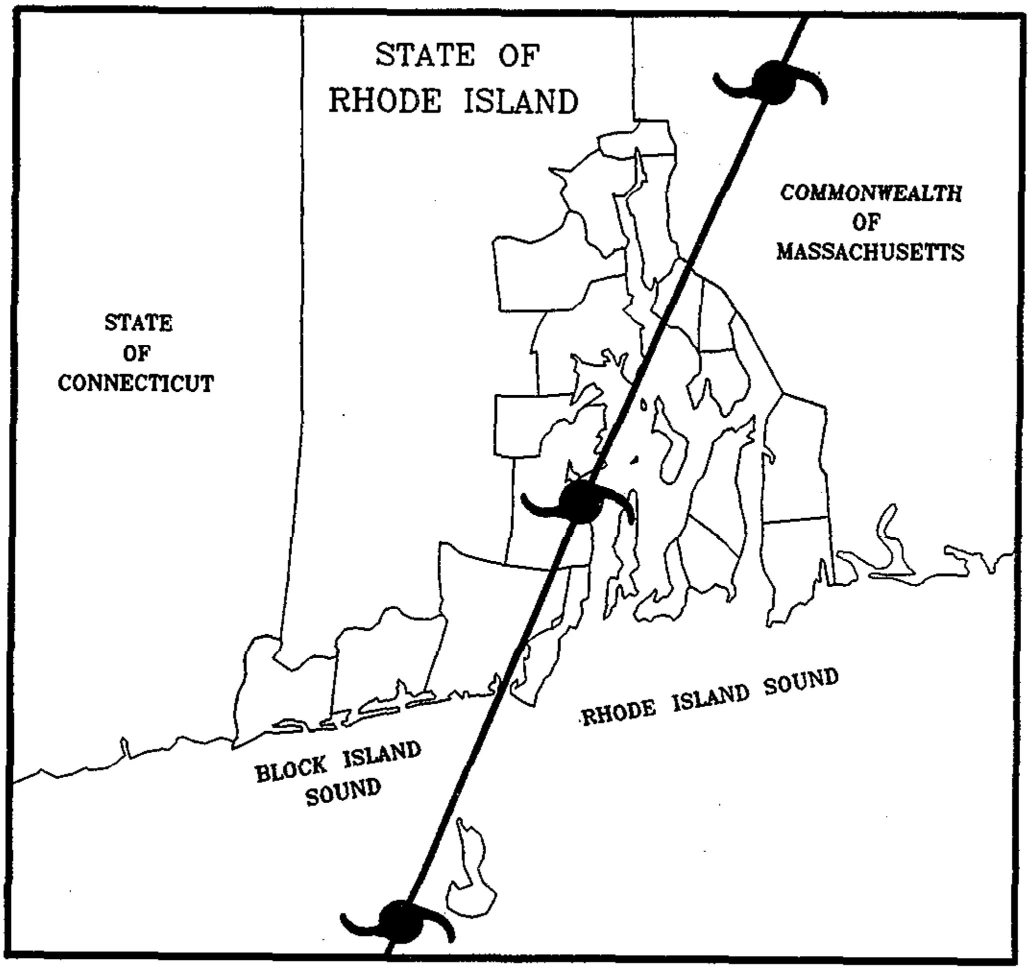
May 1995

Rhode Island 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 Rhode Island, the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers cooperatively sponsored and conducted the Rhode Island Hurricane Evacuation Study. The study was completed with direct assistance provided by the National Oceanic and Atmospheric Administration (NOAA) and the Rhode Island Emergency Management Agency. 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 purpose of this study is to provide the Rhode Island Emergency Management Agency and Rhode Island coastal communities 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. 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 Rhode Island Hurricane Evacuation Study, Technical Data Report, and two companion atlases. The first atlas, the Inundation Map Atlas, shows the areas within communities most vulnerable to flooding from hurricanes. In partnership with local officials, a second atlas, the Evacuation Map Atlas, was developed to identify land areas (evacuation zones) vulnerable to hurricane surge which should be considered for evacuation prior to a hurricane's landfall. The extent of land area included within evacuation zones is based on 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. 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 the 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 accomplish this, the Study employs the National Hurricane Center's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) computer model.

The SLOSH model simulated 536 hypothetical hurricanes of varying intensities, forward speeds, and track directions in order to calculate the potential hurricane surge which may be experienced in Rhode Island coastal communities. Simulations were performed for hurricanes of Saffir/Simpson scale intensity categories 1-4[1] (see Table 1.2 in the report), with forward speeds ranging from 20 to 60 miles per hour, and the storm track directions most likely to affect Rhode Island.

The study discusses the difficulties of forecasting the precise tracks of hurricanes and reported that the average error in the National Weather Service 12 hour track forecast is approximately 60 miles. Because of the uncertainties in hurricane track forecasting, the Study assumes that all Rhode Island locations are equally vulnerable to each hurricane forecasted to affect the region. Therefore, worst case surge inundation areas provided in the Inundation Map Atlas were developed based on a composite of the critical hurricane tracks and approach directions for all locations. The three surge inundation areas delineated in the Inundation Map Atlas are categorized based on the forward speeds and intensities of the 536 hurricanes modeled using the SLOSH model. These meteorological parameters can be more confidently forecasted by the National Weather Service. Categorized SLOSH model results can be found on Plate iii of the Study's Inundation Map Atlas.

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[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.

VULNERABILITY ANALYSIS

Approximately two thirds of Rhode Island's one million residents are concentrated in its 21 coastal communities. As a result, vulnerable population figures for coastal communities are large even though hurricane surge inundation areas tend to be geographically confined. In general, Rhode Island's surge vulnerable areas are densely developed with many businesses, multifamily housing units, and beach front and near shore homes. The Study estimates that there are approximately 80,000 residents potentially vulnerable to hurricane surge from a "weak hurricane scenario" and more than 120,000 residents vulnerable from a "strong hurricane scenario" (see Tables 3.1 and 3.2 in the report). Significantly, in the communities of Warwick and Barrington alone, more than 28,000 and 13,000 residents respectively live within hurricane surge evacuation zones. Other communities with significant flood vulnerable populations are Newport, Warren, East Providence, North Kingstown, and Narragansett.

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 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 comparing the public shelter demand, as computed using behavioral data and census information, with the results of public shelter surveys. As shown in Tables 5.1 and 5.2 in the report, the results of the Analysis identified that seven Rhode Island 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 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 which simulated vehicle movements during evacuation scenarios. Important factors that were varied with each evacuation simulation were: the timing with which the public responded and left their homes, the probable travel destinations of evacuees, hurricane severity, level of seasonal population, and the initial traffic conditions at the start of evacuation. Clearance times range from 4¼ hours to 9½ hours depending on the above factors and the location within the State where the evacuation was modeled. Based on a review of the modeled evacuation scenarios, the Corps of Engineers and FEMA recommend that the Rhode Island Emergency Management Agency and the Rhode Island coastal communities use a 7-hour clearance time for well publicized evacuations expected to occur during the daytime. An 8-hour clearance time is recommended for those evacuations expected to begin during the nighttime. The advantages of applying a uniform clearance time for all locations in the State are continuity of planning assumptions across community political boundaries and consistency of warning messages broadcasted to threatened coastal areas. Chapter Seven discusses the rationale for these recommendations.

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 or the State. **Consequently, hurricane evacuation decision-makers in Rhode Island must establish dissemination times appropriate for their areas in order to properly use the clearance times developed by this study. Failure to include dissemination time in the calculation of total evacuation time will underestimate the time it takes to ensure a safe and complete evacuation.**

The Decision Arc Method presented in Chapter Eight 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. Results from the SLOSH model show that storm surge generation in Rhode Island is significantly influenced by a hurricane's intensity category and its forward speed. The Hazards Analysis has shown that at most Rhode Island locations, surges which accompany fast moving Category 2 hurricanes (forward speeds greater than 40 mph) can generate surge levels close to the levels generated by more intense Category 3 or 4 hurricanes traveling at slower forward speeds (forward speeds of 20 mph or less). This phenomenon is caused by the increased wind stress on ocean water on the right side of the hurricane's

eye from storms which travel at faster speeds. Consequently, officials should understand that a storm's category, as well as its forward speed are both major factors in determining the storm's threat in terms of flood potential.

2. 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 Narragansett, Rhode Island in 12 hours time, and if it in fact made landfall anywhere between the vicinity of New Haven, Connecticut and eastern Cape Cod, Massachusetts, the error in forecast landfall position would be no worse than average. Even slight deviations in the forecasted track of a hurricane might mean a large difference in landfall location. Errors in forecasting complicate hurricane evacuation decision-making, and officials must understand the forecasting capabilities and inherent limitations of precise hurricane forecasting by the National Weather Service.

3. The Corps of Engineers' Fox Point Hurricane Barrier in Providence, Rhode Island is sufficient to protect against worst case storm tides estimated using the SLOSH model. For purposes of this study, all analyses were conducted assuming that the Barrier's gates would function properly protecting all areas behind the structure. The inundation map and evacuation map for the City of Providence show separate potential flood delineations for locations behind the barrier should the barrier's gates malfunction. As the results of this study are implemented, the City of Providence should consider flooding impacts and develop appropriate evacuation measures for areas behind the barrier in the unlikely event evacuation becomes necessary.

4. 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 results of this study indicate 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.

5. The Shelter Analysis determined that the expected shelter demands of four Rhode Island communities are greater than the shelter capacities of the communities. The Study recommends that these communities continue to work with local American Red Cross chapters to reach agreements on other suitable facilities to ensure adequate shelter space is available during hurricane evacuations.

6. The Study presents clearance times for 18 hurricane evacuation scenarios, each varying by public response, background traffic level during the evacuation, and hurricane intensity. The Study recommends the adoption of a 7-hour clearance time for all coastal areas in Rhode Island for daytime evacuations and an 8-hour clearance time for nighttime evacuations. Although the Study analyzed evacuation scenarios with clearance times less than 8 hours time, these times should not be used by the State or communities as a basis for evacuation planning. Officials must understand that clearance times developed by this study do not apply to the community of New Shoreham (Block Island). An Emergency Operations Plan for New Shoreham is currently being developed by the Rhode Island Emergency Management Agency which will address specific evacuation times required for the safe evacuation of non-permanent residents from the island. The plan is scheduled for completion in October 1995.

7. 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.

8. 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 Advisories and Tropical Cyclone Probability 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.

9. The completion of this multi-year study does not conclude the Corps of Engineers or the FEMA's involvement in hurricane preparedness activities in the State of Rhode Island. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. FEMA and the Rhode Island Emergency Management Agency will incorporate the results of this study into their ongoing program of improving hurricane emergency management in Rhode Island.

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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, 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 northerly 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 Taunton River was in flood, flash flooding occurred in many smaller streams, and numerous New England cities and towns experienced some of the highest flood levels reported. The City of Providence was one location which was the hardest hit. Tidal surges funneling into Narragansett Bay caused water in the downtown area to reach depths higher than ten feet in the midst of rush-hour. In other New England locations, winds destroyed entire forests, cottages and ocean front homes were washed more than a half

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

mile from the shore, and recreational boats and shipping fleets were scattered along the coastline for miles. In total, the storm gave rise to more than $400,000,000 in damages (in 1995 dollars, the estimated damages translate to $6.8 billion). An estimated 682 New England deaths were directly attributed to the Hurricane of 1938.[2]

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 levels 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 for most locations this method can, and will, significantly underestimate potential areas of flooding. Historic flood levels 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 only on historical data 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 made landfall at a different location, shifted in track direction, or increased in intensity or forward speed. Even slight variations in hurricane travel speed, point of landfall, or intensity 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 future severe events.

Historically, the frequency at which hurricanes threaten Rhode Island range from about five to ten major hurricanes each century. The State's southern facing coastline and the geomorphology of Narragansett Bay cause Rhode Island coastal cities and towns to be particularly vulnerable to all hurricanes forecasted to track towards New England. The

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

State's vulnerability is further complicated by its growing population and increased development in coastal areas, particularly along its southwest sector.

It is anticipated that hurricane evacuations conducted in Rhode Island 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 flood vulnerable 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, 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 and forward speed 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) and the US Army Corps of Engineers in cooperation with the National Oceanic and Atmospheric Administration have joined the Rhode Island Emergency Management Agency in conducting the Rhode Island Hurricane Evacuation Study.

Chapter One

INTRODUCTION

1.1 PURPOSE

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

1.2 AUTHORITY

This study was conducted by the Federal Emergency Management Agency (FEMA) and the US Army Corps of Engineers in cooperation with the National Oceanic and Atmospheric Administration (NOAA) for the Rhode Island Emergency Management Agency. 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, shown in Figure 1.1, consists of the 21 coastal communities located in Bristol, Kent, Newport, Providence, and Washington counties, including the community of New Shoreham located on Block Island. The Rhode Island study area focuses on immediate coastal communities only and does not provide specific information for the entire counties for two reasons. First, the study's main objective is to develop data to help prevent the loss of life caused by hurricane surge flooding. Therefore, only those communities directly exposed to open coasts, bay inlets, or located along rivers subject to tidal influences are included in the study area. Second, the local government structure in Rhode Island, and of other New England states, is based on the political boundaries of municipalities rather than county boundaries. Consequently, emergency management functions, including hurricane preparedness, evacuation decision making, response, and recovery are the responsibility of each individual city and town. The tidal waters affecting cities and towns along the State's southern exposed shore are Block Island Sound and Rhode Island Sound. Tidal waters feeding Narragansett Bay through the Bay's East and West Passages, and the Sakonnet River, affect eastern Rhode Island communities and adjacent areas in southern Massachusetts.

The State of Rhode Island is the smallest geographically in the Nation with a total area of 1,214 square miles, excluding the 140-square mile water area encompassed by Narragansett Bay and its tidal arms. The State has 39 cities and towns and a population totaling slightly more than 1 million in 1990. Approximately two thirds of the State's population is concentrated in its 21 coastal communities. The State has experienced little population growth during recent decades. From the time period 1970 through 1990 the permanent population has increased less than 6 percent. Urban areas in the vicinity of the City of Providence have experienced negative growth of more than 3 percent in the past twenty years. This is in contrast to the 53 percent increase in population that has occurred during this same time in the coastal communities of the State's expanding southwest sector (Westerly, Charlestown, South Kingstown, Narragansett).

Population changes due to influxes of seasonal residents to summer homes and beach front cottages vary widely by location. In coastal areas west of Point Judith, Narragansett, seasonal changes in population range as high as 28 percent of the permanent population. In other coastal areas, excluding the urban areas of Providence and vicinity, seasonal changes in population are on average approximately 5 percent of the permanent population. The State's famous Cliff Walk and historic mansions are located in the City of Newport. Although the Newport region attracts and accommodates many short term tourists, the number of long term seasonal residents is minimal because access to most shore property is owned by large estates and year round residential homes. In the State's most urban areas, Providence, Warwick, Pawtucket, Cranston, and East Providence, less than one percent increase in population occurs in the summer time due to seasonal residents.

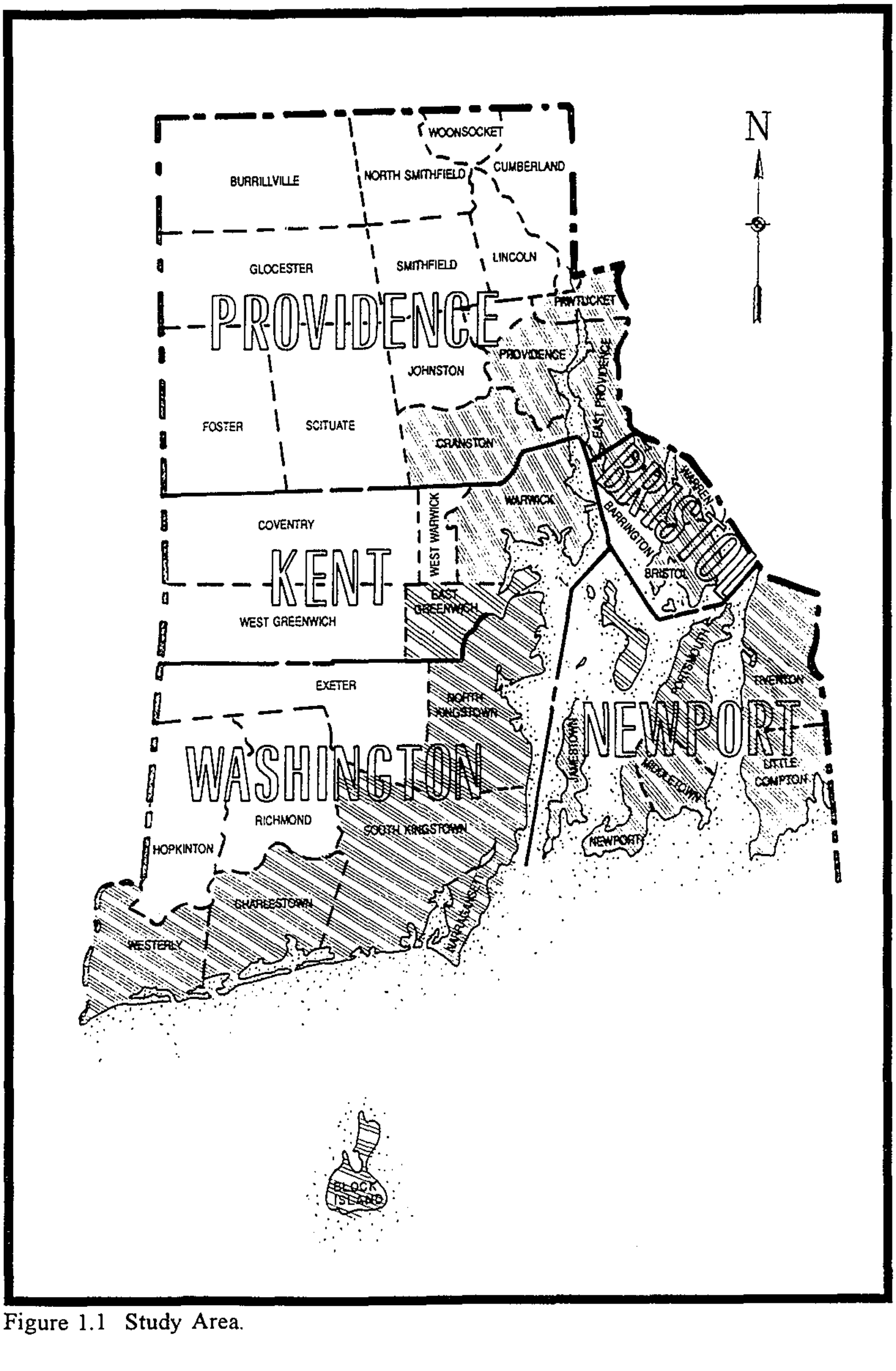


Figure 1.1 Study Area.

1.3.2 Topography and Landforms

Rhode Island's topography was formed by geological processes of glaciation and stream erosion. At the end of the glacial epoch, the terminal moraine and other materials which had been deposited by the ice sheet were partially submerged, leaving an irregular shoreline with protruding headlands after the glacier's retreat. Narragansett Bay occupies a portion of New England's lowlands and represents the glacial depression formed from surface flooding that occurred over the melting ice sheet. The present shoreline was formed principally as a result of the action of winds and waves on the glacier's material deposits. Rhode Island's land areas represent the enduring crystalline materials of the areas subsurface that were not erodible and remained intact during the glacial periods. Although Rhode Island has some land elevations greater than 500 feet, the glacier's outwash and its cyclic progression and regression motion during winter and summer seasons resulted in lowlands in most of the State.

Rhode Island's coast comprises an estimated 190 miles along Block Island Sound, including Block Island, and an estimated 150 miles of shore along Narragansett Bay for a total coastline length extending approximately 340 miles. The shore is generally characterized as irregular and marked by many headlands, sandy beaches, inlets, and rocky shores. The southwestern coast is exposed directly to the Atlantic Ocean along Block Island Sound and is primarily made up of long barrier beaches fronting a series of salt ponds. The low dunes in the backshore offer some protection from mild storm surges. Shore areas of lower Narragansett Bay on the east and west shores are geologically similar in that they have many small pockets of sandy to rocky beaches located between massive ledge outcrops. The highly urbanized northern parts of Narragansett Bay are for the most part protected by a series of manmade and natural structures.

The largest man-made protective structure is the Fox Point Hurricane Barrier built by the Army Corps of Engineers in 1966. The Barrier consists of a 700 foot gravity dam and connecting dikes extending across the Providence River at Fox Point to high ground approximately one mile from central Providence. Included in the Fox Point Hurricane Barrier are a pumping station, and three 40 foot wide river gate openings which allow access into the harbor during normal tide conditions. The Fox Point Hurricane Barrier has a top elevation of 25 feet relative to the National Geodetic Vertical Datum (NGVD 1929) providing the City of Providence with virtually complete protection against future hurricane tidal flooding.

The community of New Shoreham is located on Block Island 12 miles off the shore of the State's southwest sector. The Island is 12 square miles and has 16 miles of coastline that varies widely in character by location. It is fronted by high steep erodible bluffs to its south and low sandy barrier beaches to its north. The east and west sides of the Island have a mix of low stretch beaches, dunes, and bluffs. The year round population is less than 900 residents and during summer months the population more that triples from its seasonal occupants.

In general, Rhode Island's beaches consist of unconsolidated medium fine sand to gravelly materials susceptible to erosion. Beach berms are typically narrow which in most cases make them inadequate for protective and recreational purposes. However, the State has four prominent public beaches, the Napatree, Misquamicut, Sand Hill Cove, and Scarborough Beaches that are visited by millions of Rhode Island residents and out-of-state tourists each year.

1.3.3 General Bathymetry and Ocean Tides

Narragansett Bay separates the State's southwest sector from its eastern shore communities and southern Massachusetts. Three large islands, Aquidneck, Conanicut, and Prudence Islands, and a half dozen smaller islands divide Narragansett Bay into three major waterways. The Conanicut and Prudence Islands separate Narragansett Bay into the East and West Passages, and the largest island, Aquidneck Island, separates the East Passage from the Sakonnet River. Three major rivers, the Blackstone, Taunton, and Providence Rivers, drain most of Rhode Island and a significant portion of south eastern and central Massachusetts into Narragansett Bay. The tidal reaches of the Blackstone River, known as the Seekonk River, and the mouth of the Providence River constitute the State's most important shipping harbor, Providence Harbor. The Taunton River Basin, which drains most of southeastern Massachusetts, feeds into one of Massachusetts' most active harbors, Fall River Harbor. The Fall River Harbor is located along Mount Hope Bay and is accessed from the upper reaches of Narragansett Bay.

Ocean tides enter Narragansett Bay through the East and West Passages and the Sakonnet River. The mean range of the tide varies from 3.5 feet at Newport, to 4.4 feet at Fall River, Massachusetts, to 4.6 feet at Providence. Spring tides at the same locations have average ranges that vary from 4.4, to 5.5, to 5.7 feet, respectively. The tidal movement is nearly simultaneous throughout the bay, high and low tides for most points along the inner Bay occur within 20 minutes of high and low tides at Newport. The time interval for a complete tidal cycle averages about 12 hours and 25 minutes. This results in the daily occurrence of two low and two approximately equal high waters on an average of six out of every seven days. The present currents in the natural openings are erratic in both direction and velocity. The average velocities of flood and ebb range from about 0.5 to 1.0 knots. Currents of 2.8 knots or more occur at the head of the Sakonnet River at Tiverton.

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 non-frontal, 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 33 knots), Tropical Storm (winds 34 to 63 knots inclusive) and Hurricanes (winds greater than 64 knots).

The geographic 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 overall 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

Records of tropical cyclone occurrences since 1871 in the Atlantic Tropical Cyclone Basin have been compiled by the National Climate Center in cooperation with the National Hurricane Center. Although other researchers have compiled fragmentary data concerning tropical cyclones within the Atlantic tropical cyclone basin dating 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. 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 1886 through December 31, 1986.

1.4.3 Coastal New England

Since the year 1886, 29 hurricanes and 67 tropical storms have passed within a 150 statute mile radius of Newport, Rhode Island. Figures 1.3 and 1.4 show the estimated tracks of these storms and Table 1.1 lists the names, date of occurrence, and meteorological characteristics of each hurricane shown in Figure 1.3. The reoccurrence interval calculated from this data is 5.4 years for hurricanes and 1.7 years for tropical storms. This means that for locations within a 150 mile radius of Newport, Rhode Island, on average, a hurricane can statistically be expected to pass every 5.4 years and every 1.7 years for tropical storms.

The State of Rhode Island, as with other New England states, is particularly vulnerable to hurricanes. One reason is due to the geography of southern New England in relation to the Atlantic seaboard. Historically, most hurricanes which have struck the New England region re-curved northward on tracks which parallelled the eastern seaboard maintaining a slight north-northeast track direction. The fact that the States of Connecticut, Rhode Island, and Massachusetts geographically project easterly into the

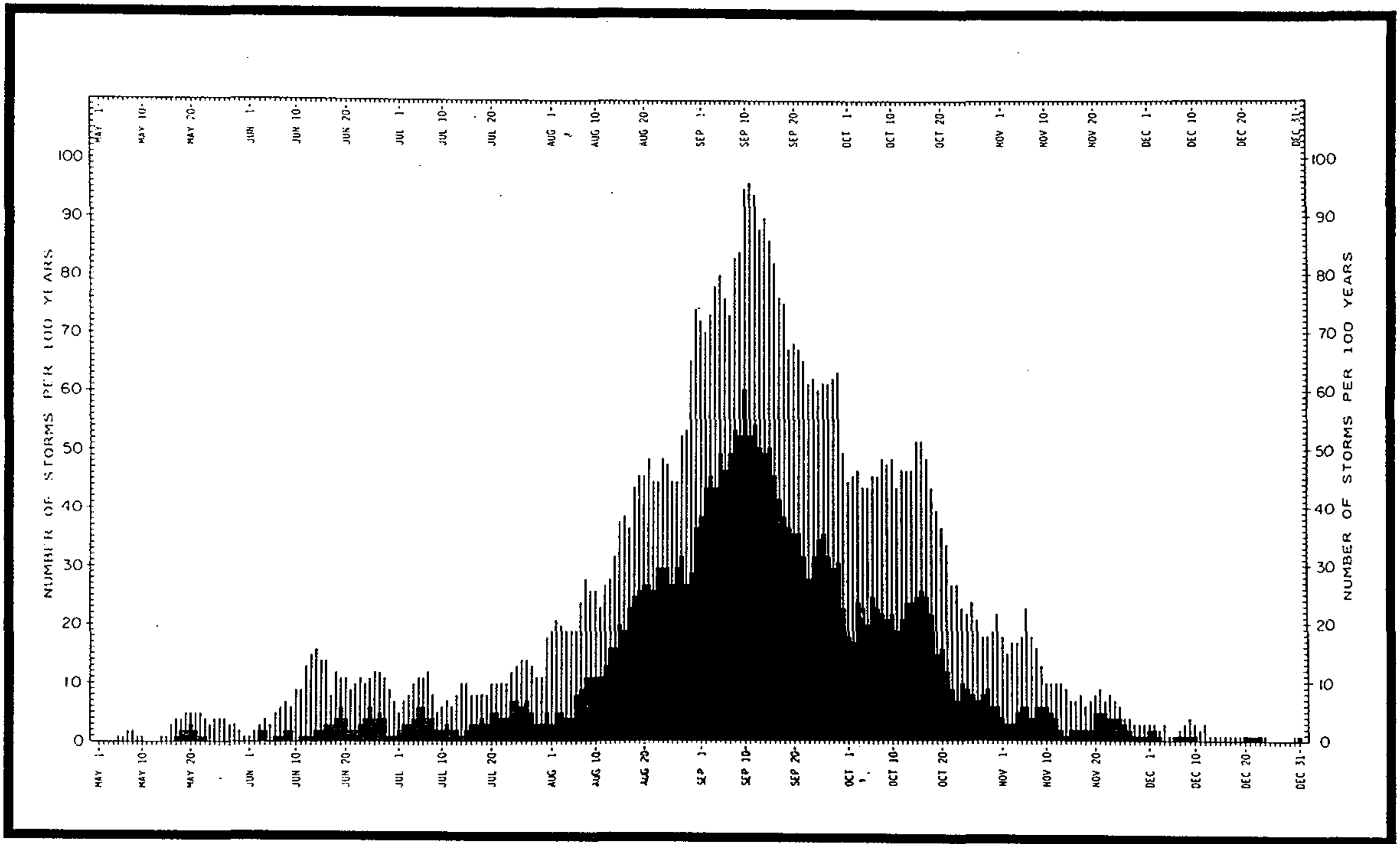


Figure 1.2 Intra-seasonal variations in the 100-year frequency of tropical cyclone occurrence. Lower bar is for hurricanes and upper bar is for hurricanes and tropical storms combined. Summary is based on period of record, 1886-1986. Source: NOAA

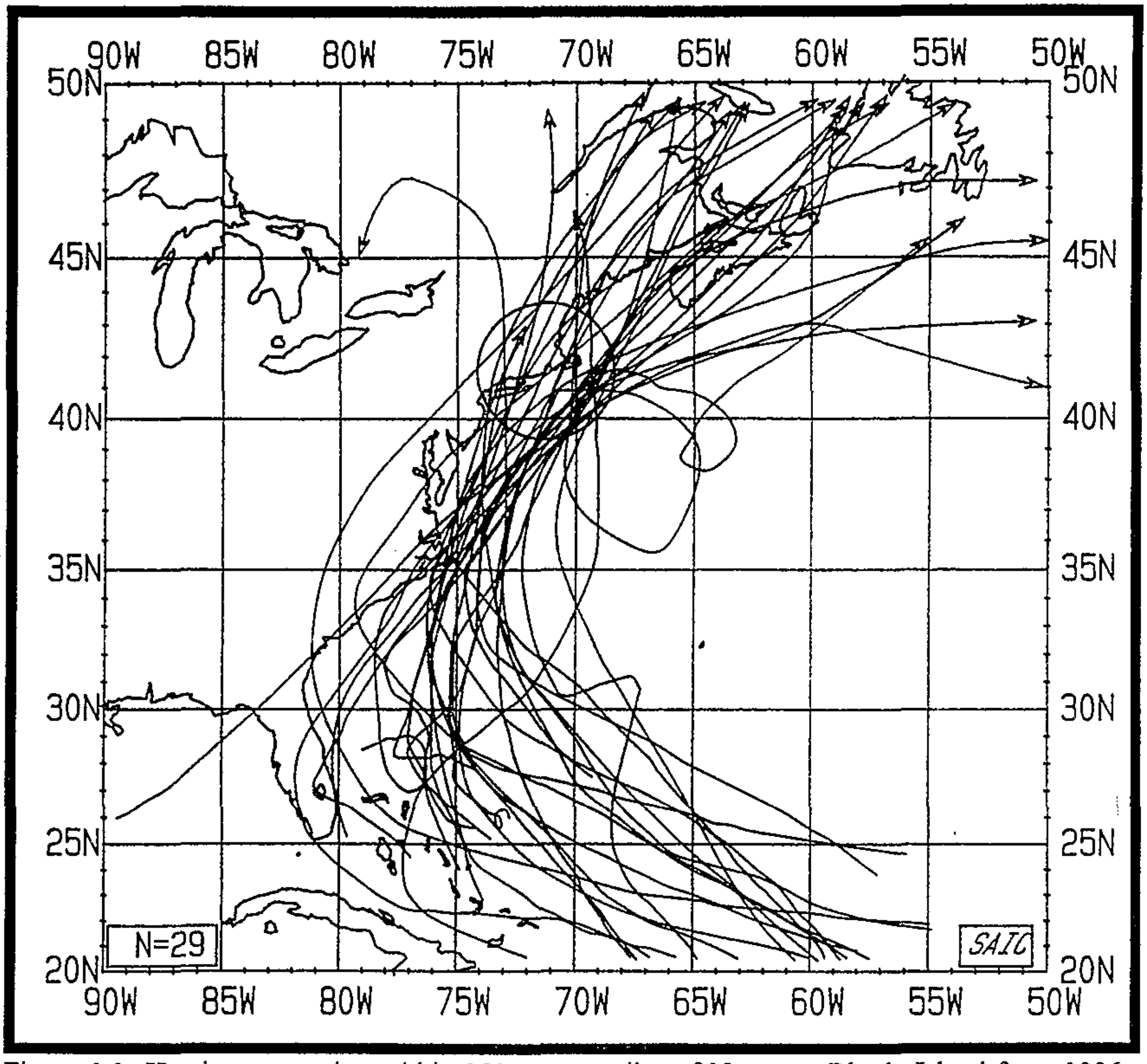


Figure 1.3 Hurricanes passing within 150 statute miles of Newport, Rhode Island from 1886-1993. Source: NHC

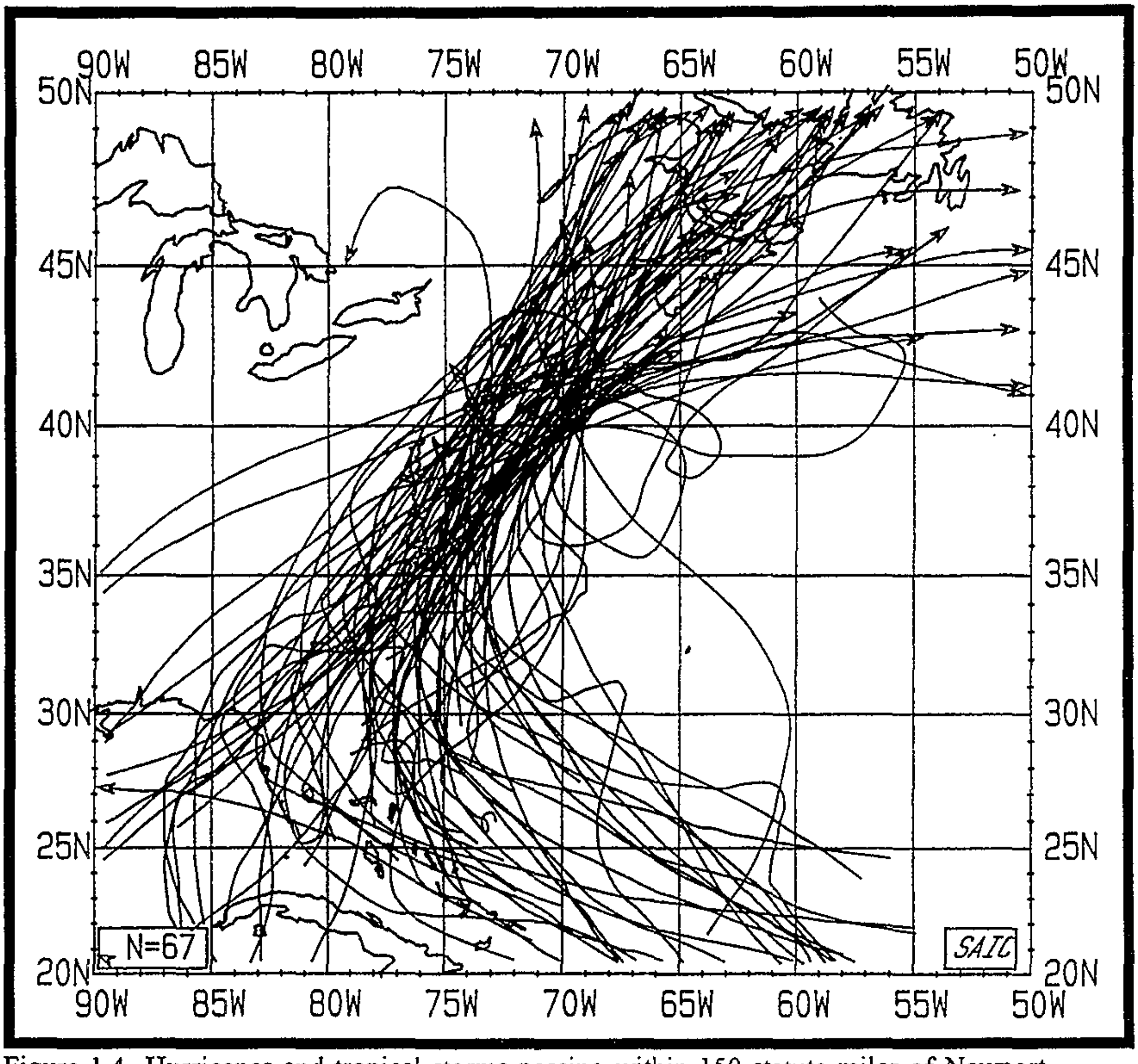


Figure 1.4 Hurricanes and tropical storms passing within 150 statute miles of Newport, Rhode Island from 1886-1993. Source: NHC

TABLE 1.1
HURRICANES WITHIN 150 STATUTE 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	76	11
1891 OCT 14	Unnamed	98	63	15
1893 JUN 18	Unnamed	87	97	15
1893 AUG 24	Unnamed	90	81	25
1893 AUG 29	Unnamed	72	85	37
1896 SEP 10	Unnamed	104	75	10
1904 SEP 15	Unnamed	75	9	52
1908 AUG 1	Unnamed	98	100	20
1916 JUL 21	Unnamed	84	22	18
1924 AUG 26	Unnamed	104	62	41
1927 AUG 24	Unnamed	104	63	48
1933 SEP 17	Unnamed	79	80	29
1936 SEP 19	Unnamed	92	37	32
1938 SEP 21	Unnamed	90	70	51
1940 SEP 2	Unnamed	80	81	26
1944 SEP 15	Unnamed	77	24	29
1950 SEP 12	Dog	75	101	21
1953 AUG 15	Barbara	86	68	23
1953 SEP 7	Carol	79	98	39
1954 AUG 31	Carol	92	41	35
1954 SEP 11	Edna	92	25	46
1958 AUG 29	Daisy	115	78	28
1960 SEP 12	Donna	95	33	39
1961 SEP 21	Ester	122	38	6
1962 AUG 29	Alma	95	74	14
1969 SEP 9	Gerda	124	86	48
1976 AUG 10	Belle	55	63	20
1985 SEP 27	Gloria	86	62	45
1991 AUG 19	Bob	98	7	32

Atlantic and have southern exposed shorelines place them in direct line of any storm which tracks in this manner. Therefore, even though New England is a relatively far distance from the tropics, its susceptibility to hurricane strikes can statistically be greater than other states closer to the tropics.

Another explanation giving evidence to New England's unique vulnerability to hurricanes is the fact that hurricanes which eventually strike the region undergo significant increases in forward speed. Historically, it can be shown that hurricanes tend to lose their strength and accelerate in a forward motion after pasting the outer banks of Cape Hatteras, North Carolina. The increase in forward speed that usually occurs simultaneously as the hurricane weakens with further northward movement can often compensate for any discounting in hurricane intensity. Consequently, surge flooding, wave effects, and wind speeds accompanying a faster moving, weaker hurricane may exceed conditions caused by more intense hurricanes. This means that for some locations, depending on the meteorology of the storm, the affects from a Category 2 hurricane traveling at 60 miles per hour (mph) might be worse than that from a Category 4 hurricane moving at 20 mph.

The vulnerability of Rhode Island to hurricane surges is further increased by the presence of Narragansett Bay. The Bay's configuration can exhibit a funneling phenomenon on tidal surges as they flood the East and West Passages and the Sakonnet River. Ocean waters entering these inlets become more restricted causing higher flood levels with continued movement into the upper reaches of the Bay. The funneled ocean waters along the shores of the Bay's northern most points tend to result in higher storm surge elevations causing a greater amount of coastal and tidal riverine flooding.

1.5 THE SAFFIR/SIMPSON SCALE

The National Hurricane Center adopted the Saffir/Simpson Hurricane Scale to categorizes hurricanes based on their intensity, and to relate 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. 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. Surges values greater than or less than the approximate ranges specified by the scale may occur due to effects of varying localized bathymetry, coastline configuration, astronomical tides, barriers, or other factors that may influence surge generation from a single event. 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 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, including the barometric pressure ranges by category, is shown in Table 1.2.

TABLE 1.2
SAFFIR/SIMPSON HURRICANE SCALE WITH CENTRAL BAROMETRIC PRESSURE RANGES

CATEGORY	CENTRAL PRESSURE MILLIBARS	CENTRAL PRESSURE INCHES	WIND SPEED MPH	WIND SPEED KNOTS	SURGE FEET	DAMAGE POTENTIAL
1	>980	>28.94	74-95	64-83	4-5	Minimal
2	965-979	28.5-28.9	96-110	84-96	6-8	Moderate
3	945-964	27.5-28.5	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

1.6 STUDY ANALYSES

The Rhode Island 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 Rhode Island Hurricane Evacuation Study and a brief 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 National Flood Insurance Rate Maps prepared in conjunction with the National Flood Insurance Program (NFIP) to conduct evacuation planning for non-tidal areas. 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 Hazards Analysis, the Vulnerability Analysis identifies land areas within the study area which can potentially become inundated for different intensity hurricanes. A companion atlas, entitled the Rhode Island Hurricane Evacuation Study, Inundation Map Atlas, May 1993, illustrates the potential inundation areas for each study area community. Inundation information and 1990 census data were used to derive appropriate evacuation zones from which estimates of the total surge vulnerable population were made. A second companion atlas, entitled the Rhode Island Evacuation Study, Evacuation Map Atlas, December 1994, presents these zones and includes the names and map locations of public shelters, medical/institutional facilities, and any mobile home/trailer park sites.

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 Rhode Island Hurricane Evacuation Study to develop the behavioral data consisted of telephone sample surveys of the public, interviews of local officials representing communities within the study area, information from other hurricane evacuation studies, and data obtained from post-hurricane assessments. The Rhode Island Behavioral Analysis was conducted as part of an analysis completed for eight Middle Atlantic and New England states in support of Corps of Engineers, FEMA, and NWS developed hurricane evacuation studies.

1.6.4 Shelter Analysis (Chapter Five)

The Shelter Analysis determines how many people will seek public shelters (public shelter demand) and presents the shelter space currently available from predesignated facilities. The numbers of people who would seek public shelters in hurricane evacuations were estimated for each community. Estimates were derived by applying the shelter usage rates developed in the Behavioral Analysis to the vulnerable population figures computed by the Vulnerability Analysis. The analysis also presents a current inventory (December 1994) of American Red Cross Mass Care Facilities and locally identified public shelters. Flood Insurance Program maps were used in the Shelter Analysis to identify public shelters, if any, susceptible to freshwater flooding.

1.6.5 Transportation Analysis (Chapter Six)

The results of the previous analyses were used in the Transportation Analysis to estimate the total time it would take to clear traffic from roadways after public dissemination of a regional level evacuation recommendation. NETVAC2 evacuation software was used to develop a mathematical model representative of the major routes and many local routes in the State of Rhode Island and Bristol County, Massachusetts. Hurricane evacuation traffic simulations were run using the model 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 estimated for evacuations considering weak and severe hurricane events under diverse initial traffic conditions, various levels of seasonal population, and multiple assumptions about evacuee trip destinations. The modeling methodology considered evacuations where the timeliness of the public to mobilize and leave their homes varied from extremes of a slow to a rapid response.

1.6.6 Evacuation Times (Chapter Seven)

Estimated roadway clearances times are calculated in the Transportation Analysis for 18 possible evacuation scenarios based on the sensitivity of clearance times to varying influential evacuation parameters (hurricane severity, public response timing, initial traffic conditions, etc.). A range of evacuation scenarios was considered to qualify the most likely 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. Furthermore, this chapter explains the importance of another component of evacuation time, termed dissemination time, which must be combined with clearance time to accurately estimate total evacuation time.

1.6.7 Decision Analysis (Chapter Eight)

The Decision Arc Method is a hurricane evacuation decision-making methodology (graphic 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 initial hurricane hazards. 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 Rhode Island Hurricane Evacuation Study that included the Rhode Island Emergency Management Agency, FEMA, Corps of Engineers, National Weather Service, American Red Cross, local chief elected officials and local emergency management directors. Several coordination meetings with study area communities were sponsored by the Rhode Island Emergency Management Agency, FEMA, and the Corps of Engineers to assure proper and thorough data gathering and coordination of the study, and to provide maximum flexibility in the study. Coordination meetings provided opportunities for 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.

Chapter Two

HAZARDS ANALYSIS

2.1 PURPOSE

The purpose of the Hazards Analysis is to quantify the surge heights 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 which might be experienced for each meteorological scenario by varying three critical parameters: landfall point, track direction, and forward speed. It is important to note that maximum storm surge heights are 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., the protection of the potentially vulnerable population.

Although hurricane winds have caused the deaths of thousands, most of the losses of human life and property in hurricanes are due to surge flooding. The principal function of the Hazards Analysis is therefore to develop accurate estimates of potential surge heights. This 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 through its 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 gale force winds arrive.

2.2 FORECASTING INACCURACIES

The worst-case approach was used in presenting possible hurricane surge effects because of the inherent inaccuracies in forecasting the precise track and other meteorological parameters of hurricanes. An error analysis conducted of hurricane forecasts issued by the National Hurricane Center suggests that a substantial margin of error exists with each forecast issued. 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. To illustrate how these errors complicate evacuation decision-making, consider a hurricane that is forecasted to landfall at Narragansett, Rhode Island in 12 hours time. If this storm were to actually landfall anywhere between the vicinity of New Haven, Connecticut and the eastern part of Cape Cod, Massachusetts, the resulting error in forecasted landfall location would be no worse than average. The complementary hypothetical situation is also valid. Suppose, for instance, a hurricane that is forecasted to strike Cape Cod actual hits Rhode Island directly, then, its associated tract error would be within error ranges typically forecasted. It follows from these examples that the State of Rhode Island is potentially vulnerable to every hurricane forecasted to reach New England.

Similar error analyses conducted for forecasted hurricane wind speed showed that the average error in the official 24-hour rotational wind speed forecast is 15 mph and the average error in the 12-hour official forecast is 10 mph. Decision-makers should note that an increase of 10 to 15 mph in rotational wind speed 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 on storm surge generation, an increase in rotational wind speed will also contribute to higher surge heights. For the particular case of Rhode Island, it can be shown that an increase in a hurricane's forward speed can have a greater effect on the resulting storm surge than an increase in the storm's intensity. Officials from Rhode Island must understand that faster moving weaker, intensity hurricanes can cause more flooding than slower moving more intense hurricanes.

Specific hurricane modeling examples illustrating this phenomenon are discussed in Section 2.5.5.

Most hurricanes which travel to New England undergo significant acceleration in forward speed with further northward movement over the cooler waters of the mid-Atlantic. As with errors in landfall forecasts, errors in the forecasted forward speeds of hurricanes can also complicate evacuation decision-making. If there is uncertainty in the forecasted forward motion of a hurricane, then there will inherently be some uncertainty in the timing at which the storm is expected to reach a certain location. If a storm accelerates unexpectedly, or if it accelerates at a greater rate than anticipated by weather officials, then the hurricane will arrive earlier than indicated by forecasts. Should a storm unexpectedly accelerate, officials will have to evacuate residents more quickly or risk not completing the evacuations in time.

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 are mostly due to storm surges produced from the combination of winds and low barometric pressure 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 that can be released 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 attractions of 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 Newport which depicts the water levels produced by the passage of Hurricane Bob in August 1991. The peak surge observed at this location was approximately 5.6 feet which means that the ocean's surface was 5.6 feet higher than it would have been under normal tide conditions. Although Hurricane Bob weakened from a Category 3 to a Category 2 hurricane after passing the outer banks of North Carolina, the storm stuck at near high tide producing significant flooding despite relatively modest surge levels for a hurricane. Rhode Island could have experienced surges in excess of 10 feet above normal tide if Hurricane Bob maintained its strength and its wind field had not expanded upon landfall.

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 the 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, water begins to pile up as it is impeded by the shoaling continental shelf causing the water surface to rise. The water level will increase shoreward until it reaches a maximum at the shoreline or at some distance inland. The most conducive bathymetry for the formation of large storm surges is a wide gently sloping continental shelf.

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 there is no depth related restrictions to water flow.

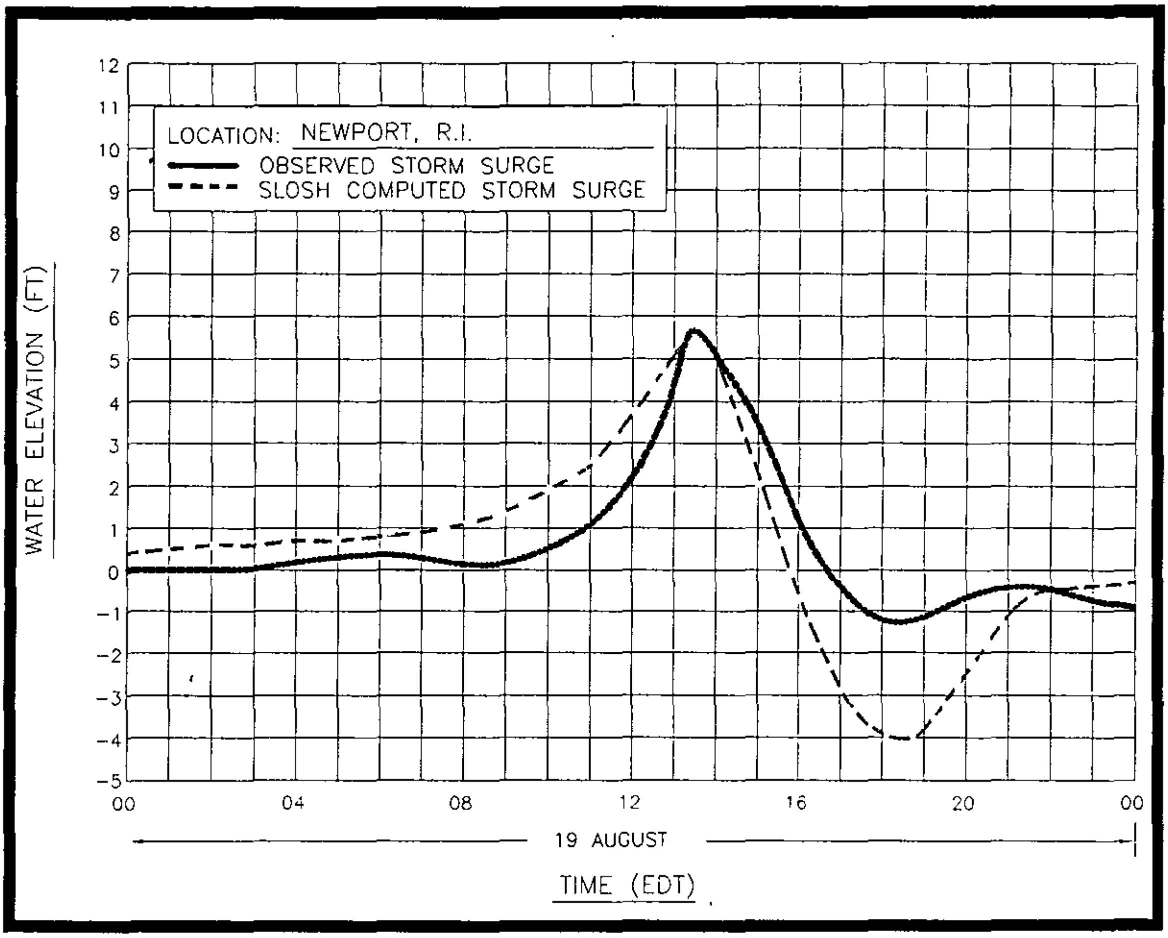


Figure 2.1 Hydrograph at Newport, Rhode Island during the passage of Hurricane Bob on August 19, 1991. Source: NHC

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; its intensity, measured by sea level pressure and maximum surface wind speeds at the storm center; its 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.

The counterclockwise rotation of the hurricane's wind field in combination with the forward motion of the hurricane typically causes the highest surge levels to occur to the right of the hurricane's forward track. This phenomenon has been observed 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. In Rhode Island, although the shoreline does not fit this description, the increased wind stress from the rotational wind field has a large effect on the level of surge. The contribution to surge generation from the forward motion of the storm can be greater than the contribution made by an increase in hurricane intensity.

2.4 STORM SURGE (SLOSH) MODEL

2.4.1 Introduction

Computer models representing the varying bathymetry and other factors affecting storm surge have been developed for specific coastal basins to numerically simulate surges from hurricanes. Because there is not sufficient historic information from which valid assessments can be made about a basin's surge potential, estimates used in this study are based on numerical simulations using a computer model rather than observed information from actual hurricanes. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is the latest and most sophisticated mathematical model developed by the National Weather Service to calculate potential surge heights from hurricanes. It calculates storm surge heights for the open ocean and coastal regions affected 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 manmade or natural barriers (i.e., hurricane barriers, dunes, islands, etc.) can be represented by the model such that 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. Consequently, the National Weather Service's SLOSH model results have become the foundation for Hurricane Evacuation Studies sponsored by FEMA and the Corps of Engineers under their national program.

The SLOSH model was applied to this study to simulate the effects of hypothetical hurricanes which could realistically impact Rhode Island, and to simulate actual hurricanes which have affected the State in the past. SLOSH model coverage to the Rhode Island study area was provided through the development of the Narragansett Bay/Buzzards Bay SLOSH Basin shown in Figure 2.2. As illustrated in Figure 2.2, this SLOSH basin's coverage extends from approximately the State of New Jersey to the outer reaches of Cape Cod, Massachusetts, and extends from the upper reaches of Narragansett and Buzzards Bays south into the Atlantic to approximately the 39 north latitude (due east off the coast of Delaware). 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 Narragansett Bay, Rhode Island and Buzzards Bay, Massachusetts Area. 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 of structure or the 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.

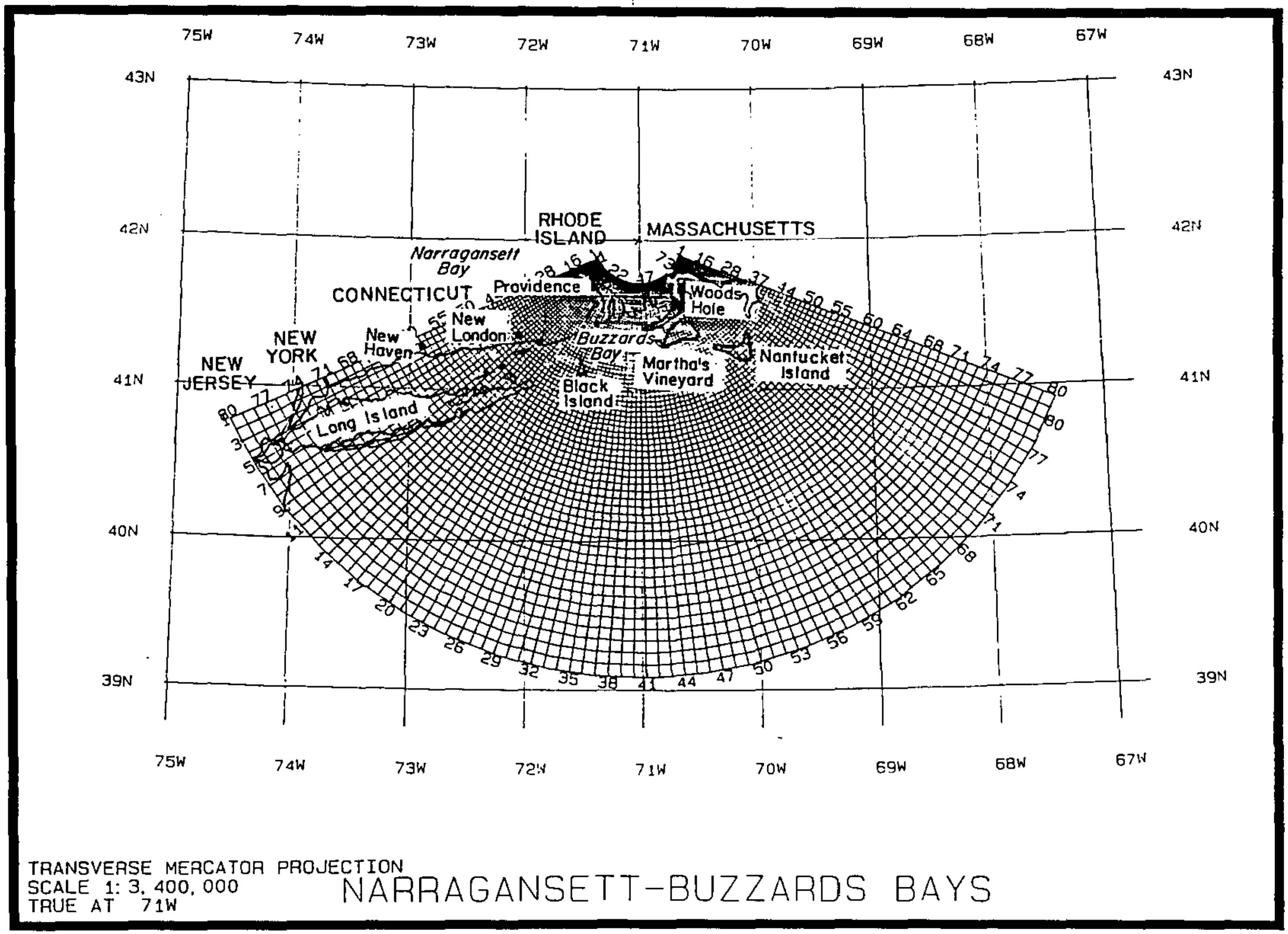


Figure 2.2 Narragansett Bay/Buzzard's Bay SLOSH Basin. Source: NHC

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 Narragansett/Buzzards Bay Basin is the National Geodetic Vertical Datum formerly known as mean sea level of 1929. The initial water surface elevation for the Narragansett/Buzzards Bay Basin was modeled one foot higher than NGVD. The one foot increase accounts for water surface anomalies which usually occur from hurricanes that 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 Narragansett/Buzzard Bay Basin. This particular grid configuration has a number of advantages over a rectilinear grid. A telescoping polar grid allows the modeler to represent the areas of greatest interest, which for this study are the areas nearest to the shore, with the highest resolution. The grid cell size is relatively small in the interior portions of the Narragansett and Buzzards Bays and along the shores of Rhode Island and southeastern Massachusetts. 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 development of the storm surge. In general, 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. Larger grid cell size in the offshore region permits the inclusion of a large geographic area in the model so that dynamic effects 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 performed. The verification experiments consist of real-time operational runs in which available meteorological data from historical storms are input in the model. These input data contain observed storm meteorological parameters from hindcasts of actual hurricanes and the initial observed sea surface height 48 hours before the storm's landfall.

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 observed surge heights but to calibrate the model 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 field investigations and verifies that topographic information input into the model agrees with actual coastline topography.

Prior to widespread application of the SLOSH model for hurricane evacuation planning, the model underwent a series of verification tests performed 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 SLOSH model's performance in these verifications justified its present use as a hurricane planning tool. Prior to 1985, only sparse records of complete time history data of hurricane meteorology and storm surge observations existed for the Narragansett/Buzzards Bay SLOSH Basin. The occurrence of Hurricane Gloria in September 1985 offered an opportunity to verify SLOSH model predictions within the basin at several Rhode Island and Massachusetts locations.

The accuracy of the SLOSH model has been evaluated using approximately 540 surge observations from historical hurricanes. To do this, the SLOSH model was programmed to approximate the precise meteorology and tracks of historical events. The computed surge values were 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 range of +/- 20 percent for significant surges with a few observations above and below this range.

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 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. Refer to Appendix A for a complete data set in this format for the storm scenarios modeled.

2.5 COASTAL RHODE ISLAND SLOSH MODELING PROCESS

2.5.1 Introduction

The geographic area covered by the SLOSH model of the Narragansett/Buzzards Bays Basin includes: portions of coastal New Jersey and New York; the entire water body of Long Island Sound; all of the coastal areas in Rhode Island including the upper reaches of Narragansett Bay; portions of southern Massachusetts from the Rhode Island border to Buzzards Bay and extending across most of Cape Cod and the Elizabethan Islands.

2.5.2 Simulated Hurricanes

In the Rhode Island Hurricane Evacuation Study, a total of 536 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 the storm surge atlas in Appendix A.

The National Hurricane Center eliminated from the analysis any hypothetical hurricanes which could not realistically occur in the Narragansett/Buzzards Bay SLOSH Basin. For example, hurricanes that follow a severe westerly or easterly track were modeled with forward speeds of 20 and 40 mph only because it is not realistic to assume that storms following these directions will travel faster. The reasoning for this is that a strong blocking front in the north must be present for hurricanes of this region to track in these directions. The presence of such a blocking front precludes the meteorological conditions necessary for a hurricane to travel in these directions at forward speeds greater than 40 mph. Therefore, the elimination of these storms from the analysis is justified.

The National Hurricane Center also eliminated Category 5 hurricanes from the analysis because New England's meteorological climate can not sustain hurricanes of this intensity. Hurricanes extract energy from the warm, moist air over the ocean. The cooler ocean waters of the mid-Atlantic and off-shore of New England tend to reduce the intensity of passing hurricanes. This weakening process, which almost always occurs, is the reason that Category 5 hurricanes have an extremely low probability of occurring in New England. However, emergency management officials must consider that a swiftly moving Category 3 or 4 hurricane can generate wind speeds considerably higher than minimum speeds required for Category 5 classification on the Saffir-Simpson scale. Storm surge is mostly caused by wind stresses and therefore hurricanes that travel at greater forward speeds tend to produce higher surges.

2.5.3 Astronomical Tide Height Effects

The ocean's normal tide fluctuates to its maximum and minimum elevations on a cyclical basis approximately every six hours regardless of the arrival of hurricane surge. The tide range (the water surface change from low tide to high tide) along Rhode Island's coast varies only slightly from one location to another, typically less than one foot. In general, the tide range is approximately 3.5 feet along Block Island Sound and the lower Narragansett Bay, and approximately 4.5 feet in the upper reaches of Narragansett Bay. The tidal movement from one location in Rhode Island to the next is nearly simultaneous. Tide range fluctuations 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 tidal cycle when peak surge is experienced. For purposes of determining worst case flood elevations, high tide elevations were added to all surges computed by the SLOSH model.

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. Hurricanes that tract towards New England have a tendency to accelerate with northward movement. Changes in a hurricane's forward speed make it even more difficult for forecasters to estimate precise landfall times which often lead to greater errors in forecasts. Even slight changes in a storm's forward speed from those forecasted can influence peak surge occurrence such that it 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 a SLOSH model run of a discrete hurricane event, the maximum water level for all 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 reasonably 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. 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. The MEOW displays the characteristic distorted geometry which results from transforming the telescoping polar coordinate grid into a rectilinear format. The contour lines show the maximum water surface elevations at all affected points on the grid for all possible landfall points modeled.

For the Rhode Island Hurricane Evacuation Study, the 536 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 and forward speed accounted for the greatest change in potential surge height. Ultimately it was determined that the 52 MEOWs could effectively be grouped into three distinct classes of hurricane events defined jointly by the storm's intensity and forward speed. This final grouping was made 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 for modeled hurricanes. These grid cells are termed "time history points". They are typically selected at locations which represent water and land areas of significance to 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. The data calculated at time history points attempts to replicate observational data collected at tide gages and weather monitoring stations during actual events.

As many as 80 time history points (39 in Narragansett Bay and along the Rhode Island shore) were pre-selected before model runs were preformed. Sites were designated by the Rhode Island 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 two time history points at Narragansett and Providence, Rhode Island which will be discussed in more detail in the paragraphs below are shown in Figure 2.3.

In Figures 2.4a through 2.7c, SLOSH model time history data computed for the two grid points located at Narragansett and Providence are plotted versus time for several hypothetical storms of varying landfall location, track direction, forward speed, and intensity. The time history data were developed for these points for purposes of demonstrating how storm surge generation is affected by varying meteorological parameters and location relative to landfall. Surge heights greater or less than those shown for these locations, or other phenomenon at different locations, may result from variations in the storms meteorology, or from changing topography and bathymetry at localized areas.

In Figures 2.4b and 2.4c, time histories data for storm surges at Narragansett and Providence were plotted versus time relative to landfall for the five hurricane tracks shown in Figure 2.4a. Each hurricane of this example has an intensity of Category 3, a forward speed of 40 mph, and makes initial landfall in the vicinity of Westerly, Rhode Island. The hurricanes differ only in their track directions which range from north-northwest to northeast. The two time history points under examination (Narragansett and Providence) are located on a plane that is less than 20 miles to the east of the initial points of landfalls, or on the critical "right side of the eye". As shown in Figures 2.4b and 2.4c, peak surge tides are approximately 12.5 feet at Narragansett and 16.0 feet at Providence. For all storm directions, particularly those ranging from north-northwest to north-northeast, peak surge heights at Narragansett vary only marginally. At Providence however, under the same hurricane scenarios, time history data indicates that peak surge

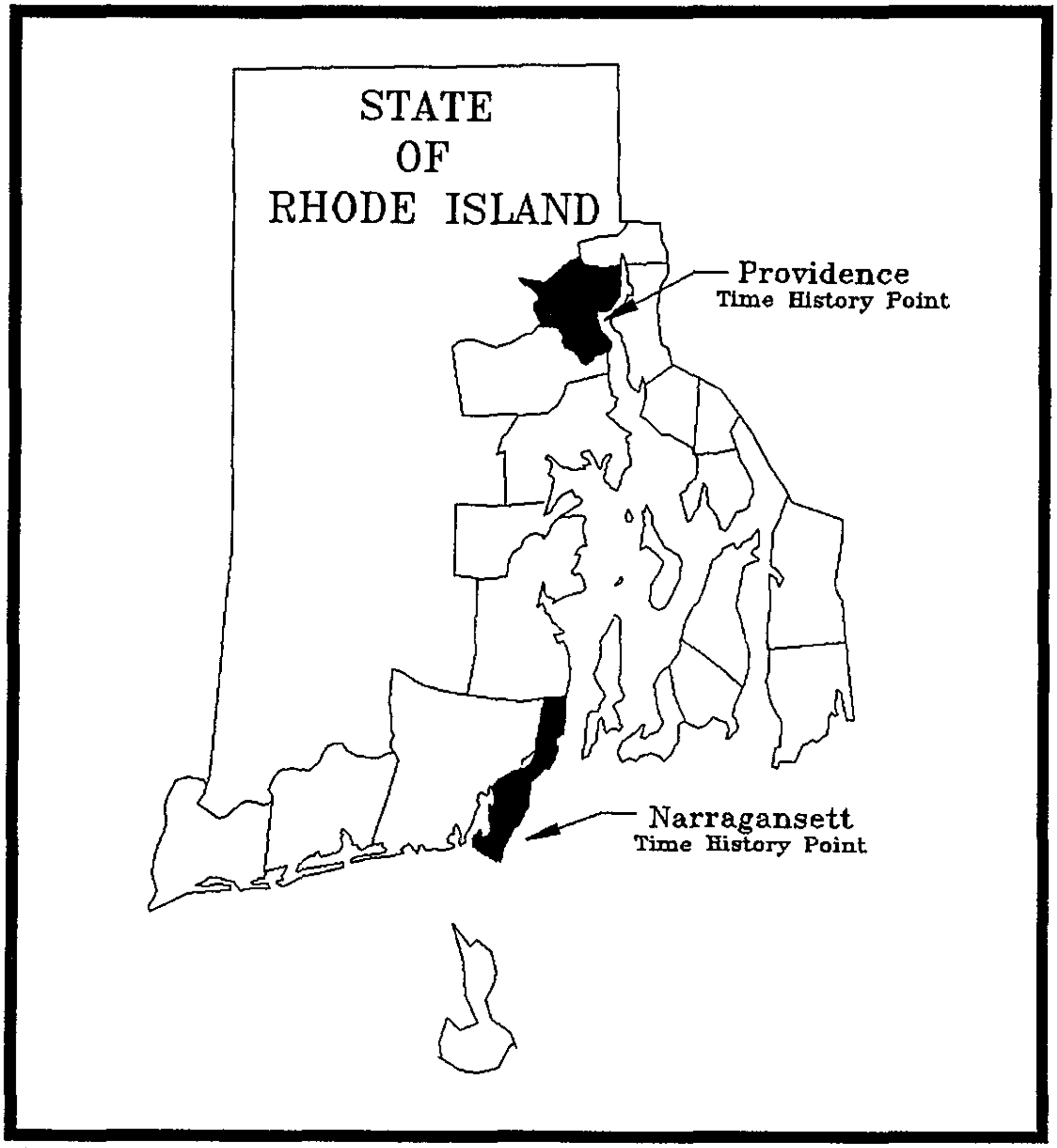


Figure 2.3 Narragansett and Providence, RI Time History Points.

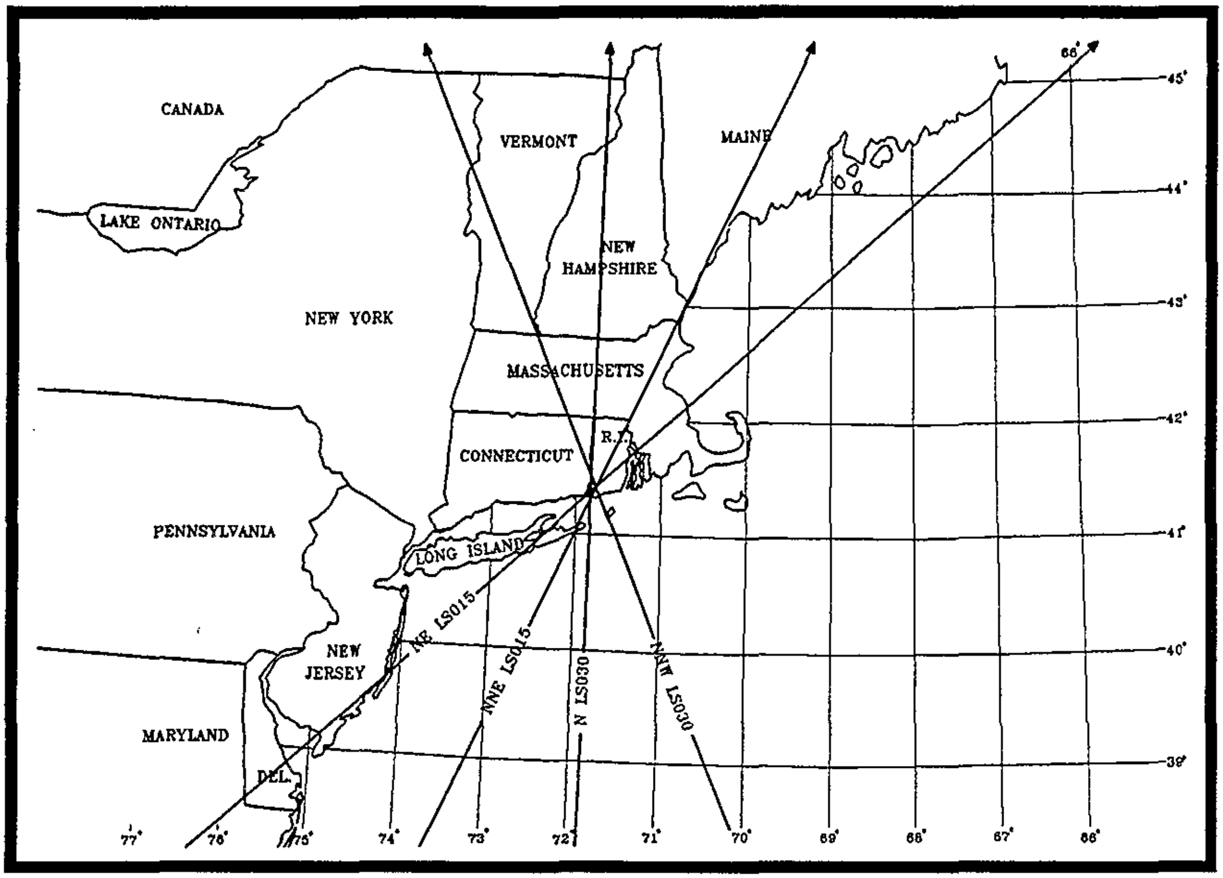


Figure 2.4a Hurricane tracks for time history data plotted in Fig. 2.4b and Fig. 2.4c.

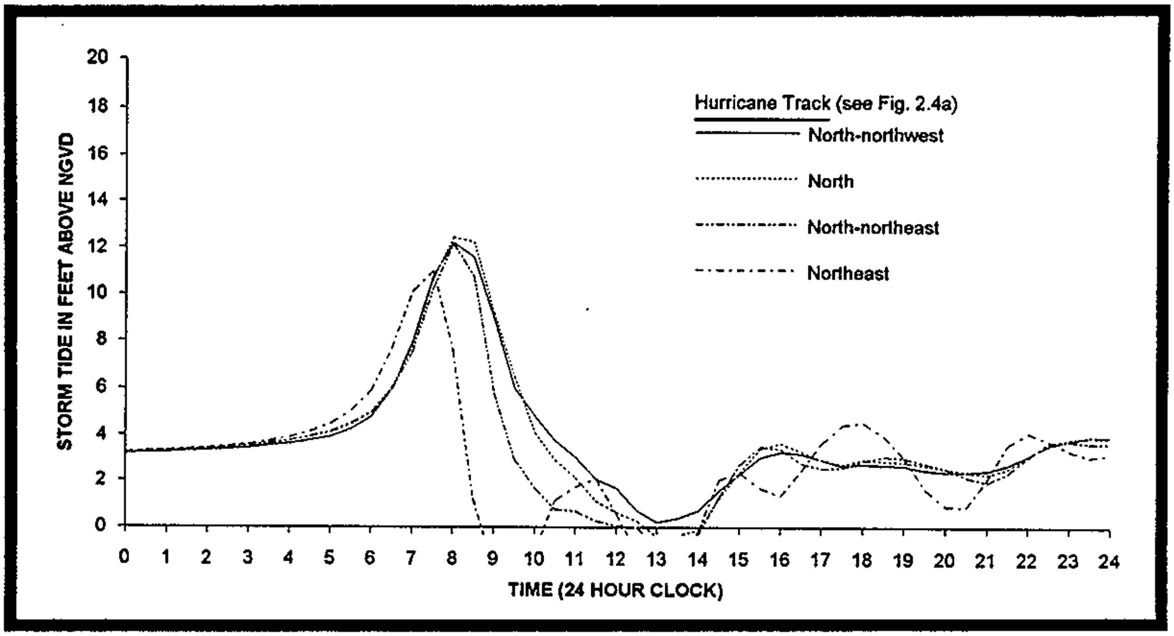


Figure 2.4b Storm tides at Narragansett, Rhode Island for varying hurricane track directions.

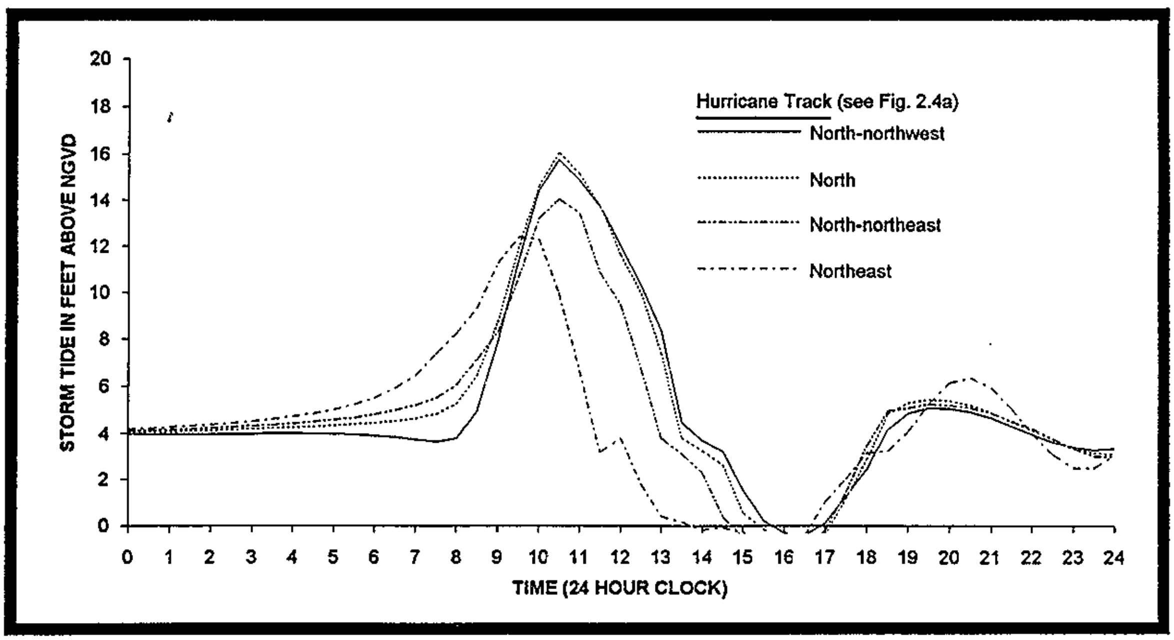


Figure 2.4c Storm tides at Providence, Rhode Island for varying hurricane track directions.

height has more variation for differences in track direction. Figure 2.4c shows that hurricanes on a direct northward track or on a northerly track with a slight westerly directional component tend to produce higher surges at the head of Narragansett Bay than hurricanes of other track directions. This example indicates that locations along the open coast of Rhode Island Sound or in the upper reaches of Narragansett Bay are vulnerable to hurricane surges irrespective of minor differences in track direction.

Figures 2.5b and 2.5c plot similar data at Narragansett and Providence for hypothetical hurricanes shown in Figure 2.5a. The hurricanes modeled in this example were all Category 3 hurricanes traveling on a north-northeast track direction at a forward speed of 60 mph. The landfall locations of the storms were varied in 30 mile increments across the Narragansett/Buzzards Bay SLOSH Basin. At both locations, the greatest values of peak surge tide (approximately 13.5 feet at Narragansett and 15.5 feet at Providence) occurred from the "LS030" storm track which makes landfall at the city of New London, Connecticut. As the track shifts to the east or west, peak surge heights from the hurricanes of this example tend to decrease. However, in the particular case of the "LS090" track hurricane, which skirts the shores of New Jersey and New York 90 miles west of Rhode Island, surges as much as 8.5 and 11.0 feet were generated at Narragansett and Providence, respectively. The time history data of this example suggests hurricanes to the west of the State, on a plane where the State is to the "right of the eye" near the radius of maximum winds, cause the maximum surge in Rhode Island. Other hurricanes, occurring either to the east or the far west of the State, may still generate significant surges in Rhode Island.

A certain degree of caution should be considered when viewing the results of individual SLOSH model runs, particularly when the model's results are used to make broad generalizations about landfall location. All hypothetical hurricanes were programmed to have a radius of maximum winds 30 miles from the eye's center. Typical radii of maximum winds of actual storms do not remain fixed and can range from about 4 miles to approximately 50 miles. Because wind forces are the primary forces governing storm surge generation, even slight expansions or contractions of a storm's radius of maximum winds can mean large differences in the storm surge generated at a particular site. In essence, a hurricane with an expanded radius of maximum winds that landfalls in western Connecticut may generate surges in Rhode Island which are equivalent to those caused by a more compact hurricane landfalling closer to the State. Moreover, because hurricane track is one of the most difficult meteorological parameters to predict, officials should base evacuation decisions on the peak surges heights from the worst case landfall position. This will eliminate the dilemma of officials being confronted with greater than expected surge heights due to sudden changes in a storm's landfall location or it's radius of maximum winds.

The affects of hurricane intensity on storm surge generation are shown by the time history data plotted for Narragansett and Providence in Figures 2.6b and 2.6c. At these locations hurricane intensity was found to be a major contributor to storm surge generation. Figure 2.6a shows the northern track of the storms modeled in this example. All of the storms were programmed to maintain a forward speed of 60 mph. As indicated in Figures 2.6b and 2.6c, peak surge height shows to have a positive, nearly linear correlation with hurricane intensity. An increase in one intensity category on the Saffir/Simpson scale resulted in an approximate 3.0 to 4.0 foot increase in storm surge at Narragansett, and an approximate 3.0 to 5.0 foot increase at Providence. Surges at Providence range on average one to three feet higher than surges generated at Narragansett under the same conditions. The elongated curves plotted for Providence in comparison to the sharper, more distinct curves plotted for Narragansett suggest that Narragansett Bay will experience near peak tidal surges for a longer duration than areas along the Rhode Island Sound for the same event.

The forward speed a hurricane travels at is another influential parameter on storm surge generation. Figures 2.7b and 2.7c show surge data plotted for time history points at Narragansett and Providence for hurricanes of different forward speeds and intensities. Figure 2.7a gives the track and direction of the hypothetical hurricanes modeled in this scenario. The plotted data at both locations indicate that higher surges accompany hurricanes that travel at faster forward speeds. Comparisons made for other meteorological scenarios at other locations in Rhode Island (not shown) give similar results.

This point can be emphasized by comparing the peak surges produced by a Category 3 hurricane traveling at 40 mph with peak surges produced from a Category 4 hurricane moving at 20 mph. At Narragansett, the Category 3 hurricane generated a 10.5 foot surge compared with only an 8.0 foot surge generated by the Category 4 hurricane. At Providence, a peak surge greater than 13.5 feet occurred from the Category 3 hurricane

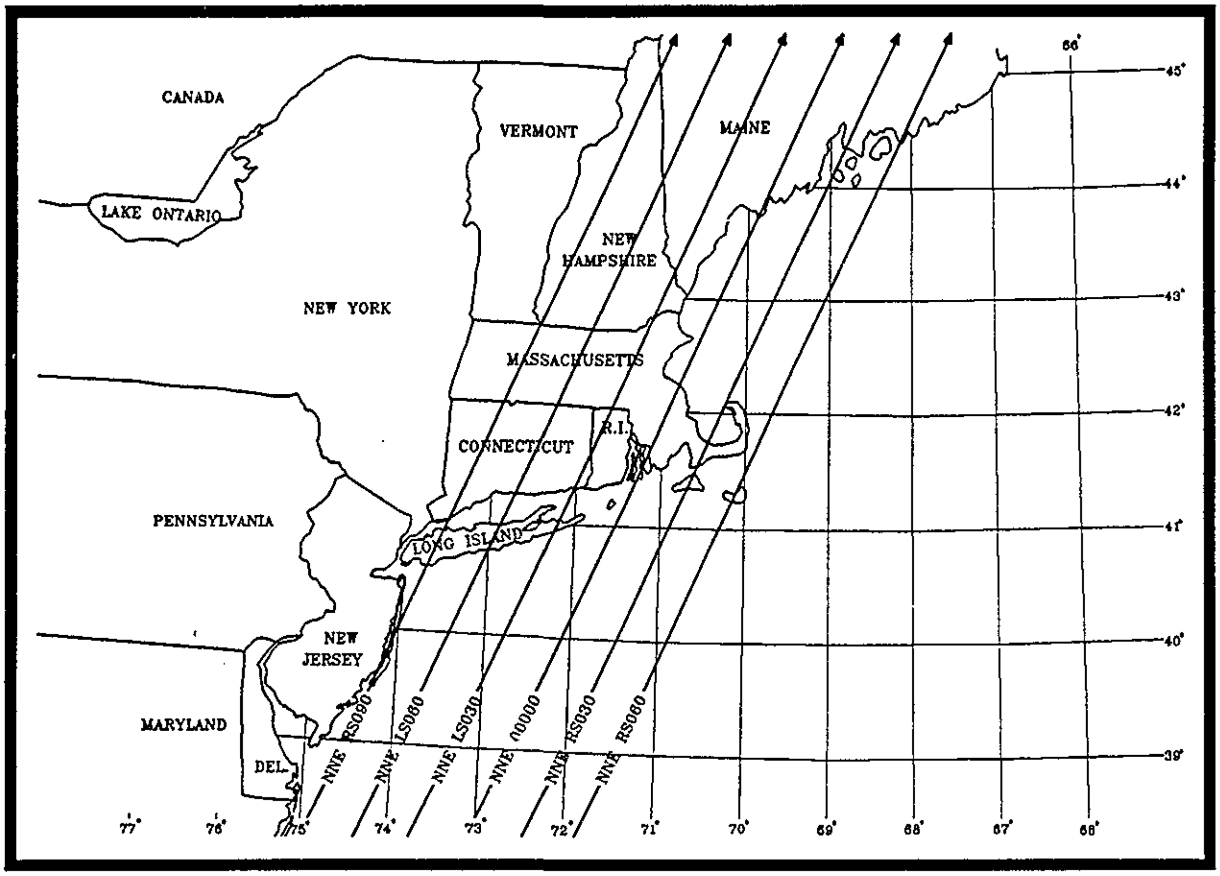


Figure 2.5a Hurricane tracks for time history data plotted in Fig. 2.5b and Fig. 2.5c.

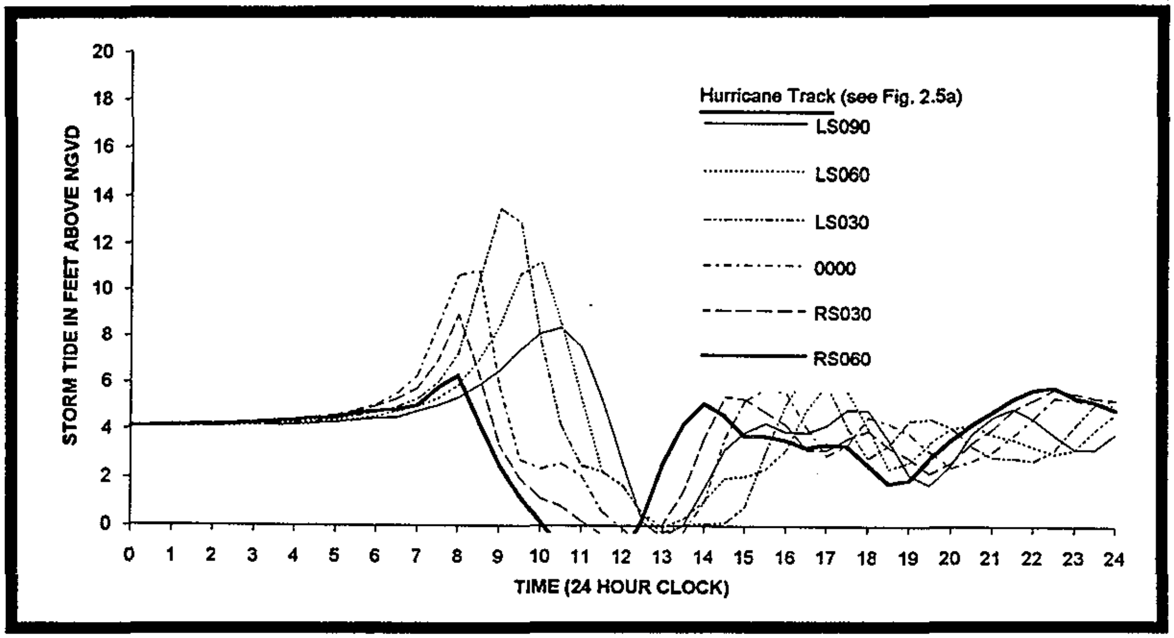


Figure 2.5b Storm tides at Narragansett, Rhode Island for varying hurricane landfall locations.

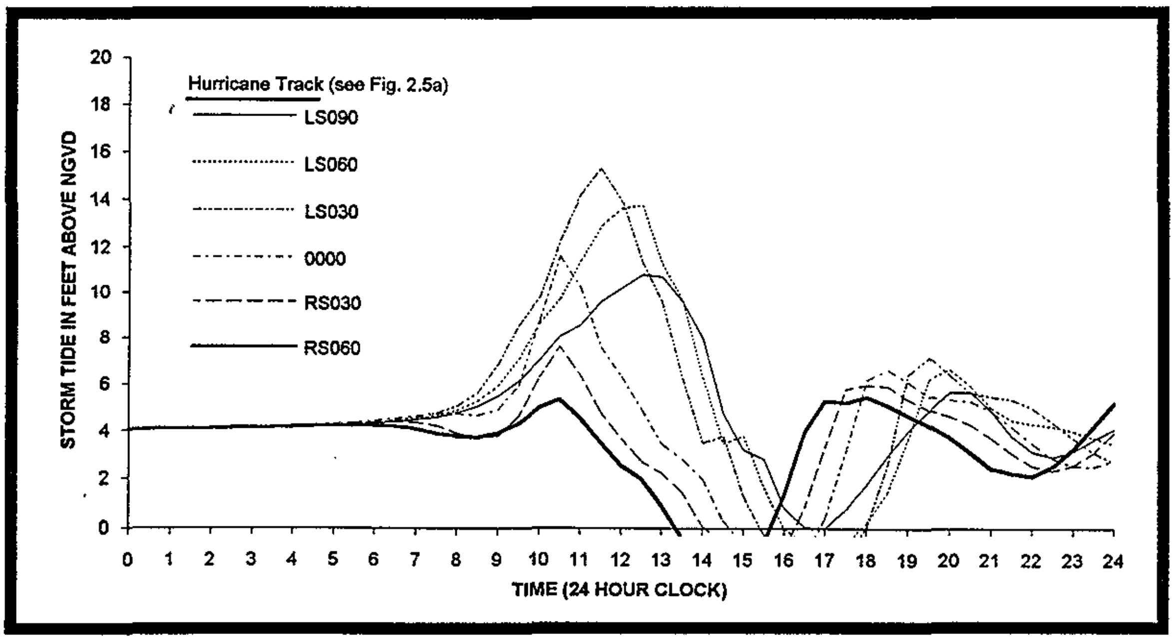


Figure 2.5c Storm tides at Providence, Rhode Island for varying hurricane landfall locations.

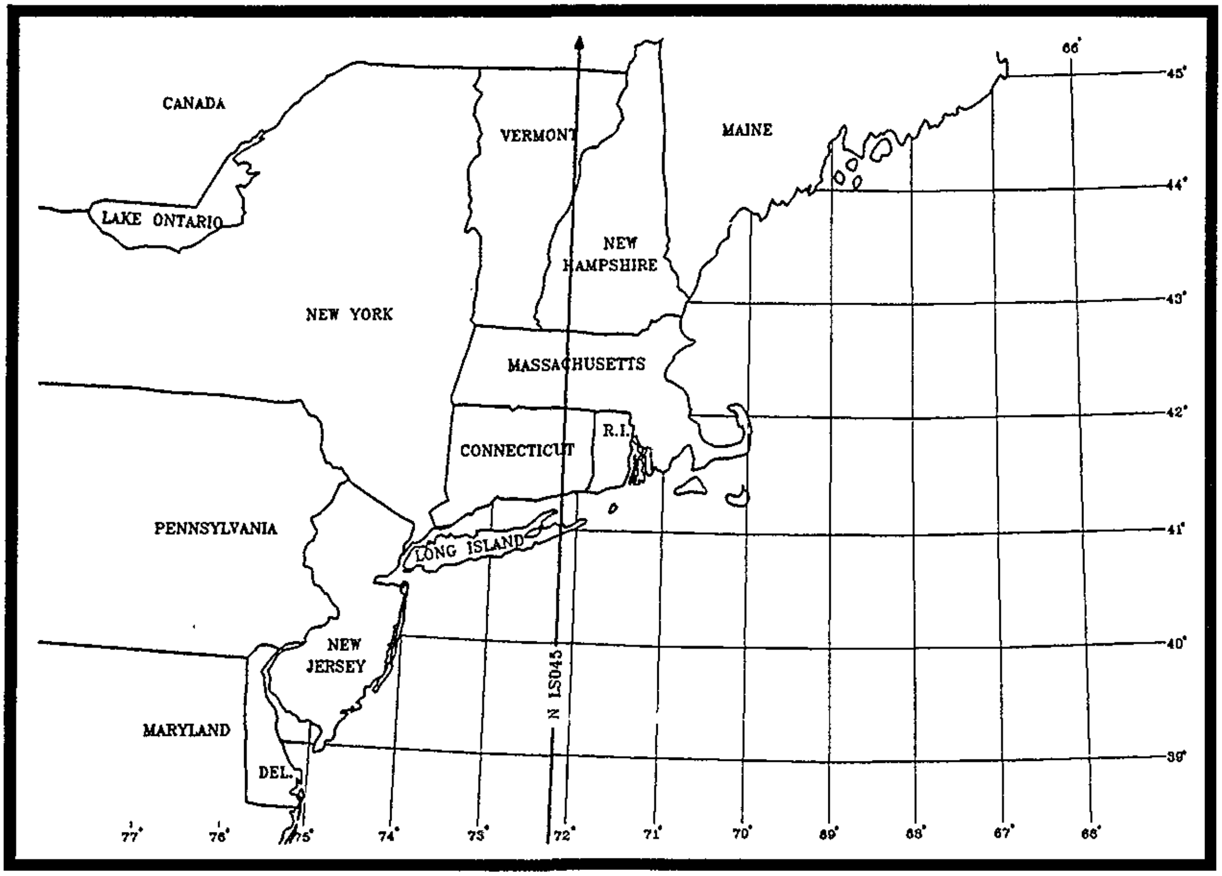


Figure 2.6a Hurricane track for time history data plotted in Fig. 2.6b and Fig. 2.6c.

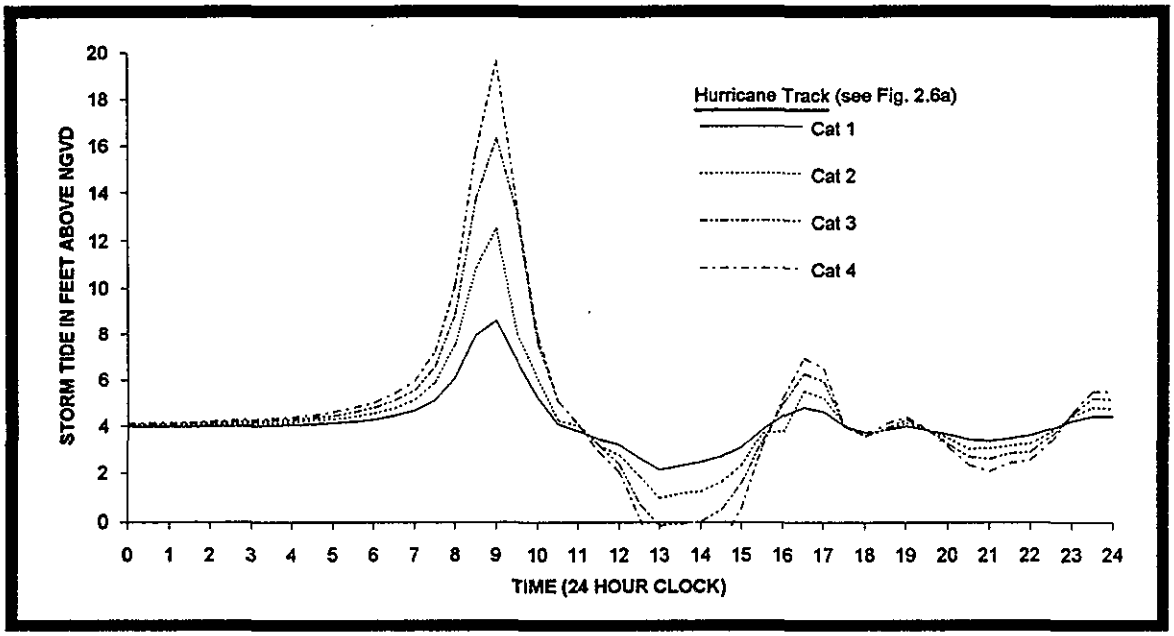


Figure 2.6b Storm tides at Narragansett, Rhode Island for varying hurricane intensity categories.

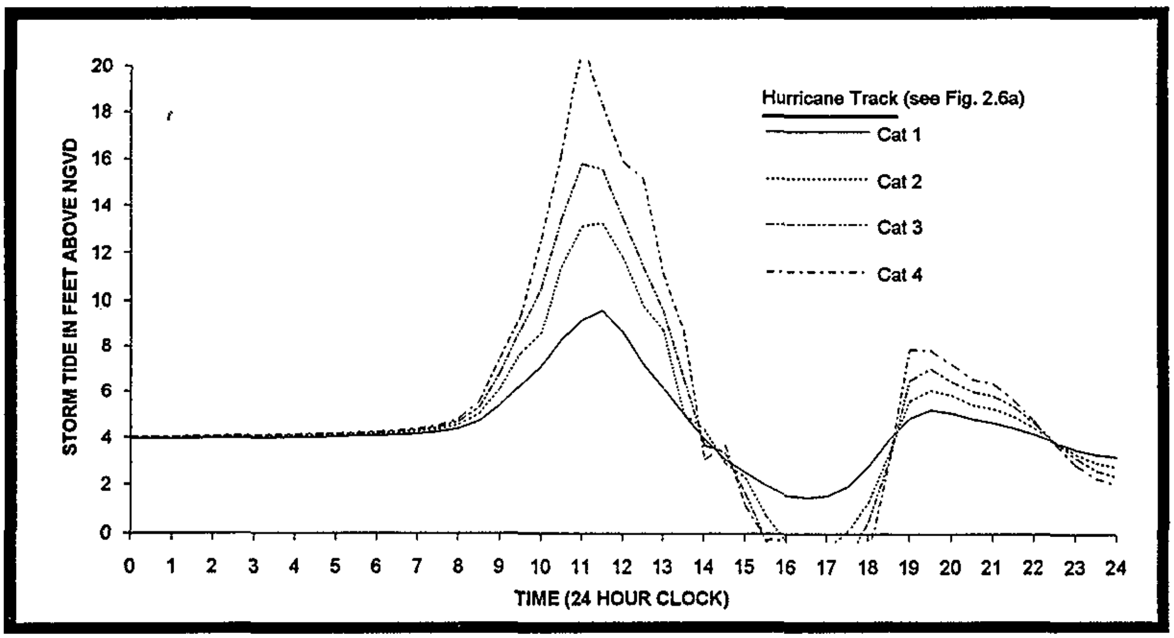


Figure 2.6c Storm tides at Providence, Rhode Island for varying hurricane intensity categories.

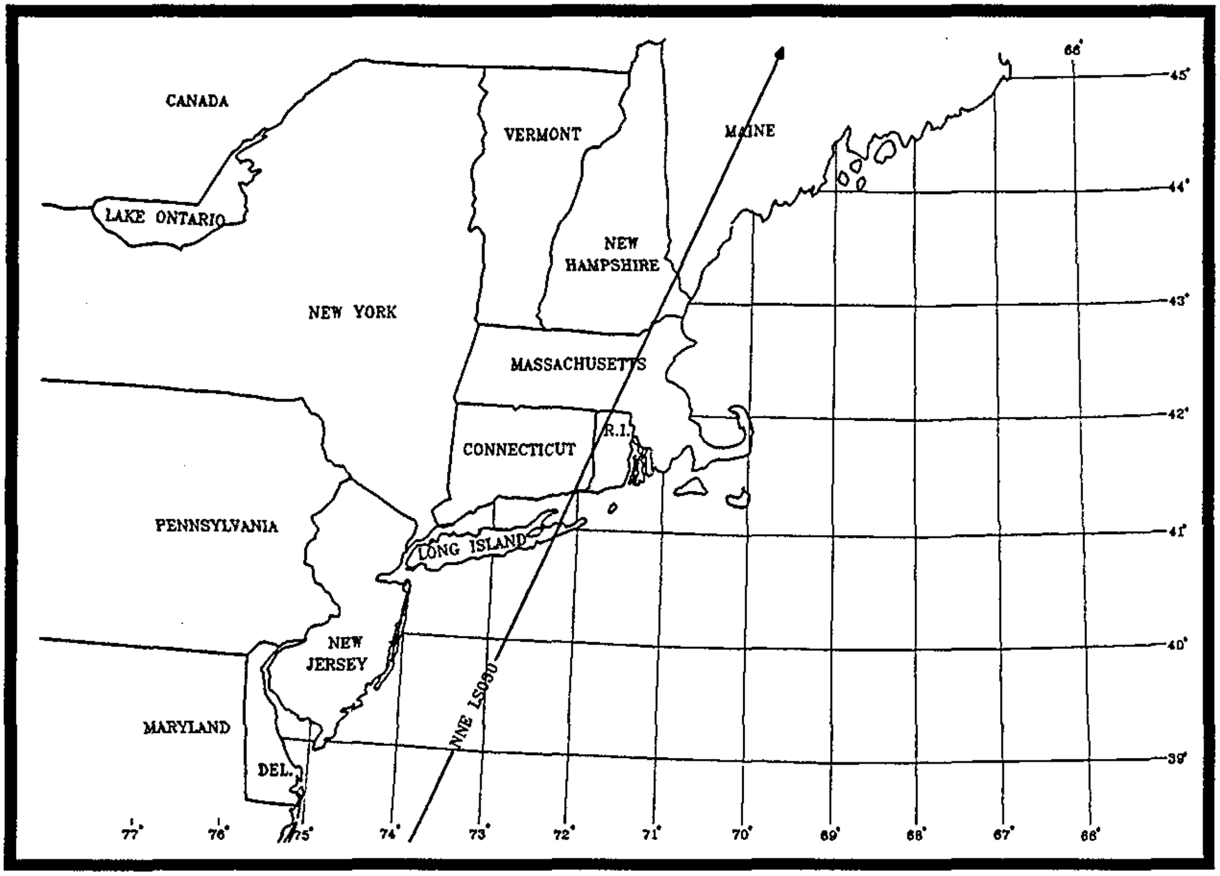


Figure 2.7a Hurricane track for time history data plotted in Fig. 2.7b and Fig. 2.7c.

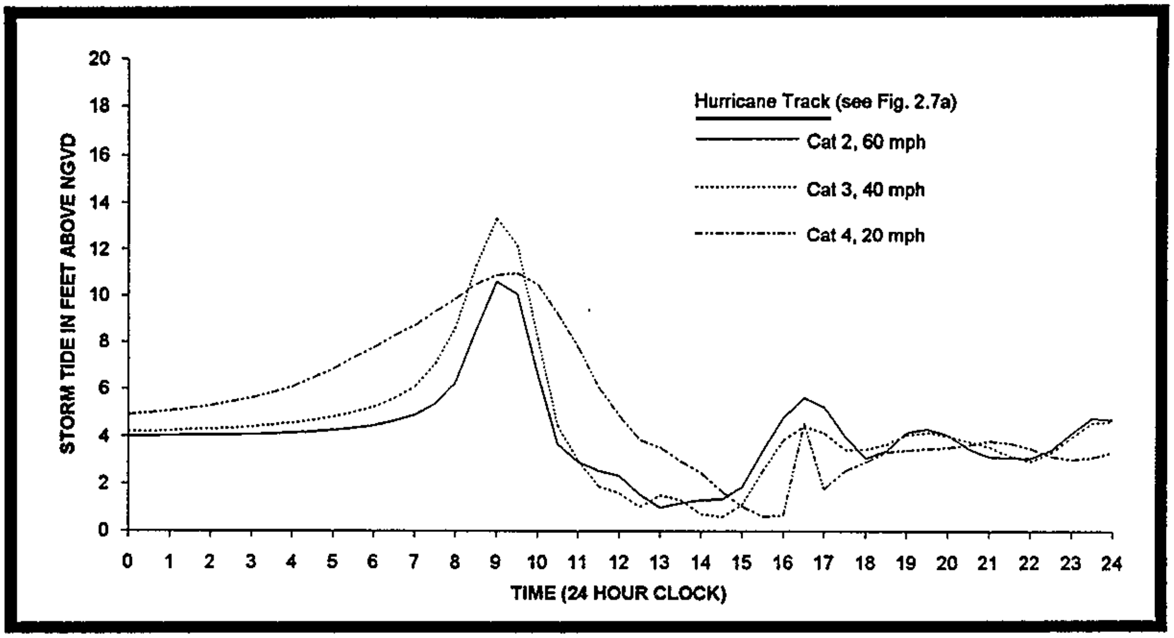


Figure 2.7b Storm tides at Narragansett, Rhode Island for varying hurricane forward speeds.

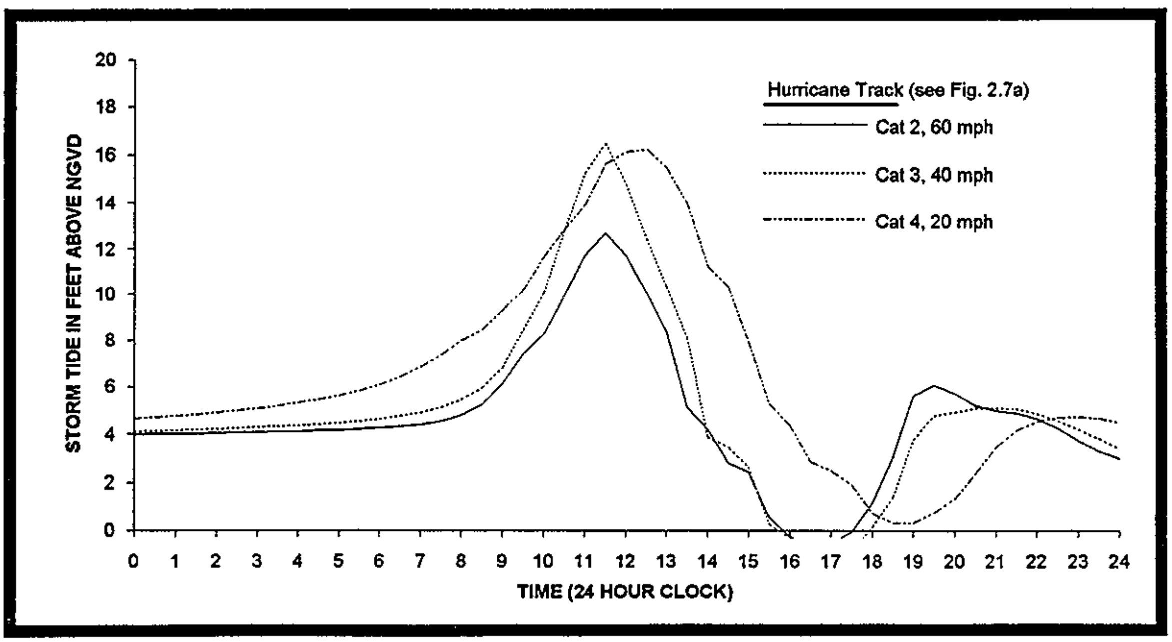


Figure 2.7c Storm tides at Providence, Rhode Island for varying hurricane forward speeds.

whereas a peak surge of less than 13.5 feet was produced from the Category 4 hurricane. This significance of this is that surges generated by a Category 3 hurricane exceed that produced by a Category 4 hurricane. For most areas within Narragansett Bay or along the open coast it can be shown that surges from a 60 mph Category 2 hurricane are comparable with surges generated by a Category 4 hurricane traveling at 20 mph. This phenomenon is explained by the fact that increased wind stresses over the ocean on the "right side of the eye" from the storm's forward speed can be more influential on surge generation than stronger rotational wind fields of higher intensity hurricanes.

Comparisons of time history plots for Narragansett and Providence under all scenarios tested in the preceding paragraphs show that peak surges at Providence arrive two to three hours after peak surges arrive at Narragansett. This is generally true for most hurricanes which approach Rhode Island. The two phenomenon which cause this delay are: the geographical distance between Providence and Narragansett, and the configuration of Narragansett Bay. First, surges generated at the mouth of Narragansett Bay (near Narragansett) require more time to move 35 miles northward in Narragansett Bay to reach Providence. Second, although Narragansett Bay has a "funneling" affect on hurricane surge, the configuration of the Bay can impede surges as they move farther northward. This in turn tends to reduce the movement of waters into the upper reaches of Narragansett Bay resulting in a slight delay in the arrival of surge at Providence.

The time history data discussed in the previous paragraphs were plotted for illustrative purposes only to demonstrate how meteorological parameters of hurricanes, the ocean's bathymetry, and coastal topography of Rhode Island can influence storm surge. Caution should be used when viewing the results from any individual SLOSH model run. Hurricanes are dynamic and difficult to forecast. Evacuation decisions based on a singe SLOSH model run may not be appropriate if the storm suddenly changes direction, increases in intensity, or accelerates. Also, errors in forecasting may also contribute to an inadequate evacuation response if an individual hurricane run is used.

2.5.6 Wave Effects

Hurricanes have great potential to generate large waves. Ultimately wave size depends on the force and duration of the driving winds, depth of water, fetch length, and the affects of natural or man-made obstructions. Breaking waves that are driven by a hurricane can run-up on shoaling beaches and overtop vertical structures well above stillwater elevations. For evacuation purposes, wave run-up should be given some consideration to assess whether areas beyond stillwater flooding limits also require evacuation. Land areas or structures vulnerable to breaking waves and wave run-up effects must be included within evacuation zones delineated by this study.

The SLOSH model does not develop data on the additional water height caused by waves above maximum stillwater elevations. For this reason, separate wave height and wave run-up analyses were performed in the Narragansett/Buzzards Bay Basin and the adjacent Long Island Sound SLOSH Basins using worst case stillwater elevations determined by the SLOSH model. The Long Island Sound SLOSH Basin provides SLOSH model coverage to coastal New York and Connecticut. Although an infinite number of coastal transects can be developed for this type of analysis, the number of transects taken along southern New England was limited to thirty. No transects were specifically designated within the State of Rhode Island. However, the transects chosen in Connecticut and Massachusetts were determined to be reasonably representative of the general bathymetry and coastal topography found along most of New England's south shore. It is beyond the objective of this study to determine precise wave heights and wave run-up effects for specific locations in the study area. Instead, the main point is to determine a general upper bound on the affects waves can have on the limits of flooding from worst case stillwater elevations, and to use this upper bound to ensure evacuation zones are delineated to include all areas vulnerable to tidal waters. It is important to note, however, that wave run-up is dependent upon local shore configuration and that even small differences in coastal topography from location to location can alter wave generation.

The methodology for analyzing wave height and corresponding wave crest elevations was developed by the National Academy of Sciences. This methodology is based on three major concepts. First, storm surge along the open coast is accompanied by waves and the maximum wave height is related to the depth of water. Second, wave heights may be diminished by energy dissipated by natural or man-made obstructions. The reduction coefficient used in the wave height calculation is a function of the physical characteristics of the obstruction. Equations have been developed by the National Academy of Sciences to determine various coefficients for natural barriers such as vegetation and dunes, and man-made barriers such as buildings, breakwaters, and seawalls. The third concept deals with unimpeded reaches between obstructions. New wave generation can occur between obstructions from continued wind action. The added energy to the formation of new waves is related to distance and mean depth of the unimpeded reach.

The methodology for analyzing wave run-up was developed by Stone & Webster Engineering Corporation. The wave run-up computer program operates using deep water wave heights, stillwater elevation, wave period, and beach slope. Wave heights and periods were determined through guidance outlined in the Corps of Engineers ETL 1110-2-305 (February 1984) using the wind speed, direction, and duration results from the SLOSH model.

As previously mentioned, wave height and wave run-up analyses were performed for 30 typical coastal transects taken at representative index locations (Mattapoisett, Falmouth, Hyannis and Nantucket, Massachusetts; and Stamford, Fairfield, Milford, Westbrook, and Stonington, Connecticut). Transects were located with consideration given to the physical and cultural characteristics of the land so that they would closely represent conditions representative of the south shore of New England.

Calculations were based on meteorological parameters of the hypothetical hurricanes derived for the SLOSH model. Of the five Saffir/Simpson categories, only Categories 2 through 4 were selected for the analysis. Category 1 storms are the least destructive and for simplicity were omitted from the analysis. As mentioned before, Category 5 hurricanes were eliminated from the overall study because of the extremely low probability of a hurricane of this magnitude ever occurring as far north as New England. The hurricane track directions that were analyzed were limited to north-northwest and north-northeast tracks because these tracks were shown to produce the greatest onshore wind speeds and surges at the index locations under analysis.

The method of fetch length determination for each index location was based on a simplification of the wave growth process. Wind speed and wind direction were assumed constant over the fetch and the fetch was assumed to be uniform in length and unlimited on either side. Fetch width does not significantly affect wave growth. For irregularly-shaped water bodies the fetch length was radially averaged over an arc centered on the wind direction. In some instances, consideration was given to circumstances which would result in diffraction or radiation of large waves to the point of interest.

Characteristics of wind-generated waves are influenced by the distance that the wind moves over the surface. Inland or sheltered water areas will have lower waves than the open coast because there is less water surface for the wind to act on. Based on the determination of limited fetch described above, the Corps of Engineers ETL 1110-2-305 (February 1984) was used with the SLOSH model to estimate the largest significant wave and period generated for the limited available fetch and wind duration.

Computations of wave run-up elevations were founded on two simplifying assumptions. First, the maximum surge associated with each hypothetical hurricane occurred simultaneously with that storm's maximum wind speed. Secondly, the maximum storm surge was assumed to arrive at each index location concurrently with high astronomic tide (MHW). As a result, the wave run-up elevation becomes the summation of high astronomical tide, maximum storm surge, and associated wave run-up.

Analysis results showed that waves do not significantly add to the areas flooded by worst case hurricane stillwater, and that their effects can usually be ignored for purposes relating to hurricane evacuation studies. This conclusion is valid for all southern New England areas except locations immediately along the open coastline, or 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 roadway embankments, buildings, dunes, vegetation, or other obstructions. The presence of these features drastically reduces wave energy. Frictional losses over inundated areas and the early breaking of waves by obstructions account for most of the dissipated energy. Unimpeded reaches are typically short which limits generation of new waves. For these reasons, it is not practical to assume wave heights and associated wave run-up will be sustained, or substantial regeneration will occur, as waves move inland over inundated areas. Thus, the analysis in general concluded that the additional area of flooding from wave run-up above worst case hurricane stillwater elevations is minimal. Accordingly, the study assumes that additional land areas vulnerable to wave effect, if any, will be included within evacuation zones delineated for worst case hurricane stillwater flooding.

2.5.7 Hurricane Barriers

The Fox Point Hurricane Barrier in the City of Providence was constructed by the Corps of Engineers in 1966 and provides virtually complete protection from hurricane surge flooding. The Barrier itself is located approximately one mile from central Providence and consists of a 700 foot concrete flood wall, 25 feet high, that extends across the Providence River. The structure contains three gate openings that prevent the entry of flood waters from the bay when closed and permit passage of small vessels when open. Each gate is 40 feet high and 40 feet wide. Two earthfilled dikes which vary between 10 to 15 feet high above ground elevation exist on either side of the main structure. The eastern dike is 780 feet long and the western dike is 1400 feet long. The Barrier has a pumping station which has five pumps and a cooling water canal that are integral parts of the project. During a tidal flood situation, the pumping station can discharge flood waters from the Providence River though the barrier into the bay. Two gated openings in the pumping station admit water into the cooling water canal that is used by an electric company which is located immediately behind the barrier. The project's design stillwater elevation is 20.5 feet NGVD; top elevation of the project was set 4.5 feet above its stillwater design elevation to prevent excessive overtopping from waves. Examination of SLOSH model results shows that the worst case surge tide estimate is 20.2 feet NGVD, assuming a high tide condition. Consequently, the Fox Point Hurricane Barrier is sufficient to protect against all worst case hurricane scenarios determined from the SLOSH model.

2.5.8 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 Rhode Island Hurricane Evacuation Study. In other analyses of the Study, areas and facilities located within inland stillwater flood hazard areas, as identified by FEMA's National Flood Insurance Program maps, were assumed to be vulnerable to potential freshwater flooding during a hurricane threat. Emergency managers should consult their community's Flood Insurance Study for 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 storm surge flooding associated with hurricanes. Storm surge data from the Hazards Analysis was 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 facilities and mobile home/trailer parks in each community.

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

3.2 INUNDATION MAP ATLAS

Areas potentially subject to tidal flooding from hurricanes of various meteorological scenarios are presented for each community in the companion Rhode Island Hurricane Evacuation Study, Inundation Map Atlas, May 1993. The flood limits delineated on each map were determined directly from surge profiles (see Plates ii and iii of the Atlas) developed from the Hazard Analysis discussed in the previous chapter. For each coastal community, the atlas groups the worst case storm tides possible from hurricanes of varying forward speed and intensity into three surge inundation areas which correspond to specific elevations relative to NGVD 1929. A particular hurricane scenario (determined by the hurricane's forward speed and intensity) may be related to an appropriate inundation area from a unique "Inundation Matrix" shown on each community's map sheet. To graphically represent the land areas that can be affected by hurricane surge, land areas with elevations equal to or lower than the storm tide elevations given in the Atlas's profiles were delineated on Rhode Island Department of Transportation (DOT) base maps. Storm tide elevations were mapped by interpolating between the 10-foot contour elevations provided by the United States Geological Survey's (USGS) 7.5 minute series quadrangle maps.

3.3 EVACUATION MAP ATLAS

Evacuation zones which correspond to the inundation areas delineated by the Inundation Map Atlas are presented in a second companion atlas entitled the Rhode Island Hurricane Evacuation Study, Evacuation Map Atlas, March 1995. The maps of this atlas serve two primary purposes. First, for each community they 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 hurricanes, and to identify public shelters, and other facilities of importance that may require special provisions during evacuation proceedings.

Two evacuation zones are presented for twelve possible hurricane scenarios that vary by a hurricane's forward speed and intensity. An "Evacuation Matrix", which is analogous to the "Inundation Matrix" developed in the Inundation Map Atlas, is provided for each community to related an appropriate evacuation zone for the approaching storm. The first evacuation zone (closest to the shore) has been termed "Evacuation Area A". It generally corresponds to the less severe hurricanes in terms of flooding potential. Likewise, the second evacuation zone (further inland away from the shore) is termed "Evacuation Area B". This evacuation zone corresponds well to those hurricanes that can cause the most severe flooding. For purposes of this study, hurricanes corresponding to "Evacuation Area A" and "Evacuation Area B" have been classified as belonging to a "weak hurricane scenario" and a "severe hurricane scenario", respectively.

The extent of land area included within each evacuation zone is based on surge inundation areas shown in the Inundation Map Atlas. Evacuation zones encompass all potentially inundated land areas as well as small "pockets" of land that could be isolated by surrounding surge. As the maps were prepared, review meetings were held with local officials to ensure that local perspectives on the delineation of evacuation zones were included in the Atlas. In most cases evacuation zone boundaries were delineated using the 1990 Census Block boundaries and generally conform 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 estimating of the total numbers of people potentially at risk from hurricane surge flooding. Moreover, census block boundaries are convenient in that they provided easily distinguishable map features that 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 population types that were included when estimating the total population living within evacuation zones are the permanent residents, as determined from census information, and seasonal residents. Seasonal residents consists of those people whose permanent residences are elsewhere, but who relocate to housing units on a temporary basis for some time during the year. The census classifies housing units used by this population type as "vacant housing units for seasonal, recreational, or occasional use". The study assumes that housing units classified by the census as such may be used to estimate the long-term seasonal persons relocating during the summertime. The study applied the same occupancy rates to these housing units as were reported for other occupied units to estimate seasonal population. The study does not explicitly attempt to quantify seasonal residents occupying hotels, motels, and campgrounds on a less permanent basis, or to determine the number of "day-trippers" visiting a particular location. The behavior and effects from this second migrant population group on the total evacuation is discussed in more detail in the Behavioral Analysis (Appendix B) and Transportation Analysis (Appendix C).

Tables 3.1 and 3.2 give estimates, by community, of the potentially vulnerable population by tabulating the total number of permanent and seasonal residents living within Evacuation Area A (weak storm scenario) and Evacuation Area B (severe storm scenario) shown in the Evacuation Map Atlas. These estimates were made based on block population totals published in the 1990 census. The vulnerable population estimates also include the community's estimated maximum mobile home population because of their particular susceptibility to hurricane winds. The maximum mobile home population is assumed equal to the rate of occupancy of occupied mobile homes multiplied by the combined total of occupied and vacant mobile homes/trailers listed for each community in the 1990 census. The mobile home population includes those people living in organized mobile home/trailer park facilities as well as those residing on a separate parcel of land.

TABLE 3.1
VULNERABLE POPULATION
WEAK HURRICANE SCENARIO

Community	Permanent Population	Seasonal Population	Total Mobile Home Population	Permanent Population Living in Evacuation Zones	Seasonal Population Living in Evacuation Zones	Total Vulnerable Population
Barrington	15,850	180	0	8,440	90	8,530
Bristol	21,630	400	0	1,680	40	1,720
Charlestown	6,480	4,010	330	710	440	1,480
Cranston	76,060	200	50	1,730	0	1,780
East Greenwich	11,870	60	110	680	0	790
East Providence	50,380	110	170	4,590	10	4,770
Jamestown	5,000	5,000 [1]	10	1,420	1,420	2,850
Little Compton	3,340	920	190	520	140	850
Middletown	19,460	240	450	520	10	980
Narragansett	14,990	4,850	10	4,800	1,390	6,200
New Shoreham	840	1,880	0	260	580	840
Newport	28,230	1,640	0	6,990	680	7,670
North Kingstown	23,790	630	540	5,550	280	6,370
Pawtucket	72,640	70	880	670	0	1,550
Portsmouth	16,860	1,380	1,080	4,930	330	6,340
Providence	160,730	330	0	220	0	220
South Kingstown	24,630	10,000 [2]	460	2,240	2,810	5,510
Tiverton	14,310	450	720	1,760	70	2,550
Warren	11,390	270	10	4,010	110	4,130
Warwick	85,430	900	210	15,800	260	16,270
Westerly	21,610	4,000 [3]	210	2,160	1,790	4,160
TOTALS	685,520	37,520	5,430	69,680	10,450	85,560

NOTES:
[1] Revised estimate determined by the Jamestown town manager based on water connections for summertime residents.
[2] Revised estimate determined by the South Kingstown emergency management director based on data obtained from the local Chamber of Commerce.
[3] Revised estimate determined by the Westerly emergency management director based on fire district data.

TABLE 3.2
VULNERABLE POPULATION
SEVERE HURRICANE SCENARIO

Community	Permanent Population	Seasonal Population	Total Mobile Home Population	Permanent Population Living in Evacuation Zones	Seasonal Population Living in Evacuation Zones	Total Vulnerable Population
Barrington	15,850	180	0	13,720	170	13,890
Bristol	21,630	400	0	3,500	50	3,550
Charlestown	6,480	4,010	330	1,330	850	2,510
Cranston	76,060	200	50	2,280	0	2,330
East Greenwich	11,870	60	110	1,120	10	1,240
East Providence	50,380	110	170	7,240	20	7,430
Jamestown	5,000	5,000 [1]	10	1,950	1,950	3,910
Little Compton	3,340	920	190	760	210	1,160
Middletown	19,460	240	450	1,550	20	2,020
Narragansett	14,990	4,850	10	6,910	2,110	9,030
New Shoreham	840	1,880	0	260	580	840
Newport	28,230	1,640	0	9,680	910	10,590
North Kingstown	23,790	630	540	6,950	330	7,820
Pawtucket	72,640	70	880	670	0	1,550
Portsmouth	16,860	1,380	1,080	5,110	340	6,530
Providence	160,730	330	0	1,010	0	1,010
South Kingstown	24,630	10,000 [2]	460	2,920	3,930	7,310
Tiverton	14,310	450	720	2,280	80	3,080
Warren	11,390	270	10	7,330	180	7,520
Warwick	85,430	900	210	28,150	400	28,760
Westerly	21,610	4,000 [3]	210	4,090	2,820	7,120
TOTALS	685,520	37,520	5,430	108,810	14,960	129,200

NOTES:
[1] Revised estimate determined by the Jamestown town manager based on water connections for summertime residents.
[2] Revised estimate determined by the South Kingstown emergency management director based on data obtained from the local Chamber of Commerce.
[3] Revised estimate determined by the Westerly emergency management director based on fire district data.

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 lists are organized in the order that community maps appear in the Evacuation Map Atlas. The location of each facility can be found by cross referencing its map key numbers with the locator symbols shown in the Atlas for a particular community. Medical and institutional facilities located within evacuation zones may require special evacuation provisions and perhaps some additional lead time prior to actual evacuations. Other 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, "None", in the column labeled "SURGE FLOODING" in Tables 3.3 through 3.6 indicates the facility is not located within a hurricane surge inundation area. No attempt has been made to determine whether or not a particular facility is located within the 100- or 500-year flood plain delineations of FEMA's NFIP maps.

TABLE 3.3
WASHINGTON COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Westerly	Westerly Hospital	Hosp.	None
2	Westerly	Watch Hill Nursing Home	Nurs.	Yes
3	Westerly	Westerly Health Center	Nurs.	None
4	Westerly	Westerly Nursing Home	Nurs.	"
5	Westerly	Elms	Nurs.	"
1	South Kingstown	South County Hospital	Hosp.	"
2	South Kingstown	Allen's Health Center	Nurs.	Yes
3	South Kingstown	Scallop Shell Nursing Home	Nurs.	None
4	South Kingstown	South Bay Manor	Nurs.	"
1	North Kingstown	Scalabrini Villa	Nurs.	"
2	North Kingstown	South County Nursing Home	Nurs.	"
3	North Kingstown	Roberts Health Center	Nurs.	"
4	North Kingstown	Lafayette Nursing Home	Nurs.	"

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.4
KENT COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	East Greenwich	Greenwich Bay Manor	Nurs.	None
2	East Greenwich	Harbour Medical	Hosp.	"
1	Warwick	Kent County Memorial Hospital	Hosp.	"
2	Warwick	Warwick Emergency Room	Hosp.	"
3	Warwick	Avalon Nursing Home	Nurs.	Yes
4	Warwick	Brentwood Nursing Home	Nurs.	None
5	Warwick	Greenwood House Nursing Home	Nurs.	"
6	Warwick	Kent Nursing Home	Nurs.	"
7	Warwick	Pawtuxet Village Nursing Home	Nurs.	Yes
8	Warwick	Sunny View Nursing Home	Nurs.	None
9	Warwick	Warwick Health Center	Nurs.	"
10	Warwick	Warwick Rest Home	Nurs.	"
11	Warwick	West Bay Manor	Nurs.	"
12	Warwick	Royal Manor	Nurs.	"

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.5
PROVIDENCE COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Cranston	RIMC General Hospital	Hosp.	None
2	Cranston	RIMC Institute of Mental Health	Hosp.	"
3	Cranston	Cedar Crest Nursing Center	Nurs.	"
4	Cranston	Cra-Mar Nursing Home	Nurs.	"
5	Cranston	Scandinavian Home for the Aged	Nurs.	"
1	Providence	Miriam Hospital	Hosp.	"
2	Providence	Rhode Island Hospital	Hosp.	"
3	Providence	Roger Williams General Hospital	Hosp.	"
4	Providence	Saint Joseph Hospital	Hosp.	"
5	Providence	Veterans Administration Hospital	Hosp.	"
6	Providence	Women and Infants Hospital	Hosp.	"
7	Providence	Ann's Rest Home	Nurs.	"
8	Providence	Bannister Nursing Care Center	Nurs.	"
9	Providence	Bay Tower Nursing Center	Nurs.	"
10	Providence	Bethany Home of Rhode Island	Nurs.	"
11	Providence	Charlesgate Nursing Center	Nurs.	"
12	Providence	Elmhurst Extended Care Facility	Nurs.	"
13	Providence	Elmwood Health Center	Nurs.	"
14	Providence	Hallworth House	Nurs.	"
15	Providence	Park View Nursing Home	Nurs.	"
16	Providence	Saint Elizabeth Home	Nurs.	"
17	Providence	Steere House	Nurs.	"
18	Providence	Summit Medical Center	Nurs.	"

TABLE 3.5 (continued)
PROVIDENCE COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
19	Providence	Tockwotton Home	Nurs.	"
20	Providence	Wayland Health Center	Nurs.	"
21	Providence	Warren Manor II	Nurs.	None
1	Pawtucket	Pawtucket Memorial Hospital	Hosp.	"
2	Pawtucket	Jeanne Jugan Residence	Nurs.	"
3	Pawtucket	Maynard Rest Home	Nurs.	"
4	Pawtucket	Oak Hill Nursing Center	Nurs	"
1	East Providence	Emma Pendleton Bradley Hospital	Hosp.	"
2	East Providence	Eastgate Nursing and Recovery Center	Nurs.	"
3	East Providence	Evergreen House Health Center	Nurs.	"
4	East Providence	Hattie Ide Chaffee Home	Nurs.	"
5	East Providence	Harris Health Center	Nurs.	"
6	East Providence	Health Havens Nursing Center	Nurs.	"
7	East Providence	Orchard View Manor	Nurs.	"
8	East Providence	Riverside Nursing Home	Nurs.	"
9	East Providence	Waterview Villa	Nurs.	Yes
10	East Providence	United Methodist Health Care Center	Nurs.	None
11	East Providence	East Bay Manor	Nurs.	Yes
12	East Providence	East Bay Geriatric Center	Nurs.	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.6
BRISTOL COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Barrington	Maple Ave. Medical Center	Hosp.	Yes
1	Warren	Warren Medical Center	Hosp.	Yes
2	Warren	Desilets Medial Center	Hosp.	None
3	Warren	Grace Barker Nursing Home	Nurs.	Yes
4	Warren	Crestwood Nursing Home	Nurs.	None
5	Warren	Desilets Nursing Home	Nurs.	"
1	Bristol	Silver Creek Manor	Nurs.	Yes
2	Bristol	Meta Manor Health Center	Nurs.	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.7
NEWPORT COUNTY
MEDICAL/INSTITUTIONAL FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Middletown	Carriage House Nursing Home	Nurs.	"
2	Middletown	Forest Farm Health Care Center	Nurs.	"
3	Middletown	Grand Islander Health Care Center	Hosp.	"
4	Middletown	John Clarke Retirement Center	Nurs.	"
1	Newport	Naval Regional Medical Center	Hosp.	Yes
2	Newport	Newport Hospital	Hosp.	None
3	Newport	Catherine Manor	Nurs.	"
4	Newport	Oakwood Health Care Center	Nurs.	"
5	Newport	Saint Clare's Home for the Aged	Nurs.	"
6	Newport	Village House	Nurs.	"

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

3.6 MOBILE HOME/TRAILER PARK FACILITIES

Tables 3.8 though 3.11 list the names of trailer and mobile home parks in each community of the study area by county. Sites where a single mobile home unit may be located are not listed. However, the estimated mobile home 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. All mobile home/trailer park data were furnished by emergency management officials from the communities. No sites were identified in coastal communities in Bristol County. The location of any facility listed may be found by cross referencing the map key numbers provided in the tables with the locator symbols identified in the Evacuation Map Atlas. Unless otherwise noted in the tables, "None" in the column labeled "SURGE FLOODING" indicates that a particular facility is not located within hurricane surge areas. Due to the susceptibility of these structures to high winds, the study recommends that officials evacuate the residents of all mobile homes and camping facilities before a hurricane strikes regardless of their flooding potential.

TABLE 3.8
WASHINGTON COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Westerly	Pucci Trailer Park	Mobile	Yes
2	Westerly	Dunes Trailer Park	Mobile	Yes
1	Charlestown	Border Hill Trailer Park	Mobile	None
2	Charlestown	Indian Cedar Trailer Park	Mobile	"
3	Charlestown	Burlingame Campground	Camp.	"
4	Charlestown	Charlestown Breach Way	Camp.	Yes
5	Charlestown	State Beach Camping Area	Camp.	Yes
1	South Kingstown	Tucker's Camp Grounds	Camp.	None
1	Narragansett	Fisherman's Memorial Park	Mobile	"
1	North Kingstown	Post Road Annex	Mobile	"
2	North Kingstown	Post Road Mobile Home Park	Mobile	"
3	North Kingstown	Razee's Trailer Park	Mobile	"
4	North Kingstown	Krzak Trailer Park	Mobile	"

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.9
KENT COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	East Greenwich	Sun Valley Park	Mobile	None
1	Warwick	Tollgate Village	Mobile	"

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.10
PROVIDENCE COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Cranston	Conetti's Trailer Park	Mobile	None
1	East Providence	Pete's Trailer Park	Mobile	None
2	East Providence	Taylor Park	Mobile	None

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

TABLE 3.11
NEWPORT COUNTY
MOBILE HOME/TRAILER PARK FACILITIES

MAP KEY[1]	COMMUNITY	FACILITY NAME	TYPE	SURGE FLOODING[2,3]
1	Portsmouth	Trailer Park #1	Mobile	None
2	Portsmouth	Trailer Park #2	Mobile	"
1	Middletown	Forest Park	Mobile	"
2	Middletown	Meadowlark Trailer Park	Mobile	"
3	Middletown	Bay View Park	Mobile	Yes
4	Middletown	Paradise Park	Mobile	None
5	Middletown	Sachuest Campground	Camp.	Yes
1	Tiverton	Pachet Brook	Mobile	None
2	Tiverton	Dadson Park	Mobile	"
3	Tiverton	Four Seasons	Mobile	"
4	Tiverton	Fairfield Trailer Park	Mobile	"
5	Tiverton	Lawrence Court Trailer Park	Mobile	Yes
1	Jamestown	Fort Getty Campground	Camp.	Yes

NOTES:
[1] Facility locations are provided in the companion Evacuation Map Atlas.
[2] "None" indicates facility is not located within hurricane surge areas.
[3] "YES" indicates facility is located in or adjacent to hurricane surge areas.

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 used 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. The timing at which 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 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 used for the analysis is a report entitled Behavioral Assumptions for Hurricane Planning in Rhode Island, 1989. This document is part of a comprehensive analysis entitled Hurricane Evacuation Behavior in the Middle Atlantic and

Northeast States, 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 data sources are 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 Rhode Island.

4.3 GENERAL RESPONSE MODEL

Most of the behavioral assumptions derived for Corps of Engineers and FEMA sponsored hurricane evacuation studies have been formulated using a "general response model". The concept of the General Response Model for hurricane evacuation studies was developed by Hazard's Management Group, Inc.. It is based on data derived from an extensive list of post-hurricane response studies conducted nation-wide over the last three decades. The Model predicts a quantitative value for behavioral response for specific evacuation situations and circumstances. Relationships and patterns between response and various parameters affecting human 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 reasonable hurricane evacuation response predictions by analyzing population characteristics of the study area. This is true whether or not the location under investigation has experienced a hurricane in the past. Once the General Response Model is applied to a study area, the Model's predicted values may be 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 Rhode Island portion of the sample survey was conducted by telephone. After consultation with State emergency management officials in Rhode Island, a telephone survey of 200 coastal residents was designed. Households in Rhode Island that were interviewed were from the communities of Newport and Warwick. Tabulated responses are given in Appendix B.

4.4 BEHAVIORAL ASSUMPTIONS

It is important to recognize that no single set of behavioral assumptions is appropriate throughout the entire coastal area of Rhode Island. The eight state survey conducted after Hurricane Gloria showed that response may vary even within relatively small geographical areas. Furthermore, behavior during the next hurricane threat might be quite different than that observed in Gloria. Fortunately, such variations can be predicted in most cases. Response patterns observed in Rhode Island 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. This information is used in later chapters to establish appropriate behavioral assumptions for the Shelter and Transportation Analyses.

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. The analysis determined that in the face of a severe hurricane, 90 percent of residents in flood-prone areas near the open coast will evacuate if public officials take aggressive action urging or ordering them to leave. In the same areas, compliance of residents will be at 80 percent if people perceive the hurricane threat as not severe. Evacuation participation among those living along inland areas less vulnerable to hurricane surge is 40 to 80 percent depending on the public's perceived danger and the storm's severity.

An important distinction made by the analysis is that 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. In post-hurricane studies, door-to-door notification methods have shown to be the most reliable because residents of particular households understand that evacuation notices are directed at them. Less aggressive or unsuccessful dissemination of evacuation notices will result in evacuation rates closer to 55 to 65 percent in open coast areas and 30 percent or less in vulnerable inland areas.

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

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 do so. Hurricane Evacuation Studies of other states tested during recent hurricanes have shown that as much as 5 percent of the "non-surge vulnerable population" in the vicinity of the evacuation will also evacuate. Although no specific behavioral data was collected in New England with regard to this statistic, it is reasonable to assume that evacuation by the "non-surge vulnerable population" in New England will be no greater than that at other locations in the United States. Most year-round homes in New England have protective subsurface foundations which offer residents in fear of hurricane winds a safe place of refuge. On grade, or slab, construction more typical of temperate climates do not offer residents this same security. People living in this type of housing unit are more vulnerable to wind hazards and therefore are more likely to evacuate.

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 of 85 to 95 percent depending on 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. Notices such as this will help to encourage tourists intending on a short stay to return home early. For those tourists who choose instead to "ride out the storm", it is important that emergency management officials have the cooperation of facility managers in order to ensure that these guests receive 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 Rhode Island even large changes in the assumed participation rates do not change roadway clearance times significantly. 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[1]	EVACUATION AREA "A"[2]	EVACUATION AREA "B"[3]	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION[4]
Weak Storm	80 %	40 %	100 %	2 %
Severe Storm	90 %	90 %	100 %	5 %

Notes:
[1] Descriptions of "weak storm" and "severe storm" scenarios are given on page 3-2.
[2] Evacuation zones closest to the coast as shown in the Evacuation Map Atlas.
[3] Evacuation zones farthest from the coast as shown in the Evacuation Map Atlas.
[4] Percentage of the total community's "non-surge vulnerable population" assumed to evacuate.

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. Fewer than 20 percent of eventual evacuees will leave before being told to leave. 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 may 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 Rhode Island after Gloria were for the most part inconclusive with regard 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 about evacuation timing can be made other than observations reported by local officials.

Even if actual response data were available for Hurricanes Gloria and Bob, evacuation timing can not be generalized from a single event data because the circumstances of each particular evacuation may vary considerably from storm to storm. This, however, does not present a problem in deriving planning assumptions about evacuation timing for a region. Figure 4.1 provides a set of planning assumptions developed for Rhode Island based on results of an eight state survey referenced in Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States (see Appendix B). In Figure 4.1, the left-most curve ("early") represents response when forecasts are early and residents are told to evacuate with plenty of warning. That scenario would probably be considered optimistic in most cases. For planning purposes, the study determined that the middle curve ("normal") is probably more typical. Warning is not quite as early in relation to the hurricane's assumed time of landfall. Finally, the right-hand curve ("late") is likely to pertain when a storm accelerates, intensifies, or changes course unexpectedly. In this scenario, people are assumed to leave promptly provided that it is made clear that they must.

As mentioned before, one of the most influential factors in evacuation timing is the action taken by local authorities. Consequently, the timing at which an evacuation order or recommendation is made in relation to when the majority of eventual evacuees leave is a critical component to any planning response curve. The curves shown in Figure

4.1 provide a starting point in developing response curves for the Rhode Island Hurricane Evacuation Study, but provide little information on the precise times evacuation orders are assumed to occur in relation to when the majority of evacuees are assumed to leave. Therefore, response curves founded and used successfully in other State's hurricane evacuation studies, personal interviews of community officials after Hurricane Bob, and discussions with emergency management officials from the State of Rhode Island provided a basis for modifying the curves in Figure 4.1.

Figure 4.2 shows the three response curves that have been derived and used by this study for Rhode Island. The curves maintain the general shape of the "normal" curve in Figure 4.1, but the length of time evacuees are assumed to mobilize and leave is much shorter, and times at which evacuation recommendations are assumed to be issued in relation to landfall are specified. The terms "slow", "moderate", and "rapid" rates of response have been adopted for consistency with methodologies applied in other states's Hurricane Evacuation Studies. A "slow response" 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 a rapid response. For purposes of this study, the planning response curves in Figure 4.2 are assumed to realistically represent the three levels of urgency that are likely to occur during hurricane evacuations in Rhode Island. The Transportation Analysis, presented in Chapter Six, discusses in detail how these curves were tested and related to roadway clearance time and total evacuation time.

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 15 percent of the surge-vulnerable residents further inland go to public shelters. Other inland residents, not

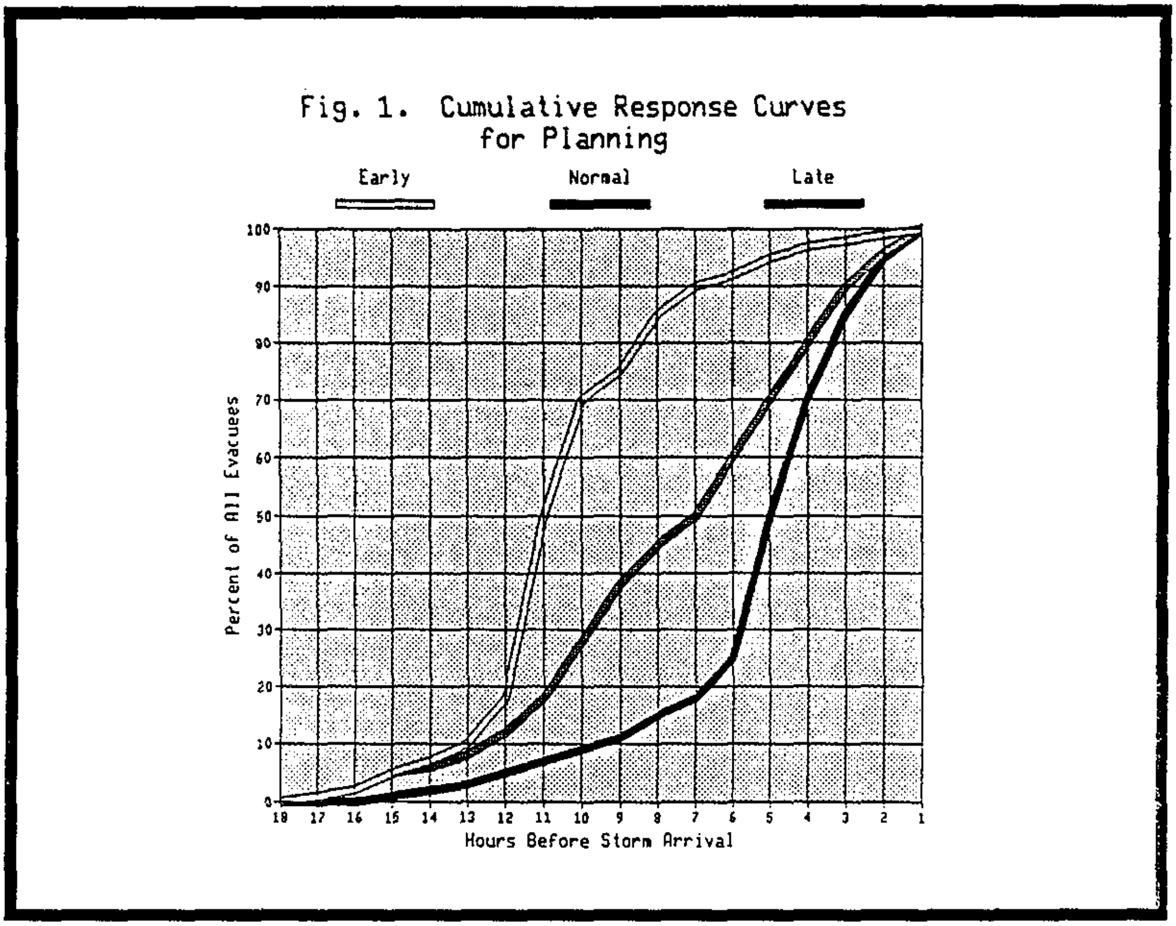


Figure 4.1 Cumulative Response Curves for Planning. Source: HMG, Inc.

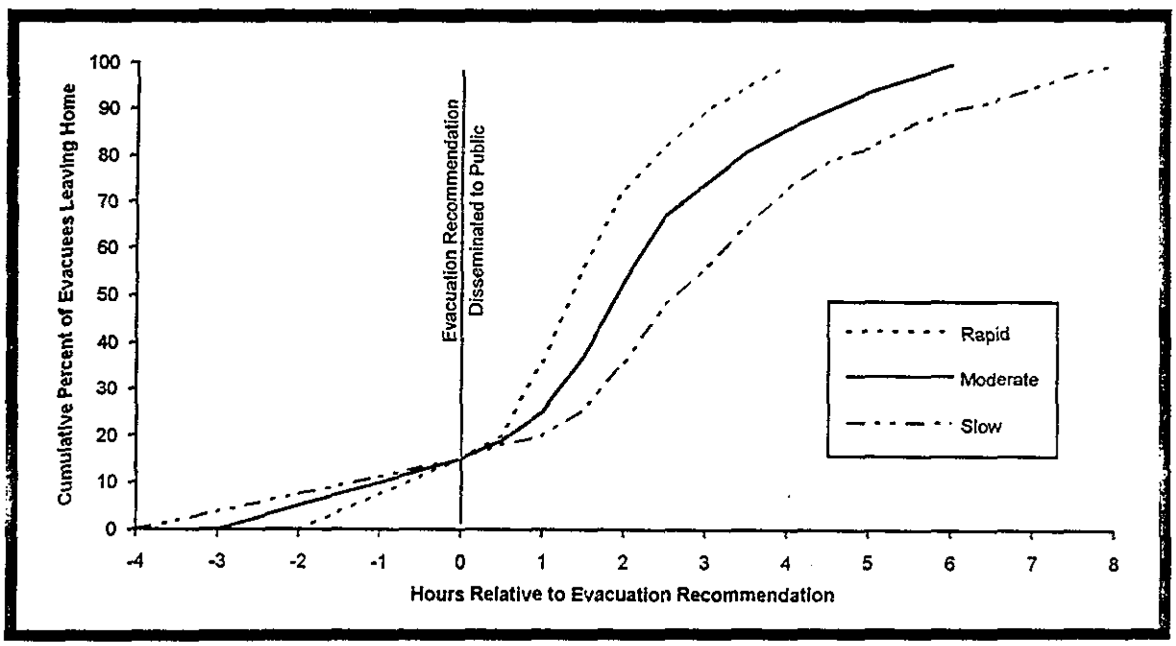


Figure 4.2 Behavioral Response Curves Assumed for Rhode Island.

threatened by hurricane flooding but who still choose to evacuate, will seek public shelters at a rate of 15 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 usage 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 out of the region. Regardless of time of day, during late or urgent evacuations proceedings, in which evacuees are asked to respond 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 people living in retirement areas are more likely to use public shelters than other population types.

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 on the evacuation circumstances of each location. Shelter usages will increase if motorist intending to travel through a community instead stop, due to worsened road conditions, and seek safe designations at local shelters. Also, shelter usage may be higher if a significant numbers of tourists decide not to return home, but instead choose to ride out the storm at a nearby shelter.

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.

TABLE 4.2
SHELTER USAGE RATES[1]

PER CAPITA INCOME[2]	EVACUATION ZONE "A"[3]	EVACUATION ZONE "B"[4]	MOBILE HOME RESIDENTS	NON-SURGE VULNERABLE POPULATION[5]
HIGH	5 %	10 %	100 %	10 %
LOW	10 %	20 %	100 %	30 %

Notes:
[1] Shelter usage rates are applied to "weak storm" and "severe storm" evacuation scenarios (see page 3-2 for definitions).
[2] Variations in usage rates due to per capita income were assessed based on the relative per capita income levels by community reported in the 1990 census.
[3] Evacuation zones closest to the coast as shown in the Evacuation Map Atlas.
[4] Evacuation zones farthest from the coast as shown in the Evacuation Map Atlas.
[5] Percentage of the community's evacuating "non-surge vulnerable population" assumed to use shelters.

Chapter Five

SHELTER ANALYSIS

5.1 PURPOSE

The shelter analysis serves two main purposes. The most apparent uses of the 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 the 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 Rhode Island Emergency Management Agency, and the majority of local emergency management departments, that during hurricane evacuations 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 the 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, the total shelter capacity provided by Mass Care Facilities in their communities are not sufficient to accommodate the shelter demands estimated by the Shelter Analysis. In response to these deficiencies, local officials have identified other buildings as public shelters for temporary safe refuge facilities until hurricane hazards diminish. Some of these buildings, however, do not provide the services of Mass Care Facilities and may not necessarily meet ARC guidelines.

Services 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 ARC chapters unless under prior contractual arrangements. These facilities are intended to be used strictly as temporary shelters until hurricane hazards diminish. During recovery operations, those communities needing expanded sheltering services would seek additional assistance from the ARC through locally or regionally located Mass Care Facilities.

5.3 SHELTER DEMAND/CAPACITY

The results of the Vulnerability and Behavioral Analyses were used to estimate the shelter demand for two levels of evacuation. As discussed in Chapter Three, the study has grouped all possible hurricane meteorological scenarios as either belonging to a "weak storm scenario" or a "severe storm scenario". Accordingly, estimates of expected shelter usage are defined for "weak" and "severe" scenarios. Tables 5.1 and 5.2 list the shelter demands computed for each community for the two scenarios. The tables also lists each community's total public shelter capacity based on inventories of ARC Mass Care Facilities and locally designated public shelters. Comparisons between shelter demand and existing capacity reveal that four communities during a severe storm scenario have less capacity than the demands computed in this analysis. 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 5.4, Shelter Inventories, presents the method for determining shelter capacities and gives the names and capacities of each shelter inventoried.

Shelter usage is one of the most difficult behavioral characteristics to predict and a wide variation in the estimated values is not uncommon. The shelter demands computed in Tables 5.1 and 5.2 assume an adequate warning period, officials actively encourage residents to leave their homes, and the public is aware of the locations and availability of public shelter facilities. It is important that officials recognize that the estimated shelter demands are intended to be used as a guide, and that 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. The specific population and behavioral assumptions used in developing the total number of evacuees and associated shelter demands are as follows:

a. The percentage of the affected population (population living in evacuation zones) assumed to evacuate depends on the meteorological scenario of the approaching hurricane. In a weak storm scenario, 80 percent of the population within Evacuation Zone A (see the Evacuation Map Atlas), and 40 percent within Evacuation Zone B, are assumed to evacuate. Under a severe storm scenario, 90 percent of the population living within either evacuation zone are assumed to evacuate.

b. The percentage of the unaffected population ("non-surge vulnerable population", excluding mobile home residents) are assumed to evacuate is 2 percent during a weak storm scenario and 5 percent during a severe storm scenario.

c. Depending on the per capita income of a particular community, evacuees from Evacuation Zone A and Evacuation Zone B are assumed to use public shelters at rates of 5 to 10 percent, and 10 to 20 percent, of the total evacuating population per zone, respectively. Depending on income, a public shelter usage rate of 10 to 30 percent is applied to the unaffected population that evacuates.

d. 100 percent of the mobile home residents are assumed to evacuate to public shelters due to their particular vulnerability to hurricane winds.

e. Seasonal residents are assumed to evacuate and use shelters at the same rates as the permanent population in their areas.

5.4 SHELTER INVENTORIES

Tables 5.3 through Table 5.23, presented at the end of this chapter, list by community the ARC Mass Care Facilities and local public shelters that have been identified for use 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 local emergency management officials. The State ARC coordinator provided the building names and capacities of the Mass Care Facilities under agreement, as of January 1994, between communities and local ARC 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 made at the local level. Shelters will be opened by local officials and ARC personnel based on a variety of circumstances including, severity of the threatening hurricane, amount of advance warning time, services available at facilities, and availability of qualified people to manage facilities. Also, shelter space will change as buildings are constructed or demolished, as ownership changes, and as agreements are reached or canceled with building owners.

TABLE 5.1
ESTIMATED PUBLIC SHELTER DEMAND/CAPACITY
WEAK HURRICANE SCENARIO

Community	Shelter Demand by Population Type				
	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Homes Residents	Total Shelter Demand	Total Shelter Capacity[1]
Barrington	1,000	10	0	1,010	9,000[4]
Bristol	250	60	0	310	1,400[4]
Charlestown	150	20	330	500	600
Cranston	170	220	50	440	550
East Greenwich	80	30	110	220	300
East Providence	530	130	170	830	1,747
Jamestown[3]	290	20	10	320	530
Little Compton	70	10	190	270	350
Middletown	110	50	450	610	2,580
Narragansett	670	30	10	710	1,100
New Shoreham	70	10	0	80	500
Newport	790	60	0	850	1,925
North Kingstown	550	50	540	1,140	4,750
Pawtucket	50	210	880	1,140	1,750
Portsmouth	430	40	1,080	1,550	1,183
Providence	70	480	0	550	20,500
South Kingstown[3]	510	80	460	1,050	5,600
Tiverton	180	40	720	940	1,165
Warren	530	10	10	550	1,375
Warwick	2,040	170	210	2,420	3,980
Westerly[3]	490	60	210	760	2,000
TOTALS	9,030	1,790	5,430	16,250	62,885

NOTES
[1] Total shelter capacity reported in Tables 5.3 through 5.23.
[2] Total shelter capacity is less than estimated total shelter demand.
[3] Shelter demand based on emergency management director's revised estimate of seasonal population (see Table 3.1).
[4] Estimate includes public shelters which may be prone to flooding (see Tables 5.3 and 5.4).

TABLE 5.2
ESTIMATED PUBLIC SHELTER DEMAND/CAPACITY
SEVERE HURRICANE SCENARIO

Community	Shelter Demand by Population Type				
	Surge Vulnerable Residents	Non-surge Vulnerable Residents	Mobile Homes Residents	Total Shelter Demand	Total Shelter Capacity[1]
Barrington	1,490	20	0	1,510	9,000[4]
Bristol	400	140	0	540	1,400[4]
Charlestown	240	60	330	630	**600**[2]
Cranston	230	560	50	840	**550**[2]
East Greenwich	120	80	110	310	**300**[2]
East Providence	770	320	170	1,260	1,747
Jamestown[3]	400	50	10	460	530
Little Compton	100	20	190	310	350
Middletown	190	130	450	770	2,580
Narragansett	940	80	10	1,030	1,100
New Shoreham	80	10	0	90	500
Newport	1,080	150	0	1,230	1,925
North Kingstown	720	130	540	1,390	4,750
Pawtucket	60	530	880	1,470	1,750
Portsmouth	500	90	1,080	1,670	**1,183**[2]
Providence	130	1,200	0	1,330	20,500
South Kingstown[3]	700	210	460	1,370	5,600
Tiverton	240	90	720	1,050	1,165
Warren	830	30	10	870	1,375
Warwick	3,130	430	210	3,770	3,980
Westerly[3]	760	140	210	1,110	2,000
TOTALS	13,110	4,470	5,430	23,010	62,885

NOTES
[1] Total shelter capacity reported in Tables 5.3 through 5.23.
[2] Total shelter capacity is less than estimated total shelter demand.
[3] Shelter demand based on emergency management director's revised estimate of seasonal population (see Table 3.2).
[4] Estimate includes public shelters which may be prone to flooding (see Tables 5.3 and 5.4).

The susceptibility of the shelters listed in Tables 5.3 through 5.23 to hurricane surge was assessed using surge limits delineated in the Inundation Map Atlas. Exposures of the shelters to 100-year and 500-year frequency flooding were assessed using the NFIP rate maps published by FEMA. 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 adjacent to or within areas that may flood. Unless otherwise noted, the lowest floor elevation of these facilities, as reported by community officials, were determined to be higher than base flood elevations and may be cautiously used during evacuations. No attempt has been made to verify the first floor elevations of other facilities, or assess the vulnerability of any shelter to effects from hurricane winds.

As mentioned before, not all locally designated public shelters facilities 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 find shelter space within their own communities will probably travel farther distances to reach shelters in other communities, or find safe destinations elsewhere. The Transportation Analysis in Chapter Six discusses how clearance times may be affected by deficiencies in shelter capacity in general.

5.5 PUBLIC SHELTER SELECTION GUIDELINES

In the future, some communities may choose to designate additional buildings as public shelters for use during 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 5.3
TOWN OF BARRINGTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Sowams School	Yes[9]	Yes[5]	1,000
2	Barrington Middle School	Yes[9]	Yes[6]	3,000
3	Barrington High School	Yes[9]	Yes[7]	3,000
4	Peck Library Community Center	No	Yes[8]	2,000
		TOTAL SHELTER CAPACITY		9,000

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 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 plains.

[5] The Sowams School is located within the 500-year flood plain, and inundation areas A, B, and C of the companion Inundation Map Atlas. The building's base floor elevation was estimated equal to 17.9 feet NGVD from sewer maps available from the Town of Barrington. Estimates of the 100- and 500-year frequency floods, and the stillwater elevations corresponding to Inundation Areas A, B, and C are 11.0, 13.0, 13.0, 15.5, and 19.5 feet NGVD, respectively.

[6] The Barrington Middle School is located within Inundation Area C of the companion Inundation Map Atlas which has a stillwater elevation of 19.5 feet NGVD. The building's base floor elevation was estimated equal to 20.3 feet NGVD from sewer maps available from the Town of Barrington.

[7] The Barrington High School is located within the 100- and 500-year flood plains, and within inundation areas A, B, and C of the companion Inundation Map Atlas. The elevation of this building needs to be surveyed to verify that the base floor elevation is higher than the 100- and 500-year frequency floods and worst case hurricane surge inundation elevations.

[8] The Peck Library Community Center is located within or adjacent to Inundation Areas A, B, and C of the companion Inundation Map Atlas. The elevation of this building needs to be surveyed to verify that the base floor elevation is higher than the worst case hurricane surge inundation elevations.

[9] The American Red Cross will not open shelters until hurricane flood hazards diminish.

TABLE 5.4
TOWN OF BRISTOL
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Bristol High School	Yes	Yes[5]	1,000
2	Andrews School	Yes	None	400
		TOTAL SHELTER CAPACITY		1,400

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 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 plains.
[5] The Bristol High School is located within the 100-year flood plain of the East Branch Silver Creek which has a base flood elevation ranging from 55 to 61 feet NGVD in this area. The building's base floor elevation was estimated at approximately 60 feet NGVD from sewer plans available from the Town of Bristol.

TABLE 5.5
TOWN OF CHARLESTOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Chariho Vocational/Technical School[5]	Yes	None	600
		TOTAL SHELTER CAPACITY		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 is an operational decision made by local emergency management officials.
[2] The Chariho Vocational/Technical School is located in Richmond, RI, due north of Charlestown, RI (see Plate E-2 of the companion Evacuation Map Atlas for a map of Charlestown, RI).
[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 plains.
[5] The Chariho Vocational/Technical School is the primary regional public shelter for the communities of Charlestown, Hopkinton, and Richmond. The Chariho Senior High School and Chariho Middle School, which are co-located at the Chariho Vocational/Technical School, are the secondary and tertiary regional shelters.

TABLE 5.6
CITY OF CRANSTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Cranston Senior Service Center	Yes	None	150
2	Park View Junior High School	No	"	200
3	Western Hills Junior High School	Yes	"	200
		TOTAL SHELTER CAPACITY		550

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 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 plains.

TABLE 5.7
TOWN OF EAST GREENWICH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Swift Gym	Yes	None	100
2	East Greenwich High School	Yes	"	200
		TOTAL SHELTER CAPACITY		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 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 plains.

TABLE 5.8
CITY OF EAST PROVIDENCE
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	East Providence High School	Yes	None	540
2	Riverside Junior High School	Yes	"	397
3	Martin Junior High School	Yes	"	560
4	Myron J. Francis School	No	"	250
		TOTAL SHELTER CAPACITY		1,747

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 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 plains.

TABLE 5.9
TOWN OF JAMESTOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Jamestown Elementary School	Yes	None	300
2	New Jamestown School	No	"	200
3	Jamestown Fire Station	No	"	30
		TOTAL SHELTER CAPACITY		530

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 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 plains.

TABLE 5.10
TOWN OF LITTLE COMPTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Josephine Wilbur School	Yes[5]	None	300
2	Little Compton Town Hall	No	"	50
		TOTAL SHELTER CAPACITY		350

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 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 plains.

[5] ARC approved, but no agreement has been established between the ARC and the community.

TABLE 5.11
TOWN OF MIDDLETOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Gaudet Middle School	Yes	None	1,000
2	Middletown High School	Yes	"	1,100
3	Middletown Senior Center	Yes	"	220
4	Town Hall	Yes	"	160
5	Aquidneck School	No	"	100
		TOTAL SHELTER CAPACITY		2,580

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 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 plains.

TABLE 5.12
TOWN OF NARRAGANSETT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Pier School	Yes	See Note 5	400
2	Narragansett High School	Yes	None	500
3	Narragansett Elementary School	Yes	"	200
		TOTAL SHELTER CAPACITY		1,100

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 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 plains.
[5] The Pier School is located within or adjacent to an area of poor drainage and may be susceptible to minor flooding during severe rainfall events. The facility is not located within surge inundation areas or the 100-year flood plain.

TABLE 5.13
TOWN OF NEW SHOREHAM
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Block Island School	Yes	None	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 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 plains.

TABLE 5.14
CITY OF NEWPORT
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Martin Luther King Center	No	None	300
2	Thompson Junior High School	Yes	"	500
3	Newport Area Vocational/Technical Center	Yes	"	200
4	Underwood School	No	"	250
5	Sheffield School	Yes	"	250
6	Sullivan School	No	"	425
		TOTAL SHELTER CAPACITY		1,925

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 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 plains.

TABLE 5.15
TOWN OF NORTH KINGSTOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	North Kingstown High School	Yes	None	1,500
2	Davisville Middle School	Yes	"	2,500
3	Stony Lane Elementary School	No	"	150
4	Wickford Middle School	Yes	"	250
5	Quidnessett School	No	"	150
6	Forest Park School	No	"	200
		TOTAL SHELTER CAPACITY		4,750

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 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 plains.

TABLE 5.16
CITY OF PAWTUCKET
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Baldwin Elementary School	Yes	None	200
2	McCabe Elementary School	Yes	"	400
3	Varieur Elementary School	Yes	"	300
4	Jenks Junior High School	Yes	"	400
5	Comfort Inn	No	"	450
		TOTAL SHELTER CAPACITY		1,750

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 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 plains.

TABLE 5.17
TOWN OF PORTSMOUTH
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Prudence Island Fire Station	No	None	40
2	Prudence School	No	"	25
3	Portsmouth High School	Yes	"	668
4	Portsmouth Middle School	Yes	"	450
		TOTAL SHELTER CAPACITY		1,183

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 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 plains.

TABLE 5.18
CITY OF PROVIDENCE
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Roger Williams Junior High School	Yes	None	2,500
2	Classical High School	Yes	"	2,000
3	Mount Pleasant High School	Yes	"	2,500
4	Hope High School	Yes	"	2,500
5	Central High School	Yes	"	2,000
6	Nathaniel Greene High School	Yes	"	2,000
7	Gilbert Stuart School	Yes	"	1,500
8	George J. West School	Yes	"	1,500
9	Nathan Bishop Middle School	Yes	"	2,000
10	Oliver Hazard Perry Junior High School	Yes	"	2,000
		TOTAL SHELTER CAPACITY		20,500

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 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 plains.

TABLE 5.19
TOWN OF SOUTH KINGSTOWN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	URI Tootel-Keaney Gym	Yes	None	5,000
2	South Kingstown High School	Yes	"	200
3	South Kingstown Junior High School	Yes	"	200
4	Peace Dale Elementary School	No	"	200
		TOTAL SHELTER CAPACITY		5,600

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 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 plains.

TABLE 5.20
TOWN OF TIVERTON
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Tiverton Middle School	Yes	None	300
2	North Tiverton Fire Station	No	"	100
3	Tiverton Senior Center	No	"	100
4	Housing for Elderly	No	"	65
5	Knights of Columbus	No	"	600
		TOTAL SHELTER CAPACITY		1,165

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 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 plains.

TABLE 5.21
TOWN OF WARREN
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Saint Mary's Church	Yes	None[5]	200
2	Saint Thomas Church	Yes	None[5]	150
3	Hugh Cole Elementary School	Yes	None	300
4	Warren Government Center	No	"	200
5	Touissett Fire Station	No	None[5]	75
6	Kickemuit Middle School	Yes	None[5]	450
		TOTAL SHELTER CAPACITY		1,375

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 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 plains.
[5] Facility is located near the 500-year flood plain and adjacent to "Inundation Area C" shown on Plate I-13 of the companion Inundation Map Atlas.

TABLE 5.22
CITY OF WARWICK
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Pilgrim High School	Yes	None	1,000
2	Warwick Veterans High School	Yes	"	1,400
3	Potowomut School	No	"	280
4	Tollgate High School	Yes	"	500
5	Warwick Central Baptist Church	No	"	50
6	CCRI Junior College	No	See Note 5	250
7	Winman Junior High School	No	None	250
8	Aldrich Junior High School	No	"	250
9	Sheraton Tara	No	"	See Note 6
10	Radisson Hotel	No	"	See Note 6
11	Holiday Inn at the Crossroads	No	"	See Note 6
		TOTAL SHELTER CAPACITY		3,980

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 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 plains.
[5] The north side of the CCRI Junior College building (the side nearest to the Pawtuxet River) is located within the 500-year flood plain.
[6] Hotel facilities have been identified as auxiliary public shelters. Actual shelter capacity varies depending on space availability.

TABLE 5.23
TOWN OF WESTERLY
PUBLIC SHELTER FACILITIES[1]

MAP KEY[2]	FACILITY NAME	ARC[3]	FLOOD POTENTIAL[4]	CAPACITY
1	Ward High School	Yes	None	1,000
2	Babcock Junior High School	Yes	"	250
3	State Street School	No	"	100
4	Tower Street School	Yes	"	100
5	Dunn's Corner School	No	"	450
6	Bradford School	No	"	100
		TOTAL SHELTER CAPACITY		2,000

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 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 plains.

Chapter Six

TRANSPORTATION ANALYSIS

6.1 PURPOSE

The purpose of the Transportation Analysis is to estimate roadway clearance times for coastal Rhode Island communities under a variety of hurricane evacuation scenarios. Clearance time is defined as the amount of time required for 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 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 Rhode Island's coast because its land areas are highly urbanized with many residents living near the immediate shore. The number of evacuating vehicles varies depending on 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 to complete a regional hurricane evacuation. 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 discusses which clearance times the Corps of Engineers and the Federal Emergency Management Agency recommend using to estimate evacuation times for decision-making purposes for Rhode Island hurricane evacuations.

A numerical model of the roadway system in Rhode Island and Bristol County, Massachusetts was developed to assist in estimating clearance times for the study area. 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 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 Rhode Island. 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 traffic that will be present on roadways as an evacuation progresses. 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.

The study considered several approaches to estimate clearance times for the Rhode Island study area. The first approach considered was the one used by the Corps of Engineers and 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 close to predicted times. These results give evidence that this approach is accurate for study areas with moderate roadway systems and where adequate behavioral data and land use information is suitable to identify evacuation routes and predict the destinations of evacuees. The following paragraphs explain some differences in the Rhode Island study area in comparison to other coastal areas, and give the reasons why the Corps of Engineers employed an alternative transportation modeling approach for Rhode Island.

One concern in using the transportation modeling approach discussed above for Rhode Island was the appropriateness of designating evacuee destinations and evacuation routes. Inundation areas in Rhode Island are relatively confined 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 each Rhode Island community tends to open public shelters as required to accommodate their own demands. Therefore, the Study concluded that it is not practical to use the behavioral information developed for Rhode Island to derive specific assumptions about evacuee destinations and evacuation routes. The Study did conclude that the Behavioral Analysis and hurricane evacuation studies developed for other study areas are useful when estimating the general response and destinations sought by residents who live in surge vulnerable areas.

The second concern in applying the modeling approach used in other studies for Rhode Island was the representation of the relationship between the number of people evacuating from vulnerable areas in comparison to the expected number of background vehicles on 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 Rhode Island should not focus on assigning evacuation routes as typically done in other study areas. Instead, the methodology should emphasize the influence background traffic can have on the overall evacuation.

To address the unique behavioral and transportation issues of the Rhode Island 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.

Empirical traffic engineering studies and traffic count data available from the Rhode Island Department of Transportation (DOT) were used to calibrate the model. 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. Large business districts and confined hurricane surge areas in most coastal communities in Rhode Island will give rise to evacuations involving mostly traffic generated by people leaving work rather than people evacuating surge areas. Analysis of traffic data collected on the days of Hurricanes Gloria and Bob support this assumption. Accordingly, the modeling strategy used in Rhode Island 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 ROAD NETWORKS

The study area for the Transportation Analysis includes the entire State of Rhode Island and Bristol County, Massachusetts as illustrated in Figure 6.1. Bristol County, Massachusetts was included as part of the Rhode Island Transportation Analysis because of the interdependence and inseparability of the eastern Rhode Island and southern Massachusetts roadway systems. The study area does not, however, include the community of New Shoreham (Block Island) and Prudence Island. Currently, the Rhode Island Emergency Management Agency, in conjunction with the community of New Shoreham, is developing an Emergency Operations Plan which will include provisions for evacuating non-permanent residents from the Island. Shelter space will be provided on Block Island for permanent residents at an ARC Mass Care Facility located at the New Shoreham High School. No permanent residents live on Prudence Island.

NETVAC2 is a special purpose, evacuation computer model that was used to create a mathematical model to represent the study area's roadway system. The road system under examination includes major State maintained highways from the Connecticut State Line to the Fairhaven-Mattapoisett, Massachusetts Town Line, extending approximately 15 miles inland from the coast. In NETVAC2, links are used to represent roadways and nodes represent the intersections that connect two or more roadways. The

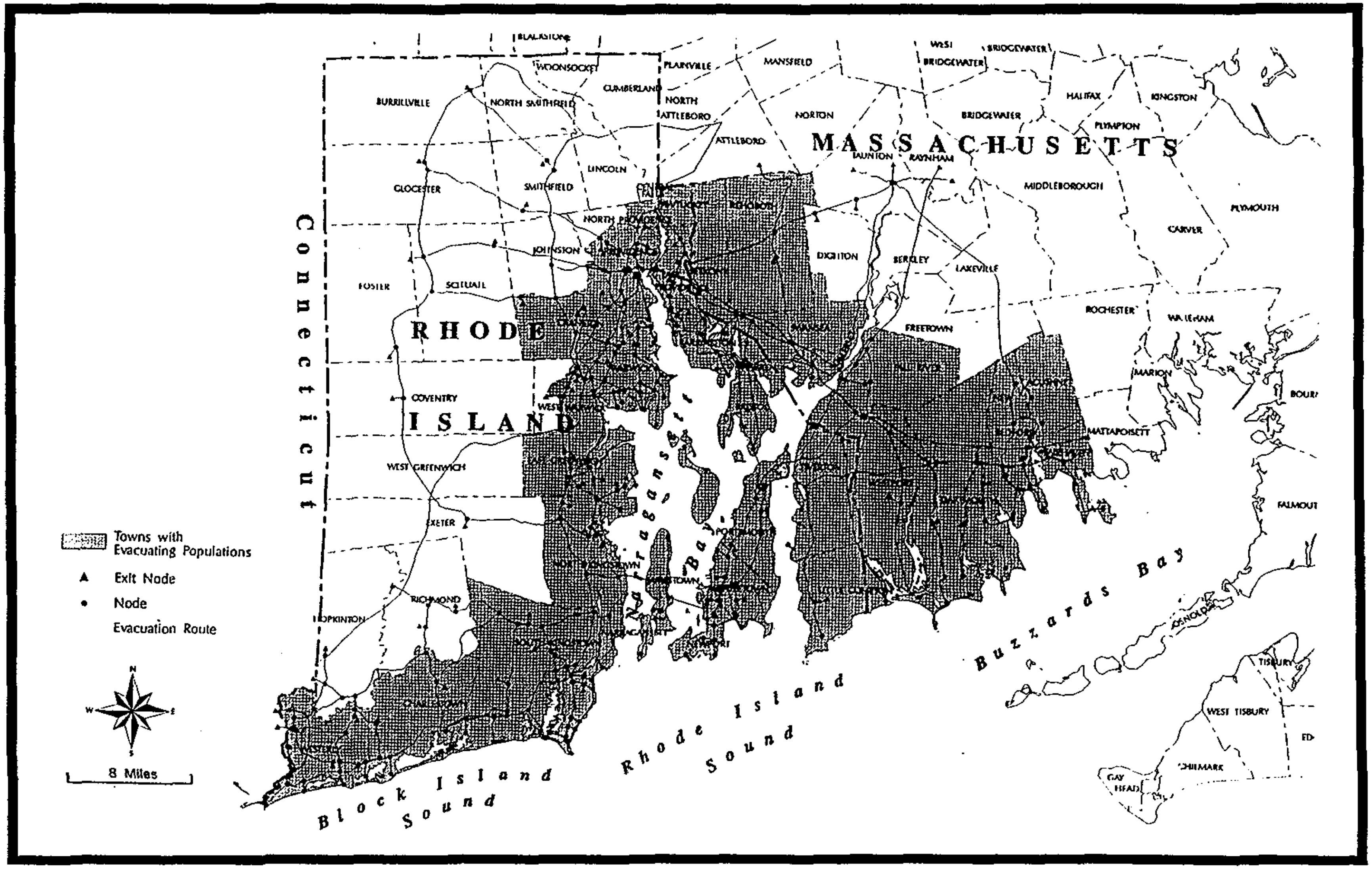


Figure 6.1 General Description of Transportation Network.

physical characteristics for links and nodes are inputs to the model necessary to compute roadway capacity constraints and legal turning movements at intersections.

All highway bridges were modeled assuming that they are fully operational during evacuations. Bridge closures typically coincide with the arrival of gale force winds, which, for purposes of this analysis, is the point in time when evacuations are assumed completed. More on this topic is discussed in Section 6.7, Evacuation Simulation Results.

The vastness of the Rhode Island and Bristol County, Massachusetts study area required that the region be divided into two approximately equal sized areas and analyzed individually. The two networks were defined as the "West Bay/Rhode Island network" and the East Bay/Massachusetts network". The West Bay/Rhode Island network extends from approximately the Connecticut-Rhode Island State Line eastward to Narragansett Bay. The East Bay/Massachusetts network extends from approximately the Narragansett Bay eastward to the Fairhaven-Mattapoisett, Massachusetts Town Line. Figure 6.1 shows a general view of the study area and modeled road network. Detailed link and node configurations are shown on Panels 1 through 9 in Appendix C.

The Rhode Island DOT provided information for the roadway and intersection data used to develop the models. Roadway and intersection data were retrieved from printouts of state routes extracted from an investigation completed by Louis Berger Associates which were provided by the Rhode Island DOT. The study contained detailed information such as the number of travel lanes and auxiliary lanes, lane widths, and intersection approach widths. The total length of each road segment was measured from a scaled map of the roadway network. Functional classification of routes and land use information were also provided by the study. As networks were created, field surveys were conducted at several locations to verify that the modeling strategy and data input in the models were consistent with physical conditions. More information pertaining to specific data coded in the networks is given in Appendix C.

6.4 MODEL CALIBRATION

Before evacuation simulations were run, each network was calibrated to represent its study area. Calibration is preformed for two 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 is initiated, 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 Rhode Island DOT, and the Massachusetts Highway Department tabulate the average daily traffic (ADT) for all state maintained roadway segments where significant changes in total traffic volume occur. The ADT represents the expected number of vehicles to pass by a given location during any normal day. The distribution of ADT over a 24-hour period varies with each hour and day of the week. In general, the percentage of ADT is usually many times greater during peak traffic periods compared with times of off-peak traffic. Figure 6.2 plots weighted averages of the hourly weekday ADT volume recorded at traffic monitoring stations in Johnston, Exeter, South Kingstown, and East Providence, Rhode Island; and Dartmouth, Massachusetts. The distribution of hourly ADT at each location was found to vary in terms of magnitude, but overall trends and variations are generally similar.

In Figure 6.2, the dotted lines delineate approximate levels of ADT corresponding to off-peak, mid-peak, and peak traffic in Rhode Island and Bristol County, Massachusetts. 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 that 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 weekday afternoon rush hour. Although the distribution of ADT in Figure 6.2 may not reflect all of the local traffic patterns for each road in the study area, it does, however, provide a reasonable representation of how most vehicle trips in coastal Rhode Island and Bristol County, Massachusetts are distributed over a normal day. Therefore, Figure 6.2 was used as a basis by which all the roadways within networks were calibrated.

For purposes of calibrating the networks, focus was placed on 31 index locations in Rhode Island and Southeastern Massachusetts to evaluate overall results (see Appendix C). The actual unidirectional ADT at all exterior nodes in the networks was entered as

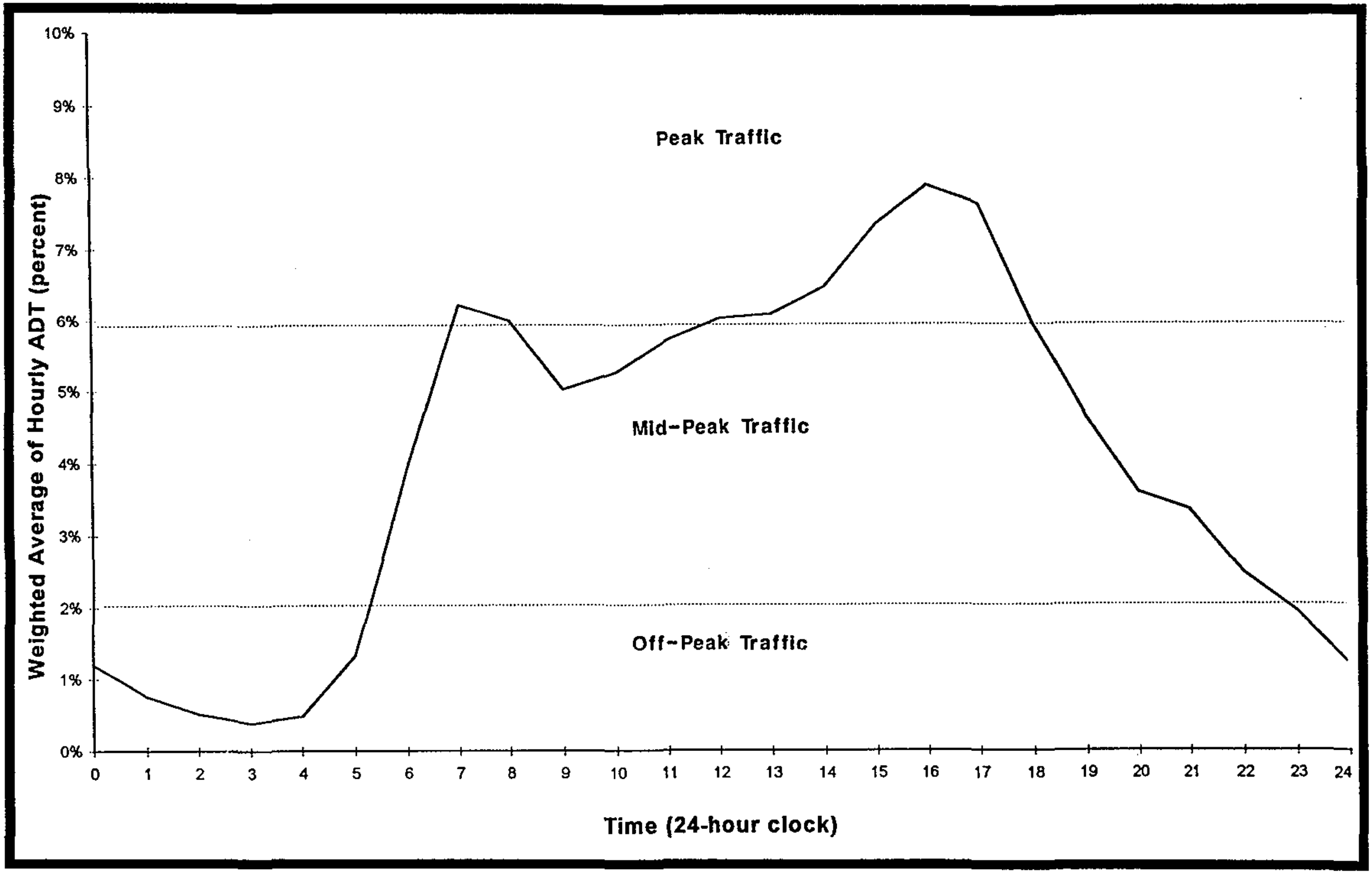


Figure 6.2 Weighted Average of Hourly ADT Along Major Routes in Rhode Island and Southern Massachusetts.

vehicles and programmed to flow throughout each system. As simulations progressed, printouts every hour of simulation time reported the cumulative link departures and link speeds, as well as any spill backs and queues found at nodes. Calibration was accomplished using an iterative process of running NETVAC2, comparing modeled two-way ADTs to actual 2-way ADTs for the 31 index locations, then adjusting link preference factors and adding traffic onto the network where appropriate before rerunning the model. During this process, a loading distribution that approximated average actual conditions for the index locations was achieved. Major corridors, such as I-95, I-195 and Route 1, were also reviewed in detail to ensure that the predesignated index locations were not isolated spots where the ADT was correlated. The transportation methodology assumed calibration was complete when the volume of vehicles on each of the 31 index links matched its corresponding actual 2-way ADT by 10% for Principal Arterials and 15% for Major Collectors, and the distribution of hourly traffic approximated actual conditions.

6.5 DEVELOPMENT OF TRAFFIC DATA

6.5.1 Classification of Motorists

After road networks were developed and calibrated, 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.

The number of vehicles assumed to participate during an evacuation from each group listed is an important factor in estimating clearance times. Human behavioral information developed in the 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. However, the motorists belonging to this group mostly comprise of people making shopping trips or commuting, which is related to the ADT distribution shown in Figure 6.2.

Tables 6.1 and 6.2 list estimates made for Rhode Island 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 weak hurricane scenario and Table 6.2 refers to evacuations for a severe hurricane scenario. Estimates of the evacuating population for Rhode Island were made by applying evacuation participation assumptions listed in Table 4.1 to the vulnerability data reported in Tables 3.1 to 3.2.

TABLE 6.1
RHODE ISLAND EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Permanent Population	Seasonal Population	Mobile Home Population	Population Evacuating Surge Areas	Population Evacuating Non-Surge Areas	Total Evacuating Population
Barrington	15,850	180	0	8,970	40	9,010
Bristol	21,630	400	20 [1]	2,980 [1]	330 [1]	3,330 [1]
Charlestown	6,480	4,010	330	1,330	160	1,820
Cranston	76,060	200	50	1,600	1,480	3,130
East Greenwich	11,870	60	110	720	210	1,040
East Providence	50,380	110	170	4,740	860	5,770
Jamestown	5,000	1,070 [2]	10	1,640	70	1,720
Little Compton	3,340	920	190	650	60	900
Middletown	19,460	240	450	840	350	1,640
Narragansett	14,990	4,850	10	6,080	220	6,310
New Shoreham	840	1,880	0	670	40	710
Newport	28,230	1,640	0	7,300	390	7,690
North Kingstown	23,790	630	540	5,240	330	6,110
Pawtucket	72,640	70	880	540	1,420	2,840
Portsmouth	16,860	1,380	1,080	4,280	230	5,590
Providence	160,730	330	0	490	3,200	3,690
South Kingstown	24,630	6,610 [2]	460	3,850	510	4,820
Tiverton	14,310	450	720	1,670	230	2,620
Warren	11,390	270	10	4,650	80	4,740
Warwick	85,430	900	210	17,840	1,150	19,200
Westerly	21,610	3,570 [2]	210	4,150	380	4,740
TOTALS	685,520	29,770	5,450	80,230	11,740	97,420

NOTES:
[1] Clearance times were estimated using evacuating populations derived from preliminary evacuation zones delineated for Bristol, RI. The evacuating population figures associated with the final evacuation zones are significantly reduced for Bristol, RI with a minor reduction in the evacuating population of the State. Moderate variations in Rhode Island's evacuating population were assessed using sensitivity testing and found to result in minor variations in estimated clearance times.
[2] Clearance times were estimated using seasonal population determined from data reported in the 1990 census. Emergency managers from Jamestown, South Kingstown, and Westerly, RI revised seasonal population estimates subsequent to this analysis. Moderate variations in seasonal population were assessed using sensitivity testing and found to result in minor variations in estimated clearance times.

TABLE 6.2
RHODE ISLAND EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Permanent Population	Seasonal Population	Mobile Home Population	Population Evacuating Surge Areas	Population Evacuating Non-Surge Areas	Total Evacuating Population
Barrington	15,850	180	0	12,500	110	12,610
Bristol	21,630	400	20 [1]	4,780 [1]	840 [1]	5,640 [1]
Charlestown	6,480	4,010	330	1,960	400	2,690
Cranston	76,060	200	50	2,050	3,700	5,800
East Greenwich	11,870	60	110	1,010	540	1,660
East Providence	50,380	110	170	6,530	2,150	8,850
Jamestown	5,000	1,070 [2]	10	2,130	190	2,330
Little Compton	3,340	920	190	870	160	1,220
Middletown	19,460	240	450	1,420	880	2,750
Narragansett	14,990	4,850	10	8,110	540	8,660
New Shoreham	840	1,880	0	760	90	850
Newport	28,230	1,640	0	9,530	960	10,490
North Kingstown	23,790	630	540	6,540	830	7,910
Pawtucket	72,640	70	880	600	3,560	5,040
Portsmouth	16,860	1,380	1,080	4,910	590	6,580
Providence	160,730	330	0	910	8,000	8,910
South Kingstown	24,630	6,610 [2]	460	4,970	1,260	6,690
Tiverton	14,310	450	720	2,130	580	3,430
Warren	11,390	270	10	6,760	210	6,980
Warwick	85,430	900	210	25,700	2,880	28,790
Westerly	21,610	3,570 [2]	210	5,960	960	7,130
TOTALS	685,520	29,770	5,450	110,130	29,430	145,010

NOTES:

[1] Clearance times were estimated using evacuating populations derived from preliminary evacuation zones delineated for Bristol, RI. The evacuating population figures associated with the final evacuation zones are significantly reduced for Bristol, RI with a minor reduction in the evacuating population of the State. Moderate variations in Rhode Island's evacuating population were assessed using sensitivity testing and found to result in minor variations in estimated clearance times.

[2] Clearance times were estimated using seasonal population determined from data reported in the 1990 census. Emergency managers from Jamestown, South Kingstown, and Westerly, RI revised seasonal population estimates subsequent to this analysis. Moderate variations in seasonal population were assessed using sensitivity testing and found to result in minor variations in estimated clearance times.

6.5.2 Evacuee Destinations

As mentioned before, the Behavioral Analysis concluded that people who evacuate surge areas are most likely to seek safe destinations at public shelters, friends'/relatives' homes, or hotels/motels. Although the specific evacuee destinations and evacuation routes used by motorists are difficult, if not impossible, to accurately predicted, the methodology attempts to simulate the general geographic locations evacuees exit the road network during evacuations. As noted previously, the preferences of background vehicles and evacuating vehicles to travel on a particular route in the model were assumed related to the traffic volume on that route during a normal day. However, this assumption does not define the geographic locations evacuees will exit the road network. The following presents the rationale used to program evacuees to exit the networks at predesignated locations in coastal and inland communities, and out of the region.

The main source of information used for guidance in deriving general evacuation destinations was the Behavioral Analysis. The Behavioral Analysis concluded the following based on actual response data collected after Hurricane Gloria in 1985.

(1) In the northeast, 55-79% of the evacuating population stay within their community.

(2) In the northeast, between 83 and 100% of the evacuating population reach their destination in approximately 30 minutes.

(3) In the northeast between 3 and 23% of the evacuating population uses public shelters.

A second source of data used in deriving assumptions about evacuees destinations for Rhode Island and southern Massachusetts are guidelines provided by FEMA for public shelter capacity. FEMA has set a standard for public sheltering at 20 percent of the threatened population. A third source of data was the sheltering capacities of affected communities reported in the Shelter Analysis. It was calculated that the vulnerable communities, in total, have capacity to shelter approximately 50 to 60 percent of Rhode Island's total evacuating population. Based on the above, the following approach for determining which exit nodes are assigned priorities was used:

(1) Assign 15% of the evacuating population to exit nodes corresponding to public shelters within their own communities.

(2) Assign an additional 40% of the evacuating population to exit nodes within the community from which they evacuate. Many of these exit nodes will be the same location as the public shelters. This brings the total evacuating population which stays within their community up to 55% between public shelters and other destinations (consistent with the 55-79% which stay within their town).

(3) Assign 25% of the evacuating population to interior exit nodes outside the affected communities but within 15 miles of the coast (corresponding to 30 minute travel time). This brings the total within 30 minutes travel time up to 80% (slightly lower than the 83-100% anticipated in the northeast but tends to be conservative).

(4) Assign 20% of the evacuating population to exterior exit nodes, roughly 15 miles or more from the inundation areas.

After each evacuation simulation was run, exit node departures reported by NETVAC2 were checked to verify that the modeled trip departures of evacuees agreed with the general trip destinations assumed above.

6.5.3 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 the Rhode Island study area, evacuation simulations were tested for three evacuation loading rates that are summarized by the response curves shown in Figure 4.2. The 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 in Rhode

Island. 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 on the aggressiveness of authorities to encourage them to leave.

6.5.4 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 on 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 column of Table 6.3 lists permanent population by community for coastal communities in Rhode Island. The second and third columns list the numbers of available vehicles per owner and renter - occupied housing units, respectively. This information was obtained from socioeconomic data reported in the 1980 census. The third column of the Table gives the number of available vehicles per person, and the fourth column gives the calculated average numbers of people that will travel in each evacuating vehicle, assuming 75 percent of the available vehicles are used. A sample calculation for Westerly, Rhode Island is shown below.

$$\textit{Available vehicles} = 10{,}500 + 4{,}530 = 15{,}030 \textit{ vehicles}$$

$$\textit{Vehicles per person} = \frac{15{,}030 \textit{ vehicles}}{21{,}610 \textit{ people}} = 0.70 \frac{\textit{vehicles}}{\textit{person}}$$

$$\textit{persons per vehicle (75\% usage)} = \frac{1}{0.70 \, x \, 0.75} = 1.90$$

The transportation methodology used the information in Table 6.3 to determine the number of vehicles that would load onto roadways during evacuations from estimates made of the evacuating population. The user enters the vehicle occupancy rates and the number of people assigned to enter the network at each node. NETVAC2's complimentary program, POPDIS, aggregates the population input for each entry node and in turn computes the effective average vehicle loading rates per minute to be input into NETVAC2 at network entry locations.

TABLE 6.3
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons per Evacuating Vehicle (75% Usage)
Barrington	15,850	10,400	890	0.71	1.88
Bristol	21,630	9,970	3,670	0.63	2.12
Charlestown	6,480	3,790	1,020	0.74	1.80
Cranston	76,060	37,370	12,210	0.65	2.05
East Greenwich	11,870	7,300	1,230	0.72	1.85
East Providence	50,380	22,500	9,240	0.63	2.12
Jamestown	5,000	3,240	730	0.79	1.69
Little Compton	3,340	2,250	490	0.82	1.63
Middletown	19,460	6,220	5,060	0.58	2.30
Narragansett	14,990	7,010	4,520	0.77	1.73
New Shoreham	840	540	240	0.93	1.43
Newport	28,230	8,140	8,020	0.57	2.34
North Kingstown	23,790	13,560	3,690	0.73	1.83
Pawtucket	72,640	24,430	18,410	0.59	2.26
Portsmouth	16,860	9,290	2,850	0.72	1.85
Providence	160,730	35,470	37,140	0.45	2.96
South Kingstown	24,630	10,900	3,380	0.58	2.30
Tiverton	14,310	9,230	1,360	0.74	1.80
Warren	11,390	5,080	2,390	0.66	2.02
Warwick	85,430	49,670	10,760	0.71	1.88
Westerly	21,610	10,500	4,530	0.70	1.90

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 can 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 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 weak or severe hurricanes. Evacuating population estimates (see Tables 6.1 through 6.4) are significantly greater (approximately double) for an evacuation due to a severe hurricane scenario when compared with that for a weak hurricane scenario. Descriptions of weak and severe hurricane scenarios are given in detail in Chapter Three and correspond to the evacuation zones identified in the companion Evacuation Map Atlas.

(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 4.2. 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 on 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 mid-morning and mid-afternoon on weekdays or weekends. The number of background vehicles on a given roadway during a model run will vary depending on each road's particular ADT and the hourly percentage of ADT assumed for the traffic condition modeled. A key point in using Figure 6.2 to derive background traffic conditions is that all traffic conditions are derived from actual traffic patterns observed for Rhode Island and Bristol County, Massachusetts rather than assumed hypothetical conditions. Figures 4a, 4b, and 4c in Appendix C show the off-peak, mid-peak, and peak background traffic distributions which were modeled to represent varied traffic conditions during simulations.

Combinations of the three key input parameters listed above were used in developing 18 possible evacuation scenarios. NETVAC2 simulations were run for weak and severe 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 factors which should be considered when deciding if an evacuation recommendation/order should be issued. The combination of these times defines a region's total evacuation time. Clearance time begins when an evacuation order/recommendation is clearly disseminated to the threatened public and ends when the last evacuees clear 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.

Dissemination time is the amount of time required by officials to notify the public to evacuate after the decision to evacuate has been made. This amount of time is subjective and may differ by region depending on the communication and warning procedures utilized by State and local officials in a particular area. The times calculated by the Transportation Analysis include only the clearance time component of evacuation time, and officials using this information must determine the dissemination time appropriate for their areas. Failure to add dissemination time to clearance time will underestimate total evacuation time, which could result in insufficient time for all evacuees to safely clear the hazard area.

Evacuations should be completed before the arrival of gale force winds (34 knot/39 mph) and/or storm surge. Vehicle accidents and reduced travel speeds from inclement weather can impede traffic flows, and potentially disrupt an evacuation. Therefore, the transportation modeling methodology assumes that evacuations will occur well enough before a hurricane to preclude possible delays caused by significant weather. Moreover, the analysis assumes that provisions would be made for removal of vehicles in distress during an evacuation. The Decision Arc Method outlined in Chapter Eight explains how clearance times, used in conjunction with dissemination times specified by officials, can be used for guidance in hurricane evacuation decision-making. The time at which gale force winds arrive is incorporated into the Decision Arc Method and therefore is not factored into the calculation of clearance time.

6.7.2 Clearance Times

Tables 6.4 and 6.5 present the clearance times estimated for the West Bay/Rhode Island and East Bay/Massachusetts networks for weak and severe hurricane scenarios, 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 by comparing computed clearance times using two levels of shelter availability. 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 estimated 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 sheltering deficiencies in some communities and in the future if community sheltering capabilities increase.

West Bay/Rhode Island Network

Results for the West Bay/Rhode Island network show that modeled clearance times may range from 4 hours and 15 minutes to 9 hours and 30 minutes. For this network, the evacuation clearance times for off-peak and mid-peak conditions under both weak and severe hurricane scenarios are only slightly higher than the assumed behavioral response times. This result suggests that behavioral response is the primary factor influencing the total clearance time in this region under these evacuation scenarios.

For the off-peak and mid-peak conditions, simulated traffic conditions are mostly free flow with no long-term congestion along the network for both the weak and severe hurricane scenarios. Some intermittent queuing, however, is predicted along Route 2 in East Greenwich; Route 1 in North Kingstown and Warwick and along Route 117 and 117A in Warwick; as well as at some off ramps from I-95 in Warwick and Providence. In general, the simulations for the off-peak conditions showed only limited congestion along I-95 and Route 1 north of Warwick.

Evacuation simulations modeling the peak traffic condition (rush-hour) developed more congestion and resulted in lower travel speeds in numerous areas, compared to simulations modeling off-peak and mid-peak traffic conditions. For example, significant queuing is predicted to occur along Route 1, from Providence to North Kingstown, along I-95 in Warwick and Providence, as well as along most ramps accessing I-95 in these communities for extended periods during the evacuation. A moderate amount of congestion is also expected to occur along Route 138, between Route 102 and the Jamestown Bridge, as well as along Routes 2 and 4 in East Greenwich. Intermittent vehicle queuing and congestion would also occur along Routes 110 and 108 in South Kingstown, and Routes 117 and 117A in Warwick. For the peak traffic condition, Route 1 in Warwick is the critical roadway expected to experience the highest level of congestion. Route I-95 in Warwick is also expected to experience prolonged delays during portions of the evacuation, with travel speeds lowering to 25-40 miles per hour. Additionally, travel speeds along Route 1 are predicted to decrease to 15 to 25 miles per hour for much of the time after the evacuation recommendation is disseminated.

In summary, the controlling factor for clearance of the West Bay/Rhode Island network is evacuee response time for off-peak and mid-peak traffic conditions. For the peak traffic condition, however, congestion extends the clearance time beyond the behavioral response time by up to 1 hour and 30 minutes. In general for all modeled scenarios, the difference in clearance times between the weak and severe hurricane scenarios are generally less than 1 hour, indicating that the number of evacuees and available roadway capacities are not the major influence on the clearance time for communities in this area.

East Bay/Massachusetts Network

For the East Bay/Massachusetts network, clearance times range from 4 hours and 15 minutes, to 8 hours and 30 minutes. The evacuation clearance times for off-peak and mid-peak conditions under the weak hurricane scenario are only slightly higher than the response times, indicating that the background traffic conditions are the primary factor influencing total clearance times for these conditions.

Traffic conditions are generally free flow throughout the network during evacuations involving weak hurricane scenarios, except for portions of Route 6 in Swansea and Fall River, MA; sections of Route 114 through Portsmouth and Middletown, RI; and sections of 103 through Barrington and Warren, RI. In these locations, intermittent vehicle queuing temporarily slows travel speeds to approximately 20 to 25 percent of the posted travel speeds. The observed intermittent congestion in these areas corresponds directly to the behavioral response assumed for evacuating traffic. The road network, however, is relatively unrestrictive such that this congestion does not cause clearance times to extend for long periods of time over the assumed behavioral response time.

For evacuation simulations involving the weak hurricane scenario and peak background traffic, and others which represent a severe hurricane scenario, significant vehicle queuing and congestion is predicted along portions of Routes 6 in Swansea, MA; and sections of Route 114 through Portsmouth and Middletown, RI. Congestion is also predicted around the major urban centers subsequent to the evacuation recommendation, including key connectors such as Routes 6, 103 and 138 in the vicinities of Fall River, Somerset, and Swansea, MA; and East Providence, Bristol, and Barrington, RI. The roadways which will experience the most significant vehicle queuing are Route 6 between Fall River, MA and East Providence, RI; and Route 114 between the Mount Hope Bridge and Route 6 in East Providence, RI. Congestion is also expected along Route 103 in Barrington and Warren, RI.

In summary, clearance times for the East Bay/Massachusetts network are generally defined by the response time for all modeled scenarios except those involving a rapid behavioral response time. Consequently, although some intermittent queuing is expected from all modeled scenarios, the major factor influencing clearance times are the times associated with the assumed behavioral response time. Results have shown that clearance time is extended up to 1 hour and 45 minutes beyond the behavioral response time when a rapid response time is assumed. Much of this added time can be associated with congestion and vehicle queuing predicted along major arterials, such as Route 6 in New Bedford, MA, and urban roadways such as Routes 114 and 24, and 103 in communities along the east side of Narragansett Bay.

Overall, a comparison of the clearance times for the East Bay/Massachusetts network indicates that the difference in evacuating population between a weak and severe storm would generally add one hour or less to the total clearance time for evacuations occurring coincident with mid-peak and off-peak background traffic conditions.

TABLE 6.4
SUMMARY OF CLEARANCE TIMES (Weak Hurricane Scenario)

	BACKGROUND TRAFFIC		
	Off-peak	Mid-peak	Peak
WEST BAY/RHODE ISLAND NETWORK	Hrs.		
Rapid Response	4¼	4½	4¾
Moderate Response	6¼	6¼	6¾
Slow Response	8	8	8¾
EAST BAY/MASSACHUSETTS			
Rapid Response	4¼	4¾	5¼
Moderate Response	6	6¼	6½
Slow Response	8	8	8½

Notes: 1. Dissemination time must be added to clearance time to estimate total evacuation time.
2. Clearance time rounded to the nearest quarter hour.

TABLE 6.5
SUMMARY OF CLEARANCE TIMES (Severe Hurricane Scenario)

	BACKGROUND TRAFFIC		
	Off-peak	Mid-peak	Peak
WEST BAY/RHODE ISLAND NETWORK	Hrs.		
Rapid Response	4½	4¾	5½
Moderate Response	6¼	6¼	7½
Slow Response	8	8	9½
EAST BAY/MASSACHUSETTS			
Rapid Response	5	5½	5¾
Moderate Response	6	6¾	7¼
Slow Response	8	8¼	8½

Notes: 1. Dissemination time must be added to clearance time to estimate total evacuation time.
2. Clearance time rounded to the nearest quarter hour.

Chapter Seven

EVACUATION TIMES

7.1 INTRODUCTION

The Transportation Analysis developed clearance times for 18 evacuation scenarios each varying by hurricane intensity, behavioral response, and the level of background traffic at the start of the 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 all coastal Rhode Island areas plan evacuations based on the same clearance time. For evacuations occurring during the daytime a 7-hour clearance time is recommended for all areas. An 8-hour clearance time is recommended for all areas for evacuations which take place during the nighttime. The rationale for this recommendation is presented in the following sections.

As noted in the Transportation Analysis, clearance time is one component of the total 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 from the clearance times developed in Chapter Six.

7.2 INFLUENCE OF BEHAVIORAL RESPONSE

As highlighted in Chapter Four, the timing with which the threatened population evacuates in response to officials' warnings is a critical factor in whether or not an evacuation will be completed before the arrival of a storm. In the Transportation Analysis, three behavioral response curves, "slow", "moderate", and "rapid" rates of response were modeled in evacuation scenarios to address the uncertainty of public response.. The following paragraphs qualify the clearance times developed from these rates of response.

The study determined that the clearance times derived from the rapid behavioral response curve in Figure 4.2 are extremely optimistic and should not be used for planning purposes for evacuations in Rhode Island. Referring to Figure 4.2, the rapid behavioral response curve assumes that 85 percent of all evacuees will leave their homes within four hours of being directed to do so by officials (15 percent of the evacuees are assumed to leave before warnings are issued by officials). This curve best represents the public's response in situations where people react quickly to aggressive warnings issued by officials. Clearance times derived from this curve characterize evacuations where officials had not expected a hurricane to impact their locations, but the storm unexpectedly changed its course and now suddenly has become a threat to the area. Other than this unusual "last minute" evacuation scenario, quick public responses on this nature are extremely optimistic for evacuation planning. Statistics reported in the Behavioral Analysis (see Appendix B) show that people tend to mobilize and evacuate over longer periods of time than this curve indicates.

For the reasons discussed above, the Corps of Engineers and FEMA concluded that evacuation scenarios modeled based on a rapid public response yields clearance times which lack an acceptable margin of safety. For example, consider the scenario where the decision to evacuate is based on clearance times derived from the rapid behavioral response curve. If, during this scenario officials delay in making evacuation recommendations to the public, or the hurricane unexpectedly accelerates, there may not be enough time to complete the full evacuation prior to the storm's arrival. If, on the other hand, officials had made evacuation decisions based on clearance times derived from the moderate behavioral response curve, there would still be enough time to complete evacuations even if there is a delay in issuing warnings, or the storm unexpectedly accelerates. Because the rapid behavioral response offers no margin of safety and is extremely optimistic during most Rhode Island 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. Some local officials commented that they believed they would be able to evacuate residents from vulnerable areas in much shorter time than the slow behavioral response curve indicates, except some who said that the slow behavioral response curve is perhaps representative of the public's response late at night or in the early morning. Referring to

Figure 4.2, the slow response curve assumes that 85 percent of evacuees will leave their homes over an eight hour period after the public is made aware of the evacuation recommendation. As discussed during coordination meetings, Rhode Island officials do not anticipate that it will take longer than six hours for the public to mobilize and leave their homes when evacuating during the daytime. Based on these comments, and a review of hurricane evacuation studies developed for other east coast states, the Corps of Engineers and FEMA recommend that clearance times based on the moderate behavioral response be used for evacuation planning for daytime hurricane evacuations. If, however, it appears that notices to evacuate will be given late at night or in the early morning; or, officials anticipate unusual delays in public response, clearance times based on the slow behavioral response curve should instead be used.

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. Background traffic level is a measure of the 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. People who evacuate and travel on roadways to safe destinations (i.e., public shelters, friends'/relatives' homes, hotels/motels, etc.) are accounted for as a separate population type in the Transportation Analysis. The analysis used a sensitivity approach to determine how clearance times would be affected by varying levels of background traffic by calculating clearance times for a range of background traffic levels. The three levels of background traffic tested were: off-peak, mid-peak, and peak traffic conditions.

Results from the Transportation Analysis (see Tables 6.4 and 6.5) show that clearance times for areas in Rhode Island are marginally affected by the level of background traffic at the start of evacuations, excluding the peak traffic condition. Also, excluding the peak traffic condition, modeling results show that clearance time is mostly a function of behavioral response time for evacuations occurring over a period of six hours or more. In these cases, the road system in Rhode Island is not restrictive in terms of the overall evacuation regardless of the severity of the approaching hurricane. However, as described in Chapter Six, intermittent pockets of congestion are predicted along several routes.

Empirical data collected for major roadways in New England on the days Hurricanes Gloria and Bob made landfall indicate that it is unlikely that background traffic will be at peak levels on a day a hurricane is forecasted. This is not to imply that the combination of evacuating and background traffic can not produce traffic conditions near, or worse than, normal peak volumes. Should a hurricane be forecasted to landfall during the daytime, it is reasonable to expect that many commuters will not risk traveling to work, assuming public officials and employers 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. The empirical traffic data showed that hourly traffic volumes preceding evacuations for Hurricanes Gloria and Bob were lower than normal. Consequently, it is perhaps more reasonable to assume that mid-peak and off-peak background traffic conditions are more representative of the level of background traffic that will precede evacuations in Rhode Island. Clearance times based on background traffic levels near peak conditions may tend to overestimate clearance time. Therefore, Rhode Island officials should consider the use of clearance times derived from the mid- and off-peak background traffic conditions rather than the peak condition.

7.4 RECOMMENDED CLEARANCE TIMES

The above sections attempt to qualify the 18 evacuation scenarios modeled in the Transportation Analysis. Referring to the clearance times listed in Tables 6.4 and 6.5, by eliminating clearance times calculated from the rapid behavioral response curve and those calculated from the peak background traffic condition, clearance times for all areas range from 6 hours to 6¾ hours for the moderate behavioral response curve. For the slow behavioral response curve, clearance times range from 8 to 8¼ hours. The narrow range of clearance times computed for these two behavioral responses justifies the use of the same clearance time for planning purposes in all Rhode Island locations. Based on this, the Corps of Engineers and FEMA recommend that the Rhode Island Emergency Management Agency and Rhode Island coastal communities use a 7-hour clearance time for well publicized evacuations expected to occur during the daytime, and an 8-hour clearance time for those evacuations expected to begin during the nighttime[1]. In special

[1] For simplicity in applying the Decision Arc Method outlined in Chapter Eight, recommended clearance times are rounded to the nearest whole hour.

circumstances, however, it may be necessary to use clearance times developed from other scenarios if specific conditions warrant their use.

In Rhode Island, the decision to conduct an evacuation is an operational decision made at the community level. The adoption of the same clearance time for all areas in the State during most evacuation scenarios should help to eliminate potential discrepancies that might surface in evacuation decision-making from one community to the next. Furthermore, a state-wide evacuation time, based on a single clearance time that is mutually agreed upon by the State and communities, would give support to clear and consistent warning messages broadcasted to all threatened coastal areas at one time.

As will be discussed in the next chapter, a hurricane evacuation should be completed prior to the arrival of sustained gale-force winds, or the onset of storm surge inundation, whichever occurs first. In Rhode Island, the constraining factor for the time an evacuation should be completed is the arrival of gale-force winds. The time at which gale-force winds are experienced in relation to eye landfall at a given location depends on the specific track of the hurricane and the symmetry of its radius of maximum winds about the eye. For the purposes of using the decision-making procedure outlined in the next chapter, the Study makes a broad assumption that all Rhode Island locations (except the community of New Shoreham, i.e., Block Island) will experience gale-force winds at approximately the same time. As noted in Chapter Two, the arrival of peak surge at Narragansett, Rhode Island might occur as much as two to three hours before peak surge arrives at Providence, Rhode Island. Because the arrival of gale-force winds is the critical factor in determining when an evacuation must be completed, delays in the arrival of peak surge should not be factored into the time at which an evacuation is initiated. Officials should understand that communities in the upper reaches of Narragansett Bay may experience peak flood conditions as much as two to three hours after a hurricane makes initial landfall.

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 of 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 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. Local warning plans may also include provisions for issuing advisories over the radio or on television, again requiring coordination time.

The hurricane preparedness procedures mentioned above are operational functions that vary from location to location. This study does not attempt to quantify dissemination time, but instead recommends that the Rhode Island Emergency Management Agency and the Rhode Island coastal communities derive dissemination times after thoroughly examining the State Warning Plan and their communication procedures.

Figure 7.1 illustrates the two components of evacuation time and the relationship 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 roadways. Evacuation time is the combined total of dissemination time and clearance time. Failure to include dissemination time in the calculation of evacuation time will underestimate the time it takes to ensure a safe and complete evacuation. Once officials estimate a suitable evacuation time for a particular scenario, the Decision Arc Method of the next chapter can be used to determine if, and when, 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 Rhode Island Emergency Management Agency 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 emergency management officials in quantifying dissemination time.

7.6 EMERGENCY OPERATIONS PLAN FOR NEW SHOREHAM

It is the intention of the community of New Shoreham and the Rhode Island Emergency Management Agency to evacuate all non-permanent residents from Block Island by ferry boat or other means possible in response to a hurricane threat. Currently,

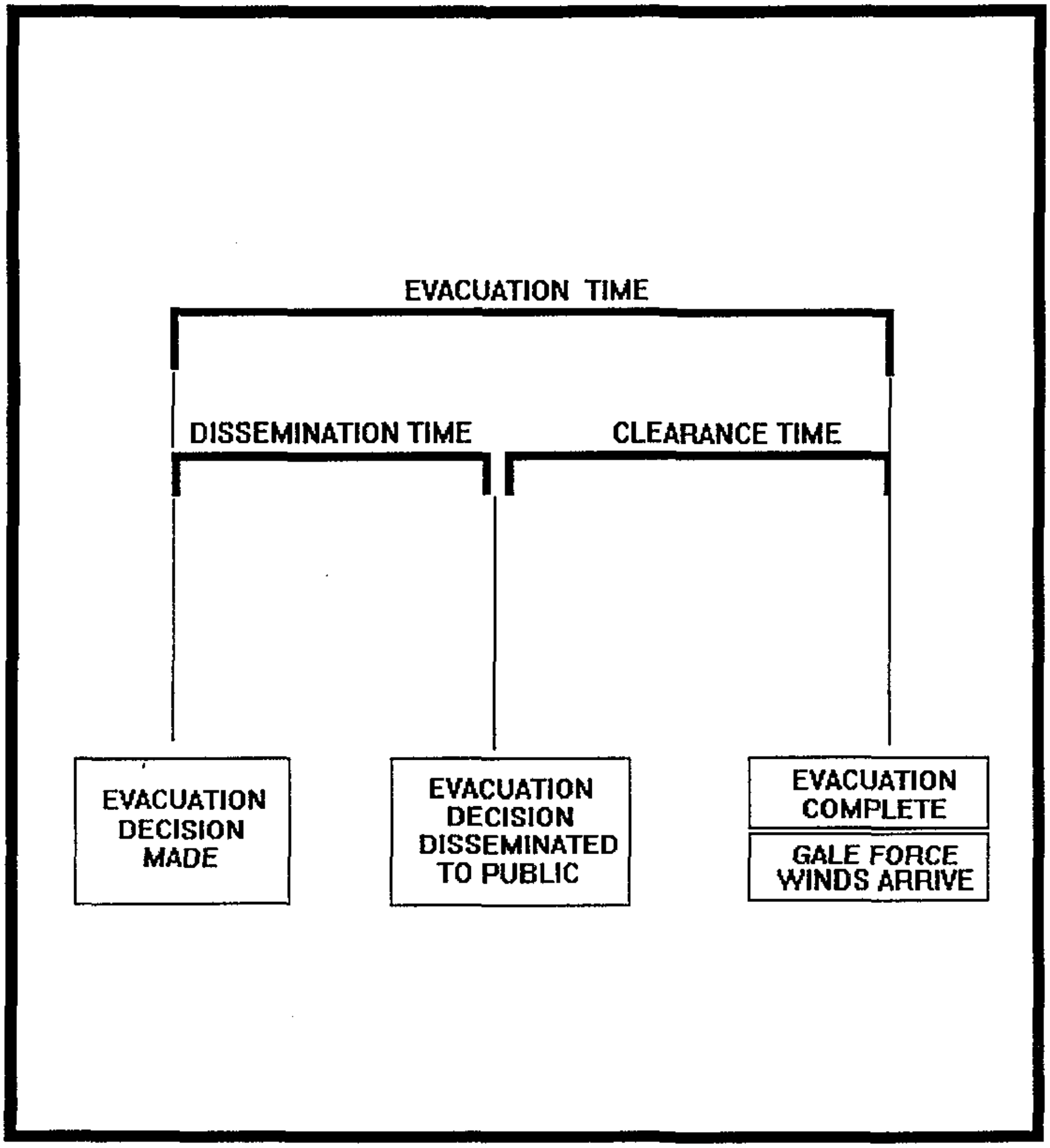


Figure 7.1 Components of Evacuation Time.

the Rhode Island Emergency Management Agency, in conjunction with the community of New Shoreham, is developing an Emergency Operations Plan which will include provisions for evacuating non-permanent residents from the Island. Shelter space will be provided on the island for permanent residents at an ARC Mass Care Facility located at the New Shoreham High School. Officials must understand that clearance times developed by the Rhode Island Hurricane Evacuation Study do not apply to the community of New Shoreham. The Emergency Operations Plan, scheduled for completion in October 1995, will address specific evacuation times required for the safe evacuation of non-permanent residents from Block Island.

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 Rhode Island.

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 difficult 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. This 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 the 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 Rhode Island 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 it was 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 be 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 eastern part of Cape Cod, Massachusetts will actually "miss" and pass well out to sea, or "hit" Rhode Island 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 Rhode Island make hurricane evacuation decision-making a difficult task. Depending on a storm's average forward speed and the evacuation time estimated by officials for a particular storm scenario (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 in a hurricane's forecasted track and the relatively low probability assigned by weather officials that a hurricane hundreds of miles away will pass by a given location. In spite of these uncertainties, evacuations must be initiated even when the probability is low that a location will be impacted. Even in situations where a hurricane may not be forecasted to reach New England, emergency management officials might still need to prepare for evacuation in the not so unlikely event the storm changes its course. It is recognized that the decision to start evacuations while storms are still several hours away is not an easy one. The information presented in this Chapter is designed to qualify some of the factors in evacuation decision-making to assist officials in using the data provided in this Study with NHC forecasts for initiating evacuations.

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 Rhode Island and is provided at the end of this chapter (see Figure 8.1). In Figure 8.1, a series of concentric arcs centered approximately at the middle of Narragansett Bay (approximately the middle of the State) have been superimposed on an ordinary hurricane tracking chart. The arcs are spaced at 50 nautical mile intervals 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 in the NHC's Tropical Cyclone Marine Advisory (Marine Advisory).

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 Rhode Island study area, the constraining factor for the time a hurricane evacuation should be completed is the arrival of sustained 34 knot winds. Decision Arcs are simply evacuation times converted to distance by accounting for the forward speed and the wind field of the hurricane. A simple calculation of multiplying the evacuation time by the hurricane's forward speed 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 is provided in Table 8.3.

As discussed in Chapter Seven, evacuation time is the combination of clearance time and dissemination time. Tables 6.4 and 6.5 list Rhode Island's clearance times developed for the most likely evacuation scenarios. For the rationale discussed in Chapter Seven, the study recommends that for planning evacuations a clearance time of 7-hours be used for evacuations expected to begin during the daytime, and an 8-hours clearance times for those anticipated to start at nighttime. After first determining an appropriate amount of time for dissemination, officials must add dissemination time to clearance time to estimate 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, evacuate their homes, and travel to their destinations. Evacuation time is therefore the total time necessary to complete a safe evacuation measured in hours before the arrival of sustained 34 knot winds.

8.4.2 Should Evacuation Be Recommended?

Probability values listed in the NHC's Tropical Cyclone Probability Advisory (Probability 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 Advisories, should be compared to values given for other locations. A comparison should also be made with the maximum probability values listed 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). As an example, for a hurricane with an average forward speed of 30 knots and a corresponding hypothetical evacuation time of 12 hours, the evacuation should be initiated before the sustained 34 knot winds approach within 360 nautical miles of the State (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 (or within 360 nautical miles of the State 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 to ensure complete evacuation before gale-force winds arrive. The hurricane probability listings provided in the Probability Advisory should be used to assist in this decision making process.

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 NHC Marine Advisory; (5) the NHC Probability Advisory.

PROCEDURE

1. From the NHC Marine Advisory, plot the last reported position of the hurricane eye on the Decision Arc Map. Notate the position with date/time. ZULU time ("Greenwich mean time" or "UTC" [Universal Coordinated Time]) used in the advisory should be converted to eastern daylight savings time by subtracting four (4) hours (see Table 8.4 for time conversions). 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 (either observed or forecast), the maximum sustained wind speed (either 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, use the Saffir/Simpson hurricane scale to determine the category of the approaching hurricane (see Table 8.1).

4. Estimate evacuation time by combining the recommended 7-hour or 8-hour clearance time with an appropriate dissemination time (**evacuation time = clearance time + dissemination time**). 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. Clearance time is defined as the amount of time required for all vehicles to clear roadways after a regional or state level hurricane evacuation recommendation

is disseminated to the public. Although clearance times were calculated for 18 possible evacuation scenarios, officials are strongly urged to use a 7-hour clearance time for daytime evacuations, and an 8-hour clearance time for those that occur at night (consult Chapter Seven for further explanation and possible exceptions to this).

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 in the Marine Advisory are provided in 12 hour intervals). Compare the forecast forward speed to the hurricane's current forward speed. A forecast speed greater than the current forward speed will indicate that the hurricane is forecasted 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 to represent the eye of the hurricane, 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., a location between the Decision Arc and your location). 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. Otherwise, if the radius of 34 knot winds lies outside of the selected Decision Arc, continue onto step number 8.

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 NHC Marine Advisory will be received prior to the Decision Point.

10. Compare probabilities shown in the Probability Advisory to determine whether an evacuation is now necessary, or is likely to become necessary (see Note c., below). 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 Probability Advisory 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 NHC advisory until a decision is made or the threat of hurricane impacts has passed.

<u>NOTES</u>:

a. As new information becomes available in subsequent NHC 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 nautical mile scales. 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 in 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 Probability 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 Probability Advisory, should be compared to other locations. A comparison should also be made with the possible maximums for the applicable forecast period shown in 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

CATEGORY	CENTRAL PRESSURE MILLIBAR	CENTRAL PRESSURE INCHES	WIND SPEED MPH	WIND SPEED KNOTS	SURGE FEET	DAMAGE 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 TROPICAL CYCLONE 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 NHC 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	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.

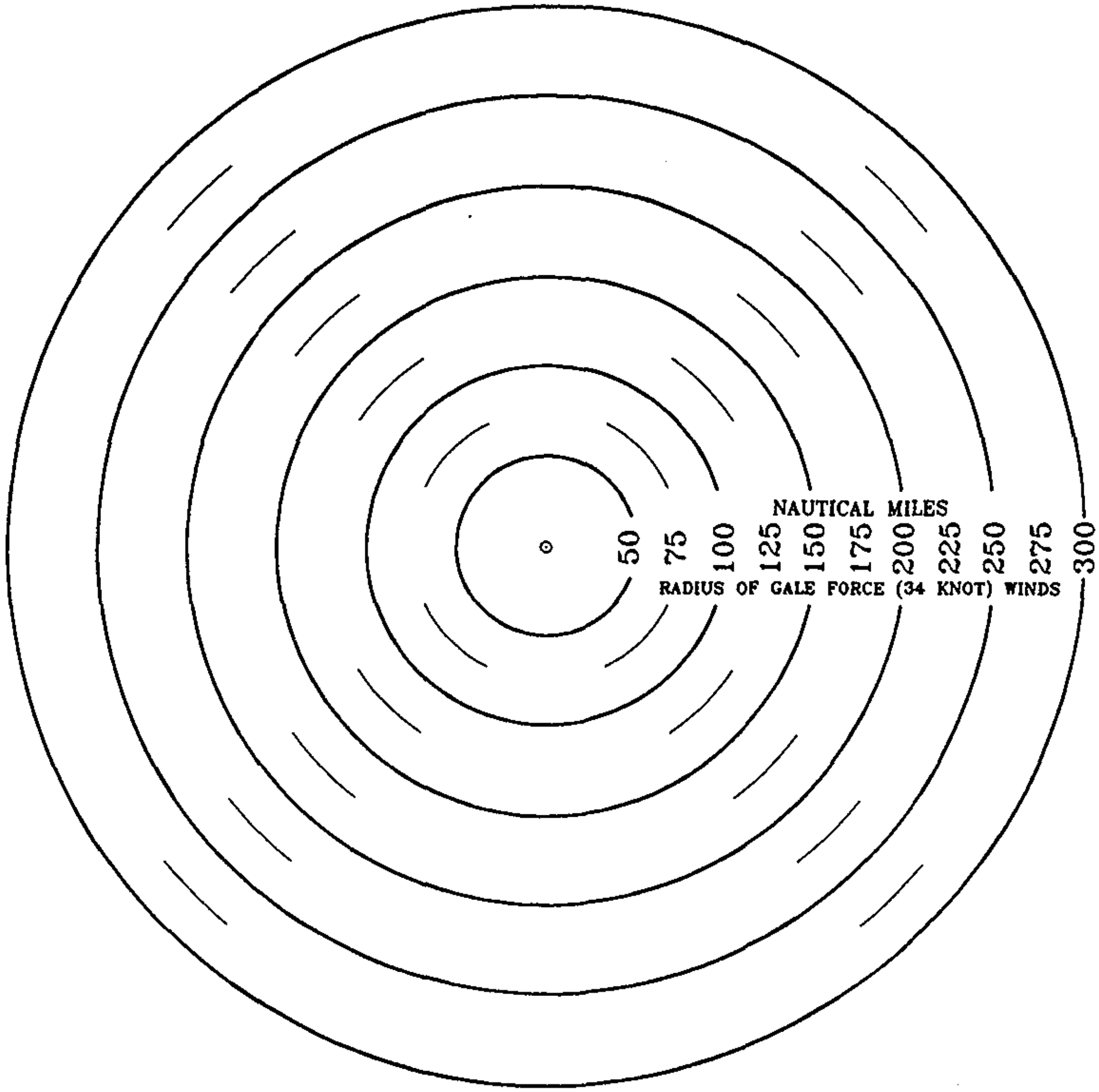
[3] Refer to steps 6 and 7 of the Decision Arc Procedure for methods of determining forecast forward speed.

TABLE 8.4
TIME CONVERSIONS

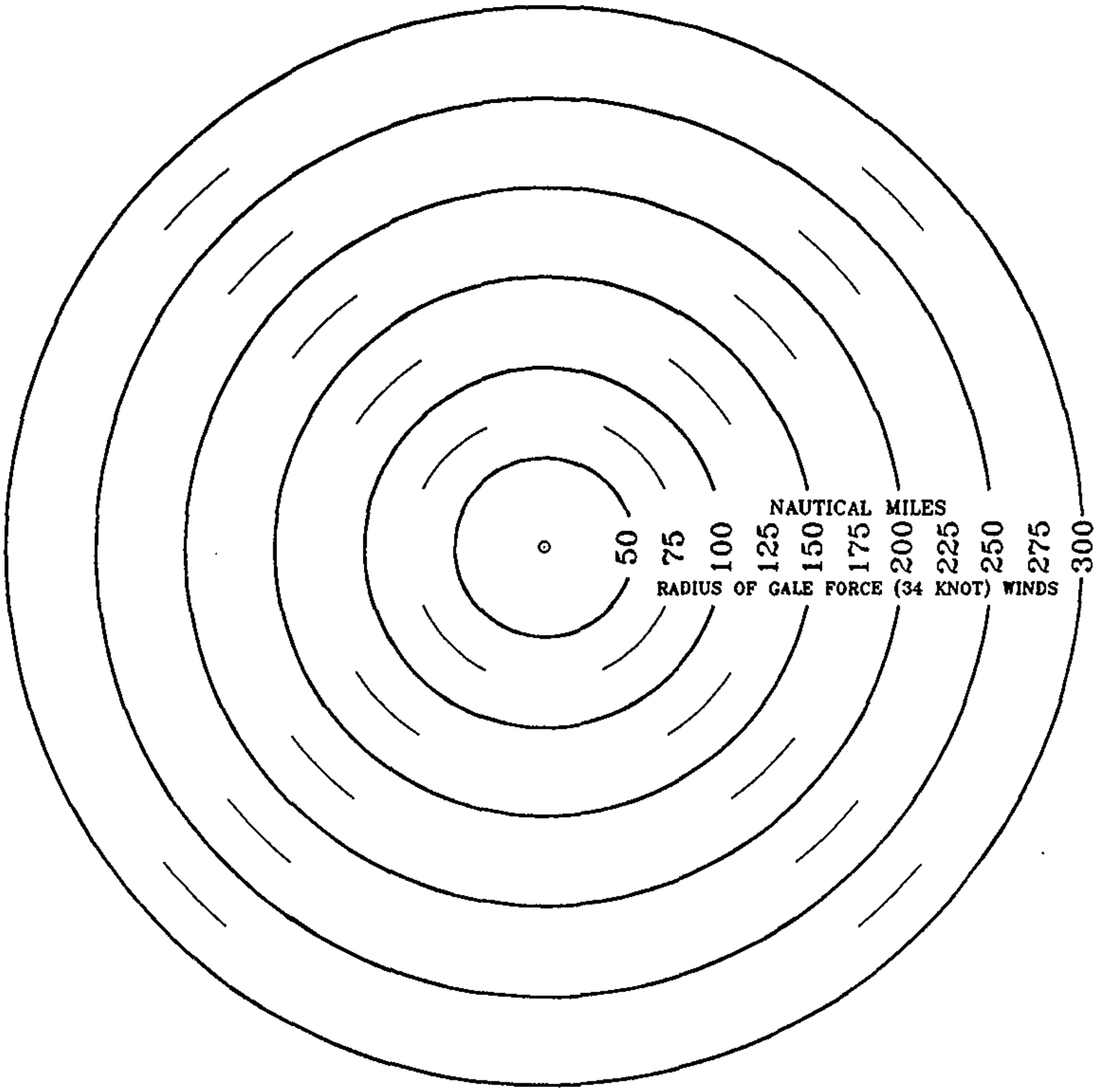
UNIVERSAL COORDINATED TIME (UTC)[2]	EASTERN DAYLIGHT SAVINGS TIME[1] (24 HOUR TIME)	CIVIL-TIME
0500 MONDAY	0100 MONDAY	1 AM MONDAY
0600	0200	2 AM
0700	0300	3 AM
0800	0400	4 AM
0900	0500	5 AM
1000	0600	6 AM
1100	0700	7 AM
1200	0800	8 AM
1300	0900	9 AM
1400	1000	10 AM
1500	1100	11 AM
1600	1200	12 NOON
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 Coordinated Time.

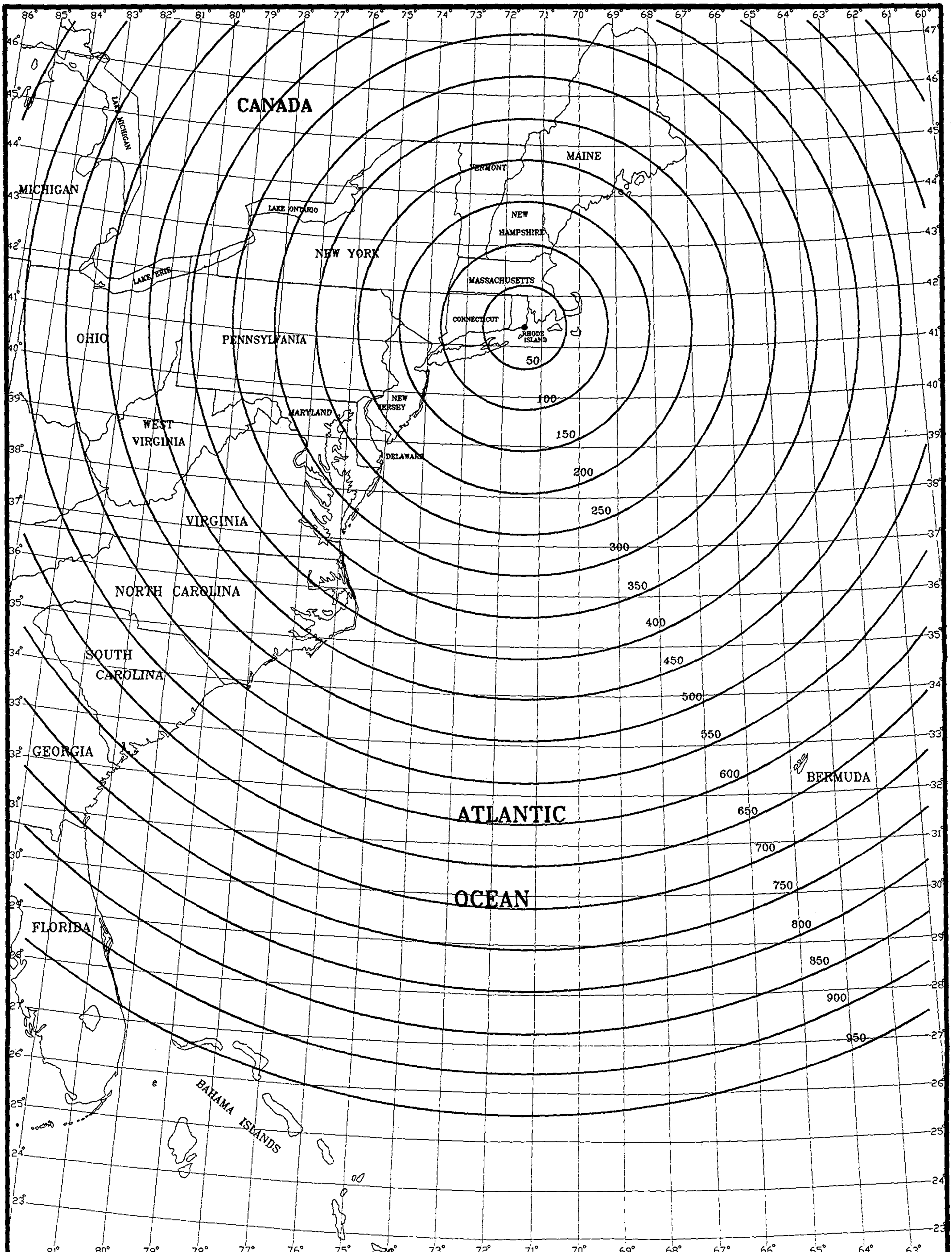
[2] UTC = Greenwich Mean Time = ZULU Time; it is expected that future NHC advisories will reference "UTC."


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

STORM


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

STORM



RHODE ISLAND
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 Rhode Island Emergency Management Agency.

Chapter Nine

SUMMARY

The purpose of this study is to provide the Rhode Island Emergency Management Agency and Rhode Island coastal communities 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 for hurricane evacuation decision-making.

In addition to this Technical Data Report and its appendices, the Study developed two companion atlases: the Inundation Map Atlas, and the Evacuation Map Atlas. The Inundation Map Atlas delineates the land areas potentially vulnerable to worst case flooding for multiple hurricane scenarios. 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 the 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 Rhode Island study area and calculated the flooding effects from each of a total of 536 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. For the Rhode Island study area, the height of peak surge at a particular location is significantly influenced by a hurricane's category and its forward speed. Consequently, the study grouped worst case hurricane surges by hurricane category and forward speed. At each location in the study area, maximum surge elevations associated with critical hurricane tracks for each group were added to mean high tide elevations to estimate worst case storm tides. 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 reported to have struck New England was the 1938 Hurricane, which researchers later classified as a strong Category 3 hurricane.

In the Hazards analysis, separate wave height and wave run-up analyses were conducted to determine the affects from waves on stillwater flood levels. At most locations, the analyses showed that there is a negligible increase in the stillwater flood level from wave effects. Wave heights along the coast and over the interior portions of the flooded land may be excessively high, but as waves propagate and break farther inland, frictional losses diminish their contributions to flooding limits beyond stillwater levels. Storm tide elevation profiles were developed for the Rhode Island coast which graphically present the worst case stillwater levels that are possible for three hurricane category and forward speed dependent scenarios.

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 by the storm tide elevation profiles. 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 known geographical 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 approximately 80,000 residents potentially vulnerable to surge flooding during "weak hurricane scenarios" and approximately 120,000 residents potentially vulnerable during "strong hurricane scenarios". 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. 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 a "weak hurricane scenario" and during a "strong hurricane scenario". 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 evacuating vehicles to clear off roadways after the public is directed to evacuate. The Transportation Analysis was undertaken to create a numerical representation of major transportation facilities in Rhode Island and Bristol County, Massachusetts to model hurricane evacuations. The model was programmed to simulate evacuations and estimate roadway clearance times for 18 possible evacuation scenarios. Important factors that were varied with each evacuation simulation were: the response of evacuees leaving their homes, the destinations of evacuees, the intensity of the approaching hurricane, level of seasonal population, and background traffic conditions at the start of evacuations. Clearance times range from 4¼ hours to 9½ hours depending on the above factors and the location within the State where the evacuation was modeled. Based on a review of the modeled evacuation scenarios, the Corps of Engineers and

FEMA recommend that the State adopt a single clearance time of 7-hours for daytime evacuations and 8-hours for night time evacuations for all coastal areas in the State. Rationale for this recommendation is discussed in Chapter Seven.

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 on 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 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. Results from the SLOSH model show that storm surge generation in Rhode Island is significantly influenced by a hurricane's intensity category and its forward speed. The Hazards Analysis has shown that at most Rhode Island locations, surges which accompany fast moving Category 2 hurricanes (forward speeds greater than 40 mph) can generate surge levels close to the levels generated by more intense Category 3 or 4 hurricanes traveling at slower forward speeds (forward speeds of 20 mph or less). This phenomenon is caused by the increased wind stress on ocean water on the right side of the hurricane's eye from storms which travel at faster speeds. Consequently, officials should understand that a storm's category, as well as its forward speed, are major factors in determining the storm's threat in terms of flood potential.

2. The average error in a 12 hour hurricane forecast is approximately 60 miles. This means that if a storm was forecasted to landfall at Narragansett, Rhode Island in 12 hours time, and if it in fact made landfall anywhere between the vicinity of New Haven, Connecticut and eastern Cape Cod, Massachusetts, the error in forecast landfall position

would be no worse than average. Even slight deviations in the forecasted track of a hurricane might mean a large difference in landfall location. Errors in forecasting complicate hurricane evacuation decision-making, and officials must understand the forecasting capabilities and inherent limitations of precise hurricane forecasting by the National Weather Service.

3. The Corps of Engineers' Fox Point Hurricane Barrier in Providence, Rhode Island is sufficient to protect against worst case storm tides estimated using the SLOSH model. For purposes of this study, all analyses were conducted assuming that the Barrier's gates would function properly protecting all areas behind the structure. The inundation map and evacuation map for the City of Providence show separate potential flood delineations for locations behind the barrier should the barrier's gates malfunction. As the results of this study are implemented, the City of Providence should consider flooding impacts and develop appropriate evacuation measures for areas behind the barrier in the unlikely event evacuation becomes necessary.

4. 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 results of this study indicate 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.

5. The Shelter Analysis determined that the expected shelter demands of four Rhode Island communities are greater than the shelter capacities of the communities. The Study recommends that these communities continue to work with local American Red Cross chapters to reach agreements on other suitable facilities to ensure adequate shelter space is available during hurricane evacuations.

6. The Study presents clearance times for 18 hurricane evacuation scenarios, each varying by public response, background traffic level during the evacuation, and hurricane intensity. The Study recommends the adoption of a 7-hour clearance time for all coastal areas in

Rhode Island for daytime evacuations and an 8-hour clearance time for nighttime evacuations. Although the Study analyzed evacuation scenarios with clearance times less than 6 hours time, these times should not be used by the State or communities as a basis for evacuation planning. Officials must understand that clearance times developed by this study do not apply to the community of New Shoreham (Block Island). An Emergency Operations Plan for New Shoreham is currently being developed by the Rhode Island Emergency Management Agency which will address specific evacuation times required for the safe evacuation of non-permanent residents from the Island. The plan is scheduled for completion in October 1995.

7. 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.

8. 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 Advisories and Tropical Cyclone Probability 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.

9. The completion of this multi-year study does not conclude the Corps of Engineers or the FEMA's involvement in hurricane preparedness activities in the State of Rhode Island. The effectiveness of this study depends upon continued hurricane preparedness training and public awareness at all levels. FEMA and the Rhode Island Emergency Management Agency will incorporate the results of this study into their ongoing program of improving hurricane emergency management in Rhode Island.

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This report contains the support documentation to the main report entitled the Rhode Island Hurricane Evacuation Study Technical Data Report, April 1995. The purpose of the study is to provide the Rhode Island Emergency Management Agency and Rhode Island coastal communities with realistic data quantifying the major factors involved in hurricane evacuation decision-making. 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.

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