1.0 Study Area

1.1 Introduction

1.1.1 Study Purpose

The National Hurricane Program (NHP), an interagency group comprised of the Federal Emergency Management Agency (FEMA), the U.S. Army Corps of Engineers (USACE) and National Oceanic and Atmospheric Administration (NOAA) - National Weather Service (NWS) conducts assessments and provides tools and technical assistance to assist state and local governments in developing hurricane evacuation plans and managing evacuation operations. Through the hurricane evacuation study (HES) process, state and local governments are provided with a range of resources, including regional demographic data, maps, evacuation clearance times, and user-friendly evacuation models. These various data and tools are consolidated and summarized in the Technical Data Report (TDR) for the study area, designed to be the primary source of regional evacuation information for federal, state and local government officials.

The study area for the Rhode Island HES TDR includes the communities vulnerable to storm surge within the counties of Bristol, Kent, Newport, Providence, and Washington. A map of the study area is depicted in Figure 1-1.

1.1.2 Funding

The Rhode Island HES and the completion of the representative TDR was funded by FEMA, in coordination with the USACE – New England District.

1.1.3 Authority

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

1.1.4 Coordination Information

FEMA is responsible for the overall program management of HESs funded through the NHP. Funding is provided from FEMA through an interagency agreement to the USACE, which in turn provides the more detailed, day-to-day management of each study effort. The USACE often engages technical experts to support their efforts and to undertake specific portions of the study process, such as the conduct of transportation analysis and evacuation modeling. State officials support FEMA and the USACE and work closely with the local emergency managers in the study area to ensure that their needs are addressed in the study process.

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None of the states in the New England region have had the benefit of a full-fledged HES as prepared under the direction of the NHP. The NHP, through a USACE contract with Battelle, prepared a transportation analysis report and abbreviated transportation model (ATM) for the state of Maine in 2007. Furthermore, various states and local governments throughout the region have initiated their own hurricane related transportation analyses for their own specific jurisdictions, but no comprehensive effort that looks at all aspects of hurricane evacuation within the state. In April 2007, the Rhode Island Department of Transportation (RIDOT) commissioned the preparation of a Hurricane Evacuation Plan which was completed in 2007. Additionally, Portsmouth, New Hampshire, commissioned a study of hurricane evacuation clearance times for the entire Seacoast Region of the State, which was completed in 2012.

The NHP started the New England HES process in 2012 with the development of Storm Tide Atlases to map the maximum storm tide inundation for the entire New England area. In coordination with FEMA and the USACE, local government officials were then able to draft new evacuation zones, which are the basis for almost all other aspects of this HES. As the mapping was in its final stages of completion, this study effort commissioned a behavioral analysis for Rhode Island, as well as for Connecticut and Massachusetts, to determine the behavioral responses of the evacuating population in response to theoretical storm scenarios. Nonetheless, given recent scares from Earl in 2010 and Sandy in 2012, the behavioral analysis also included New Englander's actual responses during those events. The Transportation Analysis portion of the study effort was kicked off in January of 2014. The USACE and its consultants met with state and local officials to finalize evacuation zones and routes and to begin the process of demographic data collection for evacuation modeling. A final stakeholder meeting presenting the HES, ATM, and the draft HURREVAC-ready clearance times was conducted in December of 2015.

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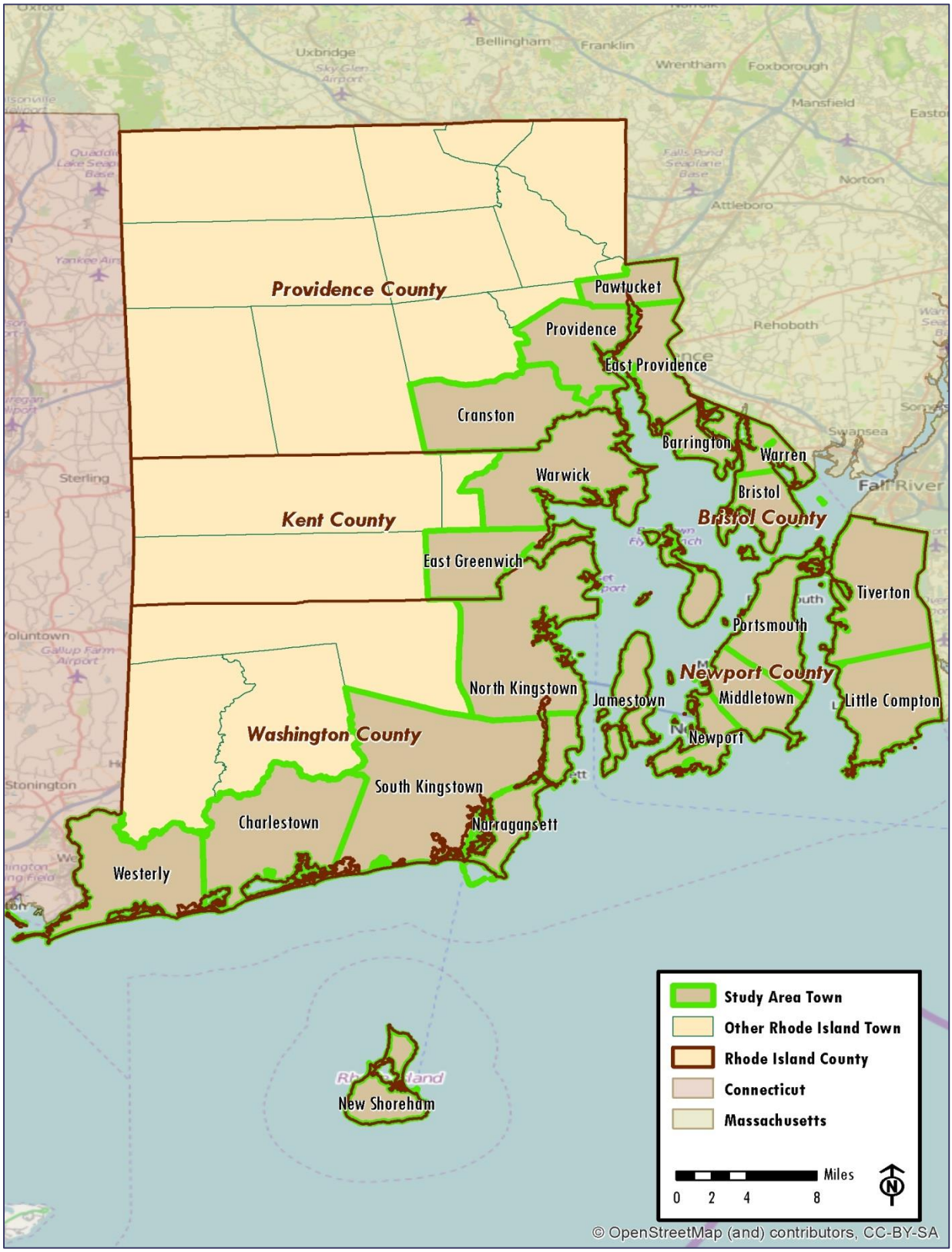

Figure 1-1: Map of Rhode Island HES TDR Study Area

1.0 Study Area

1.2 Description of Study Area

1.2.1 Geography

Rhode Island lies in the northeastern part of the United States. The state is bordered by Connecticut to the west, Massachusetts to the north and east, and the Atlantic Ocean to the south. The total coastline measures more than 400 miles and includes the many bays, coves, and offshore islands. The state, at its greatest points, is 48 miles long by 37 miles wide, with a total area of 1,214 square miles (includes land & water).[1]

The State of Rhode Island study area is comprised of the coastal communities in five counties along Block Island Sound and Narragansett Bay. Although the study encompasses Washington, Kent, Providence, Newport and Bristol, only the communities on the coast, and subject to hurricane-induced storm tides were actually studied for this analysis. This effort includes the specific communities in its various analyses as listed in Table 1-1.

Table 1-1: Rhode Island HES TDR Study Communities

County	Included Study Communities
Bristol County	Barrington, Bristol and Warren
Kent County	East Greenwich and Warwick
Newport County	Jamestown, Little Compton, Middletown, Newport, Portsmouth and Tiverton
Providence County	Cranston, East Providence, Pawtucket and Providence
Washington County	Charlestown, Narragansett, North Kingstown, South Kingstown, Westerly and New Shoreham

It must be noted, however, that for the shelter analysis which is an integral part of this overall study effort and report, it will include adjacent inland communities since these communities will likely be the destinations for many of the coastal evacuees.

Washington County has a total area of 563 square miles, of which 329 square miles is land and 234 square miles is water. To the south, the county is bounded by Block Island Sound, and to the east by Rhode Island Sound and Narragansett Bay. Kent County forms the entire county boundary to the north.

[1] "Our Geography," Rhode Island Secretary of State, Little Rhodies Kid's Zone, http://sos.ri.gov/kidszone/geography/, (May 20, 2015).

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Kent County has a land area of 188 mi^2 and shares its entire southern border with Washington County to the South and Providence County to the north. To its west, along the state line is Connecticut. To Kent County's east is Greenwich Bay, Narragansett Bay and the Providence River.

Encompassing a total of 436 square miles, Providence County is the most northern of the counties in Rhode Island and it is the largest of Rhode Island's five counties by land area. Providence County is drained by the Blackstone River, which runs partly along the east border; the Woonasquatucket River in the central part of the county, joining with the smaller Moshassuck River in downtown Providence; and the Pawtuxet, which forms a portion of the southeastern boundary of the county. The Pawtuxet is dammed in the western part of the county to form the Scituate Reservoir, which supplies drinking water for Providence and the surrounding communities. The county is bordered to the west by Connecticut and to the north and east by Massachusetts. Kent County comprises the entire southern border to the Providence River with Bristol County along the southeastern boundary.

Narragansett Bay forms the western and southern borders of Bristol County. With only 45 square miles of land area, it is the smallest county in the state, as well as its least populous. Bristol County also shares a border with Massachusetts to the north and east and Providence County to the northwest.

Newport County, with an area of 314 mi^2, straddles Narragansett Bay to the West and the Sakonnet River to the east. Much of the county is comprised of large, inhabited islands including Rhode, Conanicut, Prudence, and Hog, as well as smaller uninhabited islands such as Gould, Dutch and Hope. Its eastern border is the state line with Massachusetts, Bristol County is to the north and West Passage separates it from Washington County to the west.

1.2.2 Terrain

Rhode Island is the smallest state in the United States with an area of 1,545 square miles of which approximately 500 square miles of that is water. According to the 2010 decennial U. S. Census data, Rhode Island is densely populated at 1,018 people per square mile which ranks it second in the nation in population density behind the state of New Jersey.

Rhode Island geography is characterized by two distinct regions: the south and east Coastal Lowland and the Eastern New England Upland (ENEU). Among the major river systems in the state, the Sakonnet which runs through runs through eastern Rhode Island is really an adjunct to Narragansett Bay as are the Providence and Seekonk Rivers.

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The Coastal Lowland includes more than one-half of the land area of Rhode Island and extends to the islands in the Narragansett Bay. This area is typified by sandy beaches, salt ponds and natural lagoons. There are also some small mounds/hills with rounded slopes and very few trees. Included in the coastal lowlands are three major islands, all of which are populated year round. The largest island in the bay is Aquidneck with its rocky cliffs and dramatic scenic views of the ocean, it is the home to the famous and historic community of Newport. Conanicut Island is the site of the resort community of Jamestown. The smallest major island in Narragansett Bay is Prudence Island.

The limited variation of topography appears to be peculiar to the land forms within the state and does not extend into the waters of the Atlantic Ocean. Block Island, which constitutes the community of New Shoreham, is twelve miles offshore and has a more rugged landscape surrounded by a trickier underwater seascape, which has been responsible for many shipwrecks off the coast of this Island.

The northwestern third of the Rhode Island geography is known as the Eastern New England Upland (ENEU) and is characterized by rolling hills and a rise in elevation. ENEU has many little lakes and ponds scattered through those rolling hills.

1.2.3 Bathymetry

Shallow water close to the shore tends to increase the magnitude of hurricane-induced storm surge, thus knowing the offshore bathymetry of the study area is extremely important. For Rhode Island, Narragansett Bay and Block Island Sound are areas of concern.

Narragansett Bay is a bay and estuarine system that covers 147 square miles. It is such a major feature of Rhode Island that the state's nickname is the "Ocean State". In fact, Narragansett Bay accounts for over 256 miles of Rhode Island's shoreline. The Bay itself, which encompasses over thirty islands of various size and population, is comprised of the Sakonnet River, Mount Hope Bay/Taunton River, East and West Passage, Greenwich Bay and the Providence/Seekonk Rivers. The Bay is referred to as a shallow estuary; its water depth is an average of approximately 26 feet. However, it can vary from a shallow average of 25 feet in the West Passage to 186 feet deep in the East Passage off Castle Hill. Tides in the Bay occur twice a day with an average range of 3.6 feet at the mouth of the bay to 4.6 feet at the head. Tidal mixing is the dominant factor in affecting circulation patterns in the Bay, but non-tidal currents caused by salinity and temperature variations, as well as wind driven currents are also important. In addition, nine different watersheds drain into Narragansett Bay, namely the Blackstone, Hunt, Moshassuck, Narragansett, Pawtuxet, Taunton, Ten Mile, Warren and Woonasquatucket River basins contributing an average of approximately 2,400 million gallons of freshwater per day.

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Block Island Sound is a strait in the open Atlantic Ocean, approximately 10 miles wide, separating Block Island from the coast of mainland Rhode Island. On the west, it extends to Montauk Point on the eastern tip of Long Island, as well as Plum Island, Gardiners Island, and Fishers Island, all in New York.

1.2.4 Climate

The state has a humid continental climate, with winds predominantly from the west. Marine influences are evident by the differences between coastal and inland locations. The average monthly temperature is 29 °F (−2 °C) in January and 71 °F (22 °C) in July with the overall annual average at 51.5 °F (10 °C). The annual precipitation averages vary from 42 to 46 inches with a tendency for decreasing amounts from west to east. Average precipitation from rain and snow, can range from 40 inches in the immediate southeastern Bay area and on Block Island to as much as 48 inches in the western highlands. The major weather characteristic is variability, with extreme weather conditions such as tropical storms (including occasional hurricanes), ice storms, and heavy snow.

1.2.5 Physiography

The dominant physiographic feature of the state is the Narragansett basin, a shallow lowland area of Carboniferous sediments, extending into SE Massachusetts and, in Rhode Island, partly submerged as Narragansett Bay. The coastline between Point Judith and Watch Hill is marked by sand spits and barrier beaches, sheltering lagoons and salt marshes. Glaciation left many small lakes, and the rolling hilly surface of the state is cut by short, swift streams with numerous falls. Although more than half of Rhode Island is covered with forests, it is highly urbanized. Providence is the capital and the largest community; other important communities are Warwick, Cranston, Pawtucket, and Newport.

1.2.6 Population / Demographics

Rhode Island is the second most densely populated state in the nation, ranking only behind New Jersey. According to the last decennial census taken by the U.S. Census Bureau in 2010, Rhode Island had a total 1,052,567 permanent residents. This figure reflects an overall change from the preceding census in 2000 of +0.4%. According to the latest U.S. Census estimates, the most recent estimate of the state's population for 2014 is 1,055,173 which represents a net increase of 2.5% from the decennial figures for the entire state. Table 1-2 reflects the changes in the study area population; Table 1-3 provides a more detailed account of the demographics and housing assumptions by community for 2015.

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Table 1-2: Changes in Study Area Population (2010 – 2014)

Community	Census Data		Population Changes	
	2010	2015	(Number)	(Percent)
Barrington	16,310	16,298	-12	-0.07%
Bristol	22,954	22,531	-423	-1.84%
Charlestown	7,827	7,821	-6	-0.08%
Cranston	80,387	80,470	83	0.10%
East Greenwich	13,146	13,124	-22	-0.17%
East Providence	47,037	47,099	62	0.13%
Jamestown	5,405	5,423	18	0.33%
Little Compton	3,492	3,490	-2	-0.06%
Middletown	16,150	16,148	-2	-0.01%
Narragansett	15,868	15,809	-59	-0.37%
New Shoreham	1,051	1,051	0	0.00%
Newport	24,672	24,340	-332	-1.35%
North Kingstown	26,486	26,354	-132	-0.50%
Pawtucket	71,148	71,163	15	0.02%
Portsmouth	17,389	17,339	-50	-0.29%
Providence	178,042	178,056	14	0.01%
South Kingstown	30,639	30,599	-40	-0.13%
Tiverton	15,780	15,805	25	0.16%
Warren	10,611	10,597	-14	-0.13%
Warwick	82,672	82,378	-294	-0.36%
Westerly	22,787	22,720	-67	-0.29%
Total	**709,853**	**708,615**	**-1,238**	**-0.17%**

Sources: U.S. Census State and County QuickFacts.

Table 1-3: Rhode Island HES TDR Demographic and Housing Data by Community

Community	2015 Population	Permanent Occupied Housing Units	Mobile Home Units	Vacation / Seasonal Units	Tourist Units
Barrington	16,298	5,990	-	118	-
Bristol	22,531	8,351	-	294	77
Charlestown	7,821	3,245	92	1,647	877
Cranston	80,470	31,044	72	182	79
East Greenwich	13,124	5,014	25	61	-
East Providence	47,099	20,228	72	77	140
Jamestown	5,423	2,367	-	471	183
Little Compton	3,490	1,500	51	752	20
Middletown	16,148	6,762	172	339	1,295
Narragansett	15,809	6,679	105	2,305	423
New Shoreham	1,051	514	-	1,253	595
Newport	24,340	10,471	38	1,395	2,455
North Kingstown	26,354	10,384	222	372	146
Pawtucket	71,163	29,028	323	76	138
Portsmouth	17,339	6,968	233	879	64
Providence	178,056	62,723	160	362	2,338
South Kingstown	30,599	10,303	180	2,315	465
Tiverton	15,805	6,695	303	308	6
Warren	10,597	4,639	-	118	8
Warwick	82,378	35,108	97	484	2,213
Westerly	22,720	9,637	13	1,884	1,065
Total	**708,615**	**277,648**	**2,158**	**15,693**	**12,587**

Sources: Data represented in this table reflects data obtained and/or calculated from the 2009-2013 American Community Survey 5-Year Estimates.

1.3 Historical Hurricane Activity

Given the relatively high latitude of the entire New England coastline, it would be surprising to some people how frequently tropical cyclones have visited the region, some storms even attaining major (Category 3) hurricane status. Nonetheless, the area is subject to Atlantic basin hurricanes that originate as tropical waves that form off the coast of Africa. Also known as Cape Verde storms, these events are named for the islands from where many of these waves first coalesce into tropical cyclones. These tropical waves traverse the Atlantic Ocean, intensify as they come in contact with the Gulf Stream, and many get entrained in the jet stream, which carries them at relatively high forward speeds to the coast of New England. In fact, those

hurricanes that originate off the Southeastern U.S. and Mid-Atlantic states can present local officials in New England with the added challenge of having to plan, order and execute an evacuation with very little lead time. Figure 1-2 below displays the number of tropical systems that have come within 100 nautical miles of the New England area from 1851 to 2008.

The New England Coast is very familiar with hurricanes and tropical storms. According to the NOAA Historical Hurricane Track Database from 1851 to the present, of the 47 tropical cyclones (tropical storm and above) that have come within 100 statute miles of the Southern New England coast, 19 were hurricanes, three of them major (Category 3 and above). The most active decade for tropical cyclone activity was the 1880s with a total of 7 tropical events, but the 1860s, the 1950s and the 1960s were also busy with four storms each. With a search radius of 150 nautical miles the total number of tropical cyclones balloons to 74, many of which were just off shore, but close enough to possibly warrant some degree of protective actions in response to their approach. A few of the major storms to impact the area, including a few not included in the above database, are described in more detail below.

The Great Colonial Hurricane (GCH) – August 1635: The storm was estimated to have been a Cape Verde-type hurricane, probably a Category 4 or 5 hurricane that was likely a Category 3 when it made landfall in the vicinity of eastern Long Island and Connecticut and Rhode Island. Although it made landfall probably east of what is now Groton, there were no specific reports of damage or other impacts to Connecticut itself. Nonetheless, meteorologists believe it to be the strongest tropical cyclone ever to hit the southern New England coast.

The Great Colonial Hurricane (GCH) – August 1635: The storm was estimated to have been a Cape Verde-type hurricane, probably a Category 4 or 5 hurricane that was likely a Category 3 when it made landfall in the vicinity of eastern Long island and Connecticut and Rhode Island. Reportedly the area between Providence, Rhode Island, and the Piscataqua River in New Hampshire was seriously impacted by this storm with some evidence of damage still apparent fifty years after its occurrence. The storm tide in Narragansett Bay was reported to be 14 feet above normal tide with values as high as 22 feet recorded in other locations in New England. According to Brian Jarvinen, once the director of the National Hurricane Center's (NHC) SLOSH surge modeling program and charged with re-evaluating past historical storms for determining storm tide flooding potential, based on his analysis of the data and subsequent recreation of the storm, the GCH is probably the most intense New England hurricane in recorded history.

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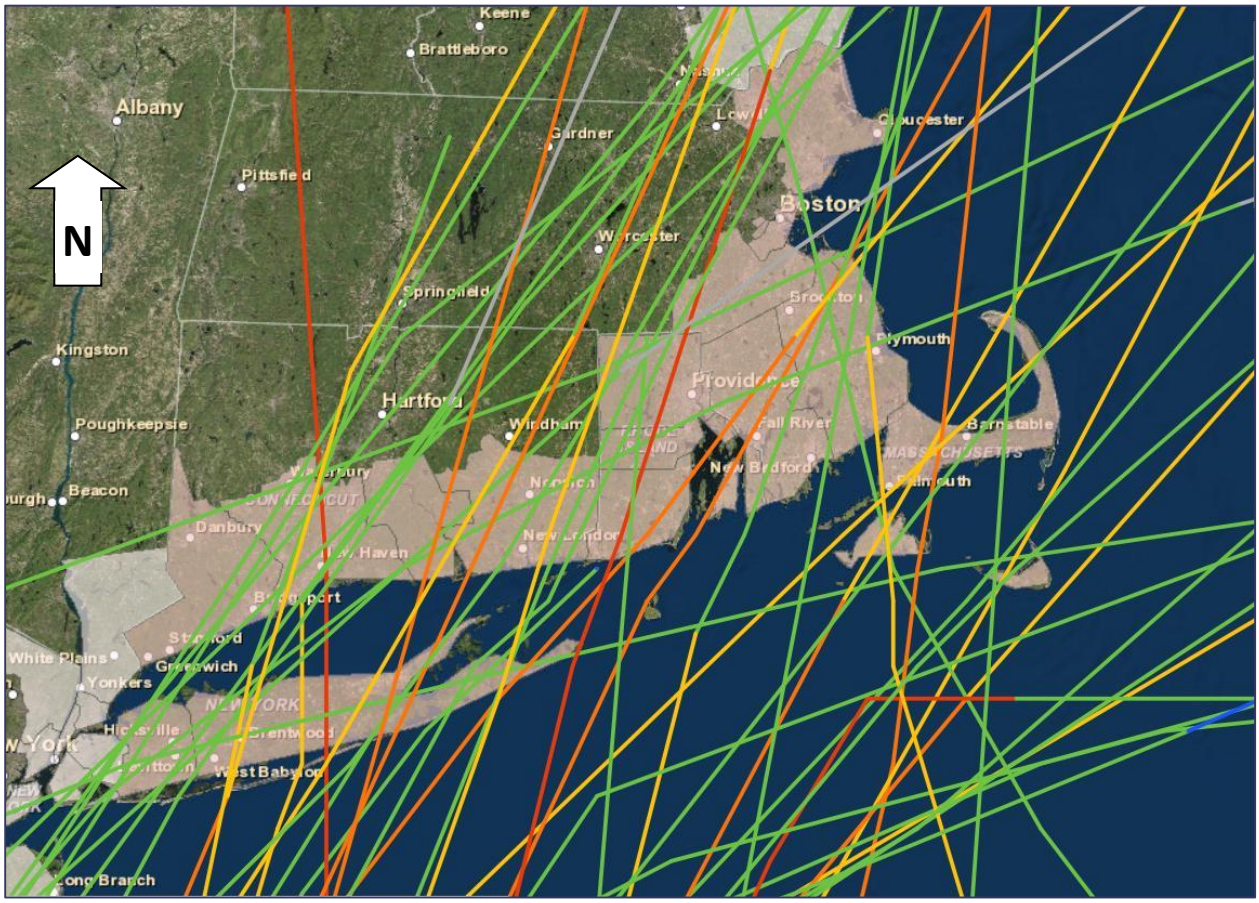

Figure 1-2: Tropical Systems impacting New England (1851 – 2008) (Image created using the National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center's Historical Hurricane Tracker, http://coast.noaa.gov/hurricanes)

The 1804 Snow Hurricane – October 1804: The tropical cyclone, which was probably spawned near Puerto Rico, proceeded up the eastern U.S. seaboard until it impacted the New England region as a Category 2 hurricane. Of interest with this particular storm is that the hurricane was assessed to be at its peak intensity when it was over Massachusetts and that it was responsible for generating widespread snow throughout the New England region as it progressed northeastward. Reportedly, the devastation in Rhode Island was widespread, especially in Providence and Newport, where houses, ships and a few lives were lost as a result of the storm.

The Great September Gale of 1815 – September 1815: This event was the first major storm to hit the New England region in 180 years (see the GHC citation above), and was assessed to be a Category 3 when it came ashore. Although it made landfall around Old Saybrook, Connecticut, much of the documented damage was reported in Providence. Reportedly an 11 foot storm

surge was funneled up Narragansett Bay where it wreaked havoc on Providence, destroying over 500 houses, 35 ships, the First Baptist Meeting House, as well as the Washington and Central (Red) bridges. Overall, the financial loss was assessed at that time was $1.5 million dollars, which constituted approximately one quarter of the overall valuation of the community.

The Great New England Hurricane of 1938 – September 1938: The most famous storm that has ever affected New England was the Unnamed storm of September 1938, also named the Yankee Clipper, or the Long Island Express. The storm formed near the coast of Africa in September becoming a Category 5 hurricane before making landfall as a Category 3 hurricane on Long Island on the afternoon of September 21, and again near New Haven, Connecticut at approximately 9 o'clock the same evening. When it made landfall, the storm was travelling at a forward speed of 47 miles per hour. The impacts of the storm surge were particularly violent in Rhode Island where it reportedly killed 100 people in Westerly and many more on Block Island. The storm's arrival in Narragansett Bay coincided with a higher than normal tide caused by the autumnal equinox and a full moon. These high tidal variations, combined with the angle of approach of the eye and the configuration of Narragansett Bay in general, caused storm surge to rise to nearly 16 feet above normal tides, flooding much of downtown Providence and causing much damage along the entire shoreline of the Bay. Providence also reported sustained winds of 100 mph, Category 2 strength, with gusts up to 125 mph. Ultimately, approximately 390 deaths in Rhode Island alone were attributed to the arrival of this storm, more than half of all the casualties recorded for the entire nation during that event.

In total, the hurricane was estimated to have killed nearly 700 people, damaged or destroyed over 57,000 homes, and caused property losses estimated at over $400 million in 1938 dollars. It remains the most powerful and deadly hurricane in recent New England history, eclipsed in landfall intensity perhaps only by the Great Colonial Hurricane of 1635.

The Great Atlantic Hurricane – September of 1944: Beginning as a tropical wave in the Lesser Antilles, it gained strength as it raked along the Mid-Atlantic and New England states. When it made landfall near Point Judith, Rhode Island, it was traveling at 47 miles an hour. This hurricane affected the New England region just six years after the 1938 Hurricane, but was said to have only caused about one-third the damage of that storm due to its lesser intensity at landfall and its acute angle of approach, which diminished its storm tide impacts. Although there are few specific reports of damage and impacts in New England, it did cause significant destruction along the Delmarva and New Jersey Coastlines. Nonetheless, about $2 million in 1944 dollars in damage were attributed to this storm in Rhode Island. The storm all along its

track caused heavy and abundant rainfall with most of Rhode Island receiving 6 inches of rain or more.

Hurricane Carol – August 1954: Hurricane Carol was among the worst tropical cyclones on record to affect the New England region of the United States. It developed from a tropical wave near the Bahamas on August 25, 1954, and slowly strengthened as it moved northwestward, eventually making landfall on Long island, New York, and Clinton, Connecticut, at the peak of its intensity. For Rhode Island, the hurricane produced a record-high wind gust of 135 mph at Block Island, while on the mainland sustained winds peaked at 90 mph in Warwick with gusts to 105 mph. Because it made landfall around high tide, Carol produced a storm surge of up to 14.4 feet in Narragansett Bay, thereby exceeding the maximums recorded for the New England Hurricane of 1938. The resulting storm surge flooded downtown Providence with 12 feet of water. Westerly also flooded, with approximately 200 homes washed away. There was also heavy damage reported in Newport, as well as in numerous other coastal communities, some of which were nearly totally destroyed. Even inland, the winds destroyed the roofs of hundreds of buildings, forcing many to evacuate to shelters during the passage of the storm. The powerful winds also downed thousands of trees and power lines, blacking out the entire state and interrupting almost all phone service in the state. Damage in Rhode Island alone totaled about $200 million, including over 700 homes and other buildings while at least 17 deaths were also recorded. Due to the damages and overall impacts, Carol had the distinction of being the first named storm to be permanently retired from the revolving list of hurricane names.

Hurricane Edna – September 1954: Arriving in the New England Region of just eleven days after Hurricane Carol, it made landfall 100 miles to the east of that storm and therefore spared Rhode Island the brunt of its impacts. It did nonetheless spur widespread protective actions all along the state's coastline and in Narragansett Bay including the closing of businesses, extensive evacuations and major sandbagging operations.

Hurricane Diane – August 1955: Originally a Category 2 storm, by the time Hurricane Diane reached New England, it was an extratropical storm. Nonetheless, it produced heavy rainfall dropping 8.45 inches of rain in Greenville, Rhode Island, and similar amounts throughout the rest of the state. Flooding was worst in the northern part of the state, primarily on the Blackstone River. The heaviest damage was in the community of Woonsocket, where the Horseshoe Dam failed and inundated the community. On the coast record high tides were also reported. In total, damage was estimated at 21 million with 3 deaths attributed to the storm.

Hurricane Bob – August 1991: Hurricane Bob made landfall in Newport, Rhode Island, as a Category 2 storm with sustained winds of over 100 miles per hour and causing a storm tide in

Narragansett Bay of between 6.6 feet (in Providence) and 16.6 feet (at the mouth of the Sakonnet River) above normal tides. The high waves caused extensive beach erosion all along the state's coastline. The peak rainfall in the state was recorded in North Foster at 7.01 inches, and there was flooding on the Pocasset River. Additional impacts to Rhode Island included power outages for more than 60 percent of all residents in the state and severe pollution in Narragansett Bay caused by the spilling of over 100 million tons of untreated sewage from adjacent treatment plants. Although the overall damages were reported at $1.5 billion, Rhode Island's share was $115 million.

Hurricane Earl – September 2010: Hurricane Earl was the first tropical cyclone to threaten the New England region since Hurricane Bob. Although it did not make landfall in New England specifically, nor the United States for that matter, it did cause mass evacuations along the Mid-Atlantic seaboard and within the study region. Earl did finally make landfall in Nova Scotia, Canada, but its approach was close enough to warrant decision makers in the United States to implement protective actions for their citizenry and tourists. Nonetheless, according to the behavioral study performed for this study, few respondents in Rhode Island recall hearing any evacuation orders issued by government officials (25% in the cat 1/2 and 12% in the cat 3/4); nonetheless, only 4% in the Category 1/2 evacuation zone, and 2.5% in the Category 3/4 zone indicated that they actually evacuated.

Hurricane/Tropical Storm Irene – 2011: Hurricane Irene was a Category 3 hurricane in the Bahamas before eventually weakening to a tropical storm in New England. The storm did not make a direct landfall in New England, but traveled inland through Connecticut and into western Massachusetts and Vermont on August 28, 2011. Despite this inland track, wind and heavy rains impacted Rhode Island with gusts of wind up to 71 mph, uprooting trees and causing extensive damage to its power grid. By the storm's end, an estimated 256,000 out of 480,281 customers were without power. The storm surge in Narragansett Bay caused some localized coastal damage, but Providence was spared downtown flooding in large measure because of its Fox Point Hurricane Barrier. There was some localized river flooding reported but with Rhode Island situated on the left side of the storm track, the winds were the main causative agent of most of the damage witnessed in the state.

Hurricane Sandy – 2012. Hurricane Sandy was a Category 3 hurricane near Cuba before weakening into a tropical storm/post-tropical cyclone. While the storm made final landfall in Atlantic City, New Jersey, on October 29, 2012, Massachusetts and the rest of New England still felt the impacts of Sandy due to the massive size of the storm. Rhode Island experienced significant coastal flooding but little wind or rain impacts. Although the storm surge was characterized as middle of the road at 4 to 5 feet, it occurred over multiple tide cycles, which

when combined with 15 to 30 foot seas caused much of the damage along the coast. Ultimately, the maximum storm tide was measured at 9.6 feet, one foot shy of the levels recorded in Hurricane Bob. Reportedly, much of the damage was along the Block Island Sound coastline where even major dune systems were obliterated by the storm tide and pounding surf, but it did also extend into Narragansett Bay.[2] Ultimately, the damage in Rhode Island totaled up to $11.2 million.[3]

1.4 Major Analysis

1.4.1 General

The Rhode Island HES was initiated in 2009 and was completed in 2015 with the publication of the TDR. It 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 are briefly summarized in the following paragraphs. Detailed descriptions of the analyses and the methodologies of each are contained in subsequent chapters of this report.

1.4.2 Hazards Analysis

The hazards analysis determines the timing and magnitude of wind and storm surge hazards that can be expected from hurricanes of various categories, tracks, and forward speeds. The Sea, Lake, and Overland Surges from Hurricanes (SLOSH) numerical model is used by the National Hurricane Center (NHC) to compute the wind speeds and surge heights. The SLOSH output is also used to map storm tide inundation limits that are then used by state and local to delineate evacuation zones. The Hazards Analysis is presented in more detail in Chapter Two.

1.4.3 Vulnerability Analysis

Utilizing the results of the hazards analysis, the vulnerability analysis identifies those areas, populations, and facilities that are vulnerable to specific hazards under a variety of hurricane threats. For this HES, hurricane evacuation zones were delineated for each community in the study area from the SLOSH storm tide inundation limit maps prepared during the Hazards Analysis phase. Population data was used to determine the vulnerable population within each evacuation zone. Further discussion on all aspects of the Vulnerability Analysis is provided in Chapter Three.

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[2] "Examining The Impacts of Hurricane Sandy on Rhode Island: A Serious Wakeup Call" Presentation by David R Vallee at the Northeast River Forecast Center, Published Apr 9, 2013.

[3] "Rhode Island Event Reports for October 29, 2012". *National Climatic Data Center*. National Oceanic and Atmospheric Administration. 2013. Retrieved February 7, 2013.

1.4.4 Behavioral Analysis

This analysis determines the expected response of the population threatened by various hurricane events in terms of the percentage of the population expected to evacuate, probable destinations of evacuees, public shelter use, and utilization of available vehicles. The methodology used to develop the behavioral data relied on telephone sample surveys of the general population within the study area and interviews with local emergency managers. A behavioral study was completed in 2013 for the Connecticut HES after Hurricane Sandy (2012). A presentation of the Behavioral Analysis can be found in Chapter Four.

1.4.5 Shelter Analysis

The shelter analysis presents an inventory of public shelter facilities, capacities of the shelters, and shelter demand for each jurisdiction. Emergency management offices furnished shelter names, capacities, and other details for their shelter inventory. Shelter demands for the Rhode Island HES were calculated using behavioral analysis data. Chapter Five contains information on the Shelter Analysis.

1.4.6 Transportation Analysis

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

1.4.7 HURREVAC/Decision Tools

HURREVAC is a hurricane evacuation decision-support tool that uses clearance times in conjunction with NHC advisories to assist local officials in arriving at a decision to evacuate or not, as well as advising on when those evacuations, when warranted, should begin. More information on this program may be found at the HURREVAC web-site at www.hurrevac.com. Chapter Seven describes the HURREVAC computer program.