CAPE COD
COMMISSION

2016 REGIONAL TRANSPORTATION PLAN

Technical Appendix H: Coastal Resiliency

Draft
June 15, 2015

COUNTY OF BARNSTABLE
MASSACHUSETTS

INTENTIONAL BLANK PAGE

Table of Contents

List of Figures

List of Tables

Technical Appendix H: Coastal Resiliency

To supplement the discussion provided in Chapter 4, this appendix provides additional information on the following:

- Climate Change Risk and Vulnerability Assessment of Regional Transportation Infrastructure
- Critical Transportation Assets and their Vulnerability to Sea Level Rise
- Restoring River and Stream Continuity

CLIMATE CHANGE RISK AND VULNERABILITY ASSESSMENT OF REGIONAL TRANSPORTATION INFRASTRUCTURE

As part of the 2013 Unified Planning Work Program, Cape Cod Commission staff conducted an assessment titled *Climate Change Risk and Vulnerability Assessment of Regional Transportation Infrastructure*.[1] 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 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.

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 will be necessary in developing mitigation and adaptation strategies for specific assets.

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

[1] http://www.capecodcommission.org/resources/transportation/UPWP_task2.5DraftReport111413.pdf

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 AND PRIORITIZATION 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. 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.

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 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). 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	

MULTI-HAZARD MITIGATION PLAN

The 2010 Multi-Hazard Mitigation Plan establishes the hazard ranking 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.

[2] Massachusetts Climate Adaptation Plan, 2011

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:

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

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. Some of the main hazards that may occur during a hurricane event are wind, heavy downpours and storm surge.

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.

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.

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.

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 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]

---

[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.

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 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. 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 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

[6] MA Hazard Mitigation Plan, 2010.
[7] IPCC, 2007, Fourth Assessment – Climate Change 2007: A Report of the Intergovernmental Panel on Climate Change.

transport and established sediment budgets will be critical for prioritizing coastal nourishment, armoring and retreat decisions.

VULNERABILITY ASSESSMENT

The assessment utilized three approaches to determine a transportation 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.

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.

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

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 and Class 3, rural minor arterial.

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 2: 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.

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 3).

TABLE 3: 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%

GIS DATASETS AND ASSESSMENT TOOLS:

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

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 storm water 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.

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. This data was compiled into an online web application called the Cape Cod Commission's Sea Level Rise Viewer. This application was released online in April 2014 and is available on the Commission's website (www.capecodcommission/sealevelrise/)

CRITICAL TRANSPORTATION ASSETS AND THEIR VULNERABILITY TO SEA LEVEL RISE

As part of the 2014Unified Planning Work Program, and as a follow-up to the previously discussed assessment, Cape Cod Commission staff conducted a vulnerability study titled *Critical Transportation Assets and Their Vulnerability to Sea Level Rise*.[8] The objective of this study was to understand the vulnerability of critical transportation assets to sea level rise, just one impact of climate change. Public transportation assets in each mode (air, highway, sea, transit and rail) were examined to determine whether the asset was critical to the network and/or the community and to assess the asset's vulnerability to sea level rise.

This study involved several activities: 1) developing online maps; 2) measuring criticality with stakeholders (defined below); 3) measuring vulnerability to sea level rise and 4) generating a list of transportation assets that are both critical to the modal system and vulnerable to sea level rise Figure 1.

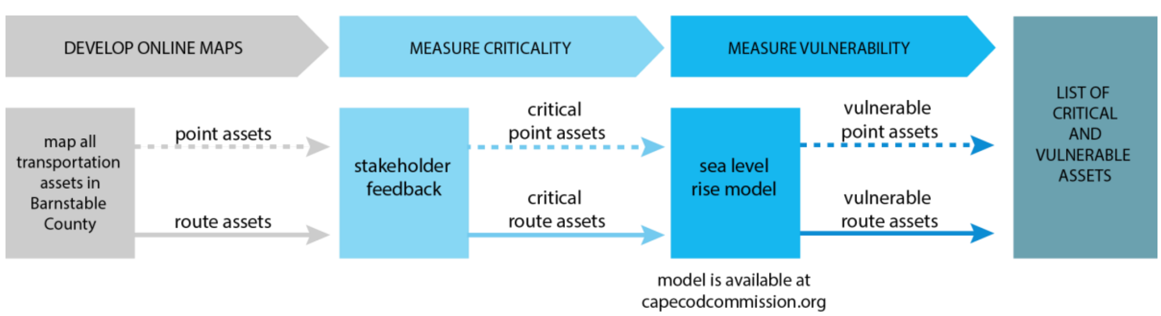

FIGURE 1. OUTLINE OF PROJECT ACTIVITIES AND DELIVERABLES

[8] http://www.capecodcommission.org/resources/transportation/UPWP3_4REPORTfinal.pdf

There are five transportation modes in Barnstable County - air, highway, rail, sea, and transit. Research was performed to determine which assets are important to the functioning on each transportation mode. This list includes point assets, such as bridges, runways, and passenger terminals that are fixed to a single point on the land as well as route assets, such as roadways, bus routes, and train lines. All point and route transportation assets were plotted on digital maps using ArcGIS online.

Representatives from the Barnstable Municipal Airport, the Highway Division of Massachusetts Department of Transportation (MassDOT), Mass Coastal Railroad, the Steamship Authority, and the Cape Cod Regional Transit Authority (CCRTA) were identified as stakeholders for this project. During stakeholder meetings, Commission Staff presented mode specific online maps. Stakeholders were asked to review the maps for errors and make additions or corrections where appropriate. They also commented on the criticality of each asset in their mode. Next, stakeholders were asked to provide volume and ridership data from the year 2013 to understand the functioning of an asset in the community. In addition to the stakeholder meetings, online maps were also presented at two Metropolitan Planning Organization meetings where the general public, members of Federal Highway Administration, and MassDOT had the opportunity to comment on the list of assets.

Commission Staff input all transportation assets into a Sea Level Rise Viewer developed by the Cape Cod Commission (http://www.capecodcommission.org/SeaLevelRise/). The model output is a list of point assets vulnerable at 1 - 6 feet of sea level rise. The model also identified portions of route assets that were vulnerable to rising sea levels. Specifically, sections of roads, train tracks, and bus routes, were identified as impassable at 3 and 6 feet of water rise. The list of vulnerable assets was then quality checked by Commission Staff to ensure the accuracy of the data.

This study defined a "critical" transportation asset as either:

- vital to the functioning of the modal transportation network (i.e. maintains the mobility and accessibility function of the network)
- important to the social and economic functioning of the community (i.e. provides access to employment centers or increases connectivity between community components)

This definition of criticality is similar to the one described in a recent study conducted in the Gulf Coast.[9]

AIR TRANSPORTATION

Stakeholders identified the runway as the most important asset to the functioning of the airport because planes cannot land safely without a runway or cleared strip of land. The air traffic

---

[9] Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase 2, Task 1: Assessing Infrastructure for Criticality in Mobile, AL, U.S. Department of Transportation, September 2011, FHWA-HEP-11-029

control tower was ranked second and the passenger terminal was identified as the third most important asset.

Stakeholders identified the Barnstable Municipal Airport as a critical airport on Cape Cod. It is the third busiest commercial airport in Massachusetts, behind Logan Airport and Nantucket Airport. Barnstable Municipal Airport plays an important role in the community; it provides access to, from and within the region, all-season emergency transportation, and full-time jobs to area residents. The present study used emplanement and employment data to quantitatively assess criticality of the airport. In 2013, the airport had over 85,000 emplanements (the number of people departing on a commercial aircraft) and provided over 2,000 jobs. For comparative purposes, Provincetown Municipal Airport had 11,288 emplanements and generated 343 jobs. It is important to note that the Provincetown Municipal Airport is also critical, but stakeholders ranked it under the Barnstable Municipal Airport because there is no control tower and it has less emplanements.

HIGHWAY TRANSPORTATION

Highway stakeholders classified Routes 6, 6A, 28, 132 and Woods Hole Road as critical to the functioning of the highway network and to the community of Barnstable County. Urban Principal Arterial Roads, Willow Street and Route 134 were also considered critical. This study used AADT (Annual Average Daily Traffic) from 2013 to quantify network criticality. Routes 6, 28 and 132 have higher AADT than other roads on the Cape. Routes 6, 28, and 132 were considered important to the connectivity of Cape Cod because they provide access to town economic centers, villages, town facilities and emergency shelters. While Route 6A has a lower AADT than other roadways, stakeholders identified it as critical because it provides access to village centers across several towns in Barnstable County. Woods Hole Road has a lower AADT than other roadways on the Cape, but it is considered critical because it provides access to village centers and technology hubs located in Woods Hole, such as the Woods Hole Oceanographic Institution, ferry service to Martha's Vineyard the Steamship Authority, the National Marine Fisheries Service and U.S. Coast Guard.

RAIL TRANSPORTATION

Stakeholders identified the railroad bridge as the most critical asset to the functioning of the rail transportation system. The railroad bridge provides the only entry/exit point for trains in Barnstable County. The Yarmouth Line was identified by stakeholders as the second most critical asset because it carries more freight and passengers than the Otis line. The Otis line was also identified as critical because it carries over 35,000 tons of solid waste off of Cape Cod each year.

SEA TRANSPORTATION

Stakeholders identified navigational aids (bells and buoys) as the primary critical asset to the functioning of the ferry system. These instruments are located in coastal waters and provide directional assistance to ferries coming into port. Ferry slips were ranked as the second most critical asset, the passenger terminal as third, and passenger parking lots as fourth.

Stakeholders considered the Steamship Authority, which operates out of Woods Hole and Hyannis, as highly critical to the network and community of Cape Cod. In 2013, the Steamship Authority ferry service carried over 2 million people, over 450,000 automobiles, and over 162,000 other vehicles (including trailers, pickups, vans, buses, campers, trucks of all sizes) between Cape Cod and the Islands. The Island Queen, which provides ferry service between Falmouth and Oak Bluffs, was also identified by stakeholders as a critical asset because it is one of the larger ferry services out of Falmouth with a 100+ occupancy. Stakeholders also ranked Patriot Party Boats as critical. This ferry service is small with a <40 person occupancy, but it is vital to the island communities since it runs early in the morning bringing over commuters and freight.

TRANSIT TRANSPORTATION

The Cape Cod Regional Transit Authority (CCRTA) is unique compared to other modes of transportation in Barnstable County because it offers two types of services: fixed route services and on-demand services. The demand response line, called the DART bus, provides 1100 rides per day and operates on every roadway on Cape Cod, including dirt roads. The DART bus is highly critical to the functioning of the community because it provides transportation to those with limited mobility options.

Stakeholders identified the fixed route H_2O Line and the Sealine as highly critical route assets in Barnstable County. Within the CCRTA network, the H_2O Line and Sealine are the most robust services, carrying 155,717 and 132,406 people, respectively. Transit stakeholders also identified Routes 6, 28, 132, 134, and Woods Hole Road as highly critical to the operation of the CCRTA buses. There are several transportation hubs located throughout the Cape; the largest is located in Hyannis. Stakeholders identified the Hyannis hub as highly critical to the transit system because it is used by CCRTA, Plymouth & Brockton, Peter Pan, and the Steamship Authority Shuttle.

VULNERABILITY TO SEA LEVEL RISE

All point assets identified in this study were run through the Cape Cod Commission's Sea Level Rise Viewer to determine whether the assets were submerged at 1 - 6 feet of water rise. Figure 2 shows the transportation assets that are vulnerable to sea level rise in Barnstable County and Figure 3 shows how many vulnerable assets are located in each town.

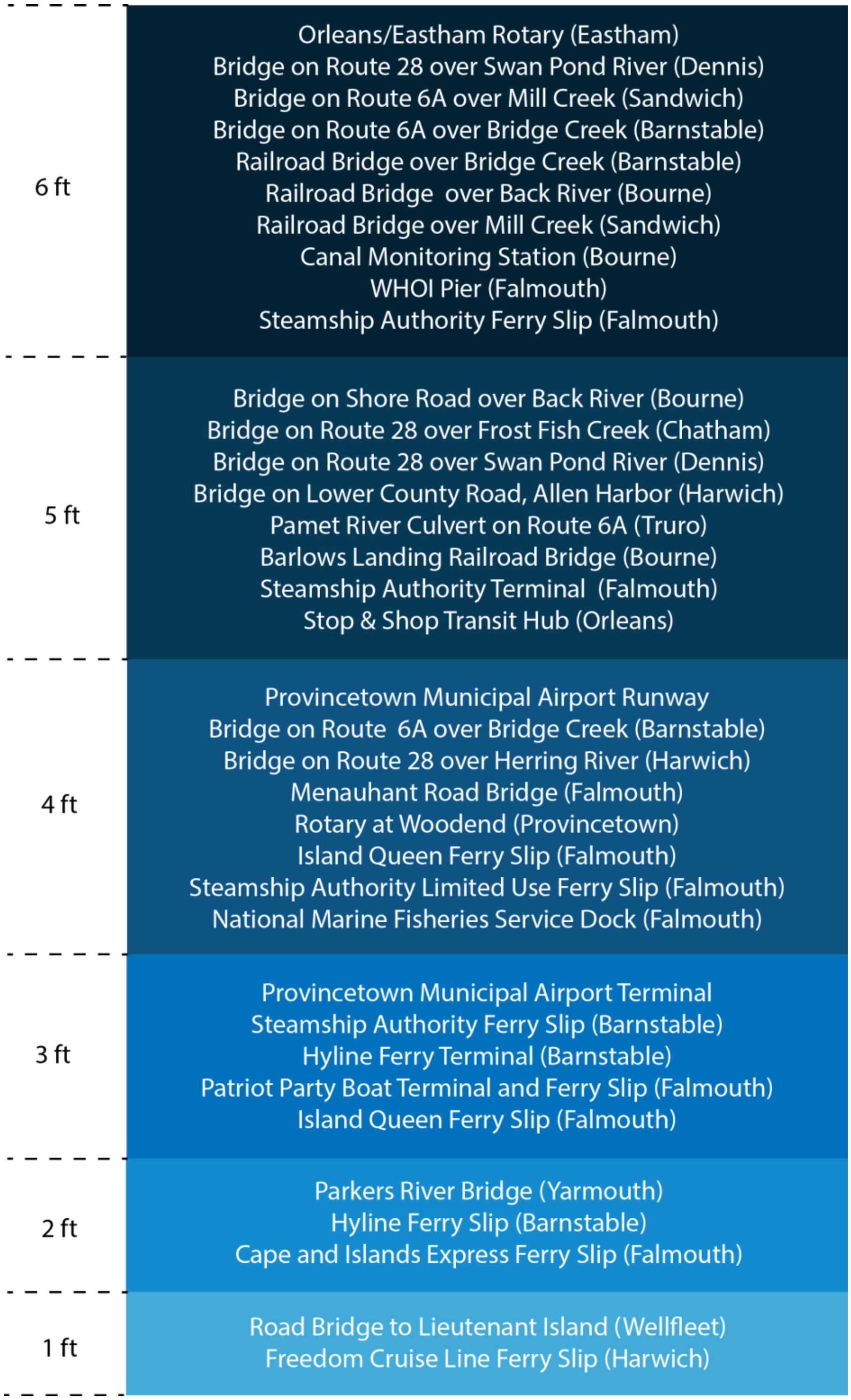

FIGURE 2. TRANSPORTATION POINT ASSETS THAT ARE VULNERABLE TO 1-6 FEET OF SEA LEVEL RISE

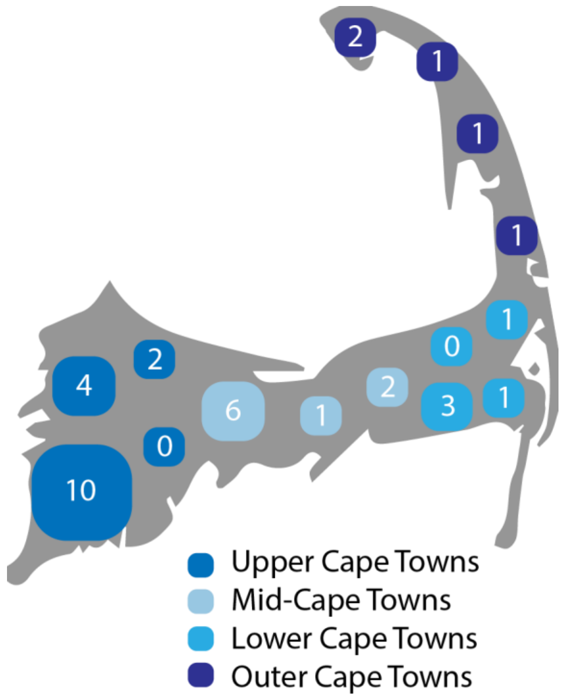

FIGURE 3. VULNERABLE TRANSPORTATION POINT ASSETS BY TOWN

The Sea Level Rise Viewer also identified areas of roads and track that are vulnerable to 3 and 6 feet of water rise. Figure 4 and Figure 5 show areas of impassable roadways at 3 feet and 6 feet of rise, respectively. Figure 6and Figure 7 highlight portions of transit routes that are impacted at 3 feet and 6 feet of water rise, respectively. Figure 8 shows the portions of track that will be submerged at 6 feet of water rise. According to the Cape Cod Commission's Sea Level Rise Viewer, track lines are not vulnerable at 3 feet of sea level rise; although stakeholders reported seeing water in the rail ballast during full moon high tides.

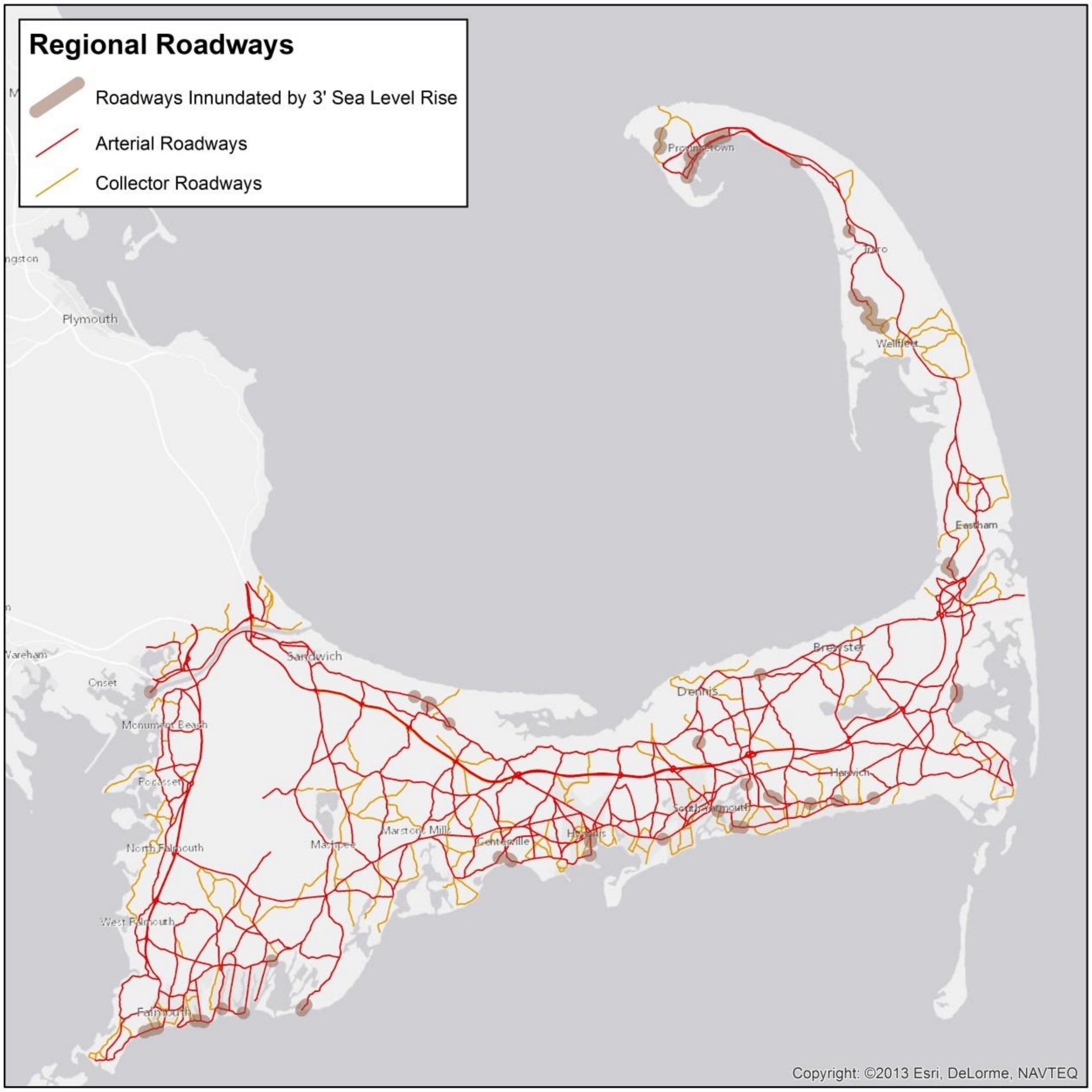

FIGURE 4. SUBMERGED REGIONAL ROADWAYS AT 3 FEET OF SEA LEVEL RISE

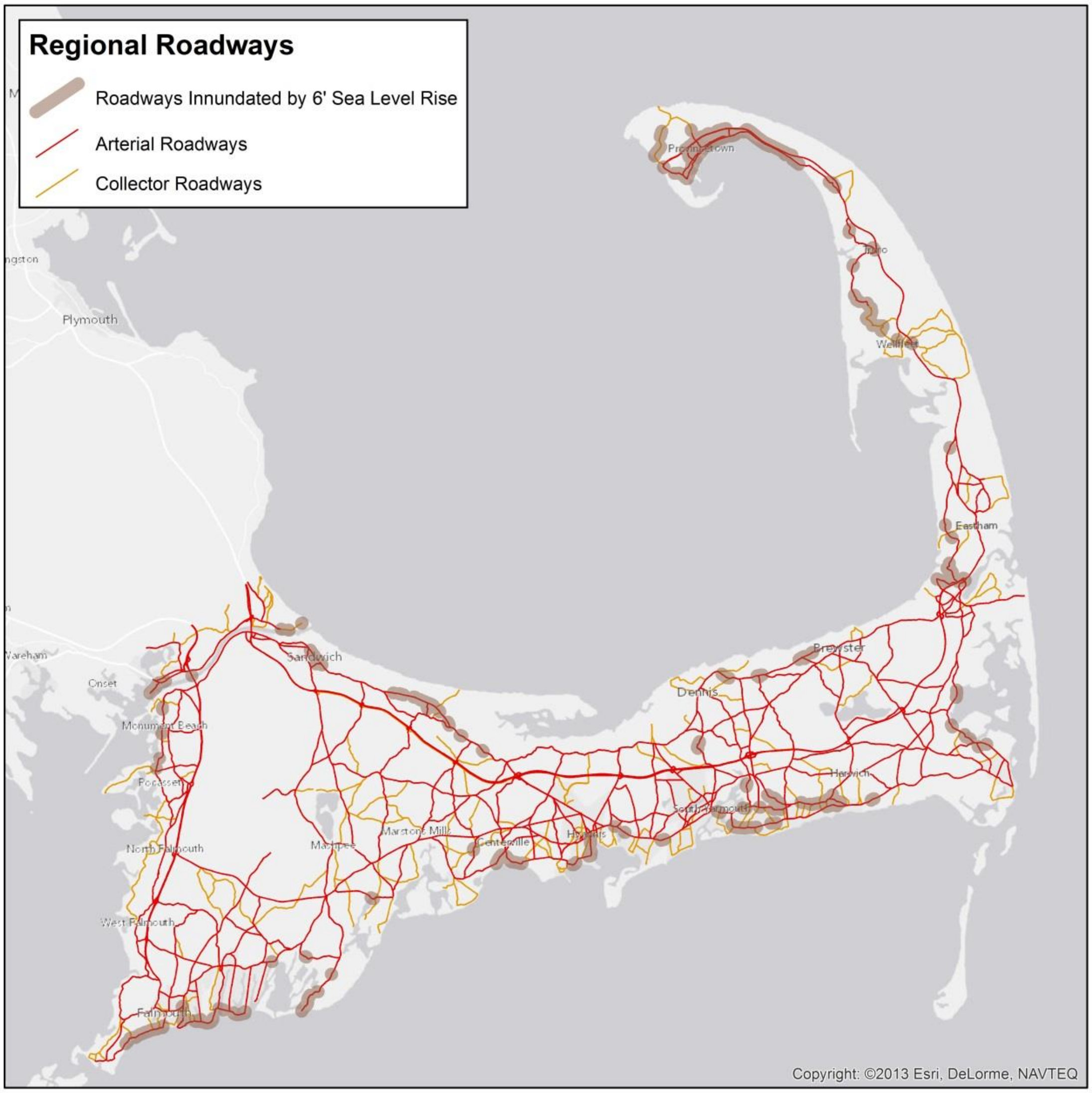

FIGURE 5. SUBMERGED REGIONAL ROADWAYS AT 6 FEET OF SEA LEVEL RISE

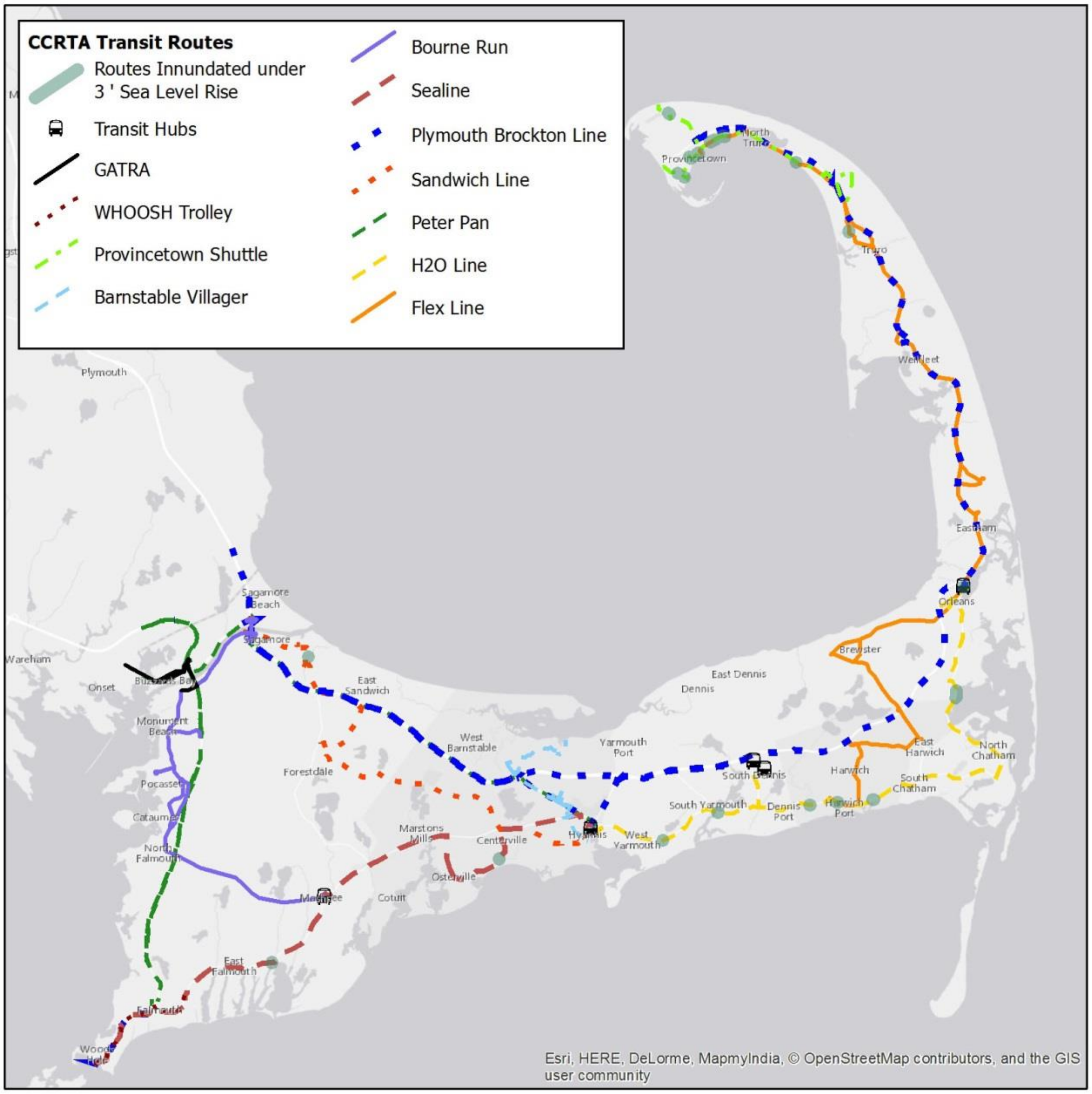

FIGURE 6. SUBMERGED TRANSIT ROUTES AT 3 FEET OF SEA LEVEL RISE

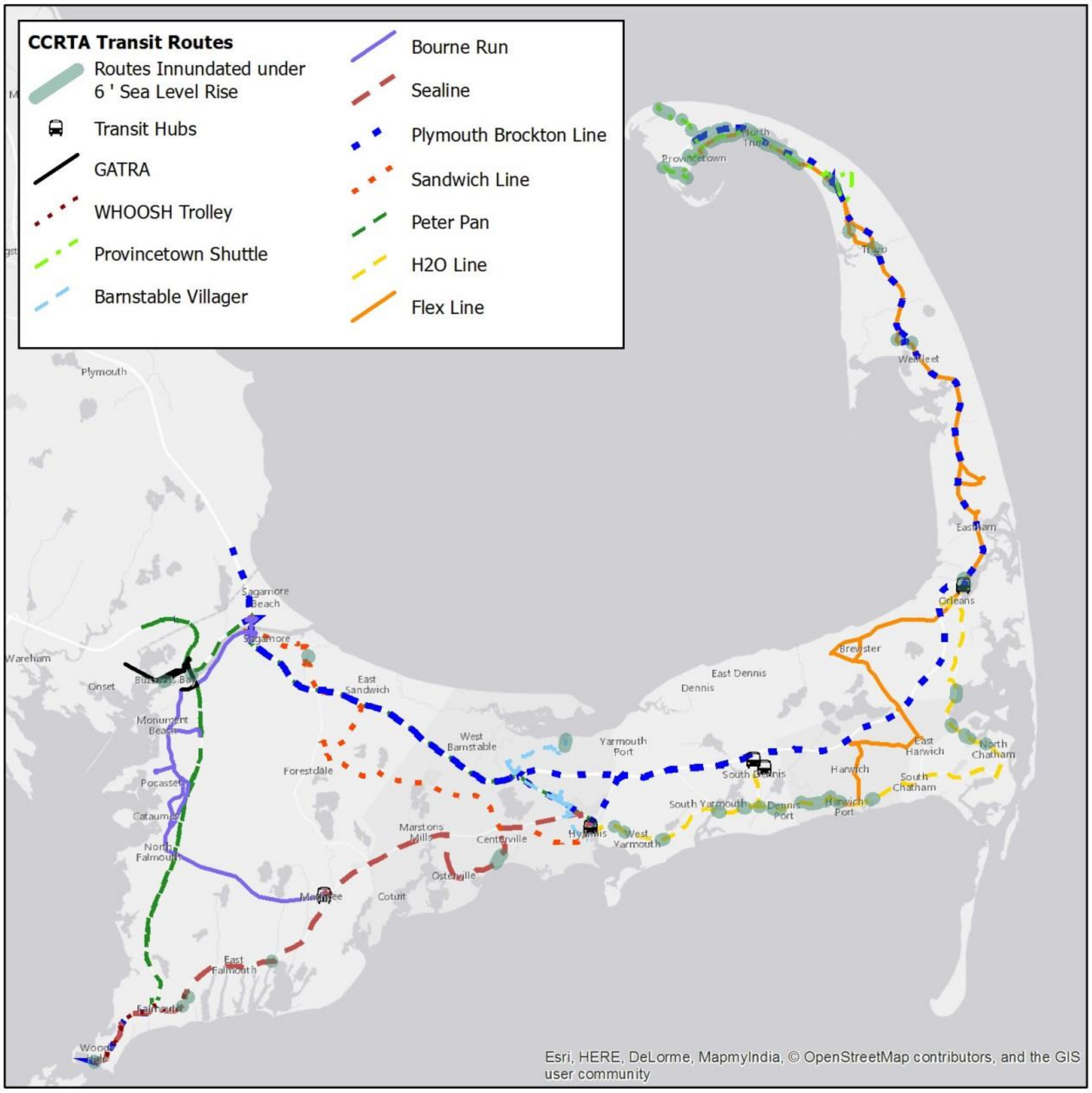

FIGURE 7. SUBMERGED TRANSIT ROUTES AT 6 FEET OF SEA LEVEL RISE

FIGURE 8. SUBMERGED TRACK AT 6 FEET OF SEA LEVEL RISE

The data collected in this study shows that Cape Cod has many transportation assets that are vulnerable to sea level rise (Figures 5-11). During the drafting of this report, MassDOT announced they are constructing a dynamic sea level rise model for the coastline of Massachusetts. While the Cape Cod Commission's Sea Level Rise Viewer is an excellent first-step, the dynamic model generated by MassDOT will be more accurate in predicting asset vulnerability. Given the number of assets vulnerable to sea level rise on Cape Cod; it is critical that this dynamic model become available to Planning and GIS Staff in Barnstable County as soon as possible. Commission staff and several Barnstable County Commissioners advocate that MassDOT construct the model starting with the southern coastline of Massachusetts.

This study identified several transportation assets that are both vulnerable to sea level rise and critical to the community and the transportation network, including:

- AIR: The runway and passenger terminal at the Provincetown Municipal Airport will likely be submerged at 3 - 4 feet of sea level rise. This asset was also identified as vulnerable in the UPWP 2.5 Report from 2013.
- HIGHWAY and TRANSIT: The Orleans/Eastham Rotary on Route 6 will likely be submerged at 6 feet of sea level rise. Once this asset is submerged, the Outer Cape will essentially become an island, completely isolating Route 6 in Eastham, Wellfleet, Truro and Provincetown from other regions. When the Rotary becomes submerged, both Highway and Transit infrastructure will be affected.
- RAIL: Portions of the Yarmouth rail line in Sandwich will likely be submerged at 6 feet of water rise. In this area, the track traverses marsh areas in the Town of Sandwich. This site was also identified as vulnerable in a report generated by the Provincetown Center for Coastal Studies[10].
- SEA: The Steamship Authority ferry slip in Barnstable will likely be submerged at 3 feet of sea level rise.

RESTORING RIVER AND STREAM CONTINUITY[11]

Where roads, rail lines, and bike paths cross freshwater streams and tidal creeks, a bridge or a culvert stream crossing carries the waterway underneath. Stable, appropriately-sized stream crossings maintain the natural hydrology and ecology of rivers and tidal wetlands. Stream crossings that are improperly sized or placed, however, often negatively impact river and stream ecosystems. To maintain healthy conditions, rivers and tidal creeks must be able to convey water, sediment, and organic material without artificial restriction, and allow fish and wildlife to move through unimpeded. When stream crossings are undersized or improperly placed, water flow and wildlife are disrupted and habitats can become degraded.

Well-designed crossings not only enhance habitat for fish and wildlife but also improve infrastructure resiliency during storms and floods. Over the last 40 years, floods and severe storms have become more frequent in New England. Climate change predictions suggest that this trend will continue. Research by The Nature Conservancy, UMass-Amherst, and others has demonstrated that undersized crossings are more likely to fail during large storms. In addition, a recent study commissioned by the Massachusetts Division of Ecological Restoration (DER) found that proactively upgrading deficient crossings to meet stream crossing standards can be more cost-effective over a 30 year period than maintaining the existing structures. Significant

[10] A Proposal to Assess Inundation Vulnerability of CCRTA Rail Infrastructure to Coastal Flooding Associated with Tides, Storms and Sea Level Rise, prepared by the Provincetown Center for Coastal Studies

[11] Information in this provided by Mr. Hunt Durey of the Massachusetts Division of Ecological Restoration, replicated with permission

long-term savings can be realized by reducing repair costs and preventing storm damage caused by road and culvert failures.

Over the past decade, resources have been developed to help transportation planners assess, prioritize, and upgrade stream crossings to protect and improve environmental health. To help identify tidal stream crossing replacement needs, towns and other partners have developed an inventory of tidal restrictions that can be obtained by contacting the Association to Preserve Cape Cod[12]. DER, UMass-Amherst, the Nature Conservancy, and others have also developed a series of tools and trainings to help communities locate and assess non-tidal stream crossings and replace undersized crossings with improved structures. More information is available at the Stream Continuity website[13]. UMass has also developed data that prioritizes road-stream crossings by ecological importance. These data are available at the Critical Linkages website.[14]

The following sections summarize the impacts of transportation infrastructure on rivers and tidal systems and propose Cape Cod RTP objectives to protect and restore river and stream continuity.

TIDAL STREAM CROSSINGS

Culverts and bridges that are too small to pass the full tidal range are known as tidal restrictions, and their impacts can be severe. Many stream crossings on Cape Cod restrict tidal flow. By limiting tidal flow, restrictions alter water levels and chemistry, diminish exchange of ocean nutrients, and can degrade entire upstream aquatic systems. Tidal restrictions often impair water quality, block the passage of fish and other aquatic life, and impede a marsh's ability to build elevation in response to sea level rise. They may also create favorable conditions for invasive species such as *Phragmites australis*. When properly designed, replacing a tidally-restrictive crossing with a larger culvert or bridge restores the natural tidal flow needed to sustain healthy tidal wetland habitats.

FRESHWATER STREAM CROSSINGS

Undersized or improperly placed crossings impact natural stream processes and prevent fish and wildlife from moving about the watershed. Streams and rivers are long, linear ecosystems that connect and nourish wetlands and other aquatic habitats. Small streams carry water, sediment, and organic material downstream into larger rivers that discharge into estuaries and the ocean, creating an interconnected and interdependent system of aquatic life. Fish and wildlife use rivers as migration corridors. Fish such as river herring and Eastern brook trout need to access different parts of the watershed at different points in their life cycles.

[12] http://www.apcc.org/
[13] http://www.streamcontinuity.org/index.htm
[14] http://www.umasscaps.org/applications/critical-linkages.html

Amphibians such as salamanders, turtles, and frogs spend much of their lives near streams and travel near and along a stream's length.

Stream crossings can disrupt stream continuity and impact freshwater ecosystems in the following ways:

- Undersized crossings restrict water flow, particularly during storms. These crossings may contribute to extensive channel scour, bank erosion, flooding, and crossing failure. Undersized crossings may be too small, and the flow may be too fast, to pass fish or wildlife.
- Shallow crossings have water depths that are too shallow for fish and other aquatic life to migrate through.
- Perched crossings have an outlet that is elevated above the level of the stream bed at the downstream end. Perched crossings block fish and wildlife from moving upstream.

CURRENT REGULATIONS

Massachusetts developed Stream Crossing Standards for freshwater streams to protect and restore aquatic habitats and fish and wildlife populations. The MA Wetlands Protection Act and Water Quality Standards now require that all new crossings meet the Standards. Existing crossings that are being repaired or replaced must also meet the Standards to the maximum extent practicable. See this handbook for more information on the Standards.[15]

OBJECTIVES TO PROTECT AND RESTORE RIVERS AND TIDAL SYSTEMS

The following objectives will help reduce the impacts of transportation stream crossings on the natural environment while also contributing to the resiliency of coastal communities facing climate change.

Objectives for the restoration and protection of freshwater river and stream continuity

- Assess existing freshwater stream crossings for stream habitat continuity using the Massachusetts Stream Continuity Assessment Protocol.[16] Contact DER[17] for additional information about assessment approaches and resources.
- Proactively replace deficient freshwater crossings with those that meet the optimal stream crossing standards at sites identified by the Critical Linkages data as having high ecological importance.
- When freshwater stream crossings require significant maintenance or replacement, upgrade with structures that meet the stream crossings standards.
- When designing new or replacement stream crossings, use current precipitation data such as that available at http://precip.eas.cornell.edu/. Data from older sources such as TP-40 may no longer be accurate and can significantly under-predict the amount of rainfall generated by storm events.

[15] http://www.mass.gov/eea/docs/dfg/der/pdf/stream-crossings-handbook.pdf
[16] http://www.streamcontinuity.org/assessing_crossing_structures/index.htm
[17] http://www.mass.gov/eea/agencies/dfg/der/

To date, few freshwater stream crossings on Cape Cod have been field evaluated for stream continuity. The Critical Linkages Project[18] identifies the locations of road-stream crossings and predicts the relative ecological importance of each crossing. The Critical Linkages data set can be used as a tool to locate crossings and prioritize their field assessment and replacement.

Freshwater Stream Crossing Highlight

The Route 6 crossing over Fresh Brook in Wellfleet has been identified as a barrier to fish and wildlife passage. Fresh Brook has been identified by the MA Division of Fisheries and Wildlife and others as a high priority for ecological restoration, as it is one of the only coldwater streams in the Outer Cape. Any work on Route 6 in the vicinity of this crossing should evaluate the potential of installing a larger culvert that meets stream crossing standards.

Objectives for the restoration and protection of tidal systems:

- When replacing crossings on tidal creeks, evaluate the need for, feasibility of, and potential benefits of installing crossings that restore passage of the full natural tidal flow (Table 4).
- Provide financial support for ongoing tidal restoration projects that have already been evaluated for restoration potential and have Town and partner support (Table 5).

The following tidal crossings have been identified by DER and others as sites for further evaluation for restoration potential. DER, the Towns, or other partners may have data and plans for many of these sites but may not have initiated a tidal restoration project yet, and potential costs have not yet been determined. Any planned road, bridge, or culvert work at these sites provides an opportunity to evaluate the degree to which tidal hydrology is currently restricted and to assess the feasibility and cost of installing an upgraded crossing that restores natural tidal flow.

[18] http://www.umasscaps.org/applications/critical-linkages.html

TABLE 4. TIDAL CROSSINGS FOR FURTHER EVALUATION AND POTENTIAL REPLACEMENT

TOWN	LOCATION (LAT. LON.)	ATLAS ID	DESCRIPTION	POTENTIAL ACRES OF TIDAL WETLAND RESTORATION
Barnstable	Lat 41.701171 Lon -70.352397	BA-4	Penn Central Railroad restriction of Brickyard Creek	8.5 acres
Barnstable	Lat 41.703529 Lon -70.288247	BA-6	Commerce Road restriction of Maraspin Creek	5 acres
Barnstable	Lat 41.639179 Lon -70.361022	BA-12	Bay Lane restriction of unnamed channel off Bumps River	10 acres
Chatham	Lat 41.667230 Lon -69.966274	CH-5	Stage Harbor Road restriction of Champlain Creek	5 acres
Chatham	Lat 41.702256 Lon -69.969693	CH-6	Route 28 restriction of Frost Fish Creek	42 acres
Harwich	Lat 41.677695 Lon -70.098274	HA-4	Lothrop Road restriction of a tributary to the Herring River.	14 acres
Truro	Lat 41.993728 Lon -70.050225	TR-3	Route 6A Restriction of Pamet River	150 acres (Inclusive of TR-4)
Truro	Lat 41.993551 Lon -70.048038	TR-4	Route 6 Restriction of Pamet River	150 acres (inclusive of TR-3)
Truro	Lat 42.050591 Lon -70.116993	TR-6	Route 6A and Route 6 obstruction of Pilgrim Lake	300 acres
Wellfleet	Lat 41.91435 Lon -69.987383	WE-3	Route 6 Restriction of Blackfish Creek	17 acres
Yarmouth	Lat 41.707358 Lon -70.249647	YA-3	Thacher Shore Road restriction of Short Warf Creek	4 acres
Several sources of information were used to inform the list above including: the 2001 Cape Cod Atlas of Tidally Restricted Marshes prepared by the Cape Cod Commission, the 2008 Atlas Update prepared by DER, the Cape Cod Conservation District (CCCD) Cape Cod Water Resources Restoration Project List, and the draft update to the Cape Cod Water Resources Restoration Plan currently under development by the CCCD, Association to Preserve Cape Cod, and MassBays Program.				

The tidal restoration projects listed in Table 5are actively in development, have Town support, partner interest, significant data, and in some cases feasibility or design-level information, but are in need of funding.

TABLE 5. ONGOING TIDAL CROSSING REPLACEMENT PROJECTS WITH HIGH RESTORATION BENEFIT

TOWN	TITLE	DESCRIPTION	ESTIMATED COST
Truro	Mill Pond	Mill Pond in Truro has been severely degraded by a tidal restriction beneath Mill Pond Road for over 150 years. The project will restore tidal flow to this 13-acre system and will benefit shellfish and finfish species while encouraging a more natural wetland plant community.	$750,000
Truro	Eagle Neck Creek	Eagle Neck Creek is a 16-acre degraded tidal marsh that flows into Pamet Harbor and Cape Cod Bay. A road and culvert crossing the creek obstruct tidal flushing of the system. The project will remove the tidal restriction to restore salt marsh functions and benefit associated shellfish, finfish, and other coastal wildlife.	$1 Million
Wellfleet	Mayo Creek	Mayo Creek is a 30-acre tidal restoration opportunity. By re-establishing tidal flow, this project will reduce invasive plant growth, improve water quality for shellfishing, and enhance fish and wildlife habitat. The Town is evaluating options for providing town water and sewer to area residents to address concerns about salt water intrusion.	$500,000
Harwich	Cold Brook	Restoration of Cold Brook will transform 66-acres of retired cranberry bogs into a diverse, self-sustaining fresh and brackish wetland. The site is located at the head of tide, and culverts under Hoyt Road and Route 28 limit tidal exchange. Increasing the hydraulic capacity of these two crossings would promote tidal restoration today and future marsh migration in response to sea level rise.	$1.5 Million
Wellfleet	Herring River	This project will replace the Chequessett Neck Road Dike with a bridge and water control structures to restore tidal flow to the 1,000-acre Herring River Estuary. Other restrictions to tidal flow will also be removed or modified.	$44 Million

Tidal River Crossing Highlight

Listed in Table 5, the Herring River Estuary Restoration Project[19] in Wellfleet and Truro is the largest, highest priority estuary restoration in the Northeastern United States. Restoration of tidal flow to this river and adjacent wetlands will generate significant social, environmental, and economic benefits. The project is currently developing engineering designs and proceeding through multiple environmental reviews. Construction is anticipated to commence in the 2018-2020 timeframe and significant funding will be needed to cover the estimated $40-$50 million construction cost.

[19] http://www.mass.gov/eea/docs/dfg/der/pdf/herringriver-project-sheet.pdf

INTENTIONAL BLANK PAGE

CAPE COD COMMISSION

3225 MAIN STREET • P.O. BOX 226 • BARNSTABLE, MASSACHUSETTS 02630
(508) 362-3828 • Fax (508) 362-3136 • www.capecodcommission.org