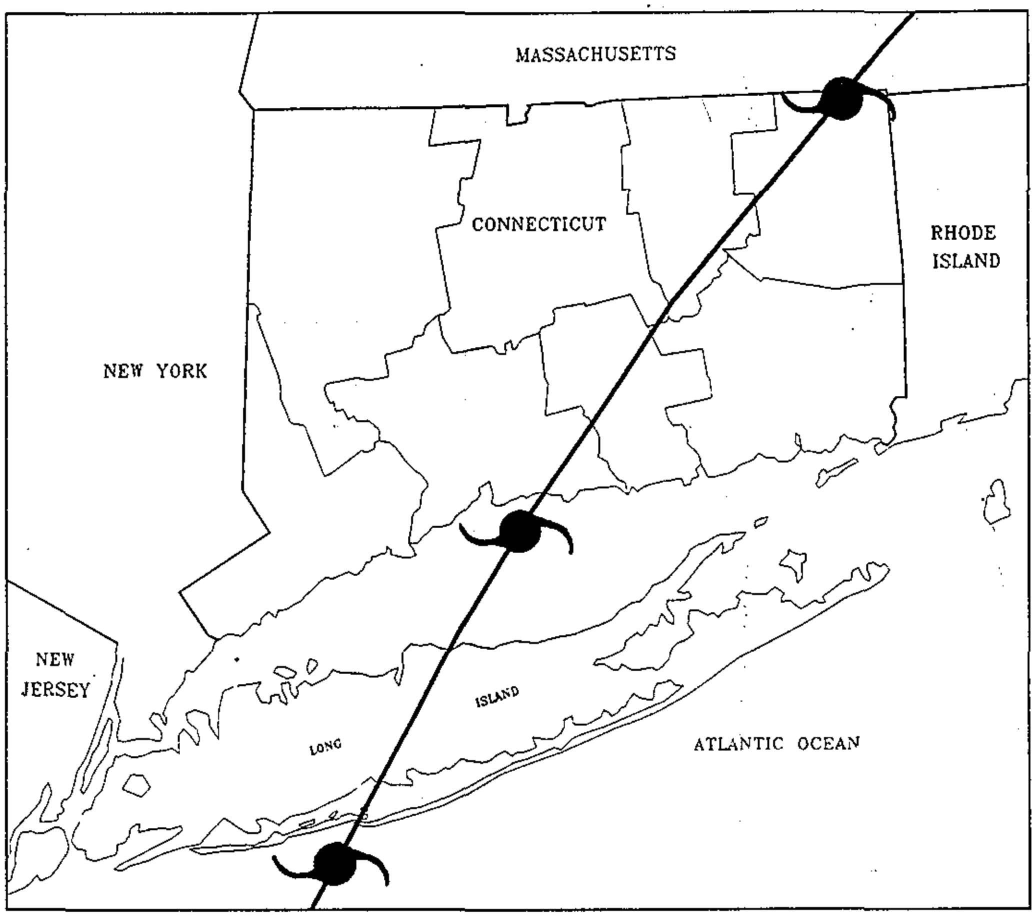
April 1994

Connecticut Hurricane Evacuation Study Technical Data Report



US Army Corps of Engineers
New England Division

FEDERAL EMERGENCY MANAGEMENT AGENCY

Executive Summary

AUTHORITY

At the request of the Governor of Connecticut, the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers, and the National Oceanic and Atmospheric Administration (NOAA) worked with the Connecticut Department of Public Safety, Office of Emergency Management to conduct the Connecticut Hurricane Evacuation Study. Funding was provided by FEMA under the Disaster Relief Act of 1974 and by the Corps of Engineers under its Flood Plain Management Services program authorized in Section 206 of the Flood Control Act of 1960.

SCOPE AND PURPOSE

The primary purpose of the Connecticut Hurricane Evacuation Study is to provide the State of Connecticut, local emergency management agencies, and evacuation decision-makers with data necessary to plan for and evacuate areas vulnerable to hurricane flooding. To accomplish this, the Study provides information on the extent and severity of potential flooding from hurricanes, the associated vulnerable population, capacities of existing public shelters and estimated sheltering requirements, and evacuation roadway clearance times. The report also provides guidance on how this information can be used with National Hurricane Center advisories for hurricane evacuation decision-making.

Products developed from the Study include the Connecticut Hurricane Evacuation Study, Technical Data Report, and two companion atlases. The first atlas, the Inundation Map Atlas, shows the areas of communities most vulnerable to flooding from hurricanes. The second atlas, the Evacuation Map Atlas, shows the evacuation zones developed from the Inundation Map Atlas in close cooperation with community officials. The Evacuation Map Atlas also gives the locations of public shelters, medical/institutional facilities, and mobile home/trailer parks.

HAZARDS ANALYSIS

The purpose of the Hazards Analysis is to develop accurate estimates of potential surge inundation areas resulting from hurricanes. Because this study focuses on protection of the vulnerable population, the Study uses "worst case" hurricane surge estimates. To do this, the Study employs the National Hurricane Center's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model.

Using a computer, the SLOSH model simulated 533 hurricanes of varying intensities, forward speeds, and track directions in order to calculate their potential inundation affects on Connecticut coastal communities. Simulations were performed for hurricanes of Saffir/Simpson scale intensity categories 1-4[1] (see Table 1-2), with forward speeds ranging from 20 to 60 miles per hour, and the storm track directions most likely to affect Connecticut.

The Study determined that the most influential meteorological factor in storm surge generation in Connecticut is not the storm's forward speed, track direction, or landfall location, but rather the intensity of the storm. Consequently, the Study categorizes storm surge tide results by storm intensity. Categorized results can be found in Figure 2-9 of the report.

VULNERABILITY ANALYSIS

Nearly one third of Connecticut's 3.3 million people live in the State's 25 coastal communities. In Bridgeport, Milford, New Haven, and other large population centers, significant numbers of people live in areas potentially vulnerable to storm surge. As a result, vulnerable population estimates in Connecticut cities and towns are large even though hurricane surge inundation areas are geographically small. In general, Connecticut surge vulnerable areas tends to be densely developed with many businesses, multifamily housing units, and beach front and near shore homes. The Study estimates that there are more than 150,000 residents living in Categories 1 and 2 hurricane evacuation zones and a total of more than 280,000 residents living in Categories 3 and 4 hurricane evacuation zones (see Tables 3-1 and 3-2 in the report).

BEHAVIORAL ANALYSIS

The Study recognizes that not all residents within evacuation zones will respond to officials' recommendations to evacuate their homes. Because varying individual responses impact the evacuation process, a behavioral analysis was conducted to provide credible estimates of how the majority of the affected public will respond. These estimates are then

[1]Category 5 hurricanes were omitted from the analysis based upon the National Hurricane Center's recommendation that the cooler ocean waters along the northeast coast of the United States are not capable of sustaining hurricanes of this intensity.

used to establish assumptions for other Study analyses, for guidance in evacuation decision-making, and for public awareness efforts. The primary objectives of the behavioral analysis were to determine: 1) how the community's population will respond to evacuation recommendations for a range of hurricane threat situations; 2) the timing of their response; 3) the number of vehicles they will use during evacuations; and 4) the percentage that will seek public shelters.

The Behavioral Analysis concluded that the two overriding factors influencing residents' decisions to evacuate are: 1) actions by local officials; and 2) the perceived degree of hazard at their location. The Study indicates that when officials take aggressive action to encourage people to leave, evacuation rates increase by approximately 25 to 50 percent. The Study also indicates that the time at which people mobilize and evacuate is closely related to local officials' actions. These conclusions are supported by two aspects of evacuation timing which have been observed during recent storms: 1) people will not begin to leave their homes in significant numbers unless directed to do so by local officials; and 2) the timing with which people leave will vary from storm to storm.

SHELTER ANALYSIS

In order to determine if adequate sheltering exists for the evacuating population, the Study conducted a Shelter Analysis. This Analysis compared the existing public shelter capacity to the expected public sheltering needs in each community by combining the public shelter demand, as computed using behavioral data and census information, with the results of public shelter surveys. As shown in Table 5-1 in the report, the results of the Analysis identified that five Connecticut coastal communities may not have adequate shelter capacity to accommodate the expected demands.

TRANSPORTATION ANALYSIS

A critical aspect of hurricane evacuation decision-making is knowing how long it will take evacuating vehicles to clear off roadways after the public is directed to evacuate (i.e., roadway clearance time). The Transportation Analysis estimated clearance times using a mathematical model of the study area's roadway system to simulate vehicle movements during evacuation scenarios. Three important factors that were varied with each evacuation simulation were the timing with which the public responded and left their homes, hurricane severity, and background traffic conditions at the start of evacuation.

Clearance times for Fairfield, New Haven, Middlesex, and New London counties ranged from 4-1/2 hours to 10 hours. The most likely evacuation scenarios however, had clearance times which ranged from 6-1/2 to 7 hours. Because of the advantages of using a single clearance time for all areas, the Study recommends the adoption of a 7-hour clearance time for all Connecticut coastal areas. **Clearance time must be combined with dissemination time (described below) to estimate the total time necessary for complete evacuation.** The advantages of a single clearance time are continuity of planning assumptions across community political boundaries, and consistency of warning messages broadcasted to threatened coastal areas. Although the Study analyzed evacuation scenarios with clearance times less than 7 hours time, these times should not be used by communities as a basis for evacuation planning.

EVACUATION DECISION-MAKING

Clearance time is one component of the total time required for complete evacuation. The total evacuation time includes a second component defined as dissemination time (see Figure 7-1 in the report for a diagram illustrating components of evacuation time). Dissemination time refers to the time officials need to make their evacuation decisions, mobilize support personnel, communicate evacuation decisions between affected communities and the State, and disseminate evacuation directives to the public. The length of dissemination time is a function of established communication and decision-making procedures of the State and individual communities, and consequently can vary greatly by community. Because of this, the Study does not attempt to quantify this time for individual communities. Instead, the Study recommends dissemination time be calculated cooperatively by the State and appropriate community decision makers.

The Decision Arc Method presented in the last chapter explains a step-by-step hurricane evacuation decision-making procedure. This method uses evacuation time in conjunction with National Hurricane Center advisories to estimate when evacuation must begin in order to be completed prior to the arrival of hurricane gale force winds. The method is designed to help compensate for forecast errors by relating evacuation decisions to hurricane position.

CONCLUSIONS

The following key points are emphasized to facilitate incorporation of this study's results into existing State and local hurricane preparedness plans.

1. The geomorphology of Long Island Sound can have amplification affects on hurricane surge. The configuration of Long Island and the Connecticut coast cause a natural funneling influence on ocean waters as they are driven east to west in the Sound by a hurricane. Consequently, officials should understand that even hurricanes which track to the east of Connecticut can generate significant flooding at all locations along Connecticut's shore. Moreover, the time of arrival of peak surge relative to eye landfall will occur at different times depending upon location. Along the western shore of the State in particular, officials must be mindful that the arrival of peak surge can be as long as two or more hours after the hurricane has made landfall.

2. The design height of the Corps of Engineers' Hurricane Barrier in Stamford, Connecticut is sufficient to protect against worst case storm tides predicted by the SLOSH model. The only exception to this is that severe hurricanes with a strong westerly track can generate higher surges than the Barrier's design height, potentially overtopping it. However, these storms have been classified as extraordinarily rare meteorological events. Therefore, the Stamford Hurricane Barrier provides protection against all worst case flooding situations reasonably expected to occur in this region. For purposes of this study, all analyses were conducted assuming that the Barrier would not be overtopped. As the results of this study are implemented, the Corps of Engineers and the City of Stamford should consider the additional impacts these rare events could have and identify special evacuation measures that would be necessary should a storm of this nature be forecasted.

3. The Corps of Engineers' Hurricane Barrier located in New London, Connecticut was designed to protect against flooding events up to the 100-year frequency flood. Results of the SLOSH model show that worst case surges generated by Categories 3 and 4 hurricanes in combination with high astronomical tides are higher than the design height of the Barrier. Therefore, for purposes of this study, it was determined that potentially vulnerable land areas located behind the Barrier should be evacuated for hurricanes of these intensities. It is therefore extremely important that officials and citizens of the City of New London understand the design height limitations of the New London Hurricane Barrier. As the results of this study are implemented, the Corps of Engineers and the City of New London need to ensure

that operational procedures for evacuating areas protected by the Barrier are in place in the event that evacuation becomes necessary.

4. The average error in a 12 hour hurricane forecast is approximately 60 miles. This means that if a storm was forecasted to make landfall at New Haven, Connecticut in 12 hours time, and it in fact made landfall anywhere between New York City and Westerly, Rhode Island, the error in forecast landfall position would be no worse than average. Forecasting errors complicate hurricane evacuation decision-making and officials must understand the limitations of the National Weather Service's forecasting capabilities.

5. Although human behavior during a hurricane evacuation is difficult to predict, two overriding factors influence whether or not residents will evacuate: 1) the actions by local officials; and 2) the perceived degree of hazard at their location. The Study indicates that when officials take aggressive action to encourage people to leave their homes, evacuation rates increase by approximately 25 to 50 percent. The Study also concluded that the time at which people mobilize and evacuate is closely related to local officials' actions. During evacuation proceedings it is recommended that clear and consistent warnings are broadcasted to the public at risk to supplement "door to door" warning efforts.

6. The Shelter Analysis determined that the expected shelter usage (shelter demand) of some communities is greater than the combined capacity of the communities' public shelters. Communities should continue working with the local American Red Cross chapters to reach agreements on other suitable facilities to ensure sufficient public shelters are available during hurricanes.

7. The Study presents clearance times for 18 hurricane evacuation scenarios, each varying by behavioral response, background traffic level during the evacuation, and hurricane severity. The Study recommends the adoption of a 7-hour clearance time for all coastal areas in Connecticut. Although the Study analyzed evacuation scenarios with clearance times less than 7 hours time, these times should not be used by communities as a basis for evacuation planning.

8. To ensure suitable evacuation times are used in hurricane evacuation decision-making, it is extremely important that State and local officials investigate existing communication and warning procedures and establish an appropriate amount of dissemination time. Dissemination

time is a critical component of evacuation time. Failure to include this time as part of total evacuation time may substantially underestimate the time required to complete evacuations safely. The Study recommends that officials refer to the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993 for information that can assist in quantifying dissemination time.

9. The Study recommends that decision-makers use the Decision Arc Method outlined in Chapter Eight to assist in determining if, and when, a hurricane evacuation should be conducted. The method requires that decision-makers have access to the latest Tropical Cyclone Marine and Public Advisories issued by the National Hurricane Center. To accomplish this, provisions should be made in the State's Warning Plan for the timely dissemination of the National Hurricane Center's weather products to all decision-makers.

10. The completion of this multi-year study does not conclude the Corps of Engineers' or FEMA's involvement in hurricane preparedness activities in the State of Connecticut. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. Using the results of this study, the Federal Emergency Management Agency will take the lead with the Connecticut Office of Emergency Management to establish a framework for which comprehensive state-community coordinated hurricane preparedness plans will be made.

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Preface

In 1938, the Great New England Hurricane was the only hurricane to threaten the east coast of the United States. It developed from a tropical storm originating off the coast of southwest Africa near the Cape Verde Islands, and within days of its formation, it reached hurricane strength and headed east toward the north Atlantic coast. As it approached the Virgin Islands, the hurricane quickly curved northward on a track that paralleled the coast. By 7:00 a.m. on September 21, the eye passed 150 miles off Cape Hatteras. High pressure areas on either side of the system funneled it on a straight track directly to New England.[1]

By 2:30 in the afternoon, Weather Bureau officials in Boston realized the system had unexpectedly accelerated to more than 50 mph, and had traveled nearly 600 miles in twelve hours. Officials aired warnings that a tropical hurricane was in the vicinity of New York and expected to move over New England's inland within two hours time. The hurricane, accompanied by sustained winds in excess of ninety-five mph, made landfall at New Haven, Connecticut at 3:30 p.m. coincident with normal high tides. Many marine crews along the Atlantic avoided the storm's wrath by either safeguarding ships far out at sea or cautiously securing them along inner harbors. The absence of weather reports from these ships, and primitive weather observation equipment of that time, resulted in sparse weather surveillance and forecasts with little detail or confidence. Many New England residents never received warnings while others gave little thought to sketchy forecasts until it was too late.

Heavy rainfall that was brought by the storm coupled with rains four days before the storm, caused severe freshwater flooding conditions in many inland areas. The banks of the Connecticut River were overtopped, flash flooding occurred in many smaller streams, and inland cities and towns experienced some of the highest flood levels ever reported. Winds destroyed entire forests, cottages and ocean front homes were washed more than a half mile from the shore, and recreational boats and large shipping fleets were scattered all along New England's coastline. In total, the storm gave rise to more than $400,000,000 in damages (in 1989 dollars, the estimated damages translates to $3.5 billion). An estimated 682 New England deaths were directly attributed to the Hurricane of 1938.[2]

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[1]Hale, Cushman & Flint, New England Hurricane, Federal Writers' Project, Boston, MA 1938.

[2]Federal Emergency Management Agency, Interagency Hazard Mitigation Report - Hurricane Bob, 1992.

In southern New England, the Hurricane of 1938 has been established by many as the benchmark storm of record by which all other hurricanes are compared. Today, hurricane preparedness plans in many coastal communities use historical flood records as a basis for identifying homes and businesses that may require evacuation. This approach for hazard area identification is perhaps effective for storms that have less severe affects than the Hurricane of 1938, but at most locations this method can, and will, significantly underestimate potential flood areas. Historic flood records can assist in public education, help to identify land areas that will initially flood before peak surge arrives, and be used to verify vulnerable areas determined from other methods. However, hurricane preparedness plans based on historical data only may compromise the public's safety by neglecting potential impacts from catastrophic events. For this reason, hurricane preparedness plans need to include worst case flood levels that may occur from hurricanes more devastating than any past New England storms.

The locations in the vicinity of the landfall of the 1938 Hurricane probably experienced storm surges that approach the worst case conditions for their areas. For most other locations, surges would have been higher had the storm traveled at a slower forward speed, shifted in track direction, or increased in intensity. Even slight variations in the travel speed, approach direction, or landfall point, compounded by the affect from local bathymetry and shore irregularities can have notable influences on the level of flooding. Consequently, hurricane evacuation plans and evacuation decisions based upon historic information alone may give emergency management officials a false sense of safety, ultimately leading to an inadequate public response during catastrophic events in the future.

Historically, the frequency at which hurricanes threaten Connecticut range from about five to ten major hurricanes each century. The State's 110 miles of southern facing coastline and the geomorphology of Long Island Sound cause Connecticut coastal cities and towns to be particularly vulnerable to all hurricanes forecasted to track towards New England. The State's vulnerability is further complicated by its growing population and increased development in coastal areas.

It can be anticipated that hurricane evacuations conducted in Connecticut will take many hours to complete. In fact, in order for an evacuation to be completed before the onset of dangerous high winds, people must begin seeking safe refuge while a hurricane is still hundreds of miles away. Tens of thousands of people leaving their work places and competing for roadway space with those evacuating homes, or making last minute shopping trips, presents a situation where people could be left stranded on highways, or in their homes, as a hurricane strikes. The destruction observed well inland in South Carolina by Hurricane Hugo in 1989 suggests that no evacuation should be considered complete until all roadways several miles inland from the coast have been cleared. Officials of some communities can reasonably estimate time required to evacuate residents to public shelters located in their own communities. It is not as apparent however, how long it will take to clear vehicles off all roadways if evacuations are conducted in several adjacent communities. The analyses of this study are intended to quantify this time.

Fortunately, along with improvements in hurricane forecasting, enormous progress has been made in recent years in the rapid dissemination of advisories to the public and local governments. Despite these advancements, weather forecasting is only one component of hurricane preparedness. State and local officials must have reliable information on potential hurricane surge and flood hazard areas (based on the intensity of the hurricane), accurate estimates of the population at risk and the number that will evacuate, public shelter capacities and locations, and estimates of the amount of time needed to complete an evacuation.

There are no anticipated advances in hurricane track forecasting that would allow the precise determination of specific areas requiring hurricane evacuation. Consequently, to ensure the safety of all threatened areas, hurricane evacuation decisions consider large shoreline areas and involve the displacement of many people. The decision of public officials to order or recommend a hurricane evacuation is not an easy one. Therefore, it is essential that those public officials responsible for ordering or recommending evacuations have at their disposal reliable data and systematic methods necessary for making their decisions.

The critical data necessary for the development of hurricane evacuation plans for many jurisdictions require comprehensive and specialized analyses. The fiscal and staffing limitations of most State and local emergency management agencies preclude the development of these data. To assist State and local governments, the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers, and the National Oceanic and Atmospheric Administration have joined the Connecticut Office of Emergency Management in conducting the Connecticut Hurricane Evacuation Study.

Chapter One

INTRODUCTION

1.1 PURPOSE

The purpose of this Study is to provide the Connecticut Office of Emergency Management and the coastal communities in Connecticut with realistic data quantifying the major factors involved in hurricane evacuation decision-making. The technical data presented in this report and associated atlases are not intended to replace the detailed operations plans developed by the State or the communities. Rather, these data will provide a framework within which State and local emergency management officials can update and revise existing hurricane evacuation plans and from which integrated State and community procedures can be developed to improve preparedness and response to future hurricane threats.

1.2 AUTHORITY

This study is a cooperative effort by the Federal Emergency Management Agency (FEMA), the US Army Corps of Engineers, and the National Oceanic and Atmospheric Administration (NOAA), for the Connecticut Department of Public Safety, Office of Emergency Management. Funding was provided by FEMA under the Disaster Relief Act of 1974 (Public Law 93-288); and by the US Army Corps of Engineers under the Flood Plain Management Services program, Section 206, of the Flood Control Act of 1960 (Public Law 86-645). These laws authorized the allocation of resources for planning activities related to hurricane preparedness.

1.3 STUDY AREA DESCRIPTION

1.3.1 Geography

The study area comprises the 25 coastal communities located in Fairfield, New Haven, Middlesex, and New London counties. Since the study is uniquely aimed at addressing concerns at the community level rather than at the county level, which is atypical of similar studies conducted for southern States, only the immediate coastal communities of the four counties were included in the study area. Tidal waters affecting the State are Long Island Sound and Block Island Sound. The study area is depicted in Figure 1-1.

A broad range of land uses exists in the study area ranging from sporadically located recreational parks and tourist areas to heavy industrial parks, commercial sites, and shipping ports. The western and central coastlines are mostly urbanized and densely populated in contrast to areas in the east that tend to be less developed and more sparsely populated.

The State of Connecticut has 169 cities and towns with a State population totaling approximately 3.3 million. Nearly one third of the State's total population is concentrated along its coast. Demographically, the State has experienced overall growth of 23 percent during the period 1960 to 1990 compared with less than an 11 percent overall growth in its coastal areas. Although Connecticut's coastal areas overall have experienced less growth than the State in total, easterly coastal communities are growing more rapidly as indicated by an approximately 35 percent population increase since 1960. Conversely, from 1960 to 1990 westerly coastal communities have grown less than 2 percent in population.

On average, the entire coast experiences less than a 5 percent increase in population during summertime due to influxes of seasonal residents to summer homes and beach front cottages. However, seasonal population can range as high as 15 to 35 percent of the permanent population in Old Saybrook, Old Lyme, and vicinities[3].

1.3.2 Topography and Landforms

The coastline of Connecticut lies along the north shore of Long Island Sound for a distance of about 110 miles by highway from the mouth of Byram River at the New York State line easterly to the Pawcatuck River at the Rhode Island State line. The entire shoreline is very irregular and marked by many bays, coves, estuaries, and promontories. Among the principal indentations in the shoreline are the harbors at Greenwich, Stamford, Norwalk, Bridgeport, and New Haven, and the estuaries of the State's three major rivers: the Housatonic, Connecticut, and Thames. These rivers respectively drain the western highlands, central lowlands, and eastern highlands of the State and serve extensive commercial navigation and recreational purposes. Connecticut's beaches, which are typically narrow and rocky with normal tides approaching the backshore, are generally inadequate as protection features or for mass size recreational purposes[4].

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[3]US Dept. of Commerce, 1990 Census of Population and Housing, STF-1, August 1991.

[4]US Army Corps of Engineers, National Shoreline Study: Regional Inventory Report-North Atlantic Region, New York, NY: USACE, 1971.

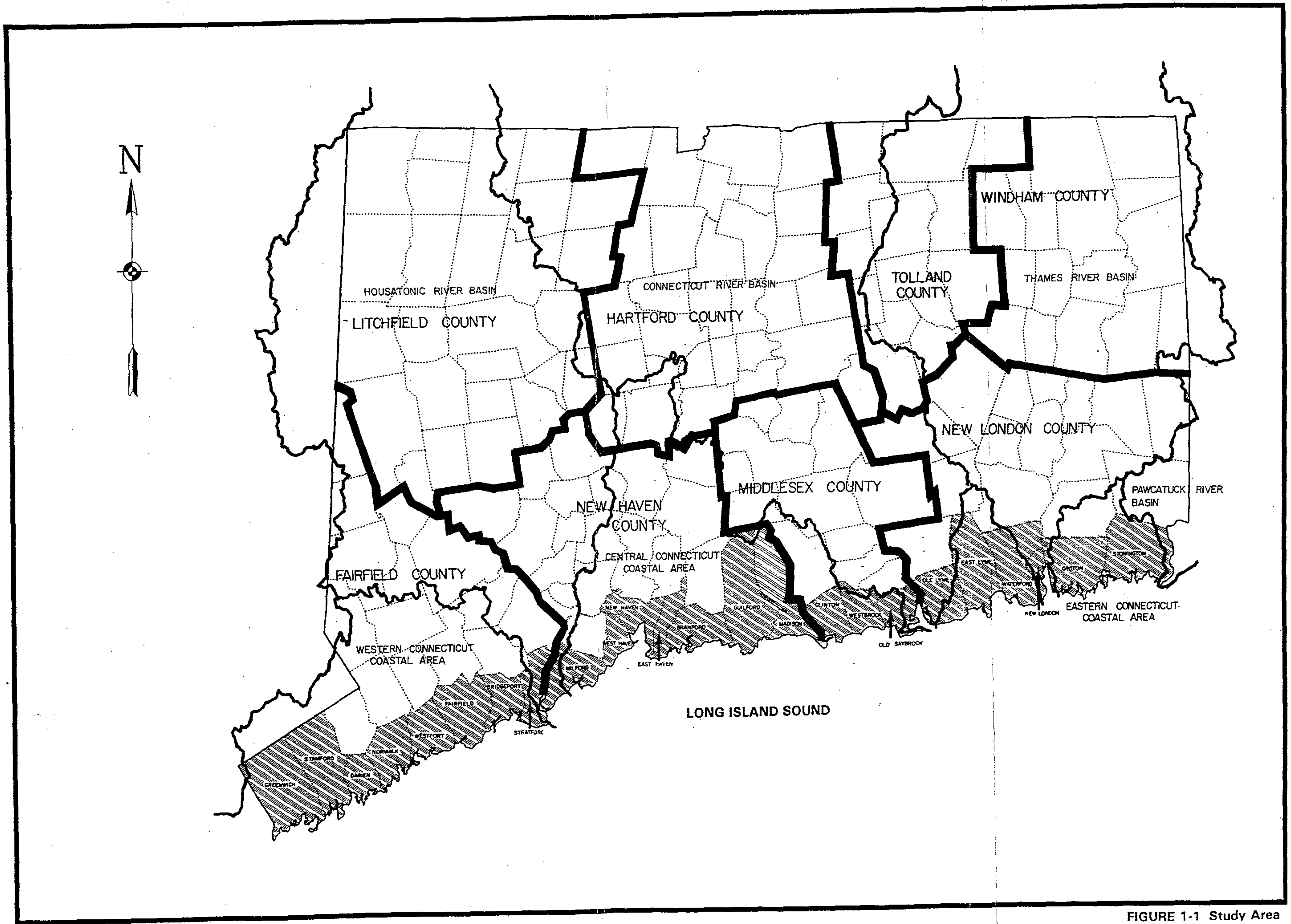

FIGURE 1-1 Study Area

Connecticut's coastal seaboard, which lies entirely within the lowland area of New England is maturely dissected with low hills and ridges rising above open valleys. Most of the region is below an elevation of 400 feet, referenced from the National Geodetic Vertical Datum (NGVD), except in the western part of Connecticut where the hills reach elevations generally higher than 500 feet. Low, rolling hills and occasional rocky lands interposed by level to undulatory sand and gravel plains are characteristic of the coastal landscape[5].

1.3.3 Bathymetry

Long Island Sound is an asymmetric, preglacial valley situated between the bedrock of southern New England and the coastal plain sediments of Long Island. Its 1300 square mile water surface area is an almost fully enclosed arm of the ocean bordered by nearly 600 miles of coastline. The estuary is unusual in that two independent and restricted passages to the ocean exist at opposite ends of the Sound. The East River, a tidal strait connected with New York Harbor, is the passage at the western end of the Sound, and at the eastern end, multiple large open passages exist connecting it to Block Island Sound.

The Sound is 113 miles long, 21 miles wide and contains 125 islands. Its average depth is 80 feet with maximum depths extending 320 feet deep[6]. About 75 rivers and streams of various lengths drain the surrounding 16,000 square mile area. The Connecticut and Thames Rivers account for more than 80 percent of the total stream flow entering the Sound.

The tidal currents and water circulation of the Sound are extremely complex due to surrounding topography, large variations in salinity at different depths and locations, and fresh water inflow. The Sound displays estuarine characteristics in its western and central portions and embayment characteristics in its eastern third. Basin geometry influences ocean tides such that still water elevations progressively increase from east to west. The mean tide range of eastern and western parts of the Sound vary from 2.5 feet to 7.8 feet respectively, and peak tides of the western part occur more than two hours after peak tides occur in the east. The Sound's amplifying characteristics on ocean waters not only contributes to large differences

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[5]US Dept. of Commerce, Office of Coastal Zone Management, State of Connecticut Coastal Management Program and Final Environmental Impact Statement,

[6]New England River Basins Commission, People and the Sound: A Plan for Long Island Sound, Volume--2, Supplement, July 1975.

in the normal tide range, but also affects surges resulting from significant weather disturbances.

1.4 HISTORICAL HURRICANE ACTIVITY

1.4.1 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 water and have definite organized circulations. Tropical cyclones are categorized based on the speed of the sustained (1-minute average) surface wind near the center of the storm. These categories are: Tropical Depression (winds less than 34 knots/39 mph), Tropical Storm (winds 34-63 knots/39-74 mph, inclusive) and Hurricanes (winds at least 64 knots/74 mph).

The geographical areas affected by tropical cyclones are called 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, but occasionally tropical cyclones occur outside this period. Early season tropical cyclones are almost exclusively confined to the western Caribbean and the Gulf of Mexico. However, by the end of June or early July, the area of formation gradually shifts eastward, with a slight decline in the frequency of storms. By late July the frequency gradually increases, and the area of formation shifts still farther eastward.

By late August, tropical cyclones form over a broad area that extends eastward to near the Cape Verde Islands located off the coast of Africa. The period from about August 20 through about September 15 encompasses the maximum of the Cape Verde type storms, many of which travel across the entire Atlantic Ocean. After mid-September, the frequency begins to decline and the formative area retreats westward. By early October, the area is generally confined to the western Caribbean. In November, the frequency of tropical cyclone occurrences declines still further.

1.4.2 Atlantic Tropical Cyclone Basin

Through research efforts by the National Climate Center in cooperation with the National Hurricane Center, records of tropical cyclone occurrences within the Atlantic Tropical

Cyclone Basin have been compiled dating from 1871. Although other researchers have compiled fragmentary data concerning tropical cyclones within the Atlantic tropical cyclone basin back as early as the late fifteenth century, the years from 1871 to the present represent the complete period of the development of meteorology and organized weather services in the United States. For the 122-year period from 1871 through 1993, nearly 1000 tropical cyclones have occurred within the Atlantic tropical cyclone basin; however, for the years 1871 through 1885 the existing data do not provide accurate determinations of the intensities of the tropical cyclones. The National Hurricane Center maintains detailed computer files of Atlantic tropical cyclone tracks back to 1886. Of the 852 known Atlantic tropical cyclones of at least tropical storm intensity occurring during the period 1886 through 1986, 499 reached hurricane intensity. Figure 1-2 provides a histogram of the total number of tropical storms and hurricanes observed for a 100-year period from May 1 through December 31, 1886 through 1986.

1.4.3 Coastal New England

Coastal Connecticut and other southern exposed coastal areas of Southern New England are particularly vulnerable to hurricanes despite moderate hurricane occurrences when compared with other areas within the Atlantic Tropical Cyclone Basin. The common notion that Long Island Sound affords the Connecticut coast protection from hurricanes, in that hurricanes passing over Long Island undergo a significant reduction in wind forces and that only limited surges can be regenerated in the narrow water surface of Long Island Sound, is inaccurate. The area's coastline geometry; regional bathymetry; and hurricane direction, intensity, and forward speed are influential parameters that affect resulting hazards. Connecticut's vulnerability to hurricanes is complex and varies greatly depending upon the weather scenario considered and the interaction of hurricane surge with topography and bathymetry of the region.

Since 1886, 29 hurricanes and 67 tropical storms have passed within a 150 mile radius of Newport, Rhode Island (the circle's radius includes New England's southern exposed coastline extending from the New York and Connecticut state boundary east beyond Cape Cod, Massachusetts). Figures 1-3 and 1-4 show the tracks of these hurricanes and tropical storms, respectively. Table 1-1 lists the names, date of occurrence, and meteorological characteristics of each hurricane shown.

1.5 THE SAFFIR/SIMPSON SCALE

The Saffir/Simpson Hurricane Scale, which has been adopted by the National Hurricane Center, categorizes hurricanes based upon their intensity, and relates this intensity to damage potential. The Scale uses the sustained surface winds (1 minute average) near the center of the system to classify hurricanes into one of five categories. A complete version of the scale is provided below.

CATEGORY 1: Winds of 74 to 95 miles per hour. Damage primarily to shrubbery, trees, foliage, and unanchored mobile homes. No real wind damage to other structures. Some damage to poorly constructed signs. Storm surge possibly 4 to 5 feet above normal. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.

CATEGORY 2: Winds of 96 to 110 miles per hour. Considerable damage to shrubbery and tree foliage; some trees blown down. Major damage to exposed mobile homes. Extensive damage to poorly constructed signs. Some damage to roofing materials of buildings; some window and door damage. No major wind damage to buildings. Storm surge possibly 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland cut by rising water 2 to 4 hours before arrival of hurricane center. Considerable damage to piers. Marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation of some shoreline residences and low-lying inland areas required.

CATEGORY 3: Winds of 111 to 130 miles per hour. Foliage torn from trees; large trees blown down. Practically all poorly constructed signs blown down. Some damage to roofing materials of buildings; some window and door damage. Some structural damage to small buildings. Mobile homes destroyed. Storm surge possibly 9 to 12 feet above normal. Serious flooding at coast and many smaller structures near coast destroyed; larger structures near coast damaged by battering waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives.

CATEGORY 4: Winds of 131 to 155 miles per hour. Shrubs and trees blown down; all signs down. Extensive damage to roofing materials, windows and doors. Complete failure of roofs on may small residences. Complete destruction of mobile homes. Storm surge possibly 13 to 18 feet above normal. Major damage to lower floors of structures near shore due to

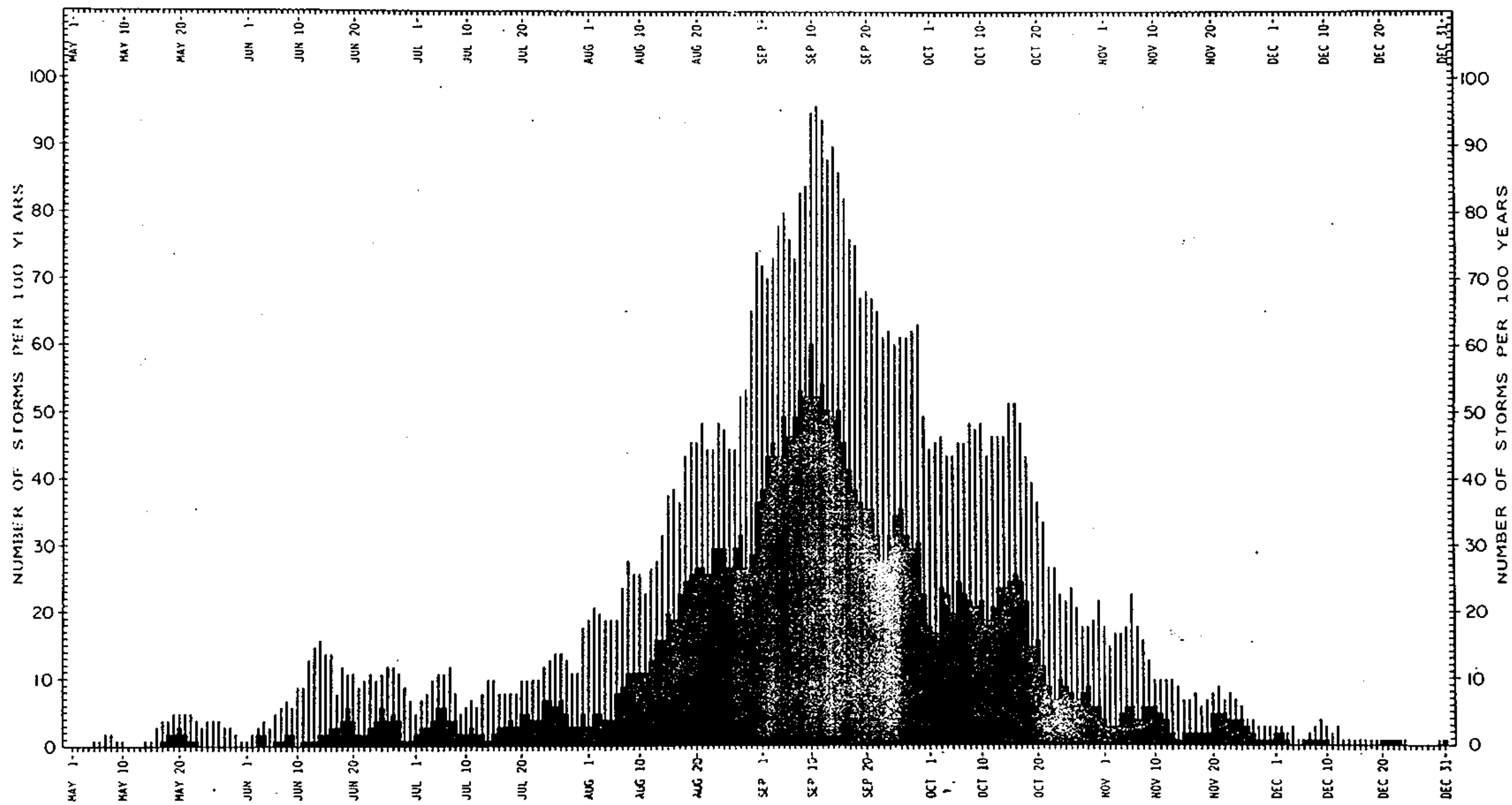


Figure 1-2. Intra-seasonal variations in the 100-year frequency of tropical cyclone occurrence. Lowerbar is for hurricanes and upper bar is for hurricanes and tropical storms combined. Summary is based on period of record, 1886-1986. Source: NOAA

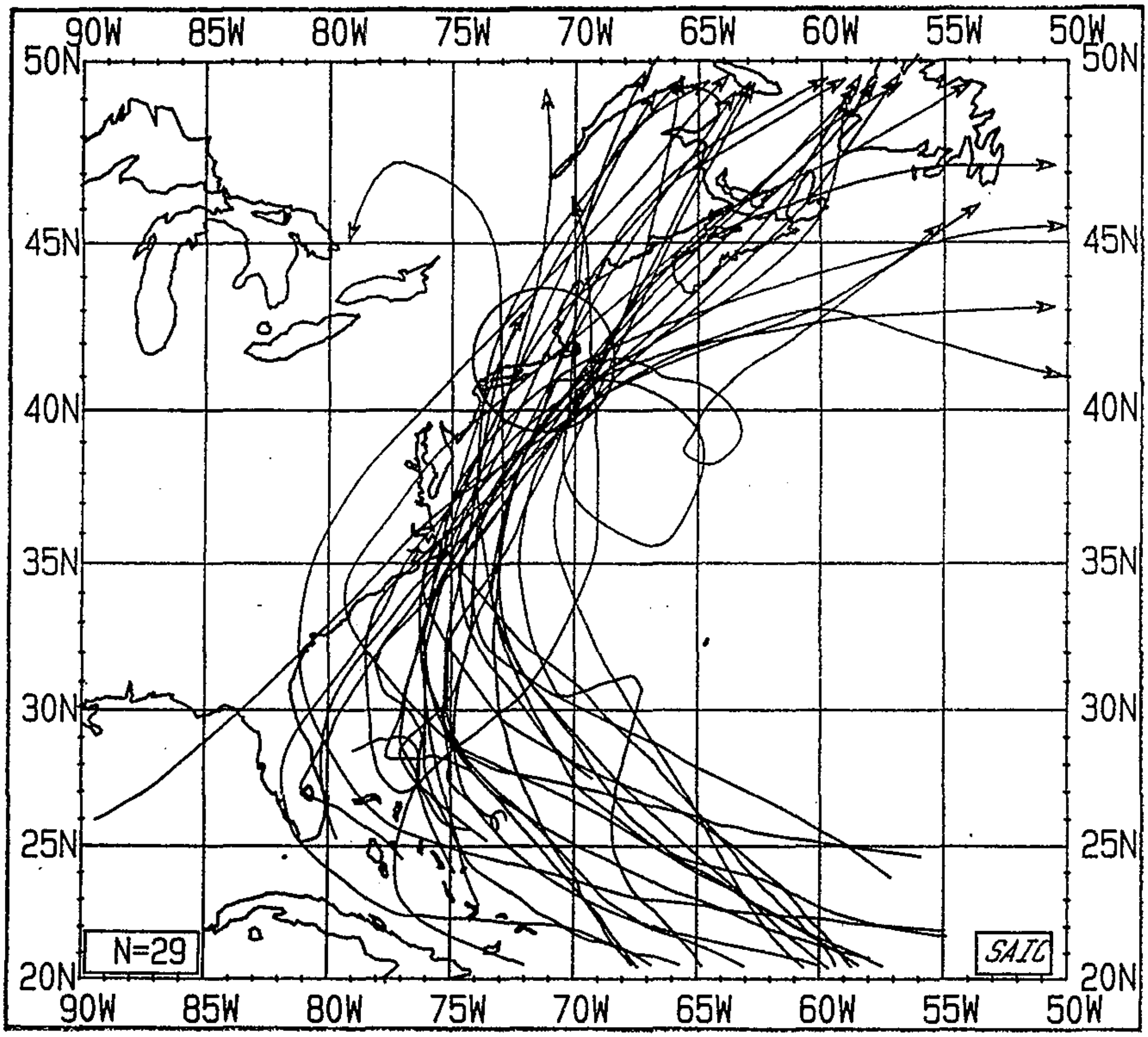


Figure 1-3. Hurricanes passing within 150 statute miles of Newport, Rhode Island from 1886-1993. Source: National Hurricane Center.

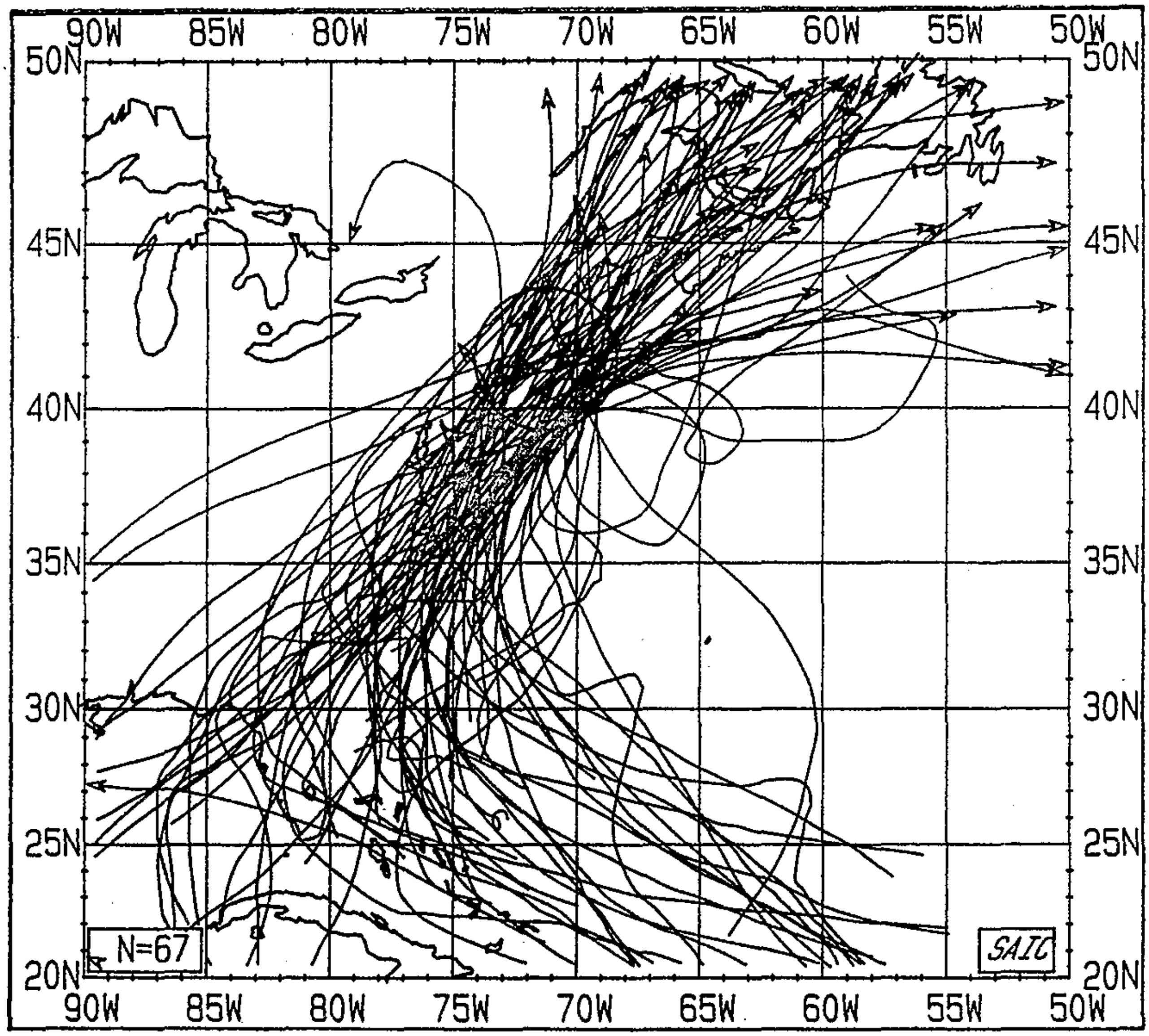


Figure 1-4. Hurricanes and Tropical Storms passing within 150 statute miles of Newport, Rhode Island from 1886-1993. Source: National Hurricane Center.

TABLE 1-1
HURRICANES WITHIN 150 MILES OF
NEWPORT, RHODE ISLAND 1886-1993

		AT CLOSEST POINT OF APPROACH		
DATE OF STORM	STORM NAME	MAXIMUM WIND (MPH)	RANGE (MILES)	FORWARD SPEED (MPH)
1888 NOV 27	Unnamed	98	100	11
1891 OCT 14	Unnamed	98	84	15
1893 JUN 18	Unnamed	87	129	15
1893 AUG 24	Unnamed	90	107	25
1893 AUG 29	Unnamed	72	113	37
1896 SEP 10	Unnamed	104	99	10
1904 SEP 15	Unnamed	75	11	52
1908 AUG 1	Unnamed	98	132	20
1916 JUL 21	Unnamed	84	29	18
1924 AUG 26	Unnamed	104	82	41
1927 AUG 24	Unnamed	104	83	48
1933 SEP 17	Unnamed	79	106	29
1936 SEP 19	Unnamed	92	48	32
1938 SEP 21	Unnamed	90	92	51
1940 SEP 2	Unnamed	80	107	26
1944 SEP 15	Unnamed	77	32	29
1950 SEP 12	Dog	75	133	21
1953 AUG 15	Barbara	86	90	23
1953 SEP 7	Carol	79	130	9
1954 AUG 31	Carol	92	54	35
1954 SEP 11	Edna	92	33	46
1958 AUG 29	Daisy	115	104	28
1960 SEP 12	Donna	95	44	39
1961 SEP 21	Ester	122	51	6
1962 AUG 29	Alma	95	98	14
1969 SEP 9	Gerda	124	114	48
1976 AUG 10	Belle	55	84	20
1985 SEP 27	Gloria	86	82	45
1991 AUG 19	Bob	98	9	32

flooding and battering by waves and floating debris. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives. Major erosion of beaches.

CATEGORY 5: Winds greater than 155 miles per hour. Shrubs and trees blown down; considerable damage to roofs of buildings; all signs down. Very severe and extensive damage to windows and doors. Complete failure of roofs on many residences and industrial buildings. Extensive shattering of glass in windows and doors. Some complete building failures. Small buildings overturned or blown away. Complete destruction of mobile homes. Storm surge possibly greater than 18 feet above normal. Major damage to lower floors of all structures less than 15 feet above sea level. Low-lying escape routes inland cut by rising water 3 to 5 hours before hurricane center arrives.

The National Hurricane Center has added a range of central barometric pressures associated with each category of hurricane described by the Saffir/Simpson scale. A condensed version of this scale with the inclusion of barometric pressure ranges by category is shown in Table 1-2.

TABLE 1-2
SAFFIR/SIMPSON HURRICANE SCALE WITH CENTRAL BAROMETRIC PRESSURE RANGES

	CENTRAL PRESSURE		WIND SPEED		SURGE	DAMAGE
CATEGORY	MILLIBARS	INCHES	MPH	KNOTS	FEET	POTENTIAL
1	>980	>28.9	74-95	64-83	4-5	Minimal
2	965-979	28.5-28.9	96-110	84-96	6-8	Moderate
3	945-964	27.9-28.5	111-130	97-113	9-12	Extensive
4	920-944	27.2-27.9	131-155	114-135	13-18	Extreme
5	<920	<27.2	>155	>135	>18	Catastrophic

The Saffir/Simpson Hurricane Scale assumes an average, uniform coastline for the continental United States and was intended as a general guide for use by public safety officials during hurricane emergencies. It does not reflect the effects of varying localized bathymetry, coastline configuration, astronomical tides, barriers or other factors that may modify surge heights at the local level during a single hurricane event.

1.6 STUDY ANALYSES

The Connecticut Hurricane Evacuation Study 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 major analyses comprising the Connecticut Hurricane Evacuation Study and a description of the methodologies for each are discussed in the following paragraphs.

1.6.1 Hazards Analysis (Chapter Two)

The Hazards Analysis determines the timing and sequence of wind and hurricane surge hazards that can be expected for hurricanes of various categories, tracks, and forward speeds impacting the study area. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model was used to develop the data. The model does not provide information regarding rainfall amounts or interior freshwater flooding, nor does this study attempt to determine freshwater flood elevations associated with hurricanes. It is assumed that local governments will use Flood Insurance Rate Maps prepared in conjunction with the National Flood Insurance Program (NFIP) to plan for evacuation of non-tidal areas. NFIP maps were used to identify, and exclude from consideration, public shelters susceptible to freshwater flooding. Separate wave run-up analyses were preformed to determine additional land areas exposed to wave impacts associated with modeled hurricanes.

1.6.2 Vulnerability Analysis (Chapter Three)

Utilizing the results of the Hazard Analysis, the Vulnerability Analysis identifies land areas within the study area which can potentially become inundated from a range of hurricane intensities. A companion atlas, entitled the Connecticut Hurricane Evacuation Study, Inundation Map Atlas, May 1992, depicts potential inundation areas in each community. With assistance of the communities, evacuation zones corresponding to the inundation areas were delineated and are shown in a second companion atlas, the Connecticut Hurricane Evacuation Study, Evacuation Map Atlas, December 1993. This atlas presents recommended evacuation zones and the names and map locations of public shelters, medical/institutional facilities, and mobile home/trailer park sites. The surge vulnerable population in all communities was estimated to be the total population living within evacuation zones, as determined from the 1990 census.

1.6.3 Behavioral Analysis (Chapter Four)

This analysis determines the expected response of the threatened population to hurricanes in terms of the percentage of the population expected to evacuate, to use public shelters, and to use available vehicles during an evacuation. The methodology employed in the Connecticut Hurricane Evacuation Study to develop the behavioral data consisted of telephone sample surveys of the public, interviews of local officials from communities within the study area, information from other hurricane evacuation studies, and data obtained from post-hurricane assessments. The Connecticut Behavioral Analysis was conducted as part of an analysis conducted for eight Middle Atlantic and New England states in support of hurricane evacuation studies.

1.6.4 Shelter Analysis (Chapter Five)

The Shelter Analysis presents an inventory of existing shelter facilities, capacities of the shelters, vulnerability of shelters to storm surge flooding, and identifies potential shelter demands for each community. Lists of existing shelters and capacities were furnished by the American Red Cross and communities. Lowest floor elevations for those shelters located in or near tidal or riverine inundation areas were determined by the communities through field surveys or "as built" construction drawings. Public shelter demands for two hurricane threat levels were developed using data from the Behavioral Analysis.

1.6.5 Transportation Analysis (Chapter Six)

Results from the previously explained analyses were used in the Transportation Analysis to estimate the total time it would take to clear traffic from roadways after dissemination of a regional level evacuation advisory. NETVAC2 evacuation software was used to develop a mathematical model representative of the Connecticut coastal roadway system. Hurricane evacuation simulations were run to forecast how competition for roadway space by evacuating traffic and traffic from other trip purposes (i.e., people leaving work early, or people making last minute shopping trips) may impact each other and possibly delay an overall evacuation. Roadway clearance times were calculated for evacuations considering weak and severe hurricane events with variations in initial traffic conditions. The transportation modeling methodology included provisions relating to slow, moderate, and rapid responses by the public to mobilize and leave their homes in an evacuation.

1.6.6 Evacuation Times (Chapter Seven)

The Transportation Analysis develops clearance times for 18 evacuation scenarios based on varying hurricane severity, public response timing, and different initial traffic conditions at the start of evacuations. A range of evacuation scenarios was considered to qualify most of the evacuation situations officials might have to contend with when deciding if, and when, an evacuation should be conducted. To assist in implementing a coordinated state and local evacuation, the rationale for recommending the use of a single clearance time for most evacuation situations is presented. Additionally, an explanation of how dissemination time is used in combination with clearance time to estimate total evacuation time is presented.

1.6.7 Decision Analysis (Chapter Eight)

The Decision Arc Method is a hurricane evacuation decision-making methodology (or tool) that uses evacuation times, in conjunction with National Hurricane Center advisories, to calculate when evacuations should begin in order for them to be completed before the onset of gale force winds. The Decision Analysis presents a step-by-step procedure for using the Decision Arc Method.

1.7 STUDY COORDINATION

A comprehensive coordination program was established for the Connecticut Hurricane Evacuation Study that included the Connecticut Office of Emergency Management, American Red Cross, FEMA, National Weather Service, Corps of Engineers, local chief elected officials and local emergency management directors. Several local level coordination meetings were sponsored by the Connecticut Office of Emergency Management, FEMA, and the Corps of Engineers to assure proper, thorough data gathering; to coordinate the progress of the study; and to provide maximum flexibility in the effort. Coordination meetings allowed product end-users to review and comment on preliminary results as analyses were completed. Draft inundation maps, draft evacuation maps, and preliminary results distributed for review by State and local emergency management officials served as interim products until final products were completed. The information contained in this report, its appendices, and associated atlases replaces all draft information previously released.

1.8 METROPOLITAN NEW YORK HURRICANE TRANSPORTATION STUDY

Concurrent with the Connecticut Study, Hurricane Evacuation Studies have also been developed for New Jersey and New York. In the course of conducting the Transportation Analyses for the three studies, FEMA and the Corps of Engineers also identified segments of the Metropolitan New York City regional transportation infrastructure that may be vulnerable to hurricane surges and/or strong winds before a storm's arrival. During evacuation proceedings, uncoordinated closures of bridges, major routes, subways, railways, etc. could severely disrupt the movements of people from the three States. State emergency management officials expressed concern that the regular, generalized treatment of transportation related issues planned for inclusion in the Technical Data Reports would be insufficient to support regional emergency transportation plans. State officials from New York and New Jersey requested that the Hurricane Studies for their respective states be expanded to provide additional information on which to base regional and local plans for operation of metropolitan area commuter networks during hurricane emergencies. The additional information would be used to plan coordinated bridge, tunnel, rail, and highway closures and alternative routes in the face of a hurricane threat. In response to the States' requests, a Metropolitan New York Hurricane Transportation Study has been initiated. When completed, the Metropolitan New York Hurricane Transportation Study will enhance regional hurricane preparedness planning between the States of Connecticut, New York, and New Jersey.

Chapter Two

HAZARDS ANALYSIS

2.1 PURPOSE

The purpose of the Hazards Analysis is to quantify the surge heights, waves, and wind speeds for various intensities and tracks of hurricanes considered to have a reasonable meteorological probability of occurrence within a particular coastal basin. Potential freshwater flooding from rainfall accompanying hurricanes is also addressed, however, due to the wide variation in amounts and times of occurrence from one storm event to another, rainfall is addressed only in general terms. Officials are encouraged to use the NFIP maps when planning evacuations in non-tidal areas.

The primary objective of the Hazards Analysis is to determine the probable worst-case flooding effects from various intensity hurricanes that could strike the region. The term "worst-case" represents the peak surge height and wind speed which might be experienced for each category of hurricane by varying three critical parameters: landfall point, track direction, and forward speed. It is important to note that maximum storm surge heights were not derived from a single hurricane event. Instead, maximum storm surge, or worst-case storm surge, is defined as the highest rise in still water elevation which can potentially occur for a particular location when all hurricanes with a reasonable likelihood of occurrence are considered. The potential surge tide is maximized by having the surge arrival coincident with the astronomical high tide. Emphasis of worst-case surge heights in this analysis is considered appropriate for the purpose of hurricane evacuation planning, i.e., protection of the potentially vulnerable population.

The principal function of the Hazards Analysis is to develop accurate estimates of potential surge heights. The focus on hurricane surge does not reflect a discounting of the dangers of hurricane winds. Wind damages to structures are extremely difficult to predict considering the uncertainties involved in forecasting the track of a hurricane and the resultant wind forces applied to structures at ground level. The National Weather Service and National Hurricane Center issue warnings and advisories which give detailed forecasts on expected sustained wind speeds and peak wind gusts. These forecasts help to prepare officials and the public for wind hazards, but there is little certainty what affects these winds may have on various structures in the region. The Decision Arc Method presented in Chapter Eight, discusses how officials may use the results of this study together with National Hurricane Center advisories for determining when an evacuation must be initiated in order for it to be completed before hazardous winds arrive.

2.2 FORECASTING INACCURACIES

The worst-case approach was used in presenting possible hurricane effects because of the inherent inaccuracies in forecasting the precise track and other meteorological parameters of hurricanes. An analysis of hurricane forecasts issued by the National Hurricane Center suggests that a substantial margin of error exists with each forecast made. From 1982 to 1991, the average error in the official 24-hour hurricane track forecast was 120 statute miles left or right of the forecasted track. The average error in the 12-hour official forecast was 62 statute miles. Forecast errors of this magnitude for example, imply that if a hurricane is forecasted to make landfall at New Haven, Connecticut in 12 hours, and if it in fact makes landfall anywhere between New York City and Westerly, Rhode Island, the error in forecasted landfall location would be no worse than average.

Error analysis results during the same period showed the average error in the official 24-hour wind speed forecast to be 15 mph, and the average error in the 12-hour official forecast to be 10 mph. Hurricane evacuation decision-makers should note that an increase of 10 to 15 mph can raise the intensity of the approaching hurricane one category on the Saffir/Simpson Hurricane Intensity Scale. Therefore, because wind speed is the primary influence of storm surge, an increase in wind speed will also contribute to higher surges.

2.3 STORM SURGE

2.3.1 General

Abnormal high water levels along ocean coasts and interior shorelines are commonly caused by storm events. These higher than expected water levels, known as storm surges, are generally the result of synoptic scale meteorological disturbances. Along the north Atlantic seaboard, extratropical storms such as "northeasters" have produced some of the highest storm surges and resultant damages on record. However, hurricanes have the potential to produce much higher storm surges because of the vast amount of energy released by these storm systems over a relatively short duration. Storm surges can affect a shoreline over distances of more than 100 miles; however, there may be significant spatial variations in the magnitude of the surge due to local bathymetric and topographic features.

Storm surge is defined as the difference between the observed water level and the normal astronomical tide. Astronomical tides represent the periodic rise and fall of the water surface resulting from the gravitational interactions between the Moon, Sun, and Earth. Positive surges occur when the observed water level exceeds the height of the predicted astronomic tide. Negative storm surges (lower than expected water levels) are produced primarily in lakes, semi-enclosed basins, and bays. These negative surges are considered more of a nuisance, such as a temporary hindrance to navigation, than a true natural hazard. It is the positive surge which has the greatest potential for property damage and loss of life.

Figure 2-1 shows a hydrograph taken at New London Harbor which depicts the water levels produced by the passage of hurricane Gloria in September 1985. The peak surge observed at this location was approximately 5.8 feet which means that the ocean's surface was 5.8 feet higher than it would have been under normal tide conditions. Although Gloria did not cause the level of surge and resultant damages that was originally anticipated, the potential for higher surges and damages was possible. Storm tides as much as 10 feet higher at some locations could have been experienced if Gloria had not rapidly dissipated prior to its landfall and if peak surges occurred coincident with high tide.

2.3.2 Generation of Storm Surge

There are a number of factors which contribute to the generation of storm surges but the fundamental forcing mechanism is wind and resultant frictional stress it imposes on the water surface. Winds blowing over a water surface generate horizontal surface currents flowing in the general direction of the wind. These surface currents in turn create subsurface currents which, depending on the intensity and forward speed of the hurricane, may extend from one to several hundred feet below the surface. If these currents are in the onshore direction, the water begins to pile up as it is impeded by the sloping continental shelf, causing a rise in the water surface. Therefore, a wide gently sloping continental shelf is particularly conducive to the formation of large storm surges. The water level will increase shoreward until it reaches a maximum at the shoreline or at some distance inland.

The reduction of atmospheric pressure within the storm system results in another surge-producing phenomenon known as the "inverted barometer" effect. Within the region of low pressure the water level will rise at the approximate rate of 13.2 inches per inch of mercury drop. This can account for a rise of one to two feet near the center of the hurricane. This effect is considered to be a more important factor in the open ocean where these is no depth related restrictions to water flow.

2.3.3 Factors Influencing Storm Surge

The magnitude of storm surge within a coastal basin is governed by both the meteorological parameters of the hurricane and the physical characteristics of the basin. The meteorological aspects include the hurricane's size, measured by the radius of maximum winds; the intensity, measured by sea level pressure and maximum surface wind speeds at the storm center; the path or forward track of the storm; and the storm's forward speed. The radius of maximum winds is measured from the center of the hurricane to the location of the highest wind speeds within the storm. This radius may vary from as little as 4 miles to as much as 50 miles. Due to the counterclockwise rotation of the wind field (in the northern hemisphere only) the highest surge levels are typically located to the right of the hurricane's forward track. This phenomenon has been seen in regions where the shoreline is typical straight, not fragmented by large inlets and bays, and when a hurricane travels generally perpendicular to the shore. For some regions however, regional and local bathymetry can influence surge such that the highest surges in some instances occur to the left of the eye. This is particularly important for Connecticut because during some hurricane scenarios Long Island Sound can have a dominant effect on storm surge such that the greatest surges actually occur far to the left of the eye track. This issue is further complicated by the large tide range differences and variations in the timing of tide cycles in Long Island Sound. The timing of the storm surge arrival is also important because of its potential of occurring coincident with the time of high astronomical tide. More on the affects of regional bathymetry on surges in Connecticut are discussed in later sections.

2.4 STORM SURGE (SLOSH) MODEL

2.4.1 Introduction

Computer models have been developed for specific coastal basins to represent the varying bathymetry and other factors affecting surge heights calculated for a location. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is the latest and most sophisticated mathematical model developed to calculate potential surge heights from hurricanes. It calculates storm surge heights for the open ocean and coastal regions affected

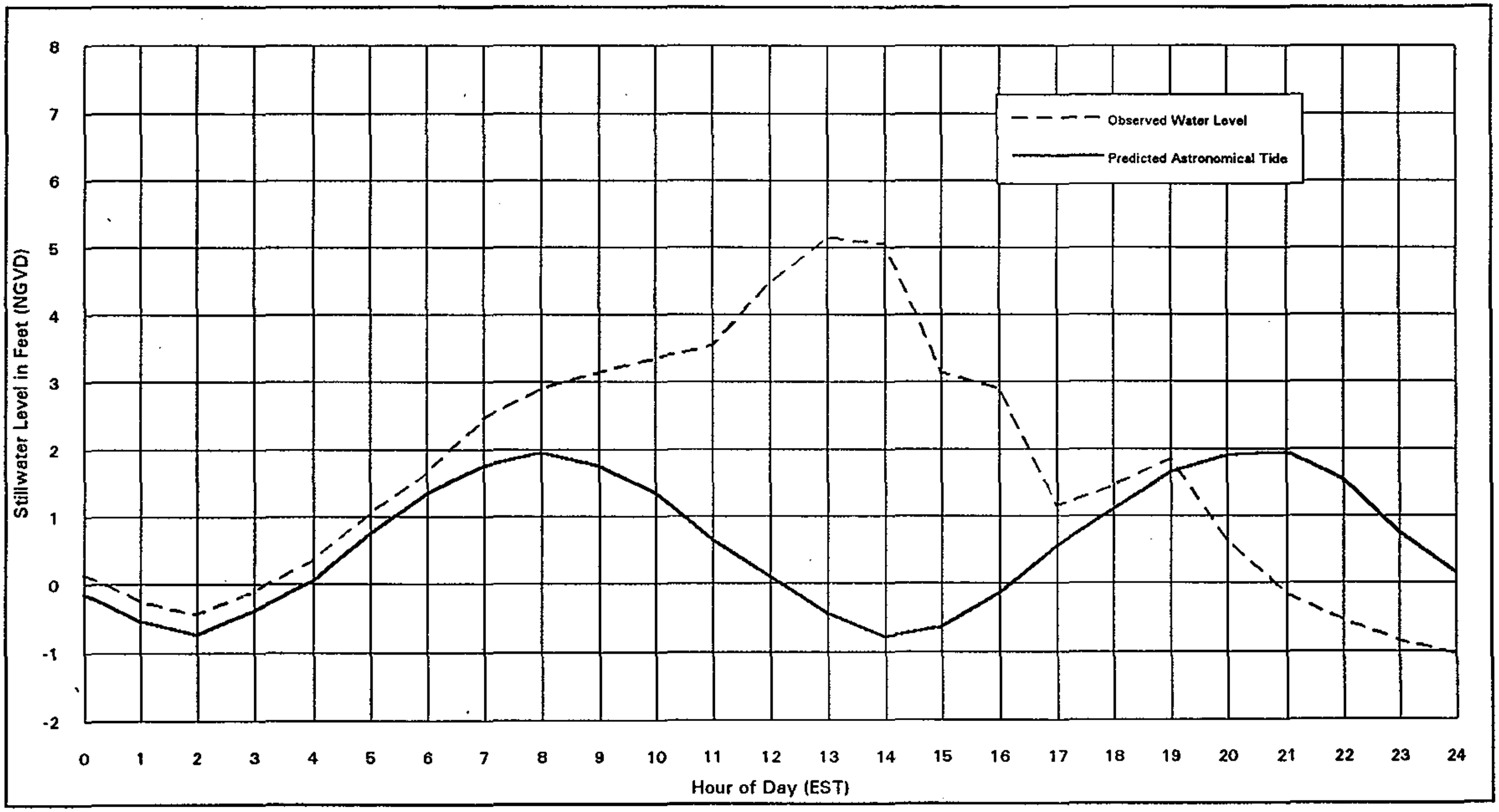


Figure 2-1. Hydrograph at New London Harbor during the passage of Hurricane Gloria on September 27, 1985.

by a given hurricane. The model also calculates surge heights for bays, estuaries, coastal rivers, and adjacent upland areas susceptible to inundation from the storm surge. Significant man-made or natural barriers (i.e., dunes, islands, etc.) are represented by the model and their effects are simulated in the calculation of surge heights.

The SLOSH model was first developed by the National Weather Service and used by the National Hurricane Center for real-time forecasting of surges from hurricanes within selected Gulf of Mexico and Atlantic coastal basins. The National Hurricane Center's success in surge forecasting has lead to utilization of the Model for hurricane preparedness planning and modeling results have become the foundation for the Hurricane Evacuation Studies.

As applied in this study, the SLOSH model was utilized to simulate the effects of hypothetical hurricanes which could realistically impact Connecticut in the future, and to simulate actual hurricanes which have affected the State in the past. Connecticut's SLOSH model coverage was provided through the development of the Long Island Sound SLOSH Basin shown in Figure 2-2. As illustrated in Figure 2-2, the Long Island Sound SLOSH Basin coverage extends from approximately north of Virginia to Maine and includes the entire Long Island Sound as well as open ocean several miles from the south and east of Connecticut. More detailed information about the Long Island Sound Basin, application of the model to the Basin, and a summary of calculated surge heights for the region are presented in Appendix A, A Storm Surge Atlas for Long Island Sound SLOSH model. The information in Appendix A was prepared by the National Hurricane Center specifically in support of this study.

The initial step in applying the SLOSH model to a particular region is to incorporate the three-dimensional geometry of the features which will influence surge. This includes specifying the depth structure or bathymetry of the continental shelf, nearshore zone, estuaries, river mouths, and adjacent bodies of water, as well as the elevations of the coastal intertidal and upland areas.

In the SLOSH model, a storm event is represented by the following types of data:

a. Latitude and longitude of storm positions at six-hour intervals for a 72 hour period.

b. The atmospheric pressure at sea level in the eye of the hurricane.

c. The storm size measured as the radius of maximum wind.

The storm's wind speeds are not directly input by the modeler; instead, the SLOSH model calculates a radial surface wind profile from the meteorological parameters outlined above.

An additional parameter specified by the modeler is the initial water surface elevation for all "water" areas of the basin. This value is referenced to the vertical datum used to specify land elevations (and water depths) within the basin. The vertical datum used in the Long Island Sound Basin is the National Geodetic Vertical Datum (NGVD), formerly known as mean sea level of 1929. The initial water surface elevation for the Long Island Sound Basin was modeled one foot higher than NGVD. The one foot increase accounts for water surface anomalies which usually occur while hurricanes are more than 24 hours away from the area of interest; and also includes an adjustment made for sea level rise since 1929.

Astronomical tide height fluctuations are not directly input for a given storm simulation. Instead, the SLOSH model is run with an assumed uniform starting water surface elevation, and any subsequent deviation from this elevation is attributable to the effects of the storm. Once results are obtained, tide heights are added to calculated surge heights to determine storm tide elevations at all locations. This topic is addressed more fully in Section 2.5.3, Astronomical Tide Height Effects.

2.4.2 Model Structure

Figure 2-2 shows the telescoping polar coordinate grid system used in conjunction with a finite difference scheme by the SLOSH model for mathematically estimating surges in the Long Island Sound Basin. This particular grid configuration has a number of advantages over a rectilinear grid. With a telescoping polar grid the area of greatest interest, which in this study is the coastal zone susceptible to hurricane surge inundation, is modeled with the highest resolution. The grid cell size is relatively smaller in Long Island Sound and along Connecticut's coast than the grid cell size in the deep, open water of the Atlantic Ocean. The smaller grid size allows more detailed representation of physical features, such as inlets, rivers, islands, dunes, etc., which can have important effects on the propagation of the storm surge.

Grid sizes range from one square mile at the grid focus and increase to 42 square miles in fringe areas. The reduced number of cells in the offshore area reduces the computing time and expense of each model run required. However, the larger grid cell size in the offshore

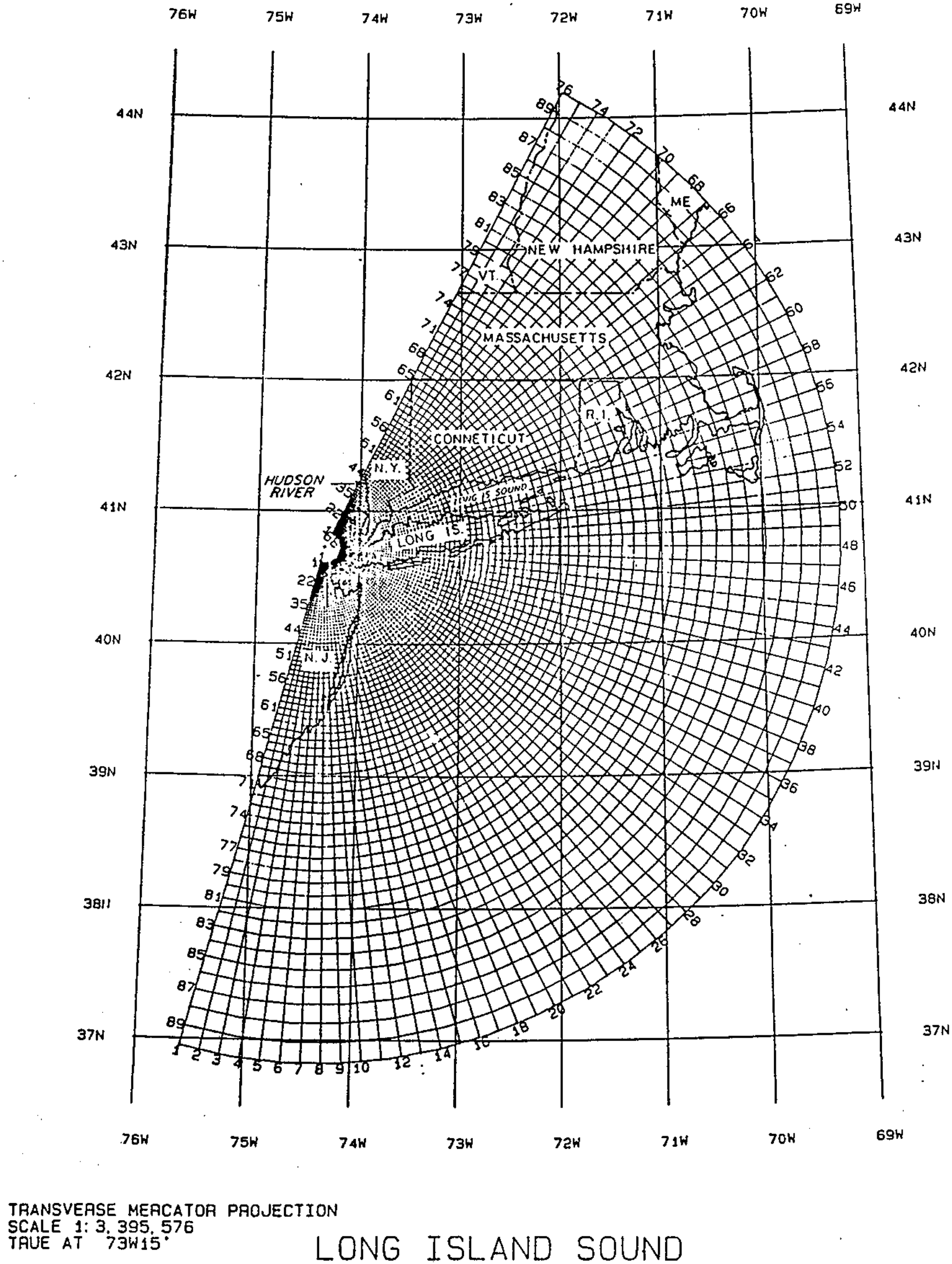


Figure 2-2. Long Island SLOSH Basin

region permits the inclusion of a large geographic area in the model, so that dynamic effects on the storm resulting from discontinuity along the basin's boundaries are diminished.

2.4.3 Model Verification

After a SLOSH model has been constructed for a coastal basin, model verification experiments are conducted. The verification experiments are performed as real-time operational runs in which available meteorological data from historical storms are input in the model. These input data consist solely of observed storm parameters and an initial observed sea surface height occurring approximately 48 hours before the storm landfalls or affects the basin.

The computed surge heights are compared with those measured from historical storms and, if necessary, adjustments are made to universal parameters such as drag and bottom stress coefficients or actual basin data. These adjustments are not made to force agreements between computed and measured surge heights from historical storms but to more accurately represent the basin characteristics or historical storm parameters. In instances where the model gives realistic results in one area of a basin but not in another, closer examination of the basin often reveals inaccuracies in the representation of barrier heights or missing values in bathymetric or topographic charts. Before commencing hurricane simulations, the modeler conducts thorough field investigations and verifies topographic information input into the model agrees with actual coastline topography.

Prior to widespread application of the SLOSH model as a tool used in hurricane evacuation planning, the model underwent verification testing by the National Weather Service. Nine hurricanes with well documented meteorology and storm surge effects were each modeled for at least one of nine discrete basins. The success of the SLOSH model in these verifications justified its present use as a hurricane planning tool. Prior to 1985, only sparse record of complete time history data of hurricane meteorology and storm surge observations existed for the Long Island Sound Basin. The occurrence of Hurricane Gloria in September 1985 offered an opportunity to verify SLOSH model predictions within the basin at several Connecticut locations.

The accuracy of the SLOSH model has been evaluated using approximately 540 surge observations from historical hurricanes. The SLOSH model is programmed to approximate the precise tracks of historical events. The computed surge values are then compared to the corresponding observations to determine how well the model performed relative to the actual storm. The surge observations were obtained from tide gage information, staff records and high water marks. These observations were taken throughout the area affected by the surge, at the periphery and along the inland water bodies. A statistical analysis of the observed data versus the calculated surge values determined an error range of +/- 20 percent of the significant surges with a few observations higher than this percentage.

2.4.4 Model Output

The standard data products from a given SLOSH model run consist of both tabulated and graphical information. The tabulated output data consist of the following:

a. An echo of input meteorological values used to represent the meteorology of the hurricane being modeled. Printed meteorological values include: latitude and longitude of the storm's center, central pressure differential, and storm size (radius of maximum winds) at six hour intervals during its 72 hour track.

b. Assumed starting water surface elevation of the basin.

c. Interpolated meteorological values calculated by the Model every hour during its 72 hour track. Interpolated values are determined from meteorological values input by the modeler for each six hour position. Printed interpolated meteorological values include: latitude and longitude of the storm's center, central pressure differential, radius of maximum winds, track direction, and forward speed.

d. Model computed values of surge height, wind speed, and wind direction at a number of predesignated sites selected by the modeler. These predesignated sites are appropriately termed "time-history" locations for the reason that the Model calculates and prints this data for selected locations every half hour for approximately 48 hours prior to storm arrival and approximately 24 hours after the storm has passed. The Model prints only the maximum surges that occurred over the entire 72 hour period at all other grid cells not specified as time history locations

The graphical data output by the model is a telescoping polar coordinate grid plotted in a rectilinear format showing calculated surges for the basin. Each grid cell is plotted at a uniform size, which in effect distorts the coastline configuration and the configurations of other topographic features. Grid cells near the origin of the polar grid are thus expanded relative to their original size; grid cells near the outer portion of the polar grid are contracted relative to their original size.

The SLOSH model's rectilinear plots provide the maximum water surface elevation attained at each grid cell over the duration of the hurricane simulated. This plot does not represent a "snapshot" of the storm surge at an instant of time. Instead, it represents the highest water level at each grid point during a hurricane irrespective of the actual time of occurrence during that storm. This plot of maximum surge heights is referred to as the "envelope" of maximum surge for a particular storm acting on a specific SLOSH modeled basin.

2.5 COASTAL CONNECTICUT SLOSH MODELING PROCESS

2.5.1 Grid Resolution for Eastern Regions of Study Area

Long Island Sound and the entire Connecticut shoreline is encompassed by the Long Island Sound Basin. However, because grid cell sizes at Connecticut's eastern shore are larger (providing less resolution) than typically used to model shore areas of interest, results from the adjacent Narragansett Bay/Buzzard's Bay SLOSH Basin also providing coverage to this region were studied. The primary area covered by the Narragansett Bay/Buzzard's Bay SLOSH Basin includes all of Rhode Island's shoreline and much of southeastern Massachusetts. This Basin does, however, extend into Long Island Sound with grid cell resolution finer than that offered by the Long Island Sound SLOSH Basin in eastern Connecticut. Results compared from each basin were found to be consistent. Therefore, the lower grid resolution in eastern portions of the Long Island Sound Basin does not have a negative effect on the SLOSH model's surge forecasting capability in this area.

2.5.2 Simulated Hurricanes

A total of 533 discrete hypothetical hurricanes were modeled. These storms were derived by specifying four influential parameters for each event: the track, direction of travel, forward speed; and hurricane intensity. The National Hurricane Center selected storm parameters based on the region's historical hurricane activity and their assessment of probable storms which could be sustained by the region's meteorological climate. In total, combinations of six storm directions (WNW, NW NNW, N, NNE, NE), four intensities (Categories 1 through 4 on the Saffir/Simpson scale), three forward speeds (20, 40, and 60 mph), and storm tracks at 15-mile intervals were considered. The tracks of all the hurricanes that were modeled are shown in Appendix A.

The National Hurricane Center eliminated from the analysis any hypothetical hurricanes which could not realistically occur in the Long Island Sound SLOSH Basin. Hurricanes exhibiting a strong westerly or strong easterly directional component were modeled with forward speeds of only 20 and 40 mph because it is not practical to assume that storms following these directions will possibly move faster. A strong blocking front in the north is necessary for hurricanes of this area to track in a strong westerly or easterly direction. The presence of such a blocking front precludes the meteorological conditions required for a hurricane to travel at a forward speed greater than 40 mph while following a strong westerly or easterly track direction. Accordingly, fast moving storms of these directions were eliminated from the analysis.

It should be noted that hurricanes of Category 5 on the Saffir/Simpson scale were not modeled because hurricanes of this strength have an extremely low probability of occurring at locations as far north in the North Atlantic cyclone basin as Connecticut. However, emergency management officials must consider that a swiftly moving hurricane of Category 3 or 4 intensity can generate wind speeds considerably higher than minimum speeds required for Category 5 classification. Moreover, because storm surge is mostly generated by wind stresses acting upon the water surface, faster forward speeds contribute to increases in wind stresses, which sometimes are reflected by higher surge levels.

2.5.3 Astronomical Tide Height Effect

The ocean's normal tide fluctuates to its maximum and minimum elevations on a cyclical basis every six hours irrespective of arrival of a hurricane's peak surge. In Connecticut, the tide range (water surface change from low tide to high tide) is approximately 2.5 feet in the east and increases gradually to a maximum range of 7.8 feet in the west. Large tide range fluctuations, like those in western and central Connecticut, are particularly important when assessing worst case storm tides. Tide affects can significantly increase or reduce resulting storm tide height depending upon the point in the tide cycle when peak surge is experienced.

For purposes of determining worst case flood elevations, high tide elevations were arithmetically added to all surges computed by the SLOSH model. Although the starting water surface elevation of the SLOSH model can be adjusted to uniformly model any desired constant tide condition of interest, this parameter was not used in the Long Island Sound Basin because of large variations in tide timing and tide ranges of the Sound.

Adding mean high tide to surge values to determine potential worst case flood elevations is considered appropriate by the nature of this study. Forecast inaccuracies of the National Hurricane Center's advisories make confident determination of when peak surge will arrive and whether it will coincide with high or low tide difficult, if not impossible. The tendency for hurricanes forecasted to track to New England's vicinity and accelerate with northward movement introduces further error in estimating precise landfall times. Even slight changes in a storm's forward speed from those forecasted can influence peak surge occurrence such that is arrives six hours earlier or later than originally expected. Applying the assumption that storm surge will be coincident with high tide eliminates the unexpected circumstance of local officials confronting higher storm tides than predicted for a particular event.

2.5.4 Maximum Envelopes of Water (MEOWS)

For each SLOSH model run, the maximum water level for grid cells affected by the storm are calculated irrespective of when maximum water levels were attained during the simulation. The imaginary surface defined by the maximum water level in each cell is termed the "envelope" of maximum water surface elevations for the storm. The largest individual value of water surface elevation for a particular storm is termed the peak surge for that event. The location of the peak surge is highly dependent upon where the storm center crosses the coastline (the landfall point). In most instances, the peak surge from a hurricane occurs to the right of the storm path and within a few miles of where the radius of maximum winds is located. This is largely due to the counterclockwise rotation of the wind field surrounding the eye of the hurricane (in the northern hemisphere). If a hurricane makes landfall generally perpendicular to the shoreline, on the right of the landfall point the winds blow toward the shoreline; on the left of the landfall point the winds blow away from the shoreline. It is important to note, however, during an actual hurricane, the least accurately predictable parameter is the point of landfall.

Because of the inability to predict exactly where a hurricane will make landfall, and because it may be necessary to begin evacuations of areas susceptible to hurricane surges before confident landfall forecasts can be made, it is necessary to predict the highest surge elevations possible for a given hurricane over a range of potential landfall points. In order to meet this need, the SLOSH model is used to develop a map termed a "MEOW", which is the maximum envelope of water from a number of individual hurricane simulations which differ only in point of landfall of the storm center. In this manner, the maximum water surface elevations for each grid cell are calculated for a particular hurricane scenario, defined by direction, forward speed, and intensity, independent of where the storm actually crosses the coastline.

For the Connecticut Hurricane Evacuation Study, the 533 SLOSH model runs were grouped such that 52 MEOWs remained (see Appendix A). These 52 MEOWs were then analyzed to determine which changes in storm parameters (i.e., intensity, forward speed, direction) resulted in the greatest differences in the values of peak surges for all locations in the modeled basin. The MEOWs were then further grouped according to overall similarities of predicted envelopes of maximum water level over the entire modeled basin. In general, it was determined that the change in storm intensity accounted for the greatest change in potential surge height. Ultimately it was determined that the 52 MEOWs could effectively be grouped into distinct classes of hurricane events defined solely by the storm intensity. This final grouping was performed in order to provide for the development of hurricane scenarios to be used in the evacuation planning process.

2.5.5 Time History Points

Pre-selected grid cells of the basin can be identified to calculate and record critical storm hazard information over the entire simulation period of each hypothetical hurricane modeled. Grid cells identified as such are termed "time history points". These points are typically selected at grid cells which represent water and land areas of significance to State emergency management officials (i.e., the locations of hurricane barriers, high volume commercial shipping harbors, estuaries, thickly settled areas, critical transportation corridors, etc.). Computed surges, wind speeds, and wind directions are recorded at these locations providing a full data set of time history information calculated every half hour beginning 48 hours before, and ending 24 hours after, eye landfall. Information calculated at time history points attempts to replicate the types of data collected at tide gages and weather monitoring stations during actual events.

As many as 120 time history points (20 along the Connecticut shore) were pre-selected before model runs were preformed. Sites were designated by the Connecticut Office of Emergency Management with assistance from the National Hurricane Center and the New England Division, Corps of Engineers, to coincide with critical locations. The locations of Connecticut's time history points are shown in Figure 2-3.

In Figures 2-4 through 2-8 SLOSH model time history data calculated for grid points located at Stamford, New Haven, Old Saybrook, and Groton, Connecticut are plotted versus time for several storms of varying landfall locations, storm directions, forward speeds, and intensities. For storms likely to occur in this region, these plots show which meteorological parameters most influence resulting surge, and at what time relative to landfall, peak surge might theoretically occur at each location. For example purposes, surges were plotted for selected storms only. Surge heights greater or less than those shown in the following plots, or other phenomenon at different time history point locations, may occur due to meteorological variations of the selected storms.

In Figure 2-4a, storm tides at Stamford, Connecticut versus time relative to eye landfall were plotted for the five hurricanes shown in Figure 2-4b. All of the storms are of the same direction, forward speed, and intensity, and they only differ by point of landfall. As shown in Figure 2-4b, hurricane tracks 10 miles and 55 miles to the right of Stamford, Connecticut (tracks RS045 and RS090) generated the greatest surges of 8.8 feet and 8.2 feet, respectively. Only a 0.6 foot difference in surge was computed at Stamford despite a 45 mile variation in landfall point.

The funneling affect imposed on ocean water as it is pushed into Long Island Sound tends to amplify peak surges as they migrate to the western end of Long Island Sound. Water forced into the Sound by the counterclockwise rotating wind field of hurricanes piles water up at the western end because the build up of water has a limited rate of passage through the East River and other outlets. The physical limitations of the East River to move water from Long Island Sound through the Upper Harbor down into the Lower Harbor causes waters funneling into the Sound to inundate shore areas of western Connecticut and Long Island, and New York. In addition, storms which parallel New Jersey's coast force water into the Lower Harbor, through the Narrows between New Jersey and Long Island, up to the Upper Harbor. Surges continue to build up and migrate northward in the East River and again inundate shores along the western part of the Sound as waters from the East River release into the Sound. In effect, communities in this vicinity are exposed to surges progressing from two directions; surges moving up the East River and surges funneling westward in Long Island Sound. This phenomenon gives support to the assumption that in Connecticut the landfall point should not be a primary consideration when assessing potential surge at a particular location.

A similar plot is shown in Figure 2-5a which compares hurricane surges at New Haven due to hurricanes moving at different constant forward speeds. The hurricanes modeled in this example all followed the same north-northeast track with a landfall point at New London, Connecticut (see Figure 2-5b), and all of the hurricanes were of a Category 3 intensity. Forward speeds of 20, 40, and 60 mph were considered. The plotted data indicates that the highest surges in the New Haven region are generated from hurricanes which move at a slower forward speed, assuming all other meteorological characteristics are the same. This phenomenon is unique to many locations in Connecticut, however, the exact opposite condition is typically true at other locations in New England exposed to open ocean.

Slower moving hurricanes travel for a greater length of time over the ocean waters than more swifter moving hurricanes. Thus, wind stress over a long period is maintained, consequently resulting in slightly higher surge levels. The affects of increased wind stress by the combination of forward speed and rotational winds are masked by the reduction in the total time that the wind stress is applied to the water surface.

Surges generated at Old Saybrook, Connecticut from five hurricanes which only differed by track direction were plotted versus hours relative to landfall time in Figure 2-6a. In this comparison, the storms modeled were all of category 3 intensity, had constant forward speeds of 20 mph, and made landfall at New Haven. Figure 2-6b illustrates the storm track direction of each of the five storms analyzed. The highest surges computed were from the westerly moving hurricane. Peak surge at Old Saybrook was found to decrease slightly with each eastward shift in track direction of the storm modeled. As shown, differences in peak surge due to changes in hurricane track direction are generally small, less than 1.5 feet decrease in surge from the extreme westerly to the extreme easterly tracked storms. Similar results were seen in other Connecticut locations where varying hurricane intensity, forward speed, and landfall points were considered. However, in the western part of Long Island Sound, hurricanes with a strong westerly direction produce the largest possible surges and these surges were found to be significantly higher than surges produced from storms of any other track direction.

In Connecticut, hurricane intensity was found to be the most influential meteorological characteristic in the generation of storm surge. Surge tide data plotted in Figure 2-7a for a time history point located at Groton, Connecticut illustrates this point. Each hurricane modeled in this comparison, had a forward speed of 40 mph, made landfall at Guilford, Connecticut, and only varied by hurricane intensity (see Figure 2-7b for storm track modeled). As indicated in Figure 2-7a, peak surge height shows to have a positive linear relationship with hurricane intensity. An increase in one category intensity resulted in approximately 2.5 feet increase in storm surge. Similarly, at other locations within the Long Island Sound Basin, hurricane intensity was also found to be the dominant meteorological factor in storm surge generation.

The previous paragraphs discussed how the regional aspects of a basin can influence the height of peak storm surge at different locations within the basin. Another important effect the Long Island's Sounds geometry can have on storm surge is its influence on the timing at which peak surge arrives at a particular location. Time history points located at Groton, Old Saybrook, New Haven, and Stamford are again used to illustrate this point.

In Figure 2-8a, surge tide was plotted versus hours relative to landfall for time history points at the above mentioned communities for a single hurricane event. The storm considered had a forward speed of 40 mph, was of a Category 3 intensity, and was assumed to make landfall at Guilford, Connecticut at 1400 hours (see Figure 2-8b for actual storm track). At all locations, peak surge occurred at different times after the hurricane passed over Guilford. The time of arrival ranged from one half hour after landfall in Groton, to as high as two and one half hours after landfall in Stamford. Depending upon the storm scenario, the western part of Connecticut can experience a delay in peak surge arrival as much as three hours or more, particularly for storms which track to the east. Emergency managers from these areas must understand that the most dangerous flooding will usually occur after the hurricane has made landfall.

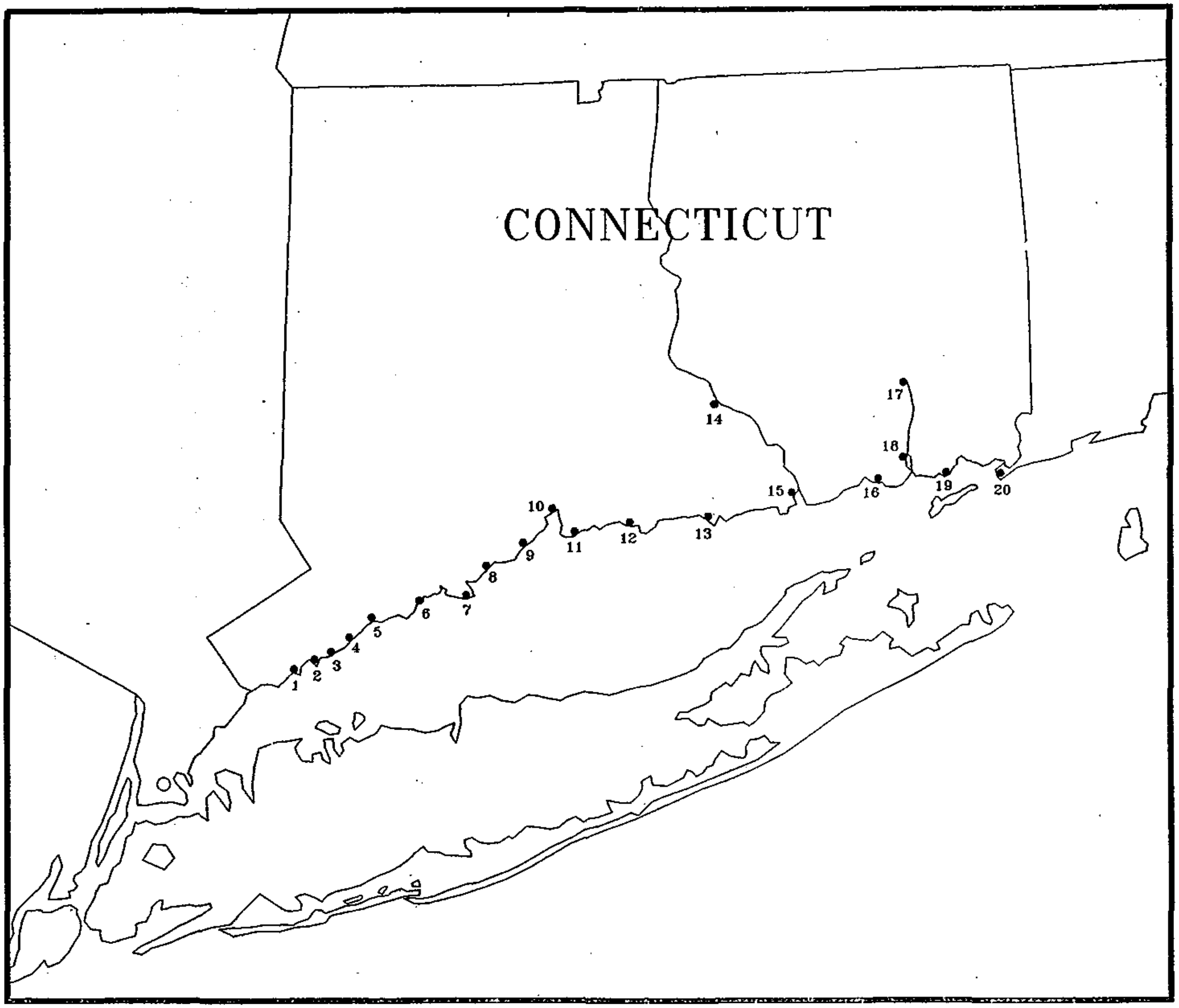
The time history data plotted in Figures 2-4 through 2-8 were developed for illustrative purposes only in an attempt to demonstrate how different meteorological parameters and the Long Island Sound's configuration affect surge. In Figure 2-9, a profile along Connecticut's shore of worst case storm tide is shown for each hurricane intensity category. Elevations depicted for each location represent the potential highest elevation of storm tide at a particular location for each category of storm modeled by the SLOSH model. The elevations shown were computed by adding maximum storm surge to high astronomical tide. Maximum surges for each category were determined by modeling hypothetical hurricanes of worst case combinations of track direction, point of landfall, and forward speed. It is important to note at a single event will not generate worst case storm surge tide at all locations.

Storm tides that could be generated from a Category 4 hurricane traveling on a west-northwest track are not included within the Category 4 delineation in Figure 2-9. National Hurricane Center grouped surges from this storm separately from all other Category 4 hurricanes because this particular event is considered extraordinarily rare and uncharacteristic of this region. SLOSH model results show that this storm can cause surges five feet higher than all other surges at locations in the western end of Long Island Sound. However, despite the increase in surge height, the additional land areas that would be flooded is minimal. This is due to the fact that the uplands in western Connecticut tend to rise steeply which minimizes the land areas that would flood. In any case, the delineation of evacuation zones (discussed in Chapter Three) include any extension to inundation areas due to Category 4 west-northwest hurricanes. In Stamford, Connecticut, however, if the Hurricane Barrier built by the Corps of Engineers is overtopped by this extraordinary event, the extent of the land areas that would flood is significant. Section 2.5.8 discusses the level of protection provided by the Stamford Hurricane Barrier and the assumptions that were made with regards to the Barrier as they pertain to this study.

2.5.6 Wave Effects

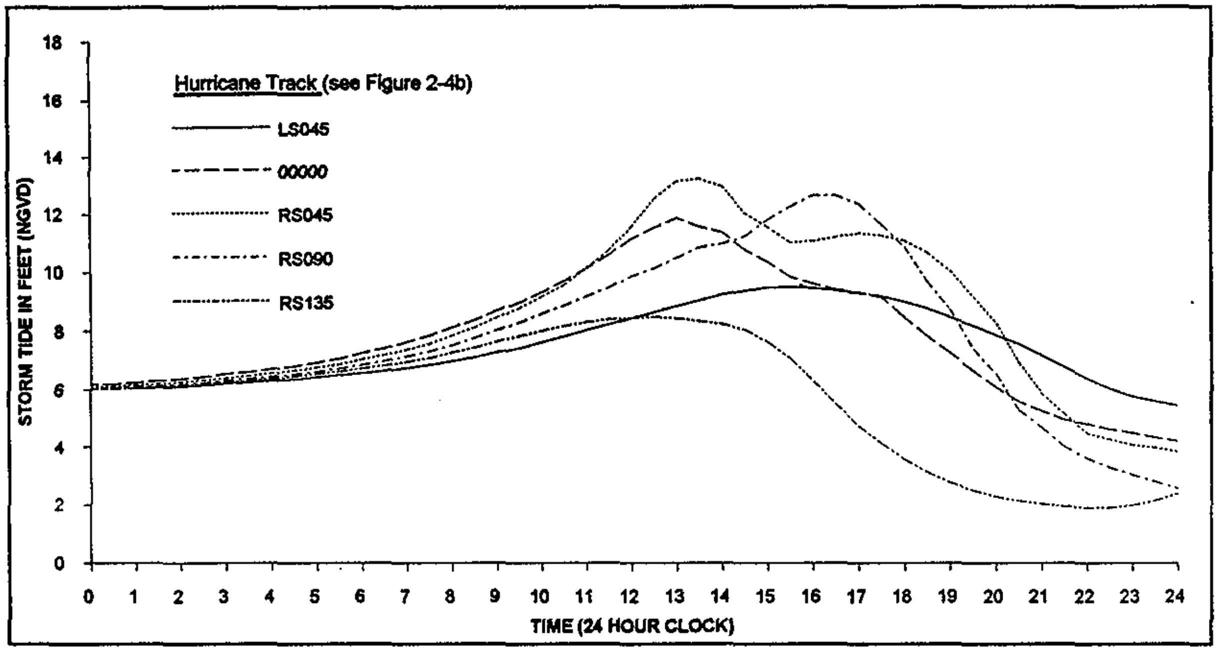
Hurricanes have great potential to generate large waves. Ultimate wave size depends upon the force and duration of the driving winds, depth of water, fetch length, and the affects of natural or man-made obstructions. Driven by a hurricane's winds, breaking waves have the potential to run-up on a shelving beach or overtop vertical structures well above stillwater elevations. Coastal areas need to be evaluated for exposure to wave run-up to determine whether local officials need to evacuate farther inland beyond areas prone to stillwater inundation.

The SLOSH model does not provide data concerning the additional heights of waves generated on top of the stillwater storm surge. For this reason, separate wave height and wave run-up analyses were performed. The calculation of wave height and corresponding wave crest elevations were based on methodologies developed by the National Academy of



MAP KEY	LOCATION
1	Greenwich Cove
2	Shippan Point
3	Stamford
4	Norwalk
5	Westport
6	Bridgeport
7	Stratford
8	Milford
9	West Haven
10	New Haven
11	East Haven
12	Thimble Islands
13	Hammonasset Point
14	Haddam
15	Old Saybrook
16	Millstone Point
17	Norwich
18	New London
19	Groton (Town)
20	Watch Hill Point

Figure 2-3. Time History Point Locations.



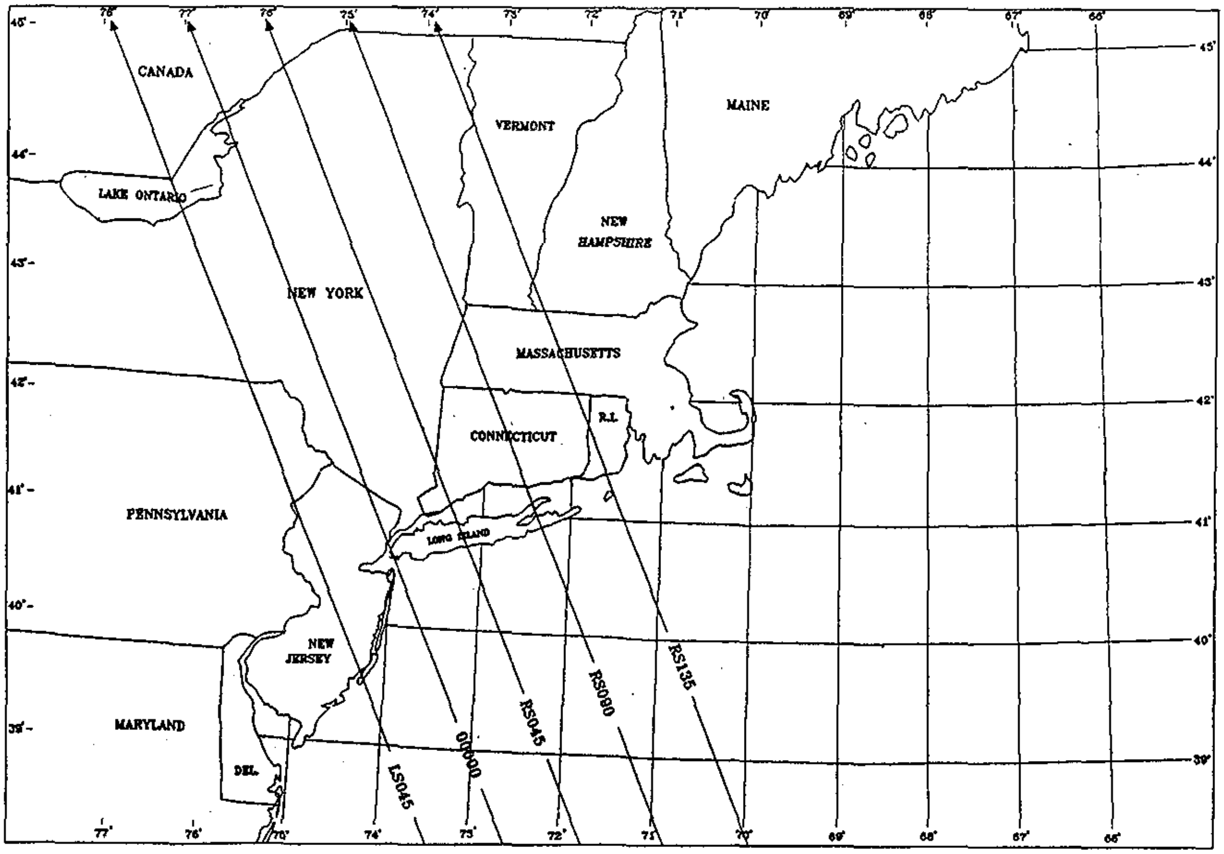
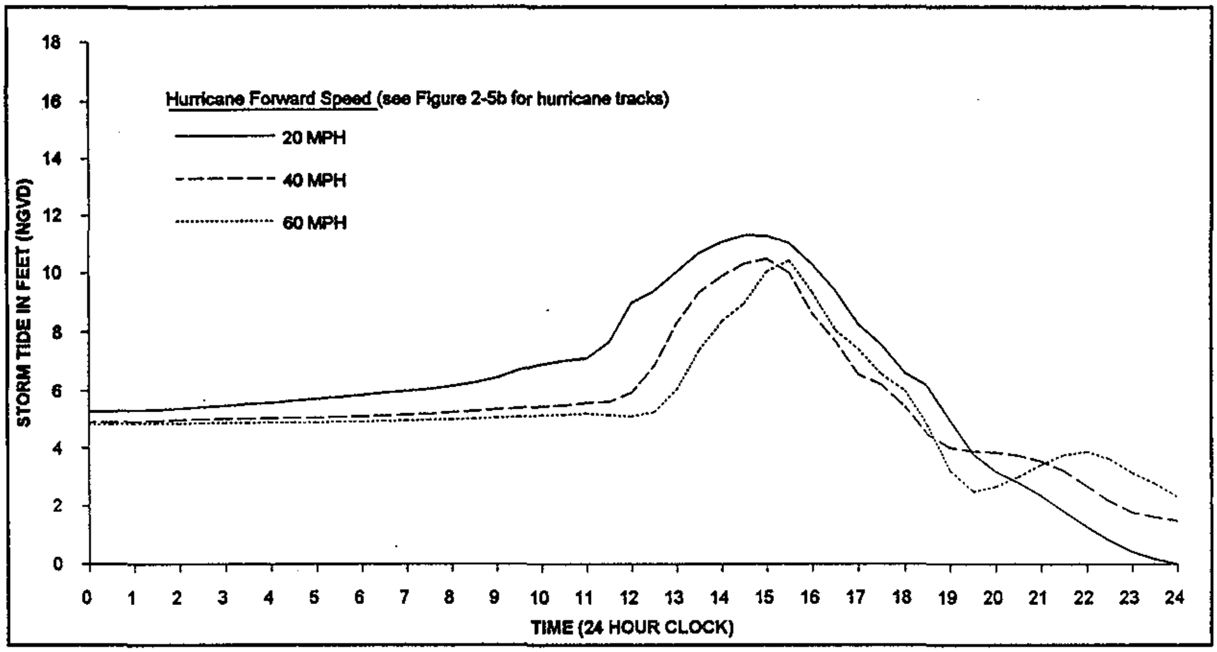


Figure 2-4a (top). Storm tides at Stamford, Connecticut for varying hurricane landfall locations.

Figure 2-4b (bottom). Hurricane tracks for hurricanes modeled in Figure 2-4a.



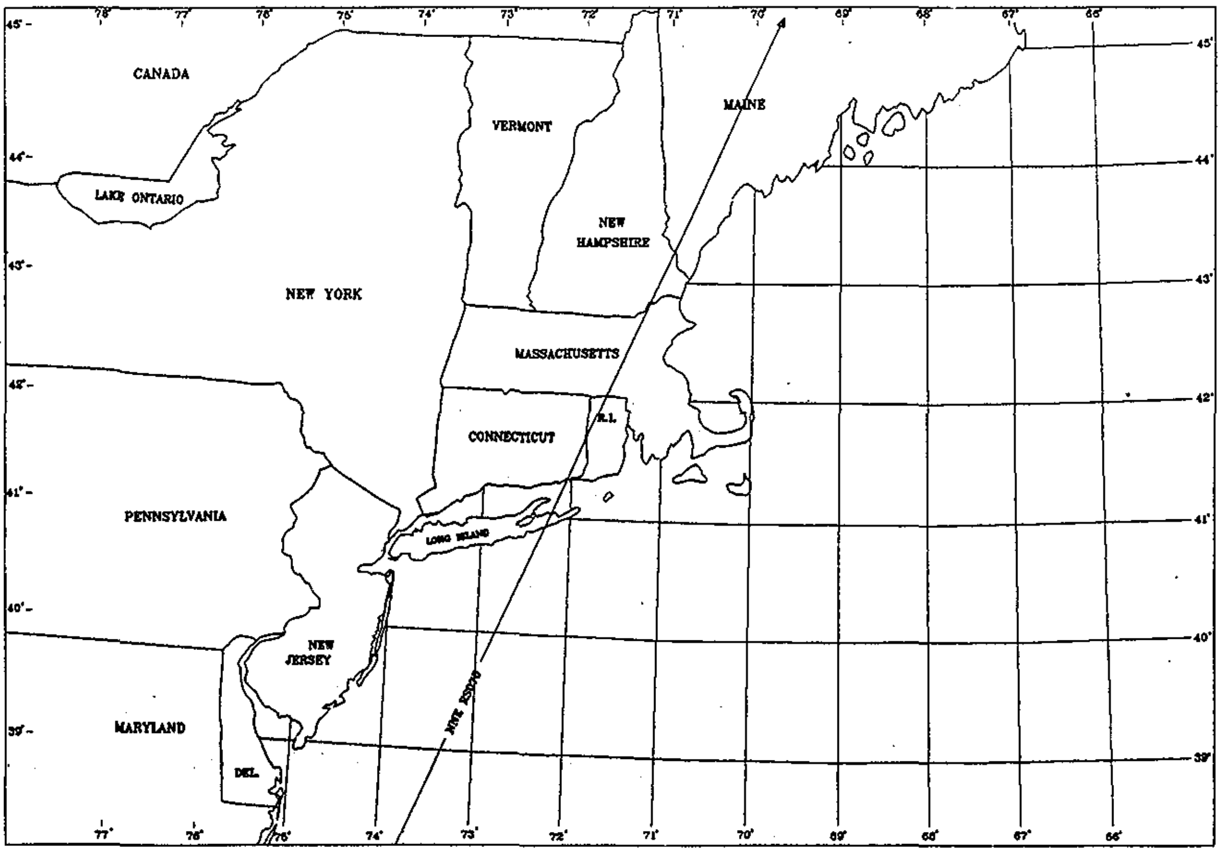
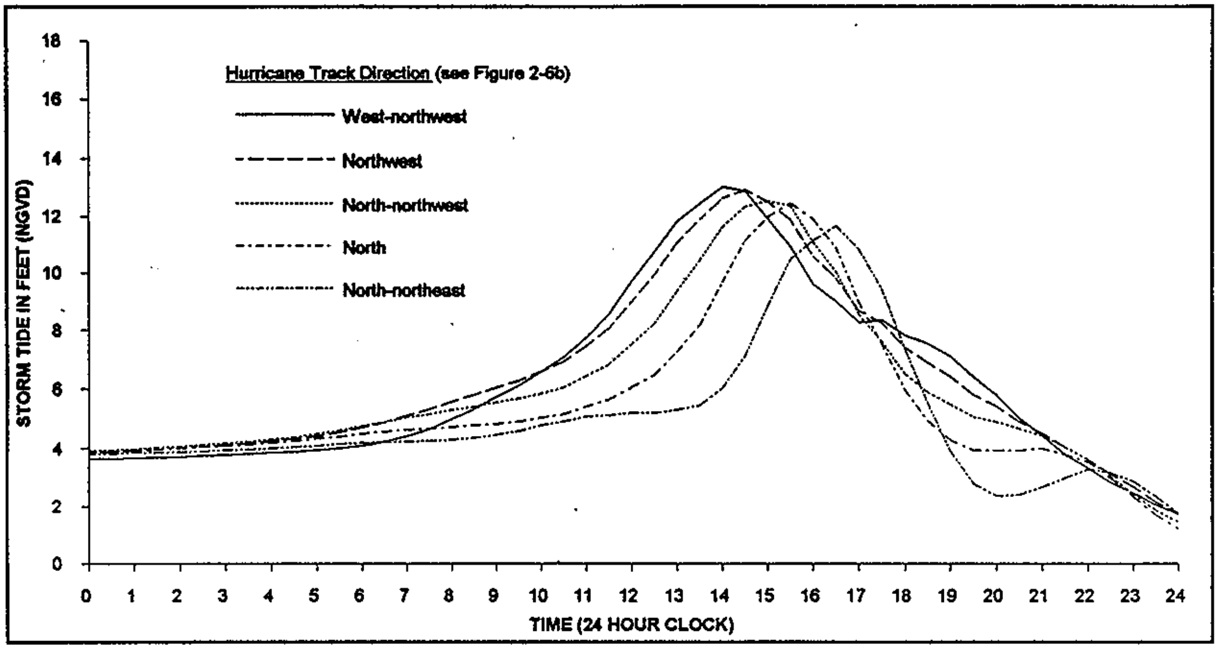


Figure 2-5a (top). Storm Tides at New Haven, Connecticut for varying hurricane forward speeds.

Figure 2-5b (bottom). Hurricane track for hurricanes modeled in Figure 2-5a.



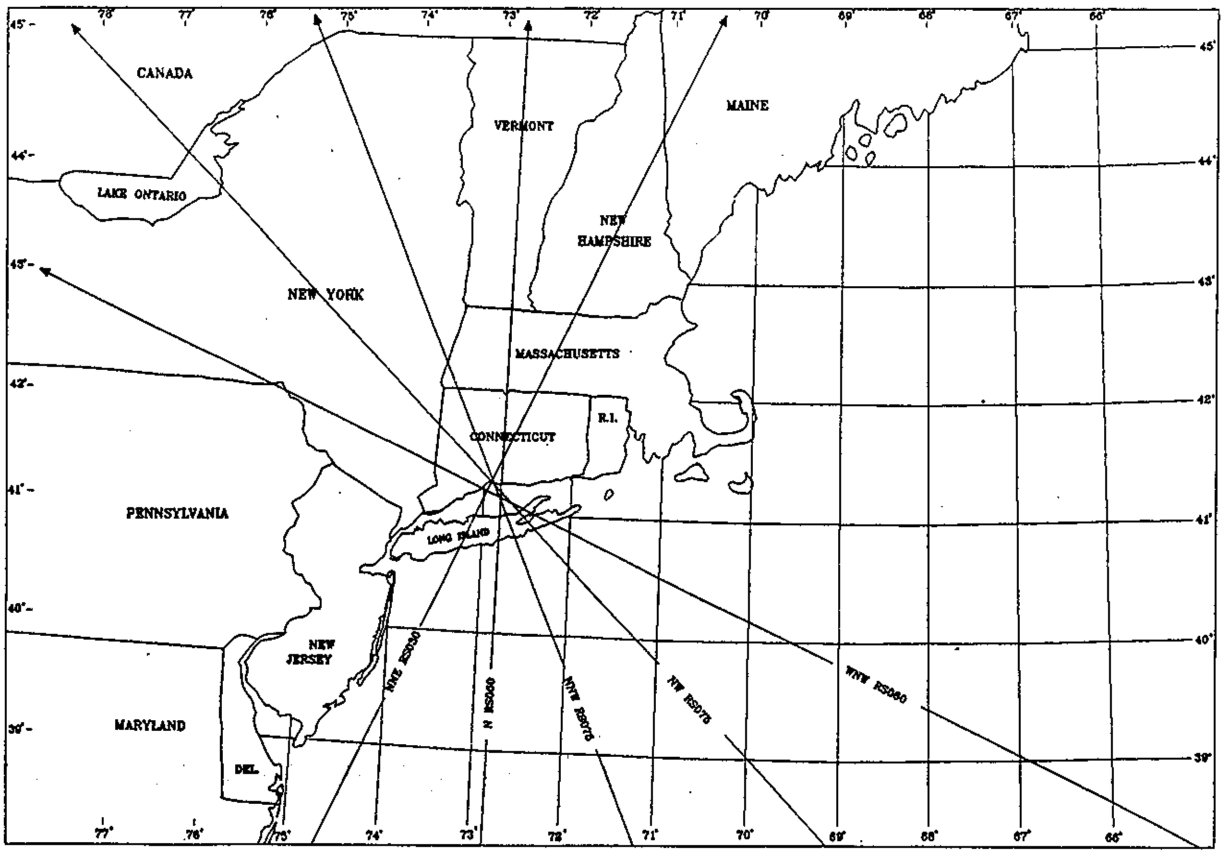
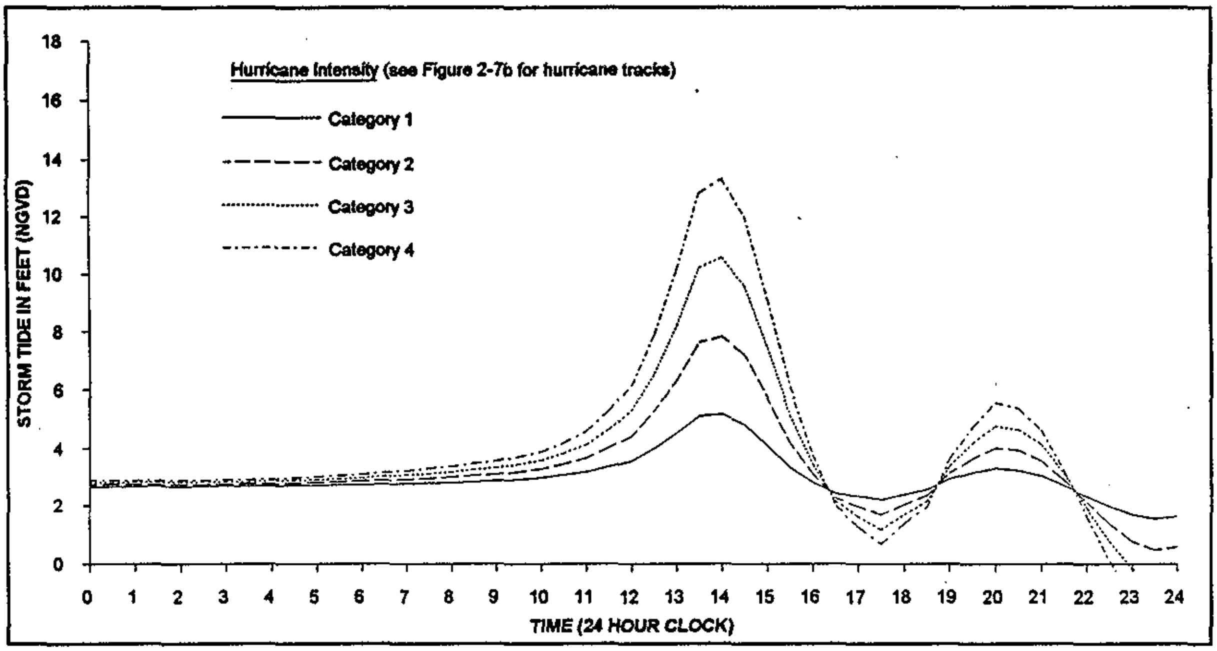


Figure 2-6a (top). Storm Tides at Old Saybrook, Connecticut for varying hurricane track directions.

Figure 2-6b. (bottom). Hurricane tracks for hurricanes modeled in Figure 2-6a.



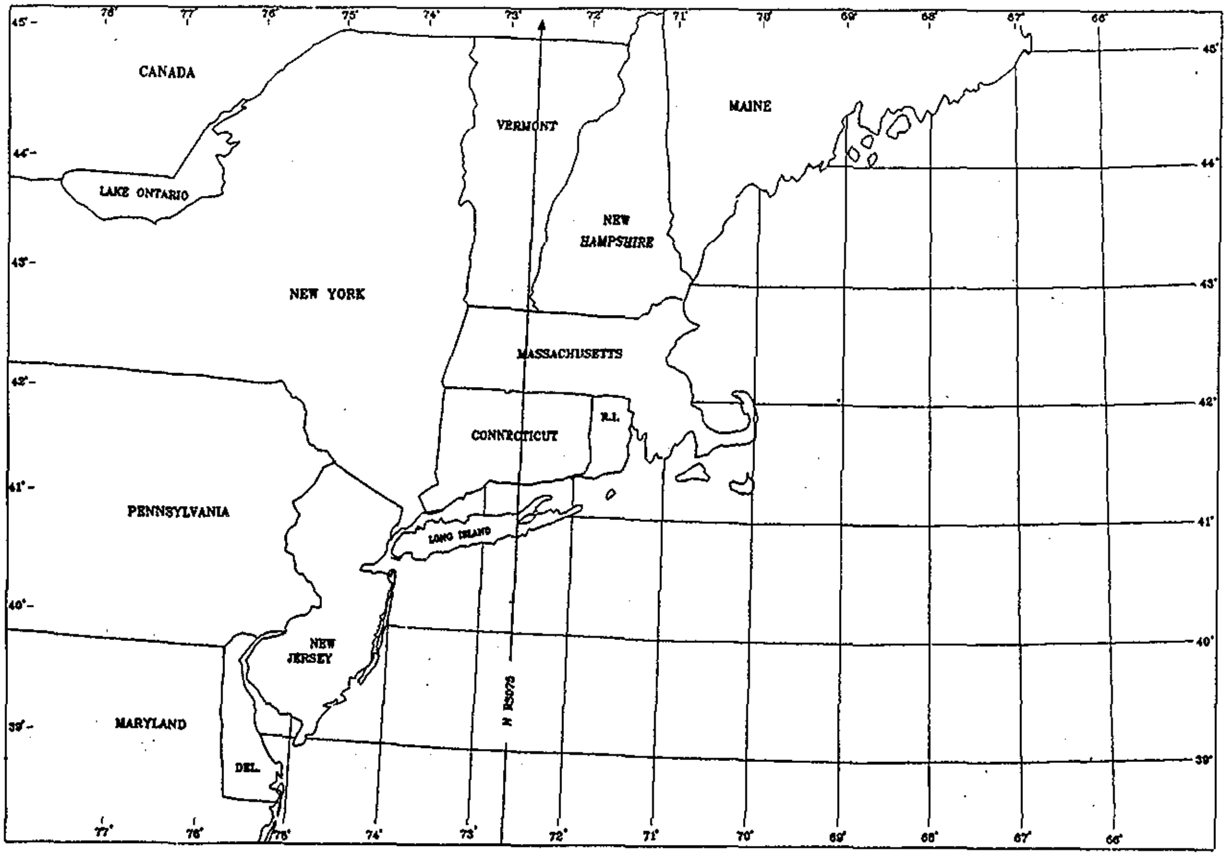
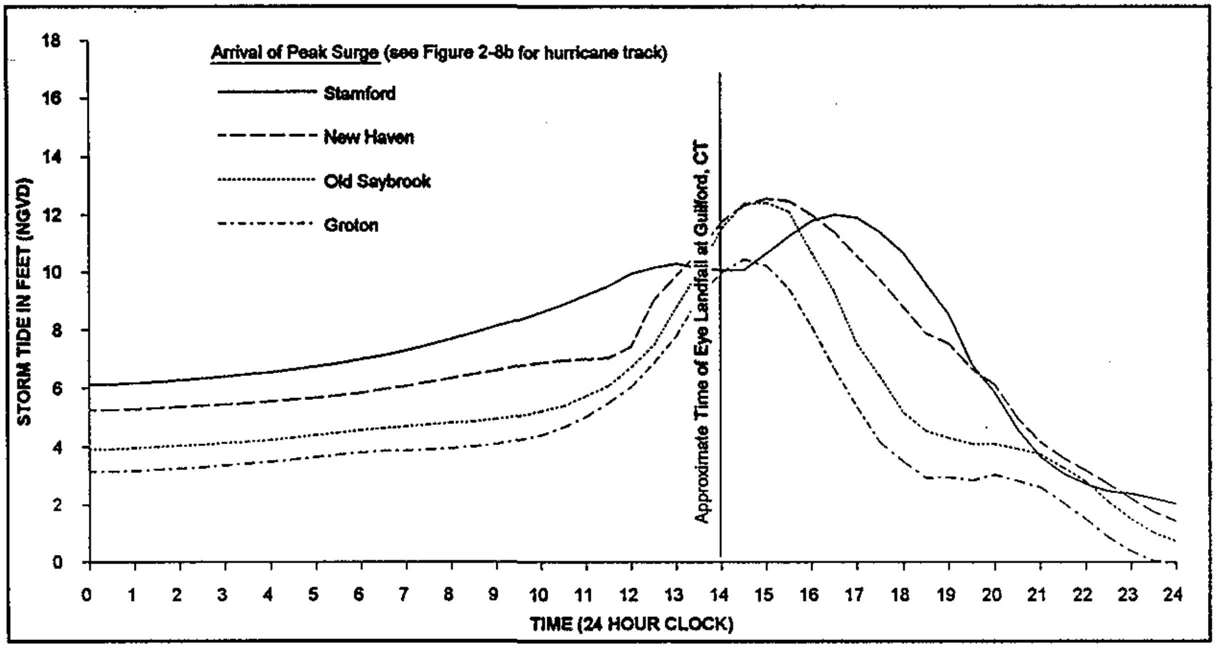


Figure 2-7a (top). Storm tides at Groton, Connecticut for varying hurricane intensity categories.

Figure 2-7b (bottom). Hurricane track for hurricanes modeled in Figure 2-7a.



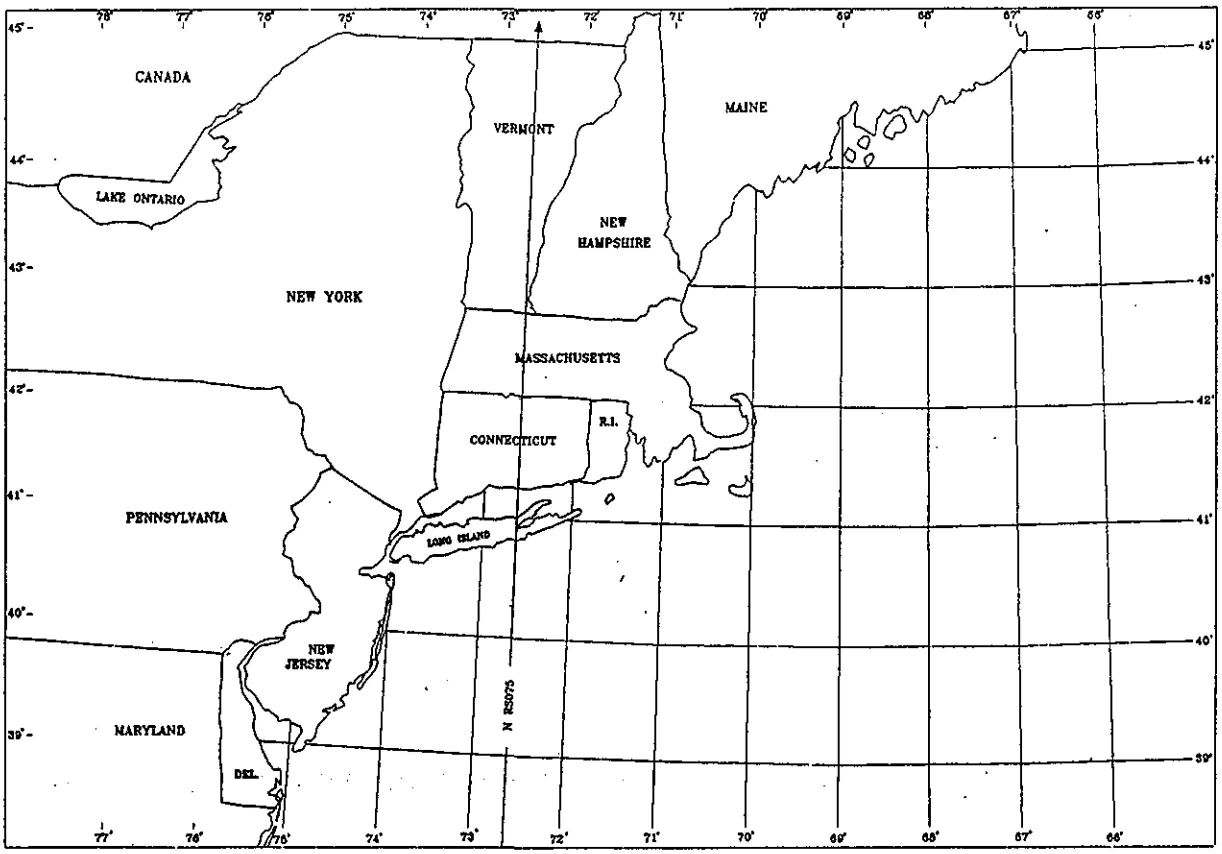


Figure 2-8a (top). Arrival of peak storm tides at various locations along the Connecticut coast.

Figure 2-8b (bottom). Hurricane track for the hurricane modeled in Figure 2-8a.

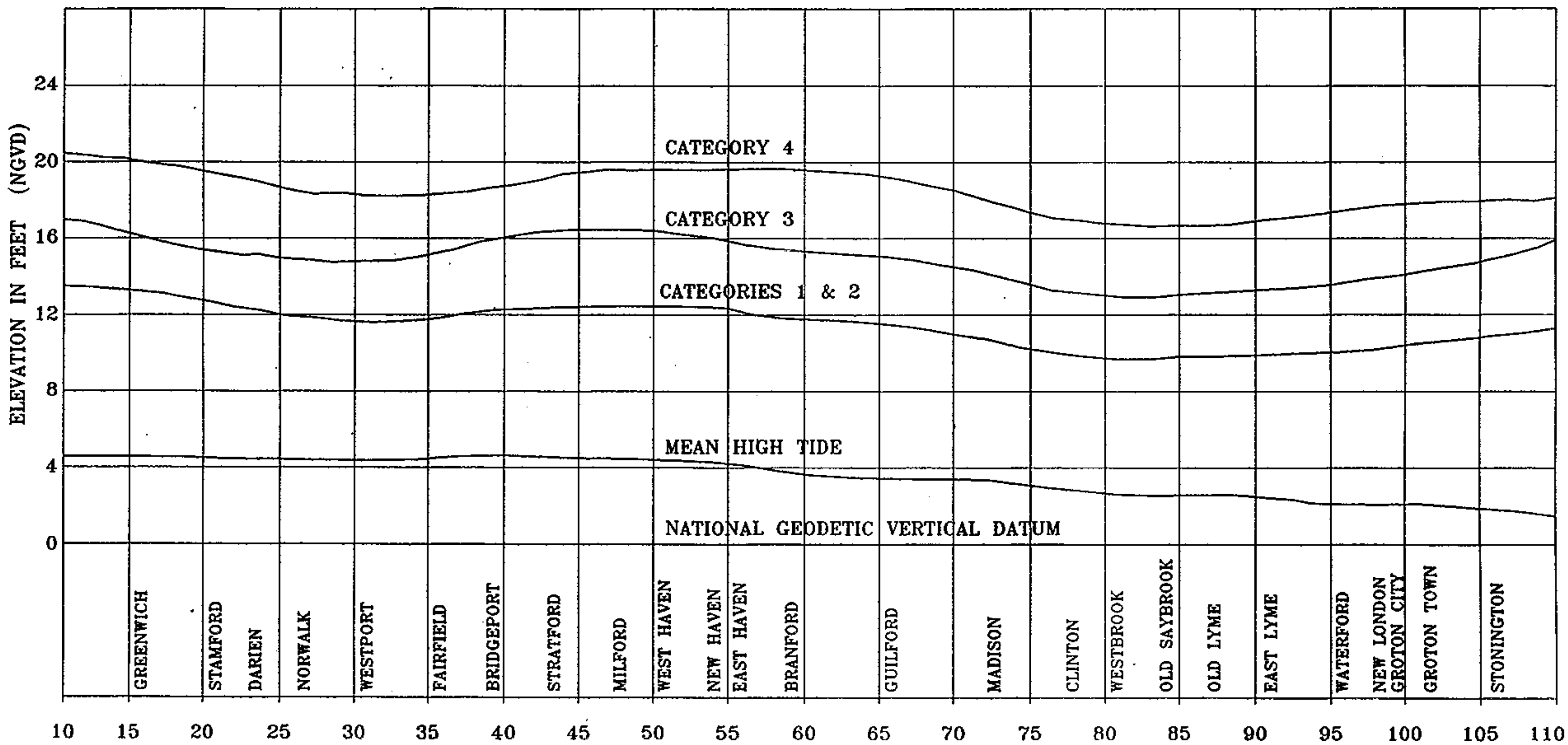


Figure 2-9. Profile of Worst Case Surges Along the Connecticut Coast

Sciences; and the wave run-up analysis followed wave runup procedures developed by Stone & Webster Engineering Corporation.

Estimates of wave height and wave period at various locations were determined for hurricanes of intensity Categories 2, 3, and 4, traveling on north-northwest tracks. A north-northwest direction was selected because storms which travel in this direction pass over Connecticut perpendicular to the shore. In general, storms that track perpendicular to coastlines can be the most threatening in terms of wave generation. Worst case surges generated from hurricanes of intensity Category 1 are only slight less than those for Category 2 hurricanes and therefore were not analyzed.

An infinite number of coastal transects can be drawn and analyzed in wave runup determination. For simplicity, transects were limited to fifteen selected at Stamford, Fairfield, Milford, Westport, and Stonington. These locations appear to be most representative of a majority of the State's bathymetry and coastal topography. It is important to note, however, that wave runup is dependent upon local shore configuration and that even small differences in coastal topography from location to location can alter wave generation.

Results showed that waves do not add significantly to the areas flooded by worst case hurricane surge and can usually be ignored except for locations immediately along the open coastline or the shorelines of very large bays and estuaries where longer fetch lengths and deeper water may exist. Since worst case surge inundation areas extend farther inland beyond open shore areas, waves moving over inundation areas must propagate through areas which have structures, dunes, and vegetation, as well as other natural and man-made obstructions. The presence of these features drastically reduce wave energy. Frictional losses over inundated areas combined with early wave breaking imparted by obstructions account for most of the energy dissipation. For this reason, it is not practical to assume wave heights and associated wave run-up will be sustained as waves move inland over inundation areas. Thus, the additional flooding from wave run-up above worst case hurricane stillwater flood elevations is minimal. Accordingly, wave run-up effects have been omitted from this Study.

2.5.7 River Analyses

The One-Dimensional Storm Tide Model developed for FEMA by the New England Coastal Engineers was used to analyze potential hurricane surge flooding in the tidal reaches of the Connecticut and Housatonic Rivers. Surges calculated by the SLOSH model for these areas were not used because flood plains were not reliably represented by the Model. The SLOSH model's grid resolution does not allow modelers to reflect the gradual river banks of these two rivers. However, the SLOSH Model does enable the steeper banks of the Thames River to be accurately modeled, and therefore the surge values computed for this river were used.

Surges computed at the mouths of the Connecticut and Housatonic Rivers were routed upstream using wind time history information for Category 1 through 4 hurricanes. At the same, steady riverine inflow was allowed to flow downstream. Daily inflows were selected to represent a range of conditions from normal to very high inflows experienced in September 1938 concurrent with the Hurricane of 1938. Results from both of the river analyses showed that in general there is no correlation between hurricane surge levels and coincident river flow. Also, flooding upstream of tidal reaches is more likely to be influenced by riverine runoff than from river backup caused by tidal surge. Consequently, during periods of significant weather it is recommended that upstream communities reference river flood forecasts issued by the National Weather Service's River Forecast Center.

2.5.8 Hurricane Barriers

The Stamford Hurricane Barrier consists of 1,500 feet of concrete flood wall and 3,480 feet of dike on the West Branch, Stamford Harbor; 500 feet of concrete flood wall, 1,320 feet of dike and a 90 foot navigation opening across the East Branch; and 4,430 feet of dike in the Westcott Cove Area. The top elevation is 17.0 feet (NGVD) in the East and West Branches and 18.0 feet (NGVD) in the Westcott Cove Area. The Barrier provides protection to approximately 600 acres of property below elevation 14.8 feet (NGVD). The barrier was designed to protect against a Standard Project Hurricane (SPH) which is defined as "the flood that might be expected from the most severe combination of meteorological and hydrological conditions that are considered reasonably characteristic of the region involved, excluding extraordinarily rare combinations". The SPH wind field was based on historic information from the hurricane that struck New England on September 15, 1944. The wind field from this hurricane was the largest likely according to SPH indices reported by the United States Weather Bureau. This storm was considered to move northward at a forward speed of 40 knots along a path 49 nautical miles west of Montauk Point, Long Island, New York (a track similar to the 1938 hurricane). The forecast surge of 10.4 was added to the level of mean spring high tide (4.4 feet NGVD) to arrive at a design stillwater level of 14.8 feet (NGVD).

The minimum barrier elevation was set at 17.0 feet (NGVD) to account for associated wave overtopping in relation to project pumping capacity.

Examination of SLOSH model results show that for a hurricane headed on a northerly track at 40 mph (similar to the SPH), surges at Stamford are 9.0 to 11.2 feet for Categories 3 and 4 hurricanes, respectively. These values are consistent when compared to the SPH surge of 10.4 feet which falls about midway between surges computed by the SLOSH model for Categories 3 and 4. However, for a storm traveling on a strong westerly track at 20 mph, the SLOSH model estimates surges of 15 to 20 feet for Category 3 and 4 storms, respectively. When added to mean high tide, a 20 foot surge would result in a stillwater level higher than 24 feet (NGVD) overtopping the barrier by more than 7 feet. As previously mentioned, a westerly component to the track tends to significantly increase surge height at the western portion of Long Island Sound. This is primarily due to the funneling geomorphology of the Sound which cause hurricanes with a westerly track direction to pile up significant amounts of water at the western end of the Sound.

Reviewing the tracks of historic hurricanes affecting New England reveals that storms have followed tracks more northerly and northeasterly. Therefore, on the basis of these tracks it is reasonable to conclude that a westerly component of track is extremely unusual and is not probable to occur in this region. Surges which result from these hurricanes are representative of an extraordinarily rare combination of meteorological and hydrological conditions, thereby exceeding the definition of the SPH. The design of the Stamford Hurricane Barrier affords protection against the most severe flooding conditions that are reasonably characteristic of the region.

Nonetheless, the scope and nature of hurricane evacuation studies justifies quantifying the amount of flooding even from those storms with only a remote possibility of occurring. Therefore, the Inundation Map Atlas, on a separate inundation area (see Plate I-2), delineates the land areas behind the barrier that would flood if a severe hurricane with a strong westerly directional component were to occur. The officials and public in Stamford should be assured that the areas behind the Barrier are protected from worst case flooding events realistic for this region, and that the land areas behind the barrier are delineated to identify only those areas that may flood during extraordinarily rare events. For purposes of this study, it is not realistic to assume the areas protected by the Barrier would require evacuation. Therefore, the remaining analyses of this study assume that the barrier will not be overtopped. As the results of this study are implemented, the Corps of Engineers and the City of Stamford, Connecticut should consider the additional impacts these rare events could have and identify special evacuation measures that would be necessary should a storm of this nature be forecasted.

The hurricane barrier at New London, Connecticut consists of 715 feet of earth dike and 800 feet of concrete flood wall situated along Shaw Cove and New London Harbor. The Barrier was originally designed to protect against a 14.0 foot (NGVD) stillwater level based upon the flood levels determined from analysis of the SPH. However, at the request of the City of New London, the Corps of Engineers lowered the design height of the Barrier to a 10.5 feet (NGVD) stillwater design which is roughly equivalent to the 100-year frequency flood and approximately 3.5 feet lower than the SPH stillwater elevation. Worst case surge tides were determined by the SLOSH model to be approximately 10.5, 14.0, and 18.0 feet (NGVD) for Categories 2, 3 and 4 hurricanes, respectively. Consequently, although this project provides protection against more frequently occurring less significant flood events, it may potentially be overtopped by worst case Categories 3 and 4 hurricanes. Therefore, the inundation areas presented in the Inundation Map Atlas show that the hurricane barrier at New London will be overtopped from flooding associated with Categories 3 and 4 hurricanes. As the results of this study are implemented, the Corps of Engineers and the City of New London need to insure that operational procedures for evacuating areas protected by the Barrier are in place in the event that evacuation becomes necessary.

2.5.9 Freshwater Flooding

Amounts and arrival times of rainfall associated with hurricanes are highly unpredictable. For most hurricanes, the heaviest rainfall begins near the time of arrival of sustained gale-force winds; however, excessive rainfall 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. Due to the inability to accurately predict rainfall amounts from hurricanes, no attempt was made to employ sophisticated modeling or analysis in quantifying the effects of rainfall for the Connecticut Hurricane Evacuation Study area. In other analyses of the Study, areas and facilities located within inland stillwater flood hazard areas as identified on FEMA's NFIP maps were assumed to be vulnerable to freshwater flooding under hurricane threats. Emergency managers should consult Flood Insurance Studies published by FEMA for specific potential freshwater flooding information.

Chapter Three

VULNERABILITY ANALYSIS

3.1 PURPOSE

The primary purpose of the vulnerability analysis is to identify the areas, populations, and facilities which are vulnerable to flooding associated with hurricanes. Storm surge data from the hazards analysis were used to map inundation areas; to determine evacuation zones and evacuation scenarios; to quantify the population at risk considering a range of hurricane intensities; to identify major medical/institutional; and to identify mobile home/trailer parks that are potentially vulnerable to hurricane wind damage.

Mobile homes are the only housing type specifically addressed in the analysis of population vulnerable to hurricane winds. These structures are particularly vulnerable to strong winds, and therefore locations and names of mobile home parks or trailer parks have been identified. No attempt was made to identify other housing types that may be vulnerable to wind damage.

3.2 INUNDATION MAP ATLAS

Surge inundation mapping was developed for each study area community using surge tide profiles shown in Figure 2-9. As stated before, the profiles in Figure 2-9 show worst case surge tide elevations representative of the combination of high astronomical tide and the maximum potential maximum storm surge possible at each location. In an effort to graphically display the land areas affected by storm tides, land areas with elevations lower than the storm tide elevations given in Figure 2-9 for a particular category storm were delineated on Connecticut Department of Transportation (DOT) base maps. Inundation areas were delineated using elevation contours from the United States Geological Survey's (USGS) 7.5 minute series quadrangle maps. Inundation maps for all study area communities are contained in a companion atlas entitled the Connecticut Hurricane Evacuation Study, Inundation Map Atlas, May 1992.

3.3 EVACUATION MAP ATLAS

Evacuation zones developed for each community are shown in a second companion atlas entitled the Connecticut Hurricane Evacuation Study, Evacuation Map Atlas, December

1993. The maps of this atlas serve two primary purposes. First, the maps identify land areas (evacuation zones) vulnerable to hurricane surge which should be considered for evacuation prior to a hurricane's landfall. Second, the facility names and map locations of public shelters, institutional/medical facilities, and mobile home/trailer parks are shown. The information is provided to assist local officials in recognizing those locations most at risk from a hurricane, and to identify public shelters, and other facilities of importance that may require special provisions during evacuation proceedings.

Two evacuation scenarios are shown by the evacuation zone maps; areas prone to surge flooding from Category 1&2 hurricanes, and the additional land areas vulnerable during Category 3&4 hurricanes. As the Evacuation Map Atlas was developed, review meetings were held with local officials so as to ensure that local perspectives on the delineation of evacuation zones were included in the Atlas.

The extent of land areas included within evacuation zones is based upon the surge inundation areas depicted in the Inundation Map Atlas. Evacuation zones encompass all land areas shown to be potentially inundated as well as small "pockets" of land that would be isolated by surrounding surge. Evacuation zone boundaries were delineated from the 1990 Census Block boundaries and generally correspond to identifiable geographic features such as streets, railways, and other man-made land features. The use of census boundaries for evacuation zone delineations aided in developing estimates of the total numbers of people potentially at risk from hurricane surge flooding. Additionally, census block boundaries are convenient in that they provided easily distinguishable map features which can assist local officials and the public in identifying those land areas most at risk. Officials using these maps can promptly and definitively convey to the public limits of land areas which should be evacuated.

3.4 VULNERABLE POPULATION

The vulnerable population is comprised of permanent and seasonal persons who reside within the evacuation zones, as well as the residents of mobile homes located elsewhere in communities. Estimates of each community's seasonal populations are based on an assumed seasonal housing occupancy rate applied to the number of seasonal housing units. The same occupancy rates were applied to the seasonal housing statistics reported in the 1990 census to determine the number of seasonal residents temporarily living in evacuation zones. The Connecticut coastal area on average has less than a 5 percent change in total population from one season to the next. However, in the towns of East Lyme, Old Saybrook, Old Lyme, and Westbrook, seasonal residents can range has high as 15 to 35 percent of the permanent population.

Tables 3-1 and 3-2 tabulate the vulnerable population for each community for the Category 1&2 and Category 3&4 hurricane scenarios, respectively. All figures shown are based on block population totals published in the 1990 census.

3.5 MEDICAL/INSTITUTIONAL FACILITIES

Inventories of major medical/institutional facilities were compiled and are listed in Tables 3-3 through 3-6 by county. Facility locations can be determined by cross referencing map key numbers listed in the tables with the locator symbols shown for each community in the Evacuation Map Atlas. Medical/institutional facilities shown to exist within mapped evacuation zones may require special evacuation provisions and perhaps some additional lead time prior to actual evacuations. Medical and institutional facilities located outside of evacuation zones are included in the Tables and shown on the maps as alternative comparable care facilities for evacuated patients. Building names and locations for all facilities in the Tables were furnished by emergency management officials in each community. Unless otherwise noted in Tables 3-3 through 3-6, "None" in the column labeled "SURGE FLOODING" indicates the facility is not located within hurricane surge inundation areas.

TABLE 3-1
VULNERABLE POPULATION CATEGORIES 1 & 2 HURRICANES

Community	Permanent Population	Seasonal Population	Mobile Home Population	Permanent Population Living in Evacuation Zones	Seasonal Population Living in Evacuation Zones	Total Vulnerable Population
Greenwich	58,440	590	10	6,410	50	6,470
Stamford	108,060	350	30	3,990	10	4,030
Darien	18,200	120	10	3,180	50	3,240
Norwalk	78,330	210	90	6,150	20	6,260
Westport	24,410	470	170	3,530	90	3,790
Fairfield	53,420	570	10	8,060	220	8,290
Bridgeport	141,690	170	30	14,810	30	14,870
Stratford	49,390	320	20	10,900	270	11,190
Milford	49,940	840	440	15,800	400	16,640
West Haven	54,020	60	100	8,210	20	8,330
New Haven	130,470	280	20	10,370	30	10,420
East Haven	26,140	150	10	9,740	130	9,880
Branford	27,600	930	660	10,050	630	11,340
Guilford	19,850	790	50	4,910	470	5,430
Madison	15,490	1,560	10	2,820	750	3,580
Clinton	12,770	1,190	580	3,690	770	5,040
Westbrook	5,410	1,390	310	2,490	910	3,710
Old Saybrook	9,550	1,990	10	6,310	1,650	7,970
Old Lyme	6,540	2,310	10	2,120	1,130	3,260
East Lyme	15,340	2,380	10	2,220	780	3,010
Waterford	17,930	350	160	3,000	120	3,280
New London	28,540	290	20	2,610	20	2,650
Groton City	9,530	70	0	470	10	480
Groton Town	35,610	1,210	1,570	2,320	430	4,320
Stonington	16,920	960	440	4,710	530	5,680
TOTALS	1,013,590	19,550	4,770	148,870	9,520	163,160

TABLE 3-2
VULNERABLE POPULATION CATEGORIES 3 & 4 HURRICANES

Community	Permanent Population	Seasonal Population	Mobile Home Population	Permanent Population Living in Evacuation Zones	Seasonal Population Living in Evacuation Zones	Total Vulnerable Population
Greenwich	58,440	590	10	12,370	90	12,470
Stamford	108,060	350	30	4,600	10	4,640
Darien	18,200	120	10	3,730	60	3,800
Norwalk	78,330	210	90	12,130	50	12,270
Westport	24,410	470	170	5,920	150	6,240
Fairfield	53,420	570	10	13,980	330	14,320
Bridgeport	141,690	170	30	43,530	110	43,670
Stratford	49,390	320	20	15,300	280	15,600
Milford	49,940	840	440	24,510	600	25,550
West Haven	54,020	60	100	18,540	30	18,670
New Haven	130,470	280	20	28,610	60	28,690
East Haven	26,140	150	10	13530	150	13,690
Branford	27,600	930	660	16,600	890	18,150
Guilford	19,850	790	50	6,720	600	7,370
Madison	15,490	1,560	10	4,480	1,100	5,590
Clinton	12,770	1,190	580	5,230	980	6,790
Westbrook	5,410	1,390	310	2,870	1,060	4,240
Old Saybrook	9,550	1,990	10	7,590	2,040	9,640
Old Lyme	6,540	2,310	10	2,530	1,580	4,120
East Lyme	15,340	2,380	10	5,740	1,720	7,470
Waterford	17,930	350	160	4,230	150	4,540
New London	28,540	290	20	4,850	80	4,950
Groton City	9,530	70	0	1,160	30	1,190
Groton Town	35,610	1,210	1570	5,960	680	8,210
Stonington	16,920	960	440	5,760	620	6,820
TOTALS	1,013,590	19,550	4,770	270,470	13,450	288,690

TABLE 3-3
FAIRFIELD COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	Greenwich	Greenwich Hospital Association	Hosp.	None
2	Greenwich	Greenwich Woods Health Care Center	Hosp.	"
3	Greenwich	Laurelton Nursing Home	Nurs.	"
4	Greenwich	Nathaniel Witherell Hospital	Nurs.	"
1	Stamford	Saint Joseph Hospital	Hosp.	"
2	Stamford	Stamford Hospital	Hosp.	"
3	Stamford	Courtland Gardens Health Center	Nurs.	"
4	Stamford	Homestead Convalescent Home	Nurs.	"
5	Stamford	Smith House Skilled Nursing Facility	Nurs.	"
6	Stamford	Queen of the Clergy	Nurs.	"
7	Stamford	Smith House Residence	Nurs.	"
8	Stamford	Tandet Center for Continuing Care	Nurs.	"
9	Stamford	Saint Camillius Home	Nurs.	"
1	Darien	Darien Convalescent Center	Nurs.	"
1	Norwalk	Norwalk Hospital	Hosp.	"
2	Norwalk	Fairfield Manor Health Care Center	Nurs.	"
3	Norwalk	Norwalk Health Care/Rehab. Center	Nurs.	"
4	Norwalk	Notre Dame Convalescent Home	Nurs.	"
5	Norwalk	Louise Carlson Senior Residence	Nurs.	"
6	Norwalk	King's Daughters and Sons Home	Nurs.	"
1	Westport	Hall Brook Hospital	Hosp.	"
2	Westport	Mediplex Nursing Home	Nurs.	"
1	Fairfield	Carolton Convalescent Home	Nurs.	"
2	Fairfield	Jewish Home for the Elderly of Fairfield	Nurs.	"
3	Fairfield	North Fairfield Geriatric Center	Nurs.	"
4	Fairfield	Southport Manor	Nurs.	"
5	Fairfield	Cambridge Manor	Nurs.	"

TABLE 3-3 (continued)
FAIRFIELD COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	Bridgeport	Bridgeport Hospital	Hosp.	None
2	Bridgeport	Park City Hospital	Hosp.	Cat. 3,4
3	Bridgeport	Saint Vincent's Medical Center	Hosp.	None
4	Bridgeport	Barnett Multi-Health Care	Nurs.	"
5	Bridgeport	Bridgeport Health Care Center	Nurs.	"
6	Bridgeport	Golden Heights Roncalli Health Care Ctr.	Nurs.	"
7	Bridgeport	Park Avenue Health Care Center	Nurs.	Cat. 4
8	Bridgeport	Roncalli Heath Center	Nurs.	None
9	Bridgeport	Sylvan Manor Health Care Center	Nurs.	"
10	Bridgeport	Thirty-Thirty Park Health Center	Nurs.	"
11	Bridgeport	Bordman Beardsley Home	Nurs.	Cat. 1,2,3,4
12	Bridgeport	Burroughs Home	Nurs.	None
13	Bridgeport	Fanny Crosby Memorial	Nurs.	"
14	Bridgeport	Laurel Avenue Rest Home	Nurs.	"
15	Bridgeport	Sterling Home of Bridgeport	Nurs.	Cat. 4
16	Bridgeport	Stonehaven Rest Home	Nurs.	None
17	Bridgeport	Greater Bridgeport Mental Health Ctr.	Nurs.	"
18	Bridgeport	Astoria Park	Nurs.	Cat. 4
1	Stratford	Lord Chamberlain Skilled Nursing Fac.	Nurs.	None

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

TABLE 3-4
NEW HAVEN COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	Milford	Milford Hospital	Hosp.	None
2	Milford	Medi-plex (Orange Ave.)	Nurs.	"
3	Milford	Medi-plex (Bridgeport Ave.)	Nurs.	"
4	Milford	Milford Health Care Center	Nurs.	"
5	Milford	Pond Point Health Care Center	Nurs.	"
6	Milford	Four Corners Rest Home	Nurs.	"
1	West Haven	V. A. Hospital	Hosp.	"
2	West Haven	Bentley Gardens Health Care Center	Nurs.	"
3	West Haven	Sound View Specialized Care Center	Nurs.	"
4	West Haven	West Haven Nursing Center	Nurs.	"
5	West Haven	Arterburn Home	Nurs.	Cat. 4
6	West Haven	Harbor View Manor	Nurs.	Cat. 4
7	West Haven	Seacrest Nursing & Retirement Center	Nurs.	None
1	New Haven	Hospital of Saint Raphale	Hosp.	"
2	New Haven	Yale-New Haven Hospital	Hosp.	"
3	New Haven	Yale University Infirmary	Hosp.	"
4	New Haven	Cove Manor Convalescent Center	Nurs.	Cat. 1,2,3,4
5	New Haven	Jewish Home for the Aged	Nurs.	None
6	New Haven	New Fairview Hall Convalescent Home	Nurs.	"
7	New Haven	New Haven Convalescent Center	Nurs.	"
8	New Haven	Parkview Medical Recovery Center	Nurs.	Cat. 4
9	New Haven	Regis Multi Health Center	Nurs.	None
10	New Haven	Saint John's Extended Care Center	Nurs.	"
11	New Haven	Winthrop Continuing Care Center	Nurs.	"
12	New Haven	Carewell Rest Home	Nurs.	"
13	New Haven	West Rock Health Care	Nurs.	"

TABLE 3-4 (continued)
NEW HAVEN COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
14	New Haven	Carlson Home for the Aged	Nurs.	None
15	New Haven	Hannah Gray Home	Nurs.	"
16	New Haven	Haven Rest Home	Nurs.	"
17	New Haven	Marionette Home for the Aged	Nurs.	"
18	New Haven	Riverview Rest Home	Nurs.	"
19	New Haven	Saint Paul's Church Home	Nurs.	Cat. 1,2,3,4
20	New Haven	Mary Wade Home	Nurs.	None
21	New Haven	Connecticut Correction Center	Corr.	"
22	New Haven	Union Ab. Detention Center	Corr.	Cat. 3,4
1	East Haven	Lombardi Rest Home	Nurs.	Cat. 4
2	East Haven	Talmadge Park Health Care	Nurs.	Cat. 3,4
3	East Haven	Stewart Rest Home	Nurs.	Cat. 1,2,3,4
4	East Haven	Teresa Rest Home	Nurs.	Cat. 1,2,3,4
5	East Haven	Willow Rest Home	Nurs.	Cat. 1,2,3,4
1	Branford	Connecticut Hospice	Hosp.	None
2	Branford	Branford Hills Health Care	Nurs.	"
3	Branford	Branford Manor	Nurs.	"
1	Guilford	Fowler Convalescent Care Center	Nurs.	Cat. 3,4
2	Guilford	West Lake Lodge Health Care	Nurs.	None
3	Guilford	Marotta Manor	Nurs.	Cat. 3,4
4	Guilford	The Gables of Guilford	Nurs.	None
1	Madison	Watrous Nursing Home	Nurs.	Cat. 4

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

TABLE 3-5
MIDDLESEX COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1] FLOODING
1	Clinton	Clinton Health Care Center	Nurs.	Cat. 4
1	Westbrook	Tidelawn Manor	Nurs.	Cat. 3,4
1	Old Saybrook	Old Saybrook Convalescent Home	Nurs.	Cat. 3,4
2	Old Saybrook	Gladview Convalescent Home	Nurs.	Cat. 1,2,3,4

NOTE:
[1] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

TABLE 3-6
NEW LONDON COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	East Lyme	Bride Brook Nursing Home	Nurs.	Cat. 3,4
2	East Lyme	J. B. Gates Prison	Corr.	None
3	East Lyme	Connecticut Correctional Institute	Corr.	"
1	Waterford	Seaside State Mental Hospital	Hosp.	Cat. 4
2	Waterford	Waterford Health and Rehab. Center	Nurs.	None
3	Waterford	Greentree Manor Convalescent	Nurs.	"
4	Waterford	New London Convalescent Home	Nurs.	"
5	Waterford	Bay View Health Care Center	Nurs.	"
1	New London	Lawrence and Memorial Hospital	Hosp.	"
2	New London	Beechwood Manor	Nurs.	"
3	New London	Camelot Nursing Home	Nurs.	"
4	New London	Nutmeg Pavilion Health Care	Nurs.	"
5	New London	Bacon and Hinkley Home	Nurs.	"
6	New London	Briarcliff Manor	Nurs.	"
7	New London	Cedar Grove Manor	Nurs.	"
1	Groton Town	Sub Base Hospital	Hosp.	"
2	Groton Town	Pequot Treatment Center	Medi.	"
3	Groton Town	Fairview Home	Nurs.	"
4	Groton Town	Regency Retirement & Nursing Home	Nurs.	"
5	Groton Town	Ritas Rest Home	Nurs.	"
6	Groton Town	Mystic Manor Convalescent	Nurs.	"
7	Groton Town	Mystic River Home	Nurs.	"
1	Stonington	Mary Elizabeth Nursing Home	Nurs.	Cat. 1,2,3,4
2	Stonington	Pendleton Nursing Home	Nurs.	Cat. 4

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

3.6 MOBILE HOME/TRAILER PARK FACILITIES

Tables 3-7 though 3-9 list the trailer and mobile home parks that exist within each community of the study area. All mobile home/trailer park data were furnished by emergency management officials from the communities. Facility site locations can be found by cross referencing the map key numbers listed in Tables 3-7 through 3-9 with the locator symbols identified in the Evacuation Map Atlas. Unless otherwise noted in Tables 3-7 through 3-10, "None" in the column labeled "SURGE FLOODING" indicates that the facility is not located within hurricane surge inundation areas.

Mobile homes and trailer parks are included as part of the vulnerability analysis because of their particular vulnerability to high winds. It is recommended that officials take actions to evacuate the residents of these units regardless of their flooding potential. Listings in Tables 3-7 through 3-10 give names and locations of parks having more than one mobile home or trailer. The names and locations of sites where a single mobile home unit may be located in a community were not identified. However, the vulnerable populations listed in Tables 3-1 and 3-2 include the residents of all mobile homes regardless of whether they are located in an organized park or on a separate parcel of land elsewhere in a community.

TABLE 3-7
FAIRFIELD COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1] FLOODING
1	Norwalk	Renzulli Trailer Park	Mobile	None
1	Westport	Sasco Creek Village	Mobile	"

NOTE:
[1] "None" indicates facility is not located within hurricane surge inundation areas.

TABLE 3-8
NEW HAVEN COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	Milford	Ryder Park	Mobile	None
2	Milford	Twin Oaks Trailer Park	Mobile	"
1	West Haven	Hebbwood Ranch	Mobile	"
2	West Haven	East Avenue & Beach Street Area	Mobile	Cat. 1,2,3,4
1	Branford	Branford Grove	Mobile	None
2	Branford	Highland Park North	Mobile	"
3	Branford	Highland Park South	Mobile	"
4	Branford	Shoreline Trailer Park	Mobile	"
5	Branford	Paved Lane Trailer Park	Mobile	"
6	Branford	Hamilton Mobile Home Park	Mobile	"
7	Branford	Kay-Dee Trailer Park	Mobile	"
8	Branford	School Ground Trailer Park	Mobile	"
9	Branford	O'Connell Trailer Park	Mobile	"
1	Guilford	Trailer Park	Mobile	"

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

TABLE 3-9
MIDDLESEX COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	Clinton	Evergreen Trailer Park	Mobile	None
2	Clinton	Rollar Homes	Mobile	Cat. 4
3	Clinton	Indian River Trailer Park	Mobile	Cat. 1,2,3,4
1	Westbrook	Jenson Trailer Park	Mobile	Cat. 4
2	Westbrook	Green Acres	Mobile	None
1	Old Saybrook	Trailer Park	Mobile	Cat. 3,4

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

TABLE 3-10
NEW LONDON COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY	COMMUNITY	FACILITY NAME	TYPE	SURGE[1,2] FLOODING
1	East Lyme	Camp Niantic by the Atlantic	Camping	None
2	East Lyme	Rocky Neck Camp Ground	Camping	Cat. 3,4
1	Waterford	Brookside Mobile Home Park	Mobile	Cat. 4
2	Waterford	Woodlawn Mobile Home Park	Mobile	None
1	Groton Town	Bay Colony Trailer Park	Mobile	"
2	Groton Town	Candlewood Trailer Park	Mobile	"
3	Groton Town	Cherry Circle Trailer Park	Mobile	"
4	Groton Town	Dan's Trailer Park	Mobile	Cat. 1,2,3,4
5	Groton Town	Dewey Avenue Trailer Park	Mobile	None
6	Groton Town	Dolphin Mobile Home Park	Mobile	"
7	Groton Town	Groton Mobile Gardens	Mobile	"
8	Groton Town	Groton Mobile Home Sites	Mobile	"
9	Groton Town	High Rock Trailer Park	Mobile	"
10	Groton Town	Laurel Hill Trailer Park	Mobile	"
11	Groton Town	Long Cove Mobile Home Park	Mobile	"
12	Groton Town	Pleasant Valley Trailer Park	Mobile	"
13	Groton Town	Roger's Trailer Park	Mobile	"
14	Groton Town	South Road Trailer Park	Mobile	Cat. 4
15	Groton Town	Whipple's Mobile Home Park	Mobile	None
16	Groton Town	Ackley Trailer Park	Mobile	"
1	Stonington	Fair Acres	Mobile	"
2	Stonington	Arlington Acres	Mobile	"
3	Stonington	Wheeler Brook	Mobile	"

NOTES:
[1] "None" indicates facility is not located within hurricane surge inundation areas.
[2] Facility is located in or adjacent to the hurricane surge inundation area(s) for the category storm(s) listed.

Chapter Four

BEHAVIORAL ANALYSIS

4.1 PURPOSE

The behavioral analysis is intended to provide reliable planning estimates of how the public in the Study Area will respond to hurricane threats. These estimates are utilized in the Shelter Analysis, Transportation Analysis, and are also intended for guidance in hurricane preparedness planning and evacuation decision-making. The specific objectives of the behavioral analysis are to determine the following:

a. The percentage of the surge-vulnerable population that will evacuate under varying hurricane threat scenarios or in response to evacuation recommendations issued by local officials. The term "surge-vulnerable population" refers to those persons residing near the coastline, the shorelines of estuaries, or in areas of low elevation near those locations that are subjected to hurricane surge flooding.

b. The percentage of the population residing in mobile homes that will evacuate their dwellings either due to hurricane wind or water hazards.

c. The percentage of the non-surge-vulnerable population that will evacuate under varying hurricane threat scenarios. "Non-surge-vulnerable population" refers to those persons residing in areas not affected by hurricane surge flooding but evacuate due to perceived danger or wind hazards.

d. When the evacuating population will leave in relation to an evacuation recommendation given by local officials or other persons of authority.

e. The percentage of available vehicles that the evacuating population will use during a hurricane evacuation.

f. The percentage of the evacuating population that will seek refuge at public shelters, if available.

4.2 DATA SOURCES

The primary data source utilized for the analysis is a report entitled <u>Behavioral Assumptions for Hurricane Planning in Connecticut</u>, 1989. This document is part of a comprehensive analysis entitled <u>Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States</u>, *1989 commissioned for use in Hurricane Evacuation Studies of eight states:*

Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, and Virginia. Both of these documents are provided in Appendix B.

Post-hurricane surveys conducted after Hurricanes Gloria in 1985 and Bob in 1991 were a secondary source of response data. These data are considered to give a reliable indication of what most people at their locations are most likely to do in the future under similar hurricane threats. However, conclusions drawn from single event data for other locations may over generalize predicted response. Evacuation participation rates as well as many other behavior patterns can be influenced by many parameters which vary from location to location. For this reason, no conclusive behavioral assumptions in this analysis have been drawn solely from post-hurricane studies, rather assumptions were founded based on a "general response model" and compared with actual data for verification.

Other sources of data are the Hurricane Evacuation Studies currently in place in other States. In many states, these studies were tested and shown to be valid when actual evacuations in response to real events were successfully conducted. Observed behavioral responses during actual evacuations which compared favorably to predicted data were heavily weighted when developing similar predictions of behavioral response for Connecticut.

4.3 GENERAL RESPONSE MODEL

Most of the behavioral assumptions derived for Hurricane Evacuation Studies have been formulated using a "general response model". The General Response Model is based on data derived from an extensive list of post-hurricane response studies. These data are considered to be the most reliable indication of what people are most likely to do in future hurricane threats. The Model predicts a quantitative value for behavioral response for specific situations and circumstances specified. Relationships and patterns between response and various parameters affecting response (such as, risk area, actions by officials, time of day, threat level, etc.) were inputs into the Model obtained from actual response surveys conducted over a period of several years. In a general sense, understanding how response varies for a wide spectrum of population characteristics and evacuation circumstances enables one to make confident hurricane evacuation response predictions by analyzing population characteristics of the study area. This is true whether or not the location under investigation experienced a hurricane in the past. Once the General Response Model is applied to a study area, the Model's predicted values are validated by comparing them with patterns observed in actual and hypothetical response data collected in the study area.

One main feature in applying the General Response Model in support of Corps' and FEMA's hurricane evacuation studies was a survey of the response by threatened populations of eight states along the eastern seaboard to Hurricane Gloria. Surveys comprised questions pertaining to the actions taken by people during Gloria's evacuation, as well as questions of intended actions during hypothetical evacuations. Criteria for selecting survey locations varied from state to state, but in most instances the locations were representative of other areas. A total of approximately 2,000 samples at both "beach" and "mainland" areas were taken across the eight states.

The Connecticut portion of the sample survey was conducted by telephone. After consultation with State emergency management officials in Connecticut, a telephone survey of 200 coastal residents was designed. Households in Connecticut that were interviewed were from the communities of Fairfield, Bridgeport, Stratford, Milford, Groton, and Stonington.

4.4 BEHAVIORAL ASSUMPTIONS

It is important to recognize that no single set of behavioral assumptions is appropriate throughout the entire coastal area of Connecticut. The eight state survey conducted after Hurricane Gloria showed that response may vary even within relatively small geographical areas. Moreover, response to the next hurricane threat might well be quite different than that observed in Gloria. Fortunately, such variations are predictable. Response patterns observed in Connecticut during Gloria were very consistent with the General Response Model developed after studying public response in many hurricane evacuations throughout the east and Gulf coasts of the United States over the past three decades.

The following paragraphs address each of the objectives established for the behavioral analysis and present generalized results for each objective. They have provided guidelines for the establishment of appropriate behavioral assumptions for use in the Shelter and Transportation Analyses of this report.

4.4.1 Participation Rates

There are two overriding factors that influence whether or not residents will evacuate, actions by public officials, and the perceived degree of hazard at the location. In flood-prone areas near the open coast, in face of a severe hurricane, 90 percent of the residents will evacuate if public officials take aggressive action urging or ordering evacuation. In the same areas, the compliance of residents will be at 80 percent if they perceive the hurricane threat as not severe. Evacuation participation among those living along inland areas less vulnerable to hurricane surge is 40 to 70 percent.

Participation rates of this magnitude will result only if officials are successful in communicating the urgency of evacuation messages. One method to ensure that messages reach the intended audience is to supplement television and radio announcements with police or other officials issuing warnings door-to-door or by loudspeakers. Less aggressive or less successful dissemination of evacuation notices will result in evacuation rates closer to 55 to 65 percent in open coast areas and less than 20 percent along inland areas.

Mobile home residents, regardless of where they reside in a community, are more likely to evacuate than their neighbors. This is particularly true if officials specifically encourage their evacuation. The willingness of mobile home residents to evacuate is generally not dependent upon storm severity because of their vulnerability to hurricane winds of even the weakest storms. Mobile home residents will evacuate at a rate of 55 to 90 percent, depending upon their location relative to the coast, if encouraged to do so by officials.

Hurricane Evacuation Studies of other states tested during recent events have shown that as much as 5 percent of the non-surge vulnerable population in the vicinity of the evacuations will also evacuate. Depending upon how severe a hurricane is and how widely its threat is broadcasted, a small group of people will always evacuate even when not specifically recommended to. People who live in wind vulnerable homes or substandard housing, not including those living in mobile homes, are also included within this percentage.

The tendency for tourists to evacuate depends on their intended length of stay and how far they traveled from their homes. The group composed of those who own or rent summer homes and stay most of the summer respond to evacuation recommendations much the same as permanent residents would. Tourists who rent for shorter periods of time tend to evacuate at slightly greater rates, 85 to 95 percent depending upon storm severity. These people most often vacation at beachfront or nearby locations of greater risk which results in increased participation rates if informed of their vulnerability by officials. "Day-tripper" (i.e., near-by residents who visit the coast during the day and return home in the evening) present no special evacuation problems, assuming that officials actively discourage such visits through news media announcements.

Officials should be aware that disseminating evacuation recommendations to tourists may be difficult because many do not watch television or listen to radio broadcasts regularly. It may be especially important that officials get word directly to hotels, motels, and rental properties that an evacuation has been recommended. Vacationers, particularly campers with travel trailers, tend to rely upon hotel/motel or campground managers for advice. It is important that emergency management officials have the cooperation of facility managers in order to ensure that guests receive the appropriate advice. Officials also need to be aware that there could be vacationers just arriving in the area, unaware that their destination is being evacuated. At the least, facility managers should know to discourage tourists who are planning to arrive at the time of, or before, an evacuation.

At coordination meetings held with State and local officials, some local officials expressed concern that participation rates appear higher than they observed in past evacuations and are higher than they would expect to observe under future threats. Officials were reminded that the willingness of people to evacuate is directly related to how aggressively officials encourage them to leave. Also, it was highlighted that behavioral studies have shown that participation rates will decrease as much as 25 to 50 percent in areas where residents fail to hear officials' recommendations. In an effort to address local concerns, a sensitivity analysis of this issue and its impacts on transportation clearance times was completed and is presented in Chapter Six, Transportation Analysis. Results showed that in Connecticut even large changes in the assumed participation rates do not increase roadway clearance time estimates. After consultation with State and local emergency management officials at subsequent coordination meetings it was decided that the evacuation participation rates shown in Table 4-1 would be used.

TABLE 4-1
EVACUATION PARTICIPATION RATES

EVACUATION SCENARIO	EVACUATION ZONE CAT. 1&2	EVACUATION ZONE CAT. 3&4	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION
CAT. 1&2	80 %	40 %	100 %	2 %
CAT. 3&4	90 %	90 %	100 %	5 %

4.4.2 Evacuation Timing

Post-hurricane response studies show a diversity in the rates evacuees leave their homes after being recommended to do so by authorities. This diversity can be primarily attributed to factors such as actions by local officials, severity of the threatening hurricane, residents' perception of the probability of the hurricane striking their location, and the evacuation difficulties for their location. The primary factor found to be the most consistent with each storm is the sharp increase in evacuation response following advice of local officials to evacuate. These increases in evacuation response following local advertisements show consistency regardless of location, relative magnitude of threat, or information previously disseminated to the threatened population.

One method to gain insight on how people will respond to local officials' recommendations in the future is to study what the same group of people did in past events. Unfortunately though, sample surveys conducted in Connecticut after Gloria were for the most part inconclusive with regards to evacuation timing. This was primarily caused by interviewing too few evacuees and by conducting interviews two years after the event occurred. When asked, many people could not recall the precise times at which they left their homes. As discussed in the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993, only local officials were interviewed. Response surveys involving the public were not conducted, thus, no confident estimates can be made other than observations reported by local officials.

Further insight on evacuation timing without actually surveying evacuees can be gained by analyzing traffic data recorded at permanent traffic counters positioned along evacuation routes. Vehicle trips recorded hourly on major coastal routes in Connecticut during Hurricanes Gloria and Bob were compared to similar data recorded during "normal" summertime days at the same locations. Traffic pattern comparisons at several locations suggest that during both events traffic flows did not vary from "normal" flows until approximately eight hours before landfall occurred. Evidence also shows that traffic levels were not significantly reduced until approximately four hours before landfall. Most evacuating activity, whether people left their work place or home, or they made last minute shopping trips, etc., generally occurred in a time period of four to eight hours before the events. Interviews with public officials after Hurricane Bob further confirm this assumption.

Despite limited data on hurricane evacuation timing in Connecticut, or New England for that matter, evacuation response rates founded and used successfully in other States' Hurricane Evacuation Studies provide at least a starting point in establishing similar information for Connecticut. By combining the information learned from hourly traffic counts with planning response curves used in other Hurricane Evacuation Studies, the planning response curves shown in Figure 4-1 were derived for Connecticut. Although these curves were based on planning assumptions used in other study areas, they have been tailored to the Connecticut study area by incorporating behavioral response information gathered in Connecticut after Hurricanes Gloria and Bob. Consistent with the methodologies used in other states, "slow", "moderate", and "rapid response" rates are presented. A "slow response" curve represents an early response in which most evacuees leave well before arrival of the storm. The "moderate response" curve assumes a fairly rapid response in the last six hours before arrival and could be expected to apply to an evacuation prompted by a well publicized, steadily moving hurricane. Finally, the "rapid response" curve represents a "last minute" evacuation. This curve has the potential to occur if a storm dramatically increases speed, or suddenly changes course unexpectedly towards the State. Officials will have to hurriedly issue evacuation notices and make residents understand the urgency of rapid response.

Operationally, two aspects of evacuation timing are very important: 1) people will not begin to leave in significant numbers until someone in a position of authority advises them to, and 2) timing will vary greatly from storm to storm. As in evacuation participation rates, actions by local officials are extremely important in influencing evacuation timing.

4.4.3 Shelter Usage

Two factors which predominantly influence whether evacuees will seek public shelters as places of refuge are income and degree of hazard of the area being evacuated. Usually 10 percent, or less of the evacuees from beach and open coast areas normally use public shelters (an exception is in last-minute evacuations when there is insufficient time to travel to preferred destinations). Seldom will more than 20 percent of the surge-vulnerable residents further inland go to public shelters. Other inland residents, not threatened by hurricane flooding but who still choose to evacuate, will seek public shelters at a rate of 30 percent if shelter space is available.

The actions of local officials can greatly influence the sheltering rates within a community. If, for example, public shelters are opened early and advertised, the public shelter use rates will most likely be significantly higher than for areas where the public is strongly advised to seek safe locations at friends'/relatives' homes, hotels and motels, or where shelter locations and shelter availability are not widely advertised.

Late night evacuations tend to maximize shelter use primarily because it is occurring with a sense of urgency, leaving no time to make alternative arrangements with friends, relatives, and motels or leaving little time to travel the distance necessary to travel out-of town. Regardless of time of day, during late or urgent evacuations proceedings, in which evacuees are asked to response rapidly, shelter demands are roughly double what they would be under a less urgent scenarios. Another factor which emergency management officials should note is that retirees living in retirement areas are more likely to use public shelters than other groups.

After consultation with American Red Cross and State emergency management officials, shelter usage rates shown in Table 4-2 were assumed for use in subsequent analyses. Officials should be mindful that these percentages may vary depending upon the evacuation circumstances of each location.

TABLE 4-2
SHELTER USAGE RATES

PER CAPITA INCOME	EVACUATION ZONE CAT. 1&2	EVACUATION ZONE CAT. 3&4	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION
HIGH	5 %	10 %	100 %	10 %
LOW	10 %	20 %	100 %	30 %

4.4.4 Vehicle Usage

Not all available vehicles are used in evacuations for fear of families being separated. Surveys taken after Gloria indicate that 65 to 75 percent of the available vehicles in a household were used during the evacuation. For the Transportation Analysis the assumption was made that in all areas 75 percent of the available vehicles will be used. This figure was applied only to households assumed to be evacuating, not to all registered vehicles.

As determined from the survey after Hurricane Gloria, none of evacuees reported that they needed public transportation or assistance from a social service agency to evacuate. However, this can be highly variable from one community to the next. To operationally respond to this need, lists of names and addresses of all people needing special assistance should be developed and maintained at the local level.

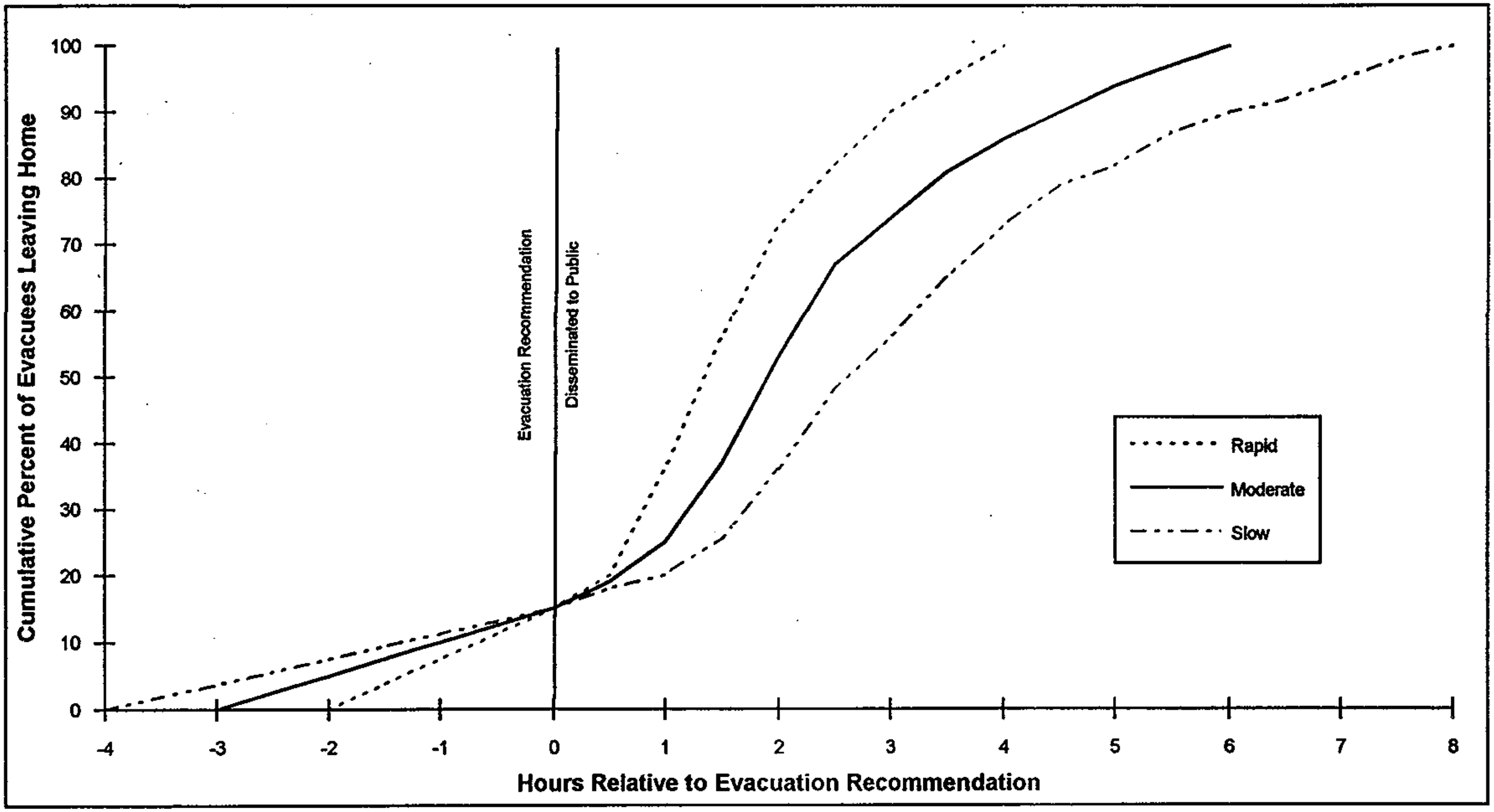


Figure 4-1. Behavioral Response Curves

Chapter Five

SHELTER ANALYSIS

5.1 PURPOSE

The shelter analysis serves two primary purposes. The most apparent uses of analysis data are to develop the number of evacuees who will seek public shelter (shelter demand) within each community and to determine the number of spaces available for those evacuees. The second purpose of the shelter analysis is to present inventories, capacities, and potential flood vulnerability of locally designated public shelters and American Red Cross (ARC) Mass Care Facilities.

5.2 REGIONAL AND LOCAL PUBLIC SHELTERS

It is the preference of the Connecticut Office of Emergency Management, and the majority of local emergency management departments, that during a hurricane evacuation communities will open and operate adequate numbers of public shelters to accommodate their own residents. To meet this goal, communities work in concert with local ARC chapters to maintain agreements for use of public buildings and other facilities during emergencies. Before agreements are reached, buildings are surveyed to establish whether they meet specific guidelines set forth by the American Red Cross in ARC 3031 (Mass Care Preparedness and Operations) and ARC Form 6564 (Mass Care Facility Survey). In some communities however, the combined capacities of their Mass Care Facilities do not provide adequate capacity to meet the shelter demands determined by the Shelter Analysis. Therefore, local officials have identified additional facilities for use as public shelters that may not necessarily meet ARC guidelines.

Amenities and operating costs of the locally designated shelters including expenses for food, cooking equipment, emergency power services, bedding, etc. are the responsibilities of communities and are generally not paid for by local American Red Cross chapters unless contractual arrangements were previously made. Many communities only intend to use these facilities on a temporary basis for providing shelter until hurricane hazards diminish. During recovery operations however, those communities needing expanded sheltering services would depend upon regionally located Mass Care Facilities operated and paid for by the American Red Cross.

5.3 SHELTER DEMAND/CAPACITY

The results of the Behavioral Analysis were used to estimate the shelter demand for two hurricane evacuation scenarios. All possible hurricane evacuation situations were classified as a Category 1&2 evacuation scenario, or a Category 3&4 evacuation scenario. The scenarios correspond to the two evacuation zone delineations shown on evacuation maps in the Evacuation Map Atlas. Table 5-1 lists the shelter demands for all communities assuming that officials encourage residents within the evacuation zones to leave their homes. Table 5-1 also lists the total public shelter capacity per community based on inventories made of predesignated public shelters. Comparisons made of shelter demand to existing shelter capacity reveals that five communities have deficient shelter capabilities for hurricane evacuations. The Corps of Engineers and FEMA recommend that these communities continue to work with local ARC chapters to identify additional public shelters to meet estimated sheltering needs. Section 5.5, Shelter Inventories, presents how shelter capacities were determined and gives the names and capacities of each shelter inventoried.

The computation of shelter demand assumes an adequate warning period for an approaching hurricane and sufficient public knowledge concerning the locations and availability of public shelter facilities. Officials must recognize that the shelter demands listed in Table 5-1 should be used as a guide, and more or less public shelter space will be needed depending on the evacuation circumstances and the aggressiveness of officials encouraging people to use public shelters. Shelter usage is one of the most difficult behavioral characteristics to predict and a wide variation in the estimated values is not uncommon. The behavioral assumptions listed in Tables 4-1 and 4-2 that were used in developing the total number of evacuees and public shelter demands are as follows:

a. The percentage of the affected population (population living in evacuation zones) that will evacuate depends upon the evacuation scenario. In a Category 1&2 evacuation scenario, 80 percent of the population within Category 1&2 evacuation zones, and 40 percent within Category 3&4 evacuation zones, will evacuate. During a Category 3&4 evacuation scenario, 90 percent of the population living within either evacuation zone will evacuate.

b. The percentage of the unaffected population (population living outside evacuation zones, excluding mobile home residents) assumed to evacuate is 2 percent for the Category 1&2 scenario and 5 percent for the Category 3&4 scenario.

c. Depending on a community's per capita income, evacuees from Category 1&2 and Category 3&4 evacuation zones will use public shelters at rates of 5 to 10 percent, and 10 to 20 percent, respectively by evacuation zone. The unaffected population that evacuates will use public shelters at rates of 10 to 30 percent depending upon income.

d. 100 percent of the mobile home residents will evacuate to public shelters.

e. Seasonal residents will evacuate and use public shelters at the same rates as the permanent population in their particular area.

5.4 SHELTER INVENTORIES

Table 5-2 through Table 5-26, presented at the end of this chapter, list by community the Mass Care Facilities and locally designated public shelters that may be used during hurricane evacuations. The Tables include each building's maximum sheltering capacity, a map key number corresponding to a building's location shown in the Evacuation Map Atlas, and the susceptibility of buildings to surge and freshwater flooding. Names, capacities, and locations of locally designated shelters were furnished by community emergency management representatives. The State ARC coordinator provided the building names and maximum capacities of Mass Care Facilities, under agreement as of November 1993, between communities and local chapters. It is important to note that a listing in this report does not imply that a building will be used in a given hurricane evacuation. The choice of shelters for a specific evacuation is an operational decision. Shelters will be opened by local officials and ARC personnel based on a variety of circumstances including, intensity and direction of the threatening hurricane, amount of advance warning time, services available at facilities, and availability of qualified people to manage facilities. Additionally, available shelter space will change as buildings are constructed or demolished, as ownership changes, and as agreements are reached or canceled with building owners.

The susceptibility of all shelters to hurricane surge was assessed using surge limits delineated in the Inundation Map Atlas. Exposures of shelters to 100-year and 500-year freshwater flooding were assessed using the FEMA's National Flood Insurance Rate Maps. Shelters not located in inundation areas, 500-year, and/or 100-year flood zones have been classified as not vulnerable to flooding. In a few instances, public shelters were found to be located within Category 3&4 evacuation zones. Unless otherwise noted, these facilities are not prone to hurricane surges and may be used during evacuations despite the fact that they

TABLE 5-1
ESTIMATED PUBLIC SHELTER CAPACITY/DEMAND

COMMUNITY	TOTAL SHELTER CAPACITY	HURRICANE EVACUATION SCENARIO	
		CAT. 1&2	CAT. 3&4
Greenwich	4,040	610	1,080
Stamford	2,337	1,020	2,060
Darien	1,950	190	280
Norwalk	12,750	1,460	2,710
Westport	1,420	450	650
Fairfield	4,125	1,390	2,430
Bridgeport	11,635	4,110	8,020
Stratford	4,125	1,470	2,330
Milford	3,700	2,600	3,890
West Haven	1,125	1,800	3,230
New Haven	1,830	2,930	5,780
East Haven	2,600	1,180	1,760
Branford	1,330	2,120	3,000
Guilford	1,900	710	1,080
Madison	1,570	520	870
Clinton	1,300	1,120	1,410
Westbrook	800	640	750
Old Saybrook	500	790	1,060
Old Lyme	1,000	370	530
East Lyme	4,100	670	1,240
Waterford	5,500	600	880
New London	3,750	550	1,020
Groton City	688	150	300
Groton Town	4,918	2,270	2,940
Stonington	1,800	1,020	1,280
TOTALS	80,793	30,740	50,580

are included within evacuation zones. No attempt has been made to assess the vulnerability of any shelter to the effects of winds from hurricanes.

As noted before, not all locally operated facilities currently meet shelter selection guidelines established by the American Red Cross, nor do all communities currently have enough shelter capacity to meet estimated demands. Evacuees who are not able to be accommodated in public shelters located in their communities will perhaps travel farther distances to reach shelters in other communities, or to find other safe destinations. The Transportation Analysis discusses how clearance times may be affected by deficiencies in shelter capacity.

5.5 PUBLIC SHELTER SELECTION GUIDELINES

In the future, some communities may choose to predesignate additional buildings as public shelters for hurricane evacuations. In others, it can be expected that shelter lists will change from year to year. Whichever the case, it is extremely important that care be taken in shelter selection. In July 1992, the American Red Cross established guidelines for selecting shelters (ARC 4496). The guidelines, which were prepared by an inter-agency group, reflect the application of technical data compiled in Hurricane Evacuation Studies, other hazard information, and research findings related to wind loads and structural integrity. They are intended to supplement information contained in ARC 3031 and ARC Form 6564. These guidelines, which are reprinted on the following pages, are also appropriate for use by municipalities operating and selecting their own shelters.

Planning considerations for hurricane evacuation shelters involve a number of factors and require close coordination with local officials responsible for public safety. Technical information contained in Hurricane Evacuation Studies, storm surge and flood mapping, and other data can now be used to make informed decisions about the suitability of shelters.

In the experience of the American Red Cross, the majority of people evacuating because of a hurricane threat generally provide for themselves or stay with friends and relatives. However, for those who do seek public shelter, **safety from the hazards associated with hurricanes must be assured.** These hazards include-

- Surge inundation.
- Rainfall flooding.
- High winds.
- Hazardous materials.

Recommended guidelines follow for each of these hurricane-associated hazards.

Surge Inundation Areas

In general, hurricane evacuation shelters should not be located in areas vulnerable to hurricane surge inundation. The National Weather Service has developed mathematical models, such as Sea, Lake, and Overland Surges from Hurricanes (SLOSH) and Special Program to List Amplitudes of Surges from Hurricanes (SPLASH), that are critical in determining the potential level of surge inundation in a given area.

- Carefully review inundation maps in order to locate all hurricane evacuation shelters outside Category 4 storm surge inundation zones.
- Avoid buildings subject to isolation by surge inundation in favor of equally suitable buildings not subject to isolation. Confirm that ground elevations for all potential shelter facilities and access routes obtained from topographic maps are accurate.
- Do not locate hurricane evacuation shelters on barrier islands.

Rainfall Flooding

Rainfall flooding must be considered in the hurricane evacuation shelter selection process. Riverine inundation areas shown on Flood Insurance Rate Maps (FIRMSs), as prepared by the National Flood Insurance Program, should be reviewed. FIRMs should also be reviewed in locating shelters in inland counties.

- Locate hurricane evacuation shelters outside the 100-year floodplain.
- Avoid selecting hurricane evacuation shelters located within the 500-year floodplain.
- Do not locate hurricane evacuation shelters in areas likely to be isolated due to riverine inundation of roadways.
- Make sure a hurricane evacuation shelter's first floor elevation is on an equal or higher elevation than that of the base flood elevation level for the FIRM area.
- Consider the proximity of shelters to any dams and reservoirs to assess flow upon failure of containment following hurricane-related flooding.

Wind Hazards

Consideration of any facility for use as a hurricane evacuation shelter must take into account wind hazards. Both design and construction problems may preclude a facility from being used as a shelter. Local building codes are frequently inadequate for higher wind speeds.

Structural Considerations

- If possible, select buildings that a structural engineer has certified as being capable of withstanding wind loads according to ASCE (American Society of Engineers) 7-88 or ANSI (American National Standards Institute) A58 (1982) structural design criteria. Buildings must be in compliance with all local building and fire codes.
- Failing a certification (see above), request a structural engineer to rank the proposed hurricane evacuation shelters based on his or her knowledge and the criteria contained in these guidelines.
- Avoid uncertified buildings of the following types:
  - Buildings with long or open roof spans
  - Un-reinforced masonry buildings
  - Pre-engineered (steel pre-fabricated) buildings built before the mid 1980s
  - Buildings that will be exposed to the full force of hurricane winds
  - Buildings with flat or lightweight roofs
- Give preference to the following:
  - Buildings with steep-pitched, hipped roofs; or with heavy concrete roofs

- Buildings more than one story high (if lower stories are used for shelter)
- Buildings in sheltered areas
- Buildings whose access routes are not tree-lined

Interior Building Safety Criteria During Hurricane Conditions

Based on storm data (e.g., arrival of gale-force winds), determine a notification procedure with local emergency managers regarding when to move the shelter population to pre-determined safer areas within the facility. Consider the following guidelines:

- Do not use rooms attached to, or immediately adjacent to, un-reinforced masonry walls or buildings.
- Do not use gymnasiums, auditoriums, or other large open areas with long roof spans during hurricane conditions.
- Avoid areas near glass, unless the glass surface is protected by an adequate shutter. Assume that windows and roof will be damaged and plan accordingly.
- Use interior corridors or rooms.
- In multi-story buildings, use only the lower floors and avoid corner rooms.
- Avoid any wall section that has portable or modular classrooms in close proximity, if these are used in your community.
- Avoid basements if there is any chance of flooding.

Hazardous Materials

The possible impact from a spill or release of hazardous materials should be taken into account when considering any potential hurricane evacuation shelter.

All facilities manufacturing, using, or storing hazardous materials (in reportable quantities) are required to submit Material Safety Data Sheets (emergency and hazardous chemical inventory forms) to the Local Emergency Planning Committee (LEPC) and the local fire department. These sources can assist you in determining the suitability of a potential hurricane evacuation shelter or determining precautionary zones (safe distances) for facilities near potential shelters that manufacture, use, or store hazardous materials.

- Facilities that store certain types or quantities of hazardous materials may be inappropriate for use as hurricane evacuation shelters.
- Hurricane evacuation shelters should not be located within the ten-mile emergency planning zone (EPZ) of a nuclear power plant.
- Service delivery units must work with local emergency management officials to determine if hazardous materials present a concern for potential hurricane evacuation shelters.

Hurricane Evacuation Shelter Selection Process

General procedures for investigating the suitability of a building or facility for use as a hurricane evacuation shelter are as follows:

- Identify potential sites. Evacuation and transportation route models must be considered.
- Complete a risk assessment on each potential site. Gather all pertinent data from SLOSH and/or SPLASH (storm surge), FIRM (flood hazard), facility base elevation, hazardous materials information, and previous studies concerning each building's suitability.
- Inspect the facility and complete a *Red Cross Facility Survey Form and a Self-Inspection Work Sheet/Off-Premises Liability Checklist*, in accordance with ARC 3031. Note all potential liabilities and the type of construction. Consider the facility as a whole—one weak section may seriously jeopardize the integrity of the building.
- Have the building certified as being capable of withstanding the wind loads according to ASCE 7-88 or ANSI A58 (1982) structural design criteria. In the absence of certification, have a structural engineer review the facility and rate its suitability to the best of his or her ability.
- Ensure that an exhaustive search for shelter space has been completed. Work with local emergency management officials and others to identify additional potential sites.
- Review, on a regular basis, all approved hurricane evacuation shelters. Facility improvements, additions, or deterioration may change the suitability of a selected facility as a hurricane evacuation shelter. Facility enhancements may also enable previously rejected facilities to be used as hurricane evacuation shelters.
- If possible, work with officials, facility managers, and school districts on mitigation

opportunities. Continue to advocate that the building program for new public buildings, such as schools, should include provisions to make them more resilient to possible wind damage. It may also be possible to suggest a minor modification of a municipal, community, or school building in the planning stages to make for a more useful hurricane evacuation shelter site, such as the addition of hurricane shutters.

Least-Risk Decision Making

Safety is the primary consideration for the American Red Cross in providing hurricane evacuation shelters. When anticipated demands for hurricane evacuation shelter spaces exceed suitable capacity as defined by the preceding criteria, there may be a need to utilize marginal facilities. It is therefore critical that these decisions be made carefully and in consultation with local emergency management and public safety officials. Guidance should be obtained from Disaster Services at national headquarters, in consultation with the Risk Management Division.

This process should include the following considerations:

- No hurricane evacuation shelter should be located in an evacuation zone for obvious safety reasons. All hurricane evacuation shelters should be located outside of Category 4 storm surge inundation zones. **Certain exceptions may be necessary, but only if there is a high degree of confidence that the level of wind, rain, and surge activities will not surpass established shelter safety margins.**
- When a potential hurricane evacuation shelter is located in a flood zone, it is important to consider its viability. By comparing elevations of sites with FIRMs, one can determine if the shelter and a major means of egress are in any danger of flooding. Zone AH (within the 100-year flood plain and puddling of 1-3 feet expected) necessitates a closer look at the use of a particular facility as a sheltering location. Zones B, C, and D may allow some flexibility. **It is essential that elevations be carefully checked to avoid unnecessary problems.**
- In the absence of certification by a structural engineer, any building selected for use as a hurricane evacuation shelter must be in compliance with all local building and fire codes. Certain exceptions may be necessary, but only after evaluation of each facility, using the aforementioned building safety criteria.
- The Red Cross uses the planning guideline of 40 square feet of space per shelter resident. During hurricane conditions, on a short-term basis, shelter space requirements may be reduced. Ideally, this requirement should be determined using no less than 20 square feet per person. Adequate space must be set aside for registration, health services, and safety and fire considerations. Disaster Health Services areas should still be planned using a 40 square feet per person calculation. On a **long-term recovery basis, shelter space requirements should follow guidelines established in ARC 2021,** *Mass Care: Preparedness and Operations.*

TABLE 5-2
TOWN OF GREENWICH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Central Middle School	Yes	None	500
2	Christ Church	No	"	600
3	Eastern Middle School	Yes	"	390
4	Greenwich Catholic School	No	"	500
5	Greenwich High School	Yes	"	1,000
6	Julian Curtiss	No	"	150
7	New Lebanon School	No	"	250
8	Old Greenwich Civic Center	No	See Note[5]	250
9	Western Middle School	Yes	"	400
		TOTAL SHELTER CAPACITY		4,040

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-1 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The Old Greenwich Civic Center is located in the Category 4 hurricane surge inundation area. The base floor elevation determined by the Town of Greenwich is 21.24 feet (NGVD), which is above the worst case Category 4 hurricane surge tide height. To ensure the building will not flood from interior runoff and vehicular access will be preserved, the Town of Greenwich must maintain the flow capacity of the box culvert under the Metro North Conrail, adjacent to the site.

TABLE 5-3
CITY OF STAMFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Belltown Fire Department	Yes	None	38
2	Cloonan Middle School	Yes	See Note [5]	400
3	Glenbrook Fire Department	Yes	None	41
4	Long Ridge Fire Department	Yes	See Note [5]	43
5	Northeast School	Yes	None	200
6	Rippowan High School	Yes	"	466
7	Springdale Fire Department	Yes	"	39
8	Stamford High School	Yes	"	360
9	Turn of River Fire Department Station #1	Yes	"	50
10	Westhill High School	Yes	"	400
11	Stamford Government Center	No	See Note [5]	100
12	Stamford YMCA	Yes	See Note [5]	200
			TOTAL SHELTER CAPACITY	2,337

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-2 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The emergency management department from the City of Stamford was unable to confirm the precise locations of these facilities or the suitability of these buildings for use as hurricane public shelters at the time of report printing. The elevations of these public shelters have not been verified and consequently these facilities may be exposed to hurricane surge inundation, and/or the 100-year and 500-year frequency floods.

TABLE 5-4
TOWN OF DARIEN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Darien Convalescent Center	No	None	100
2	Darien Fire Department	No	"	100
3	Darien High School	No	"	500
4	Middlesex Middle School	No	"	500
5	Noroton Fire Department	Yes	"	100
6	Noroton Heights Fire Dept.	Yes	"	100
7	Post 53 EMS Headquarters	No	"	150
8	Town Hall	No	See Note [5]	400
			TOTAL SHELTER CAPACITY	1,950

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-3 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The Darien Town Hall is located adjacent to the Category 4 hurricane inundation area, 500-year, and the 100-year flood plains. The base floor elevation determined by the Town of Darien is 20.25 feet (NGVD), which is above the worst case hurricane surge tide elevation and the 500-year frequency flood elevation.

TABLE 5-5
CITY OF NORWALK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Brien McMahon High School	No	None	4,000
2	Congregational Church on the Green	No	"	100
3	Kiwanis Shelter	No	"	100
4	National Guard Armory	No	"	500
5	Norwalk High School	Yes	"	6,000
6	Pouns Ridge Junior High School	No	"	2,000
7	Emergency Operations Ctr. / Fire Dept.	No	"	50
		TOTAL SHELTER CAPACITY		12,750

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-4 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-6
TOWN OF WESTPORT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Coleytown Elementary School	No	None	200
2	Coleytown Middle School	No	"	400
3	Long Lots Middle School	Yes	"	400
4	Staples High School	No	"	400
5	Emergency Operations Center	No	"	20
			TOTAL SHELTER CAPACITY	1,420

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-5 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-7
TOWN OF FAIRFIELD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Dwight School	No	None	350
2	Fairfield High School	No	"	700
3	Fairfield Woods School	No	"	250
4	First Presbyterian Church	Yes	"	500
5	Holy Family Church and School	No	"	150
6	Jennings School	No	"	150
7	Ludlowe Community Center	Yes	"	700
8	Notre Dame Catholic High School	No	"	700
9	Lady of Assumption Church School	No	"	250
10	Saint Plus X Church and School	No	"	350
11	Emergency Operations Center	No	"	25
		TOTAL SHELTER CAPACITY		4,125

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-6 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-8
CITY OF BRIDGEPORT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Beardsley Elementary School	No	None	200
2	Blackham Middle School	No	"	200
3	Bridgeport City Hall	No	"	500
4	Community Mental Health Center	No	"	300
5	Bridgeport Police Academy	No	"	500
6	Bullards Haven Tech.	No	"	1,000
7	Central High School	Yes	"	1,800
8	Columbus Elementary School	No	"	800
9	The Discovery Museum	No	"	800
10	East Side Middle School	No	"	500
11	Hall Elementary School	No	"	100
12	Harding High School	No	"	1,000
13	Housatonic Community College	No	"	500
14	James Curiale Elementary School	Yes	"	585
15	Park City Magnet Elementary School	No	"	300
16	Read Middle School	No	"	800
17	Saint Ambrose School	No	"	500
18	Saint Andrews School	No	"	200
19	Wilbur Cross Elementary School	No	"	400
20	Winthrop Middle School	No	"	650
		TOTAL SHELTER CAPACITY		11,635

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-7 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-9
TOWN OF STRATFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Bunnell High School	Yes	None	1,500
2	David Wooster Middle School	No	"	975
3	Harry B. Flood Middle School	Yes	"	130
4	Town Hall	No	"	20
5	Emergency Operations Center / Police Dept.	No	"	50
6	Stratford High School	Yes	"	1,500
			TOTAL SHELTER CAPACITY	4,175

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-8 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-10
CITY OF MILFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Senior Citizen Service Center	Yes	None	100
2	Jonathan Law High School	Yes	"	800
3	Foran High School	Yes	"	800
4	East Shore Middle School	No	"	200
5	Meadow Side School	No	"	200
6	Orchard Hill School	No	"	200
7	Platt Technical School	No	"	800
8	Pumpkin Delight School	No	"	200
9	Saint Gabriel School	No	"	200
10	Harbor Side Middle School	No	"	200
		TOTAL SHELTER CAPACITY		3,700

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-9 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-11
CITY OF WEST HAVEN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Alma E Pagels School	No	None	100
2	Anna V Molloy School	No	"	100
3	Bailey Middle School	Yes	"	100
4	Carrigan Middle School	Yes	"	100
5	City Hall	Yes	"	25
6	Forest Elementary School	Yes	See Note [5]	100
7	West Haven High School	Yes	None	100
8	St Louis RC School	No	"	200
9	Our Lady of Victory RC School	No	"	200
10	Thompson Elementary School	No	"	100
		TOTAL SHELTER CAPACITY		1,125

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-10 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The Forest Middle School is located adjacent to the 500-year and 100-year flood plains. The base floor elevation determined by the City of West Haven is 131.85 feet (MSL), which is above the 500-year frequency flood elevation.

TABLE 5-12
CITY OF NEW HAVEN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	James Hillhouse High School	Yes	None	300
2	Roberto Clemente Middle School	Yes	"	430
3	Wilbur Cross High School	Yes	See Note [5]	1,100
			TOTAL SHELTER CAPACITY	1,830

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-11 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The Wilbur Cross High School is located adjacent to the 500-year and the 100-year flood plains, and within the Category 4 hurricane inundation area. The elevation of this building needs to be surveyed to verify that the base floor elevation is higher than the worst case hurricane surge tide elevation.

TABLE 5-13
TOWN OF EAST HAVEN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Deer Run School	No	None	600
2	East Haven Middle School	No	See Note [5]	1,500
3	Foxon Station #3	No	None	200
4	Hayes School	No	"	300
		TOTAL SHELTER CAPACITY		2,600

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-12 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

[5] The East Haven Middle School is located in the Category 4 hurricane inundation area, 500-year, and the 100-year flood plains. The elevation of this building needs to be surveyed to verify that the base floor elevation is higher than the worst case hurricane surge tide elevation and 500-year frequency flood elevation.

TABLE 5-14
TOWN OF BRANFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Branford Intermediate School	No	None	850
2	Mary Murphy School	No	"	480
		TOTAL SHELTER CAPACITY		1,330

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-13 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-15
TOWN OF GUILFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Adams Middle School	Yes	None	400
2	Guilford High School	Yes	"	600
3	Community Center	No	"	800
4	North Guilford Fire House	No	"	100
			TOTAL SHELTER CAPACITY	1,900

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-14 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-16
TOWN OF MADISON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Academy Street Elementary School	Yes	None	250
2	Daniel Hand High School	No	"	500
3	First Congregation Church House	Yes	"	100
4	J Milton Jeffrey Elementary School	No	"	200
5	Kathleen H Ryerson Elementary School	No	"	150
6	North Madison Congregational Church	No	"	120
7	Robert H Brown School	No	"	250
		TOTAL SHELTER CAPACITY		1,570

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-15 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-17
TOWN OF CLINTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Jared Eliot School	Yes	None	300
2	Joel School	No	"	900
3	Morgan High School	No	"	100
		TOTAL SHELTER CAPACITY		1,300

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-16 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-18
TOWN OF WESTBROOK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Daisy Ingraham School	Yes	None	200
2	Westbrook Fire Department	No	"	100
3	Westbrook High School	Yes	"	500
		TOTAL SHELTER CAPACITY		800

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-17 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-19
TOWN OF OLD SAYBROOK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Senior High School	Yes	See Note [5]	500
		TOTAL SHELTER CAPACITY		500

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-18 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.
[5] The Old Saybrook Senior High School is located within the Category 4 hurricane inundation area, and adjacent to the 500-year and 100-year flood plains. The base floor elevation determined by the Town of Old Saybrook is 18.05 feet (MSL), which is above the worst case hurricane surge tide elevation and the 500-year frequency flood elevation. Vehicular access to this facility will be limited or temporarily cutoff during worst case flood events.

TABLE 5-20
TOWN OF OLD LYME
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Old Lyme Center School	Yes	None	250
2	Old Lyme High School	Yes	"	500
3	Old Lyme Middle School	Yes	"	250
		TOTAL SHELTER CAPACITY		1,000

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-19 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-21
TOWN OF EAST LYME
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Community Center	Yes	None	1,200
2	East Lyme High School	No	"	1,600
3	East Lyme Middle School	No	"	700
4	Flanders School	No	"	600
		TOTAL SHELTER CAPACITY		4,100

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-20 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-22
TOWN OF WATERFORD
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Waterford High School	Yes	None	5,000
2	Cohanzie Elementary School	No	"	500
		TOTAL SHELTER CAPACITY		5,500

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-21 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-23
CITY OF NEW LONDON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Martin Center	Yes	None	750
2	New London High School	Yes	"	1,500
3	New London Junior High School	Yes	"	1,500
		TOTAL SHELTER CAPACITY		3,750

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-22 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-24
CITY OF GROTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	City Municipal Building	No	None	250
2	West Side Middle School	No	"	438
		TOTAL SHELTER CAPACITY		688

NOTES

[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.

[2] See Plate E-23 of the companion Evacuation Map Atlas for locations of shelters.

[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.

[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-25
TOWN OF GROTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Fitch High School	No	None	1263
2	Fitch Middle School	No	"	845
3	Noank School	No	"	269
4	S. B. Buttler School	No	"	401
5	Claude Chester School	No	"	500
6	Charles Barnum School	No	"	500
7	Mary Morrigan School	No	"	500
8	Pleasant Valley School	No	"	500
9	Groton Senior Center	Yes	"	140
		TOTAL SHELTER CAPACITY		4,918

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-24 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

TABLE 5-26
TOWN OF STONINGTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Deans Mill School	Yes	None	500
2	Pawcatuck Middle School	Yes	"	500
3	Stonington High School	Yes	"	800
		TOTAL SHELTER CAPACITY		1,800

NOTES
[1] Inclusion on this list does not indicate that a facility will be used in a given hurricane evacuation. The choice of public shelters for a specific evacuation is an operational decision made by local emergency management officials.
[2] See Plate E-25 of the companion Evacuation Map Atlas for locations of shelters.
[3] American Red Cross. "Yes" indicates that the ARC has agreed to operate the facility as a Mass Care Facility.
[4] "None" indicates the facility is not located in hurricane inundation areas, 500-year, and/or 100-year flood zones.

Chapter Six

TRANSPORTATION ANALYSIS

6.1 PURPOSE

The purpose of the Transportation Analysis is to estimate roadway clearance times for coastal Connecticut communities under a variety of hurricane evacuation scenarios. Clearance time is defined as the amount of time required for all vehicles to clear the roadways after a regional or state level hurricane evacuation recommendation is disseminated to the public. During an evacuation, a large number of vehicles have to travel on a road system in a relatively short period of time. A virtually infinite number of different vehicle trips are possible, varying by trip origination, time of departure, and trip destination. The number of vehicle trips becomes particularly significant for an area such as Connecticut's coast because its land areas are highly urbanized with many residents living near the immediate shore. The number of evacuating vehicles varies depending upon the intensity of the hurricane, actions taken by local authorities, and certain human behavioral response characteristics of the area's population. Motorists evacuating their homes and intermixing with traffic from people leaving work or traveling for other trip purposes can lead to significant traffic congestion and backups, ultimately delaying the evacuation.

This analysis establishes the clearance time portions of evacuation times. Clearance time is one component of the total time required for a regional hurricane evacuation to be completed. An additional time component, which considers the amount of time necessary for public officials to notify people to evacuate, must be combined with clearance time to determine the total evacuation time. Chapter Seven, Evacuation Times, discusses which clearance times the Corps of Engineers and the Federal Emergency Management Agency recommend using to calculate evacuation times for decision-making during most hurricane evacuations in Connecticut.

A transportation modeling methodology and a roadway representation were developed for all counties in the study area to conduct the analysis and estimate clearance times. General information and data related to the Transportation Analysis are presented in summary form in this chapter. A more detailed description of the transportation analysis methodology is provided in Appendix C, Transportation Analysis Support Documentation.

6.2 METHODOLOGY

The Behavioral Analysis discussed in Chapter Four presents information about which destination types evacuees are most likely to choose during an evacuation in Connecticut. The analysis concludes that people who evacuate surge areas are most likely to seek safe destinations at public shelters, friends'/relatives' homes, or hotels/motels. Although behavioral data provided in Chapter Four can give some guidance in predicting the actual geographic areas people will evacuate to and the evacuation routes people may use to reach their destinations, assumptions of this nature tend to be subjective. This is caused by the vast number of possible destinations and routes available to evacuees in highly populated areas. Clearance time calculations are further complicated by the affects of significant and varying amounts of "background"[1] traffic that will be present on roadways as an evacuation progresses.

The study considered several approaches to estimate clearance times for the Connecticut study area. The first approach considered was the one used by the Corps of Engineers and the FEMA to complete hurricane evacuation studies in the Gulf and southern Atlantic coast states. This approach assigns destinations and evacuation routes for the evacuating population by matching probable evacuee destinations (determined by a behavioral analysis) with the land uses known for the region. A mathematical model of the study area's roadway system is then used to calculate clearance times based on the trip distributions assumed for the evacuation. The time required for all evacuees to reach their predetermined destination is considered the clearance time. As reported in a post-hurricane assessment of Hurricane Hugo in 1989, the transportation analyses conducted for the North Carolina and South Carolina Hurricane Evacuation Studies were found to be very accurate in that the clearance times experienced during evacuations were very near predicted times. These results give evidence that this approach is accurate for study areas with moderate roadway systems and where adequate behavioral data and landuse information is suitable to identify evacuation routes and predict the destinations of evacuees. The following paragraphs explain some differences in the Connecticut study area in comparison to other areas, and give the reasons why the Corps of Engineers employed and alternative transportation modeling approach for Connecticut.

[1]"Background" Traffic refers to vehicle trips by people who leave work early and return home, people who travel through the region, and trips made by people preparing for the arrival of hurricane conditions or engaged in normal activities.

One concern in using the transportation modeling approach discussed above for Connecticut was the appropriateness of designating evacuee destinations and evacuation routes. Inundation areas in Connecticut are relatively narrow, but densely populated. The complex system of interconnecting freeways, undivided state routes, and numerous local streets offer evacuees, and others on the roadways, many possible travel routes to reach their destinations. The region is generally characterized by diverse land uses in small geographic areas. Hotels and motels are sporadically located in most communities, friends' and relatives' homes could well be distributed over the entire area, and Connecticut communities tend to open public shelters to accommodate their individual demands. The Study concluded that it is not practical to use the behavioral information developed for Connecticut to derive assumptions about evacuee destinations and evacuation routes. The Study did conclude that the behavioral response curves presented in the Behavioral Analysis, and used in other hurricane evacuation studies, are suitable to predict the general response of the people who live in vulnerable areas.

The second concern in using the modeling approach used in other studies was the relationship between the number of people evacuating from vulnerable areas in comparison to the number of background vehicles that would be on the roadways during evacuations. Although surge areas are densely populated, the relatively small land areas that they encompass include only a fraction of the region's total population. When viewing the region's roadways as an entire transportation system, most of the traffic on roadways during initial and mid stages of an evacuation is likely to be from people leaving work early and from vehicles passing through the region. The problem during evacuations is that evacuating vehicles are forced to compete for roadway capacity with a larger amount of background traffic. This can cause increased congestion, potentially delaying the overall evacuation. Because background traffic will travel in both directions on nearly all roadways during evacuations, the Study determined that the transportation methodology for Connecticut should not focus on assigning evacuation routes as typically done in other study areas. Instead, the methodology should focus on analyzing the influence background traffic can have on the overall evacuation.

To address the unique behavioral and transportation issues of the Connecticut study area, an alternative modeling strategy was used. A mathematical model of the road system was developed and calibrated to simulate the traffic flows of a normal week day. Traffic count data used to calibrate the model were available from the State's Department of Transportation (DOT), which collects information on vehicle movements, volumes, and other traffic data every day. The transportation modeling methodology assumes that the preferences of evacuees to travel on given routes are related to the traffic patterns of a normal day, except where it is clear that evacuees will travel directly to public shelters. The large portion of vehicles associated with background traffic enables the methodology to neglect assigning specific destinations and evacuation routes to evacuees traveling to hotels/motels and friends'/relatives' homes. This is supported by the fact that Connecticut's large coastal business community and its generally narrow hurricane surge areas will give rise to evacuations involving traffic mostly attributed to people leaving work rather than people evacuating surge areas. Analysis of traffic data collected on the days Hurricanes Gloria and Bob further support this assumption. Accordingly, the modeling strategy used in Connecticut focuses on estimating clearance times which qualitatively measure how competition by evacuating traffic may affect, possibly delay, the movement of all traffic during an evacuation.

6.3 DEVELOPMENT OF ROAD NETWORKS

NETVAC2 is a special purpose, evacuation computer model that was used to create a mathematical model to represent the study area's roadway system. A series of link and node configurations were used to model all state roadways located 12 to 18 miles inland from the coast, from the New York State line to the Rhode Island State border.

In NETVAC2, links are used to represent roadways and nodes represent the intersections that connect two or more roadways. The physical characteristics for links and nodes are inputs to the model necessary to compute roadway capacity constraints and legal turning movements at intersections. The vastness of the Connecticut coastline required that the study area be divided into three approximately equal sized areas and analyzed individually. For convenience, boundaries which generally conform to Fairfield, New Haven, and Middlesex/New London county boundaries where used to divide the study area into networks. The link and node configurations of the three study areas are shown in Figures 1,2, and 3 in Appendix C.

The Connecticut DOT provided all of the roadway and intersection data to develop road networks. This data included detailed information on the numbers of travel lanes, lane widths, the widths of intersections, and the total length of each modeled road segment. As networks were created, field surveys conducted at several locations verified that the modeling strategy and data input in the models were consistent with physical conditions.

6.4 MODEL CALIBRATION

Before evacuation simulations were run, each network was first calibrated for its study area. Calibration is preformed for two primary reasons. First, it establishes the route preferences that will be used by all vehicles during an evacuation simulation (route preferences control the numbers of vehicles assigned to travel on each road). Second, it determines how many vehicles must be loaded at a given loading rate to achieve traffic patterns typical of a normal day. Before an evacuation takes place, the modeling methodology assumes traffic patterns of a normal day occur. Therefore, NETVAC2 was programmed to simulate normal traffic patterns at the start of all model runs. Only after a hurricane threat becomes imminent, and people begin responding to warnings, are changes in normal day traffic anticipated.

The Connecticut DOT tabulates the average daily traffic (ADT) for all state maintained roadway segments where significant changes in total traffic volume occur. ADT represents the expected number of vehicles to pass by a given location during any normal day. The amount of ADT on any given roadway over a 24-hour period varies with each hour and day of the week. In general, ADT is usually many times greater during peak traffic periods compared with times of off-peak traffic. Figure 6-1 plots averages of the hourly weekday ADT volume recorded at traffic monitoring stations in Branford, East Lyme, Groton, Norwalk, and Wallingford, Connecticut along portions of US Route 1, and Interstate Routes 91 and 95. The distribution of hourly ADT at each location was found to be similar regardless of monitoring site or direction of travel.

In Figure 6-1, dashed lines delineate approximate levels of ADT corresponding to off-peak, mid-peak, and peak traffic. For the most part, off-peak traffic refers to light traffic volumes that typically occur late at night or in the early morning. Mid-peak traffic refers to moderate traffic conditions similar to those generally experienced in the late morning or early afternoon on weekdays, or on weekend days. Peak traffic represents the volume of traffic that is typical during rush hour.

Although the distribution of ADT in Figure 6-1 may not reflect all of the local traffic patterns for each road in the study area, it does provide a reasonable representation of how most of the vehicle trips in coastal Connecticut are distributed over a normal day. Consequently, Figure 6-1 was used to calibrate all roadways in the networks. This calibration was performed using an iterative process of 1) running NETVAC2; 2) comparing the distribution of vehicles on major routes modeled to the distribution in Figure 6-1; 3) adjusting link preference factors; and 4) rerunning the model. The transportation methodology assumed calibration was complete when the volume of vehicles on each link approximately matched its corresponding ADT volume; and the distribution of traffic shown in Figure 6-1 was attained for all major routes modeled.

6. 5 DEVELOPMENT OF TRAFFIC DATA

6.5.1 Classification of Motorists

After road networks were developed, the next steps of the analysis were to estimate the total number of vehicles that will load onto roadways, and determine the rates at which vehicles will load onto roadways over the course of an evacuation. To facilitate the development of this information, vehicles were classified as belonging to one of four major categories listed below:

(1) Surge Vulnerable Evacuees: Permanent and seasonal residents living in evacuation zones who evacuate when directed to do so by authorities.

(2) Non-Surge Vulnerable Evacuees: Permanent and seasonal residents, excluding mobile home residents, living outside evacuation zones who choose to evacuate. Most of the evacuees of this category leave their homes because of perceived dangers and not necessarily because of real flooding threats. However, in some cases, officials may deem it necessary to evacuate small groups of people who live in substandard housing units particularly vulnerable to hurricane winds, or those who live in or near areas that may be exposed to freshwater flooding.

(3) Mobile Home Evacuees: All permanent and seasonal mobile home residents of coastal communities. The analysis assumes all mobile home residents will be told to evacuate by local officials due to their high risk to strong winds from storms of even modest intensities.

(4) Background Vehicles: The population associated with all remaining vehicle trip purposes. Examples are: Trips made by people who leave work early and return home, people who travel through the region, and trips made by persons preparing for the arrival of hurricane conditions or engaged in normal activities. This traffic can also includes transit vehicles (vans/buses) used to pick up evacuees without personal transportation.

The number of vehicles assumed to participate during an evacuation from each group listed is an important factor in estimating clearance times. Fortunately, human behavioral information developed in Chapter Four, Behavioral Analysis, gives clear estimates of the participation that can be expected from the first three groups. The fourth group, Background Vehicles, is not addressed by the Behavioral Analysis. The motorists belonging to this group

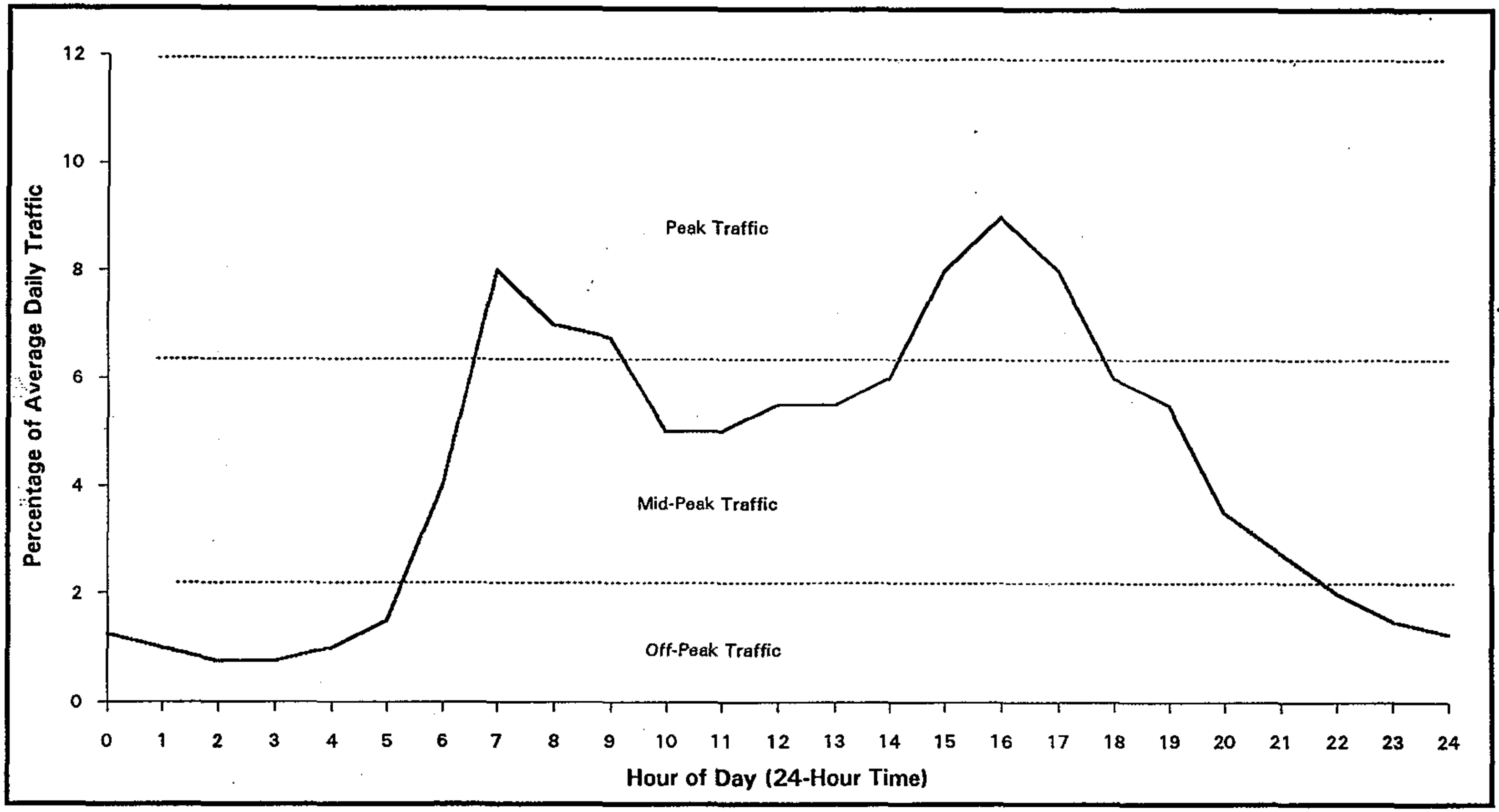


Figure 6-1. Average of Hourly ADT Along Major Routes in Connecticut.

are mostly made up of people who leave their work places early, which is related to the ADT distribution shown in Figure 6-1.

Tables 6-1 and 6-2 list estimates made of the numbers of permanent and seasonal people who were assumed to evacuate their homes by population type for two levels of hurricane threat. Table 6-1 refers to evacuations for a Category 1 or Category 2 hurricane, and Table 6-2 gives similar estimates for a Category 3 or Category 4 hurricane. Evacuation participation assumptions listed in Table 4-1 were applied to the vulnerability data reported in Tables 3-1 to 3-2 to arrive at these estimates.

6.5.2 Behavioral Response of Motorists

Perhaps one of the most critical assumptions that must be considered when estimating clearance times is at what time relative to an evacuation advisory evacuees will load onto roadways. Behavioral data from research obtained from past hurricane evacuations show that mobilization and actual departures of the evacuating population occur over a period of many hours and sometimes several days. For Connecticut, evacuation simulations were tested for three evacuation rates that are summarized by the response curves in Figure 4-1. Behavioral response curves describe the percentages of the evacuating population who leave their homes and load onto roadways at hourly intervals relative to when an evacuation recommendation is disseminated to the public.

The behavioral response curves are intended to include the most probable range of public responses that will be experienced in a future hurricane evacuation. The rapid response curve depicts the quickest mobilization response by evacuating households. For analysis purposes, the rapid response curve includes two hours of response time occurring before the evacuation recommendation is disseminated to the public, and four hours after it is disseminated. For the moderate response curve, three hours of response time is assumed before dissemination of the evacuation recommendation, and six hours after. The slow response curve includes four hours of response time before notification of the evacuation recommendation, and eight hours after. The public's response before evacuation accounts for people who choose to evacuate their homes before being directed to do so by authorities. Regardless of the behavioral response curve used, 85 percent of all people who will eventually leave their homes are assumed to leave after being directed to do so by officials. This is an important point because people's timeliness in responding to a hurricane evacuation is extremely dependent upon the aggressiveness of authorities to encourage them to leave.

TABLE 6-1
EVACUATING POPULATION CATEGORIES 1&2 HURRICANES

COMMUNITY	POPULATION EVACUATING SURGE AREAS	POPULATION EVACUATING MOBILE HOMES	POPULATION EVACUATING NON-SURGE AREAS	TOTAL COMMUNITY EVACUATING POPULATION
Greenwich	7,570	10	930	8,510
Stamford	3,450	30	2,080	5,560
Darien	2,810	10	290	3,110
Norwalk	7,340	90	1,330	8,760
Westport	3,880	170	370	4,420
Fairfield	9,040	10	790	9,840
Bridgeport	23,390	30	1,960	25,380
Stratford	10,700	20	680	11,400
Milford	16,530	440	500	17,470
West Haven	10,720	100	710	11,530
New Haven	15,630	20	2,040	17,690
East Haven	9,500	10	250	9,760
Branford	11,260	660	210	12,130
Guilford	5,080	50	270	5,400
Madison	3,660	10	230	3,900
Clinton	4,270	580	140	4,990
Westbrook	2,930	310	50	3,290
Old Saybrook	7,030	10	40	7,080
Old Lyme	2,940	10	100	3,050
East Lyme	4,180	10	210	4,400
Waterford	3,000	160	280	3,440
New London	3,020	20	480	3,520
Groton City	670	0	170	840
Groton Town	3,750	1,570	570	5,890
Stonington	4,650	440	220	5,310
TOTALS	177,000	4,770	14,900	196,670

TABLE 6-2
EVACUATING POPULATION CATEGORIES 3&4 HURRICANES

COMMUNITY	POPULATION EVACUATING SURGE AREAS	POPULATION EVACUATING MOBILE HOMES	POPULATION EVACUATING NON-SURGE AREAS	TOTAL COMMUNITY EVACUATING POPULATION
Greenwich	11,210	10	2,330	13,550
Stamford	4,160	30	5,190	9,380
Darien	3,410	10	730	4,150
Norwalk	10,960	90	3,320	14,370
Westport	5,460	170	930	6,560
Fairfield	12,880	10	1,980	14,870
Bridgeport	39,280	30	4,910	44,220
Stratford	14,010	20	1,710	15,740
Milford	22,600	440	1,260	24,300
West Haven	16,710	100	1,770	18,580
New Haven	25,810	20	5,100	30,930
East Haven	12,310	10	630	12,950
Branford	15,740	660	520	16,920
Guilford	6,590	50	660	7,300
Madison	5,020	10	570	5,600
Clinton	5,590	580	360	6,530
Westbrook	3,540	310	130	3,980
Old Saybrook	8,660	10	100	8,770
Old Lyme	3,690	10	240	3,940
East Lyme	6,710	10	510	7,230
Waterford	3,950	160	690	4,800
New London	4,440	20	1,200	5,660
Groton City	1,070	0	420	1,490
Groton Town	5,970	1,570	1,430	8,970
Stonington	5,740	440	550	6,730
TOTALS	255,510	4,770	37,240	297,520

6.5.3 Vehicle Usage

In the Behavioral Analysis, it was estimated that approximately 75 percent of the vehicles available to evacuees will be used during evacuations. For the most part, families usually evacuate using one vehicle for fear of separation, but some households evacuate using two or more vehicles depending upon how many are available to them. Differences in vehicle ownership may vary with variations in access to public transportation, household income, and other socioeconomic characteristics of the region.

The first and second columns of Table 6-3 list by community the average numbers of people and cars per occupied housing unit. This information was obtained from socioeconomic data reported in the 1980 census. The third column of the Table gives the calculated average numbers of people assumed to travel in each evacuating vehicle, provided that 75 percent of the available vehicles are used. A sample calculation for Greenwich, Connecticut is shown below.

$$\frac{\text{2.63 people per occupied housing unit}}{\text{1.84 cars per housing unit} \times 75\%} = \text{1.91 people per evacuating car}$$

The transportation methodology used the information in Table 6-3 to determine the vehicles that would load onto roadways during evacuations. A complementary program for use with NETVAC2, entitled POPDIS, converts the population that is assigned to enter onto roadways to an equivalent number of vehicles. The modeler enters the vehicle occupancy rates and the number of people assigned to enter roadways at various locations within the study areas. POPDIS aggregates the population input at each location and in turn computes the effective average vehicle loading rates per minute to be input into NETVAC2 at entry locations specified by the modeler.

6.6 EVACUATION SCENARIOS

Since all hurricanes differ from one another in some respect, it becomes necessary to set forth clear assumptions about storm characteristics and evacuees' expected response before evacuation simulations are run. Not only does a storm vary in its track, intensity and size, but also in the way it is perceived by residents in potentially vulnerable areas. These factors cause a wide variance in the behavior of the vulnerable population. Even the time of day at which a storm makes landfall influences the time parameters of an evacuation response. The Transportation Analysis computes clearance times based on sets of assumed conditions and

TABLE 6-3
VEHICLE USAGE BY COMMUNITY

COMMUNITY	PEOPLE PER OCCUPIED HOUSING UNIT	CARS PER OCCUPIED HOUSING UNIT	PEOPLE PER EVACUATING CAR
Greenwich	2.63	1.84	1.91
Stamford	2.58	1.58	2.18
Darien	2.84	2.03	1.87
Norwalk	2.56	1.73	1.97
Westport	2.63	2.02	1.74
Fairfield	2.76	1.94	1.90
Bridgeport	2.71	1.18	3.06
Stratford	2.56	1.73	1.97
Milford	2.65	1.83	1.93
West Haven	2.54	1.51	2.24
New Haven	2.66	1.01	3.51
East Haven	2.60	1.81	1.92
Branford	2.37	1.75	1.81
Guilford	2.76	1.98	1.86
Madison	2.78	2.01	1.84
Clinton	2.74	1.90	1.92
Westbrook	2.39	1.77	1.80
Old Saybrook	2.55	1.86	1.83
Old Lyme	2.54	2.03	1.67
East Lyme	2.79	1.90	1.96
Waterford	2.58	2.00	1.72
New London	2.66	1.23	2.88
Groton City	3.04	1.59	2.55
Groton Town	3.04	1.59	2.55
Stonington	2.41	1.76	1.83

behavioral responses. It is likely that an actual storm will differ from a simulated storm for which clearance times are calculated in this analysis. Therefore, key input parameters were varied to derive a range of evacuation scenarios idealizing many possible situations officials may have to contend with. The three major parameters that were varied with each simulation are described below.

(1) Hurricane Severity: Storms are classified as either Categories 1&2 hurricanes, or Categories 3&4 hurricanes. Evacuating population estimates (see Tables 6-1 and 6-2) are significantly greater (approximately double) for an evacuation due to Categories 3&4 hurricanes when compared with that for Categories 1&2 hurricanes. Category 5 hurricanes were not considered because the cooler waters of the Northeast can not sustain hurricanes of this intensity.

(2) Behavioral Response: The time in which evacuees mobilize to leave their homes and enter onto the roadway system is characterized by the behavioral response curves shown in Figure 4-1. Behavioral response curves are defined for rapid, moderate, and slow responses.

(3) Background Traffic Condition: The traffic condition at the start of an evacuation will depend upon the time of day the evacuation begins as well as other factors that may influence initial traffic conditions. As the NETVAC2 models were run, initial traffic conditions corresponding to peak, mid-peak, and off-peak ADT levels were analyzed.

The Transportation Analysis simulated evacuations occurring during rush hour by programming evacuees to load onto roadways that were initially set at peak ADT volumes. Conversely, an evacuation occurring at times of light traffic, such as late at night or in the early morning, was modeled by running the model with background vehicles initially set at off-peak ADT volumes. Simulations run with background traffic at mid-peak ADT volumes represented moderate traffic volumes typical of midmorning and mid-afternoon on weekdays or weekends. The number of background vehicles on any roadway during a model run will vary depending upon each road's particular ADT and the hourly percentage of ADT assumed for the traffic condition modeled. A key point in using Figure 6-1 to derive background traffic conditions is that all traffic conditions are derived from actual traffic patterns observed for Connecticut rather than assumed hypothetical conditions. Figures 7a-7c in Appendix C show off-peak, mid-peak, and peak background traffic distributions modeled during evacuation simulations.

Combinations of the three key input parameters listed above were used in developing 18 possible evacuation scenarios. NETVAC2 simulations were run for Categories 1&2 and Categories 3&4 hurricane evacuations; evacuee loading rates defined by slow, moderate and rapid behavioral responses; and traffic conditions corresponding to off-peak, mid-peak, and peak traffic.

6.7 EVACUATION SIMULATION RESULTS

6.7.1 General

Clearance time and dissemination time are two major considerations in deciding when an evacuation recommendation should be issued. The combination of these times defines a region's total evacuation time. Clearance time begins when the public is first made aware of an evacuation and ends when the last evacuee clears the road system. This time includes the time required by evacuees to secure their homes and prepare to leave (mobilization time), the time spent by evacuees traveling along the road network (travel time), and the time lost due to traffic congestion (queuing delay time). Clearance time does not relate solely to the time any one vehicle spends traveling on the road system.

Evacuations must be completed before the arrival of gale force hurricane winds (34 knot/39 mph) and/or storm surge. Otherwise, traffic accidents and reduced travel speeds due to inclement weather can impede traffic flows, and potentially disrupt the evacuation. The analysis assumes that evacuations will occur prior to the arrival of the hurricane to preclude possible delays caused by significant weather, and that provisions would be made for removal of vehicles in distress during the evacuation.

6.7.2 Clearance Times

Tables 6-4 and 6-5 present the clearance times estimated for Fairfield, New Haven, and Middlesex/New London Counties for Categories 1 & 2, and 3 & 4 hurricanes, respectively. Times are organized by intensity of hurricane, by the rate of response of the evacuating population, and by the level of background traffic at the start of evacuations.

The clearance times were calculated assuming that each community is capable of sheltering its individual demands and no shelter capacity deficiencies exist. The Transportation Analysis tested how inadequate shelter capacity might influence clearance times using a range of different assumed shelter usage rates. Results showed that deficiencies in shelter capacity have a minimal effect on clearance time. This point is explained by the fact that the numbers of vehicles determined to travel to public shelters is very small in comparison to all vehicles on roadways. Consequently, the clearance times provided in Tables 6-4 and 6-5 are considered valid for the existing condition of deficient community shelter capacity and in the future if community sheltering capabilities improve.

The highest clearance time calculated by the Transportation Analysis was ten hours for the New Haven network. This time assumed a slow behavioral response during a Categories 3&4 hurricane evacuation scenario occurring at rush hour. Referring to the slow behavioral response curve in Figure 4-1, the last evacuees do not leave their homes until eight hours after being directed to do so. The late response by these people combined with the effects of heavy traffic from a peak traffic condition creates a substantial amount of congestion along Interstate 95 northbound at the junction of Interstate 91. Simulation results showed that traffic queuing on Interstate 95 northbound (near the interchanges with US Route 1 and Route 162) can impede people leaving Milford and West Haven exiting US Route 1 and Route 162 onto Interstate 95. Even more queuing was observed in this area when the moderate and rapid behavioral response curves were used. In these simulations, the same numbers of evacuees were loaded onto roadways over shorter periods of time thereby reducing the capacities of intersections and roadways still further.

Clearance times for the New Haven network were appreciably reduced with changes in the assumed behavioral response and background traffic condition modeled. Clearance time was estimated to be 8 hours for Categories 3&4 evacuation scenarios occurring at peak background traffic assuming a moderate behavioral response. The same scenario modeled using a mid-peak background traffic condition estimated clearance time to be 7 hours. The reduction in background vehicles under a mid-peak traffic condition resulted in a decrease in clearance time by one hour. The off-peak traffic condition further reduced clearance time by 1/2 hour for a total of 6 1/2 hours time.

For the Middlesex/New London and Fairfield networks, clearance times estimated for the moderate and slow behavioral responses are nearly independent of the background traffic condition and severity of the hurricane. Instead, clearance times are directly correlated to behavioral response. For both networks, clearance times for Categories 1&2 and 3&4 hurricanes were estimated to be 6 1/2 hours assuming a moderate behavioral response and 8 1/2 hours assuming a slow behavioral response. Referring to the behavioral response curves in Figure 4-1, under a moderate behavioral response, the last evacuees leave their homes 6 hours after being advised to do so. Similarly, under a slow behavioral response, the last evacuees leave 8 hours after being advised to do so. Referring to Figure 4-1, clearance times of 6 1/2 and 8 1/2 hours suggest that an additional 1/2 hour is required by the last evacuees leaving their homes to travel to safe destinations.

As people respond more quickly to evacuation orders, more vehicles enter onto roadways in a shorter period of time. In effect, roadway capacities are reduced, resulting in slower travel speeds, and more vehicles competing for the rights of way at intersections. The outcome of this can be seen by reviewing the clearance times estimated using the rapid behavioral response. As shown in Figure 4-1, a rapid behavioral response implies that the last evacuees leave their homes 4 hours after being directed to do so. Clearance times were estimated to be 4 1/2 to 5 hours for the Middlesex/New London and Fairfield networks, and range from 4 1/2 to 6 1/2 hours for the New Haven network. For the New Haven network these results suggest that the last people to evacuate will experience travel times of 1/2 to 2 1/2 hours depending upon the severity of the hurricane and the background traffic condition assumed. In the Middlesex/New London and Fairfield networks, the capacities of the roadway systems are such that in these counties the last people to evacuate will have travel times of one hour or less.

TABLE 6-4
SUMMARY OF CLEARANCE TIMES (Categories 1&2 Hurricanes)

	BACKGROUND TRAFFIC CONDITION		
	Off-peak	Mid-peak	Peak
FAIRFIELD COUNTY			
Rapid Response	4-1/2 hrs.	4-1/2	4-1/2
Moderate Response	6-1/2	6-1/2	6-1/2
Slow Response	8-1/2	8-1/2	8-1/2
NEW HAVEN COUNTY			
Rapid Response	4-1/2	4-1/2	6
Moderate Response	6-1/2	6-1/2	7
Slow Response	8-1/2	8-1/2	9
MIDDLESEX/NEW LONDON COUNTY			
Rapid Response	4-1/2	5	5
Moderate Response	6-1/2	6-1/2	6-1/2
Slow Response	8-1/2	8-1/2	8-1/2

NOTE: Dissemination time must be added to the clearance times listed in the table to estimate total evacuation time.

TABLE 6-5
SUMMARY OF CLEARANCE TIMES (Categories 3&4 Hurricanes)

	BACKGROUND TRAFFIC CONDITION		
	Off-peak	Mid-peak	Peak
FAIRFIELD COUNTY			
Rapid Response	4-1/2 hrs.	4-1/2	5
Moderate Response	6-1/2	6-1/2	6-1/2
Slow Response	8-1/2	8-1/2	8-1/2
NEW HAVEN COUNTY			
Rapid Response	5-1/2	6	6-1/2
Moderate Response	6-1/2	7	8
Slow Response	8-1/2	9	10
MIDDLESEX/NEW LONDON COUNTY			
Rapid Response	4-1/2	5	5
Moderate Response	6-1/2	6-1/2	6-1/2
Slow Response	8-1/2	8-1/2	8-1/2

NOTE: Dissemination time must be added to the clearance times listed in the table to estimate total evacuation time.

Chapter Seven

EVACUATION TIMES

7.1 INTRODUCTION

The Transportation Analysis developed clearance times for 18 evacuation scenarios each varying by hurricane severity, behavioral response, and the level of background traffic at the start of an evacuation. A range of evacuation scenarios were used to quantify most of the evacuation situations officials might have to consider when deciding if, and when, an evacuation should be conducted. Despite the broad range of scenarios modeled, there is not a wide variation in the computed clearance times. To assist in implementing a coordinated state and local evacuation, this Study recommends that a single clearance time of seven (7) hours be used in nearly all instances. The rationale for this recommendation is presented in the following sections.

As mentioned in the Transportation Analysis, clearance time is one component of evacuation time. An additional time component, dissemination time, must be added to clearance time to determine the total time necessary to conduct a complete evacuation after the decision has been made to evacuate. This chapter further explains how evacuation times can be estimated.

7.2. INFLUENCE OF BEHAVIORAL RESPONSE

How the threatened population responds to public officials' warnings can be a critical factor in whether an evacuation will be completed before the arrival of a storm. Three behavioral response curves were considered in the Transportation Analysis which represent a slow, moderate and rapid response by the public. The rapid behavioral response curve (see Figure 4-1) assumes that 85 percent of all evacuees will leave their homes within four hours time of being directed to do so by officials. This curve represents the public's response in a situation where people react quickly to aggressive warnings issued by public officials. The use of clearance times derived assuming a rapid behavioral response most typically characterizes an evacuation scenario where officials had not expected the hurricane to impact their locations, yet the storm unexpectedly changed its course and now suddenly threatens the State. In most evacuations, "quick" public responses of this nature are extremely optimistic; people generally require more time to mobilize and leave their homes.

The use of clearance times based on a rapid public response yields clearance times which lack an acceptable margin of safety. If officials delay making an evacuation recommendation to the public, and the hurricane unexpectedly accelerates, it may not be possible to complete the evacuation prior to the arrival of the storm. Conversely, if the officials had made an evacuation decision based upon the moderate behavioral response, it would still be possible to complete evacuations even if the storm accelerated. Because the rapid behavioral response offers no margin of safety and is extremely optimistic during most evacuations, the Corps of Engineers and FEMA recommend that evacuation decisions not be based on clearance times derived from this curve.

As preliminary clearance times were developed in the Transportation Analysis, meetings were held with State and local officials to present modeling assumptions and obtain input to be incorporated into the development of the final clearance times. Many local officials expressed concern that the slow behavioral response curve (see Figure 4-1) yielded clearance times longer than they realistically expected. This curve assumes that 85 percent of evacuees will leave their homes over an eight hour period after an evacuation recommendation is issued. Officials stated that they would be able to evacuate vulnerable residents in less time than the slow behavioral response curve indicates. Some officials reasoned that smaller cities and town have advantages over large metropolitan areas in that more officials are available to personally notify residents to leave. They indicated that dissemination of evacuation recommendations by door to door notification, or by issuing warnings over loud speakers of emergency vehicles will reduce the behavioral response time. After discussions with all communities and officials from the Connecticut Office of Emergency Management, it was determined that the clearance times developed from the slow behavioral response curve were not representative and should only be presented for comparative purposes.

In conclusion, this report recommends that state and local officials use clearance times based on the moderate response curve because of the limited margin of safety afforded by the rapid behavioral response curve and the general lack of acceptance of the slow response curve.

7.3 INFLUENCE OF BACKGROUND TRAFFIC

The amount of existing traffic (background traffic) on roadways at the start of an evacuation is another factor that can influence the safe completion of the overall evacuation. The Transportation Analysis used a sensitivity approach to determine how clearance times would be affected by varying levels of background traffic. The analysis considered three levels of background traffic: off-peak, mid-peak, and rush hour conditions. The results showed that only the clearance times for the coastal areas of New Haven County were significantly impacted by background traffic. In the other counties background traffic levels have little influence on the calculated clearance times.

It is unlikely that background traffic will be at a level as high as rush hour on a day for which a hurricane is forecasted. This is not to imply, however, that the combination of evacuating and background traffic can not produce traffic conditions near, or worse than, rush hour volumes. Should a hurricane be forecasted to landfall during the day time, it is reasonable to expect that many of the commuters will not risk traveling to work, assuming that public officials discourage their attendance at work that day. News and weather forecasts will certainly discourage some employers from opening. Businesses that do open will probably shut down early allowing people time to travel home before the storm arrives. Traffic data collected in Connecticut on the days of Hurricanes Gloria and Bob showed that during these two events traffic levels were lower than that routinely experienced during rush hour on a normal day. Mid-peak or off-peak background traffic conditions more realistically represent the background traffic that will be present during evacuation along the Connecticut coast. Therefore, officials should consider the use of clearance times derived from these background traffic conditions rather than the peak condition.

7.4 RECOMMENDED CLEARANCE TIMES

In summary, by eliminating clearance times calculated from either a rapid behavioral response or slow behavioral response, or from the peak background traffic condition, clearance times for all areas range from 6 1/2 to 7 hours (see Tables 6-4 and 6-5). Therefore, it is recommended that the Connecticut Office of Emergency Management and communities use a 7 hour clearance time for all evacuation scenarios, except if special circumstances warrant the use of one of the other clearance times calculated in the Study. Some circumstances that may warrant use of different clearance times are cases where the approaching hurricane accelerates, changes course, or if an unusual behavioral response or background traffic condition are anticipated. However, the Corps of Engineers and FEMA recommend that clearance times less than 7 hours time not be used by communities as a basis for evacuation planning.

In Connecticut, the decision to conduct an evacuation is an operational decision made at the community level. The adoption of a seven hour clearance time for most evacuation scenarios helps to eliminate discrepancies that might surface in evacuation decision-making from one community to the next. Furthermore, a state-wide evacuation time, developed from the seven hour clearance time which is mutually agreed upon by the State and communities, would give support to clear and consistent warning messages to be broadcasted to all threatened coastal areas at one time.

7.5 CALCULATION OF EVACUATION TIME

Dissemination time is the amount of time required by officials to notify the public to evacuate after the decision to evacuate is made. This includes necessary time for emergency management agencies to mobilize support personnel, coordinate the evacuation among all affected areas, and to issue consistent warnings to the public. It is not reasonable to assume that once the State has made an evacuation recommendation to communities that all 25 communities will immediately respond by issuing evacuation notices to the public. Dissemination time accounts for the necessary coordination time between State and local officials. However, dissemination time is not simply limited to this. Inherently, an amount of time is associated with mobilizing emergency officials within communities such that they can begin activating sirens, broadcasting warnings from emergency vehicles, and travel door to door to warn the public. Moreover, warning plans may include provisions for issuing advisories over the radio or on television, again requiring coordination time.

The hurricane preparedness procedures listed above are operational functions that will vary from location to location. This study does not attempt to quantify dissemination time, but instead recommends that the Connecticut Office of Emergency Management derive dissemination times after it thoroughly examines its own State Warning Plan and communication procedures. Dissemination time is a critical element necessary for effective implementation of this study's results.

Figure 7-1 illustrates the two components of evacuation time and the relation of this time with respect to hurricane landfall. As shown, evacuation time starts once an evacuation decision is made and ends after the last evacuating vehicles clear off roadways. Evacuation time is the combined total of dissemination time and clearance time (seven hour clearance time is recommended for most evacuations). Once officials select a suitable evacuation time, the

Decision Arc Method of the next chapter can be used to determine when, and if, evacuation proceedings should be initiated.

One of the specific objectives of the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York completed in May 1993 was to identify the roles, standard procedures, and communication systems the Connecticut Office of Emergency Management and local communities use during hurricane emergencies. Officials are encouraged to refer to this document as there are important recommendations and information that can aid the State in quantifying dissemination time.

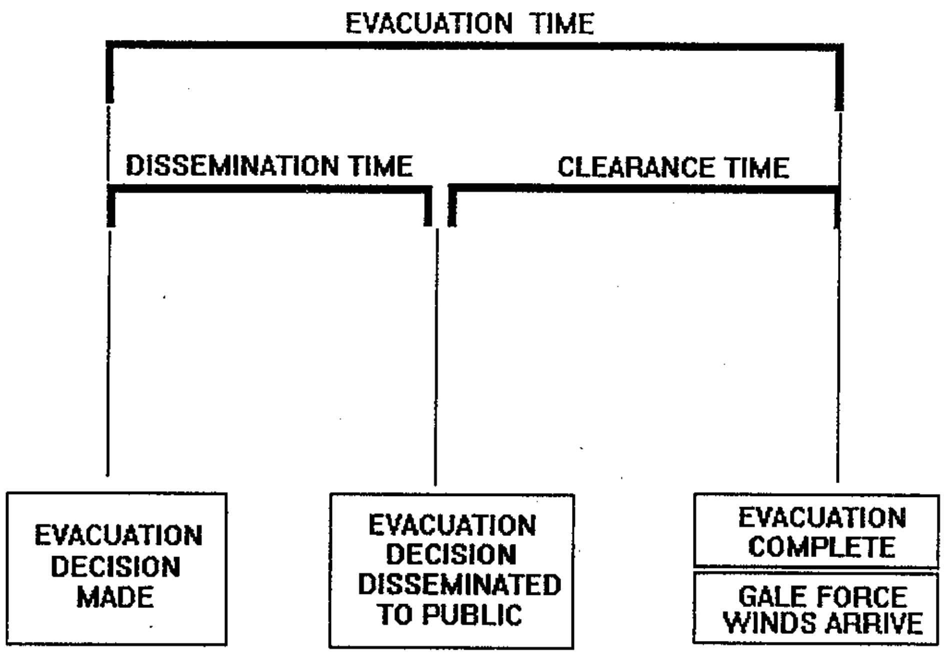


FIGURE 7-1. COMPONENTS OF EVACUATION TIME

Chapter Eight

DECISION ANALYSIS

8.1 PURPOSE

The Decision Arc Method is a tool that uses a region's evacuation time in conjunction with National Hurricane Center advisories to calculate when evacuations must begin in order for them to be completed prior to the arrival of a hurricane's gale force winds. This chapter discusses the usefulness of the Decision Arc Method and provides a step-by-step procedure of how this method can be applied in Connecticut.

8.2 BACKGROUND

The two meteorological parameters which determine a hurricane's point of landfall and the time it will arrive at its landfall location are its track and forward speed. These two parameters are inherently challenging to predict for hurricanes that impact New England. Hurricanes moving from the tropics into the mid-Atlantic region encounter a dramatic change in steering currents, which usually result in a rapid acceleration of forward speed. Invariably, a New England hurricane needs to be relatively fast moving to avoid losing strength over the cooler waters north of Cape Hatteras. The timing of when such an acceleration in forward speed will take effect is difficult to predict which results in a corresponding uncertainty in the expected time of landfall. Table 1-1 in Chapter One provides information on hurricanes passing within 150 statute miles of Newport, Rhode Island. Of the 29 hurricanes listed in this table, 18 of them (51 percent) accelerated to 25 mph or more, 11 (31 percent) accelerated to 35 mph or more, and 6 (17 percent) accelerated to 45 mph or more.

In situations where a hurricane is still hundreds of miles from the Connecticut coast and forecasters are reasonably confident of the average forward speed the hurricane will travel, estimates of the time of landfall can be reasonably accurate. On the other hand, when weather officials are unable to make confident forecasts of a storm's forward speed, a great uncertainty exists in its time of landfall. For example, a hurricane that undergoes an increase in its forecasted forward speed from 30 mph to 40 mph over a 12 hour period can mean the storm will arrive 3 hours sooner than originally forecasted. Officials who had planned on having 12 hours time for issuing warnings and evacuating the public now have to hurriedly conduct evacuations and risk not completing them in time.

Similarly, errors in forecasted track direction create other problems for public officials. If for example, a hurricane makes a slight shift in its direction of travel while still several hours away from its predicted landfall location, its actual landfall location may occur more than one hundred miles from that originally forecasted. A one hundred mile deviation in landfall location might mean that a hurricane forecasted to landfall in the vicinity of Cape Cod, Massachusetts will actually "miss" and pass well out to sea or "hit" Connecticut directly. Thus, what might appear to be a non-evacuation situation could quickly change to be an urgent evacuation scenario.

The combination of inaccuracies in hurricane forecasting and the lengths of the clearance times calculated for Connecticut make hurricane evacuation decision-making a difficult task. Depending upon the average forward speed of a hurricane, and the evacuation time computed by State and local officials (see Chapter Seven), evacuations may have to be initiated while a storm is still hundreds of miles away. The decision to evacuate becomes more difficult when officials consider the uncertainty that exists at this point in a hurricane's track as to whether or not the hurricane will even make landfall in New England. Regardless of these uncertainties, officials must initiate evacuations even when the probability is low that their locations will be impacted. Even if a hurricane that is off the coast of North Carolina is not forecasted to strike Connecticut directly, officials might still need to begin evacuation proceedings in the event the storm unexpectedly changes course. It is recognized that the decision to start evacuations while storms are still several hours away is not easy one. Therefore, the information presented in this Chapter is designed to assist emergency management officials in using the data provided by this Study with the National Hurricane Center's Marine and Public Advisories for evacuation decision-making.

8.3 DECISION ARC COMPONENTS

8.3.1 General

The Decision Arc Method employs two separate but related components which, when used together, depict the hurricane situation as it relates to the State. A specialized hurricane tracking chart, the Decision Arc Map, is teamed with a transparent two-dimensional hurricane graphic, the STORM, to describe the approaching hurricane and its location in relation to the State.

8.3.2 Decision Arc Map

In order to properly evaluate the last reported position and track of an approaching hurricane, a special hurricane tracking chart has been developed for Connecticut and is provided at the end of this chapter. Superimposed on ordinary tracking charts are series of concentric arcs with their centers at New Haven, Connecticut (approximately the centerline of the State's coast). The arcs are spaced at 50 nautical mile intervals. These arcs are measured from their centers and labeled in nautical miles to correspond with the units of nautical miles given in the NHC's advisories.

8.3.3 Storm

The Special Tool for Omni-directional Radial Measurements (STORM) is used as a two-dimensional depiction of an approaching hurricane. It is a transparent disk with concentric circles spaced at 25 nautical mile intervals, their center representing the hurricane's eye. These circles form a scale used to note the radius of 34 knot winds (gale force) reported by the National Hurricane Center in the Marine Advisory (sample Marine Advisory and Public Advisories on pages 8-11 through 8-14).

8.4 DECISION ARC METHOD

8.4.1 General

A hurricane evacuation should be completed prior to the arrival of sustained 34 knot (gale-force) winds or the onset of storm surge inundation, whichever occurs first. In the Connecticut Hurricane Evacuation Study area, the limiting factor for hurricane evacuation is the arrival of sustained 34 knot winds.

The evacuation time is computed as the combination of clearance time and dissemination time. Tables 6-4 and 6-5 list Connecticut's clearance times for all modeled scenarios. However, as noted in Chapter Seven, a clearance time of seven hours is recommended for most hurricane evacuations. Officials, after determining an appropriate dissemination time, must add this value to the clearance time to determine the total evacuation time. Evacuation time specifies when officials need to disseminate evacuation notices to the public to ensure all evacuees have enough time to mobilize and leave their homes, and all vehicles have time to travel off roadways. Evacuation time is measured in hours required prior to the arrival of sustained 34 knot winds.

Decision Arcs are simply evacuation times converted to distance by accounting for the forward speed of the hurricane. A simple calculation of multiplying the evacuation time by the forward speed of the hurricane in knots is necessary to translate evacuation time into nautical miles for use with a Decision Arc Map. This calculation yields the distance in nautical miles that the 34 knot wind field will move while the evacuation is underway. For convenience, a Decision Arc table that converts a matrix of evacuation times and forward speeds to respective Decision Arcs in nautical miles has been provided in Table 8-3.

8.4.2 Should Evacuation Be Recommended?

Probability values shown in the National Hurricane Center's Public Advisory describe in percentages the chance that the center of a storm will pass within 65 nautical miles of the listed locations. To check the relative probability for a particular area, the total probability value for the closest location, shown on the right side of the probability table in the Public Advisory, should be compared to other locations. A comparison should also be made with the possible maximums shown in the listing of maximum probability values provided in Table 8-3. There is no one threshold probability which should prompt an evacuation under any and every hurricane threat. The size and intensity of the storm, as well as its anticipated approach track will need to be considered.

8.4.3 When Evacuation Should Begin

As a hurricane approaches, the Decision Arc Method requires officials to make an evacuation decision prior to the time at which the radius of sustained 34 knot winds intersects the appropriate Decision Arc (the Decision Point). For example, with an evacuation time of 12 hours, and a hurricane with an average forward speed of 30 knots, the evacuation should be initiated before the sustained 34 knot winds approach within a 360 nautical miles distance (12 hours x 30 nautical miles per hour = 360 nautical miles). The 360 mile distance can be linearly interpolated between the "350" and "400" mile arcs on the Decision Arc Map. Once the sustained 34 knot winds move across the Decision Arc (within 360 nautical miles of your location for this example), there may not be sufficient time to safely evacuate the affected population.

8.5 STEP-BY-STEP DECISION ARC PROCEDURE

The following procedure has been developed to provide assistance in determining IF an evacuation should be initiated and WHEN an evacuation decision must be made. The National Weather Service hurricane probability listing included in the Public Advisory is used to assist in this decision making process (see sample Public Advisory p. 8-13).

There are five basic "tools" needed in this evacuation decision procedure: (1) Decision Arc Map; (2) Decision Arc Table; (3) transparent STORM disk; (4) the National Hurricane Center Marine Advisory; (5) the National Hurricane Center Public Advisory.

PROCEDURE

1. From the National Hurricane Center Marine Advisory, plot the last reported position of the hurricane eye on the Decision Arc Map. Notate position with date/time. ZULU time (Greenwich mean time or UTC [Universal Coordinated Time]) used in the advisory should be converted to eastern daylight time by subtracting four (4) hours (see Table 8-4 for conversion of times). Plot and notate the five forecast positions of the hurricane from the advisory.

2. From the Marine Advisory, note the maximum radius of 34 knot winds (observed or forecast), the maximum sustained wind speed (observed or forecast), and the current forward speed. Plot the maximum radius of 34 knot winds onto the STORM disk.

3. Using the maximum sustained wind speed previously noted, enter the Saffir/Simpson hurricane scale table (Table 8-1) and determine the category of the approaching hurricane.

4. Estimate evacuation time by combining the recommended 7-hour clearance time with an appropriate dissemination time (**evacuation time = clearance time + dissemination time**). Although clearance times were calculated for 18 possible evacuation scenarios, officials are strongly recommended to use a 7-hour clearance time for nearly all evacuation scenarios (for further explanation, and possible exceptions to this, consult Chapter Seven, Evacuation Times). Dissemination time refers to the time officials need to make evacuation decisions, mobilize support personnel, communicate evacuation decisions between affected communities and the State, and disseminate evacuation directives to the public.

5. Determine the forecast forward speed of the hurricane in knots. The forecast speed can be determined by measuring the distance in nautical miles between the first and second forecast positions and dividing that distance by 12 (forecast positions are provided for 12 hour intervals). Compare the forecast forward speed to the current forward speed noted previously. A forecast speed greater than the current forward speed will indicate that the hurricane is forecast to accelerate, reducing the time available to the decision-maker.

6. With the appropriate evacuation time, and the greater of the current or forecast forward speeds, enter Table 8-3 and determine the recommended Decision Arc in nautical miles. Mark this arc on the Decision Arc Map; interpolate between arcs as necessary.

7. Using the center of the STORM as the hurricane eye, locate the STORM on the Decision Arc Map at the last reported hurricane position. Determine if the radius of 34 knot winds falls within the selected Decision Arc; i.e., past the Decision Point (the point at which the radius of 34 knot winds crosses into the recommended Decision Arc). If so, public evacuation should be initiated in order to ensure a prompt public response and completion of the evacuation prior to the arrival of sustained 34 knot winds.

8. Move the STORM to the first forecast position. Determine if the radius of 34 knot winds is past the Decision Point. If so, the Decision Point will be reached prior to the hurricane eye reaching the first forecast position.

9. Estimate the hours remaining before a decision must be made by dividing the number of nautical miles between the radius of 34 knot winds and the Decision Point by the forward speed used for the Decision Arc table. Determine if the next National Hurricane Center Marine Advisory will be received prior to the Decision Point.

10. Compare probabilities shown in the Public Advisory to determine whether an evacuation is now necessary or is likely to become necessary (See Note [c.] next page). Check inundation maps to determine where flooding may occur, and evacuation zone maps for zones that should prepare to evacuate.

11. At the Decision Point, check the Public Advisory probability table for your location. There is no one threshold probability which should prompt an evacuation under any and every hurricane threat (See Note [c.] below). The size and intensity of the storm, as well as its approach track will need to be considered.

12. Steps 1 through 10 should be repeated after each National Hurricane Center advisory until a decision is made or the threat of hurricane impacts has passed.

NOTES:

a. As new information becomes available in subsequent National Hurricane Center advisories, evacuation operations should progress so that, if evacuation becomes necessary, the recommendation to evacuate can be given at the Decision Point.

b. Because information given in the Marine Advisory is in nautical miles and knots, the Decision Arc Maps and STORM have a nautical miles scale. When utilizing hurricane information from sources other than the Marine Advisory, care should be taken to assure that distances are given in or converted to nautical miles and speeds to knots. Statute miles can be converted to nautical miles by dividing the statute miles value by 1.15. Similarly, miles per hour can be converted to knots by dividing the miles per hour value by 1.15.

c. Probability values shown in the Public Advisory describe in percentages the chance that the center of a storm will pass within 65 miles of the listed locations. To check the relative probability for your particular area, the total probability value for the closest location, shown on the right side of the probability table in the Public Advisory, should be compared to other locations. A comparison should also be made with the possible maximums for the applicable forecast period shown in the table of maximum probability values listed on Table 8-2. These comparisons will show the relative vulnerability of your location to adjacent locations and to the maximum possible probability.

TABLE 8-1
SAFFIR/SIMPSON HURRICANE SCALE WITH CENTRAL BAROMETRIC PRESSURE RANGES

	CENTRAL PRESSURE		WIND SPEED		SURGE	DAMAGE
CATEGORY	MILLIBAR	INCHES	MPH	KNOTS	FEET	POTENTIAL
1	>980	>28.9	74-95	64-83	4-5	Minimal
2	965-979	28.5-28.9	96-110	84-96	6-8	Moderate
3	945-964	27.9-28.5	111-130	97-113	9-12	Extensive
4	920-944	27.2-27.9	131-155	114-135	13-18	Extreme
5	<920	<27.2	>155	>135	>18	Catastrophic

TABLE 8-2
MAXIMUM PUBLIC ADVISORY PROBABILITY VALUES

FORECAST PERIOD	MAXIMUM PROBABILITY
72 Hours	10 %
60	11
48	13
36	20
30	27
24	35
18	45
12	60

Probabilities listed are the maximum assigned to any location in advance of predicted landfall. To illustrate: the National Hurricane Center would not assign a higher than 35% probability that a hurricane would strike Montack Point in 24 hours, or a higher than 20% probability that a hurricane would strike in 36 hours.

TABLE 8-3
DECISION ARCS

ESTIMATED EVACUATION TIME (HRS.)[1]	FORECAST HURRICANE FORWARD SPEED (KNOTS)[3]										
	10	15	20	25	30	35	40	45	50	55	60
	DECISION ARCS IN NAUTICAL MILES										
4[2]	40	60	80	100	120	140	160	180	200	220	240
5[2]	50	75	100	125	150	175	200	225	250	275	300
6[2]	60	90	120	150	180	210	240	270	300	330	360
7[2]	70	105	140	175	210	245	280	315	350	385	420
8	80	120	160	200	240	280	320	360	400	440	480
9	90	135	180	225	270	315	360	405	450	495	540
10	100	150	200	250	300	350	400	450	500	550	600
11	110	165	220	275	330	385	440	495	550	605	660
12	120	180	240	300	360	420	480	540	600	660	720
13	130	195	260	325	390	455	520	585	650	715	780
14	140	210	280	350	420	490	560	630	700	770	840
15	150	225	300	375	450	525	600	675	750	825	900
16	160	240	320	400	480	560	640	720	800	880	960
17	170	255	340	425	510	595	680	765	850	935	1020
18	180	270	360	450	540	630	720	810	900	990	1080

NOTES:

[1] Evacuation time is the combination of dissemination time and clearance time. Refer to Chapter Seven, Evacuation Times, for more information on dissemination time and recommended clearance times.

[2] It is not expected that evacuation times of less than 7 hours will be used except in cases where a hurricane shifts direction or accelerates unexpectedly, or during evacuations where an unusual behavioral response is anticipated.

[3] Refer to steps 6 and 7 of the Decision Arc Procedure for methods of determining forecast forward speed.

TABLE 8-4
TIME CONVERSIONS

UNIVERSAL COORDINATED TIME (UTC)[2]	EASTERN DAYLIGHT TIME[1] (24 HOUR TIME)	CIVIL-TIME
0500 MONDAY	0100 MONDAY	1 AM MONDAY
0600	0200	2 AM
0700	0300	3 AM
0800	0400	4 AM
0900	0500	5 AM
1000	0600	6 AM
1100	0700	7 AM
1200	0800	8 AM
1300	0900	9 AM
1400	1000	10 AM
1500	1100	11 AM
1600	1200	12 NOON
1700	1300	1 PM
1800	1400	2 PM
1900	1500	3 PM
2000	1600	4 PM
2100	1700	5 PM
2200	1800	6 PM
2300	1900	7 PM
2400 (0000)	2000	8 PM
0100 TUESDAY	2100	9 PM
0200	2200	10 PM
0300	2300	11 PM
0400	2400 (0000)	12 MIDNIGHT
0500	0100 TUESDAY	1 AM TUESDAY

[1] For late season hurricanes (Eastern Standard Time) subtract 5 hours from Universal Time.
[2] UTC = Greenwich Mean Time = ZULU Time; it is expected that future NHC advisories will reference "UTC."

SAMPLE*

MARINE ADVISORY

MIATCMAT1
TTAA00 KNHC 200922
HURRICANE HUGO MARINE ADVISORY NUMBER 38
NATIONAL WEATHER SERVICE MIAMI FL
1000Z [6 AM] WED SEP 20 1989

TROPICAL STORM WARNINGS IN EFFECT FOR CENTRAL AND NORTHWESTERN BAHAMAS AND DISCONTINUED FOR SOUTHEASTERN BAHAMAS.

HURRICANE CENTER LOCATED NEAR 24.9N 70.5W AT 20/1000Z.
POSITION ACCURATE WITHIN 15 MILES BASED ON AIRCRAFT AND SATELLITE.

PRESENT MOVEMENT TOWARDS THE NORTHWEST OR 325 DEGREES AT 11 KT.

DIAMETER OF EYE 15 NM.
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 105 KT.
RADIUS OF 64 KT WINDS 60NE 60SE 40SW 60NW.
RADIUS OF 50 KT WINDS 100NE 100SE 50SW 100NW.
RADIUS OF 34 KT WINDS 150NE 125SE 100SW 175NW.
RADIUS OF 12 FT SEAS OR HIGHER 150NE 125SE 100SW 175NW.

REPEAT CENTER LOCATED AT 24.9N 70.5W AT 20/1000Z.

FORECAST VALID 20/1800Z 26.0N 71.4W.
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 105 KT.
RADIUS OF 50 KT WINDS 100NE 100SE 50SW 100NW.
RADIUS OF 34 KT WINDS 150NE 125SE 100SW 175NW.

FORECAST VALID 21/0600Z 27.8N 72.9W.
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 105 KT.
RADIUS OF 50 KT WINDS 100NE 100SE 50SW 100NW.

RADIUS OF 34 KT WINDS 150NE 125SE 100SW 175NW.

(CONTINUED)

*This advisory was issued approximately 42 hours before Hurricane struck the South Carolina coast near midnight on September 21, 1989.

SAMPLE
MARINE ADVISORY
(CONTINUED)

FORECAST VALID 21/1800Z 29.2N 74.8W.
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 105 KT.
RADIUS OF 50 KT WINDS 100NE 100SE 50SW 100NW.
RADIUS OF 34 KT WINDS 150NE 125SE 100SW 175NW.

REQUEST FOR 3 HOURLY SHIP REPORTS WITHIN 300 MILES OF
24.9N 70.5W.

EXTENDED OUTLOOK
THE FOLLOWING FORECASTS SHOULD BE USED ONLY FOR GUIDANCE
PURPOSES BECAUSE ERRORS MAY EXCEED A FEW HUNDRED MILES

OUTLOOK VALID 22/0600Z 30.5N 78.0W.
MAX SUSTAINED WINDS 90 KT WITH GUSTS TO 105 KT.
RADIUS OF 50 KT WINDS 100NE 100SE 50SW 100NW.

OUTLOOK VALID 23/0600Z 33.5N 81.0W.
MAX SUSTAINED WINDS 60 KT WITH GUSTS TO 75 KT.
RADIUS OF 50 KT WINDS 100SE .
NEXT ADVISORY AT 20/1600Z.

SAMPLE*
PUBLIC ADVISORY

88
MIATCPAT1
ETTAA00 KNHC 200925
BULLETIN
HURRICANE HUGO ADVISORY NUMBER 38
NATIONAL WEATHER SERVICE MIAMI FL
6 AM EDT WED SEP 20 1989

A TROPICAL STORM WARNING IS IN EFFECT FOR THE CENTRAL AND NORTHWESTERN BAHAMAS AND IS DISCONTINUED FOR THE SOUTHEASTERN BAHAMAS.

AT 6 AM EDT THE CENTER OF HUGO WAS LOCATED NEAR LATITUDE 24.9 NORTH LONGITUDE 70.5 WEST OR ABOUT 435 MILES EAST OF NASSAU IN THE BAHAMAS.

THE CENTER OF HUGO HAS BEEN MOVING TOWARD THE NORTHWEST AT 12 MPH AND THIS GENERAL MOTION IS EXPECTED TO CONTINUE FOR THE NEXT 24 HOURS.

MAXIMUM SUSTAINED WINDS ARE NEAR 105 MPH AND LITTLE CHANGE IN STRENGTH IS LIKELY TODAY. HURRICANE FORCE WINDS EXTEND OUTWARD UP TO 60 MILES FROM THE CENTER AND TROPICAL STORM FORCE WINDS EXTEND OUTWARD UP TO 200 MILES. THE LATEST MINIMUM PRESSURE REPORTED BY AN AIR FORCE RECONNAISSANCE PLANE IS 957 MILLIBARS...28.26 INCHES.

REPEATING THE 6 AM EDT POSITION...24.9N...70.5W. MOVEMENT... NORTHWESTWARD AT 12 MPH. MAXIMUM SUSTAINED WINDS...105 MPH. CENTRAL PRESSURE...957 MB.

THE NEXT ADVISORY WILL BE ISSUED BY THE NATIONAL HURRICANE CENTER AT NOON EDT WITH AN INTERMEDIATE ADVISORY AT 9 AM.

(CONTINUED)

*This advisory was issued approximately 42 hours before Hurricane Hugo struck the South Carolina coast near midnight on September 21, 1989.

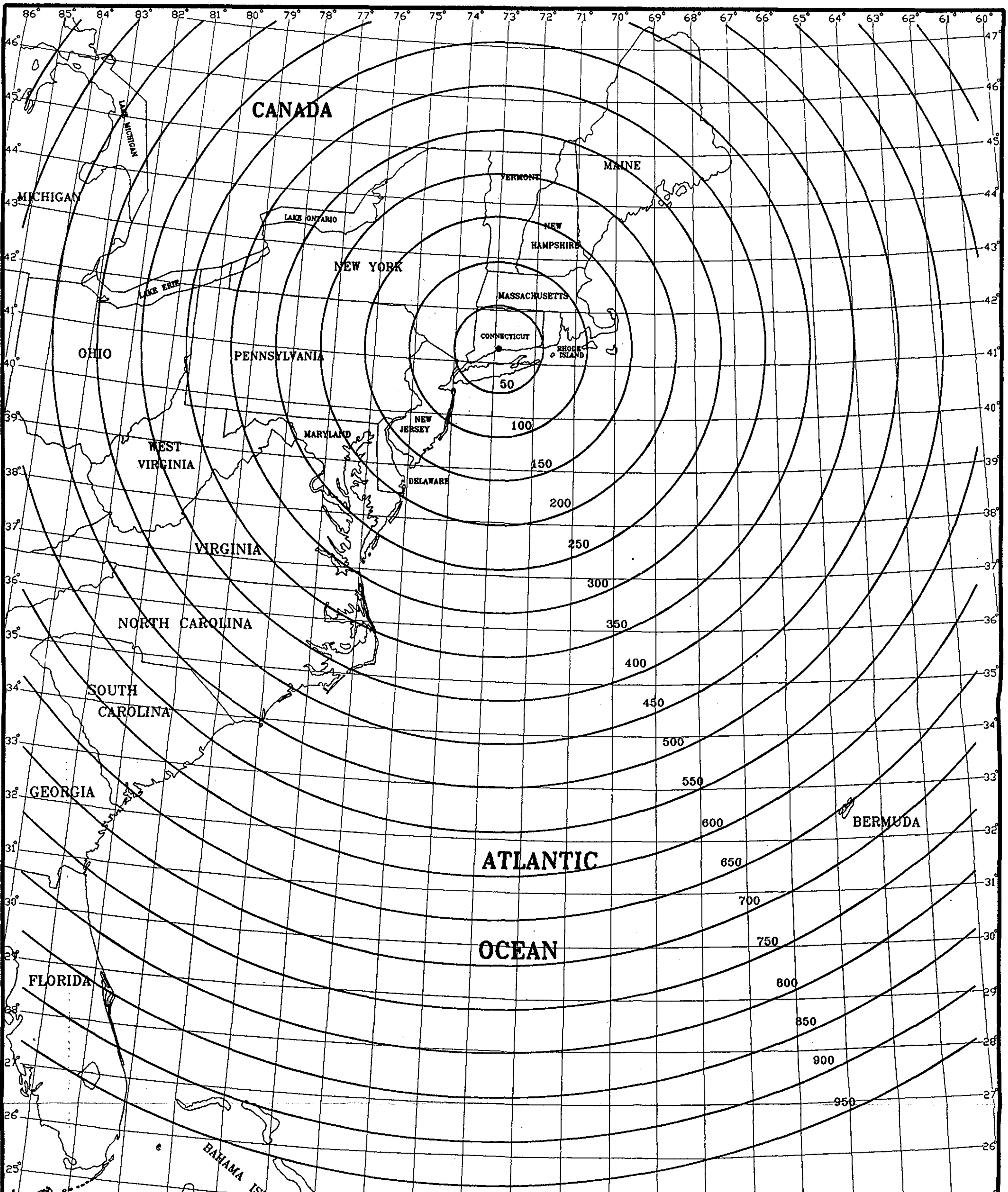
SAMPLE
PUBLIC ADVISORY
(CONTINUED)

ADVISORY NUMBER 38 HURRICANE HUGO PROBABILITIES
FOR GUIDANCE IN HURRICANE PROTECTION PLANNING
BY GOVERNMENT AND DISASTER OFFICIALS

CHANCES OF CENTER OF HUGO PASSING WITHIN 65 MILES OF
LISTED LOCATIONS THROUGH 2 AM EDT SAT SEP 23 1989
CHANCES EXPRESSED IN PER CENT...TIMES EDT

		ADDITIONAL PROBABILITIES			
COASTAL LOCATIONS	2 AM THU THRU 2 AM THU	2 PM THU THRU 2 PM THU	2 AM FRI THRU 2 AM FRI	THRU 2 AM SAT	TOTAL THRU 2 AM SAT
MYSM 241N 745W	1	2	X	1	4
MYEG 235N 758W	X	1	1	X	2
MYAK 241N 776W	X	1	1	1	3
MYNN 251N 775W	X	3	2	1	6
MYGF 266N 787W	X	3	5	2	10
MARATHON FL	X	X	2	2	4
MIAMI FL	X	1	3	2	6
W PALM BEACH FL	X	1	5	2	8
FT PIERCE FL	X	1	6	3	10
COCOA BEACH FL	X	1	7	3	11
DAYTONA BEACH	X	1	6	4	11
JACKSONVILLE FL	X	X	6	5	11
SAVANNAH GA	X	X	5	6	11
CHARLESTON SC	X	X	6	6	12
MYRTLE BEACH	X	X	6	5	11
WILMINGTON NC	X	X	5	6	11
MOREHEAD CITY	X	X	5	5	10
CAPE HATTERAS	X	X	4	5	9
NORFOLK VA	X	X	1	6	7
OCEAN CITY MD	X	X	X	5	5
ATLANTIC CITY NJ	X	X	X	4	4
NEW YORK CITY	X	X	X	3	3
MONTAUK POINT	X	X	X	2	2
PROVIDENCE RI	X	X	X	2	2
NANTUCKET MA	X	X	X	2	2

"X" MEANS LESS THAN ONE PERCENT

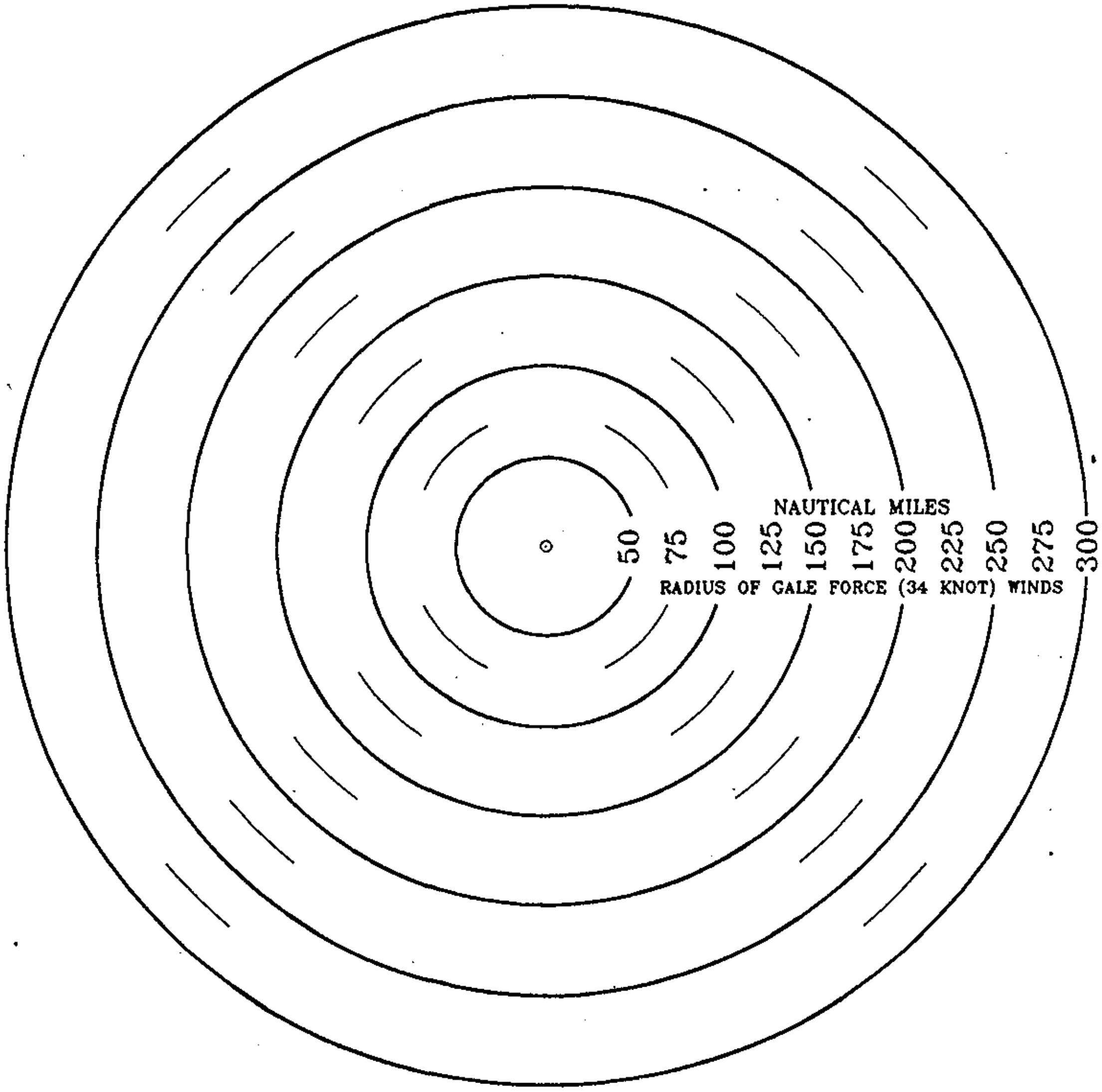


CONNECTICUT HURRICANE EVACUATION STUDY DECISION ARC MAP

SCALE: 100 50 0 100 200 Nautical Miles

Prepared by the U.S. Army Corps of Engineers, New England Division in cooperation with the Federal Emergency Management Agency, Region I for the State of Connecticut, Office of Emergency Management.

FIGURE 8-1 Decision Arc Map


NAUTICAL MILES
50
75
100
125
150
175
200
225
250
275
300
RADIUS OF GALE FORCE (34 KNOT) WINDS

STORM

Chapter Nine

SUMMARY

The purpose of this study is to provide Connecticut state and local emergency management agencies with data quantifying the major factors involved in hurricane evacuation decision-making. The results of this study are not intended to replace existing hurricane preparedness plans but rather to provide State-of-the-art information that can be used to update or revise current plans. This information includes the extent and severity of potential flooding, estimates of vulnerable population, public shelter locations and capacities, and roadway clearance times. The study also presents a step-by-step decision-making procedure outlining how this information can be used with National Hurricane Center advisories in making hurricane evacuation decisions.

Additionally, two companion atlases, the Inundation Map Atlas, and the Evacuation Map Atlas were completed as part of this study. The Inundation Map Atlas delineates the land areas potentially vulnerable to worst case flooding for four hurricane categories. The Evacuation Map Atlas shows the evacuation zones developed for each community and presents the locations of public shelters and other critical facilities.

Throughout the report, several important assumptions and key points are made. The following paragraphs summarize some of the major steps completed in this study and re-emphasize many key points and assumptions.

In the Hazards Analysis, the National Hurricane Center applied the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model to the Connecticut study area and calculated the flooding effects from each of a total of 533 hypothetical hurricanes. The focus of the modeling was to determine the maximum storm surges that could be reasonably expected from hurricanes of worst case combinations of meteorological parameters. It was determined for the Connecticut study area that the height of peak surge at a particular location is predicated mostly on the intensity of the modeled hurricane rather than other meteorological characteristics such as hurricane forward speed, direction, or point of landfall. Therefore, worst case hurricane surges were grouped by category of storm and added to mean high tide elevations to estimate the worst possible storm tides for each category of storm. Category 5 hurricanes were omitted from the analysis by the National Hurricane Center because the cooler ocean waters of the northeast United States are not capable of sustaining a hurricane of Category 5 intensity. Historically, the most intense hurricane that New England has experienced was the 1938 Hurricane, which researchers have classified as a strong Category 3 hurricane.

A separate analysis for associated wave run-up was performed which showed that wave effects do not significantly contribute to increased flooding of land areas. Wave heights along the coast and over the interior portions of the flooded land can be excessively high, however, as waves propagate and break farther inland, frictional losses diminish their contributions to flooding beyond stillwater levels. A storm tide elevation profile was developed for the Connecticut coast which graphically presents the worst case coastal flood levels that are possible for each of the hurricane categories modeled.

The Vulnerability Analysis used the worst case flood elevations determined from the Hazards Analysis to develop an Inundation Map Atlas for the State. This Atlas delineates the land areas that may become inundated from hurricane surge for the three flooding scenarios characterized in the storm tide elevation profile. A second atlas, the Evacuation Map Atlas, used the flooding information from the Inundation Map Atlas to develop evacuation zones for each community. With the assistance of community officials, evacuation zones were delineated using the 1990 census block boundaries to aid in the development of vulnerable population estimates. The evacuation zone boundaries were selected such that they generally conform to man-made physical features. The reason for this is that officials using these maps would be able to promptly and definitively convey to the public, land area limits which should be considered for evacuation. Additionally, the names and locations of public shelters, medical/institutional facilities, and mobile homes/trailer parks are listed and shown in the Evacuation Map Atlas.

The Vulnerability Analysis determined that the State has more than 150,000 residents potentially vulnerable to hurricane surge from Categories 1 and 2 hurricanes and 280,000 residents are potentially vulnerable to surges from Categories 3 and 4 hurricanes. A Behavioral Analysis was preformed to establish the best estimates of how the vulnerable population would respond in future hurricane threats. Factors investigated were: the percentage of residents that would leave vulnerable areas if directed to do so by authorities, the percentage of the evacuating population who would use public shelters, and the rates at which people would leave their homes once advised to do so. Behavioral assumptions were primarily derived using a "general response model" which qualitatively estimates human behavior during hurricanes based on behavioral information collected after many hurricanes occurring over the past three decades. Several meetings were held with the State and communities to discuss and establish the behavioral assumptions that would be used for the remainder of the study.

The next step of the study was the Shelter Analysis. In this analysis, behavioral assumptions and vulnerable population statistics were used to estimate the numbers of people in each community who would seek public shelters during a hurricane evacuation (shelter demand). Estimates were made for two levels of hurricane threat, namely, the numbers of people who are expected to use public shelters during Categories 1 and 2 hurricanes, and during Categories 3 and 4 hurricanes. Communities and local American Red Cross chapters working together inventoried existing facilities and attempted to predesignate additional public shelters to meet expected demands. The Shelter Analysis determined that in some communities there is an inadequate amount of public shelter capacity. Shelter selection guidelines established by the American Red Cross are reprinted in this report to assist in future work by communities to locate additional public shelters.

An important aspect in hurricane evacuation decision-making is knowing how long it will take to clear evacuating vehicles off roadways after the public is directed to evacuate. The Transportation Analysis was undertaken to estimate roadway clearance times for Connecticut considering a variety of different hurricane evacuation scenarios. An evacuation simulation computer model was used to create a mathematical representation of the road system in coastal Connecticut. The model was used to simulate evacuations and estimate roadway clearance times. Three important factors that were varied with each evacuation simulation were: the behavioral response of evacuees leaving their homes, hurricane severity, and background traffic conditions that might occur as evacuation proceedings are initiated. Clearance times range from 4 1/2 hours to 10 hours depending upon the above three factors and the county in which the evacuation simulations were modeled. In all counties, the adoption of a 7 hour clearance time is recommended for nearly all evacuation situations, and the use of other clearance times presented in this report are recommended only if sudden changes in the storm's behavior is observed, or if unexpected conditions warranted their use. **Clearance time must be combined with dissemination time (described below) to estimate the total time necessary for complete evacuation.**

Evacuation time is defined as the combination of roadway clearance time and dissemination time. Dissemination time includes time for officials to make evacuation decisions, mobilize support personnel, communicate between affected communities and the State, and disseminate evacuation directives to the public. Dissemination time is a subjective amount of time that will vary depending upon established communication and decision making procedures of the State and communities. This study does not attempt to quantify dissemination time. Officials using the results of this study, after careful examination of their existing communication and warning procedures, must determine an appropriate amount of dissemination time. The Decision Analysis presents a step-by-step procedure that uses evacuation time and the National Hurricane Center's Marine and Public Advisories for hurricane evacuation decision-making.

The following key points are emphasized to facilitate incorporation of this study's results into existing State and local hurricane preparedness plans.

1. The geomorphology of Long Island Sound can have amplification affects on hurricane surge. The configuration of Long Island and the Connecticut coast cause a natural funneling influence on ocean waters as they are driven east to west in the Sound by a hurricane. Consequently, officials should understand that even hurricanes which track to the east of Connecticut can generate significant flooding at all locations along Connecticut's shore. Moreover, the time of arrival of peak surge relative to eye landfall will occur at different times depending upon location. Along the western shore of the State in particular, officials must be mindful that the arrival of peak surge can be as long as two or more hours after the hurricane has made landfall.

2. The design height of the Corps of Engineers' Hurricane Barrier in Stamford, Connecticut is sufficient to protect against worst case storm tides predicted by the SLOSH model. The only exception to this is that severe hurricanes with a strong westerly track can generate higher surges than the Barrier's design height, potentially overtopping it. However, these storms have been classified as extraordinarily rare meteorological events. Therefore, the Stamford Hurricane Barrier provides protection against all worst case flooding situations reasonably expected to occur in this region. For purposes of this study, all analyses were conducted assuming that the Barrier would not be overtopped. As the results of this study are implemented, the Corps of Engineers and the City of Stamford should consider the additional impacts these rare events could have and identify special evacuation measures that would be necessary should a storm of this nature be forecasted.

3. The Corps of Engineers' Hurricane Barrier located in New London, Connecticut was designed to protect against flooding events up to the 100-year frequency flood. Results of the SLOSH model show that worst case surges generated by Categories 3 and 4 hurricanes in combination with high astronomical tides are higher than the design height of the Barrier. Therefore, for purposes of this study, it was determined that potentially vulnerable land areas located behind the Barrier should be evacuated for hurricanes of these intensities. It is therefore extremely important that officials and citizens of the City of New London understand the design height limitations of the New London Hurricane Barrier. As the results of this study are implemented, the Corps of Engineers and the City of New London need to ensure that operational procedures for evacuating areas protected by the Barrier are in place in the event that evacuation becomes necessary.

4. The average error in a 12 hour hurricane forecast is approximately 60 miles. This means that if a storm was forecasted to make landfall at New Haven, Connecticut in 12 hours time, and it in fact made landfall anywhere between New York City and Westerly, Rhode Island, the error in forecast landfall position would be no worse than average. Forecasting errors complicate hurricane evacuation decision-making and officials must understand the limitations of the National Weather Service's forecasting capabilities.

5. Although human behavior during a hurricane evacuation is difficult to predict, two overriding factors influence whether or not residents will evacuate: 1) the actions by local officials; and 2) the perceived degree of hazard at their location. The Study indicates that when officials take aggressive action to encourage people to leave their homes, evacuation rates increase by approximately 25 to 50 percent. The Study also concluded that the time at which people mobilize and evacuate is closely related to local officials' actions. During evacuation proceedings it is recommended that clear and consistent warnings are broadcasted to the public at risk to supplement "door to door" warning efforts.

6. The Shelter Analysis determined that the expected shelter usage (shelter demand) of some communities is greater than the combined capacity of the communities' public shelters. Communities should continue working with the local American Red Cross chapters to reach agreements on other suitable facilities to ensure sufficient public shelters are available during hurricanes.

7. The Study presents clearance times for 18 hurricane evacuation scenarios, each varying by behavioral response, background traffic level during the evacuation, and hurricane severity. The Study recommends the adoption of a 7-hour clearance time for all coastal areas in Connecticut. Although the Study analyzed evacuation scenarios with clearance times less than 7 hours time, these times should not be used by communities as a basis for evacuation planning.

8. To ensure suitable evacuation times are used in hurricane evacuation decision-making, it is extremely important that State and local officials investigate existing communication and warning procedures and establish an appropriate amount of dissemination time. Dissemination time is a critical component of evacuation time. Failure to include this time as part of total evacuation time may substantially underestimate the time required to complete evacuations safely. The Study recommends that officials refer to the Hurricane Bob Preparedness Assessment for Coastal Areas of Southern New England and New York, May 1993 for information that can assist in quantifying dissemination time.

9. The Study recommends that decision-makers use the Decision Arc Method outlined in Chapter Eight to assist in determining if, and when, a hurricane evacuation should be conducted. The method requires that decision-makers have access to the latest Tropical Cyclone Marine and Public Advisories issued by the National Hurricane Center. To accomplish this, provisions should be made in the State's Warning Plan for the timely dissemination of the National Hurricane Center's weather products to all decision-makers.

10. The completion of this multi-year study does not conclude the Corps of Engineers' or FEMA's involvement in hurricane preparedness activities in the State of Connecticut. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. Using the results of this study, the Federal Emergency Management Agency will take the lead with the Connecticut Office of Emergency Management to establish a framework for which comprehensive state-community coordinated hurricane preparedness plans will be made.