1.1/-	1.3/-	
Lexington Avenue	9.9	8.4	12.7 [4]	16.4 [4]	20.4 [4]	0.0/-	0.3/-	0.6/-	1.0/-	
LONG ISLAND RAIL ROAD										
Long Beach Line @ Oceanside	6.2	7.3 [4]	16.2 [4]	21.9 [4]	26.9 [4]	0.1/-	1.3/-	1.8/-	2.2/-	
Port Washington Line @ Flushing	9.2	6.6	11.6 [4]	16.2 [4]	20.9 [4]	-/-	0.2/-	0.8/-	1.3/-	
Far Rockaway Line	9.2	8.1	15.4 [4]	20.5 [4]	26.2 [4]	-/-	0.8/-	1.3/-	1.5/-	
Oyster Bay Station	9.5	5.7	10.3 [4]	15.2 [4]	19.8 [4]					
METRO-NORTH										
Croton River	6.3	2.8	7.5 [4]	8.5 [4]	14.5 [4]	-/-	0.2/-	0.3/-	1.0/-	
Spuyten Duyvil	7.7	6.1	13.0 [4]	14.8 [4]	24.6 [4]	-/-	0.6/-	1.0/-	1.5/-	
Grand Central Terminal	11.0	9.2	14.1 [4]	17.4 [4]	22.3 [4]	-/-	0.3/-	0.6/-	1.0/-	
Fairfield, Connecticutt	9.6	12.0 [4]	12.0 [4]	15.5 [4]	18.5 [4]	-	-	-	-	
Westport, Connecticutt	9.8	11.5 [4]	11.5 [4]	15.0 [4]	18.5 [4]	-	-	-	-	
AMTRAK/L.I.R.R.										
PENN STATION										
East River Tunnel, L.I. Shaft	9.0	9.2 [4]	14.1 [4]	17.4 [4]	22.3 [4]	-/-	0.6/-	0.9/-	1.3/-	
West Side Storage Yard	10.0	7.5	17.2 [4]	20.5 [4]	30.8 [4]	-/-	0.5/-	1.0/-	1.2/-	
NEW JERSEY TRANSIT-RAIL										
Pascack Valley @ E. Rutherford	-	8.2 [4]	9.1 [4]	10.2 [4]	13.9 [4]	-	-	-	-	
Bergen County Line @ Secaucus	-	8.5 [4]	10.0 [4]	13.4 [4]	15.9 [4]	-	-	-	-	

TABLE 13
FACILITY VULNERABILITY

FACILITY	CRITICAL [1] ELEVATION (NGVD)	POTENTIAL HURRICANE SURGE (FT)[2] ABOVE NORMAL TIDE				TIME HAZARDS COULD OCCUR[3] SURGE/WIND				BRIDGE CENTER SPAN (NGVD)
		CAT 1	CAT 2	CAT 3	CAT 4	CAT 1	CAT 2	CAT 3	CAT 4	
Main Line @ Lyndhurst	-	8.2 [4]	9.1 [4]	10.2 [4]	13.9 [4]	-	-	-	-	
Boonton Line @ Kearney	-	9.9 [4]	11.1 [4]	12.7 [4]	16.8 [4]	-	-	-	-	
North Jersey Coast Line										
@ Perth Amboy	-	11.1 [4]	17.2 [4]	20.2 [4]	28.0 [4]	-	-	-	-	
@ Sayreville	-	11.4 [4]	18.4 [4]	24.6 [4]	28.0 [4]	-	-	-	-	
@ Oceanport	-	5.1 [4]	7.2 [4]	15.1 [4]	20.7 [4]	-	-	-	-	
NEW YORK CITY D.O.T.										
Manhattan/Queensboro Bridges		No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	135
Brooklyn/Williamsburg Bridges		No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	133
FDR Drive above 59th Street	6.0	9.1 [4]	14.1 [4]	17.4 [4]	22.3 [4]	0.5/-	1.2/-	1.5/-	2.0/-	
FDR Dr. vic. Williamsburg Bridge	6.0	9.7 [4]	14.7 [4]	22.0 [4]	24.9 [4]	0.5/-	1.3/-	1.8/-	2.2/-	
Battery Park Tunnel	9.0	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.2/-	0.8/-	1.4/-	1.7/-	
West Street	9.0	10.6 [4]	16.4 [4]	24.3 [4]	28.6 [4]	0.2/-	0.8/-	1.4/-	1.7/-	
NEW JERSEY D.O.T.										
U.S. Highway 1										
@ Rahway	9.4	-	-	16.4 [4]	21.8 [4]	-	-	-	-	
@ Elizabeth	9.6	11.3 [4]	13.2 [4]	16.5 [4]	20.3 [4]	-	-	-	-	
@ Linden	11.0	12.0 [4]	13.7 [4]	17.3 [4]	21.0 [4]	-	-	-	-	
U.S. Highways 1 and 9										
@ Jersey City	2.0	9.8 [4]	11.9 [4]	14.6 [4]	17.2 [4]	-	-	-	-	
@ Newark	6.8	11.0 [4]	12.2 [4]	14.8 [4]	18.3 [4]	-	-	-	-	
@ North Bergen Township	8.0	8.4 [4]	9.8 [4]	11.1 [4]	14.8 [4]	-	-	-	-	
I-95 @ Bergen County	5.8	8.2 [4]	9.1 [4]	10.2 [4]	13.9 [4]	-	-	-	-	
N.J. Route 17 @ Bergen County	3.9	8.2 [4]	9.1 [4]	10.2 [4]	13.9 [4]	-	-	-	-	
U.S. Highway 46 @ Little Ferry	5.6	8.2 [4]	9.1 [4]	10.2 [4]	13.9 [4]	-	-	-	-	
N.J. Route 3 @ Secaucus	8.0	8.2 [4]	9.1 [4]	10.2 [4]	13.8 [4]	-	-	-	-	
N.Y. STATE THRUWAY										
Tappan Zee Bridge		No Surge Hazard				-/3.0	-/5.0	-/6.0	-/7.0	150
N.Y. STATE PARKS										
Meadowbrook Parkway	7.3	4.7	15.4 [4]	23.8 [4]	28.0 [4]	-/-	1.0/-	1.7/-	2.0/-	
Wantaugh Parkway	6.3	4.4	14.0 [4]	22.3 [4]	29.2 [4]	-/-	0.8/-	1.8/-	2.2/-	

TABLE 13
FACILITY VULNERABILITY

FACILITY	CRITICAL [1] ELEVATION (NGVD)	POTENTIAL HURRICANE SURGE (FT)[2] ABOVE NORMAL TIDE				TIME HAZARDS COULD OCCUR [3] SURGE/WIND				BRIDGE CENTER SPAN (NGVD)
		CAT 1	CAT 2	CAT 3	CAT 4	CAT 1	CAT 2	CAT 3	CAT 4	
CONNECTICUT D.O.T.										
I-95										
@ Fairfield	16.0	12.0	12.0	15.5	18.5 [4]	-	-	-	-	
@ Westport	13.3	11.7	11.7	15.0 [4]	18.5 [4]	-	-	-	-	

[1] Elevation of Initial Facility Flooding

[2] SLOSH Model Worst-Case Surge Height

[3] Time in Hours Before Closest Approach of Hurricane Eye (assumes Category 3 Hurricane w/Radius Tropical Storm Winds 120 Miles, Moving 40 MPH)

[4] Surge Height That Exceeds Facility Critical Elevation

NOTE: See Appendix A for additional facilities information.

TABLE 14

CRITICAL ELEVATIONS FOR TUNNEL FLOODING

Mass Transit	Elevation (NGVD)
TA-Cranberry Street Tunnel @ Front St Vent	7.0
PATH-Exchange Place Station	7.0
TA-14th Street Tunnel @ Avenue D Vent	7.2
PATH-Morton Street Shaft	7.3
PATH-Hoboken Station	7.4
TA-Montague Street Tunnel @ grates in Broad St	7.5
PATH-Washington Street Shaft	7.6
PATH/TA-World Trade Center Ramp D	8.1
TA-Greenpoint Jackson Ave (Newtown Cr)	8.1
TA-A,C,E Lines @ Canal Street Station	8.7
AMTRAK/LIRR-East River Tunnel @ L.I. Shaft	9.0
TA-South Ferry Station	9.1
TA-Whitehall Street Station	9.1
TA-Clark Street Tunnel @ Front Street Vent	9.1
PATH-15th Street Shaft	9.6
PATH-Railroad Avenue Shaft	9.7
PATH-Grove Street Station	9.8
TA-Joralemon Tunnel @ State Street Grate	9.8
TA-1,2,3,9 Lines @ Canal Street Grate	9.8
TA-Lexington Ave Tunnel @ 135th St Bronx Vent	9.9
PATH-Pavonia Avenue Station	10.0
AMTRAK/LIRR @ West Side Yard	10.0
TA-53rd Street Tunnel @ Nott Avenue Vent	10.0
TA-Rutgers Street Tunnel @ South Street Vent	10.6
TA/METRO NORTH-Steinway Tunnel @ 50th Ave Vent	11.0
AMTRAK/LIRR @ East River Tunnel Top-of-Ramp	12.0
AMTRAK/LIRR @ Weehawken Shaft	12.3
PATH/TA-World Trade Center Concourse	12.6
TA-63rd Street Tunnel @ Queensbridge Vent	12.7
TA-Yankee Stadium Tunnel @ 157th Street Vent	12.8
AMTRAK/LIRR @ East River Tunnel 1st Ave Shaft	14.5

Highway Tunnels	
Holland Tunnel New Jersey Entrance	7.6
Holland Tunnel New Jersey Land Vent Shaft	7.6
Brooklyn-Battery Tunnel West Street Entrance	8.6
Brooklyn-Battery Tunnel Battery Ent @ Morris St	8.6
Holland Tunnel New York River Vent Shaft	8.6
Holland Tunnel New York Land Vent Shaft	8.6
Holland Tunnel New York Entrance	9.5
Holland Tunnel New Jersey River Vent Shaft	10.6
Lincoln Tunnel New Jersey Vent Shaft	10.6

TABLE 14--Cont'd

CRITICAL ELEVATIONS FOR TUNNEL FLOODING

Highway Tunnels	Elevation (NGVD)
Lincoln Tunnel New York Third Tube Vent Shaft	10.6
Queens Midtown Tunnel Queens Entrance	10.6
Lincoln Tunnel New York River Vent Shaft	11.6
Brooklyn-Battery Tunnel Brooklyn Entrance	11.6
Queens Midtown Tunnel Queens Vent Shaft	12.6
Brooklyn-Battery Tunnel Governors Is Vent	12.6
Brooklyn Battery Tunnel Manhattan Vent Shaft	13.6
Queens Midtown Tunnel Manhattan Entrance	14.6
Brooklyn-Battery Tunnel Brooklyn Vent Shaft	14.6
Lincoln Tunnel New York Land Vent Shaft	19.6
Lincoln Tunnel New York Entrance	22.6
Queens Midtown Tunnel Manhattan Vent Shaft	22.6
Lincoln Tunnel New Jersey Entrance	27.6

TABLE 15

CRITICAL ELEVATIONS FOR FLOODING BY AGENCY AND FACILITY

Facility	Elevation (NGVD)
New York City Transit Authority	
Station Entrances	
IRT,IND,BMT Divisions, Lines 1,9,2,3,A,C,E,N,R	
World Trade Center Ramp D	8.1
World Trade Center Concourse	12.6
BMT Division, Lines M,N&R	
Whitehall Street	9.1
Canal Street	14.0
IND Division, Lines A,C,&E	
Canal Street	8.7
IRT Division, Lines 1&9	
South Ferry	9.1
Canal Street (Grate nr Entrance)	9.8
Franklin Street	12.9
Rector Street	13.8
IRT Division, Lines 4&5	
Canal Street	16.8
Bowling Green	16.9
BMT Division, Line F	
W 4th Street (Washington Sq)	19.6
BMT Division, Lines B,D,&Q	
W 4th Street (Washington Sq)	19.6
River Tunnels	
Cranberry Street (A&C Lines) Front St Vent	7.0
14th Street (L Line) Avenue D Vent	7.2
Montague St (M,N&R Lines) Grates in Broad St	7.5
Greenpoint-Jackson Ave(Newtown Cr)(G Line)	8.1
Clark Street (2&3 Lines) Front Street Vent	9.1
Joralemon St (4&5 Lines) State Street Grate	9.8
Lexington Ave (4,5&6 Lines) 135th St Bronx	9.9
53rd Street (E&F Lines) Nott Ave Vent	10.0
Rutgers Street (F Line) South Street Vent	10.6
Steinway (7 Line) 50th Ave Vent	11.0
63rd Street (B&Q Lines) Queensbridge Vent	12.7
Yankee Stadium (C&D Lines) 155th St Vent	12.8

TABLE 15--Cont'd

CRITICAL ELEVATIONS FOR FLOODING BY AGENCY AND FACILITY

	Elevation (NGVD)
AMTRAK/Long Island Rail Road	
Penn Station	
Flood Sources	
East River Tunnel Long Island Shaft	9.0
West side Storage Yard 100yr storm berm	10.0
East River Tunnel Top-of-Ramp	12.0
North (Hudson) River Weehawken Shaft	12.3
East River Tunnel 1st Avenue Shaft	14.5
Top-of-Rail Elevation	-6.3
Long Island Rail Road on Long Island	
Long Beach Branch line @ Oceanside	6.2
Port Washington Branch line @ Flushing	9.2
Far Rockaway Branch line	
@Far Rockaway	9.2
@Valley Stream	11.4
Oyster Bay station	9.5
Port Authority of New York & New Jersey	
Port Authority Trans-Hudson Corp (PATH)	
Open Territory @ Kearny N.J.	6.0
Substation #8 Kearny N.J.	6.0
Substation #4 Exchange Place N.J.	6.0
Henderson Car Shop	7.0
Exchange Place	7.0
Substation #7 Broadway & Hallerick N.J.	7.0
Substation #9 Harrison N.J.	7.0
Morton Street Shaft	7.3
Hoboken Station	7.4
Washington Street Shaft	7.6
Substation #2-2a Washington Street N.J.	7.9
World Trade Center Ramp D	8.1
15th Street Shaft	9.6
Railroad Avenue Shaft	9.7
Grove Street Station	9.8
Pavonia Avenue Station	10.0
Substation #3 (WTC)	10.0
Hoboken Shop	11.9

TABLE 15--Cont'd

CRITICAL ELEVATIONS FOR FLOODING BY AGENCY AND FACILITY

	Elevation (NGVD)
Tunnel Floor Elevation	
World Trade Center	-50.8
Christopher Street Station	-14.6
9th Street Station	-15.0
12th Street Station	0.0
14th Street Station	6.1
19th Street Station	16.0
Hoboken Station	-12.0
Exchange Place Station	-71.0
Grove Street Station	-15.6
Pavonia Station	-43.0
Holland Tunnel	
New Jersey Top-of-Ramp	7.6
New Jersey Land Vent	7.6
New York River Vent	8.6
New York Land Vent	8.6
New York Top-of-Ramp	9.5
New Jersey River Vent	10.6
Lincoln Tunnel	
New Jersey Vent	10.6
New York Third Tube Vent	10.6
New York River Vent	11.6
New York Land Vent	19.6
New York Top-of-Ramp	22.6
New Jersey Top-of-Ramp	27.6
Marine Terminals (average elevation)	
Passenger Ship Terminal	8.9
Pier 40	8.9
Autoport	9.5
Port Newark & Elizabeth	9.6
Red Hook Marine Terminal	9.8
Howland Hook	9.9
Airports	
Teterboro Airport	5.0
LaGuardia Airport	6.8
Newark International	10.3
John F. Kennedy International	11.7
Bridges (Lowest Approach Elevation)	
Goethals @ Staten Island Expressway	15.0
Bayonne @ John F. Kennedy Ave	20.+
Outerbridge	50.+
George Washington	200.+

TABLE 15--Cont'd

CRITICAL ELEVATIONS FOR FLOODING BY AGENCY AND FACILITY

	Elevation (NGVD)
MTA Bridges and Tunnels	
Queens Midtown Tunnel	
Queens Entrance	10.6
Queens Vent	12.6
Manhattan Entrance	14.6
Manhattan Vent	22.6
Brooklyn Battery Tunnel	
Manhattan West Street Entrance	8.6
Manhattan Battery Ent @ Morris Street	8.6
Brooklyn Entrance	11.6
Governors Island Vent	12.6
Manhattan Vent	13.6
Brooklyn Vent	14.6
Bridges	
Verrazano-Narrows @ Shore Parkway	8.0
Marine Parkway @ Beach Channel Dr	8.0
Cross Bay Parkway @ Cross Bay Blvd	8.0
Throgs Neck @ Throgs Neck Expwy	10.0
Bronx-Whitestone @ Hutchinson R Pkwy	12.0
Triborough @ E. 125th/2nd Ave.	15.0
Henry Hudson Parkway	100.+
Metro-North	
Grand Central Terminal	
Flood Source	
IRT Steinway Tube Queens Vent (7 Line)	11.0
Top-of-Rail Elevations	
IRT Steinway Tube	-14.0
IRT 4,5,& 6 Lines	8.0
Lowest Metro-North level	12.0
Hudson Line	
1500 ft South of Croton River (2 tracks)	6.3-6.5
Croton River Bridge (2 tracks)	7.0-7.5
Spuyten Duyvil	7.7
New Haven Line	
Fairfield County Connecticut	
Town of Westport @ Sherwood Millpond	9.8
@ Sasco Creek	12.5
Town of Fairfield @ Grasmere Brook	9.6
@ Rooster River	17.0
Town of Stratford @ Bruce Brook	22.0

TABLE 16

CRITICAL ELEVATIONS FOR INTERCONNECTED MASS TRANSIT TUNNELS

Station(s)	Interconnecting Facilities- Flood Source	Elevation (NGVD)
World Trade Center	A,C,E Lines-Cranberry Tunnel	7.0
site	PATH-Exchange Place Station	7.0
	N&R Lines-Montague Tunnel	7.5
	WTC-Ramp D	8.1
	1&9 Lines-South Ferry Station	9.1
	2&3 Lines-Clark St. Tunnel	9.1
Fulton Street	A,C Lines-Cranberry Tunnel	7.0
	M Line-Montague St. Tunnel	7.5
	2&3 Lines-Clark St. Tunnel	9.1
	4&5 Lines-Joralemon Tunnel	9.8
Chambers Street/ Brooklyn Br-City Hall	M,J,& Z Lines-Montague Tunnel	7.5
	4,5,& 6 Lines-Joralemon Tunnel	9.8
Canal Street	N&R Lines-Montague Tunnel	7.5
	M,J,& Z Lines-Montague Tunnel	7.5
	4,5,& 6 Lines-Joralemon Tunnel	9.8
Essex Street/ Delancy Street	M,J,& Z Lines-Montague Tunnel	7.5
	F Line-Rutgers Street Tunnel	10.6
Bleeker Street/ Broadway-LaFayette	4,5,& 6 Lines-Joralemon Tunnel	9.8
	B,D,F,& Q-Rutgers St Tunnel	10.6
W 4th St-Washington Square	A,C,& E Lines-Cranberry Tunnel	7.0
	B,D,F,& Q-Rutgers St Tunnel	10.6
14th Street-Union Sq	L Line-14th Street Tunnel	7.2
	N,R Lines-Montague St Tunnel	7.5
	4,5,& 6 Lines-Joralemon Tunnel	9.8
14th Street-6th Ave	L Line-14th Street Tunnel	7.2
	PATH-Hoboken Station	7.4
	1,2,3,& 9 Lines-South Ferry	9.1
	B,D,F,& Q-Rutgers St Tunnel	10.6
14th Street-8th Ave	A,C,& E Lines-Cranberry Tunnel	7.0
	L Line-14th Street Tunnel	7.2
33rd Street-6th Ave	N,R Lines-Montague St Tunnel	7.5
	AMTRAK/LIRR-East River Tunnel	9.0
	B,D,F,& Q-Rutgers St Tunnel	10.6

Note: WTC & Fulton Street Stations are connected by the A&C Lines and the 2&3 Lines

Vulnerability to Wind Hazards

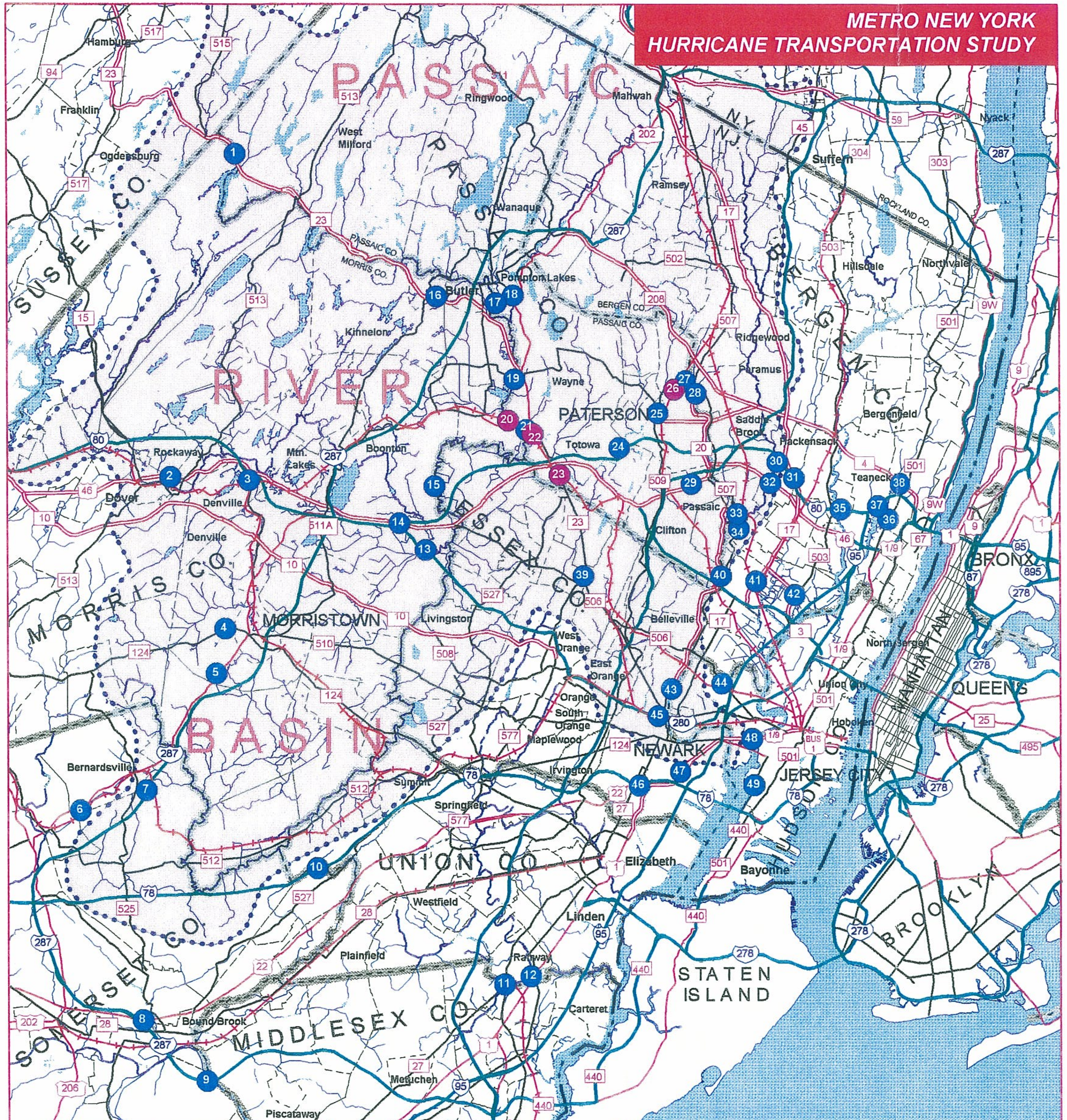
Within the transportation network, high-rise bridges are particularly vulnerable to the hazards of extreme winds. Although some could experience wind-related structural problems, traffic hazards will probably stop travel before this can become a significant factor. As mentioned previously, several major high-rise bridges were closed during the nor'easter of December 1992 after gale-force winds caused traffic accidents. Based on past experience with overturned high profile vehicles, a limiting wind speed should be established for normal bridge operations in the Metro area. Major facilities should be equipped with wind measurement devices to monitor on-site velocities, and bridge traffic should be restricted or closed before the limiting speed is exceeded.

In the study area, complete structural failure of tall buildings due to extreme winds is not a major concern. However, past wind storms in other locations have shown that combinations of wind forces on multi-story buildings, as described in the hazards analysis section, can result in window breakage, the destruction of interior partitions, and loss of exterior cladding, creating the potential for high numbers of casualties. Not only could building occupants be endangered, but debris falling onto the streets from high above could create an extreme hazard to pedestrians. During an intense storm, wind pressures on upper portions of tall structures can be much greater than those at ground level. These pressures can cause significant problems during even a moderate hurricane. Building owners should review their structure's design standards and consider methods of retrofitting to improve its resistance to wind damage. Any plans for providing areas of vertical refuge should include an evaluation of potential wind damage and related hazards inside the building. As discussed in the "Evacuation Alternatives" section, vertical evacuation should not be planned as an alternative to horizontal evacuation.

Vulnerability to Rainfall Flooding

Riverine flooding in the Passaic River Basin has historically caused extensive property damage and taxed the emergency management resources of New Jersey's State, county, and municipal governments. Several of the passenger rail lines and major highways that link commuters with Manhattan lie in those flood-prone areas.

From an emergency management perspective, whether before, during, or after a coastal storm, riverine flooding can disrupt regional rail and highway traffic and operations. Low-lying segments and spot locations along Passaic Region rail lines and highways, and areas with a history of disruption because of poor drainage, are shown in Figure 19. Transportation agencies should consider these potential flood problems in their overall planning efforts.



MAP KEY	TYPE	SOURCE	LOCATION
1	Hwy	DOT	NJ 23, mp 23.8; Rockaway, Morris Co.
2	Hwy	DOT	US 46, mp 39.0 to 40.0; Parsippany-Troy Hills, Morris Co.
3	Hwy	DOT	NJ 53, mp 0.0 to 7.4; Morris Plains Borough thru Denville T., Morris Co.
4	Hwy	DOT	NJ 24, mp 0.0 to 7.4 ; Morris T. & Jefferson T., Morris Co.
5	Hwy	DOT	US 202, mp 39.0 to 47.0; Ha
6	Hwy	DOT	US 202, mp 34.3 to 34.6; Bernardsville Bor., Somerset Co.
7	Hwy	DOT	I-287, mp 28.1 SB; Bernards T., Somerset Co.
8	Hwy	DOT	US 22, mp 32.0 EB at I-287 Interchange; Bridgewater T.
9	Hwy	DOT	I-287, mp 12.1 NB; Franklin T., Somerset Co.
10	Hwy	DOT	I-78, mp 42.2, Esit 41; Watchnung Bor., Somerset Co.
11	Hwy	DOT	NJ 35, mp 58.0; Rahway, Union Co.
12	Hwy	DOT	US 1/9, mp 38.6; Rahway, Union Co.
13	Hwy	FIS	Edwards Road over Whippany River; Hanover T./Parsippany Hills T.
14	Hwy	DOT	US 46 WB at I-80; Parsippany-Troy Hills, Morris Co.
15	Hwy	FIS	Horsneck Road Bridge over Passaic R.; Fairfield T./ Montville T.
16	Hwy	DOT	NJ 23, mp 13.6 and 15.2; Butler T., Morris Co.
17	Hwy	FIS	Riverdale Rd. at Pequannock River; Riverdale T.
18	Hwy	FIS	Paterson-Hamburg Tpk. over Ramapo River; Pompton Lakes T.
19	Hwy	FIS	Pompton Tpk. over Pompton River in Pequannock T.
20	NJT	FIS	NJ Transit Boonton Line over Pompton River; Wayne T.
21	Hwy	FIS	US 202 over Pompton River; Lincoln Park
22	NJT	1984	NJ Transit Boonton Line over Pequannock River;
23	NJT	FIS	NJ Transit Boonton Line over Passaic River at Little Falls
24	Hwy	FIS	Totowa Road Bridge; W. Paterson/Totowa
25	Hwy	FIS	Arch St. Bridge in Paterson
26	NJT	FIS	NJ Transit Main Line over Passaic River at Paterson
27	Hwy	FIS	NJ 20/Lincoln Ave; Paterson/Hawthorne
28	Hwy	DOT	NJ 20, mp 3.3 along Passaic River in Paterson, Passaic Co.
29	Hwy	DOT	US 46, mp 62.5 to 62.8; Clifton, Passaic Co.
30	Hwy	DOT	I-80 WB, mp 63.9; vicinity of Saddle River in Lodi, Bergen Co
31	Hwy	DOT	NJ 17, mp 10.0; Lodi, Bergen Co.
32	Hwy	DOT	US 46, mp 66.5 over Saddle River in Lodi
33	Hwy	FIS	Wall St. Bridge in Passaic
34	Hwy	FIS	8th Street Bridge in over Passaic River
35	Hwy	DOT	I-80 EB, mp 67.1; vicinity of Hackensack River in Bogota Bor.
36	Hwy	DOT	NJ 93, mp 1.7 to 2.6; Leonia Bor., Bergen Co.
37	Hwy	DOT	I-95 SB, mp 74.1; Teaneck T., Bergen Co.
38	Hwy	DOT	NJ 4, mp 9.7: Englewood, Bergen Co.
39	Hwy	DOT	NJ 23 NB, mp 0.3; Verona Bor., Bergaen Co.
40	Hwy	FIS	NJ 21 mp 9.9 to 10.9, Clifton
41	Hwy	DOT	NJ 17, mp 4.93 & mp 5.2 to 5.8; East Rutherford
42	Hwy	DOT	NJ 120, mp 1.0; Carlstadt/E. Rutherford vicinity of Sports Complex
43	Hwy	DOT	NJ 21 NB, mp 4.5; City of Newark
44	Hwy	DOT	NJ 7, mp 3.1 to 3.6; Kearny
45	Hwy	DOT	I-280, mp 13.8 to 14.5; City of Newark
46	Hwy	DOT	I-78 EB, mp 56.2 to 57.0; City of Newark
47	Hwy	DOT	US 1/9 SB, mp 49.4; City of Newark
48	Hwy	DOT	US 1/9T, mp 1.45; Kearny vicinity of Hackensack River
49	Hwy	DOT	NJ 440, mp 22.1; Jersey City

(21) HIGHWAY FLOOD PROBLEM LOCATION

(22) NEW JERSEY TRANSIT FLOOD PROBLEM LOCATION

SOURCES

DOT = Locations Subject to Traffic Disruption from Flooding as reported by NJ Department of Transportation Construction & Maintenance Offices 1992.

FIS = Locations Identified as Subject to Flooding by National Flood Insurance Program (NFIP) Flood Insurance Studies.

1984 = Track Problems Reported by New Jersey Transit - 1984 Passaic Basin Flooding.

This figure shows selected highway and rail flood problem locations in and near the Passaic River Basin. See Appendices for additional locations.

PASSAIC BASIN REGION

RAIL AND HIGHWAY FLOOD PROBLEM LOCATIONS

FIGURE 19

Possible Sequence of Facility Closures

Table 17 shows a possible sequence of facility closures for a Category 3 hurricane (radius of tropical storm winds of 120 miles and 40 mph forward speed) directly affecting the Metro New York area. This table is a theoretical series that shows the point at which facilities would have to be closed based on expected pre-landfall hazards. **Closures are determined by thresholds of vulnerability and no time is included for securing facilities. Coordinated decision making must take place well in advance of the times shown in Table 17. During an actual event, lead times could be considerably longer.** The meteorological characteristics of the approaching storm and system closure details would have to be taken into account.

Theoretically, the first facilities to shut down will be the marine terminals as winds begin to affect water surface conditions from 7 to 12 hours before eye landfall (or the closest approach of the eye). Next, the high level bridges will begin to close as extreme winds make travel very hazardous, if not impossible, and somewhat later the lower-level bridges will close. Ground transportation problems for arriving passengers at airports, bus, and rail terminals will probably prompt the early closure of those facilities, possibly on the order of 6 hours before eye landfall. Soon winds will cause individual airlines and the Federal Aviation Administration to curtail airport operations. In the final 2 to 3 hours before eye landfall, highway and rail tunnels, as well as low-lying road segments, will close due to anticipated and initial flooding.

The expected short intervals between individual facility closures during a hurricane emergency make planning extremely difficult. Very probably, major systems will be affected nearly simultaneously and less vulnerable systems will have little time to adjust before they, too, must curtail operations. This is true of both highway and rail facilities although some highway travel may continue after several high level bridges are closed. These conditions must be anticipated and early action taken rather than reacting to events as they unfold.

TABLE 17

POSSIBLE SEQUENCE OF FACILITY CLOSURES FOR A CATEGORY 3 HURRICANE DIRECTLY AFFECTING THE METRO NEW YORK AREA

Hours Before Eye Landfall or Closest Approach of Eye	New York City Department of Transportation and Triborough Bridge and Tunnel Authority	Rail Transit Provider Agencies and The Port Authority of New York and New Jersey
7-12		Red Hook Marine Terminal Pier 40 Passenger Ship Terminal Auto Marine Terminal Howland Hook Marine Terminal Port Newark and Elizabeth
6	Verrazano-Narrows Bridge Throgs Neck Bridge Triborough Bridge Bronx-Whitestone Bridge Henry Hudson Parkway Bridge Manhattan Bridge Queensboro Bridge Brooklyn Bridge Williamsburg Bridge	George Washington Bridge Bayonne Bridge Outerbridge Goethals Bridge John F. Kennedy Int'l Airport LaGuardia Airport Newark Int'l Airport Teterboro Airport
3-1/2	Marine Parkway Bridge Cross Bay Pkwy. Bridge	
2-1/2		Long Island Rail Road Tunnels New Jersey Transit Facilities
2	FDR Drive	PATH Substations PATH Tunnels NYC Transit Authority Tunnels
1-1/2	Brooklyn-Battery Tunnel Battery Park Tunnel West Street	Holland Tunnel Metro-North Commuter Railroad
1	Queens Midtown Tunnel	Lincoln Tunnel

Note: This hypothetical sequence of facility closures is provided only as an example of what could happen for a Saffir-Simpson Category 3 hurricane moving at 40 mph forward speed directly to the New York Metro area. The hurricane is assumed to have a radius of tropical storm winds of 120 miles. Various Category 3 hurricanes can have widely different size and forward speed characteristics; therefore, it is essential that agencies receive timely hurricane forecasts and updates during an actual event. Marine advisories from the National Weather Service contain this important data.

Hurricane Damage Implications

At midnight, September 22, 1989, one of the strongest and costliest hurricanes to strike the Atlantic coast made landfall in South Carolina. Hurricane Hugo, a Category 4 storm, caused an estimated seven billion dollars damage. The National Hurricane Center considers a storm of this intensity within the range of possibility for the Metro area and, for the Hurricane Evacuation Study, used the SLOSH model to compute the possible surge heights that could result from such a storm.

Table 18 shows the resulting damage to insured property in three boroughs of New York City if approximately the same percentage lost to Hurricane Hugo in coastal counties of South Carolina is applied to New York City. Insured values for the Bronx and Manhattan are not available.

TABLE 18

INSURED COASTAL PROPERTY EXPOSURES (Residential and Commercial)

SOUTH CAROLINA

County	Insured Value 1988	Actual Hugo Losses $	% Loss
Charleston	13.8	1.90	14
Georgetown	2.1	0.24	11
Horry	7.7	0.94	12
Coastal Total*	23.6	3.08	13

NEW YORK

County	Insured Value 1988	Projected 10% Loss	Projected 15%
Richmond	15.6	1.56	2.34
Kings	60.2	6.02	9.03
Queens	69.0	6.90	10.35
Bronx	unknown	unknown	unknown
Manhattan	unknown	unknown	unknown
Coastal Total*	144.8+	14.48+	21.72+

*All Dollar Amounts in Billions

MITIGATION MEASURES

Physical Protection from Surge

Although the relatively short storm tide record for the Metro New York area is not sufficient to establish a surge height vs. frequency relationship with complete confidence, there is no doubt that moderate flood proofing measures in strategic locations would yield substantial dividends in terms of protecting transportation facilities and the public. A coordinated effort between agencies to flood proof vulnerable tunnel openings and raise roadways to a reasonable level could provide valuable insurance against shallow flooding. A project of this nature was recently undertaken along a portion of the Meadowbrook Parkway in Nassau County. Protection from coastal storm surge should be a consideration in all capital programs planning.

Operational Adjustments

At the latitude of New York City it is not uncommon for hurricanes to move at 40-60 mph. Considering the case of a seven hour system clearance time and a hurricane approaching at 60 mph, operational adjustments for evacuation will have to begin when the eye of the storm is abeam Charleston, South Carolina. **Because of the rapidity of meteorological events associated with such a storm, decision makers must be prepared for the timely closure of vulnerable bridges and tunnels based on forecast weather conditions.** These closures would require detailed coordinating procedures with all agencies and government.

The most effective means of mitigating the results of such a decision would be activation of a plan similar to existing snow emergency plans, whereby government and private business is curtailed or closed prior to the beginning of the work day. A declaration of a "hurricane (coastal storm) emergency day" would alleviate pressure on the mass transportation systems and roadways, facilitating operational adjustments. Otherwise, timing of the event may dictate system reversals and/or closures on short notice, possibly during rush hours, resulting in complications and confusion. Contingency plans must also provide protection for transportation agency personnel, equipment and infrastructure.

Officials of the primary law enforcement agencies should devise comprehensive traffic control plans that provide reasonable alternatives to the routes that are expected to close. Private organizations such as the Downtown-Lower Manhattan Association and the Contingency Planning Exchange could help inform the business community of potential risks and specifics of hurricane emergency plans.

EVACUATION ALTERNATIVES

Vertical evacuation is the planned relocation of occupants of vulnerable areas to the upper levels of specifically identified and assigned multi-story buildings. Vertical refuge is the similar relocation of those occupants due to inadequate time or opportunity for them to leave the area. In the latter case, the action is one of last resort, when multi-story structures offer the only hope of escaping unharmed. **Because of safety and legal issues, vertical evacuation or in-place sheltering in tall buildings generally should not be planned as an alternative to horizontal evacuation.** However, in Manhattan there may not be reasonable alternatives. Occupants who may be forced to take refuge in those structures should be aware of the dangers described in the "Vulnerability to Wind Hazards" section. The safest areas of the building should be designated as refuges.

CONCLUSIONS AND IMMEDIATE WORK NEEDS

The Situation

The day will come when a hurricane far more intense than the storm of December 11, 1992 will strike the Metro area. Information contained in this report describes the magnitude of potential hurricane hazards and outlines the extent of the area's vulnerability. Governmental and transportation agencies must strive to provide the greatest public safety possible under what may prove to be extremely difficult conditions. One point of particular concern is the safety of people seeking refuge from severe winds and rain in underground facilities. As high winds begin to damage windows on upper floors of buildings and pedestrians flee street level sidewalks, many will probably turn to subway or PATH stations and their connecting walkways for shelter. Since hurricane surge could quickly fill those tunnels, even if the elevation at the surface is above potential flood levels, they are not safe shelters from severe extratropical storms or hurricanes. Accordingly, major transportation agencies should initiate an education campaign designed to support necessary public safety measures and decision making.

Coastal Storm Emergency Response and Recovery Plans

Due to the lack of data on coastal storm hazards and vulnerabilities prior to this Metro Study, transportation emergency operations have been primarily reactionary with response and recovery planning resting with the management of each facility. However, the potential surge heights, rates-of-rise, and wind velocities discussed previously in the Hazards Analysis section necessitate plans to close vulnerable roadways, bridges, and tunnels before a threat becomes imminent. Detailed and coordinated coastal storm response and recovery plans are of the utmost importance in protecting the public. Such plans should be developed by each transportation agency for all operating arms as well as the organization as a whole.

In addition, a single unified Metro New York plan should be devised that crosses agency lines and establishes clear protocols for facility closure, transportation system operational adjustments, and evacuation decision making. Procedures should be instituted to ensure the coordination of each agency's response efforts with those of other transportation agencies and state and local emergency management offices. Plans must be incorporated into a compatible system among all agencies and governments so that the actions of one can be anticipated and accomplished in concert with others, minimizing hazards and disruptions to the public. This coordination is the responsibility of the State Offices of Emergency Management in New Jersey and New York.

Decision-Making Aids

Plans should include decision points at which the various facilities will close, allowing sufficient time for public information dissemination, system operational adjustments, evacuee travel, and facility security. Existing decision-making aids for hurricane evacuation, for example, Decision Arcs and the HURREVAC computer program, should be modified to identify these decision points. Each agency should use these aids to make operational decisions based on predetermined time frames and specific weather forecasts. These aids would also provide the information each agency must have on the timing of other agencies' actions. Decision makers can stay abreast of current storm surge, rainfall, and wind forecasts through close coordination with the local National Weather Service office, and be prepared to take timely and appropriate actions.

Mitigation

The most effective single action that could be taken to facilitate hurricane response for the Metro area would be a timely, coordinated decision to curtail or close government and private business prior to the beginning of the work day. This would greatly reduce the number of people using the transportation systems and, potentially, seeking public shelter (see Mitigation Measures, Operational Adjustments).

Emergency Operations

Each major transportation agency in the Metro area should establish an emergency management office with a designated director primarily responsible for coordinated, unified, interagency planning for coastal storm emergencies. The Port Authority's ongoing Coastal Storm Emergency Planning Project includes centralization of emergency planning and decision-making. Responsibility for initiating specific emergency actions, including adjusting system operations, should be a function of that office.

Communication between all government and private agencies and access to vital information is extremely important. Each emergency management office should have a suitably equipped emergency operations center (EOC) that, when activated, is responsible for decision making and communication. All participating EOC's should be linked with compatible, hardened radio systems with generators, designed to operate through hurricane-force winds. With responsibilities being shared by state and city governments, coordination between agencies must be carefully planned. The emergency management agencies should determine the most effective coordination system. The New York City Emergency Operations Center could possibly serve as a central clearinghouse, also handling communication with the National Weather Service.

Assistance With Future Tasks

Based on information contained in this Metro Hurricane Transportation Study and the New York, New Jersey, and Connecticut Hurricane Evacuation Studies, the USACE, FEMA, NOAA, New York City, and the States of New York and New Jersey should assist local government and private agencies with needed training and with developing or revising their hurricane response plans. Those plans must be tested and assistance should also be provided for devising and executing appropriate exercises. A major media presentation should be planned to inform the public of the purpose of the study and the goals of the exercise. Additional public education efforts concerning hurricane threats should target the users of specific systems, raising their awareness of possible hazards and planned operational adjustments.

LIST OF ACRONYMS

LIST OF ACRONYMS

Decision Arcs -	Aid to Evacuation Decision Making
EOC -	Emergency Operations Center
FEMA -	Federal Emergency Management Agency
HURREVAC -	Computer Program for Evacuation Decision Making
METRO -	Metropolitan New York City
Metro Study -	Metro New York Hurricane Transportation Study
m.p.h. -	miles per hour
m.s.l. -	mean sea level
MTA -	Metropolitan Transportation Authority
NGVD -	National Geodetic Vertical Datum
NOAA -	National Oceanic and Atmospheric Administration
NOS -	National Ocean Service
NYCDOT -	New York City Department of Transportation
NWS -	National Weather Service
PATH -	Port Authority Trans-Hudson rail facilities
SLOSH -	Sea, Lake, and Overland Surge from Hurricanes
Subway -	New York City Transit Authority
USACE -	U.S. Army Corps of Engineers

ATTACHMENT

Letter Dated June 4, 1990, From

Joseph J. Craparotta, Major
Deputy State Director, Office of Emergency Management, State of New Jersey
Department of Law and Public Safety, Division of State Police
Emergency Management Section

State of New Jersey

DEPARTMENT OF LAW AND PUBLIC SAFETY
DIVISION OF STATE POLICE

EMERGENCY MANAGEMENT SECTION
POST OFFICE BOX 7068
WEST TRENTON, NEW JERSEY 08628-0068
(609) 882-2000

ROBERT J. DEL TUFO
Attorney General

COLONEL JUSTIN J. DINTINO
Superintendent

June 4, 1990

Brigadier General Gerald C. Brown
Commander U.S. Engineering
Division North Atlantic, CENAD
90 Church St
New York, New York 10007-2979

Dear General Brown:

As you likely know, the New Jersey Hurricane Study is currently entering its final stages. My purpose in writing is to bring to your attention the concern that the Technical Data Report (TDR) as currently designed, will not provide sufficient information to allow New Jersey to prepare the Phase II local Emergency Operations Plans. Two specific shortcomings should be stressed. The first is based on the problem related to the daily rail and motor vehicle commuting between New York City and New Jersey. The issues raised by Alan MacDuffie at the May 21, 1990 meeting regarding closure of the Hudson River crossings need to be studied and incorporated into both the New York and New Jersey studies.

The second issue is the exclusion of hurricane induced riverine flooding from consideration in the study. As you know, the Passaic River basin has a long history of flooding whose impacts, when resulting from hurricane rains, are likely to affect the entire metropolitan region. Although the thrust of the hurricane study has been the storm surge effect, not including the rainfall induced flooding would, in our opinion, result in a T.D.R. of limited usefulness to the North Jersey metropolitan area.

I request the Corps pursue the possibility of amending the scope of study to address the above issues. Thank you for your consideration in this matter.

Sincerely,

Joseph J. Craparotta, Major
Deputy State Director
Office of Emergency Management

vsl

EXHIBITS

COMMITTEE MEMBERS

EXECUTIVE STUDY COMMITTEE

John P. DiNuzzo	New York State Emergency Management Office
Peter Jespersen	New Jersey State Police, Office of Emergency Management
Mel Hartman	New Jersey State Police, Office of Emergency Management
Captain Joe Murphy	NYC Police Department, Office of Emergency Management
Sgt. Louis LaPietra	NYC Police Department, Office of Emergency Management
Sgt. Peter Picarillo	NYC Police Department, Office of Emergency Management
Barney Puleo, A.S.A.	NYC Police Department, Office of Emergency Management
Clark Gilman	New Jersey Department of Environment Protection & Energy
Bruce Swiren	Federal Emergency Management Agency, Region II
Gene Zeizel	Federal Emergency Management Agency, Headquarters
Michael Wyllie	National Weather Service, Brookhaven New York
Brian Jarvinen	National Weather Service, National Hurricane Center
Donald Lewis	Post, Buckley, Schuh & Jernigan
Charles Chesnutt	US Army Corps of Engineers, National Headquarters
Diane Dunnigan	US Army Corps of Engineers, North Atlantic Division
Allan McDuffie	US Army Corps of Engineers, Wilmington District
Frank Schaefer	US Army Corps of Engineers, Philadelphia District
Joseph Gavin	US Army Corps of Engineers, Philadelphia District
John Craig	US Army Corps of Engineers, New England Division
John Kennelly	US Army Corps of Engineers, New England Division
Michael Tarnowski	US Army Corps of Engineers, New England Division

Exhibit 1

AGENCY TECHNICAL COMMITTEE

Lance Weight	State of New Jersey Department of Transportation
James J. Barnack	Division of Traffic & Safety, New York State Department of Transportation
Anthony F. Siragusa	State of Connecticut Department of Transportation
Marygrace Parker	Director of Traffic Management, New York State Thruway Authority
William A. Behrens	Manager Traffic Safety Services, New York State Thruway
Robert F. Dale	Director of Operations, New Jersey Turnpike Authority
Joseph Crawford	Vice President & General Manager, Rail Operations, New Jersey Transit
Mel Hartman	Population Protection Planning, New Jersey State Police
John P. DiNuzzo	New York State Emergency Management Office
John O'Leary	Connecticut State Police
Lee Home	Regional Transportation Planning, Port Authority New York & New Jersey
John Valles	Assistant Commissioner, New York City Department of Transportation
Sgt. Louis LaPietra	New York City Police Department, Office of Emergency Management
P. M. Rao	General Superintendent Engineering, New York City Transit Authority
Clark Hampe	Penn Station Terminal Superintendent, AMTRAK
Andrew Sparberg	Assistant Manager, Resource Planning, Long Island Rail Road
Andrew Favilla	METRO-NORTH Operations
Gideon Davis	Staff Director, MTA Bridges & Tunnels
Cmdr. Bill Helgeson	US Coast Guard, Captain of the Port
Captain Wm. Hemming	US Coast Guard, East Coast Coordinator of Bridges

Exhibit 2

APPENDIXES A - I

APPENDIX A

PORT AUTHORITY OF NEW YORK AND NEW JERSEY

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

PATH TUNNELS

CRITICAL ELEVATIONS (NGVD)

Exchange Place Station	7.0 ft.
Morton Street Shaft	7.3 ft.
Hoboken Station	7.4 ft.
Washington Street Shaft	7.6 ft.
World Trade Center (Ramp D)	8.1 ft.
15th Street Shaft	9.6 ft.
Railroad Avenue Shaft	9.7 ft.
Grove Street Station	9.8 ft.
Pavonia Avenue	10.0 ft.
World Trade Center Concourse	12.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.9 ft.
Category 2	17.7 ft.
Category 3	23.3 ft.
Category 4	28.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.3 hours	—
Category 2	1.2 hours	—
Category 3	1.7 hours	—
Category 4	2.0 hours	—

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

PATH SUB-STATIONS (power)

CRITICAL ELEVATIONS (NGVD)

#4 @ Exchange Place	6.0 ft.
#8 @ Kearny NJ	6.0 ft.
#9 @ Harrison NJ	7.0 ft.
#7 @ Broadway & Hallerick	7.0 ft.
#2-2A @ Washington Street	7.9 ft.
#3 @ World Trade Center	10.0 ft.

POTENTIAL HURRICANE SURGE

	Exchange Place	Kearny/ Harrison
Category 1	10.6 ft.	6.8 ft.
Category 2	16.4 ft.	9.0 ft.
Category 3	24.3 ft.	11.8 ft.
Category 4	28.6 ft.	14.4 ft

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.5 hours	2.0 hours
Category 2	1.5 hours	3.0 hours
Category 3	2.0 hours	3.5 hours
Category 4	2.3 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

LINCOLN TUNNEL

CRITICAL ELEVATIONS (NGVD)

New Jersey Vent Shaft	10.6 ft.
New York 3rd Tube Vent Shaft	10.6 ft.
New York River Vent Shaft	11.6 ft.
New York Land Vent Shaft	19.6 ft.
New York Top-of-Ramp	22.6 ft.
New Jersey Top-of-Ramp	27.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	7.5 ft.
Category 2	17.2 ft.
Category 3	20.5 ft.
Category 4	30.8 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	—
Category 2	0.5 hours	—
Category 3	1.0 hours	—
Category 4	1.2 hours	—

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

HOLLAND TUNNEL

CRITICAL ELEVATIONS (NGVD)

New Jersey Land Vent Shaft	7.6 ft.
New Jersey Top-of-Ramp	7.6 ft.
New York River Vent Shaft	8.6 ft.
New York Land Vent Shaft	8.6 ft.
New York Top-of-Ramp	9.5 ft.
New Jersey River Vent Shaft	10.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.9 ft.
Category 2	17.7 ft.
Category 3	23.3 ft.
Category 4	28.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.2 hours	—
Category 2	1.0 hours	—
Category 3	1.6 hours	—
Category 4	1.9 hours	—

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

GEORGE WASHINGTON BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	213.0 ft.
Lowest Approach	200.0+ ft.

POTENTIAL HURRICANE SURGE

Category 1
Category 2
Category 3
Category 4 (No hurricane surge hazard)

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	—	6.0 hours
Category 4	—	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

GEOTHALS BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	140.0 ft.
Staten Island Expressway Approach	15.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	8.8 ft.
Category 2	10.7 ft.
Category 3	14.4 ft.
Category 4	17.7 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	—	6.0 hours
Category 4	0.2 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

BAYONNE BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	150.0 ft.
John F. Kennedy Ave.	20.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	9.8 ft.
Category 2	14.5 ft.
Category 3	19.8 ft.
Category 4	27.5 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	—	6.0 hours
Category 4	0.4 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

OUTER BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	145.0 ft.
Lowest Approach	50.0+ ft.

POTENTIAL HURRICANE SURGE

Category 1
Category 2
Category 3
Category 4 (No hurricane surge hazard)

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	—	6.0 hours
Category 4	—	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

JOHN F. KENNEDY INTERNATIONAL AIRPORT

CRITICAL ELEVATIONS (NGVD)

Lowest Point on Runway	11.7 ft.

POTENTIAL HURRICANE SURGE

Category 1	6.6 ft.
Category 2	15.6 ft.
Category 3	24.5 ft.
Category 4	31.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.3 hours	3.0 hours
Category 3	0.8 hours	3.5 hours
Category 4	1.2 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

TETERBORO AIRPORT

CRITICAL ELEVATIONS (NGVD)

Lowest Point on Runway	5.0 ft

POTENTIAL HURRICANE SURGE

Category 1	5.0 ft.
Category 2	6.0 ft.
Category 3	7.5 ft.
Category 4	10.5 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.1 hours	3.0 hours
Category 3	0.3 hours	3.5 hours
Category 4	1.0 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

LAGUARDIA AIRPORT

CRITICAL ELEVATIONS (NGVD)

Lowest Point on Runway	6.8 ft

POTENTIAL HURRICANE SURGE

Category 1	6.4 ft.
Category 2	11.2 ft.
Category 3	15.7 ft.
Category 4	20.8 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.5 hours	3.0 hours
Category 3	1.3 hours	3.5 hours
Category 4	2.0 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

NEWARK INTERNATIONAL AIRPORT

CRITICAL ELEVATIONS (NGVD)

Lowest Point on Runway	10.3 ft

POTENTIAL HURRICANE SURGE

Category 1	8.4 ft.
Category 2	10.3 ft.
Category 3	13.6 ft.
Category 4	17.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	@ peak	3.0 hours
Category 3	0.3 hours	3.5 hours
Category 4	0.5 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

PORT NEWARK AND ELIZABETH

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	9.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	8.4 ft.
Category 2	10.3 ft.
Category 3	13.6 ft.
Category 4	17.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.1 hours	3.0 hours
Category 3	0.3 hours	3.5 hours
Category 4	0.5 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

HOWLAND HOOK TERMINAL

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	9.9 ft.

POTENTIAL HURRICANE SURGE

Category 1	8.8 ft.
Category 2	10.7 ft.
Category 3	14.4 ft.
Category 4	17.7 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	@ peak	3.0 hours
Category 3	0.3 hours	3.5 hours
Category 4	0.5 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

PIER 40

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	8.9 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.9 ft.
Category 2	17.7 ft.
Category 3	23.3 ft.
Category 4	28.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.1 hours	2.0 hours
Category 2	0.8 hours	3.0 hours
Category 3	1.2 hours	3.5 hours
Category 4	1.5 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

RED HOOK MARINE TERMINAL

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	9.8 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.5 ft.
Category 2	16.6 ft.
Category 3	24.0 ft.
Category 4	28.7 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.1 hours	2.0 hours
Category 2	0.5 hours	3.0 hours
Category 3	1.2 hours	3.5 hours
Category 4	1.4 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

PASSENGER SHIP TERMINAL

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	8.9 ft.

POTENTIAL HURRICANE SURGE

Category 1	7.4 ft.
Category 2	17.5 ft.
Category 3	22.6 ft.
Category 4	28.9 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.8 hours	3.0 hours
Category 3	1.3 hours	3.5 hours
Category 4	1.5 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

AUTO-MARINE TERMINAL

CRITICAL ELEVATIONS (NGVD)

Facility Low Point	9.5 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.1 ft.
Category 2	15.6 ft.
Category 3	21.8 ft.
Category 4	26.8 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.1 hours	2.0 hours
Category 2	0.5 hours	3.0 hours
Category 3	1.2 hours	3.5 hours
Category 4	1.4 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

APPENDIX B

MTA BRIDGES AND TUNNELS
(TRIBOROUGH BRIDGE AND TUNNEL AUTHORITY)

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

BROOKLYN-BATTERY TUNNEL

CRITICAL ELEVATIONS (NGVD)

Manhattan West Street Entrance	8.6 ft.
Manhattan Battery Entrance	8.6 ft.
Brooklyn Plaza at Hamilton Avenue	11.6 ft.
Governor's Island Blower Bldg. Floor	12.6 ft.
Manhattan Blower Bldg. Floor	13.6 ft.
Brooklyn Blower Bldg. Floor	14.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	10.5 ft.
Category 2	16.6 ft.
Category 3	24.0 ft.
Category 4	28.7 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	0.2 hours	—
Category 2	0.8 hours	—
Category 3	1.4 hours	—
Category 4	1.7 hours	—

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

TRIBOROUGH BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	145.6 ft.
E. 125th/2nd Avenue Approach	15.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	8.4 ft.
Category 2	12.7 ft.
Category 3	16.4 ft.
Category 4	20.4 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	0.1 hours	6.0 hours
Category 4	0.4 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

BRONX–WHITESTONE BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	138.6 ft.
Hutchinson River Pkwy. Approach	12.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	6.5 ft.
Category 2	11.3 ft.
Category 3	16.6 ft.
Category 4	22.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	0.3 hours	6.0 hours
Category 4	0.8 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

HENRY HUDSON PARKWAY BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	145.6 ft.
Lowest Approach	100.0+ ft.

POTENTIAL HURRICANE SURGE

Category 1	6.1 ft.
Category 2	13.0 ft.
Category 3	14.8 ft.
Category 4	24.6 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	—	5.0 hours
Category 3	—	6.0 hours
Category 4	—	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

MARINE PARKWAY BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	57.6 ft.
Beach Channel Drive Approach	8.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	7.0 ft.
Category 2	14.4 ft.
Category 3	20.6 ft.
Category 4	27.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.9 hours	3.0 hours
Category 3	1.4 hours	3.5 hours
Category 4	1.8 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

THROGS NECK BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	145.6 ft.
Throgs Neck Expwy. Approach	10.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	6.5 ft.
Category 2	11.3 ft.
Category 3	16.6 ft.
Category 4	22.2 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	0.1 hours	5.0 hours
Category 3	0.5 hours	6.0 hours
Category 4	1.1 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

VERRAZANO-NARROWS BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	230.6 ft.
Shore Parkway Approach	8.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	7.9 ft.
Category 2	15.4 ft.
Category 3	21.1 ft.
Category 4	26.0 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	3.0 hours
Category 2	0.9 hours	5.0 hours
Category 3	1.4 hours	6.0 hours
Category 4	1.8 hours	7.0 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

CROSS BAY PARKWAY BRIDGE

CRITICAL ELEVATIONS (NGVD)

Center Span	57.6 ft.
Cross Bay Blvd. Approach	8.0 ft.

POTENTIAL HURRICANE SURGE

Category 1	6.3 ft.
Category 2	13.7 ft.
Category 3	21.4 ft.
Category 4	27.5 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	2.0 hours
Category 2	0.9 hours	3.0 hours
Category 3	1.4 hours	3.5 hours
Category 4	1.8 hours	4.5 hours

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

QUEENS MIDTOWN TUNNEL

CRITICAL ELEVATIONS (NGVD)

Queens Plaza at Borden Avenue	10.6 ft.
Queens Blower Bldg. Floor	12.6 ft.
Manhattan Plaza at 36th Street	14.6 ft.
Manhattan Blower Bldg. Floor	22.6 ft.

POTENTIAL HURRICANE SURGE

Category 1	9.6 ft.
Category 2	14.4 ft.
Category 3	21.0 ft.
Category 4	23.6 ft.

TIME HAZARDS COULD OCCUR (HOURS BEFORE CLOSEST APPROACH OF EYE)

	SURGE FLOODING*	SUSTAINED TROPICAL STORM WINDS*
Category 1	—	—
Category 2	0.5 hours	—
Category 3	1.0 hours	—
Category 4	1.2 hours	—

* Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

APPENDIX C

NEW YORK CITY TRANSIT AUTHORITY (SUBWAYS)

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

WORLD TRADE CENTER

Critical Locations

Entrance Ramp D-West Street	8.1 feet
World Trade Center Concourse	12.6 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.6 feet
Category 2	16.4 feet
Category 3	24.3 feet
Category 4	28.6 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.3 hours
Category 2	0.9 hours
Category 3	1.4 hours
Category 4	1.8 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

CRANBERRY STREET TUNNEL (A& C Lines)

Critical Locations

Front Street at Fulton Street Fan Plant	7.0 feet
Furman Street at Cranberry Street Fan Plant	12.8 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.2 feet
Category 2	16.0 feet
Category 3	25.1 feet
Category 4	31.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.3 hours
Category 2	1.1 hours
Category 3	1.7 hours
Category 4	2.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

14TH STREET TUNNEL (L Line)

Critical Locations

14th Street at Avenue D Fan Plant	7.2 feet
N. 7th Street (Brooklyn) Fan Plant	9.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.7 feet
Category 2	14.7 feet
Category 3	22.0 feet
Category 4	24.9 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	1.0 hours
Category 3	1.6 hours
Category 4	1.8 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

NEWTOWN CREEK TUNNEL (G Line)

Critical Locations

Vernon Blvd. at 54th Avenue Fan Plant	8.1 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.7 feet
Category 2	14.7 feet
Category 3	22.0 feet
Category 4	24.9 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	0.8 hours
Category 3	1.2 hours
Category 4	1.5 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

LEXINGTON AVENUE TUNNEL
(4, 5 & 6 LINES)

Critical Locations

135th Street at Park Avenue, Bronx Fan Plant 9.9 feet
131st Street at Harlem River Drive Fan Plant 11.2 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.4 feet
Category 2	12.7 feet
Category 3	16.4 feet
Category 4	20.4 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.3 hours
Category 3	0.6 hours
Category 4	1.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

STEINWAY TUNNEL
(7 Line)

Critical Locations

Steinway Street Fan Plant/50th Street Vent 11.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.3 hours
Category 3	0.6 hours
Category 4	1.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

MONTAGUE STREET TUNNEL
(M, N & R Lines)

Critical Locations

Broad Street Fan Plant	7.5 feet
Whitehall Station	9.1 feet
South Street Fan Plant	11.6 feet
Furman Street Fan Plant	12.5 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.5 feet
Category 2	16.6 feet
Category 3	24.0 feet
Category 4	28.7 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.3 hours
Category 2	1.0 hours
Category 3	1.6 hours
Category 4	1.8 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

HARLEM RIVER TUNNEL
(2 Line)

Critical Locations

Harlem River Drive Vent Shaft	10.0 feet (est.)

Potential Hurricane Surge (above NGVD)

Category 1	8.4 feet
Category 2	12.7 feet
Category 3	16.4 feet
Category 4	20.4 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.3 hours
Category 3	0.6 hours
Category 4	1.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

53RD STREET TUNNEL
(E & F Lines)

Critical Locations

44th Drive (Nott Avenue) Fan Plant 10.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.4 hours
Category 3	0.7 hours
Category 4	1.2 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

63RD STREET TUNNEL
(B & Q Lines)

Critical Locations

Vernon Blvd. at 41st Avenue
(Queensbridge) Fan Plant 12.7 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.1 hours
Category 3	0.3 hours
Category 4	0.8 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

RUTGERS STREET TUNNEL
(F Line)

Critical Locations

Rutgers Street at South Street Fan Plant	10.6 feet
Jay Street at Plymouth Street Fan Plant	12.1 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.2 feet
Category 2	16.0 feet
Category 3	25.1 feet
Category 4	31.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.4 hours
Category 3	1.0 hours
Category 4	1.3 hours

*** assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size**

YANKEE STADIUM TUNNEL
(C & D Lines)

Critical Locations

155th Street at 8th Avenue Fan Plant	12.8 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.4 feet
Category 2	12.7 feet
Category 3	16.4 feet
Category 4	20.4 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	–
Category 3	0.3 hours
Category 4	0.7 hours

*** assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size**

CLARK STREET TUNNEL
(2 & 3 LINES)

Critical Locations

Old Slip at Front Street Fan Plant	9.1 feet
Furman Street at Clark Street Fan Plant	10.7 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.5 feet
Category 2	16.6 feet
Category 3	24.0 feet
Category 4	28.7 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	0.8 hours
Category 3	1.3 hours
Category 4	1.5 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

SOUTH FERRY
(1 & 9 LINES)

Critical Locations

IRT Station Entrance	9.1 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.5 feet
Category 2	16.6 feet
Category 3	24.0 feet
Category 4	28.7 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	0.8 hours
Category 3	1.3 hours
Category 4	1.5 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

JORALEMON STREET TUNNEL (4 & 5 Lines)

Critical Locations

State Street (Battery Park) Fan Plant/Grate 9.8 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.5 feet
Category 2	16.6 feet
Category 3	24.0 feet
Category 4	28.7 feet

Time Hazards Could Occur (hours before closest approach of eye)

	Surge Flooding *
Category 1	at closest approach
Category 2	0.5 hours
Category 3	1.1 hours
Category 4	1.3 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

APPENDIX D

LONG ISLAND RAIL ROAD

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

PENN STATION - NORTH (HUDSON) RIVER TUNNEL

Critical Locations

West Side Storage Yard Berm	10.0 feet
Weehawken Shaft	12.3 feet

Potential Hurricane Surge (above NGVD)

Category 1	7.5 feet
Category 2	17.2 feet
Category 3	20.5 feet
Category 4	30.8 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.5 hours
Category 3	1.0 hours
Category 4	1.2 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

LONG BEACH BRANCH

Critical Locations

Oceanside	6.2 feet

Potential Hurricane Surge (above NGVD)

Category 1	7.3 feet
Category 2	16.2 feet
Category 3	21.9 feet
Category 4	26.9 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.1 hours
Category 2	1.3 hours
Category 3	1.8 hours
Category 4	2.2 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

EAST RIVER TUNNEL (shared with AMTRAK)

Critical Locations

Long Island Shaft	9.0 feet
1st Avenue Shaft	14.5 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.6 hours
Category 3	0.9 hours
Category 4	1.3 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

FAR ROCKAWAY BRANCH

Critical Locations

Far Rockway	9.2 feet
Valley Stream	11.4 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.1 feet
Category 2	15.4 feet
Category 3	20.5 feet
Category 4	26.2 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.8 hours
Category 3	1.3 hours
Category 4	1.5 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

PORT WASHINGTON BRANCH

Critical Locations

Flushing	9.2 feet

Potential Hurricane Surge (above NGVD)

Category 1	6.6 feet
Category 2	11.6 feet
Category 3	16.2 feet
Category 4	20.9 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.2 hours
Category 3	0.8 hours
Category 4	1.3 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

APPENDIX E

NEW JERSEY TRANSIT
(RAIL LINES)

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

PASCACK VALLEY LINE

Critical Locations

Union Avenue at East Rutherford (track)
Track between East Rutherford and
I-80 (switch circuit euipment)

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

Riverine Flooding Potential

No Issues Identified

BERGEN COUNTY LINE

Critical Locations

Hackensack River location at Secaucus (signal cases)
Pascack Junction at Rutherford (signal cases)

Potential Hurricane Surge (above NGVD)

Category 1	8.5 feet
Category 2	10.0 feet
Category 3	13.4 feet
Category 4	15.9 feet

Riverine Flooding Potential

No Issues Identified

MAIN LINE

Critical Locations

Valley Brook Road at Lyndhurst (track)
Passaic River Crossing (bridge and track)

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

Riverine Flooding Potential

Track at Passaic River Crossing could be flooded by 500 year flood event – bridge could be flooded by 50 year flood event – no hurricane surge problems anticipated here

MORRISTOWN AND ESSEX LINE

Critical Locations

Meadowlands segment (track and equipment)

Potential Hurricane Surge (above NGVD)

Category 1	9.8 feet
Category 2	11.9 feet
Category 3	14.6 feet
Category 4	17.2 feet

Riverine Flooding Potential

No Issues Identified

HOBOKEN TERMINAL AND BERGEN TUNNEL

Critical Locations
Hoboken Terminal
Bergen Tunnel

Potential Hurricane Surge (above NGVD)

Category 1	13.5 feet
Category 2	19.0 feet
Category 3	26.4 feet
Category 4	31.4 feet

Riverine Flooding Potential
No Issues Identified

BOONTON LINE

Critical Locations
Hackensack River Crossing at Kearney

Potential Hurricane Surge (above NGVD)

Category 1	9.9 feet
Category 2	11.1 feet
Category 3	12.7 feet
Category 4	16.8 feet

Riverine Flooding Potential
No Issues Identified

BOONTON LINE

Critical Locations

Passaic River Crossing at Little Falls Township
Pompton River Crossing at Wayne Township

Potential Hurricane Surge (above NGVD)

Category 1	–
Category 2	–
Category 3	–
Category 4	–

Riverine Flooding Potential

Bridge at Passaic River Crossing could be flooded by 500 year Flood event – bridge at Pompton River Crossing could be flooded by 100 year flood event

NORTH JERSEY COAST LINE

Critical Locations

Raritan River Crossing at Perth Ambay
Morgan area at Sayreville (electrical equipment)
Chessquake Creek Crossing at Sayreville

Potential Hurricane Surge (above NGVD)

Category 1	11.4 feet
Category 2	18.4 feet
Category 3	24.6 feet
Category 4	28.0 feet

Riverine Flooding Potential

No Issues Identified

NORTH JERSEY COAST LINE

Critical Locations

Oceanport Creek area (track and swing bridge switches)

Potential Hurricane Surge (above NGVD)

Category 1	5.1 feet
Category 2	7.2 feet
Category 3	15.1 feet
Category 4	20.7 feet

Riverine Flooding Potential

No Issues Identified

NEW JERSEY TRANSIT RAIL LINES - FLOOD DATA

ne*	Mile Post	Map Symb.	Location	County	Municipality	December 92 Flood Damage Report	EQUIPMENT ELEVATIONS**		FLOOD DATA TIDAL/RIVERINE***			
							TRACK	BRIDGE	Cat. 1	Cat. 2	Cat. 3	Cat. 4
/	7.6-12.4	PV-1	Length of track	Bergen	Several	Switch circuit equipment submerged			8.2	9.1	10.2	13.9
/	8.2	PV-2	Union Avenue	Bergen	East Rutherford	Track flooded/ crossing under water			8.2	9.1	10.2	13.9
C	5.6	BC-1	Hackensack River	Bergen	Secaucus	Water in signal case			8.5	10.0	13.4	15.9
					East Rutherford							
C	7.6	BC-2	Pascack Junction	Bergen	Rutherford	Signal cases under water (non-tidal ?)			8.2	9.1	10.2	13.9
					E. Rutherford							
L	5.8	ML-1	Valley Brook Road	Bergen	Lyndhurst	Track flooded			8.2	9.1	10.2	13.9
										50 Yr.	100 Yr.	500 Yr.
L	17.34	ML-2	Passaic River	Passaic	Paterson		47'	41'		42'	44'	50'
					Hawthorne							
									Cat. 1	Cat. 2	Cat. 3	Cat. 4
E	2.0-3.8	ME-1	Meadowlands	Hudson	Harrison	Track washout; damage to equipment due to high water.			9.8	11.9	14.6	17.2
V			No flood damages reported on Raritan Valley Line from Dec. 92 Northeaster									
			Hoboken Terminal	Hudson	Hoboken	Extensive and varied flood damage			13.5	19.0	26.4	31.4
	1.0		Bergen Tunnel	Hudson	Jersey City	Cable grounded in tunnel			13.5	19.0	26.4	31.4
					Hoboken							
O	2.6-4.2	BO-1		Hudson	Kearny	Track washed out			9.9	11.1	12.7	16.8
O	4.2	BO-2	Hackensack River Drawbridge	Hudson	Kearny	Track flooded			9.9	11.1	12.7	16.8
O	4.2-5.4	BO-3		Hudson	Kearny	Track washed out				9.9	10.4	15.1
O	19.43	BO-4	Passaic River	Passaic	Little Falls Twp.					50 Yr.	100 Yr.	500 Yr.
					Wayne Twp.							
O	21.86	BO-5	Pompton River	Passaic	Wayne Twp.		173'	170.5'		167'	169.5'	172'
					Lincoln Park Bor.							
							175'	170'		169'	170'	173.5'
									Cat. 1	Cat. 2	Cat. 3	Cat. 4
JC	.40-.70	NJC-1	Raritan River Crossing	Middlesex	Perth Amoby	Track washouts; drawbridge, signal & other electrical			11.1	17.2	20.2	28.0
					South Amboy	equipment damaged by flooding and by sand barge.						
JC	1.9	NJC-2	Morgan area	Middlesex	Sayreville	High tidal waters covering electrical equipment			11.4	18.4	24.6	28.0
JC	2.6-3.0	NJC-3	Chessquake Creek Crossing	Middlesex	Sayreville	Track washout; damage to signal, traction and			11.1	17.8	23.7	27.0
					Old Bridge Twp.	other electrical equipment; navigation lights submerged.						
JC	20.0	NJC-4	Oceanport Creek	Monmouth	Oceanport	Track washout; swing bridge switches fully covered by water.			5.1	7.2	15.1	20.7

Line Abrevations

V Pascack Valley Line
C Bergen County Line
IL Main Line
IE Morristown and Essex Line
V Raritan Valley Line
O Boonton Line
JC North Jersey Coast Line

**** Equipment Elevations**
Track and underside bridge elevations listed were obtained from FEMA Flood Insurance Study stream profiles.

***** Flood Data**
SLOSH Model worst case surge elevations are listed for locations subject to tidal flooding.
Flood Insurance Study flood elevations are listed for locations subjected to fluvial flooding.

\QPW\METRDATA\TRANSTAB.WB1

APPENDIX F

METRO - NORTH

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

GRAND CENTRAL TERMINAL

Critical Locations

IRT SteinwayTube Queens Vent (7 line) 11.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.3 hours
Category 3	0.6 hours
Category 4	1.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

NEW HAVEN LINE

Critical Locations

Bruce Brook at Town of Stratford 22.0 feet

Potential Hurricane Surge (above NGVD)

Category 1 & 2	12.5 feet
Category 3	16.5 feet
Category 4	19.0 feet

Other Flood Parameters

10 Year Flood Frequency	22.0 feet
50 Year Flood Frequency	22.2 feet
100 Year Flood Frequency	22.4 feet
500 Year Flood Frequency	22.8 feet

NEW HAVEN LINE

Critical Locations

Sasco Creek at Town of Westport 12.5 feet

Potential Hurricane Surge (above NGVD)

Category 1 & 2	11.5 feet
Category 3	15.0 feet
Category 4	18.5 feet

Other Flood Parameters

10 Year Flood Frequency	8.8 feet
50 Year Flood Frequency	10.3 feet
100 Year Flood Frequency	11.0 feet
500 Year Flood Frequency	12.4 feet

NEW HAVEN LINE

Critical Locations

Sherwood Millpond at Town of Westport 9.8 feet

Potential Hurricane Surge (above NGVD)

Category 1 & 2	11.5 feet
Category 3	15.0 feet
Category 4	18.5 feet

Other Flood Parameters

10 Year Flood Frequency	9.1 feet
50 Year Flood Frequency	10.6 feet
100 Year Flood Frequency	11.2 feet
500 Year Flood Frequency	not available

HUDSON LINE

Critical Locations
Spuyten Duyvil 7.7 feet

Potential Hurricane Surge (above NGVD)

Category 1	6.1 feet
Category 2	13.0 feet
Category 3	14.8 feet
Category 4	24.6 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.6 hours
Category 3	1.0 hours
Category 4	1.5 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

NEW HAVEN LINE

Critical Locations
Rooster River at Town of Fairfield 17.0 feet

Potential Hurricane Surge (above NGVD)

Category 1 & 2	12.0 feet
Category 3	15.5 feet
Category 4	18.5 feet

Other Flood Parameters

10 Year Flood Frequency	10.0 feet
50 Year Flood Frequency	13.5 feet
100 Year Flood Frequency	14.5 feet
500 Year Flood Frequency	18.0 feet

HUDSON LINE

Critical Locations

Croton River 6.5 feet

Potential Hurricane Surge (above NGVD)

Category 1	2.8 feet
Category 2	7.5 feet
Category 3	8.5 feet
Category 4	14.5 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.2 hours
Category 3	0.3 hours
Category 4	1.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

NEW HAVEN LINE

Critical Locations

Grasmere Brook at Town of Fairfield 9.6 feet

Potential Hurricane Surge (above NGVD)

Category 1 & 2	12.0 feet
Category 3	15.5 feet
Category 4	18.5 feet

Other Flood Parameters

10 Year Flood Frequency	8.6 feet
50 Year Flood Frequency	10.3 feet
100 Year Flood Frequency	11.0 feet
500 Year Flood Frequency	12.2 feet

FLOOD VULNERABILITY FACT SHEET
METRO NORTH RAILWAY
FAIRFIELD COUNTY, CONNECTICUT

Map Key Number	Community	Location	Estimated Elevation	Surge Elev. Cat. 1&2	Surge Elev. Cat. 3	Surge Elev. Cat. 4	10-year freq. flood	50-year freq. flood	100-year freq. flood	500-year freq. flood
1	Stratford-Bridgeport TL	Bruce Brook	22.0' Note 1	12.5'	16.5'	19.0'	22.0'	22.2'	22.4'	22.8'
2	Bridgeport-Fairfield TL	Rooster River	17.0' Note 2	12.0'	15.5'	18.5'	10.0'	13.5'	14.5'	18.0'
3	Fairfield	Crasmere Brook	9.6' Note 3	12.0'	15.5'	18.5'	8.6'	10.3'	11.0'	12.2'
4	Fairfield-Westport TL	Sasco Creek	12.5' Note 4	11.5'	15.0'	18.5'	8.8'	10.3'	11.0'	12.4'
5	Westport	Sherwood Mill Pond	11.6' Note 4	11.5'	15.0'	18.5'	9.0'	10.5'	11.2'	N/A
6	Westport	Sherwood Mill Pond	9.8' Note 4	11.5'	15.0'	18.5'	9.1'	10.6'	11.2'	N/A

(ELEVATIONS REFERENCED TO NGVD, 1929)

NOTES:

[1] Determined from Plate 01P (Flood Profile of Bruce Brook), FEMA's FIS for the Town of Stratford, April 16, 1990.

[2] Determined from Plate 19P (Flood Profile of Rooster River), FEMA's FIS for the City of Bridgeport, September 6, 1989.

[3] Determined from Plate 10P (Flood Profile of Grasmere Brook), FEMA's FIS for the City of Fairfield, August 19, 1986.

[4] Determined from Construction Drawings, CT Department of Transportation.

APPENDIX G

AMTRAK

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

PENN STATION - NORTH (HUDSON) RIVER TUNNEL

Critical Locations

West Side Storage Yard Berm	10.0 feet
Weehawken Shaft	12.3 feet

Potential Hurricane Surge (above NGVD)

Category 1	7.5 feet
Category 2	17.2 feet
Category 3	20.5 feet
Category 4	30.8 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.5 hours
Category 3	1.0 hours
Category 4	1.2 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

EAST RIVER TUNNEL

Critical Locations

Long Island Shaft	9.0 feet
1st Avenue Shaft	14.5 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.6 hours
Category 3	0.9 hours
Category 4	1.3 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

APPENDIX H

NEW JERSEY HIGHWAYS

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

U.S. HIGHWAY 1

Critical Locations

Milepost 41.8 in Union County at Linden at Peach Orchard Brook — 11.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	12.0 feet
Category 2	13.7 feet
Category 3	17.3 feet
Category 4	21.0 feet

U.S. HIGHWAY 1

Critical Locations

Milepost 38.9 in Union County at Rahway at intersection with Lawrence Street — 9.4 feet

Potential Hurricane Surge (above NGVD)

Category 1	--
Category 2	--
Category 3	16.4 feet
Category 4	21.8 feet

INTERSTATE 280

Critical Locations

Milepost 17.65 in Hudson County at Kearney at ramp to EB Turnpike (east alignment) — 7.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.8 feet
Category 2	11.9 feet
Category 3	14.6 feet
Category 4	17.2 feet

NEW JERSEY ROUTE 27

Critical Locations

Milepost 28.4 in Union County at Rahway at Central Ave. near Robinson Br. — 13.9 feet

Potential Hurricane Surge (above NGVD)

Category 1	10.6 feet
Category 2	12.5 feet
Category 3	15.1 feet
Category 4	17.1 feet

U.S. HIGHWAY 1

Critical Locations

Milepost 46.25 in Union County at Elizabeth just over line in Newark — 9.6 feet

Potential Hurricane Surge (above NGVD)

Category 1	11.3 feet
Category 2	13.2 feet
Category 3	16.5 feet
Category 4	20.3 feet

NEW JERSEY ROUTE 35

Critical Locations

Milepost 57.9 in Middlesex County at Woodbridge at Union County Line — 15.2 feet

Potential Hurricane Surge (above NGVD)

Category 1	--
Category 2	--
Category 3	16.4 feet
Category 4	21.8 feet

U.S. HIGHWAY 1 AND 9

Critical Locations

Milepost 2.1 in Hudson County at Jersey City near Communitarian Avenue	2.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	9.8 feet
Category 2	11.9 feet
Category 3	14.6 feet
Category 4	17.2 feet

NEW JERSEY ROUTE 7

Critical Locations

Milepost 2.2 in Hudson County at Kearney under Turnpike Eastern Alignment	5.3 feet
Milepost 3.65 in Hudson County at Kearney over Saw Mill Creek	6.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	--
Category 2	9.9 feet
Category 3	10.4 feet
Category 4	15.1 feet

NEW JERSEY ROUTE 17

Critical Locations

Milepost 4.95 in Bergen County at East Rutherford Borough	3.9 feet
Milepost 8.2 in Bergen County at Hasbrouck Heights South of Williams Ave.	8.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

NEW JERSEY ROUTE 3

Critical Locations

Milepost 9.25 in Hudson County at Secaucus	8.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.8 feet

NEW JERSEY ROUTE 169

Critical Locations

Milepost 2.15 in Hudson County at Bayonne at East 21st Street	10.1 feet

Potential Hurricane Surge (above NGVD)

Category 1	11.7 feet
Category 2	13.3 feet
Category 3	16.7 feet
Category 4	21.9 feet

INTERSTATE 95

Critical Locations

Milepost 74.8 at Teaneck Township in Bergen County at Overpeck Creek	5.8 feet
Milepost 74.15 at Teaneck Township in Bergen County under Fort Lee/ Degraw Ave. Overpass	6.9 feet
Milepost 73.2 at Ridgefield Park Township in Bergen County South of Teaneck Twp. line	9.3 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

NEW JERSEY ROUTE 4

Critical Locations

Milepost 8.5 in Bergen County at Englewood City at Overpeck Creek — 11.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

U.S. HIGHWAY 1 AND 9

Critical Locations

Milepost 58.05 in Hudson County at N. Bergen Township at 42nd Street — 8.0 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.4 feet
Category 2	9.8 feet
Category 3	11.1 feet
Category 4	14.8 feet

NEW JERSEY ROUTE 120

Critical Locations

Milepost 1.0 in Bergen County at East Rutherford Borough opposite race track — 8.2 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

U.S. HIGHWAY 46

Critical Locations

Milepost 69.9 in Bergen County at Little Ferry Borough West of Route 124 — 5.6 feet

Potential Hurricane Surge (above NGVD)

Category 1	8.2 feet
Category 2	9.1 feet
Category 3	10.2 feet
Category 4	13.9 feet

NEW JERSEY ROUTE 21

Critical Locations

Milepost .95 in Essex County at Newark at Vanderpool — 8.3 feet

Potential Hurricane Surge (above NGVD)

Category 1	---
Category 2	--
Category 3	14.9 feet
Category 4	18.7 feet

U.S. HIGHWAY 1 AND 9

Critical Locations

Milepost 47.35 in Essex County at Newark under Haynes Avenue Overpass — 6.8 feet

Potential Hurricane Surge (above NGVD)

Category 1	11.0 feet
Category 2	12.2 feet
Category 3	14.8 feet
Category 4	18.3 feet

Tidal Flooding Highway Locations in New Jersey

BERGEN COUNTY

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Rutherford B.	NJ 3	6.3	14.4	8.2	9.1	10.2	13.8
Rutherford B.	NJ 3	6.6	8.0	"	"	"	"
East Rutherford B.	NJ 3	7.25	8.2	"	"	"	"
East Rutherford B.	NJ 3	7.4	10.0	"	"	"	"
East Rutherford B.	NJ 3	7.6	8.0	"	"	"	"
East Rutherford B.	NJ 3	8.0	15.0	"	"	"	"
River Edge B.	NJ 4	5.2	15.0	"	"	"	"
Englewood City	NJ 4	8.5	11.0	"	"	"	"
Rutherford B.	NJ 17	4.75	5.0	"	"	"	"
East Rutherford B.	NJ 17	4.95	3.9	"	"	"	"
East Rutherford	NJ 17	5.45	5.0	"	"	"	"
East Rutherford	NJ 17	5.8	11.0	"	"	"	"
Carlstadt B.	NJ 17	5.9	8.0	"	"	"	"
Carlstadt B.	NJ 17	6.25	9.0	"	"	"	"
Hasbrouck Hts.	NJ 17	7.2	8.6	"	"	"	"
Hasbrouck Hts.	NJ 17	7.45	9.5	"	"	"	"
Hasbrouck Hts.	NJ 17	7.65	8.0	"	"	"	"
Hasbrouck Hts.	NJ 17	8.2	8.0	"	"	"	"
Hasbrouck Hts.	NJ 17	8.85	21.0	"	"	"	"
Little Ferry B.	US 46	69.4	8.0	"	"	"	"
Little Ferry B.	US 46	69.9	5.6	"	"	"	"
Little Ferry B.	US 46	70.05	9.0	"	"	"	"
Ridgefield Park	US 46	70.7	13.5	"	"	"	"
Ridgefield Park	US 46	70.85	9.0	"	"	"	"
Ridgefield Park	US 46	71.2	14.0	"	"	"	"
TeterB B.	Interstate 80	65.85	10.7	"	"	"	"
South Hackensack	Interstate 80	66.2	10.5	"	"	"	"
South Hackensack	Interstate 80	66.4	13.8	"	"	"	"
Hackensack City	Interstate 80	66.55	11.0	"	"	"	"
Teaneck T.	Interstate 80	67-68		"	"	"	"

There are several low spots in the vicinity of the Interstates 80/95 intersection (Including on/off ramps). Chronic flooding problems noted by NJDOT appear to be rainfall induced.

Municipality	Road/Route	Mile Post	Road Elevation	Cat. 1	Cat. 2	Cat. 3	Cat. 4
Teaneck T.	Interstate 95	73-74		8.2	9.1	10.2	13.8
Ridgefield Park T.	Interstate 95	72.5	11.2	"	"	"	"
Ridgefield Park T.	Interstate 95	73.2	9.3	"	"	"	"
Teaneck T.	Interstate 95	74.15	6.9	"	"	"	"
Teaneck T.	Interstate 95	74.8	5.8	"	"	"	"
East Rutherford B.	NJ 120	0.3	17.0	"	"	"	"
East Rutherford B.	NJ 120	1.0	8.2	"	"	"	"
East Rutherford B.	NJ 120	2.1	13.1	"	"	"	"

Tidal Flooding Highway Locations in New Jersey

ESSEX COUNTY

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Newark	US 1/9	46.3	9.6	-	-	15	19
Newark	US 1/9	47.75	12.0	"	"	"	"
Newark	US 1/9	46.95	12.0	"	"	"	"
Newark	US 1/9	47.35	6.8	"	"	"	"
Newark	US 1/9	47.55	9.5	"	"	"	"
Newark	US 1/9	47.75	18.0	"	"	"	"
Newark	US 1/9	47.85	8.7	"	"	"	"
Newark	US 1/9	47.9	25.0	"	"	"	"
Newark	US 1/9	48.1	8.0	"	"	"	"
Newark	US1/9 (Truck)	51.25	13.0	"	"	"	"
Newark	US1/9 (Truck)	51.55	13.0	"	"	"	"
Newark	NJ 21	0.9	9.1	9.9	11.9	14.6	17.6
Newark	NJ 21	0.95	8.3	"	"	"	"
Newark	NJ 21	1.1	10.5	"	"	"	"
Newark	NJ 21	1.7	12.7	"	"	"	"
Newark	NJ 21	2.2	15.8	"	"	"	"
Newark	NJ 21	2.7	22.0	"	"	"	"
Newark	NJ 21	3.3	13.5	"	"	"	"
Newark	NJ 21	3.5	12.0	"	"	"	"
Newark	NJ 21	4.3	16.0	"	"	"	"
Newark	NJ 21	5.2	17.4	"	"	"	"
Newark	NJ 21	5.55	11.0	"	"	"	"
Newark	NJ 21	5.75	20.0	"	"	"	"
Belleville	NJ 21	5.95	15.0	"	"	"	"
Belleville	NJ 21	6.1	7.5	"	"	"	"
Belleville	NJ 21	6.3	32.0	"	"	"	"
Belleville	NJ 21	6.8	15.0	"	"	"	"
Belleville	NJ 21	7.2	10.0	"	"	"	"
Belleville	NJ 21	8.0	12.1	"	"	"	"
Nutley	NJ 21	8.4	11.8	"	"	"	"
Nutley	NJ 21	9.0	18.0	*See Passaic River non-tidal flood elevations as NJ 21 goes upstream.*			
	NJ 21						
Newark	US 22	58.6	11.0	-	-	14.9	18.7
Newark	US 22	59.2	12.0	"	"	"	"
Newark	US 22	60.2	10.3	"	"	"	"
Newark	I - 78	57.2	14.0	9.9	11.9	14.6	17.6
Newark	I - 78	57.4	12.0	"	"	"	"
Newark	I - 78	57.95	11.8	"	"	"	"
Newark	I - 78	58.45	11.5	"	"	"	"

MIDDLESEX COUNTY

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Woodbridge T.	US1/9	38.2	21.9	-	-	16.4	22.3
Woodbridge T.	NJ 35	54.1	21.5	11.1	17.8	20.4	26.2
Woodbridge T.	NJ 35	54.2	26.6	"	"	"	"
Woodbridge T.	NJ 35	54.3	16.2	"	"	"	"
Woodbridge T.	NJ 35	55.2	25.0	"	"	"	"
Woodbridge T.	NJ 35	57.9	15.1	-	-	16.4	22.3
Woodbridge T.	NJ 27	27.0	15.2	"	"	"	"
Woodbridge T.	NJ 27	27.1	19.1	"	"	"	"
Woodbridge T.	NJ 27	27.2	21.2	"	"	"	"

Tidal Flooding Highway Locations in New Jersey

HUDSON COUNTY

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Jersey City	US 1/9	55.4	15.0	9.9	11.1	12.7	16.8
Jersey City	US 1/9	55.45	20.0	"	"	"	"
Jersey City	US 1/9	55.7	13.0	"	"	"	"
Jersey City	US 1/9	55.95	22.0	8.4	9.8	11.1	14.8
N. Bergen T.	US 1/9	56	15.7	"	"	"	"
N. Bergen T.	US 1/9	56.4	13.3	"	"	"	"
N. Bergen T.	US 1/9	56.7	12.1	"	"	"	"
N. Bergen T.	US 1/9	57.45	14.8	"	"	"	"
N. Bergen T.	US 1/9	57.95	8.5	8.2	9.0	10.2	13.1
N. Bergen T.	US 1/9	57.98	10.0	"	"	"	"
N. Bergen T.	US 1/9	58.05	8.0	"	"	"	"
N. Bergen T.	US 1/9	58.85	15.0	"	"	"	"
N. Bergen T.	US 1/9	59.05	10.0	"	"	"	"
Kearney	US 1/9T	1.15	12.0	-	9.9	10.2	13.1
Kearney	US 1/9T	1.45	2.0	"	"	"	"
Kearney	US 1/9T	1.6	22.0	"	"	"	"
Jersey City	US 1/9T	2	14.5	9.9	11.9	14.7	17.5
Jersey City	US 1/9T	2.1	2.0	"	"	"	"
Jersey City	US 1/9T	2.4	6.3	"	"	"	"
Jersey City	US 1/9T	2.5	7.7	"	"	"	"
Jersey City	US 1/9T	2.7	7.0	"	"	"	"
Jersey City	US 1/9T	2.85	11.6	"	"	"	"
Jersey City	US 1/9T	3.1	9.0	"	"	"	"
Jersey City	US 1/9T	3.45	10.0	"	"	"	"
Secaucus	NJ 3	8.5	14.0	8.4	9.8	11.1	14.8
Secaucus	NJ 3	9.1	14.0	"	"	"	"
Secaucus	NJ 3	9.15	10.0	"	"	"	"
Secaucus	NJ 3	9.25	8.0	"	"	"	"
Secaucus	NJ 3	9.45	10.0	"	"	"	"
Secaucus	NJ 3	9.8	9.5	"	"	"	"
Secaucus	NJ 3	10.1	9.5	"	"	"	"
Secaucus	NJ 3	10.45	11.6	"	"	"	"
Secaucus	NJ 3	10.5	13.4	"	"	"	"
Jersey City	NJ 7	0.1	20.0	9.9	11.9	14.7	17.5
Jersey City	NJ 7	0.25	11.0	"	"	"	"
Kearney	NJ 7	5	10.6	"	"	"	"
Kearney	NJ 7	2.2	5.3	"	"	"	"
Kearney	NJ 7	2.7	5.9	"	"	"	"
Kearney	NJ 7	3.65	6.0	"	"	"	"
Kearney	NJ 7	5.3	12.8	"	"	"	"
Bayonne	NJ 169	1.82	20.0	13.1	19.3	24.9	29.5
Bayonne	NJ 169	2.15	10.1	"	"	"	"
Bayonne	NJ 169	2.85	10.6	"	"	"	"
Bayonne	NJ 169	3.2	13.0	"	"	"	"
Bayonne	NJ 169	3.6	14.6	13.4	18.8	25.9	31.1
Bayonne	NJ 169	3.85	16.3	"	"	"	"
Jersey City	NJ 169	4.1	16.7	"	"	"	"
Jersey City	NJ 169	5.05	21.6	"	"	"	"
Bayonne	NJ 169	5.5	10.0	"	"	"	"
Jersey City	NJ 185	0.55	15.0	13.4	18.8	25.9	31.1
Jersey City	NJ 185	0.7	12.1	"	"	"	"

(CONTINUED)

Tidal Flooding Highway Locations in New Jersey

HUDSON COUNTY (CONTINUED)

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Harrison	Interstate 280	15.4	15.0	10.6	12.5	15.1	17.1
Harrison	Interstate 280	15.6	12.0	"	"	"	"
Harrison	Interstate 280	15.75	13.8	"	"	"	"
Kearny	Interstate 280	15.9	12.0	"	"	"	"
Kearny	Interstate 280	16.45	15.5	"	"	"	"
Kearny	Interstate 280	16.55	10.4	"	"	"	"
Kearny	Interstate 280	17.05	15.7	"	"	"	"
Kearny	Interstate 280	17.1	12.7	"	"	"	"
Kearny	Interstate 280	17.65	7.0	"	"	"	"
Kearny	Interstate 280	17.85	7.0	"	"	"	"
Bayonne	NJ 440	20.55	11.3	11.1	12.2	14.8	18.3
Bayonne	NJ 440	20.8	13.0	"	"	"	"
Bayonne	NJ 440	20.9	10.8	"	"	"	"
Jersey City	NJ 440	21.1	10.5	"	"	"	"
Jersey City	NJ 440	21.3	11.1	"	"	"	"
Jersey City	NJ 440	21.9	10.2	"	"	"	"
Jersey City	NJ 440	22.15	9.4	"	"	"	"
Jersey City	NJ 440	22.55	9.7	9.9	11.9	14.7	17.5
Jersey City	NJ 440	22.65	9.8	"	"	"	"
Jersey City	NJ 440	22.9	10.0	"	"	"	"
Jersey City	NJ 440	23.15	11.0	"	"	"	"
Jersey City	NJ 440	23.3	9.0	"	"	"	"

UNION COUNTY

Municipality	Road/Route	Mile Post	Road Elevation	SLOSH Surge Elevations Cat. 1	Cat. 2	Cat. 3	Cat. 4
Rahway	US 1	38.4	13.2	-	-	16.4	21.8
Rahway	US 1	38.9	9.4	"	"	"	"
Rahway	US 1	39.2	19.0	"	"	"	"
Rahway	US 1	39.4	20.0	"	"	"	"
Rahway	US 1	39.55	17.6	"	"	"	"
Rahway	US 1	39.7	16.7	"	"	"	"
Linden	US 1	39.85	15.8	"	"	"	"
Linden	US 1	40.9	13.0	12.0	13.7	17.3	21.0
Linden	US 1	41.05	14.7	"	"	"	"
Linden	US 1	41.25	16.0	"	"	"	"
Linden	US 1	41.55	24.8	"	"	"	"
Linden	US 1	41.8	11.0	"	"	"	"
Linden	US 1	42.3	21.5	"	"	"	"
Linden	US 1	42.4	19.6	"	"	"	"
Linden	US 1	42.6	15.2	"	"	"	"
Linden	US 1	42.85	20.3	"	"	"	"
Elizabeth	US 1	43.0	26.5	"	"	"	"
Elizabeth	US 1	43.3	15.0	"	"	"	"
Elizabeth	US 1	43.4	12.6	"	"	"	"
Elizabeth	US 1	43.6	13.3	"	"	"	"
Elizabeth	US 1	43.8	15.7	"	"	"	"
Elizabeth	US 1	45.4	18.6	11.3	13.2	16.5	20.3
Elizabeth	US 1	45.5	14.0	"	"	"	"
Elizabeth	US 1	46.25	9.6	"	"	"	"
Rahway	NJ 27	27.3	14.0	-	-	16.4	22.3
Rahway	NJ 27	27.4	19.0	"	"	"	"
Rahway	NJ 27	27.5	15.6	"	"	"	"
Rahway	NJ 27	28.2	23.8	-	-	16.4	21.8
Rahway	NJ 27	28.4	13.9	-	-	16.4	21.8
Elizabeth	NJ 439	0.0	22.3	12.0	13.7	17.3	21.0
Elizabeth	NJ 439	0.15	16.6	"	"	"	"
Elizabeth	NJ 439	0.3	15.6	"	"	"	"

Municipality(ies) Left Side*	Right Side*	Road/Route	Mile Post	Top of Road	Bottom of Bridge	Distance (ft.) Above Mouth	Flood Elevations. 500 yr.	100 yr.	50 yr.	10 yr.
PASSAIC RIVER										
Essex Co.	*Bergen Co.*									
Belleville	N. Arlington	NJ7	5.26	15.5	11.0	44,380	15.5	11.0	9.6	7.2
Passaic Co.	*Bergen Co.*									
Nutley	Lyndhurst	Kingsland Ave.		17.8	16.8	54,100	17.0	12.3	10.6	7.5
Clifton City		NJ 21	9.0	18.0	N.A.	58,800	17.7	13.0	11.0	8.0
Clifton City		NJ 21	9.2	19.2	N.A.	59,200	17.7	13.0	11.0	8.0
Clifton City		NJ 21	9.8	19.0	N.A.	62,000	18.0	13.1	11.2	8.1
Clifton City		NJ 21	9.9	12.0	N.A.	63,000	18.1	13.1	11.2	8.2
Passaic City		NJ 21	10.9	16.0	N.A.	68,000	18.8	14.0	11.8	8.6
Passaic Co.										
Passaic	Rutherford	Union Ave.		19.5	18.0	68,000	19.0	14.0	11.8	8.8
Passaic	Rutherford	Gregory Ave./Maine Ave.		19.5	15.5	72,720	19.5	14.8	12.0	9.0
Bergen Co.										
Wallington		NJ 21	11.9	16.5	N.A.	74,800	20.2	15.8	13.0	9.4
Passaic Co.										
Passaic	Wallington	Second St.		21.5	17.5	76,050	20.5	16.0	13.2	9.6
Passaic	Wallington	West 8th St.		14.2	9.2	79,050	21.0	16.2	13.5	10.0
						82,200	*Saddle River confluence*			
Passaic	Garfield	Wall St.		13.5	12.0	83,050	21.5	17.0	14.0	10.8
Passaic	Garfield	Monroe St.		22.6	16.6	84,800	22.8	19.2	15.2	11.0
Clifton	Garfield	Ackerman Ave.		27.8	20.0	89,420	23.5	21.0	17.0	13.0
						91,800	*Dundee Dam*			
Paterson	Elmwood Park	Market St.		43.0	34.0	99,800	35.5	34.6	33.0	31.5
Paterson	Fair Lawn	Wagner Bridge/Maple Ave.		44.0	41.0	117,000	47.0	42.0	40.0	37.0
	Passaic Co.									
Paterson	Hawthorne	Lincoln Ave. - Begin NJ 20		45.5	39.0	118,150	49.0	43.0	40.5	37.6
Paterson	Paterson	Straight St.		50.5	46.5	127,100	51.0	48.0	46.0	43.0
Paterson	Paterson	Arch St.		46.0	44.0	128,800	52.5	50.0	47.5	46.0
Paterson	Paterson	Main St.		51.0	48.0	129,700	53.0	50.5	49.0	47.0
Paterson	Paterson	Mulberry St.		52.5	46.5	130,750	57.0	55.5	53.0	47.5
						133,850	*Great Falls*			
W. Paterson	Totowa	Totowa Road		127.0	124.5	141,300	131.0	128.0	126.0	122.8
W. Paterson	Totowa	Lackawanna Ave.		133.0	131.0	150,500	134.0	133.0	131.5	128.0
Little Falls T.	Totowa	NJ 23	4.5	174.0	170.0	162,980	174.5	170.0	168.5	166.5
Little Falls T.	Totowa	US 46	55.4	176.5	170.5	171,080	176.0	173.0	171.0	168.8

*** Left/right side of river facing upstream.**

Metro New York Hurricane Transportation Study: Riverine Flooding Highway Locations in New Jersey

Municipality(ies) Left Side*	Right Side*	Road/Route	Mile Post	Top of Road	Bottom of Bridge	Distance (ft.) Above Mouth	Flood Elevations. 500 yr.	100 yr.	50 yr.	10 yr.
PASSAIC RIVER (Continued)										
Essex Co. ◆	*Morris co.*					*173,800*	*Pompton River confluence*			
Fairfield T.	◆ Lincoln Park	Two Bridges Rd		175.0	170.0	173,950	176.0	173.0	171.0	169.0
Fairfield T.	◆ Montville T.	Horseneck Rd.		173.5	171.0	219,000	176.8	173.5	172.0	170.0
Fairfield T.	◆ Montville T.	US 46	51.4	181.0	172.5	234,700	177.5	174.5	173.0	171.0
Fairfield T.	◆ Montville T.	Bloomfield Ave.		180.5	173.0	236,000	178.0	175.0	173.5	171.5
SADDLE RIVER										
Bergen Co. ◆	*Bergen Co.*									
Garfield T.	◆ Wallington T.	Midland Ave.		18.0	11.0	300	21.0	16.8	14.0	10.5
Garfield T.	◆ Wallington T.	River Road		15.0	11.5	3,120	24.0	20.8	20.5	18.0
Lodi T.	◆ Lodi T.	Terrace Ave.		23.2	19.0	8,180	29.0	26.8	26.2	21.2
Lodi T.	◆ Lodi T.	Passaic Ave.		23.5	19.5	9,800	30.5	28.0	27.2	24.0
Lodi T.	◆ Lodi T.	US 46	66.5	38.5	34.5	13,950	34.0	31.8	31.0	29.5
Lodi T.	◆ Lodi T.	Outwater Lane		42.0	36.5	16,520	39.2	37.5	36.0	33.5
POMPTON RIVER										
Passaic Co. ◆	*Passaic Co.*									
Lincoln Park	◆ Wayne T.	US 202 (Boonton Turnpik	62.4	173.0	170.0	7,430	177.5	175.5	174.5	171.5
Pequannock T.	◆ Wayne T.	Pompton Turnpike		180.8	175.8	24,380	183.0	181.5	180.8	177.8
Pequannock T.	◆ Wayne T.	NJ 23	9.6	190.0	181.0	27,290	184.5	183.0	182.0	179.3
RAMAPO RIVER										
Morris Co.	*Passaic Co.*									
Pomp. Lakes T.	◆ Wayne T.	Dawes Hwy		189.5	187.5	7336	192.0	189.5	188.5	187.0
Pomp. Lakes T.	◆ Wayne T.	Paterson-Hamburg Tpk.		190.5	188.5	9,850	197.0	194.0	193.0	188.0
PEQUANNOCK RIVER										
Passaic Co. ◆	*Passaic Co.*									
Riverdale T.	◆ Pomp. Lakes T.	Riverdale Road		192.0	187.5	10,300	192.5	191.5	190.0	187.5
ROCKAWAY RIVER										
Morris Co. ◆	*Morris Co.*									
Parsip. Hills T.	◆ Montville T.	US 46		178.0	173.0	12,000	179.0	176.0	175.0	173.0
Parsip. Hills T.	◆ Montville T.	Vail Road		177.0	174.0	20,000	181.0	179.0	178.0	175.0
WHIPPANY RIVER										
Morris Co. ◆	*Morris Co.*									
Hanover T.	◆ Parsip. Hills T.	Edward's Road		171.0	168.0	1,625	178.5	177.0	175.5	173.0

*** Left/right side of river facing upstream.**

Flooding Induced Traffic Disruption Locations*

NJDOT Region	County	Municipality	Road/Route	Mile Post
II	Bergen	Englewood	4	9.7
II		Lodi	17 N	10
II		E. Rutherford	17 N	4.93
II		Lodi	46	6.65
II		Lodi	80 W	63.9
II		Bogota	80 E	67.1
II		Leonia	93	1.7 - 2.6
II		Teaneck	95 S	74.1
II		Carlstadt	120 N	1.0
II	Essex	Newark	1&9 S	49.4
II		Newark	21 N	4.5
II		Verona	23 N	0.3
II		Newark	78 E	56.2 - 57.0
II		Newark	280	13.8 - 14.5
II	Hudson	Kearny	1&9t E	1.45
II		Kearny	7	3.1 - 3.6
II		E. Rutherford	17	5.2 - 5.8
II		Jersey City	440	22.1
I	Hunterdon	Readington T.	22WB	26.9
III	Middlesex	No. Brunswick T.	1 NB	22.4
III		Edison T.	1 SB	28.7 - 29
III		Woodbridge T.	1 & 9	36.7
III		So. Brunswick T.	1 SB	15.9
III		Old Bridge T.	9 NB	125.3
III		Woodbridge T.	9 SB	133.5
III		Woodbridge T.	9 NB	135.3
III		Woodbridge T.	9 NB	135.6
III		Woodbridge T.	9	135.8
III		E. Brunswick T.	18	37.1
III		E. Brunswick T.	18 EB	38.9
III		New Brunswick	18 EB	41.2
III		South Plainfield Boro.	28WB	6.0
III		Monroe T.	33	17.3
III		Old Bridge T.	35	45.3
III		Sayreville	35	50.7
III		No. Brunswick T.	91	0.7
III		Cranbury T.	130	72.7
III		Sayreville	440	Ramp GM
I	Morris	Morristown	24	0.0 - 7.4
I		Riverside Boro.	23	13.6
I		Butler Boro.	23	15.2
I		West Mitford T.	23	23.8

(CONTINUED)

*As reported by NJDOT Regional Construction & Maintenance Offices

Flooding Induced Traffic Disruption Locations*

NJDOT Region	County	Municipality	Road/Route	Mile Post
I		Dover Twp.	46	39.0 - 40.0
I		Rockaway T. & Montville Twp.	46WB	49.5
I		Morris Plains Bor. thru Denville T.	53	0.0 - 7.4
I		Harding T. to Morris Plains B.	202	39.0 - 47.0
II	Passaic	Paterson	20	3.3
II		Clifton	46	62.5 - 62.8
I	Somerset	Readington T.	22WB	28.6
I		Branchburg T.	22WB	29.9
I		Bridgewater T.	22EB @ I-287 Inter.	32.0
I		Bridgewater T.	22WB	36.8
I		North Plainfield Bor.	22WB	43.8, 45.1
I		North Plainfield Bor.	22WB	45.3
I		Watchnung Bor.	78	42.2 (Exit 41)
I		Bernardsville Bor.	202	34.3 - 34.6
I		Franklin T.	287NB	12.1
I		Bernards Twp.	287SB	28.1
II	Union	Rahway	1&9	38.6
III		Rahway	35	58.0

*As reported by NJDOT Regional Construction & Maintenance Offices

APPENDIX I

NEW YORK AND CONNECTICUT HIGHWAYS

POTENTIAL HURRICANE HAZARDS

AND

FACILITY VULNERABILITY

FDR DRIVE

Critical Elevations (NGVD)

Above 59th Street Bridge 6.0 feet

Potential Hurricane Surge

Category 1	9.2 feet
Category 2	14.1 feet
Category 3	17.4 feet
Category 4	22.3 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.5 hours
Category 2	1.2 hours
Category 3	1.5 hours
Category 4	2.0 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

BROOKLYN BRIDGE, WILLIAMSBURG BRIDGE

Critical Elevations (NGVD)

Center Span 133.0 feet

Potential Hurricane Surge

Category 1	–
Category 2	–
Category 3	–
Category 4	–

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *	Sustained Tropical Strom Winds*
Category 1	–	3.0 Hours
Category 2	–	5.0 Hours
Category 3	–	6.0 Hours
Category 4	–	7.0 Hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

MANHATTAN BRIDGE, QUEENSBORO BRIDGE

Critical Elevations (NGVD)

Center Span 135.0 feet

Potential Hurricane Surge

Category 1	–
Category 2	–
Category 3	–
Category 4	–

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *	Sustained Tropical Strom Winds*
Category 1	–	3.0 Hours
Category 2	–	5.0 Hours
Category 3	–	6.0 Hours
Category 4	–	7.0 Hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

FDR DRIVE

Critical Elevations (NGVD)

Vincinity of Williamsburg Bridge 6.0 feet

Potential Hurricane Surge

Category 1	9.7 feet
Category 2	14.7 feet
Category 3	22.0 feet
Category 4	24.9 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.5 hours
Category 2	1.3 hours
Category 3	1.8 hours
Category 4	2.2 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

WEST STREET

Critical Elevations (NGVD)

Low Point	9.0 feet

Potential Hurricane Surge

Category 1	10.6 feet
Category 2	16.4 feet
Category 3	24.3 feet
Category 4	28.6 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	0.8 hours
Category 3	1.4 hours
Category 4	1.7 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

MARINE PARKWAY BRIDGE APPROACHES

Critical Elevations (NGVD)

Beach Channel Drive Approach	8.0 feet

Potential Hurricane Surge

Category 1	7.0 feet
Category 2	14.4 feet
Category 3	20.6 feet
Category 4	27.2 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	–
Category 2	0.9 hours
Category 3	1.4 hours
Category 4	1.8 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

BATTERY PARK TUNNEL

Critical Elevations (NGVD)

Entrance Low Point	9.0 feet

Potential Hurricane Surge

Category 1	10.5 feet
Category 2	16.6 feet
Category 3	24.0 feet
Category 4	28.7 feet

Time Hazards Could Occur
(hours before closest approach of eye)

	Surge Flooding *
Category 1	0.2 hours
Category 2	0.8 hours
Category 3	1.4 hours
Category 4	1.7 hours

* assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size

GRAND CENTRAL PARKWAY/ WHITESTONE EXPRESSWAY

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	6.6 feet
Category 2	11.6 feet
Category 3	16.2 feet
Category 4	20.9 feet

BRONX RIVER PARKWAY, CROSS BRONX EXPRESSWAY, HUTCHINSON RIVER PARKWAY, THROGS NECK EXPRESSWAY

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	6.5 feet
Category 2	11.4 feet
Category 3	16.2 feet
Category 4	22.7 feet

HARLEM RIVER DRIVE

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	8.4 feet
Category 2	12.7 feet
Category 3	16.4 feet
Category 4	20.4 feet

BELT PARKWAY/CROSS BAY BOULEVARD AT JAMAICA BAY

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	6.6 feet
Category 2	15.6 feet
Category 3	24.5 feet
Category 4	31.2 feet

CROSS ISLAND PARKWAY

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	6.3 feet
Category 2	11.5 feet
Category 3	18.5 feet
Category 4	25.0 feet

ARTHUR KILL ROAD

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	9.9 feet
Category 2	16.0 feet
Category 3	20.0 feet
Category 4	26.2 feet

FATHER CAPODANNO BOULEVARD

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	9.3 feet
Category 2	15.3 feet
Category 3	20.5 feet
Category 4	26.5 feet

BELT PARKWAY AT GRAVESEND BAY

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	9.2 feet
Category 2	15.2 feet
Category 3	20.8 feet
Category 4	27.2 feet

BROOKLYN-QUEENS EXPRESSWAY NEAR BROOKLYN BRIDGE

No Critical Facility Elevation Data Available

Potential Hurricane Surge

Category 1	10.2 feet
Category 2	16.0 feet
Category 3	25.1 feet
Category 4	31.3 feet

MAJOR ARTERIAL FLOODING LOCATIONS
New York City Department of Transportation

MANHATTAN

1. F.D.R. DRIVE SOUTHBOUND JACKSON STREET
2. F.D.R. DRIVE SOUTHBOUND CHERRY STREET
3. F.D.R. DRIVE NORTHBOUND GRAND AVE - HOUSTON ST.
4. F.D.R. DRIVE BOTH DIRECTIONS 23 ST. - 25 ST.
5. F.D.R. DRIVE NORTHBOUND 63 ST. - 70 ST.
6. F.D.R. DRIVE BOTH DIRECTIONS 106 ST.
7. F.D.R. DRIVE BOTH DIRECTIONS 118 ST. - 120 ST.
8. HARLEM RIVER DRIVE NORTHBOUND 125 ST.
9. HARLEM RIVER DRIVE BOTH DIRECTIONS 145 ST.-155 ST.
10. HARLEM RIVER DRIVE BOTH DIRECTIONS 175 ST. - 190 ST.
11. HENRY HUDSON PARKWAY SOUTHBOUND 79 ST.
12. HENRY HUDSON PARKWAY SOUTHBOUND 95 ST.
13. HENRY HUDSON PARKWAY NORTHBOUND 96 ST. - 125 ST.
14. HENRY HUDSON PARKWAY NORTHBOUND 180 ST.

BROOKLYN

1. BELT PARKWAY BOTH DIRECTIONS 79 ST. - HOWARD BEACH
2. BELT PARKWAY WESTBOUND 95 STREET
3. BELT PARKWAY AT PLUM BEACH (EASTBOUND)
4. BELT PARKWAY EASTBOUND LEFT LANE ROCKAWAY PARKWAY - PENNSYLVANIA AVENUE
5. BELT PARKWAY WESTBOUND LEFT LANE 17 AVENUE
6. BROOKLYN QUEENS EXPRESSWAY EASTBOUND BROOKLYN BRIDGE
7. BROOKLYN QUEENS EXPRESSWAY EASTBOUND RAPLEY STREET TUNNEL
8. PROSPECT EXPRESSWAY SOUTHBOUND LEFT LANE CATON AVENUE
9. PROSPECT EXPRESSWAY NORTHBOUND LEFT LANE 4TH AVENUE

BRONX

1. BRONX RIVER PARKWAY BOTH DIRECTIONS/GUN HILL ROAD ENTRANCE
2. BRONX RIVER PARKWAY BOTH DIRECTIONS WESTCHESTER AVENUE
3. BRUCKNER EXPRESSWAY NORTHBOUND MIDDLETOWN ROAD
4. CROSS BRONX EXPRESSWAY BOTH DIRECTIONS JEROME AVENUE
5. CROSS BRONX EXPRESSWAY BOTH DIRECTIONS GRAND CONCOURSE
6. HENRY HUDSON PARKWAY SOUTHBOUND IN THE AREA OF BROADWAY
7. MOSHOLU SOUTHBOUND RIGHT LANE FROM NORTHBOUND HENRY HUDSON PARKWAY
8. HUTCHINSON RIVER PARKWAY SOUTHBOUND RIGHT LANE JUST BEFORE BRUCKNER
9. CROSS BRONX EXPRESSWAY WESTBOUND WESTCHESTER AVENUE

STATEN ISLAND

1. STATEN ISLAND EXPRESSWAY RIGHT SHOULDER BOTH DIRECTIONS HYLAN BOULEVARD
2. STATEN ISLAND EXPRESSWAY RIGHT SHOULDER EASTBOUND RICHMOND AVENUE EXIT
3. STATEN ISLAND EXPRESSWAY WESTBOUND BRADLEY AVENUE EXIT
4. STATEN ISLAND EXPRESSWAY EASTBOUND VICTORY BOULEVARD EXIT
5. STATEN ISLAND EXPRESSWAY WESTBOUND RICHMOND AVENUE EXIT
6. MARTIN LUTHER KING EXPRESSWAY NORTHBOUND FOREST AVENUE ENTRANCE
7. MARTIN LUTHER KING EXPRESSWAY BOTH DIRECTIONS WALKER STREET UNDERPASS

MAJOR ARTERIAL FLOODING LOCATIONS
(Continued)
New York City Department of Transportation

QUEENS

1. GRAND CENTRAL PARKWAY, NORTHBOUND KEW GARDENS INTERCHANGE TO LONG ISLAND EXPRESSWAY
2. CROSS ISLAND PARKWAY, SOUTHBOUND BELL-NORTHERN BOULEVARD
3. CROSS ISLAND PARKWAY NORTHBOUND-EXIT RAMPS BOTH DIRECTIONS NORTHERN BOULEVARD
4. WHITESTONE EXPRESSWAY NORTHBOUND 14 AVE.
5. LONG ISLAND EXPRESSWAY-GRAND CENTRAL PARKWAY TO VAN WYCK EXPRESSWAY
6. VAN WYCK EXPRESSWAY SOUTHBOUND-LONG ISLAND EXPRESSWAY TO JEWEL AVENUE
7. VAN WYCK EXPRESSWAY SOUTHBOUND ENTRANCE RAMPS FROM JEWEL AVENUE
8. INTERBORO PARKWAY-METROPOLITAN AVENUE TO MYRTLE AVENUE
9. LONG ISLAND EXPRESSWAY BOTH DIRECTIONS R/R/ OVERPASS TO MAURICE AVENUE
10. BROOKLYN QUEENS EXPRESSWAY EASTBOUND NORTHERN BOULEVARD
11. GRAND CENTRAL PARKWAY EASTBOUND RIGHT LANE BET. STEIWNWAY & 71 STREET
12. VAN WYCK EXPRESSWAY NORTHBOUND LIBERTY AVE

Source: NYCDOT September 28, 1993 Memo from William T. Donley (Director, Arterial Highways) to Frank N. Gallo (Assistant Commissioner) regarding Arterial Flooding Locations.

NEW YORK THRUWAY

Critical Elevations (NGVD)

Tappan Zee Bridge Center Span	150 feet

Potential Hurricane Surge

Category 1	----
Category 2	----
Category 3	----
Category 4	----

Time Hazards Could Occur (Hours Before Closest Approach of Eye)

	Surge Flooding*	Sustained Tropical Storm Winds*
Category 1	------	3.0 hours
Category 2	------	5.0 hours
Category 3	------	6.0 hours
Category 4	------	7.0 hours

*Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

NEW YORK STATE OFFICE OF PARKS, RECREATION, AND HISTORIC PRESERVATION

Critical Elevations (NGVD)

Meadowbrook State Parkway in Nassau County	7.3 feet

Potential Hurricane Surge

Category 1	4.7 feet
Category 2	15.4 feet
Category 3	23.8 feet
Category 4	28.0 feet

Time Hazards Could Occur (Hours Before Closest Approach of Eye)

	Surge Flooding*
Category 1	-----
Category 2	1.0 hours
Category 3	1.7 hours
Category 4	2.0 hours

*Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.

NEW YORK STATE OFFICE OF PARKS, RECREATION, AND HISTORIC PRESERVATION

Critical Elevations (NGVD)

Wantagh State Parkway in Nassau County	6.3 feet

Potential Hurricane Surge

Category 1	4.4 feet
Category 2	14.0 feet
Category 3	22.3 feet
Category 4	29.2 feet

Time Hazards Could Occur (Hours Before Closest Approach of Eye)

	Surge Flooding*
Category 1	-----
Category 2	0.8 hours
Category 3	1.8 hours
Category 4	2.2 hours

*Assumes 40 mph forward speed and hypothetical SLOSH model storm parameters regarding storm intensity and size.