# NEW YORK STATE HURRICANE EVACUATION RESTUDY TECHNICAL DATA REPORT

*for New York City, Nassau, Suffolk, and Westchester Counties*

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## INTRODUCTION

### STUDY PURPOSE

The *New York State Hurricane Evacuation Restudy (HES) Technical Data Report (*TDR*)* was developed to evaluate the major factors that must be considered in hurricane preparedness and to provide New York emergency management officials timely, state of the art information needed for sound hurricane evacuation decision making. State, county and city agencies can use the technical data presented in this report to supplement and/or revise their hurricane evacuation plans and operational procedures, enabling them to more effectively respond to future hurricane threats.

The study areas for the TDR include the boroughs of New York City (Manhattan, Brooklyn, Queens, Staten Island, and the Bronx) as well as Nassau, Suffolk, and Westchester Counties. A map of the study area is depicted in Figure 1-1.

Figure 1-1: *Study Area Map*

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## FUNDING

The *New York State (HES) TDR* was funded by the FEMA, the USACE, and New York City Office of Emergency Management (NYCOEM) in coordination with the New York State Emergency Management Office (NYSEMO), Nassau, Suffolk, and Westchester Counties. Although funding was not directly provided by NYSEMO, significant staff time was dedicated to develop a number of products and information contained in this study.

## AUTHORITY

The authority for the USACE's participation in this study is Section 206 of the Flood Control Act of 1960, as amended (Public Law 86-645). FEMA's participation is authorized by the Disaster Relief Act of 1974 (Public Law 93-288). These laws authorize the allocation of resources for planning activities related to hurricane preparedness.

## COORDINATION INFORMATION

A coordination system was established for the *New York State HES TDR* which included state and local emergency management officials and representatives from other organizations having direct responsibilities in hurricane emergencies. The NYSEMO maintains close contact with the county emergency management coordinators. The USACE and FEMA relied on this established system during the study effort.

# DESCRIPTION OF STUDY AREA

## GEOGRAPHY

Information and assistance for the Geography, and Geology and Topography sections was provided by Dr. Nicholas K. Coch, Queens College, City University of New York, School of Earth and Environmental Sciences.

The *New York State HES TDR* area includes approximately 135 miles of Atlantic Ocean coastline and 575 miles of sound/bay/riverine shoreline in New York City, Nassau, Suffolk and Westchester Counties.

The Atlantic Ocean coastline of New York lies on two large islands: Long Island and Staten Island. Long Island, composed of the New York City boroughs of Brooklyn and Queens, Nassau County and Suffolk County, is separated from the New England mainland by Long Island Sound and from the boroughs of Manhattan and the Bronx, to the west, by the East River. Long Island is about 120 miles long and has an area of approximately 800 square miles. Staten Island, a borough of New York City, is located in the extreme western portion of the study area and covers 52 square miles. Staten Island is separated from New Jersey by the Arthur Kill and Kill Van Kull and from the other New York City boroughs by The Narrows and the Upper Bay of New York Harbor.

The Harlem River divides the boroughs of Manhattan and the Bronx, and both boroughs are separated from New Jersey, to the west, by the Hudson River. Westchester County, immediately north of New York City, is bordered on the west by the Hudson River, and on the east by Long Island Sound.

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There is an abrupt change in the orientation of the coastline from north-south along the New Jersey shore to east-west along the south shore of Long Island. This bend in the shoreline, referred to as the New York Bight, creates a geographic "funnel" with respect to the Atlantic Ocean. The New York Bight leaves this area vulnerable to storm generated, ocean water surges. Specifically, in the presence of a hurricane, the cyclonic winds along the northern edge of the storm could drive a higher than usual storm surge to the west, laterally along the southern coast of Long Island and into Lower New York Bay. The angle of the New York Bight would leave little outlet for the surge and bring widespread flooding into New York City.

## GEOLOGY AND TOPOGRAPHY

The topography of the study area is quite varied and unique, reflecting the geologic processes that have shaped the surface features. Long Island is the northeastern limit of the Atlantic coastal plain; the mainland to the north consists of bedrock of Lower Paleozoic and Precambrian ages that extends to the shore. The island is a relict of glaciation. It is composed of Mesozoic and Cenozoic sedimentary strata overlain by glacial deposits. Its surface was shaped by the Late Pleistocene Wisconsinian glaciers. West to east trending terminal and recessional moraines make up the center of the island. Outwash plains extend southward from the moraines toward the Atlantic Ocean.

Along the south shore of Long Island, a chain of barrier beaches stretches eastward for about 80 miles from Rockaway Point to Southampton, separated from the "mainland" of Long Island by bays in some areas over 3 miles wide. The width of these barriers varies from a few hundred feet to over a half-mile and, in some locations, their dunes afford considerable protection to Long Island from wave action in the Atlantic Ocean. However, most of these barriers are subject to overwash by surge accompanying hurricanes and extra-tropical storms (nor'easters). Much of the development on these islands is subject to storm surge inundation, wave action and extreme winds.

Although elevations on Long Island exceed 300 feet above sea level, extensive areas along the south shore west of Southampton are vulnerable to surge inundation. Because of the gentle slope of the glacial outwash plain bordering the large bays, storm surge inundation accompanying an intense hurricane could extend over 2 miles inland. From Southampton eastward to Montauk Point, about 30 miles, the shoreline lies along the Ronkonkoma Moraine. Erosion of that moraine has resulted in cliffed headlands bordered by narrow beaches. In some places, cliffs rise abruptly to more than 100 feet above sea level. Small bays and barrier beaches occur at a few locations.

Another Island in the study area, Staten Island, has varied topography which is a result of its location at the junction of three different geologic terrains. The western portion of the island lies along the eastern boundary of the Newark Triassic-Jurassic Basin. This rift basin formed as the North American and African continental plates diverged and opened the Atlantic Ocean in the latter part of the Mesozoic Era. Here the shoreline along Arthur Kill is bordered by wide areas of tidal marsh. The topography rises fairly rapidly from the edge of the marsh eastward toward the uplands.

The highlands in the central part of Staten Island are comprised of ancient Lower Paleozoic Era metamorphic rocks of oceanic origin overlain by Wisconsinian glacial deposits. The terminal moraine of the most recent glaciation runs from the northeast corner of the island, near The Narrows, southwestward along the east coast to Tottenville. Maximum elevations inland reach 400 feet above sea level.

The previously mentioned New York Bight includes major shipping channels into New York Harbor. The sea floor of the Bight consists largely of continental shelf and includes the Hudson Canyon, an undersea Pleistocene submarine canyon, probably from the extension of the Hudson River during the ice ages, when the sea level was lower. The dolomite and serpentine marble rocks which compose the Island of Manhattan are the same that underlie the county of Westchester. Westchester County is known for its hilly terrain.

The eastern shore of Staten Island borders The Narrows on the north, the Lower Bay of New York Harbor on the east, and Raritan Bay on the south. The gently sloping surface extending from the central highlands eastward to the shore is glacial outwash underlain by coastal plain deposits. This relatively low, flat, topography could allow storm surge inundation to reach over a mile inland at some locations. Because there is no protective barrier beach, the shoreline is subject to direct wave action.

## BATHYMETRY

Since shallow water close to shore tends to increase the magnitude of hurricane-induced storm surge, the slope of the ocean bottom (bathymetry) offshore is extremely important when considering possible storm surge impacts. Along the south shore of Long Island, the bathymetry varies considerably. From Montauk Point to the western tip of Fire Island, the 10-fathom (60 feet below mean low water) contour generally parallels the coastline about 1.5 miles offshore. However, just westward from Fire Island Inlet, the 10-fathom contour lies about 4 miles offshore, and at Rockaway Point, about 6 miles offshore. The 20-fathom contour lies about 8 miles offshore near Montauk Point but diverges with the coastline and reaches 30 miles offshore at Rockaway Point. From east to west, the 100-fathom contour varies from about 80 to 100 miles offshore. The configuration of the bathymetry tends to exacerbate the effects of the geographic "funnel" mentioned previously by increasing the magnitude of potential storm surge from Montauk Point westward to Staten Island.

## DEMOGRAPHICS

The study area is a combination of metropolitan and suburban, with most of the population and tourists concentrated in the boroughs of New York City. Table 1-1 shows the population, total dwelling units, and seasonal tourist units for the study area as gathered from the 2000 U.S. Census data.

The New York State study area was grouped into four regions. The regions include New York City consisting of its five boroughs, Nassau County, Suffolk County, and Westchester County. One of the foremost challenges continuing to face the New York emergency management community is describing who should evacuate in a way that is succinct and meaningful to the public and yet is responsive to anticipated storm surge limits for varying categories of hurricanes. Based on these issues, Table 3-1 in Chapter 3 describes the county groupings designed for this study.

| Borough/County | 2000 Population | Permanent Occupied Dwelling Units | Seasonal Tourist Units |
|---|---|---|---|
| New York City | | | |
| Manhattan | 1,537,228 | 738,642 | 82,611 |
| Brooklyn | 2,465,327 | 880,727 | 3,892 |
| Queens | 2,229,379 | 782,664 | 10,770 |
| Staten Island | 443,728 | 156,341 | 1,120 |
| Bronx | 1,332,228 | 463,212 | 962 |
| Nassau | 1,334,549 | 447,387 | 8,000 |
| Suffolk | 1,419,370 | 469,299 | 46,770 |
| Westchester | 923,460 | 337,142 | 8,386 |
| TOTALS | 11,685,269 | 4,275,414 | 162,511 |

**Table 1-1:** *Population Characteristics of the New York Study Area*

## HISTORICAL HURRICANE ACTIVITY

### GENERAL

Hurricanes are a classification of tropical cyclones, which are defined by the National Weather Service as nonfrontal, low-pressure synoptic scale (large-scale) systems that develop over tropical or subtropical waters and have a definite organized circulation. The classification of tropical cyclones into tropical depressions, tropical storms, or hurricanes depends upon the speed of the sustained (1-minute average) surface winds near the center of the system. Tropical depressions are < 34 knots (39 mph), tropical storms are 34 to 63 knots (39-73 mph) inclusive, and hurricanes are > 64 knots (74 mph).

The geographical areas affected by tropical cyclones are referred to as tropical cyclone basins. The Atlantic tropical cyclone basin is one of six in the world and includes much of the North Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. The official Atlantic hurricane season begins on June 1 and extends through November 30 of each year; however, occasional tropical cyclones can occur outside of this period.

Early season tropical cyclones are almost exclusively confined to the western Caribbean and the Gulf of Mexico. By the end of June or early July, the area of formation gradually shifts eastward. By late July, the frequency begins to slowly increase, and the area of formation shifts still farther eastward. By late August, tropical cyclones form over a broad area that extends as far east as the Cape Verde islands near the coast of Africa. The period from about August 20 through September 15 produces the maximum number of Cape Verde type storms, many of which travel across most of the width of the Atlantic Ocean. After mid-September, the frequency begins to decline and the formative area retreats westward. By early October, the area of maximum occurrence returns to the western Caribbean.

## ATLANTIC TROPICAL CYCLONE BASIN

Through the research efforts of the National Hurricane Center (NHC), records of tropical cyclone occurrences within the Atlantic tropical cyclone basin have been compiled dating back to 1851. From 1851 through 2008, approximately 1,387 tropical cyclones have occurred within the Atlantic tropical cyclone basin. Of the known Atlantic tropical cyclones of at least tropical storm intensity, approximately 836 have reached hurricane intensity. Figure 1-2 illustrates the distribution of tropical storms and hurricanes observed from May 1 through December 31 and shows that mid September is the peak of the season.

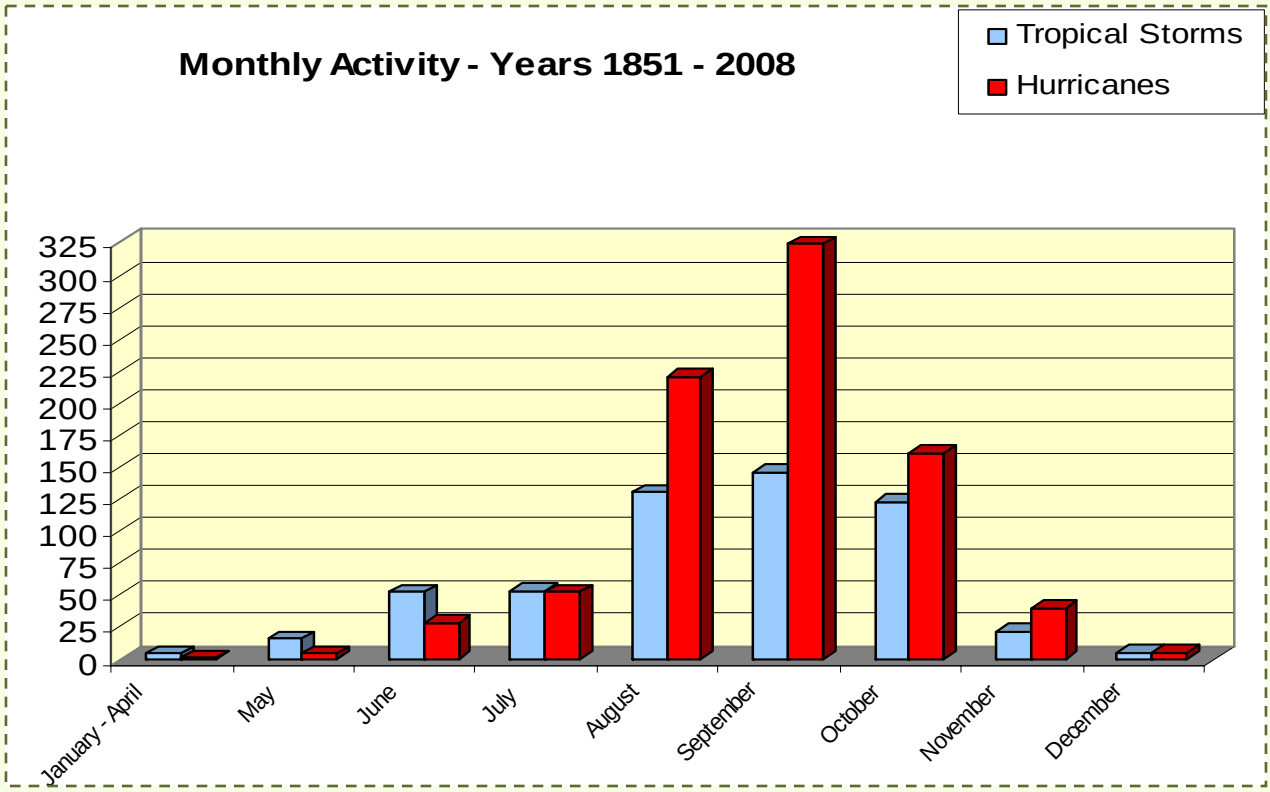


**Figure 1-2:** *Atlantic Tropical Cyclone Basin Hurricane Activity (1851-2008)*

## NEW YORK CITY / LONG ISLAND

New York City and Long Island are one of many hurricane vulnerable locations along the coastline of the United States. Since 1851, hurricanes have been a known, documented threat for the area. Historically, major hurricanes have not threatened the area on a regular basis, either directly or indirectly; however, the possibility still exists.

The Historical Hurricane Tracks for the impacting the eastern coast of the United States are displayed in Figure 1-3. The Historical Hurricane Tracks impacting the New York State area are shown in Figure 1-4. Both images have been provided courtesy of National Oceanic and Atmospheric Administration, Coastal Services Center (NOAA CSC).

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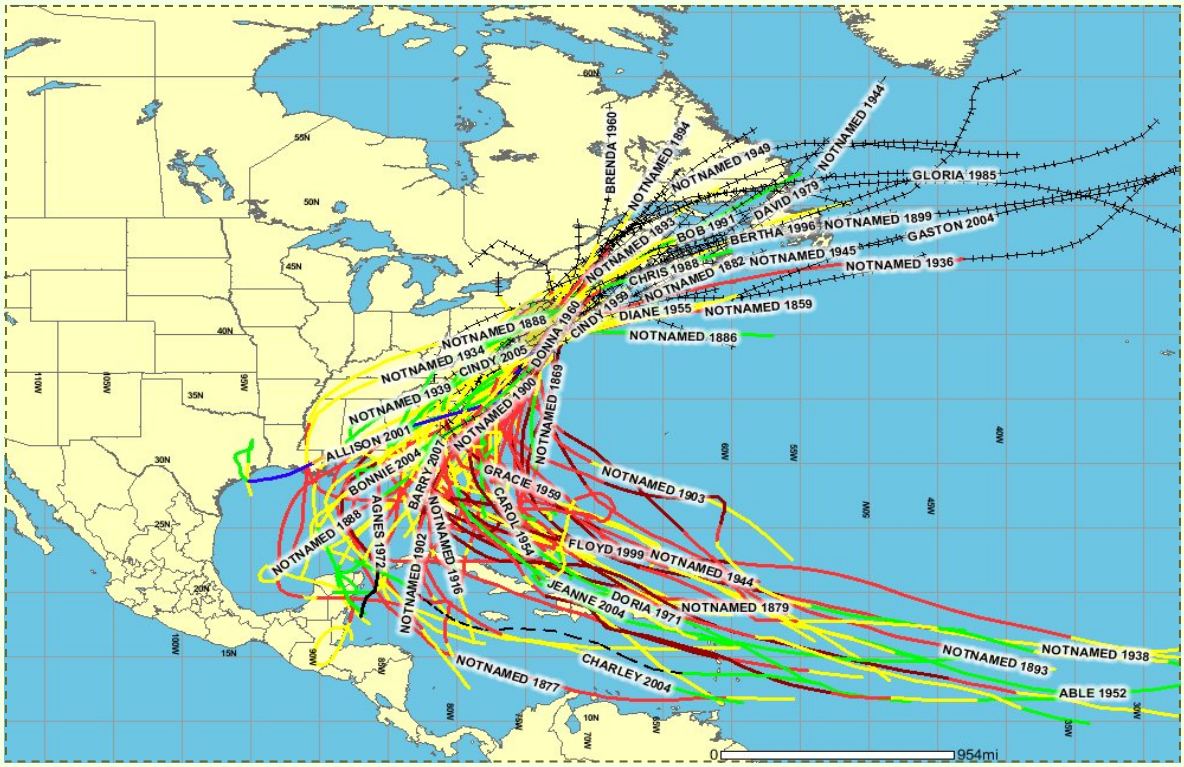


**Figure 1-3:** *Historical Hurricane Tracks—East Coast United States (Images Courtesy of NOAA CSC)*

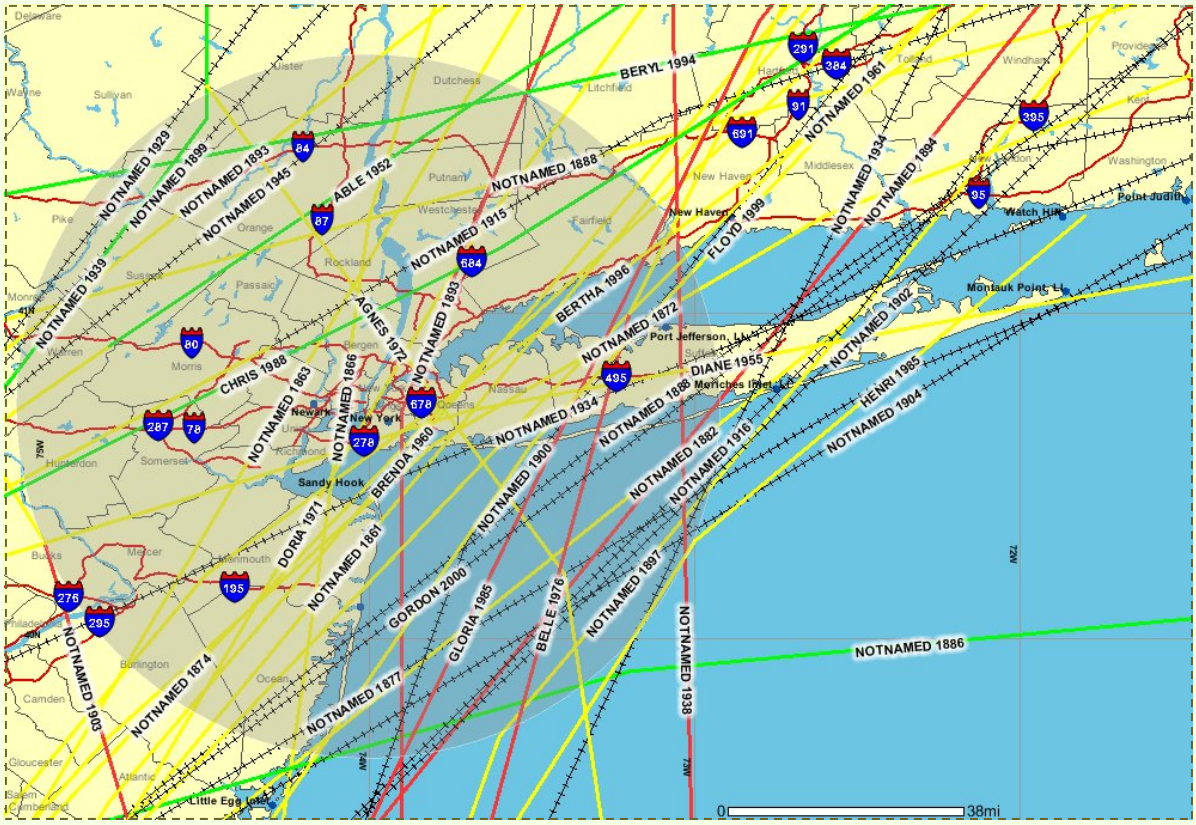


**Figure 1-4:** *Historical Hurricane Tracks—New York Area (Images Courtesy of NOAA CSC)*

## HURRICANE EVACUATION STUDIES ANALYSES

### GENERAL

The *New York State HES TDR* consists of several related analyses that develop technical data concerning hurricane hazards, vulnerability of the population, public response to evacuation advisories, timing of evacuations, and sheltering needs for various hurricane threat situations. The HES process consists of five major analyses, which are briefly described in the following paragraphs. Detailed descriptions of the analyses and the methodologies of each are contained in subsequent chapters of this report.

### HAZARDS ANALYSIS

The hazards analysis determines the timing and magnitude of wind and storm surge hazards that can be expected from hurricanes of various categories, tracks, and forward speeds. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) numerical model was used by the National Hurricane Center to compute the wind speeds and surge heights. The Hazards Analysis is presented in more detail in Chapter 2.

### VULNERABILITY ANALYSIS

Utilizing the results of the hazards analysis, the vulnerability analysis identifies those areas, populations, and facilities that are vulnerable to specific hazards under a variety of hurricane threats. Inundation maps were produced and evacuation scenarios were developed. Hurricane evacuation zones were delineated for boroughs and counties in the study area. Population data was used to determine the vulnerable population within each evacuation zone. The approximate ground elevations of critical facilities were determined by GIS overlay of critical facility locations with Digital Elevation Models (DEM). The information contained in this chapter should be considered preliminary since 1) a single coordinate is used to represent a building, 2) horizontal accuracy of the facility coordinate has not been verified, and 3) accuracy concerns of DEMs used to compare with critical facility coordinate. Further discussion on all aspects of the Vulnerability Analysis is provided in Chapter 3.

### BEHAVIORAL ANALYSIS

This analysis determines the expected response of the population threatened by various hurricane events in terms of the percentage of the population expected to evacuate, probable destinations of evacuees, public shelter use, and utilization of available vehicles. The methodology employed to develop the behavioral data relied on telephone sample surveys within the study area, information from other Hurricane Evacuation Studies, and post-hurricane behavioral studies from other regions. A presentation of the Behavioral Analysis can be found in Chapter 4.

### SHELTER ANALYSIS

The shelter analysis presents an inventory of public shelter facilities, capacities of the shelters, vulnerability of shelters to storm surge flooding, and shelter demand for each borough and county. Emergency management offices in each borough and county furnished shelter names and capacities. Shelter demands were estimated from behavioral analysis data. Chapter 5 contains information on the Shelter Analysis.

## TRANSPORTATION ANALYSIS

The principal purpose of the Transportation Analysis is to; 1) determine the time required to evacuate the vulnerable population (clearance times); and 2) evaluate traffic control measures that could improve the flow of evacuating traffic. Complete details on the Transportation Analysis are presented in Chapter 6.

## HURREVAC / DECISION TOOLS

Chapter 7 describes the HURREVAC computer program and its importance to evacuation planners. The HURREVAC program is a hurricane evacuation decision assistance tool that uses clearance times in conjunction with National Hurricane Center advisories to help determine when and if evacuations should begin.

The following is a brief overview of the various components of HURREVAC:

- Wind Fields – extent and strength of wind fields and projected wind strength along the storms anticipated path;
- Rainfall Forecasts – allows user to view the expected rainfall expectations as the storm approaches;
- River Gages – monitor river flooding, both along the coast and inland;
- Tide Gages – monitor tide stages to better determine evacuation decisions.