CAPE COD COMMISSION

UPWP Task 2.5
Climate Change Risk and Vulnerability Assessment of Regional Transportation Infrastructure

November 15, 2013

CAPE COD COMMISSION

INTRODUCTION

In conjunction with the Joint Transportation Committee (JTC), the Cape Cod Commission facilitates the efforts of the Metropolitan Planning Organization (MPO) for Barnstable County. As the Regional Planning Agency (RPA), the Commission is also charged with updating the Regional Transportation Plan (RTP) for Cape Cod, and for conducting long-range transportation planning efforts through the Unified Planning Work Program (UPWP). Preparing our transportation infrastructure for climate change begins by identifying the threat climate impacts pose for the regional transportation modes and assets that comprise that infrastructure. Understanding and managing the level of risk under different climate scenarios is a necessary long-range planning activity, for the ongoing debate in the scientific community is not about whether climate change will occur, but the rate at and extent to which it will occur and the adjustments needed to address its impacts.[1]

This baseline assessment has been developed by Commission staff consistent with the Federal Highway Administration's (FHWA) policy objective of incorporating climate change adaptation strategies in to transportation planning efforts. In 2010, the FHWA funded five separate pilot projects to "test drive" a conceptual model, *Assessing Criticality in Transportation Adaptation Planning* (2011) for use in conducting risk and vulnerability assessments of infrastructure and assets to the projected impacts of global climate change. The purpose was to assist the State DOT's and MPO's selected as pilots to advance adaptation assessment activities in their transportation planning and decision making. The original 5 pilot projects were successfully completed in 2011. This assessment draws upon both the original conceptual model and the lessons learned throughout that process, which became the *Climate Change & Extreme Weather Vulnerability Assessment Framework* (2012). FHWA's vulnerability assessment framework is comprised of three key steps: defining study objectives and scope; assessing vulnerability; and incorporating results into decision making. This study focuses primarily on the first two steps. A separate initiative, funded through the UPWP FY2014, will develop a mitigation strategy for decision makers that build upon the results of this analysis.

OBJECTIVE

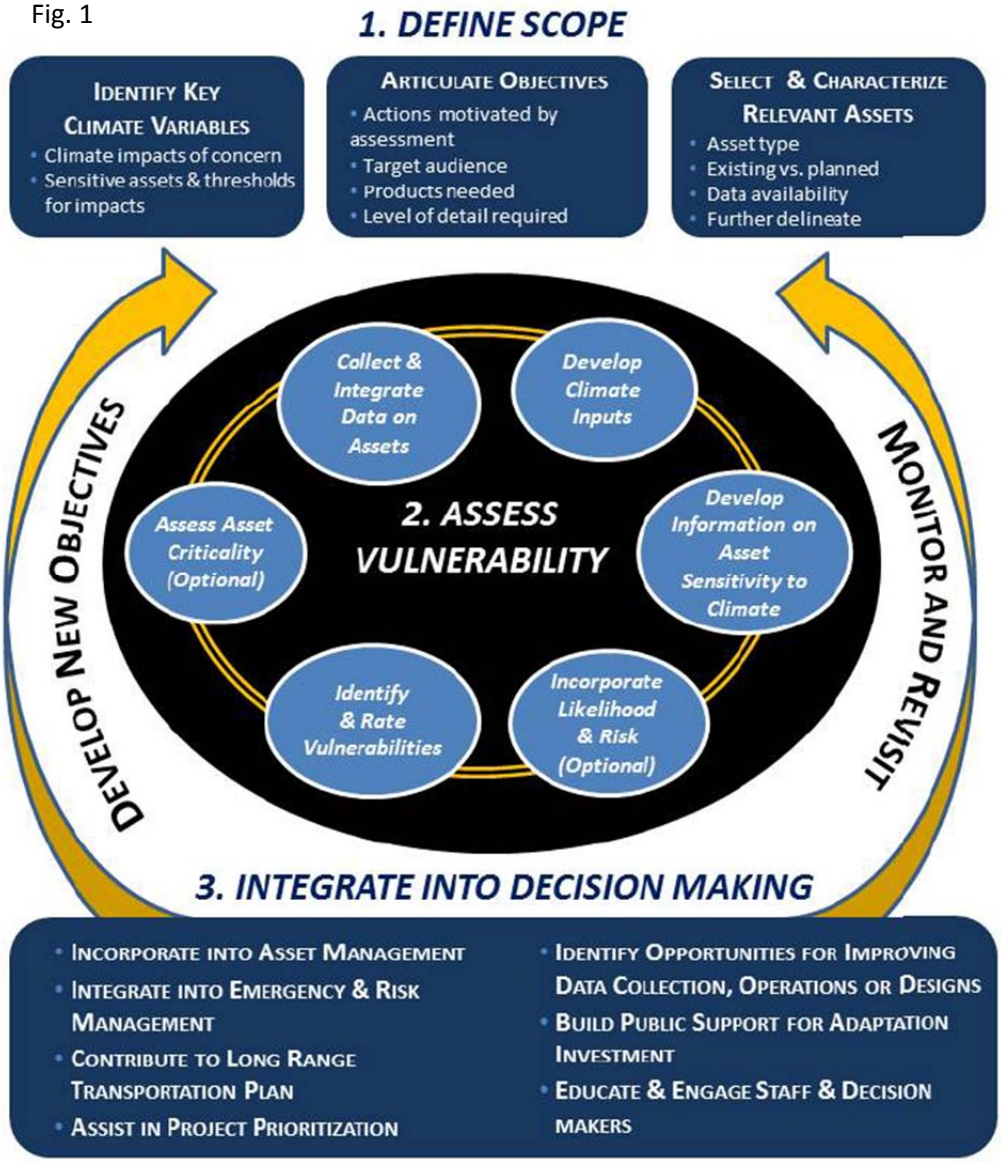
The primary intent of this assessment is to identify critical transportation modes and assets that make up our regional transportation infrastructure and understand the potential vulnerabilities of those modes and assets to particular climate change threats. This assessment has been conducted as a research

[1] Massachusetts Climate Change Adaptation Report (2011)

effort by Commission staff, and should be considered a preliminary step in addressing climate change vulnerabilities throughout our region. Intended users of this assessment include state and regional transportation officials, planners and decision makers.

FHWA'S CLIMATE CHANGE & EXTREME WEATHER VULNERABILITY ASSESSMENT FRAMEWORK

Fig. 1



METHODOLOGY

This assessment has been conducted primarily by Commission staff as a research effort combining both the desk review and expert elicitation approaches to determine criticality, as outlined by FHWA's report, *Assessing Criticality in Transportation Adaption Planning* (June 2011). The expertise of regional and local planners', transportation engineers, and emergency response professionals contributed to the prioritization of a range of modes and assets determined to be critical to regional transportation infrastructure. However, it is important to note that this hybrid approach may be limited in determining the appropriateness of specific adaptation decisions. The authors of this assessment acknowledge that further study involving a more robust public process may be necessary in developing mitigation and adaptation strategies for specific assets.

Assessing Criticality

For the purposes of this assessment, critical transportation infrastructure assets will be defined as infrastructure that comprises both significant regional modes of transportation, such as marine, air, bus and auto, as well as more traditional fixed infrastructure assets, such as road and railways, bridges, ports, and airports. The Hazard Identification section of this report provides an overview of the hazards the region faces under severe weather conditions. These hazards are addressed more completely in the Regional Multi-Hazard Mitigation Plan, however climate impacts, particularly to transportation infrastructure, are not adequately addressed under that plan. This assessment builds upon the Regional MHM Plan by looking at the climate impacts of greatest concern to transportation assets in our region from flooding due to high precipitation events, storm surge and sea level rise. To examine the potential vulnerability of critical assets to these events, the following data sets were utilized; 2013 Preliminary FEMA Flood Insurance Rate Maps (FIRMs); 2013 Sea, Lake and Overland Surge from Hurricanes (SLOSH); NOAA's Digital Coast Sea Level Rise viewer and our own sea-level rise analysis based on further refined topographic data than was utilized by NOAA in developing the viewer. The rationale for choosing these data sets and mapping tools and their limitations is discussed further in the Data & Limitations section.

Defining Study Scope & Audience for Vulnerability Assessment

Fixed Assets include permanent, immovable infrastructure. The following fixed assets have been identified within our region using the best available Geographic Information Services (GIS) data:

- Bridges
- Regional Roadways (principal arterial and rural minor arterial)
- Transportation centers
- Bus routes

- Passenger rail
- Port and airport infrastructure
- Public landings

Soft assets can be manipulated and relocated (to some extent) and include the following:

- Key evacuation routes
- Transit system facilities and vehicles
- Back-up power, communication, fueling, and other emergency operations systems
- Intelligent Transportation Systems (ITS)
- Signs and other roadside assets

Inventory of Assets

While it is important to consider both public and private assets that are integral to our regional transportation infrastructure, only public assets were included at this preliminary level of analysis. Private assets should be assessed prior to developing a comprehensive mitigation and adaptation strategy for regional critical transportation infrastructure. Furthermore, assets deemed most critical and potentially vulnerable should be assessed according to the age of the asset, its geographic location, current condition, level of use, replacement cost and design lifetime.

Assets deemed both potentially vulnerable and with medium to high regional significance are discussed in detail in this assessment. A complete inventory of assets considered for this report is available in Appendix (x).

Prioritization of Assets

Commission staff presented a preliminary assessment of the regional significance of assets and modes considered in this report to regional transportation planners and engineers. Comments from this review process were incorporated into the assessment and asset significance was revised accordingly.

HAZARD IDENTIFICATION

Climate Change impacts threatens our region in many ways, but perhaps most significantly, by exacerbating the impacts from hazards the region is already subject to. Storm surge, erosion, wind damage and inland flooding from heavy precipitation events and coastal storms are no stranger to our region. However, as these hazards threaten to become more frequent and intense under climate

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change projections, our preparedness and response must also be considered with a heightened level of scrutiny.

The following climate change projections for our region were identified in the Massachusetts Climate Change Adaptation Plan (2011) and were developed in part based on the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment (AR4) released in 2007. These projections combined with the best available GIS data have been used to guide this assessment.

Table 1: Regional Climate Change Projections[2]

annual temperature increase	4 - 5° F (winter 2 - 5° F; summer 4 - 5° F)
annual seas surface temperature increase	3° F
annual precipitation increase	5% - 8% (winter 6% - 16%; summer -1% - 3%)
drought lasting 1 – 3 months	5 – 7 times every 30 years
snow days	- 2 days per month
sea-level rise	8 – 16 inches by 2050
increased hurricane intensity	
increased storm frequency and duration	

The 2010 Multi-Hazard Mitigation Plan establishes the hazard ranking (Appendix A) for Cape Cod, Massachusetts, and subsequently, this report. It is the basis for the county's determination of the most likely and most damaging natural hazards to which Cape Cod is vulnerable. This matrix was compiled based on the best judgment and knowledge of the members of the Regional Multi-Hazard Committee. Note that one hazard can be the result of numerous events. For example, flooding is a natural hazard that can be caused by a hurricane, winter storm, or nor'easter. Therefore, it is the potential impact of the damaging hazard—the flooding—and not the event—a hurricane or a nor'easter—that this matrix ranks. Climate change is an event to which Cape Cod has become vulnerable. The projected impacts of climate change are covered through existing events and hazards, such as hurricanes and intensification of coastal erosion. However, heavy downpours, a more recent phenomenon expected to worsen over time has been included as a hazard associated with climate change, as it can occur in any season, independent of a Nor'easter or hurricane.

Using the rating system and the definition of ranges from the FEMA *Local Mitigation Planning Handbook* (2013), hazards are ranked from most likely and damaging to least likely and damaging. Generally, Cape Cod is subject to the following types of events that are expected to occur more frequently and with greater intensity under climate change projections:

[2] Massachusetts Climate Adaptation Plan, 2011

- Hurricanes — which can cause hazards such as flooding and storm surge, shoreline change (episodic erosion), wind, tornadoes, water spouts, and heavy downpours
- Sea level rise — which can cause shoreline change, long-term coastal erosion, and flooding
- Winter storms / Nor'easters — which can cause wind, snow and ice accumulation, shoreline change (episodic erosion), and flooding
- Drought — which can contribute to the risk of wildfires

HURRICANES

Of all the natural threats that might affect Cape Cod, hurricanes have the potential to cause the most property damage and loss of life if adequate planning and preparation is not undertaken. Although hurricanes can produce tremendous damage they can, unlike other threats, be tracked for several days before impacting a community—giving residents and visitors time to prepare and evacuate if necessary. We cannot, however, plan to move or remove infrastructure when a hurricane is predicted.

The Atlantic hurricane season runs from June 1st through November 30th. Based on the number and intensity of storms, mid-August through mid-October is defined as the peak period. However, hurricanes or other severe storms can occur at any time. During the months of June and July, hurricanes tend to form in the Caribbean and the Gulf of Mexico. By mid-August, as the waters of the tropical Atlantic warm, the focus turns to the Eastern Atlantic in the vicinity of the Cape Verde Islands off the African coast. The tropical waves intensify as they move westward, become tropical depressions, then tropical storms and finally hurricanes. Most of these storms turn northward around the peripheries of the semi-permanent Bermuda and Azores high-pressure areas, but in some cases can affect the Atlantic and Gulf Coast states. By early October, the waters over the Atlantic begin to cool and the focus for storm development shifts back to the Caribbean and the Gulf of Mexico. Climate change threatens to alter this cooling effect through warming ocean water temperatures. While it is impossible to pinpoint the exact impact this phenomenon will have on our region, both the intensity and frequency of hurricanes is expected to rise.

What are the Real Hazards During a Hurricane?

It is difficult to visualize the total devastation that a hurricane can cause. Few of our citizens have experienced the massive damage from the Hurricane of 1938. Hurricane Bob, while destructive in its own right, was only a relatively weak Category 2 storm that struck on a low-tide cycle. In 2009 Tropical Storm Bill impacted the south-facing coast with very minor impacts. It can get much worse. The following are some of the main hazards that may occur during a hurricane event.

Wind

Strong surface winds can cause a barrage of flying debris. Hurricanes are categorized by sustained winds of 74 mph to 200 mph, which can cause tremendous debris problems. The Barnstable County Multi-Hazard Mitigation Plan (2010) states that Southern New England has been affected by 41 tropical cyclones between 1900—2010. Twelve of these storms have caused significant landfall damage. Each of these storms brought high winds resulting in heavy precipitation and coastal flooding. The angle at which the majority of these storms made landfall was approximately 60 to 90 degrees—a storm track generally perpendicular to the coastline, worsening the storm surge in north-south orientated bays and inlets. As a result, much of the Nantucket Sound shoreline was adversely affected. Major storms of the last 100 years have behaved in a relatively consistent manner: each storm bringing the Cape high winds and heavy precipitation resulting in varying levels of coastal flooding. The time frame for their arrival (August/September) coincides with the zenith of Cape Cod's tourist season. The potential damage that could be inflicted by a significant storm event on the surrounding environment will most likely be complicated by the burden of additional populations located in and around potential hazard areas.

Tornadoes & Waterspouts

Tornadoes may form in the rain bands of a hurricane and cause significant damage. They can also form over water (waterspouts) with little or no warning. Tornadoes are commonly found in the right front quadrant of an approaching storm. Although these tornadoes are not as intense as those that form in the Midwest tornado belt they can still inflict tremendous damage with little or no warning. There were four reports of tornadoes on Cape Cod as Hurricane Bob came ashore.

Heavy Downpours

Torrential rains are associated with slow moving or stationary tropical weather systems. In addition to flooding residences and businesses, heavy rain can overcome the Cape's storm drain systems and cause severe flooding or structural failure of roads or culverts. Climate change projections suggest an increase in frequency and occurrence of heavy rainstorms over the next 30 years. While these heavy rains can have a disastrous effect on agricultural interests by drowning crops and increasing the probability of disease and pest infestations in surviving crops, coastal flooding and storm surge inundation are of primary concern to Cape Cod.

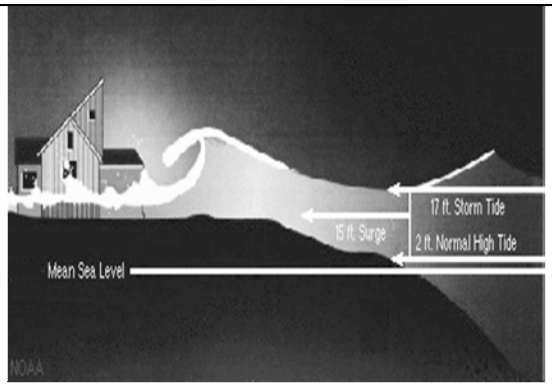
Coastal flooding is the main risk faced by Cape Cod's residents and visitors during a serious weather event such as a hurricane or winter storm. It doesn't take a major event for flooding to result in many areas—many of our storm

drain systems are overcome during small rain events, which flood roadways and personal property.

Storm Surge

Rapidly rising storm surge is the hurricane's main threat to life. Storm surge is a dome of water that moves ashore to the right of the hurricane eyewall. It can be the primary risk to life if adequate evacuations are not done. In the case of Cape Cod Bay, storm surge will actually affect the shoreline, and particularly Wellfleet Harbor, shortly *after* the storm has passed. Residents and visitors should be aware to remain well above surge elevations until all threats have passed. Damage amounts depend on the hurricane's intensity, size and its direction of movement. Storm surge causes salt water flooding that can render evacuation routes impassable, cripple communications, cause sewers and storm water basins to back up, and contaminate drinking water supplies. Storm surge flooding can wash out roads and leave streets filled with sand and debris, rendering them impassible long after surge waters have receded.

Storm Surge Model, courtesy FEMA



History of Hurricanes in New England

Two of the worst hurricanes to affect Cape Cod and the Islands were the Great New England Hurricane of 1938, which caused severe damage to the Upper Cape, and the Great Atlantic Hurricane of 1944, which heavily damaged the Middle and Lower Cape. The 1938 Hurricane struck on September 21 at a high tide that coincided with the highest astronomical tide of the year, pushing a storm surge of 12 to 15 feet across the south coast and up the many bays and inlets. The destructive power of the storm surge was felt throughout the coastal community. Sections of Falmouth and New Bedford were submerged under as much as 8 feet of water. Winds of over 120 miles per hour blew across the coastal regions. Extensive damage occurred to roofs, trees, and crops. Widespread power outages occurred, which in some areas lasted several weeks. In Connecticut, downed power lines resulted in catastrophic fires to sections of New London and Mystic. Parts of interior Connecticut and Massachusetts not only bore the brunt of high winds, but also experienced severe river flooding as rain from the hurricane combined with heavy rains earlier that week and produced rainfall totals of up to 17 inches. This resulted in some of the worst river flooding ever experienced in parts of Connecticut and Massachusetts. This powerful storm caused 564 deaths and over 1,700 injuries. Nearly 9,000 homes and businesses were destroyed with over 15,000 damaged. Damage to the

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fishing fleets in southern New England was catastrophic, with a total of 2,605 vessels destroyed and 3,369 damaged.

It is not uncommon for New England to be impacted more than once in a given season. The Cape has been impacted by two or more tropical storms or hurricanes in one season a total of 11 times. The most notable season was 1954, when southeastern Massachusetts faced Hurricanes Carol, Edna, and Hazel. Carol and Edna each rated as Category 3 storms.

WINTER STORMS

In contrast to a hurricane, winter storms that affect Cape Cod tend to concentrate their effects on the north shore, where the normal tidal range is 8 feet (and up to 14 feet in some places). The geography on the north side often gains elevation more quickly as distance from the shore increases. A main thoroughfare and evacuation route, Route 6A, crosses tidal creeks and marshes in many locations and is subject to inundation during storms. The result is that isolated residential areas may be free of flooding but may still be entirely isolated in terms of evacuation and emergency services. These impacts are projected to worsen over time as climate change related impacts, such as flooding, storm surge and sea-level rise, are expected to intensify.

A winter storm can range from moderate snow to blizzard conditions. A severe winter storm deposits four or more inches of snow during a 12-hour period or six inches of snow during a 24-hour period. A blizzard is a snowstorm with sustained winds of 40 miles per hour (mph) or more or gusting up to at least 50 mph with heavy falling or blowing snow, persisting for one hour or more, temperatures of 10 degrees Fahrenheit or colder, and potentially life-threatening traveling conditions. From 1971 to 2009 there were three ice storm events in Barnstable county causing major disruptions in power and transportation services.

A northeast coastal storm, known as a nor'easter, is typically a large counter-clockwise wind circulation around a low-pressure center often resulting in heavy snow, high winds, and rain. The storm radius is often as much as 1000 miles, reaching from the Carolinas to the Gulf of Maine. These storms occur most often in Late fall and early winter. Sustained 66 wind speeds of 20-40 mph are common during a nor'easter with short-term wind speeds gusting up to 50-60 mph. Nor'easters are among winter's most ferocious storms. These strong areas of low pressure often form either in the Gulf of Mexico or off the east coast in the Atlantic Ocean. The low will then either move up the east coast into New England and the Atlantic provinces of Canada or out to sea. These winter weather events are notorious for producing heavy snow, rain, and oversized waves that crash onto Atlantic beaches, often causing beach erosion and structural damage. Wind gusts associated with these storms can exceed

hurricane force in intensity. Nor'easters may also sit stationary for several days, affecting multiple tide cycles and extended heavy precipitation. The level of damage in a strong hurricane is often more severe than a nor'easter but historically,
Massachusetts has suffered more damage from nor'easters because of the greater frequency of these coastal storms (1 or 2 per year).[3]

Nor'easters are a common winter occurrence in New England and repeatedly result in flooding, various degrees of wave and erosion damage to structures, and erosion of natural resources, such as beaches, dunes and coastal bluffs. The erosion of coastal features commonly results in greater potential for damage to shoreline development from future storms.

Most winter storms bring to the Cape both storm surge and high winds, making our coastline particularly vulnerable to damage. Because the coastline is highly developed, infrastructure is at significant risk. If a storm should coincide with a high tide, an additional layer of vulnerability and associated risk is added. Infrastructure and critical facilities may be impacted by these events, with associated power outages and transportation disruptions (i.e., snow and/or debris-impacted roads, as well as hazards to navigation and aviation).

SEA LEVEL RISE

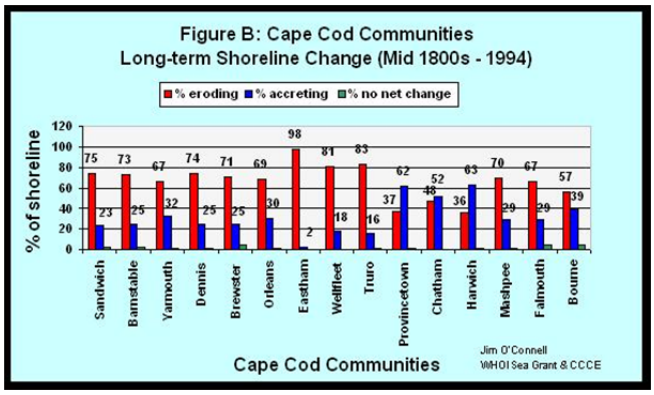
Cape Cod's shore is, for the most part, eroding.[4] Of the 586 miles of Cape Cod's tidal shore, a shoreline change analysis of 238 miles of its outer shore, including the landward side of major barrier beaches was completed in 2002.[5]

A 2003 study by the Barnstable County Extension and the WHOI Sea Grant program revealed that approximately 66% (157 miles) of Cape Cod's shore shows long-term erosion, 32% (76 miles) exhibits long-term accretion, while 2% (5 miles) shows no long-term net change. These figures of the linear length of shoreline changes closely match the state-wide averages. Twelve of the Cape's 15 communities exhibit a long-term erosion trend; while only three of those show long-term accretion (Figure B) in certain areas. It is important to note, however, that both erosion and accretion occur along a community's shoreline

[3] MA Hazard Mitigation Plan, 2010.
[4] O'Connell, J.F., 2003, New Shoreline Change Data Reveal Massachusetts Is Eroding, WHOI Sea Grant and Cape Cod Cooperative Extension, Marine Extension Bulletin, March, 2003.

[5] O'Connell, J.F., Thieler, E.R., and Schupp, C, 2002, New Shoreline Change Data and Analysis for the Massachusetts Shore, with Emphasis on Cape Cod and the Islands: Mid 1800s-1994, Environment Cape Cod, Vol. 5, No. 1. See also Thieler, E.R., O'Connell, J.F., and Schupp, C., 2002, The Massachusetts Shoreline Change Project: 1800s – 1994, Technical Report, U.S.G.S. Administrative Report, Woods Hole, MA.

and site-specific shoreline change data need to be analyzed for planning purposes. This work is currently being undertaken by the Provincetown Center for Coastal Studies for several communities along Cape Cod bay. The result of this research establish quantities of sediment transport from certain locations and will further sediment management planning for areas most vulnerable to erosion.



Note that communities that exhibit the highest erosion rates and linear length of eroding shore are primarily those that include shorelines facing the open ocean, such as Truro, Wellfleet, and Eastham. (Chatham also has a highly erosive shore but much of the shore was not included in the data analysis due to complex barrier beach migration and breaching.) Communities that exhibit the lowest shoreline change and erosion rates are those that generally are sheltered from significant storm waves, such as the Buzzards Bay and eastern Nantucket Sound areas. Significant accretion areas are generally at the ends of barrier beaches, the updrift side of jetties and groins, and downdrift of significant sediment sources.

The causes of shoreline change, particularly erosion, are both natural and human-induced. The primary natural causes of erosion in Massachusetts are relative sea-level rise. Records of tide gauges around Boston, Woods Hole, and Nantucket indicate that our relative sea level (the combination of a rising water surface with land subsidence) has risen approximately 10 inches over the past 100 years[6]. The most important cause of human-induced erosion is interruption of sediment sources and longshore sediment transport. Examples include the armoring of sediment source coastal bluffs (banks) with revetments, seawalls, and bulkheads, and interruption of longshore sediment transport by the construction of jetties and groins.

Natural coastal erosion is an important geologic process. Without erosion, flooding, storms, relative sea-level rise, and unimpeded longshore sediment

[6] MA Hazard Mitigation Plan, 2010.

transport, the beaches, dunes, barrier beaches, and biologically important bays and estuaries with their associated tidal flats would not exist today. Due to extensive armoring of sediment source coastal banks, beaches and dunes in areas of Cape Cod are slowly diminishing in size and volume. In fact, due to human activity in some areas of Cape Cod, beaches no longer exist at high tide due to a lack of sediment supply coupled with continuing relative sea-level rise (i.e. Surf Drive in Falmouth). The rate of sea-level rise is accelerating, and could possibly triple over the next century.[7]

Beaches, dunes, and barrier beaches are part of the environmental, ecological, and economic vitality of Cape Cod and its communities. They also provide storm damage reduction and flood control to landward resources and infrastructure. As part of on-going climate adaptation planning work, current projects to develop a better understanding of regional sediment transport and established sediment budgets will be critical for prioritizing coastal nourishment, armoring and retreat decisions.

DROUGHT & WILDFIRE

Though more commonly associated as a hazard in Western forests, the Cape is not unfamiliar with wildfires. Western forests differ from most eastern forests because they contain mostly evergreen trees that have resin rich needles. This resin burns readily, creating an explosive flame that rages up the crown, where it jumps easily from tree to tree. However, because of the Cape's extensive pitch pine, we are vulnerable to these types of burns, particularly when the Cape faces drought conditions.

Table 2: Historic Long-term Drought Event Details for Cape Cod and Islands, MA	
Occurrences between 1919-2013:	
# of Distinct Warnings	7
# of Distinct Emergencies	4
Total # of Months in Emergency	31
# of Months in Emergency per 100 Years	37
# of Emergencies per 100 Years	5
# of Warnings per 100 Years	8

In the past many wildfires have begun and spread quickly throughout large tracts of pitch pine forest and large salt marsh areas in which *Phragmites* is prolific. *Phragmites* is an invasive plant that has taken over many of the Cape's salt marshes in which the natural tidal system has been disrupted and saltwater flow has been restricted or limited. Even the salt hay itself would be quick to

[7] IPCC, 2007, Fourth Assessment – Climate Change 2007: A Report of the Intergovernmental Panel on Climate Change.

burn and is considered susceptible to wildfire. Cape residents and visitors must take extra precautions and be diligent to prevent fires from starting in or threatening these areas. While wildfires can be started in these areas naturally, such as by a lightning strike, more often they are started as a result of human carelessness or intervention.

Wildfire season begins in March in coastal and southern New England, gradually extending to central, western, and northern areas, and usually ends in late November. The majority of wildfires usually occur in April and May, when home owners are cleaning up (burning brush) from the winter months, and when the majority of vegetation is void of any appreciable moisture, making it highly flammable. Once "green-up" takes place in late May to early June (a period of ample spring rain), the fire danger usually is reduced somewhat.

Drought Activity Affecting Cape Cod

While drought conditions certainly add to the Cape's susceptibility to wildfires, drought conditions in our region have not prevailed since the 2004 PDM Plan. We've experienced more normal to extremely moist periods of precipitation since 2003[8], with February 2008 the wettest on record. This trend is expected to continue under current climate change projections. Table 2 details the Cape and Islands historic long-term drought details based on the precipitation data from the Massachusetts Department of Conservation and Recreation precipitation database.

Table 3: Normal Precipitation Amounts for Cape Cod, MA (Inches)

Month (2012 - 2013)	Normal	Actual
AUG ('12)	3.89	4.36
SEP	3.68	4.45
OCT	3.75	3.21
NOV	4.30	2.69
DEC	4.19	6.46
JAN ('13)	3.87	1.78
FEB	3.47	5.05
MAR	4.18	4.98
APR	4.09	3.36
MAY	3.65	4.71
JUN	3.14	8.35
JUL	2.85	2.93

[8] National Oceanic and Atmospheric Administration National Climatic Data Center, Annual Climate Drought.

CUMULATIVE	45.06	**52.33**

Table 3 shows *normal* and *actual* precipitation amounts for the Cape Cod region. These precipitation composites, developed by the MA Department of Conservation and Recreation for the Cape & Island region, show an annual increase in precipitation consistent with the climate change projections of an increase in precipitation of 5% to 8% by mid-century[9].

ASSESSING VULNERABILITY

This assessment utilized three approaches to determine an asset's vulnerability to climate impacts; the Federal Emergency Management Agency's 2013 Preliminary Flood Insurance Rate Maps (FIRMs); the U.S. Army Corps of Engineers (USACE) 2013 Sea, Lake and Overland Surge from Hurricanes (SLOSH) model; and two methods for considering Sea-Level Rise - the National Oceanic Atmospheric Administration's (NOAA) Digital Coast Sea-Level Rise Viewer, and our own Digital Elevation Modeling approach to examine sea-level rise impacts. These are explained in greater detail in the Data and Limitations section.

FINDINGS

Transportation Centers

Of the three identified multi-modal transportation centers on Cape Cod; Woods Hole, Hyannis and Provincetown, only MacMillan Pier in Provincetown was identified as vulnerable. A 2006 feasibility study of MacMillan Pier estimated 120,000 ferry trips and approximately 90,000 – 110,000 bus trips during a 21 week summer season. The report estimated that these trips would grow in the future, and thus may be higher today. The pier was significantly renovated and expanded during 2003-2005 with USDA rural development funds. In 2005, the Provincetown Public Pier Corporation entered into a 20-year operational lease agreement. The pier is located in a Velocity Zone (or V-Zone) on both the existing and preliminary FEMA Flood Insurance Rate Maps (FIRMs) and in the Sea, Lake and Overland Surge from Hurricanes (SLOSH) zone for a category 1 hurricane. Given the marine use of the pier, this in not atypical, but noteworthy for the purposes of this assessment. Further, according to the sea level rise analysis conducted as part of this assessment, the pier and its continued function as a multi-modal transportation hub could become seriously jeopardized under a 3-foot sea level rise scenario, projected mid-to-late century, when coupled with the cumulative effects of interim storms during that time period.

[9] Hayhoe et al., 2006. Past and future changes in climate and hydrological indicators in the U.S. Northeast.

Airports
The Barnstable Municipal Airport and the Otis Airfield located on Joint Base Cape Cod are the largest and most significant airports serving the region of Cape Cod. Both locations are proximate to areas expected to experience coastal flooding, storm surge inundation and sea-level rise, however the entirety of the airports is located outside these mapped hazard areas as examined through this assessment.

While less regionally significant than the Barnstable Municipal Airport and Otis Airfield, the Provincetown Municipal Airport is located on low lying, federally owned land within the Cape Cod National Seashore. It has serviced the Outer Cape since the 1940's. The runway, hangars and terminal building lie within the existing FIRM AE Zone with a base flood elevation (BFE) of 10 feet. Under the preliminary FIRMs, the zone designation remains the same, however the BFE has increased to 12. Under the SLOSH model, the airport would be completely inundated from storm surge under a category 3 hurricane. A 3' sea-level rise scenario could result in open water for the entirety of the airport property by mid-century.

A Capital Infrastructure Plan for the airport is being developed which will require an expansion of the terminal building to better meet TSA security requirements. Regulatory agencies involved in the permitting of that plan are examining ways to elevate the terminal building responsive to projected flood and storm surge conditions. These measures will help to reduce the vulnerability of the terminal building; however, other structures at the airport remain at risk and long-term operation of the airport under sea-level rise projections is grim unless significant and innovative infrastructure investments are made.

Chatham's Municipal Airport is entirely upland of hazard areas identified through this assessment.

Regional Roadways – Principal Arterial and Rural Minor Arterial
For the purposes of this assessment, two categories of roadway segments classified by the Massachusetts Department of Transportation (MassDOT) were selected; Class 2, principal arterial (red) and Class 3, rural minor arterial (blue). These line segment classifications are depicted in Figure 2.

Fig. 2

The two classifications of road segments comprise all of the Cape's major, regional thoroughfares, including: Route 6, 6A, 28, 28A, 124, 130, 132, 134, 151 and the portion of Willow Street connecting Rote 6 with Iyannough Road in Yarmouth. The following table shows the miles of roadways located within flood and SLOSH zones.

Table 4. Roadway Segments in Vulnerable Areas (Miles)		
	Class 2	**Class 3**
Existing FIRM Total	2.69	5.24
Preliminary FIRM Total	4.72	10.82
SLOSH Total	11.60	17.08

Ferry Terminals

The network of piers, bulkheads and dredged harbors that make up the infrastructure needed to support a range of ferry operations are of significant concern for our region. They are a critical asset for both our tourist based economy, and for the delivery of goods and services to and from the Cape & Islands region. By virtue of their location in V-zones, these facilities are clearly vulnerable to present and future storm surge and sea-level rise, however, at this

level of analysis there is great uncertainty as to the vulnerability of the assets that comprise this infrastructure. A greater level of analysis will be required to determine the age of the asset components, maintenance and repair costs, and replacement costs. Long range management strategies will be greatly informed by this cost analysis. It is a recommendation of this assessment that the FY14 UPWP Task 3.4 – *Climate Change Mitigation and Adaptation Strategy for Critical Transportation Infrastructure* provide this level of detailed analysis.

Marinas and Public Landings

Marinas and public landings were included in this assessment because they provide structured access to water for marine transportation (even though primarily recreational), and because cemented landings can act as funnels during storm surge events. While these characteristics are important for emergency planning and response, this assessment found no significant regional upland transportation assets vulnerable to the examined hazards.

Buses & Shuttles

The assessment examined the three major bus lines servicing the region, the Plymouth Brockton, Peter Pan and the Flex bus. The percentage of roadway in potentially vulnerable areas for these routes is relatively low, although worthy of note so that potential service disruptions can be properly planned for. Several sub regional bus services may be at a higher risk for service disruptions given the percentage of current routes that travel through flood zones and SLOSH areas (see Table 5).

Table 5. Regional Bus Route Vulnerability

Bus Line	Regional Significance	Total Miles	% in SLOSH	% in FIRM
Plymouth Brockton Line	High	101.6	8%	4%
Peter Pan Bus Line	High	85.77	4%	2%
Flex Line	High	53.31	11%	8%
GATRA	Medium	5.5	52%	31%
Sealine	Medium	25.9	12%	5%
H20 Line	Low	32.14	37%	17%
Provincetown Shuttle	Low	15.29	32%	30%
Barnstable Villager	Low	11.1	5%	3%
Bourne Run	Low	24.5	17%	4%
Sandwich Line	Low	24.2	4%	3%

Evacuation Routes & *ITS Systems*

Evacuation Routes and Intelligent Transportation Systems (ITS) are considered soft assets within the context of this assessment. Currently, local evacuation

route planning is done on Town by Town basis, with little coordination with adjacent communities. Regional evacuation route planning, as undertaken by the Massachusetts Emergency Management Agency in the Cape Cod Emergency Traffic Plan, presents implementation challenges with Joint Base Cape Cod capacity limitations and raises questions about unofficial shelter in place policies for Cape residents during disaster related events. It is a recommendation of this report to coordinate local evacuation route planning within the region and integrate those routes with on-going, regional ITS system planning initiatives.

DATA & LIMITATIONS

This assessment incorporated the best available GIS data sets and tools to determine vulnerability. It is important to note that modes and assets determined vulnerable to storm surge using the USACE SLOSH model, or located within flood hazard areas using the preliminary FEMA FIRMs, are vulnerable today. Neither of these data sets account for climate change projections intensifying the impacts they are modeling. To account for some level of analysis that takes into account future climate conditions on these modes and assets, the NOAA sea-level rise viewer was utilized along with our own methodology for creating digital elevation models to examine sea-level rise.

However, both approaches utilize the “bathtub” model of future sea-level rise conditions, which doesn’t reflect the dynamic changes that will occur on our coastline incrementally over time. While compelling graphically, the “bathtub” models project such little confidence in the already highly uncertain realm of anticipating impacts from se-level rise.

SLOSH maps represent potential flooding from "worst case" combinations of hurricane direction, forward speed, landfall point, and high astronomical tide. It does not include riverine flooding caused by hurricane surge or inland freshwater flooding. The mapping was developed for the coastal communities in New England using the computer model (developed by the National Weather Service to forecast surges that occur from wind and pressure forces of hurricanes), Long Island Sound Bathymetry and New England coastline topography. In Massachusetts, hurricane category is the predominant factor in "worst case" hurricane surges. The resulting inundation areas are grouped into Category 1 and 2, Category 3, and Category 4 classifications. The hurricane category refers to the Saffir/Simpson Hurricane Intensity Scale.

USACE considered the highest wind speed for each category, the highest surge level, combined with worst case forward motion and developed a model to depict areas that would be inundated under those combined conditions for each category of storm. It should be noted that the model considers only storm surge height and does not consider the effects of waves, nor does it accurately reflect

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the onset direction of Nor'easters which are common events in our region that can result in significant storm surge.

Sea Level Rise Mapping – NOAA's Digital Coast

NOAA's Digital Coast Sea-Level Rise viewer was one tool for assessing vulnerability of particular modes and assets to sea-level rise. This web mapping application allows users to examine their coastal region under sea-level rise scenarios of 1' – 6' of sea-level rise in 1' increments. For the purposes of this assessment, a 3' sea-level rise scenario was chosen for Barnstable County. This scenario is in the range of potential mid—to-late century sea-level rise impacts consistent with the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment (AR4) high emissions scenario.

While the viewer is one of the best tools currently available for examining potential impacts of sea-level rise, there are three noteworthy disclaimers about the tool. One, the data in the map do not consider natural processes such as erosion or marsh migration that will be affected by future sea level rise. Two, there is not 100% confidence in the elevation data and/or mapping process. Three, the data may not completely capture an area's hydrology, such as canals, ditches, and stormwater infrastructure. While this type of "bathtub" modeling approach is limited in its ability to provide a better understanding of sea-level rise impacts in a dynamic coastal region, it is a compelling visual aid and useful for inclusion in a baseline assessment. A recommendation of this report will be to examine more sophisticated sea-level rise mapping methodologies based on refined elevation data for our region for improve vulnerability assessments.

Sea Level Rise Mapping – CCC Digital Elevation Model

To map the predicted sea level rise for Barnstable County (Cape Cod) the most accurate elevation data was obtained and adjusted to account for vertical datum variations and localized tidal information. The adjusted data was separated into areas below sea level and into 1 ft increments (up to 6ft) above sea level. The process is detailed below.

Topographical elevation data was sourced from remotely sensed LiDAR data collected in the Winter and Spring of 2011, while no snow was on the ground, rivers were at or below normal levels and within 90 minutes of the daily predicted low tide. For Barnstable County, the LiDAR was processed and classified to meet a bare earth Fundamental Vertical Accuracy (FVA) of 18.13 cm at a 95% confidence level.

The sourced topological elevation data was in a grid format, as a Digital Elevation Model (DEM) with a cell size of 1 meter. In order to incorporate tidal variability within an area when mapping sea level rise, a "modeled" surface (or raster) is needed to represent this variability. In addition, this surface must be represented in the same vertical datum as the elevation data. To account for

the datum and tidal differences across the county the DEM was adjusted to localized conditions using the NOAA VDatum (Vertical Datum Transformation) software. The VDatum program was used to convert a 500m grid of points covering Barnstable County from the source of North American Vertical Datum 88 (NAVD 88) to Mean Higher High Water (MHHW). MHHW is the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. The 500m MHHW grid was then interpolated into a 1m grid identical in spatial extent to the 1m topographical DEM. The topographical DEM was adjusted on a cell-by-cell basis to account for the MHHW elevation.
The MHHW adjusted DEM was separated into seven different dataset. One represented any area with an elevation value below 0. This area is expected to be inundated by tidal water at least once a day. Six additional datasets were created in 1ft increments to represent the inundated area at 1 to 6ft sea level rise.

RECOMMENDATIONS

The desk assessment was conducted over several months utilizing GIS and local knowledge and found:

- This baseline assessment should be used to inform the UPWP Task 3.4 – *Climate Change Mitigation and Adaptation Strategy for Critical Transportation Infrastructure* (FY14).
- As part of the UPWP Task 3.4 – *Climate Change Mitigation and Adaptation Strategy for Critical Transportation Infrastructure* (FY14), an existing conditions assessment of the 24 tidal restrictions that intersect with significant regional and local roadways, including Route 6, Route 6A, Route 28 and Lower County Road should be conducted. This analysis should include the age of the asset, maintenance and repair estimates, replacement costs, and elevation of the asset relative to mean high higher water (MHHW).
- Local evacuation route planning should be coordinated within the region and compiled as a dataset that can be integrated with regional ITS system planning initiatives.
- The FY14 UPWP Task 3.4 – *Climate Change Mitigation and Adaptation Strategy for Critical Transportation Infrastructure* should conduct an existing conditions assessment of the infrastructure components (i.e. piers, bulkheads, dredging) for the critical ferry assets identified within this baseline analysis.

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- The CCC Digital Elevation Model developed for this assessment to examine potential sea-level rise scenarios should be further utilized to more closely examine actual asset elevations and potential vulnerabilities.
- Regionally significant transportation centers should use the finding of this assessment to inform their multi-modal passengers carrier services of the level of potential risk along certain routes, especially bus routes and rail lines that traverse SLOSH zones.

APPENDIX

Hazard Ranking for Cape Cod

Regional Transportation Assets

MAPS

Map 1: Critical Facilities & SLOSH
Map 2: Historic Hurricane Tracks (1938 – Present)

APPENDIX

Excerpted from Barnstable County Regional MHM Plan (2010)

TABLE 1: Hazard Ranking for Cape Cod, Massachusetts

Natural Hazard:	Location† Rate: 1=small 2=medium 3= large	Frequency of Occurrence†† Rate: 0=unlikely 1=possible 2=likely 3=highly likely	Magnitude / Severity††† Rate: 1=limited 2=significant 3=critical 4=catastrophic	Hazard Ranking
Flood	2	3	4	9
Shoreline change (long term, sea level rise, or storm-induced)	2	3	4	9
Heavy downpours	3	2	2	7
Wildfire	2	2	4	8
Snow and Ice Accumulation	3	3	2	8
Wind	3	3	2	8
Tornado	1	2	3	6
Drought	3	1	1	5
Earthquake	2	1	2	5

† **Location**

1=small	(isolated to a specific town during one event)
2=medium	(occurring in multiple towns across county during one event)
3= large	(affecting a significant portion of Barnstable County during one event)

†† ***Frequency of Occurrence***

0=unlikely	(less than 1% probability in the next 100 years)
1=possible	(between 1 and 10% probability in the next year; or at least one chance in next 100 years)
2=likely	(between 10 and 100% probability in the next year; or at least one chance in next 10 years)
3=highly likely	(near 100% probability in the next year)

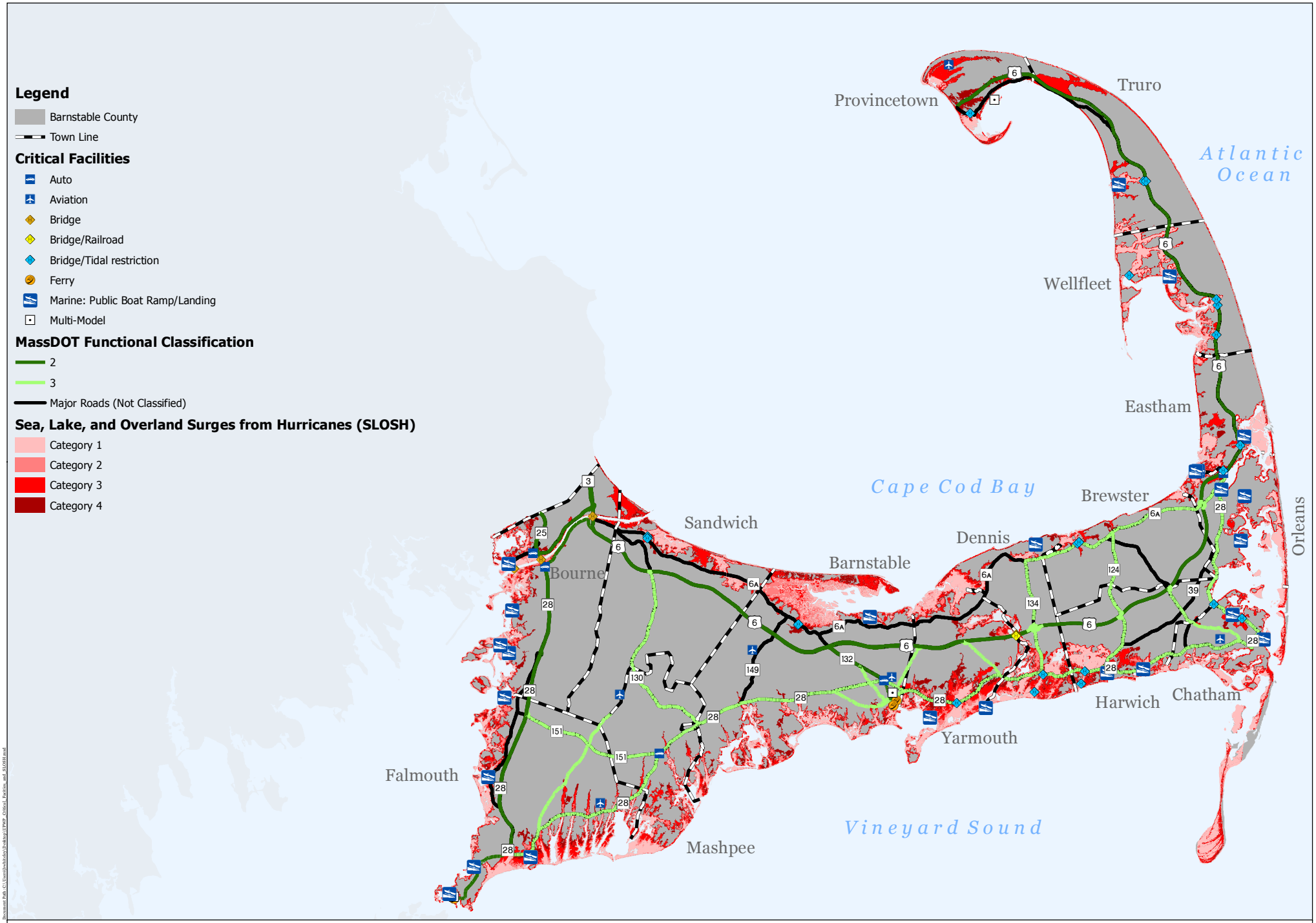
††† ***Magnitude/Severity***

1=limited	(injuries and/or illnesses are treatable with first aid; minor "quality of life" loss; shutdown of critical facilities and services for 24 hours or less; property severely damaged < 10%)
2=significant	(injuries and/or illnesses do not result in permanent disability; shutdown of several critical facilities for more than one week; property severely damaged <25% and >10%)
3=critical	(injuries and/or illnesses result in permanent disability; complete shutdown of critical facilities for at least two weeks; property severely damaged <50%, >25%)
4=catastrophic	(multiple deaths; complete shutdown of facilities for 30 days or more; property severely damaged >50%)

UPWP FY2013, Task 2.5 - Critical Transportation Infrastructure Modes & Assets

Fixed Assets	Mode	Location 2	Lat	Long	Regional Significance (1=high, 2=medium, 3=low)	SLOSH Category	Existing FIRM A/V	Preliminary FIRM A/V	BFE (prelim)	NOAA SLR Viewer (3ft) (I=Inundated) (V=vulnerable)
Ferry - Falmouth	ferry	Falmouth	-70.600342	41.550684	1	1	A	A	15	V
Ferry - Hyannis (Steamship)	ferry	Barnstable	-70.276669	41.651369	1	2	A	A	12	V
Ferry - Hyannis (Hyline)	ferry	Barnstable	-70.279295	41.647910	1	1	A	A	12	V
Ferry - Harwich (Freedom)	ferry	Harwich	-70.059213	41.669547	1	1	V	A	14	V
Orleans/Eastham Rotary	Auto	Eastham	-69.983935	41.798862	1	3	A	A	12	V
Belmont Rotary	Auto	Bourne	-70.597069	41.752024	1	2	A	A	16	
Railroad bridge	bridge	Bourne	-70.613602	41.741965	1	1	V	A	16	V
Cape Flyer	train	multi			1	1	A	A	13	V
Mass Coastal "trash train"	train	multi			1	1	A	A	13	V
Route 6 at Bass River	bridge	Dennis	-70.169701	41.69385	1	1	A	A	11	I
Plymouth Brockton Line	bus	multi			1	1	A	A		V
Haynnis Transportation Center	multi	Barnstable	-70.279899	41.656658	1					
MacMillan Pier	multi	Provincetown	-70.181657	42.049185	1	1	V	V	13	V
Ferry - Woods Hole	ferry	Falmouth	-70.67004	41.52342	1	1	V	V	15	V
Barnstable Municipal Airport	aviation	Barnstable	-70.280531	41.666768	1					
Otis Airfield	aviation	JBCC	-70.521574	41.657738	1					
Bourne Rotary	Auto	Bourne	-70.586451	41.7431	1					
Mashpee Rotary	Auto	Mashpee	-70.487022	41.61838	1					
Rt 28/132 Rotary	Auto	Barnstable	-70.287322	41.665035	1					
Sagamore Bridge	bridge	Bourne	-70.543367	41.776299	1					
Bourne Bridge	bridge	Bourne	-70.589564	41.747839	1					
Class 2 Roads - Principle Arterial	Auto	Barnstable County			1					
Class 3 Roads - Rural Minor Arterial	Auto	Barnstable County			1					
Memorial Circle	Auto	Bourne	-70.618074	41.745971	1	4				V
Woods Hole, Town Dock	multi	Woods Hole	-70.669972	41.524527	2	1	A	A	12	V
Bourne Marina	marine: Public Boat Ra	Bourne	-70.618837	41.745085	2	1	V	A	17	V
Falmouth Harbor	marine: Public Boat Ra	Falmouth	-70.602125	41.550313	2	1	A	A	15	V
Barnstable Marina	marine: Public Boat Ra	Barnstable	-70.299141	41.70704	2	1	A	A	14	V
Town Landing	marine: Public Boat Ra	Dennis	-70.151326	41.753593	2	1	A	A	14	V
Ryder's Cove	marine: Public Boat Ra	North Chatham	-69.97806	41.704531	2	1	A	A	11	V
Town Cove	marine: Public Boat Ra	Orleans	-69.985843	41.788015	2	1	V	A	12	V
Meetinghouse Pond	marine: Public Boat Ra	Orleans	-69.965324	41.783166	2	1	A	A	13	V
Rock Harbor	marine: Public Boat Ra	Eastham	-70.006558	41.80064	2	1	A	A	17	V
Provincetown Municipal Airport	aviation	Provincetown	-70.221867	42.072741	2	3	A	A	12	I
Monument Beach Marina	marine: Public Boat Ra	Bourne	-70.615703	41.714138	2	1	V	V	18	V
Hen Cove Marina	marine: Public Boat Ra	Bourne	-70.619047	41.686089	2	1	V	V	17	V
Barlow's Landing	marine: Public Boat Ra	Bourne	-70.626691	41.691046	2	1	V	V	17	V
Megansett Harbor (Fiddlers Cove) Marina	marine: Public Boat Ra	Falmouth	-70.623643	41.656207	2	1	V	V	16	V
Snug Harbor Marina	marine: Public Boat Ra	Falmouth	-70.638503	41.603926	2	1	V	V	18	V
Quisset Harbor	marine: Public Boat Ra	Falmouth	-70.652252	41.544091	2	1	V	V	18	V
Great Harbor	marine: Public Boat Ra	Falmouth	-70.674061	41.526409	2	1	A	V		V
Bass River Marina	marine: Public Boat Ra	South Yarmouth	-70.197869	41.645366	2	1	A	V	11	V
Lewis Bay	marine: Public Boat Ra	West Yarmouth	-70.247222	41.63988	2	1	V	V	13	V
Saquatucket Harbor	marine: Public Boat Ra	Harwichport	-70.057952	41.66942	2	1	A	V	14	V
Allen Harbor	marine: Public Boat Ra	Harwich	-70.089831	41.667467	2	1	A	V	13	V
Chatham Fish Pier	marine: Public Boat Ra	Chatham	-69.951026	41.688098	2	1	V	V	15	V
Portanimicut	marine: Public Boat Ra	South Orleans	-69.969272	41.753904	2	1	V	V	16	V
Rock Harbor	marine: Public Boat Ra	Orleans	-70.008434	41.799993	2	1	A	V	17	V

Fixed Assets	Mode	Location 2	Lat	Long	Regional Significance (1=high, 2=medium, 3=low)	SLOSH Category	Existing FIRM A/V	Preliminary FIRM A/V	BFE (prelim)	NOAA SLR Viewer (3ft) (I=Inundated) (V=vulnerable)
Salt Pond Bay	marine: Public Boat Ra	Eastham	-69.964948	41.822884	2	1	V	V	13	V
Wellfleet Harbor	marine: Public Boat Ra	Wellfleet	-70.028574	41.929901	2	1	A	V	15	V
Pamet Harbor	marine: Public Boat Ra	Truro	-70.072332	41.991357	2	1	V	V	13	V
Chatham Municipal Airport	aviation	Chatham	-69.989412	41.688579	2					
Bass River Bridge	bridge	South Yarmouth			2					V
GATRA	bus	multi			2					V
Sealine	bus/shuttle	multi			2					V
Flex Line	bus/shuttle				2					V
West Barnstable Airfied (Marstons Mills)	aviation	Barnstable	-70.403609	41.686299	3					
Falmouth Airpark	aviation; private	Falmouth	-70.5399	41.585848	3					
H20 Line	bus/shuttle				3					V
Provincetown Shuttle	bus/shuttle				3					V
Barnstable Villager	bus/shuttle				3		0.28 (A)			V
Bourne Run	bus/shuttle				3					V
Sandwich Line	bus/shuttle				3					V
Bridge Creek Phase 2	Barnstable									
Village Marsh	Sandwich									
Village Marsh	Sandwich									
Bridge Creek Phase 2	bridge/tidal restriction	Barnstable	-70.3629863	41.70256852		4	AE	A	11	
Village Marsh	bridge/tidal restriction	Sandwich	-70.4953689	41.76253788			AE	A	11	
Village Marsh	bridge/tidal restriction	Sandwich	-70.4953755	41.76102186			AE			
Bridge Creek	bridge/tidal restriction	Barnstable	-70.3624528	41.70318054		4	AE	A	11	
Shore Road	bridge/tidal restriction	Yarmouth	-70.2234724	41.64913136		1	AE	A	10	
Swan River (Lower County Rd)	bridge/tidal restriction	Dennis	-70.154586	41.65552345			VE	A	10	
Swan River (SR28)	bridge/tidal restriction	Dennis	-70.1464813	41.66725264			AE	A	10	
Stony brook (Tributary)	bridge/tidal restriction	Brewster	-70.1142127	41.75387874		3	AE	A	13	
Stony Brook	bridge/tidal restriction	Brewster	-70.1128321	41.75458794		3	AE	A	13	
Herring River (Lower County Rd)	bridge/tidal restriction	Harwich	-70.1128405	41.66087666			AE	A	9	
Herring River (SR 28)	bridge/tidal restriction	Harwich	-70.1093574	41.6688866			AE	A	7	
Bass River (US 6)	bridge/tidal restriction	Dennis	-70.1697927	41.6932966			AE			
Province Land Road	bridge/tidal restriction	Provincetown	-70.2033471	42.04022594		3	AE	A	10	
Pamet River (Old Route 6A)	bridge/tidal restriction	Truro	-70.050156	41.99369004		3	AE	A	11	
Pamet River (US6)	bridge/tidal restriction	Truro	-70.048041	41.99340656			X			
Town Cove Tributary	bridge/tidal restriction	Eastham	-69.9683672	41.81696178		3	AE	A	10	
Boat Meadow Creek	bridge/tidal restriction	Eastham	-69.9835849	41.80058324		3	AE	A	11	
Fresh Brook (US 6)	bridge/tidal restriction	Wellfleet	-69.9877915	41.89046833			AE			
Herring River	bridge/tidal restriction	Wellfleet	-70.0643496	41.93114338		4	AE			
Townline (Route 28)	bridge/tidal restriction	Chatham/Harwich	-69.994183	41.71185776			X			
Frost Fish Creek (SR 28)	bridge/tidal restriction	Chatham	-69.969593	41.7022693		3	AE	A	11	
US6	bridge/tidal restriction	WellFleet	-69.9864364	41.91035499			AE			
Black Fish Creek (US 6)	bridge/tidal restriction	Wellfleet	-69.9873407	41.91431278		3	AE			



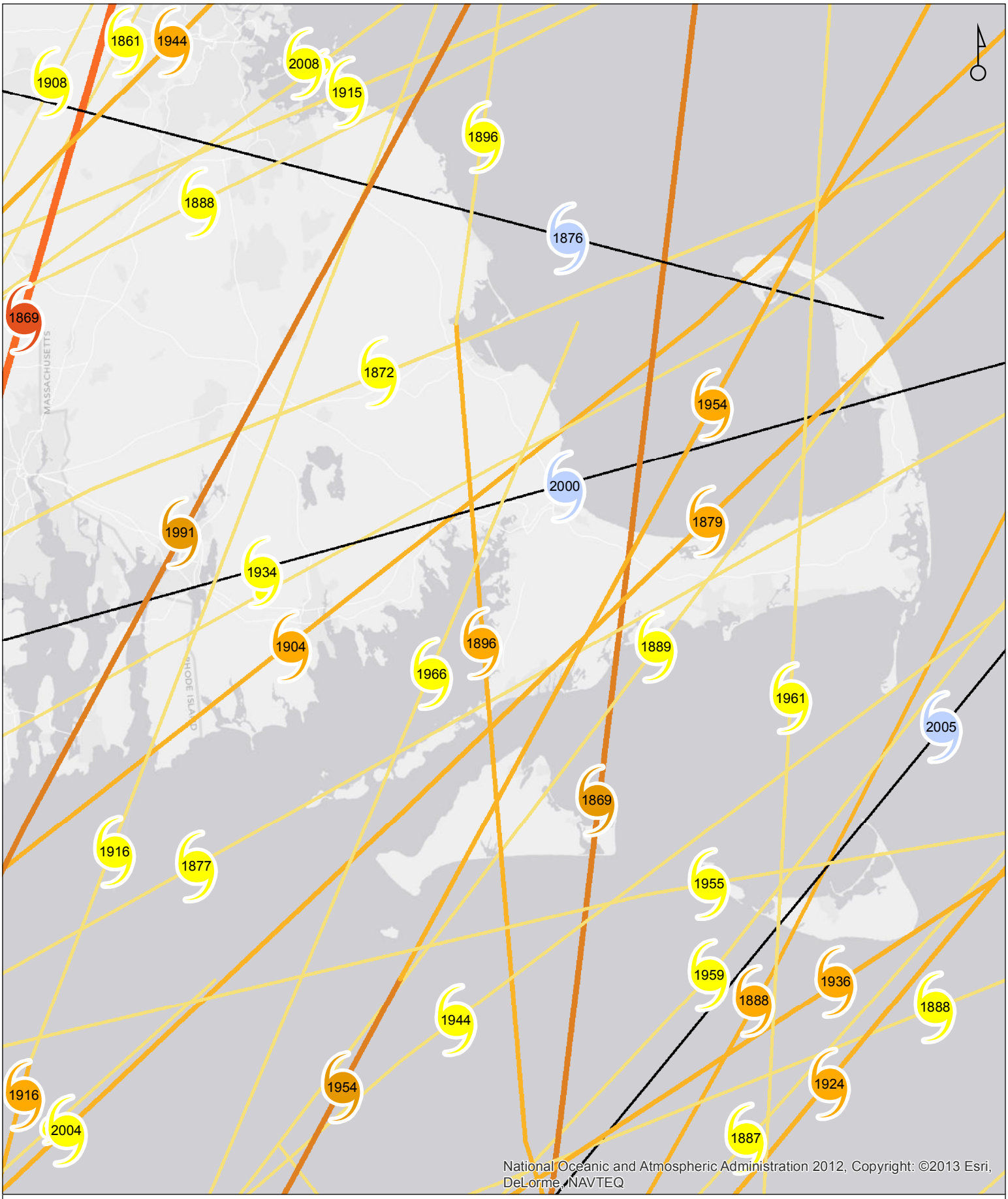
Crictical Facities, SLOSH and Roadway Functional Classification

The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.

Date: 11/13/2013
User: BWhiteley

0 1 2 4 6 Miles

CAPE COD COMMISSION



Hurricane Tracks: 1851 - 2011

Data Source: National Oceanic and Atmospheric Administration (2011)

Storm Year Label
- Tropical Depression
- Tropical Storm
- Category 1
- Category 2
- Category 3

Storm Category
- Tropical Depression (<=34Kts)
- Tropical Storm (35Kts - 63Kts)
- Category 1 (64Kts - 82Kts)
- Category 2 (83Kts - 95Kts)
- Category 3 (96Kts - 112Kts)

2 0 2 4 6
Miles

CAPE COD COMMISSION

The information depicted on these maps is for planning purposes only. It is not adequate for legal boundary definition, regulatory interpretation, or parcel level analysis. It should not substitute for actual on-site survey, or supersede deed research.

User: BWhiteley

Date: 11/14/2013