Commonwealth of Massachusetts Tropical Cyclone Profile

August 2021

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Description

Tropical cyclones, a general term for tropical storms and hurricanes, are low pressure systems that usually form over the tropics. These storms are referred to as "cyclones" due to their rotation. Tropical cyclones are among the most powerful and destructive meteorological systems on earth. Their destructive phenomena include storm surge, high winds, heavy rain, tornadoes, and rip currents. As tropical storms move inland, they can cause severe flooding, downed trees and power lines, and structural damage. Once a tropical cyclone no longer has tropical characteristics, it is then classified as a post-tropical system.

The National Hurricane Center (NHC) has classified four stages of tropical cyclones:

- **Tropical Depression**: A tropical cyclone with maximum sustained winds of 38 mph (33 knots) or less.
- **Tropical Storm**: A tropical cyclone with maximum sustained winds of 39 to 73 mph (34 to 63 knots).
- **Hurricane**: A tropical cyclone with maximum sustained winds of 74 mph (64 knots) or higher.
- **Major Hurricane**: A tropical cyclone with maximum sustained winds of 111 mph (96 knots) or higher, corresponding to a Category 3, 4 or 5 on the Saffir-Simpson Hurricane Wind Scale.

Primary Hazards

Storm Surge and Storm Tide

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tide. Storm surge and large waves produced by hurricanes pose the greatest threat to life and property along the coast. They also pose a significant risk for drowning.

Storm tide is the total water level rise during a storm due to the combination of storm surge and the astronomical tide. This rise in water level can cause extreme flooding in coastal areas, particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 20 feet or more in some cases.

Coastal areas, including areas away from the immediate shoreline, are vulnerable to storm surge. The destructive power of storm surge and large battering waves can result in loss of life, destruction of homes and other buildings, beach erosion, and road damage along the coast.

Local National Weather Service (NWS) Forecast Offices coordinate with the National Hurricane Center (NHC) and issue a Storm Surge Watch when there is a possibility of life-threatening inundation (from rising water moving inland from the coastline) in the Watch area during the next 48 hours. A Storm Surge Warning is issued when there is a likelihood of life-threatening inundation (from rising water moving inland from the coastline) in the Warning area during the next 36 hours.

Heavy Rainfall and Inland Flooding

Tropical storms and hurricanes often produce widespread, torrential rains that can exceed 6 inches, which may result in deadly and destructive floods.

Flash flooding (defined as a rapid rise in water levels), both on small streams and in urban areas, can occur quickly due to intense rainfall and pose a significant threat to life.

Rainfall amounts are not directly related to the strength of tropical cyclones, but rather to the speed and size of the storm, as well as the geography of the area. Slower moving and larger storms can produce more rainfall. Generally, the heaviest rain will occur to the north and west of a hurricane or tropical storm track that affects New England.

Rip Currents

The strong winds of a tropical cyclone can cause dangerous waves and high-energy swell that pose a significant hazard to unsuspecting coastal residents and visitors. When surf breaks along the coast, deadly rip currents can occur, even at large distances ahead of and behind the storm.

Rip currents are channeled currents flowing away from the shore, usually extending past the line of breaking waves. They can quickly drag people out to sea.

The south coast of Massachusetts is particularly vulnerable to this hazard due to the depth of coastal waters south of New England.

Tornadoes

Hurricanes and tropical storms can produce tornadoes. These tornadoes most often occur in thunderstorms embedded in rain bands in the northeast quadrant of an approaching tropical cyclone. Usually, tornadoes produced by tropical cyclones are relatively weak and short-lived, but they still pose a significant threat.

High Winds

Hurricanes are categorized according to the Saffir-Simpson Hurricane Wind Scale (SSHWS) as outlined in Table 1 below. The scale categorizes a tropical cyclone based on sustained wind speeds. Hurricane categories range from one (1) through five (5), with Category 5 being the strongest (winds greater than 155 mph). The scale is designed to give public officials and the general public usable information on the magnitude of a storm. It gives an indication of the potential wind damages associated with each hurricane category. Please note the category of a storm only pertains to windspeed and not other hazards such as storm surge, rain, flooding, or tornadoes which are often the more dangerous aspects of hurricane-related weather.

Table 1: Saffir-Simpson Hurricane Wind Scale[1]

Wind Speed Wind Speed	Typical Effects
Category One (1) Hurricane – Weak	
74-95 mph (64-82 kt)	**Very dangerous winds will produce some damage**: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap, and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
Category Two (2) Hurricane – Moderate	
96-110 mph (83-95 kt)	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks
Category Three (3) Hurricane – Strong	
111-129 mph (96-112 kt)	**Devastating damage will occur:** Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes
Category Four (4) Hurricane - Very Strong	
130-156 mph (113-136 kt)	**Catastrophic damage will occur:** Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted, and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
Category Five (5) Hurricane – Devastating	
157 mph or greater (137 kt)	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to

[1] The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based only on a hurricane's maximum sustained wind speed. This scale does not consider other potentially deadly hazards such as storm surge, rainfall flooding, and tornadoes.

	possibly months. Most of the area will be uninhabitable for weeks or months.

Tropical storm-force winds are strong enough to be dangerous to those caught in them. For this reason, evacuations and other preparedness actions should be completed *before* the onset of tropical storm-force winds, not hurricane-force winds.

Watches and Warnings

Hurricane and tropical storm watches and warnings for winds on land as well as storm surge watches and warnings can be issued for storms that the NWS believes will become tropical cyclones but have not yet attained all of the characteristics of a tropical cyclone (i.e., a closed low-level circulation, sustained thunderstorm activity, etc.). In these cases, the forecast conditions on land warrant alerting the public. These storms are referred to as "potential tropical cyclones" by the NWS.

Hurricane, tropical storm, and storm surge watches and warnings can also be issued for storms that have lost some or all their tropical cyclone characteristics but continue to produce dangerous conditions. These storms are called "post-tropical cyclones" by the NWS.

- Storm Surge Watch: There is a possibility of life-threatening inundation from rising water moving inland from the shoreline somewhere within the specified area, generally within 48 hours.
- Hurricane Watch: Hurricane conditions (sustained winds of 74 mph or greater) are possible within your area. Because it may not be safe to prepare for a hurricane once winds reach tropical storm force, The NHC issues hurricane watches 48 hours before it anticipates tropical storm-force winds.
- Tropical Storm Watch: Tropical storm conditions (sustained winds of 39 to 73 mph) are possible within the specified area within 48 hours.
- Storm Surge Warning: There is a danger of life-threatening inundation from rising water moving inland from the shoreline somewhere within the specified area, generally within 36 hours. If you are under a storm surge warning, check for evacuation orders from your local officials.
- Hurricane Warning: Hurricane conditions (sustained winds of 74 mph or greater) are expected somewhere within the specified area. NHC issues a hurricane warning 36 hours in advance of tropical storm-force winds to give you time to complete your preparations. All preparations should be complete. Evacuate immediately if so ordered.
- Tropical Storm Warning: Tropical storm conditions (sustained winds of 39 to 73 mph) are expected within your area within 36 hours.
- Extreme Wind Warning: Extreme sustained winds of a major hurricane (115 mph or greater), usually associated with the eyewall, are expected to begin within an hour. Take immediate shelter in the interior portion of a well-built structure.

Situation

The National Hurricane Center (NHC) cannot predict with 100% certainty the track of a hurricane or the timing and extent of storm surge flooding. Surge impact may occur before, during, or after storm landfall, may impact areas far from the storm's track, is the greatest potential threat in a tropical storm or hurricane, and may result in thousands of homes and businesses destroyed and affected areas requiring long-term recovery.

The official hurricane season for the Atlantic Basin (the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico) is from 1 June to 30 November. Peak hurricane season in Massachusetts occurs from mid-August to late October. However, hurricanes can occur anytime in the hurricane season. Because Massachusetts' hurricane season overlaps with tourist season, response operations must consider evacuation and sheltering of tourists and other visitors.

Direct landfall in Massachusetts by a hurricane or tropical storm is unusual, though not impossible. It is more likely that these types of storms, which can extend hundreds of miles across, will make landfall at a different location, farther south along the Atlantic coastline of the United States and may subsequently impact Massachusetts. The last hurricane that made a direct landfall was Hurricane Bob in 1991.

Atlantic Hurricane Season Prediction for 2021 (updates noted in blue text/italics)

An above-normal 2021 Atlantic hurricane season is expected, according to forecasters with the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center. The outlook predicts a *65%* chance of an above-normal season, a *25%* chance of a near-normal season and only a 10% chance of a below-normal season. However, experts do not anticipate the historic level of storm activity seen in 2020. NOAA's Climate Prediction Center is forecasting a likely range of *15 to 21* named storms (winds of 39 mph or higher), of which *7 to 10* could become hurricanes (winds of 74 mph or higher), including 3 to 5 major hurricanes (category 3, 4 or 5; with winds of 111 mph or higher). NOAA provides these ranges with a 70% confidence. *The updated graphics below includes the 5 named storms that have formed thus far, with Hurricane Elsa becoming the earliest 5th named storm on record.*

Figure 1: NOAA's 2021 Hurricane Season Outlook

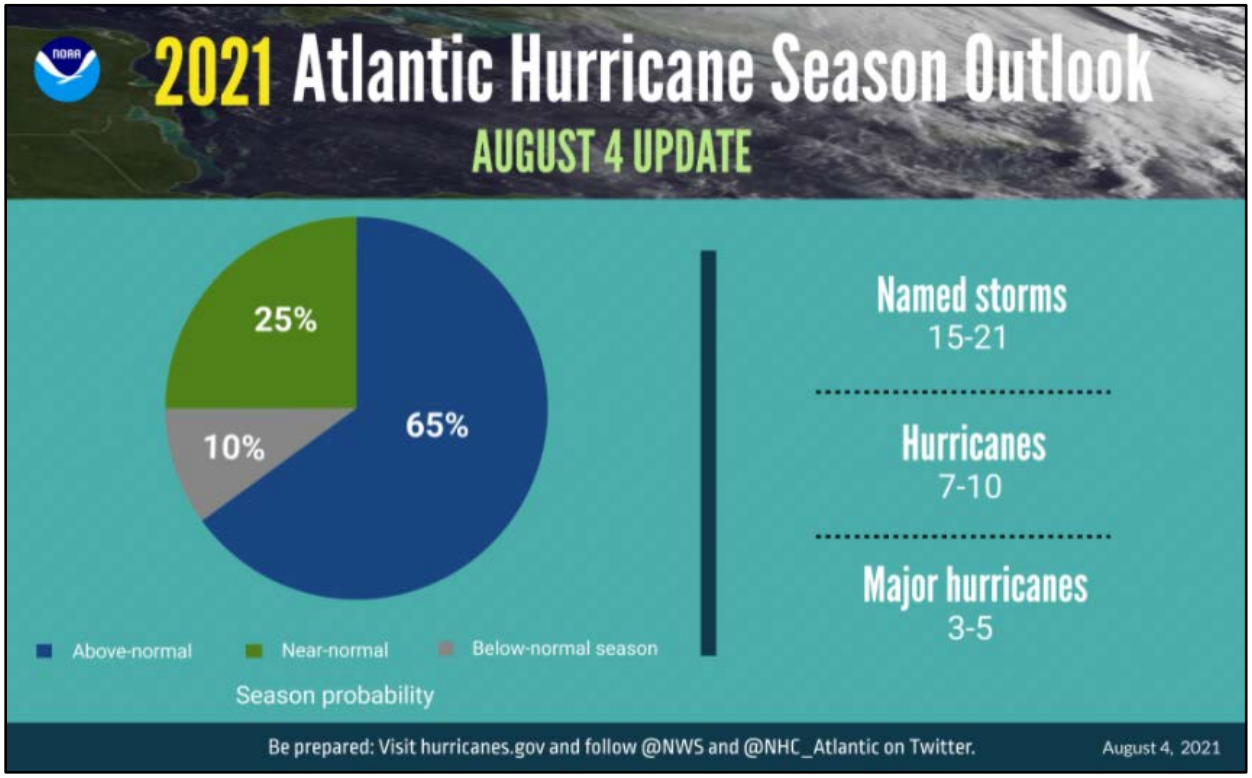


Figure 2: NOAA's 2021 Atlantic Tropical Cyclone Names

Location

Massachusetts, as with other New England states, is vulnerable to hurricanes and tropical storms, as seen in Figures 3-5 below in part because of the geography of southern New England in relation to the Atlantic seaboard. Connecticut's, Rhode Island's, and Massachusetts's land masses project easterly into the Atlantic, and all 3 states have southern exposed shorelines. This geography places these states in direct line of any storm that tracks all the way to New England, thus placing these states at a greater statistical risk than states closer to the tropics. Historically, most hurricanes that have struck the New England region re-curved northward on tracks, which paralleled the eastern seaboard, maintaining a slight north-northeast track direction.

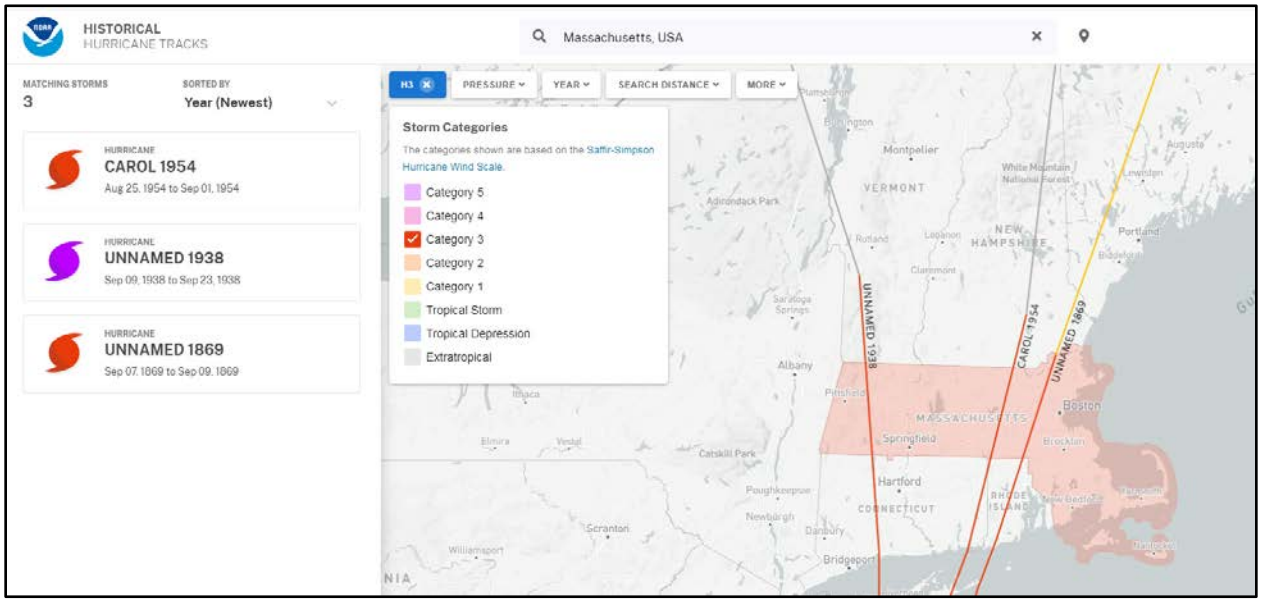
The entire Commonwealth is vulnerable to hurricanes and tropical storms, depending on each storm's track. Massachusetts's 78 coastal communities are more susceptible to damaging impacts of high winds and storm surge associated with hurricanes and tropical storms. As coastal development increases, the amount of property and infrastructure exposed to this hazard will increase. Inland areas, especially those in floodplains, are at risk for flooding from heavy rainfall associated with tropical storms and hurricanes, as well as wind damage.

Previous Occurrences

Hurricanes and tropical cyclones impact Massachusetts infrequently. Massachusetts often prepares for hurricanes and tropical cyclones that are forecasted to potentially impact Massachusetts; however, more often than not, the track veers and Massachusetts is not impacted.

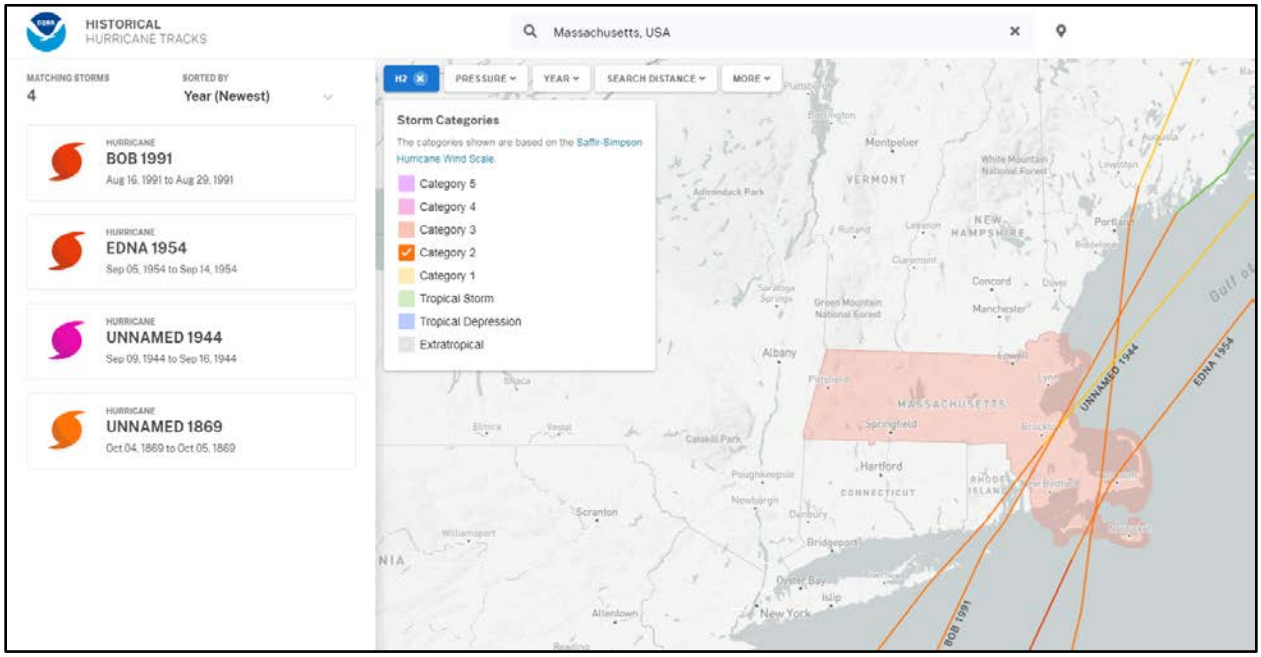
According to NOAA's Historical Hurricane Tracker, 39 hurricane or tropical storm events have occurred in the vicinity of Massachusetts between 1842 and 2020. Within this time period the Commonwealth was not impacted by any Category 4 or 5 hurricanes, however the state was impacted by three Category 3 hurricanes, four Category 2 hurricanes, ten Category 1 hurricanes, and twenty-five tropical storms. In addition, within this time period a total of 31 tropical depressions and extratropical events impacted the Commonwealth.

Figure 2: Number of Category 3 Hurricanes Impacting MA from 1842- 2020



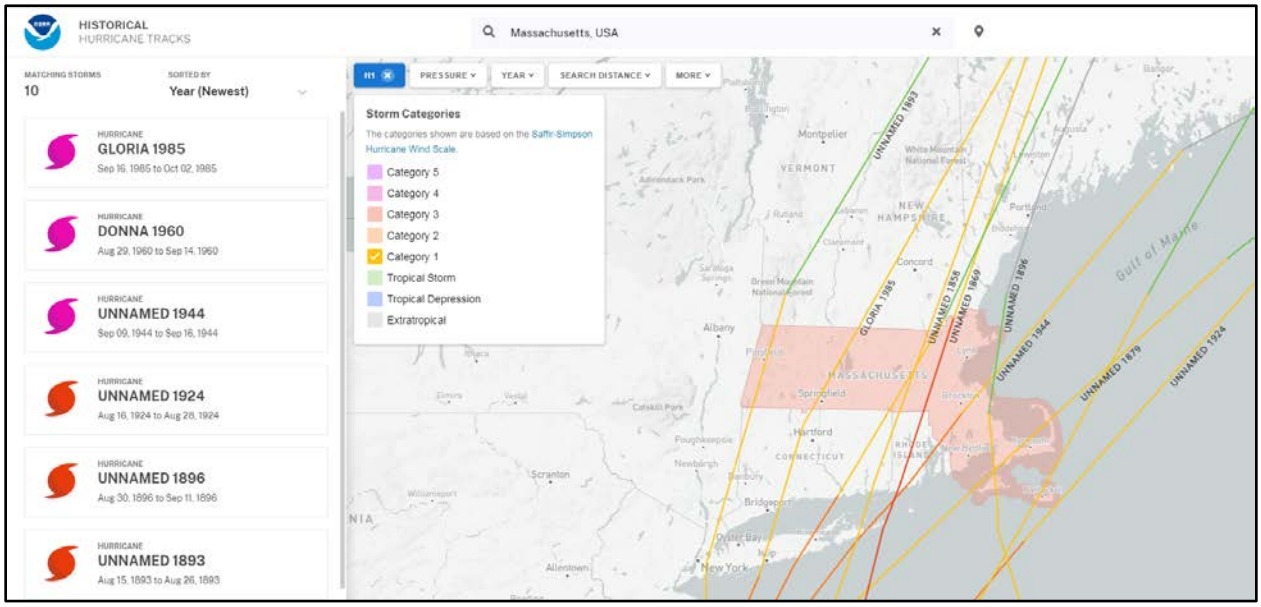
Note: According to the NOAA historical hurricane data, Unnamed September 1869 is categorized as a Category 3 and Category 1 hurricane.

Figure 3: Number of Category 2 Hurricanes Impacting MA from 1842- 2020



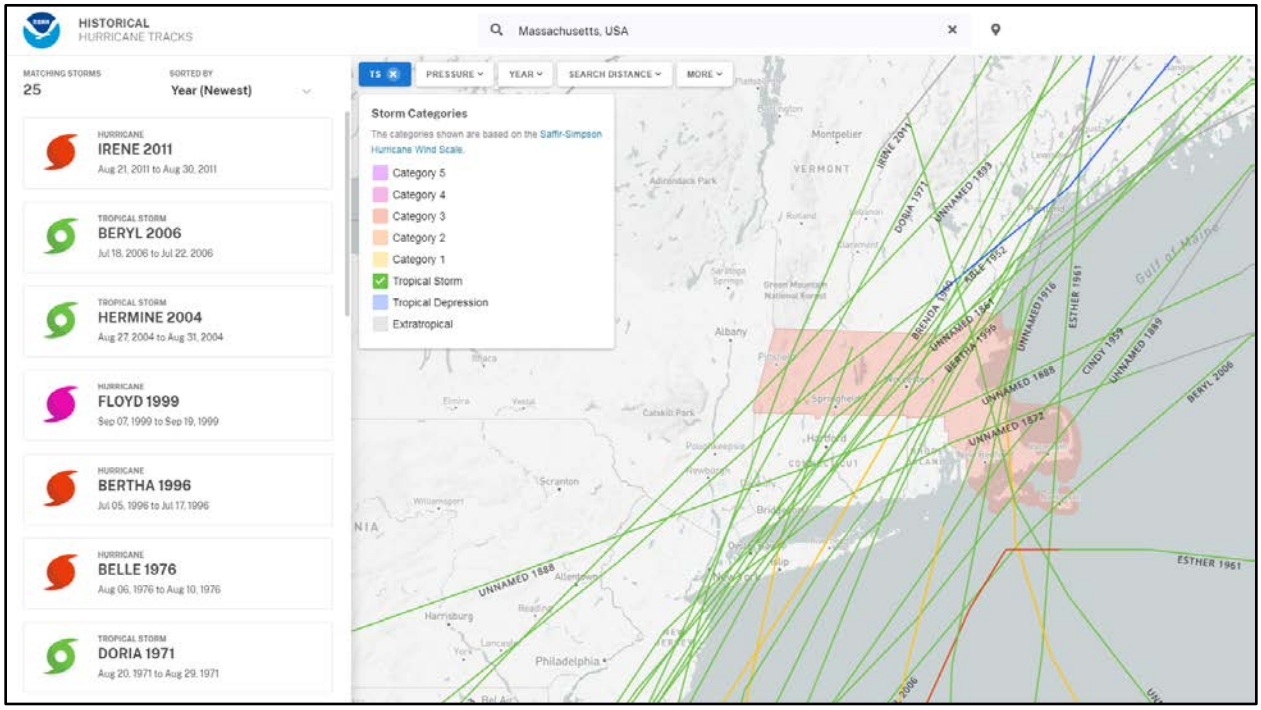
Note: According to the NOAA historical hurricane data, Unnamed September 1944 is categorized as a Category 2 and Category1 hurricane.

Figure 4: Number of Category 1 Hurricanes Impacting MA from 1842- 2020



Note: According to the NOAA historical hurricane data, Unnamed September 1896 is categorized as a Category 1 hurricane and tropical storm.

Figure 5: Number of Tropical Storms Impacting MA from 1842- 2020



Risk and Vulnerability to Populations

All of the population of Massachusetts is at risk for impacts from hurricanes and tropical storms. The population of Suffolk County is the most exposed to the hurricane-related storm surge hazard. Barnstable and Middlesex Counties also have relatively high exposure to this hazard. It should be noted, however, that impacts from individual hurricane events vary widely; therefore, the populations of all coastal counties are vulnerable to the impacts of a hurricane or tropical storm. In addition, all populations in Massachusetts are vulnerable to the risks associated with inland flooding when hurricanes and tropical storms bring heavy rainfall, and those associated with high winds when hurricanes and tropical storms bring damaging winds.

Populations that live or work in proximity to facilities that use or store hazardous materials are at greater risk of exposure to these substances during a flood event. Among the exposed populations, the most vulnerable include people with low socioeconomic status, people over the age of 65, people with medical needs, and those with low English language fluency. For example:

- People with low socioeconomic status may not evacuate due to the costs associated with evacuation.
- Individuals with medical needs may have trouble evacuating and accessing needed medical care while displaced.
- Those who have low English language fluency may not receive or understand the warnings to evacuate.
- People between the ages of 10 and 29 and over 60 years of age are found to be more vulnerable to floods.
- During and after an event, rescue workers and utility workers are vulnerable to impacts from: high water, swift currents, rescues, and submerged debris.

- Vulnerable populations may also be less likely to have adequate resources to recover from the loss of their homes and jobs or to relocate from a damaged neighborhood.
- An extended loss of power would exacerbate all of these impacts to general and vulnerable populations.

Table 2: Population Exposed to Hurricane-Related Storm Surge

County	Population	Category 1		Category 2		Category 3		Category 4	
		Number	% Total	Number	% Total	Number	% Total	Number	% Total
Barnstable	215,888	5,537	2.6	8,393	3.9	10,543	4.9	11,528	5.3
Bristol	548,285	2,975	0.5	4,134	0.8	4,773	0.9	29,679	5.4
Dukes	16,535	310	1.9	301	1.8	475	2.9	562	3.4
Essex	743,159	13,390	1.8	16,324	2.2	18,091	2.4	18,835	2.5
Middlesex	1,503,085	27,589	1.8	80,390	5.3	43,427	2.9	44,816	3.0
Nantucket	10,172	99	1.0	117	1.2	104	1.0	187	1.8
Norfolk	670,850	13,275	2.0	14,150	2.1	12,744	1.9	12,720	1.9
Plymouth	494,919	10,563	2.1	13,137	2.7	10,098	2.0	8,912	1.8
Suffolk	722,023	76,395	10.6	119,445	16.5	42,807	5.9	30,930	4.3
Total	**4,924,916**	**150,133**	3.0	**256,391**	5.2	**143,062**	2.9	**158,169**	3.2

Source: Massachusetts Hazard Identification and Risk Assessment, 2019

Evacuation Clearance Time

Evacuation clearance time is the time it takes from the first vehicle entering the evacuation roadway network until the last vehicle enters an assumed point of safety.

HURREVAC, the National Hurricane Program's hurricane web-based decision support tool, can be utilized by local, state and federal emergency managers to better calculate evacuation clearance time based on the category of storm, response speed, and tourist occupancy. The calculated clearance times found in the *New England Hurricane Evacuation Study, June 2016* have been entered into the HURREVAC tool. HURREVAC takes the current forecast arrival time of tropical storm force winds and combines it with those pre-calculated evacuation clearance times to provide the user an evacuation start time.

Note: New England Hurricane Evacuation Study was published in June 2016. The information in this section is based on 2016 data.

Clearance times have been calculated for each Massachusetts coastal community as shown in Table 3. The tables provide the estimated clearance times by town, by low tourist occupancy/high tourist occupancy and according to slow, medium, and fast response times.

Figure 6 below provides an example of the HURREVAC Evacuation Scenario Tool for the town of Barnstable MA; toggled for medium response speed and high tourist occupancy.

Figure 6: Example of HURREVAC Scenario Tool

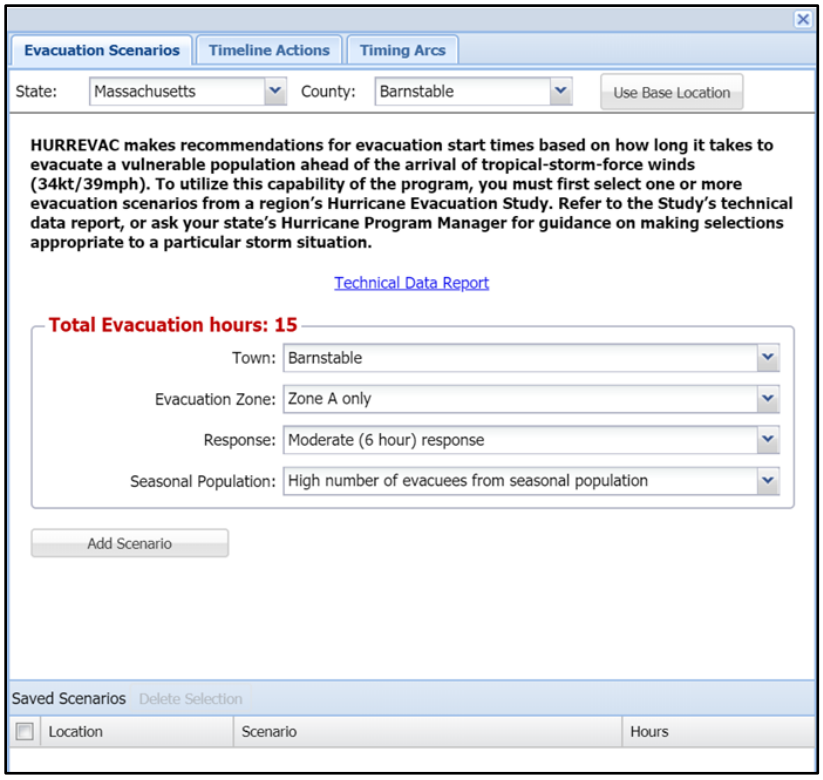


Table 3: Massachusetts Evacuation Clearance Times (in hours)

County	Town	SLOW Response				MEDIUM Response				RAPID Response			
		Category 1-2		Category 3-4		Category 1-2		Category 3-4		Category 1-2		Category 3-4	
		Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.
Barnstable	Barnstable	10.6	16.4	15.5	23.3	9.6	15.4	14.5	22.3	8.9	14.9	14.0	22.1
	Bourne	10.7	16.5	15.9	23.9	9.9	15.6	15.1	23.0	9.3	15.3	14.8	23.0
	Brewster	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Chatham	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Dennis	10.6	16.4	15.5	23.3	9.6	15.4	14.5	22.3	8.9	14.9	14.0	22.1
	Eastham	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Falmouth	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	Harwich	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Mashpee	10.6	16.4	15.5	23.3	9.6	15.4	14.5	22.3	8.9	14.9	14.0	22.1
	Orleans	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Provincetown	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Sandwich	10.6	16.4	15.5	23.3	9.6	15.4	14.5	22.3	8.9	14.9	14.0	22.1
	Truro	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Wellfleet	21.4	24.1	20.1	33.8	12.2	22.1	18.1	31.7	11.7	22.0	17.8	32.1
	Yarmouth	12.1	16.7	15.5	23.3	10.6	15.2	12.7	18.4	9.3	14.1	11.5	17.4
Bristol	Acushnet	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Berkley	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Dartmouth	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Dighton	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Fairhaven	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Fall River	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9

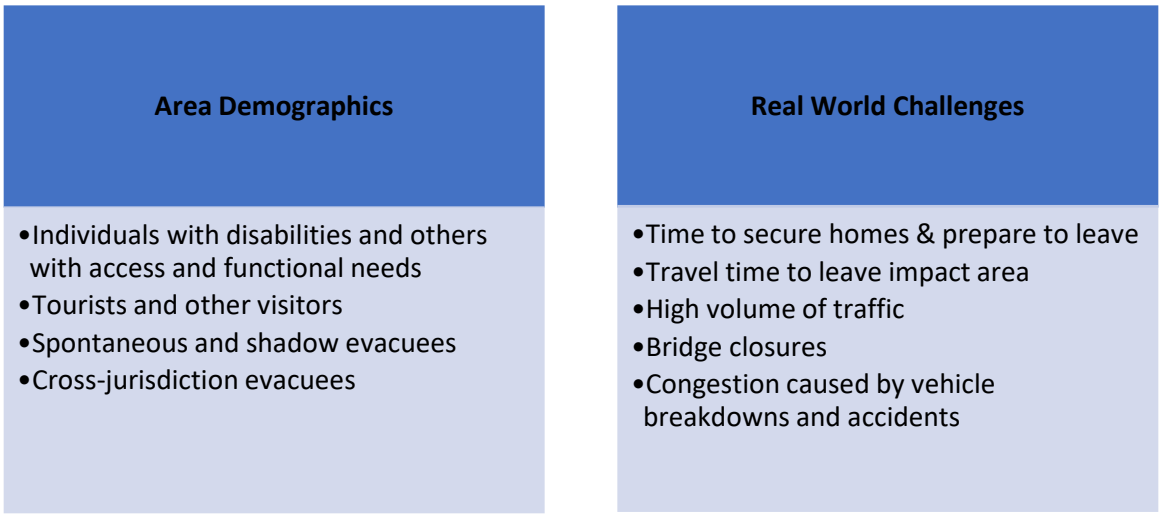
County	Town	SLOW Response				MEDIUM Response				RAPID Response			
		Category 1-2		Category 3-4		Category 1-2		Category 3-4		Category 1-2		Category 3-4	
		Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.
Bristol	Freetown	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
(continued)	New Bedford	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Raynham	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Rehoboth	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Seekonk	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Somerset	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Swansea	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Taunton	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Westport	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
Dukes	Aquinnah	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	Chilmark	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	Edgartown	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	Oak Bluffs	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	Tisbury	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
	West Tisbury	8.7	11.3	11.5	15.5	7.9	10.5	10.7	14.6	7.3	10.0	10.2	14.3
Essex	Beverly	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Danvers	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Essex	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Gloucester	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Ipswich	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Lynn	11.3	11.5	13.5	13.7	10.0	10.1	12.1	12.3	8.7	8.9	11.0	11.2

County	Town	SLOW Response				MEDIUM Response				RAPID Response			
		Category 1-2		Category 3-4		Category 1-2		Category 3-4		Category 1-2		Category 3-4	
		Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.
Essex (continued)	Manchester	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Marblehead	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Nahant	11.3	11.5	13.5	13.7	10.0	10.1	12.1	12.3	8.7	8.9	11.0	11.2
	Newbury	9.6	10.0	11.4	12.1	8.1	8.6	10.0	10.6	6.7	7.2	8.7	9.3
	Newburyport	9.6	10.0	11.4	12.1	8.1	8.6	10.0	10.6	6.7	7.2	8.7	9.3
	Peabody	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Rockport	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Rowley	9.6	10.0	11.4	12.1	8.1	8.6	10.0	10.6	6.7	7.2	8.7	9.3
	Salem	12.6	13.2	15.0	15.9	10.9	11.5	13.4	14.2	9.3	9.9	11.9	12.8
	Salisbury	9.6	10.0	11.4	12.1	8.1	8.6	10.0	10.6	6.7	7.2	8.7	9.3
	Saugus	11.3	11.5	13.5	13.7	10.0	10.1	12.1	12.3	8.7	8.9	11.0	11.2
	Swampscott	11.3	11.5	13.5	13.7	10.0	10.1	12.1	12.3	8.7	8.9	11.0	11.2
Middlesex	Arlington	4.3	4.4	4.9	5.1	3.6	3.7	4.2	4.4	2.9	3.1	3.5	3.7
	Belmont	4.3	4.4	4.9	5.1	3.6	3.7	4.2	4.4	2.9	3.1	3.5	3.7
	Everett	13.6	13.9	16.5	17.0	12.7	13.1	15.6	16.1	12.3	12.7	15.4	15.9
	Malden	10.8	11.1	12.5	12.9	9.1	9.5	10.8	11.3	7.5	7.8	9.3	9.7
	Medford	13.6	13.9	16.5	17.0	12.7	13.1	15.6	16.1	12.3	12.7	15.4	15.9
	Newton	9.3	9.8	11.0	11.7	8.0	8.5	9.7	10.3	6.7	7.2	8.5	9.1
	Somerville	16.7	17.3	17.3	18.0	15.7	16.3	16.3	17.0	15.3	16.0	16.0	16.7
	Waltham	9.3	9.8	11.0	11.7	8.0	8.5	9.7	10.3	6.7	7.2	8.5	9.1
	Watertown	9.3	9.8	11.0	11.7	8.0	8.5	9.7	10.3	6.7	7.2	8.5	9.1
	Winchester	10.8	11.1	12.5	12.9	9.1	9.5	10.8	11.3	7.5	7.8	9.3	9.7

County	Town	SLOW Response				MEDIUM Response				RAPID Response			
		Category 1-2		Category 3-4		Category 1-2		Category 3-4		Category 1-2		Category 3-4	
		Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.	Low Tour Occ.	High Tour Occ.
Nantucket	Nantucket	10.6	16.4	15.5	23.3	9.6	15.4	14.5	22.3	8.9	14.9	14.0	22.1
Norfolk	Braintree	10.8	14.1	14.3	18.7	9.3	12.6	12.8	17.2	7.9	11.3	11.5	16.1
	Brookline	9.0	9.3	11.3	11.7	7.7	8.0	0.0	0.0	6.3	6.6	0.0	0.0
	Cohasset	10.8	14.1	14.3	18.7	9.3	12.6	12.8	17.2	7.9	11.3	11.5	16.1
	Milton	6.7	6.7	10.9	11.4	5.0	5.0	9.1	9.6	3.0	3.0	7.3	7.8
	Quincy	17.2	18.1	20.3	21.3	16.2	17.1	19.2	20.2	15.7	16.7	18.9	20.0
	Weymouth	10.8	14.1	14.3	18.7	9.3	12.6	12.8	17.2	7.9	11.3	11.5	16.1
Plymouth	Duxbury	14.2	19.9	19.7	27.5	12.9	18.6	18.3	26.1	11.8	17.8	17.6	25.7
	Hingham	10.7	16.5	15.9	23.9	9.9	15.6	15.1	23.0	9.3	15.3	14.8	23.0
	Hull	10.7	16.5	15.9	23.9	9.9	15.6	15.1	23.0	9.3	15.3	14.8	23.0
	Kingston	14.2	19.9	19.7	27.5	12.9	18.6	18.3	26.1	11.8	17.8	17.6	25.7
	Marion	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Marshfield	14.2	19.9	19.7	27.5	12.9	18.6	18.3	26.1	11.8	17.8	17.6	25.7
	Mattapoisett	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Plymouth	14.2	19.9	19.7	27.5	12.9	18.6	18.3	26.1	11.8	17.8	17.6	25.7
	Rochester	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
	Scituate	10.7	16.5	15.9	23.9	9.9	15.6	15.1	23.0	9.3	15.3	14.8	23.0
	Wareham	8.6	9.8	10.6	12.4	7.3	8.5	9.3	11.1	6.0	7.3	8.1	9.9
Suffolk	Chelsea	13.6	13.9	16.5	17.0	12.7	13.1	15.6	16.1	12.3	12.7	15.4	15.9
	Revere	13.6	13.9	16.5	17.0	12.7	13.1	15.6	16.1	12.3	12.7	15.4	15.9
	Winthrop	13.6	13.9	16.5	17.0	12.7	13.1	15.6	16.1	12.3	12.7	15.4	15.9

Source: New England Hurricane Evacuation Study Technical Data Report, 2016

Jurisdictional analysis of clearance times should include, but are not limited to, consideration factors such as area demographics and public behavior. See graphic below for a few of the important considerations.



Sheltering

The choice of public shelters for a specific evacuation is a state and local government/emergency management decision. State and local authorities will open shelters based on a variety of circumstances including storm intensity, storm direction, availability of qualified shelter operators and other factors such as which shelters are not in an area at risk of inundation from storm surge.

Note: New England Hurricane Evacuation Study was published in June 2016. The information in this section is based on 2016 data.

Table 4 below depicts public shelter demand by county (number of evacuees expected to seek public shelter). This data is based on both the behavioral and shelter analysis completed as part of the 2016 New England Hurricane Evacuation Study.

Table 4: Public Sheltering Demand for Category 1 and Category 2 Hurricane

Area	Low Tourist Occupancy	High Tourist Occupancy
Barnstable County	5184	7372
Boston	2853	2986
Bristol County	2714	2817
Cambridge	241	287
Dukes County	431	767
Essex County	5808	6017
Middlesex County	6521	6583
Nantucket County	269	517
Norfolk County	4165	4211
Plymouth County	4335	4685
Suffolk County	3403	3416

Source: 2016 New England Hurricane Evacuation Study.

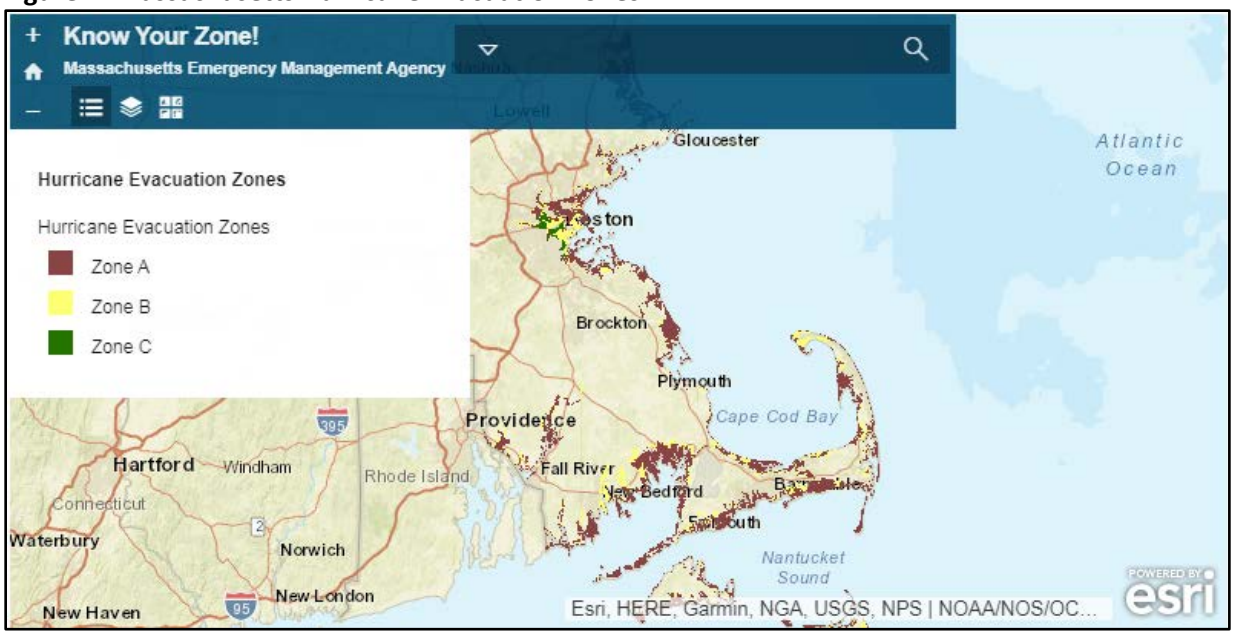
Hurricane Evacuation Zones

The US Army Corps of Engineers (USACE) completed hurricane evacuation zone maps for Massachusetts coastal communities, based on Hurricane Inundation Maps (see information below) and input from FEMA, State, and Local emergency managers. Massachusetts has the following evacuations zones:

- **Zone A & B (TS, Cat 1 & 2) -** These zones include areas that, depending on predicted inundation, may flood first from storm surge during a tropical storm or hurricane. Areas in Zone A would flood before areas in Zone B.
- **Zone C** – **(Cat 3 & 4) -** The cities of Boston and Cambridge have designated a third zone, Zone C, which may flood depending on the track and intensity of the storm.

These Hurricane Evacuation Zones can be used as a resource for local evacuation decision-making during hurricanes. These maps are available on the MEMA website both with an Interactive Mapping Tool and in PDF Maps by Community.

Figure 7: Massachusetts Hurricane Evacuation Zones



Inundation Areas

The National Oceanic and Atmospheric Administration (NOAA), specifically the National Weather Service's (NWS) National Hurricane Center (NHC), utilizes the hydrodynamic Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model to simulate storm surge in 27 basins along the U.S East and Gulf Coasts. This information is provided to federal, state, and local partners to assist in a range of planning processes, risk assessment studies, and decision making. Based on climatology, tens of thousands of hypothetical hurricanes are simulated in each basin, and the potential storm surges are calculated.
In partnership with State and Local emergency managers, The U.S. Army Corps of Engineers (USACE), FEMA, and NOAA created new worst-case scenario hurricane surge inundation maps and evacuation zones in 2013-2014 for the Massachusetts Emergency Management Agency and coastal communities to identify vulnerable areas and guide evacuation activities.

Emergency managers and public safety officials in communities along the coast or in communities with waterways connecting to the ocean can view their respective Hurricane Inundation Maps to determine potential inundation areas. They can also use this information to inform their community of potential risk and for preparedness and emergency planning efforts, including the need for evacuations in conjunction with Hurricane Evacuation Zones.

Hurricane Inundation Maps are available on the MEMA website.