TABLES

FIGURES

SECTION 6. COASTAL EROSION AND SHORELINE CHANGE

6.1 GENERAL BACKGROUND

Erosion and flooding are the primary coastal hazards that lead to the loss of lives or damage to property and infrastructure in developed coastal areas. Coastal storms are an intricate combination of events that impact a coastal area. A coastal storm can occur any time of the year and at varying levels of severity. One of the greatest threats from a coastal storm is coastal flooding due to storm surge. This is the inundation of land areas along the oceanic coast and estuarine shoreline by seawaters over and above normal tidal action.

Many natural factors affect erosion of the shoreline, including shore and nearshore geology, nearshore bathymetry, shoreline orientation, and climate change through increased storm frequency, temperature, and precipitation. Coastal shorelines change constantly in response to wind, waves, tides, sea level fluctuation, seasonal and climatic variations, human alteration, and other factors that influence the movement of sand and material within a shoreline system. High winds, erosion, heavy surf, and unsafe tidal conditions are ordinary coastal hazard phenomena. Some or all of these can occur during a coastal storm, often resulting in detrimental impacts on the surrounding coastline. Storms, including nor'easters and hurricanes, decreased sediment supplies, and sea-level rise contribute to these coastal hazards.

Loss (erosion) and gain (accretion) of coastal land are visible results of the way these conditions reshape shorelines (www.mass.gov/czm/hazards/shoreline_change/shorelinechangeproject.htm). Shorelines tend to change seasonally, accreting slowly during summer when sediments are deposited by relatively low energy waves and eroding dramatically during winter when sediments are moved offshore by high-energy storm waves, such as those generated by nor'easters. Regardless of the season, coastal storms typically cause erosion. With anticipated changes in climate, an increase in intensity of storms is expected (Emanuel, 2013). This will increase the likelihood of severe erosion along the Massachusetts coast.

Coastal erosion and shoreline change can result in significant economic loss through the destruction of buildings, roads, infrastructure, natural resources, and wildlife habitats. Damage often results from the combination of an episodic event with severe storm waves and dune or bluff erosion. Some of the methods used by property owners to stop, or slow down, coastal erosion or shoreline change can actually exacerbate the problem. Attempting to halt the natural process of erosion with seawalls and other hard structures typically worsens the erosion in front of the structure, prevents any sediment behind the structure from supplying down drift properties with sediment, and subjects down drift beaches to increased erosion. Without the sediment transport associated with erosion, some of the Commonwealth's greatest assets and attractions—beaches, dunes, barrier beaches, salt marshes, and estuaries—are threatened and will slowly disappear as the sediment sources that feed and sustain them are eliminated.

The Office of Coastal Zone Management (CZM) is the lead for coastal policy and technical assistance in the Commonwealth. The CZM has been collecting new data and studying and monitoring shoreline change for an extended time; it is beyond the scope of this document to provide all of relevant data captured during this process; however, as appropriate, information has been included within this risk assessment which is relevant, as well as in the various other portions of this document which support mitigation efforts, such as the capabilities matrix and other relevant hazard profiles. Likewise, additional information on shoreline change may also be found in CZM's *Fact Sheet on Massachusetts Shoreline Change Project* at http://www.mass.gov/czm/hazards/shoreline_change/shorelinechangeproject.htm.

In 2001, CZM completed an update of the Shoreline Change Project, using 1994 National Oceanic and Atmospheric Administration (NOAA) aerial photographs of the Massachusetts shoreline. CZM established an agreement with the U.S. Geological Survey (USGS), the Woods Hole Oceanographic

Institution Sea Grant Program, and Cape Cod Cooperative Extension to produce a 1994 shoreline map, add it to the previous project, and update the statistics and calculate erosion rates. The work was conducted by Rob Thieler and Courtney Schupp at the USGS and Jim O'Connell at the Woods Hole Oceanographic Institution Sea Grant Program and Cape Cod Cooperative Extension. The maps and statistical analysis of shoreline change now cover the time period from the mid-1800s to 1994.

In 2013, through collaboration with the USGS, CZM completed an updated of the Massachusetts Shoreline Change Project with a new shoreline that spans 2007 to 2009. The USGS delineated and analyzed this latest shoreline with other shorelines at 50-meter intervals to compute long-term (approximately 150-year) and short-term (approximately 30 year) rates of shoreline change. Other shorelines added as part of this update include a 2000 shoreline derived by USGS that covers most of the ocean-facing coastline, as well as a 2001 shoreline for the South Shore that was delineated by Applied Coastal Research and Engineering. New shorelines and more than 26,000 transects with updated change rates, uncertainty values, and net distances of shoreline movement have been added to the Massachusetts Ocean Resources Information System Shoreline Change Browser.

Figure 6-1 is an example map created using the Massachusetts Ocean Resources Information System Shoreline Change Browser for an area in Winthrop, Massachusetts. Local communities may refer to the Shoreline Change Browser for a more detailed look at the shoreline and associated data: http://maps.massgis.state.ma.us/map_ol/czm_shorelines.php.

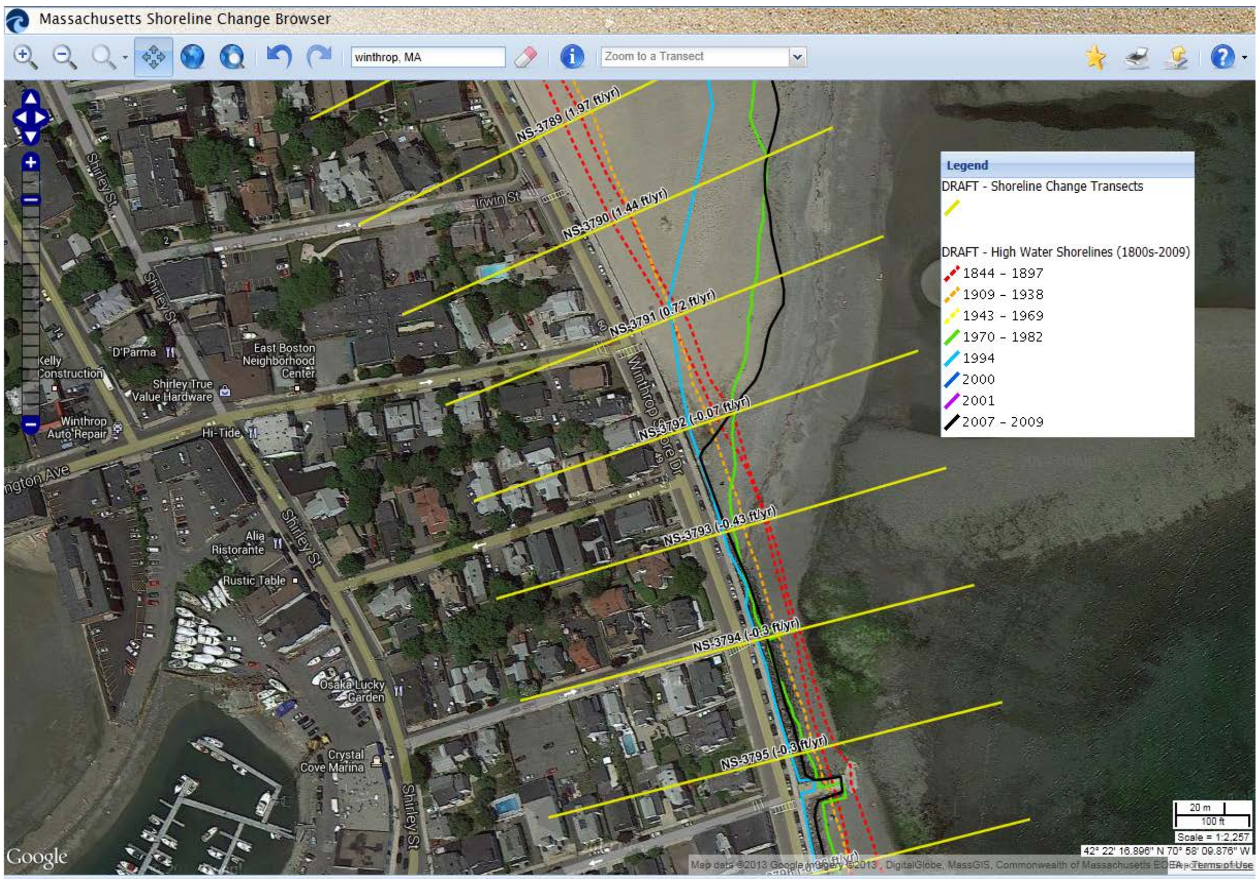

Figure 6-1. Map Generated Using Massachusetts Shoreline Change Browser

6.1.1 Challenges in Interpreting Shoreline Change Data

To interpret and apply the shoreline change data, both general shoreline trends and long- and short-term rates must be analyzed and evaluated in light of current shoreline conditions, recent changes in shoreline uses, and the effects of human-induced alterations to natural shoreline movement. In areas that show shoreline change reversals (i.e., where the shoreline fluctuates between erosion and accretion) and areas that have been extensively altered by human activities (e.g., seawalls and jetties), professional judgment and knowledge of natural and human impacts are typically required for proper data interpretation and incorporation of the data into project planning and design.

For example, a group of 10 transects along Sankaty Head on Nantucket indicate a generally stable (close to zero) long-term trend of shoreline change from 1846 to 2009. The beach is not stable, however, as illustrated by the short-term erosion rates of approximately -9.5 feet per year and the approximately 300-feet of erosion experienced in this area from 1978 to 2009. In this particular example, the beach was accreting up until the 1950s, when it began to erode rapidly. The accretion and erosion in essence mathematically "cancel each other out," leaving a long-term shoreline change rate of around zero.

Where the shoreline has been armored with sea walls, revetments, and other structures, the shoreline change data must be looked at very closely to determine the effects of the structures. The natural sources of beach sand for North Scituate Beach were severely diminished by seawall and revetment construction during the 1940s through the 1970s. Consequently, the trend of erosion is not only continuing in this area—it is increasing from approximately -0.5 to -2.5 feet per year.

Transects on Scusset Beach in Bourne show long-term accretion rates of more than 7 feet per year. However, the short-term accretion rates of about 5 feet per year are more reflective of current shoreline trends. The north jetty of the Cape Cod Canal was constructed in the early 1900s and resulted in an initial rapid growth of Scusset Beach, contributing to the higher long-term rates that have since leveled off.

In addition, the shorelines were derived from different historical maps, aerial photographs, and LIDAR (light detection and ranging) data sources. Each shoreline was assigned an uncertainty value based on an estimate of errors inherent in the source material and method used to delineate the local high water line. These estimates of total shoreline position uncertainty, which ranged from 11.6 meters (38.1 feet) for 1800s shorelines to 1.27 meters (4.17 feet) for LIDAR-derived shorelines, should be considered when analyzing shoreline movement over time and were included in the calculation of uncertainty at each transect. Each transect has long- and short-term rates, with estimated uncertainty values for those rates. The shoreline change rates should be looked at as a range, particularly for transects with uncertainty values greater than the shoreline change rate. For example, for a transect with an erosion rate of -1.0 foot per year with an uncertainty range of ±2.5 feet per year, the range for the shoreline change rate would be +1.5 to -3.5 feet per year—meaning that the area may be either eroding or accreting. To protect coastal properties in the long term, the greatest rate of erosion over the expected life of the structure should be used for design (http://www.mass.gov/czm/hazards/shoreline_change/shorelinechangeproject.htm).

Human activity is not the sole reason for trend reversals and shoreline changes. In some areas, such as the southeastern shore of Nantucket, natural processes are responsible for large trend reversals (accretion to erosion back to accretion to erosion) over the 150-year study period. In this area, the data reveal that the shoreline has fluctuated between 50 to 100 feet of both erosion and accretion resulting in a long-term average suggesting stability. The shoreline is, however, exceptionally variable.

6.1.2 Decreased Sediment

Coastal landforms such as coastal banks are essential to maintaining a supply of sediment to beaches and dunes. Where engineered structures are used to stabilize shorelines, the natural process of erosion is interrupted, decreasing the amount of sediment available and causing erosion to adjacent areas. Under conditions of reduced sediment, the ability of coastal resource areas such as dunes and beaches to provide storm damage prevention and flood control benefits is continually reduced. A major challenge is to ensure that regional sediment supplies are managed effectively and in ways that allow the beneficial storm damage prevention and flood control functions of natural coastal processes to continue—both for future projects and, where possible, existing coastal development.

6.1.3 Sea-Level Rise

Local sea level rise is produced by the combined effects of global sea level rise and local factors such as the following:

- Vertical land deformation, caused by phenomena such as:
  - Tectonic movement
  - Subsidence
  - Isostatic rebound in response to climate change after removal of a load from glaciers, not only in New England but also globally (e.g., Greenland and Antarctica)
- Seasonal ocean elevation changes due to atmospheric effects
- Glacial melt
- Thermal expansion of the ocean
- Ocean currents

The melting of glaciers, thermal expansion of the ocean, vertical land deformation (tectonics, subsidence, isostatic rebound), atmospheric effects, and ocean currents will likely continue to increase sea level for many hundreds of years into the future. For instance, there is increasing evidence that the collapse of the West Antarctic Ice Sheet will produce a 25-percent additional sea level rise along the Atlantic coast above the global average due to redistribution of mass in the asthenosphere, change in polar rotation axis and loss of gravitational attraction of water to the ice sheet when large ice sheets melt (Bamber et al., 2009). Figure 6-2 depicts some of the causes associated with sea level rise.

Source: Douglas et al, 2010

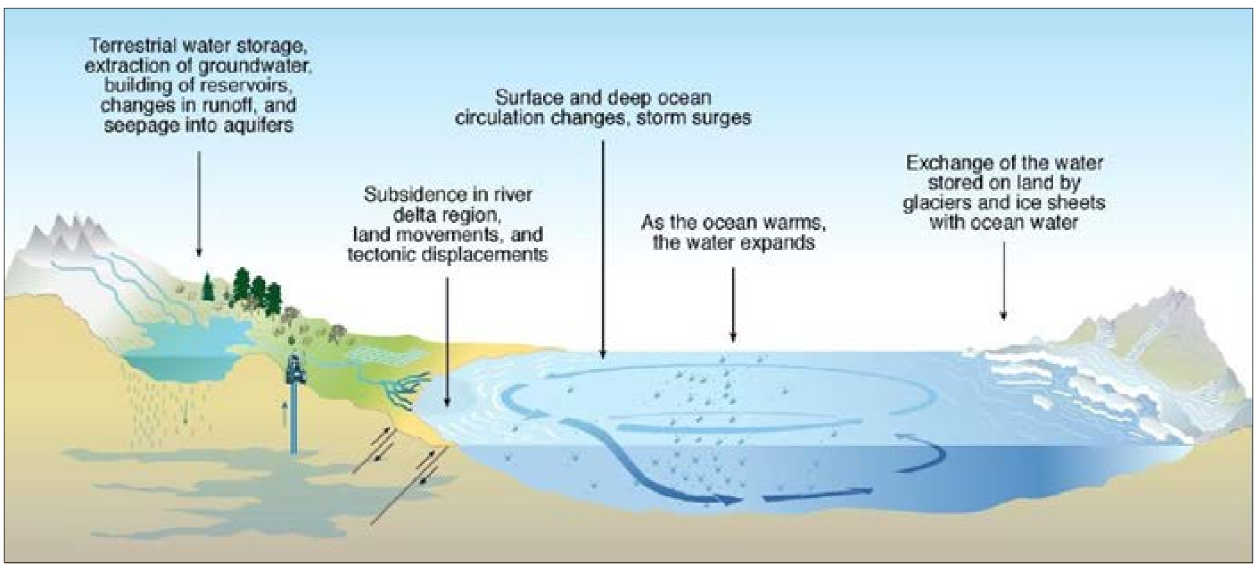

Figure 6-2. What Causes the Sea Level to Change?

The *Fourth Assessment Report of the Intergovernmental Panel on Climate Change* projects global sea level rise over the course of this century to be between 7 and 15 inches for the lowest emissions scenario, and between 10 and 23 inches for the highest emissions scenario. According to the Intergovernmental Panel on Climate Change (IPCC), current model projections indicate substantial variability in future sea level rise between different locations. Some locations could experience sea level rise higher than the global average projection, while others could have a fall in sea level. The same factors that currently cause sea level to rise more rapidly along the Mid-Atlantic and Gulf Coasts, and less rapidly in parts of the Pacific Northwest, are likely to continue. Changes in winds, atmospheric pressure, and ocean currents will also cause regional variations in sea level rise - but those variations cannot be reliably predicted.

Since the Fourth Assessment Report of the Intergovernmental Panel on Climate Change was published in 2007, the climate has continued to change with resulting effects on the U.S. The trends described in the IPCC Fourth Assessment Report have continued and the U.S. average temperature has increased by 1.5 degrees Fahrenheit since 1895; more than 80 percent of this increase has occurred since 1980. The most recent decade was the nation's hottest on record. Through most regions of the U.S. are experiencing warming, the changes in temperature are not uniform. In general, temperatures are rising more quickly at higher latitudes, but there is considerable observed variability across the regions of the U.S.

U.S. temperatures will continue to rise, with the next few decades projected to see another 2ºF to 4ºF of warming in most areas. The warming by the end of the century is projected to correspond closely to the cumulative global emissions of greenhouse gases up to that time: roughly 3 to 5 degrees Fahrenheit under a lower emissions scenario involving substantial reductions in emissions after 2050 (referred to as the "B1 scenario"), and 5 to 10 degrees Fahrenheit for a higher emissions scenario assuming continued increased in emissions (referred to as the "A2 scenario") (National Climate Assessment Development Advisory Committee, 2013). This increase in temperature has wide-ranging impacts throughout the world, including sea-level rises, changing precipitation patterns, and an increase in extreme weather events. Figure 6-3 demonstrates the predicted sea level rise associated with increasing world temperatures.

Source: Douglas et al, 2010

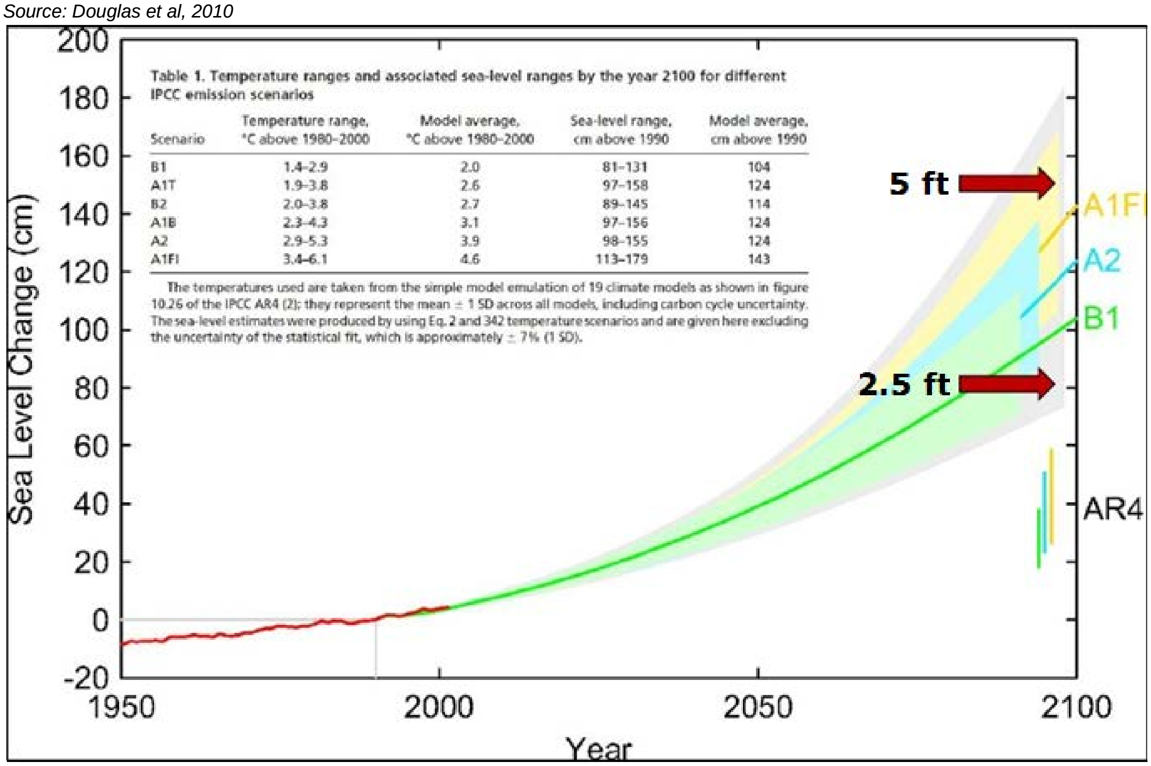

Table 1. Temperature ranges and associated sea-level ranges by the year 2100 for different IPCC emission scenarios

Scenario	Temperature range, °C above 1980–2000	Model average, °C above 1980–2000	Sea-level range, cm above 1990	Model average, cm above 1990
B1	1.4–2.9	2.0	81–131	104
A1T	1.9–3.8	2.6	97–158	124
B2	2.0–3.8	2.7	89–145	114
A1B	2.3–4.3	3.1	97–156	124
A2	2.9–5.3	3.9	98–155	124
A1FI	3.4–6.1	4.6	113–179	143

The temperatures used are taken from the simple model emulation of 19 climate models as shown in figure 10.26 of the IPCC AR4 (2); they represent the mean ± 1 SD across all models, including carbon cycle uncertainty. The sea-level estimates were produced by using Eq. 2 and 342 temperature scenarios and are given here excluding the uncertainty of the statistical fit, which is approximately ± 7% (1 SD).

Figure 6-3. Sea-Level Rise Projections

Based on current science, the IPCC has estimated the sea level rise for the Massachusetts coast line to be 19 inches over the next 100 years which is an accelerated rate over what has been observed over the last 100 years (10 inches). The seas along the East Coast from North Carolina to New England are rising three to four times faster than the global average, and coastal cities, utilities, beaches, and wetlands are increasingly vulnerable to flooding, especially from storm surges, according to the US Geological Survey.

As a result of sea level rise, low-lying coastal areas will eventually be inundated by seawater or periodically over-washed by waves and storm surges. Coastal wetlands will become increasingly brackish as seawater inundates freshwater wetlands. New brackish and freshwater wetland areas will be created as seawater inundates low-lying inland areas or as the freshwater table is pushed upward by the higher stand of seawater.

Some of the potential impacts of sea level rise on the coast of Massachusetts are as follows:

- Loss of coastal habitats and resources
- Increased beach-bluff-dune-marsh erosion
- Loss of recreation resources (beaches, marshes)
- Salt–water intrusion to water wells, septic systems
- Elevated storm-surge flooding levels
- Greater, more frequent coastal inundation
- Increased risk to urban infrastructure
- Greater risk to human safety & development

6.2 HAZARD PROFILE

6.2.1 Location

Massachusetts and its 68 coastal communities are vulnerable to the damaging impacts of major storms, such as nor'easters and hurricanes, along more than 1,500 miles of varied coastline. Figure 6-4 shows the Massachusetts coastal communities. As development and re-development increases along shorelines, less-intense storms that occur more regularly and predicted sea-level rise will lead to periods of increased occurrence.

For the purposes of this Plan, the wetland types identified in the MassDEP wetlands spatial layer (barrier beach, coastal beach, coastal dune, coastal bank, rocky intertidal shore, salt marsh, and tidal flat) are considered areas that are likely to be impacted by coastal erosion. Figure 6-5 shows the estimated potential coastal erosion hazard area. Each area of the coast is impacted differently by each type of coastal hazard and has varying vulnerability.

North Shore

Following the coastline from Salisbury to Revere, industrial activity is moderate in comparison to other portions of the coast. The Merrimack River carries industrial effluent, including treated sewage and industrial process water, to the ocean waters of this region. Merrimack River, Cape Ann, and Salem Sound areas are homeport to significant fleets of fishing and tourism vessels, and the Annisquam River is also heavily used for tourism and recreational fishing purposes. The waters between Nahant and Manchester and between Gloucester and Rockport are the two most productively fished areas in the region, making up a large percentage of the total state lobster catch. Great Marsh is a major recreational destination. North of Cape Ann is characterized by public beaches of regional and national significance.

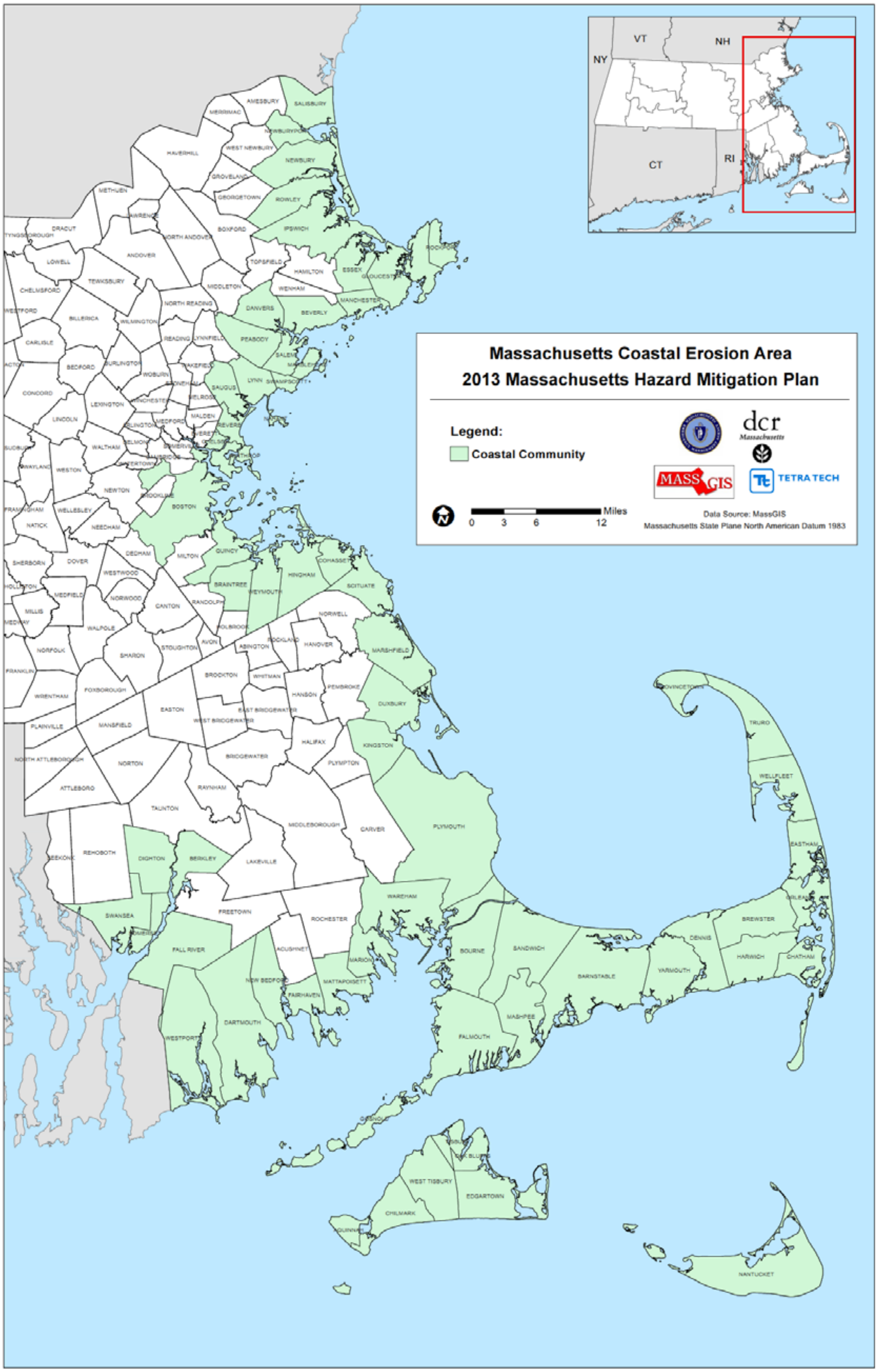

Figure 6-4. Massachusetts Coastal Communities

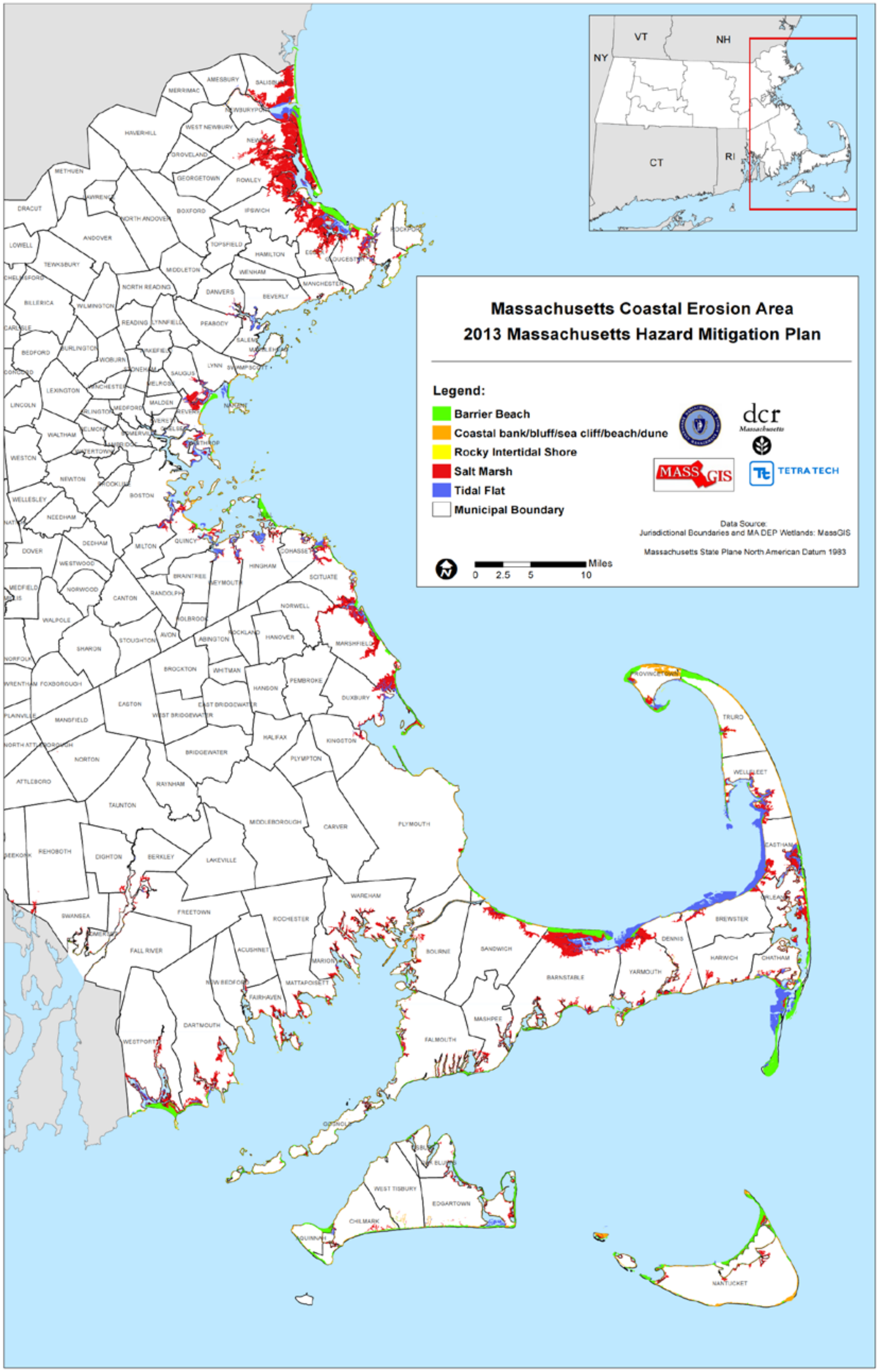

Figure 6-5. Coastal Erosion Hazard Area

Boston Harbor/Massachusetts Bay

Covering the coastal communities from Winthrop to Weymouth, inclusive of the City of Boston. The Massachusetts Water Resources Authority treatment plant treats sewage from metropolitan Boston communities and releases treated effluent nine miles offshore. The Stellwagen Bank National Marine Sanctuary, which is eastward of the state ocean waters of this region, is a highly productive area of nutrient upwelling that provides abundant food for a variety of species of fish, marine mammals, and sea birds, including the endangered humpback and northern right whales.

Industrial activity and shipping are heavy in this region. The Port of Boston is a maritime industrial hub for New England, and it has direct calls by large container vessels from Europe and the Far East. Fourteen million tons of bulk cargo enter its waters each year. In 2002, 250,000 cruise passengers and more than 100,000 automobiles came across its docks. The Port of Boston is estimated to have an $8 billion impact on the economy, producing more than 9,000 direct jobs. The Conley container terminal, the complex of uses on the Mystic River, Logan Airport, and Chelsea Creek are major industrial features. The Weymouth Back River, with its gas pipeline and ships carrying petroleum products, is an area of localized industrial activity. A natural gas pipeline (the Hubline) extends from Weymouth to Salem, and two offshore liquefied natural gas ports have pipelines that connect to the Hubline east of Marblehead. Recreational boating is significant throughout Massachusetts Bay. Major destinations include Stellwagen Bank for fishing and whale watching and the Boston Harbor Islands for boating, hiking, fishing, and diving. Figure 6-6 demonstrates the mean sea level trend as established at a NOAA Station within Boston.

Source: http://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?stnid=8443970

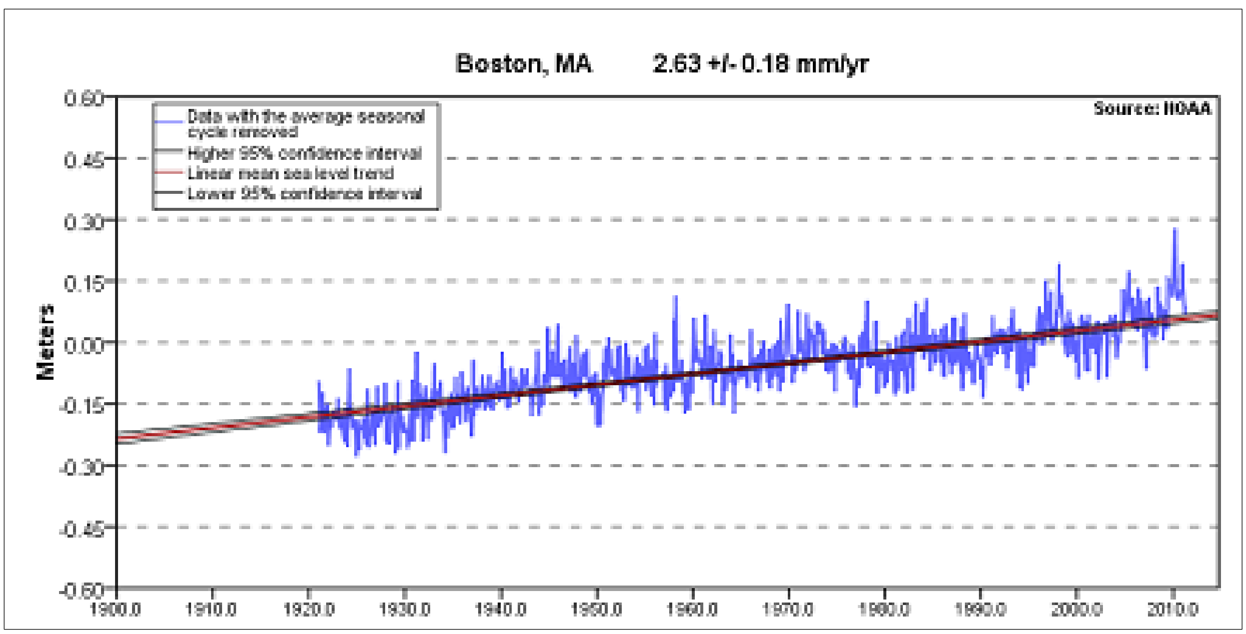

Figure 6-6. Mean Sea Level Trend at the NOAA Station 8443970 in Boston

The NOAA station in Boston (8443970) indicates a rise in sea level since 1921. The mean sea level trend is 2.63 millimeters/year with a 95-percent confidence interval of +/- 0.18 mm/year based on monthly mean sea level data from 1921 to 2006 which is equivalent to a change of 0.86 feet in 100 years.

Projections of sea-level rise for Boston range from 2 feet to as much as 6 feet by the end of the century, depending on how fast ice in Greenland and Antarctica melt (see Figure 6-7). For additional data on sea-level rise in Boston, please refer to Section 1.5.4 and to: http://www.tbha.org/preparing-rising-tide-report

Source: http://www.cityofboston.gov/climate/sealevelriseboston.asp

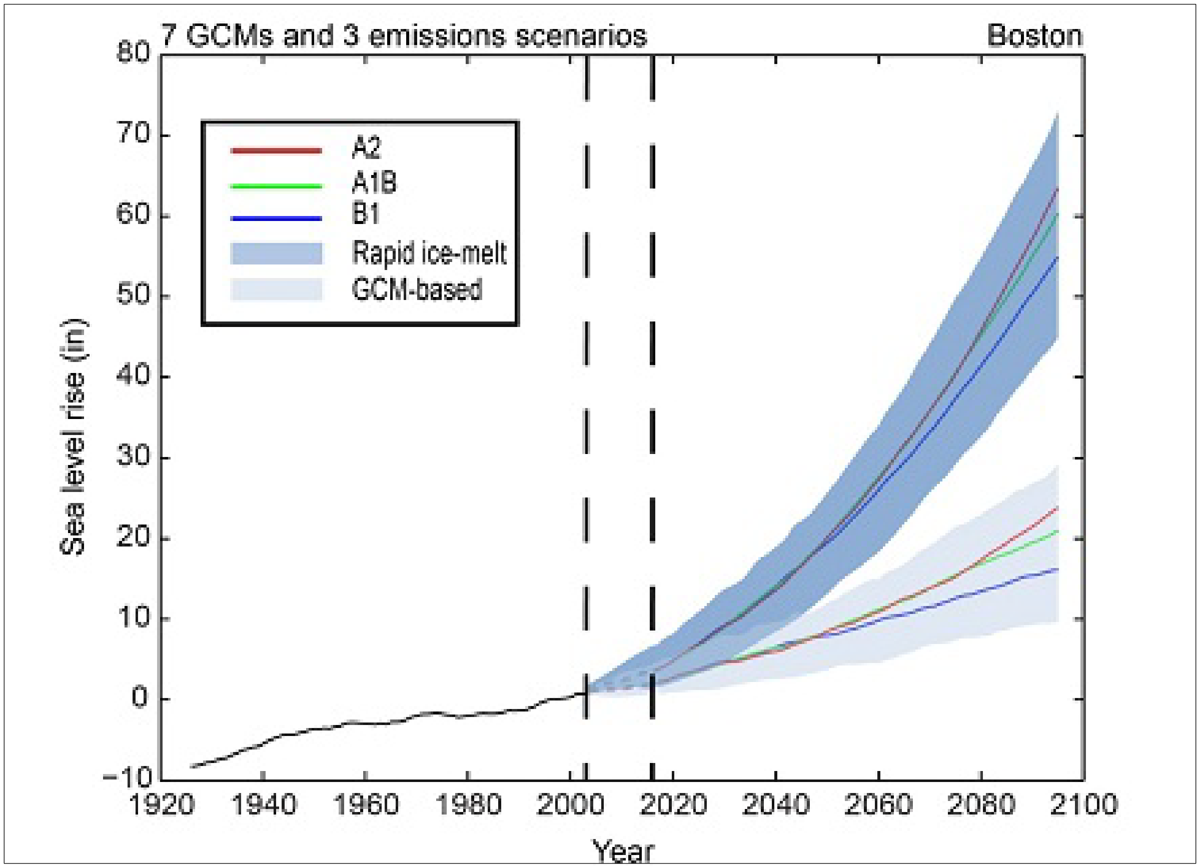

Figure 6-7. Sea-level Rise Projections for Boston

South Shore

Extending from Hingham to Plymouth, the South Shore beaches are composed of mixed sand, gravel, and cobble. Erosion is an issue, particularly on these beaches and coastal banks. A large portion of Cape Cod Bay is designated critical habitat for northern right whales, which typically inhabit the waters during winter and early spring, although individual whales may periodically stay on later in the year. There are relatively few industrial uses on the South Shore and in Cape Cod Bay. The water-cooled Pilgrim Nuclear Power Station in Plymouth is the only major industrial facility in the region. Small commercial boating, including fishing operations, whale watching, sightseeing, and commuter ferry service out of Hingham, are major uses in this region.

Cape Cod and Islands

This region covers Cape Cod Bay from Bourne to Provincetown, Martha's Vineyard, and Nantucket. Cape Cod and the Islands are characterized by sandy barrier beaches backed by coastal dunes and banks along much of the coast. There are thousands of acres of salt marsh, and the area is significant to several endangered species of birds and vegetation. Cape Cod Bay is critical habitat for the endangered northern right whale. Other species of whales, marine mammals, and turtles also inhabit the bay. Water quality is generally good and locally excellent (e.g., Wellfleet Harbor is designated as a body of outstanding Resource Water.) Industrial uses of the area are primarily related to fuel transport and storage. There are tank facilities in Vineyard Haven, Gosnold, and Nantucket. Fuel is transported by barge to these facilities in significant quantities. There are also industrial transport activities associated with the year-round ferry service to the islands from Hyannis and Woods Hole. Woods Hole also supports a fleet of deep-sea research vessels and fisheries vessels operated by the National Oceanic and Atmospheric Administration and National Marine Fisheries Service. Commercial fishing takes place with various fleet sizes in many of the harbors across the Cape and the Islands. The entire region is largely dependent on tourism.

South Coast

Covering the coastal communities westward of Cape Cod includes all of Buzzards Bay. Buzzards Bay is a relatively shallow estuary, and it receives relatively warm waters from the south through the Gulf Stream. It is home to some of the richest shellfish resources in the Commonwealth. Buzzards Bay provides vital habitat for endangered and rare species, including piping plovers, leatherback turtles, diamondback terrapins, and more than half of the North American population of the endangered roseate tern. The industrial ports of New Bedford and Fall River are significant economic engines for the region. Focusing on New Bedford, the port is predominated by approximately 400 large fishing vessels, but also receives cargo ships and, increasingly, cruise vessels. New Bedford is also home to a large and vibrant fish-processing center that not only processes catch landed locally, but also large quantities of fish from around the globe brought in by freighter and airplane. In addition, there are significant large boat repair operations within the harbor.

Buzzards Bay is the center of extensive shipping activity, serving as the southern funnel to the Cape Cod Canal, through which pass vast quantities of petroleum and cargo bound for Boston and other ports farther north. It is estimated that approximately 2 billion gallons of petroleum products pass through Buzzards Bay each year. Since 2000, New Bedford has been ranked the highest dollar-value fishing port in the nation, with the annual fish landings valued at more than $268 million in 2007.

6.2.2 Previous Occurrences

Hurricanes (DR-22)—September 1954

Two hurricanes 12 days apart in 1954 caused widespread coastal damage in southern New England.

Hurricane Carol

On the morning of August 31, 1954 Hurricane Carol, the most destructive hurricane to strike Southern New England since the Great New England Hurricane of 1938, came crashing ashore near Old Saybrook, Connecticut, leaving 65 people dead in her wake. Sustained winds of 80 to 100 mph roared through the eastern half of Connecticut, all of Rhode Island, and most of eastern Massachusetts. Scores of trees and miles of power lines were blown down. Strong winds also devastated crops in the region. Nearly 40 percent of apple, corn, peach, and tomato crops were ruined from eastern Connecticut to Cape Cod. Hurricane Carol arrived shortly after high tide, causing widespread tidal flooding. Narragansett Bay and New Bedford Harbor received the largest surge values of over 14 feet in the upper reaches of both water ways. On Narragansett Bay, just north of the South Street Station site, the surge was recorded at 14.4 feet, surpassing that of the 1938 Hurricane. However, since Hurricane Carol arrived after high tide, the resulting storm tide was lower. The heaviest amounts of rainfall, up to 6 inches, occurred in the New London, Connecticut area in the vicinity of landfall, and across extreme north central Massachusetts. Hurricane Carol destroyed nearly 4,000 homes, along with 3,500 automobiles and over 3,000 boats. All of Rhode Island, much of eastern Connecticut, and much of eastern Massachusetts lost electrical power. In addition, as much as 95 percent of all phone power was interrupted in these locations. Carol is estimated to have been a Category 3 Hurricane (NOAA, 2013 (a)).

Hurricane Edna

Following closely on the heels of Hurricane Carol was Hurricane Edna. Edna made landfall during the morning of September 11, passing over Martha's Vineyard and Nantucket, then across the eastern tip of Cape Cod, Massachusetts. Hurricane force winds of 75 to 95 mph buffeted all of eastern Massachusetts and coastal Rhode Island. Inland, sustained winds of 50 to 70 mph were common west of the Connecticut

River Valley. Peak wind gusts included 120 mph on Martha's Vineyard, 110 mph on Block Island, and 100 mph at Hyannis, Massachusetts. The strong winds knocked out electrical power across sections of Rhode Island, eastern Massachusetts, and nearly all of Cape Cod and the Islands. The lowest recorded pressure was 28.02 inches at Edgartown on Martha's Vineyard. Edna arrived during a rising tide and resulted in severe flooding across Martha's Vineyard, Nantucket, and Cape Cod, where storm surges of over 6 feet were common. Farther west, storm surge values were 4 feet or less, resulting in storm tides that remained below flood stage. Damage to the boating community was severe across Cape Cod, but was much less across the remainder of Massachusetts and Rhode Island. Edna's track across the extreme eastern part of the region did result in heavy rainfall and inland flooding.

Rainfall amounts of 3 to 6 inches were common, with over seven inches across northeastern Massachusetts. This rainfall aggravated the already saturated conditions caused by Hurricane Carol ten days earlier. The total combined rainfall for Carol and Edna ranged from 5 to 7 inches along and west of the Connecticut River and over Cape Cod, to as much as 11 inches from southeast Connecticut, across most of Rhode Island, to northeast Massachusetts. Considerable urban and small stream flooding occurred. Numerous street washouts were common, along with some major river flooding in Rhode Island and northeast Massachusetts, where rivers rose several feet above flood stage. Edna was responsible for 21 deaths across the region (Vallee and Dion, Date Unknown).

Coastal Storms, Flood, Ice, Snow (DR-546)—February 1978

The February 1978 Blizzard remains as the benchmark storm for comparison by all subsequent nor'easters. This life-threatening nor'easter crippled most of the Commonwealth with blizzard conditions, extraordinarily heavy snow, high winds, and devastating coastal flooding. The storm claimed 73 lives in Massachusetts and 26 in neighboring Rhode Island. Over 10,000 people had to be sheltered. An unprecedented ban on non-emergency vehicle traffic lasted for a week in much of eastern Massachusetts.

The combination of strong northeast winds and a slow moving storm system along with astronomically high tides brought in a large fetch of water along coastal communities. This caused serious coastal flooding and beach erosion problems resulting in broken seawalls and massive property loss (Strauss, Date Unknown). This event resulted in a federal disaster declaration (DR-546) (Strauss, date unknown).

Hurricane Bob (DR-914)—August 1991

Hurricane Bob was the second named storm and the first hurricane of the 1991 hurricane season, reaching a Category 3 status. Winds were sustained at 115 mph, impacting North Carolina, Mid-Atlantic States, New England, and Atlantic Canada, causing 15 fatalities. This event resulted in a federal disaster declaration (DR-914).

Severe Coastal Storm (DR-920)—October-November 1991

This storm was unusual event, as the large Nor'easter moved south and gained strength when it joined what remained of Hurricane Grace, becoming what some refer to as the Perfect Storm. Winds from this event were measured over 80 MPH, with and waves over 30 feet in some parts of the coastline. This storm caused flooding and wind damage in several counties. This event resulted in a federal disaster declaration (DR-920).

Coastal Storm (DR-975)—December 1992

This event caused more than $12.6 million in public infrastructure damage (roads, bridges, public utilities, etc.) and resulted in 1,874 NFIP claims in Massachusetts at a cost of nearly $12.7 million.

Severe Storms and Flooding (DR-1364)—March-April 2001

A series of storms occurred in Massachusetts between March 5 and April 16. These events included a major winter storm, heavy rainfall, and melting snow. On March 5, a major winter storm impacted Massachusetts with near-blizzard conditions, high winds, and coastal flooding. Over 2 feet of snow fell across the interior portion of the Commonwealth. Approximately 80,000 people were without power and businesses and schools were closed for several days. Snowfall totals ranged between 2 and 30 inches across Massachusetts. High tides ran 2 to 3 feet above normal, resulting in widespread coastal flooding along the entire east-facing coastline. Beachfront homes and roadways were flooded and sea walls were damaged. Between March 22 and March 31, flooding occurred throughout Massachusetts as a result of melting snow and heavy rainfall. The most severe flooding occurred in the Merrimack Valley. An event on March 30, with heavy snow in parts of interior Massachusetts and heavy rain and strong winds in coastal communities, caused flooding along rivers and streams in the eastern portion. Over 6 inches of rain fell in some areas. This series of flooding events resulted in a federal disaster declaration (DR-1364).

Nor'easter (Not Declared)—January 2005

The January 2005 Nor'easter event impacted the entire Commonwealth of Massachusetts. This storm was rated by the National Weather Service as a "top 5" in historical snowfall events in the U.S. The snow was very powdery and drifted, as it occurred with very low temperatures and high winds.

Coastal Storm / Nor'easter (DR-1614)—October 2005

A strong Nor'easter, combined with the remnants of Tropical Storm Wilma, brought heavy rainfall, damaging winds, and coastal flooding to the eastern portion of Massachusetts. Rainfall totals ranged between two and 2.5 inches. The high winds brought down limbs, trees, and wires, resulting in power outages to thousands of people. This event caused approximately $733,000 in property damage.

Severe Storms and Inland and Coastal Flooding (DR-1701)—April 2007

An intense coastal storm (April 15-16, 2007) brought wet snow, sleet, and rain to parts of western Massachusetts. Rainfall totals ranged between three and six includes and lead to minor flooding across the affected areas. Heavy rain and snowmelt also led to minor flooding of small streams and creeks in parts of the Commonwealth as well. This event resulted in a federal disaster declaration (DR-1701). Those counties included in this disaster received over $8 million in public assistance from FEMA. The storm was primarily a rain event due to warmer temperatures; however, higher elevations experienced significant snow and ice accumulations.

Tropical Storm Irene (DR-4028)—August 2011

Tropical Storm Irene (August 27-29, 2011) produced significant amounts of rain, storm surge, inland and coastal flooding, and wind damage across southern New England and much of the east coast of the U.S. In Massachusetts, rainfall totals ranged between 0.03 inches (Nantucket Memorial Airport) to 9.92 inches (Conway, MA). These heavy rains caused flooding throughout the Commonwealth and a presidential disaster was declared (DR-4028). Tropical Storm Irene was closely followed by the remnants of Tropical Storm Lee, which brought additional heavy rain to Massachusetts and extended flooding. Severe river erosion occurred in northwestern Massachusetts, closing State Route 2. Landslides were also triggered by the heavy rain and wet soil in this area of steep slopes containing layers of glacial lake clay. The Commonwealth received over $31 million in individual and public assistance from FEMA.

Hurricane Sandy (DR-4097)—October-November 2012

Hurricane Sandy was the largest Atlantic hurricane on record, with winds spanning 1,100 miles in diameter, reaching sustained forces of 110 mph. Estimated losses due to damage and business interruption are still being calculated, but are estimated to exceed $65 billion. At present count (December 2012), at least 253 people were killed along the path of the storm, with 131 of those deaths occurring within the U.S. although no deaths occurred in Massachusetts.

Tide Records

Hurricanes and Nor'easters have varied impact on the coast, depending on a number of variables. There are three gauge stations, Boston, Woods Hole, and Nantucket, measuring tide and surge in Massachusetts. Each gauge has a varied recording history, Boston dates back to 1922, Woods Hole 1933, and Nantucket only to 1965; however, the information provides relevant comparisons. An analysis was conducted to rank the top, or highest, tides for each gauge. Table 6-1 shows the top 10 highest tides for each gauge.

TABLE 6-1.
TOP 10 HIGHEST TIDES AT MASSACHUSETTS GAUGES

Station: 8443970 **Begin Date:** 19001024
Name: Boston, MA **End Date:** 20130422
Product: High/Low **Units:** Feet
Datum: StnDatum **Quality:** Verified

Rank	Highest	Highest	Date	Zone	Lowest	Lowest	Date	Zone
1	18.62	19780207	10:36	LST	-0.20	19280125	00:00	LST
2	17.72	19870102	12:18	LST	-0.20	19400324	00:00	LST
3	17.66	19911030	16:54	LST	-0.10	19230403	00:00	LST
4	17.56	19790125	00:00	LST	0.00	19300314	00:00	LST
5	17.55	19921212	12:42	LST	0.00	19220213	00:00	LST
6	17.32	20070418	03:48	GMT	0.00	19241226	00:00	LST
7	17.30	20050525	04:36	GMT	0.13	19771210	00:00	LST
8	17.22	20101227	08:18	GMT	0.15	19800319	06:54	LST
9	17.19	20050526	05:24	GMT	0.20	19220116	00:00	LST
10	17.10	20120605	03:54	GMT	0.20	19361228	00:00	LST

The top tides shared by all three gauges, occurred during wintertime (October-May) northeast storms. The Woods Hole gauge's top five storms are hurricanes occurring in August and September and did not typically generate top tides in Boston or Nantucket.

Erosion

Section 6.1.1 discusses the historical shoreline change data available for the Commonwealth.

6.2.3 Frequency

Coastal erosion is measured as the rate of change in the position or horizontal displacement of a shoreline over a specific period of time, measured in units of feet or meters per year. Erosion rates vary as a function of shoreline type and are influenced primarily by episodic events. Monitoring of shoreline change based on a relatively short period of record does not always reflect actual conditions and can misrepresent long-term erosion rates. The long-term patterns of coastal erosion are difficult to detect because of substantial and rapid changes in coastlines in the short-term (that is, over days or weeks from storms and natural tidal processes). It is usually severe short-term erosion events, occurring either singly or cumulatively over a few years, that cause concern and lead to attempts to influence the natural processes. Analysis of both long- and short-term shoreline changes are required to determine which is more reflective of the potential future shoreline configuration.

The return period of an episodic erosion event is directly related to the return period of a coastal storm, hurricane or tropical storm. The one-percent annual chance erosion event can be determined using a predictive model that establishes the one-percent annual chance tide and water surface level, or surge elevation and the resulting wave heights. Storm wave heights, periods and directions have specific impacts on the tides, currents, and other erosion processes. Analyses of coastal erosion impacts from the one-percent annual chance flood event are included in high-hazard zone determinations shown on NFIP maps. The impacts may vary for each reach of coastline.

A more significant measure of coastal erosion is the average annual erosion rate. Erosion rates can be used in land-use and hazard management to define areas in which development should be limited or where special construction measures should be used. The average annual erosion rate is based on analysis of historical shorelines derived from maps, charts, surveys, and aerial photography obtained over a period of record.

6.2.4 Severity

Coastal erosion is measured at the rate of change in the position or horizontal displacement of a shoreline over a period of time. A number of factors determine whether a community exhibits greater long-term erosion or accretion:

- Exposure to high-energy storm waves,
- Sediment size and composition of eroding coastal landforms feeding adjacent beaches,
- Near-shore bathymetric variations which direct wave approach,
- Alongshore variations in wave energy and sediment transport rates,
- Relative sea level rise,
- Frequency and severity of storm events, and
- Human interference with sediment supply (e.g. revetments, seawalls, jetties).

Such erosion may be exacerbated by activities such as boat wakes, shoreline hardening or dredging.

Natural recovery after erosive episodes can take months or years. If a dune or beach does not recover quickly enough via natural processes, coastal and upland property may be exposed to further damage in subsequent events. Coastal erosion can cause the destruction of buildings and infrastructure.

6.2.5 Warning Time

Meteorologists can often predict the likelihood of weather events which can impact shoreline communities, and ultimately the shoreline. NOAA’s National Weather Service monitors potential events, and provides forecasts and information, in advance of a storm through multiple means varying in system characteristics and time issued. The National Weather Service provides early notification through its Hazardous Weather Outlook, which is a narrative statement produced and issued on a routine basis, to provide information regarding the potential of significant weather expected during the next 1 to 5 days (NWS, 2009). Additionally, for nor’easters the National Weather Service issues Coastal Flood Advisories when minor flooding is possible; Coastal Flood Watches when flooding with significant impacts is possible; or Coastal Flood Warnings when flooding that will pose a serious threat to life and property is occurring, imminent or highly likely (NWS, 2009). For tropical, subtropical, or post-tropical systems the National Weather Service will issue a Hurricane or Tropical Storm Warning 36 hours in advance of the anticipated onset of tropical-storm-force winds or a Hurricane or Tropical Storm Watch 48 hours in advance of the anticipated onset of tropical-storm-force winds (NWS, 2013).

The National Weather Service uses common terms like minor, moderate, major, and severe to categorize the severity of forecasted beach erosion in statements, advisories, watches, and warnings. Although commonly used, no formal definition exists within the National Weather Service Glossary for these descriptors.

With shore structures increasing along the coastline, the shoreline becomes increasingly modified. Impact from weather incidents will continue to influence the Commonwealth's coastal areas, intensifying and exacerbating the situation.

6.2.6 Secondary Hazards

Windstorm events can blow beach and dune sand overland into adjacent low-lying marshes, upland habitats, inland bays, and communities. Flooding from extreme rainfall events can scour and erode dunes as inland floodwaters return through the dunes and beach face into the ocean.

Shore protection structures such as seawalls and revetments often are built to attempt to stabilize the upland property. However, typically, they eliminate natural wave run-up and sand deposition processes and can increase reflected wave action and currents at the waterline. Increase wave action can cause localized scour in front of structures and prevent settlement of suspended sediment.

6.3 CLIMATE CHANGE IMPACTS

Coastal shores change constantly due to wind, waves, tides, sea level fluctuation, seasonal and climatic variation, human alteration, and other factors that influence the movement of sand and material within a shoreline system.

Climatic trends can change a beach from naturally accreting to eroding due to increased episodic erosion events caused by waves from an above-average number of storms and high tides, or the long-term effects of fluctuations in sea or lake level. The coastal zone is being severely impacted by erosion and flooding due in part to climate change and sea-level rise. It is likely that the impact will increase in the future as sea levels continue to rise at the current rate or rises at an accelerated rate.

Impacts of climate change can lead to shoreline erosion, coastal flooding, and water pollution, affecting man-made coastal infrastructure and coastal ecosystems (http://www.epa.gov/climatechange/impacts-adaptation/coasts.html). Coastal areas may be impacted by climate change in different ways. Coastal areas are sensitive to sea level rise, changes in the frequency and intensity of storms, increase in precipitation, and warmer ocean temperatures. Additionally, oceans are absorbing more carbon dioxide, due to the rising atmospheric concentrations of the gas, and the oceans are becoming more acidic. This could have significant impacts on coastal and marine ecosystems (http://www.epa.gov/climatechange/impacts-adaptation/coasts.html).

6.3.1 Change in Coastal Geology

The cumulative impacts of global climate change and sea level rise will drastically change the coastal landscape of the coastlines around the world. The primary factors and processes driving changes are:

- Geologic framework and character
- Coastal plain geomorphology and slope
- Relative sea-level change
- Global change, land subsidence/uplift
- Major storm events, tropical storms/ hurricanes, extra-tropical storms nor'easters
- Seasonal coastal processes
  - Waves and tidal currents
  - Winds
  - Cold fronts and local storms
- Sediment budgets

  - Sediment sources (headlands, bluffs)
  - Sediment sinks (wash-over, inlets)

- Human activities
  - Coastal engineering structures
  - Dredging channels, inlets, canals
  - River modification (dams, levees)
  - Fluid (oil-gas-water) extraction
  - Climate change (sea-level rise, storms)

One component changing coastal landscape is coastal erosion. Coastal erosion is caused by scour of wave action against the sandy beaches and dunes of the coast line. This wave action can cause both aggregation and degradation. Sea level rise increases coastal erosion in several ways. First, as the sea level rises, wave action moves higher onto the beach. The surf washes sand and dunes out to sea or make the sand migrate parallel to the shoreline. The loss of the beach equals a loss in a buffer zone between the land and the sea, and this can lead to erosion of inland areas.

The loss of coastal wetlands also contributes to coastal erosion. Some IPCC models suggest that 33 percent of the global coastal wetlands will be under water by the year 2080. Areas with small tide ranges, such as sandy beaches, will see the greatest effect. The waves, tides, and currents erode beaches, dunes, and banks, resulting in landward retreat of these landforms, reducing the buffer they provide to existing development. More sediment is washed out to sea, rather than settling on the shore.

Storms are the biggest factor in coastal erosion. The intensity, number, and duration of the storms affect how much of the shore is eroded. The increase in the intensity and number of storms in the past few decades has eroded a number of coastlines. Storm surge and wave height increases devastate beaches. The higher the sea level, the further the storm surge moves onto the beach. Humans contribute to the increase in coastal erosion through engineering techniques used to protect homes. Many times, humans move sand dunes in an attempt to protect a specific structure, only to have the dune wash away. Sea walls can protect structures but often lead to complete loss of beaches, dunes, and banks. The Massachusetts Wetlands Protection Act and associated regulations, protect the ability of sand dunes and wetlands to migrate naturally, without human inference. The intent behind this theory is by allowing nature to take its course, less coastal loss will occur over time.

6.4 EXPOSURE

Coastal erosion, shoreline change, and sea-level rise are a significant concern to the Commonwealth because of the large number of communities and cultural resources located along the coast. Healthy beaches, dunes, and banks serve as a buffer and protect the built environment and other natural resources on the mainland from coastal storm events such as hurricanes, tropical storms and nor'easters which can cause shoreline erosion or accretion.

To understand risk, the assets exposed to the hazard areas are identified. For the purposes of this Plan, the wetland types in the MassDEP wetlands spatial layer (barrier beach, coastal beach, coastal dune, coastal bank, rocky intertidal shore, salt marsh, and tidal flat) are considered coastal resource areas that may be impacted by coastal erosion. This section discusses exposure of the following to coastal erosion:

- Population
- State facilities
- Critical facilities
- Economy.

Shoreline change, whether erosion or accretion, is dependent upon several factors including location (e.g., open-ocean facing shore) and exposure to high-energy storm waves. The coastal high hazard area (or V zone where "V" stands for velocity wave action) is the most hazardous part of the coastal floodplain due to its exposure to wave effects. Storm surge inundation can exceed regulatory floodplain boundaries (V and A zones), which also can contribute to coastal erosion. More information is available in Section 10, which discusses assets in the V zone and exposed to storm surge. Sea-level rise inundation and depth grids were not available to conduct a quantitative analysis for this plan update. The coastal hazard is discussed qualitatively below.

6.4.1 Population

To estimate the population exposed to the shoreline change hazard, the 2010 Census blocks with their centroid in the identified MassDEP coastal resource areas identified as vulnerable to coastal erosion were determined. Please note Census blocks do not follow the boundary of the wetland types, and the results of this methodology should only be used as an estimate. This figure does not account for the increase in population (both residents and tourists) during the summer months. Table 6-2 summarizes the estimated 2010 U.S. Census population exposed to the coastal erosion hazard by County.

TABLE 6-2.
ESTIMATED POPULATION EXPOSED TO THE COASTAL EROSION HAZARD

County	Total Population	Estimated Population Exposed	% of Total
Barnstable	215,888	4,281	2.0
Berkshire	131,219	—	—
Bristol	548,285	1,224	0.2
Dukes	16,535	78	0.5
Essex	743,159	9,870	1.3
Franklin	71,372	—	—
Hampden	463,490	—	—
Hampshire	158,080	—	—
Middlesex	1,503,085	0	—
Nantucket	10,172	8	0.1
Norfolk	670,850	3,515	0.5
Plymouth	494,919	12,748	2.6
Suffolk	722,023	4,985	0.7
Worcester	798,552	—	—
Total	**6,547,629**	**36,709**	**0.6**

Source: U.S. Census, 2010; MassGIS, 2012

6.4.2 State Facilities

To assess the exposure of the state-owned and leased facilities provided by DCAMM and the Office of Leasing, an analysis was conducted with the identified MassDEP coastal resource areas identified as vulnerable to coastal erosion. Using ArcMap, GIS software, the selected wetland types were overlaid with the state facility data to estimate the number of state facilities exposed to coastal erosion. Table 6-3 summarizes these state facilities by County. Figure 6-8 illustrates these facilities.

TABLE 6-3.
NUMBER OF STATE-OWNED AND STATE-LEASED BUILDINGS

County	State-Owned Buildings	State-Leased Buildings	**Total**
Barnstable	15	—	**15**
Berkshire	—	—	**—**
Bristol	23	—	**23**
Dukes	—	—	**—**
Essex	6	—	**6**
Franklin	—	—	**—**
Hampden	—	—	**—**
Hampshire	—	—	**—**
Middlesex	—	—	**—**
Nantucket	—	—	**—**
Norfolk	—	—	**—**
Plymouth	14	—	**14**
Suffolk	—	—	**—**
Worcester	—	—	**—**
Total	**58**	**0—**	**58**

Source: DCAMM, 2012; MassGIS, 2012
Note: Building data are updated as agencies change or modify them. The state-owned building information is current as of October 3, 2012, and the state-leased building information is current as of October 10, 2010 with a total of 6,765 buildings.

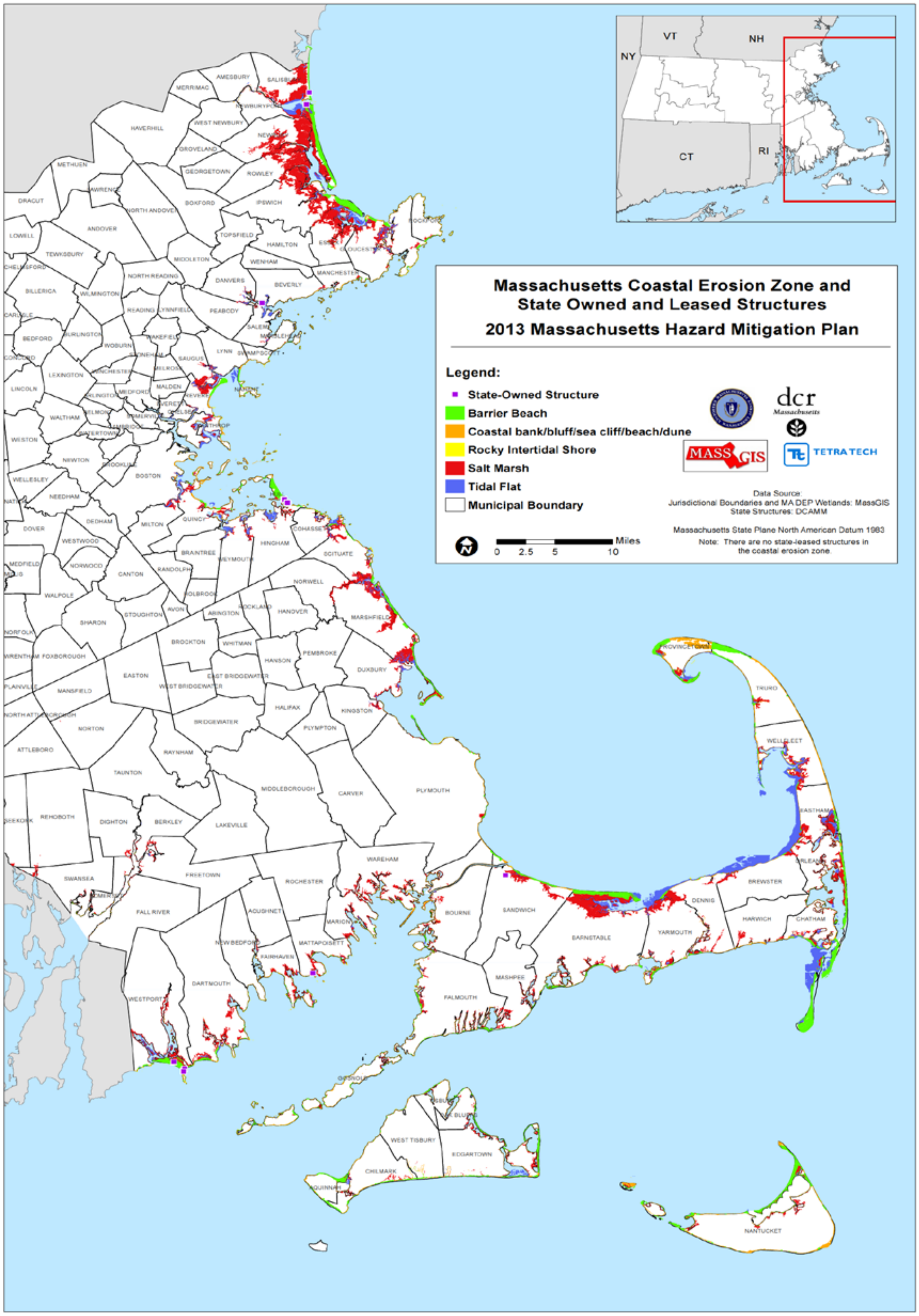

Figure 6-8. State-Owned and State-Leased Facilities Exposed to the Coastal Erosion Hazard

6.4.3 Critical Facilities

Wetland types identified as vulnerable to the coastal erosion hazard were analyzed in order to assess the exposure of critical facilities. Using GIS software, the selected coastal resource areas identified as vulnerable to coastal erosion were overlaid with critical facility data provided by MassGIS to determine the number of facilities within this area. Table 6-4 summarizes the number of critical facilities exposed to the coastal erosion hazard by County.

TABLE 6-4.
NUMBER OF CRITICAL FACILITIES EXPOSED TO THE COASTAL EROSION HAZARD

County	Police	Fire	Hospital	Emergency Operation Center	School	Colleges
Barnstable	—	—	—	—	1	—
Berkshire	—	—	—	—	—	—
Bristol	—	—	—	—	—	—
Dukes	—	—	—	—	—	—
Essex	—	—	—	—	—	—
Franklin	—	—	—	—	—	—
Hampden	—	—	—	—	—	—
Hampshire	—	—	—	—	—	—
Middlesex	—	—	—	—	—	—
Nantucket	—	—	—	—	—	—
Norfolk	—	—	—	—	—	—
Plymouth	—	2	—	—	1	—
Suffolk	—	1	—	—	—	—
Worcester	—	—	—	—	—	—
Total	**0**	**3**	**0**	**0**	**2**	**0**

Source: MassGIS, 2012

Coastal erosion can also severely impact roads and infrastructure. As the coastline evolves, evacuation and emergency routes need to be considered. The number of highway bridges in the wetland types identified as vulnerable to coastal erosion was determined by County, as summarized in Table 6-5. Please note this analysis may underestimate the number of bridges identified as exposed because in some instances the defined coastal erosion hazard area may not extend across the water where the bridge point is located.

TABLE 6-5.
NUMBER OF BRIDGES EXPOSED TO THE COASTAL EROSION HAZARD

County	Total Bridges Exposed	Federal	State	Local
Barnstable	12	—	4	8
Berkshire	—	—	—	—
Bristol	1	—	1	—
Dukes	1	—	1	—
Essex	8	—	3	5
Franklin	—	—	—	—
Hampden	—	—	—	—
Hampshire	—	—	—	—
Middlesex	—	—	—	—
Nantucket	1	—	—	1
Norfolk	1	—	1	—
Plymouth	2	—	1	1
Suffolk	2	—	2	—
Worcester	—	—	—	—
Total	**28**	**0**	**13**	**15**

Source: Hazus-MH v. 2.1; MassGIS, 2012

6.4.4 Economy

As noted earlier, the beaches, parks, and natural resources along the Massachusetts coast greatly contribute to the local economy especially during the summer season where the population can more than double. Figure 6-9 illustrates the greater than 200 linear miles of public and semi-public beaches in the Commonwealth that attract residents and tourists and contribute to the local economy.

"Massachusetts's coastal and ocean areas include abundant natural, recreational, and economic resources that have shaped the state's history, economy, and way of life."

– Massachusetts Office of Coastal Zone Management, 2011

Numerous natural coastal resources that protect the shoreline and have enormous ecological and economic value. Another valuable coastal resource and line of defense from coastal erosion are the barrier beaches. There are 29.6-square miles (or nearly 19,000 acres) of state-designated barrier beach in the Commonwealth. Figure 6-10 displays the locations of the state-designated barrier beaches.

Salt marshes are another coastal resource that protects the shoreline from coastal storms, flooding, erosion, and sea level rise. One such example is illustrated in Figure 6-11 for the Parker River/Essex Bay Area of Critical Environmental Concern project. The purpose of the project was to develop a regional picture of past, current, and potential restoration sites along with supporting information to help future restoration planning (MassGIS, 2012).

Source: MassGIS, 2012

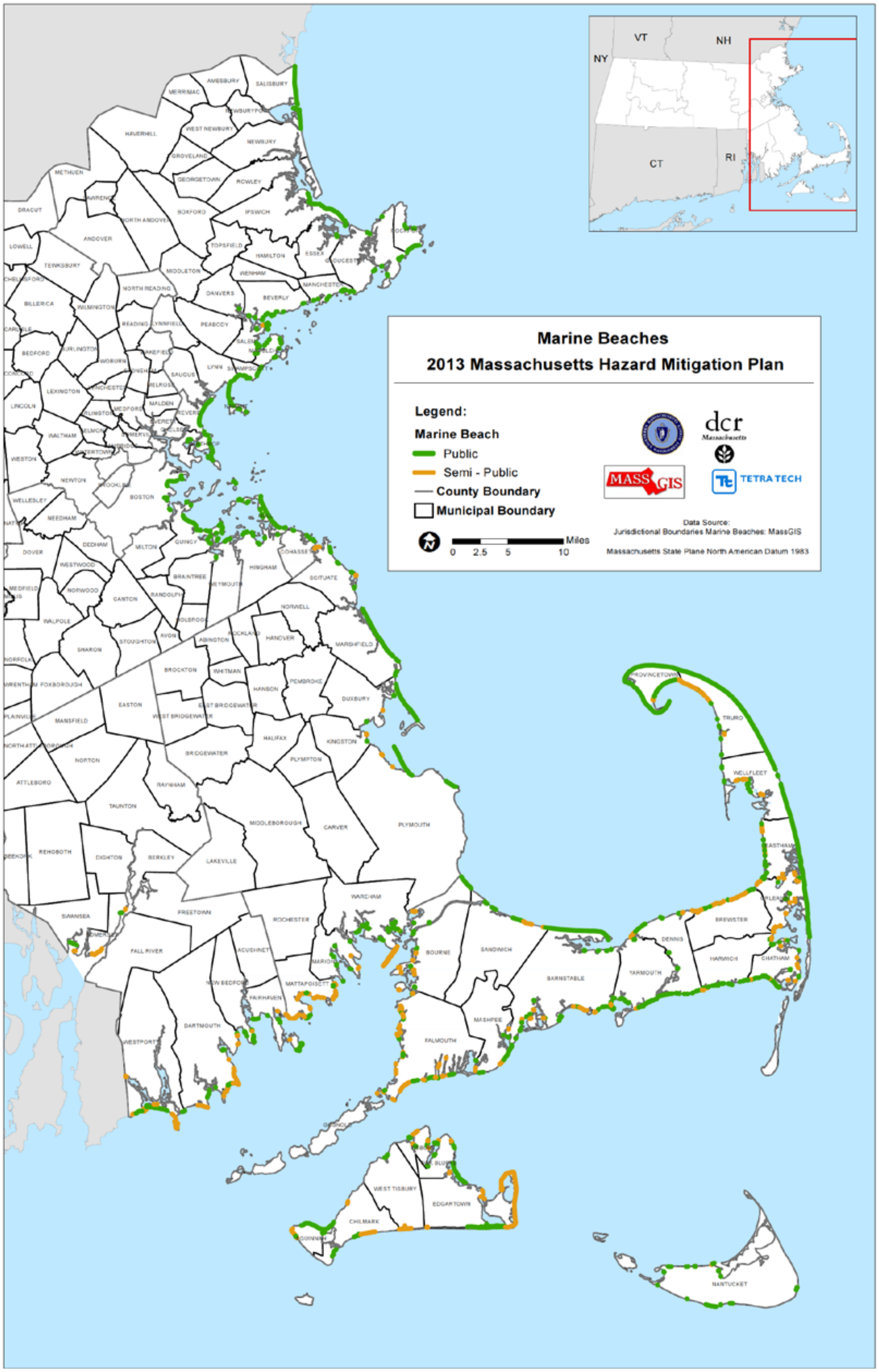

Figure 6-9. Marine Beaches in the Commonwealth of Massachusetts

Source: MassGIS, 2012

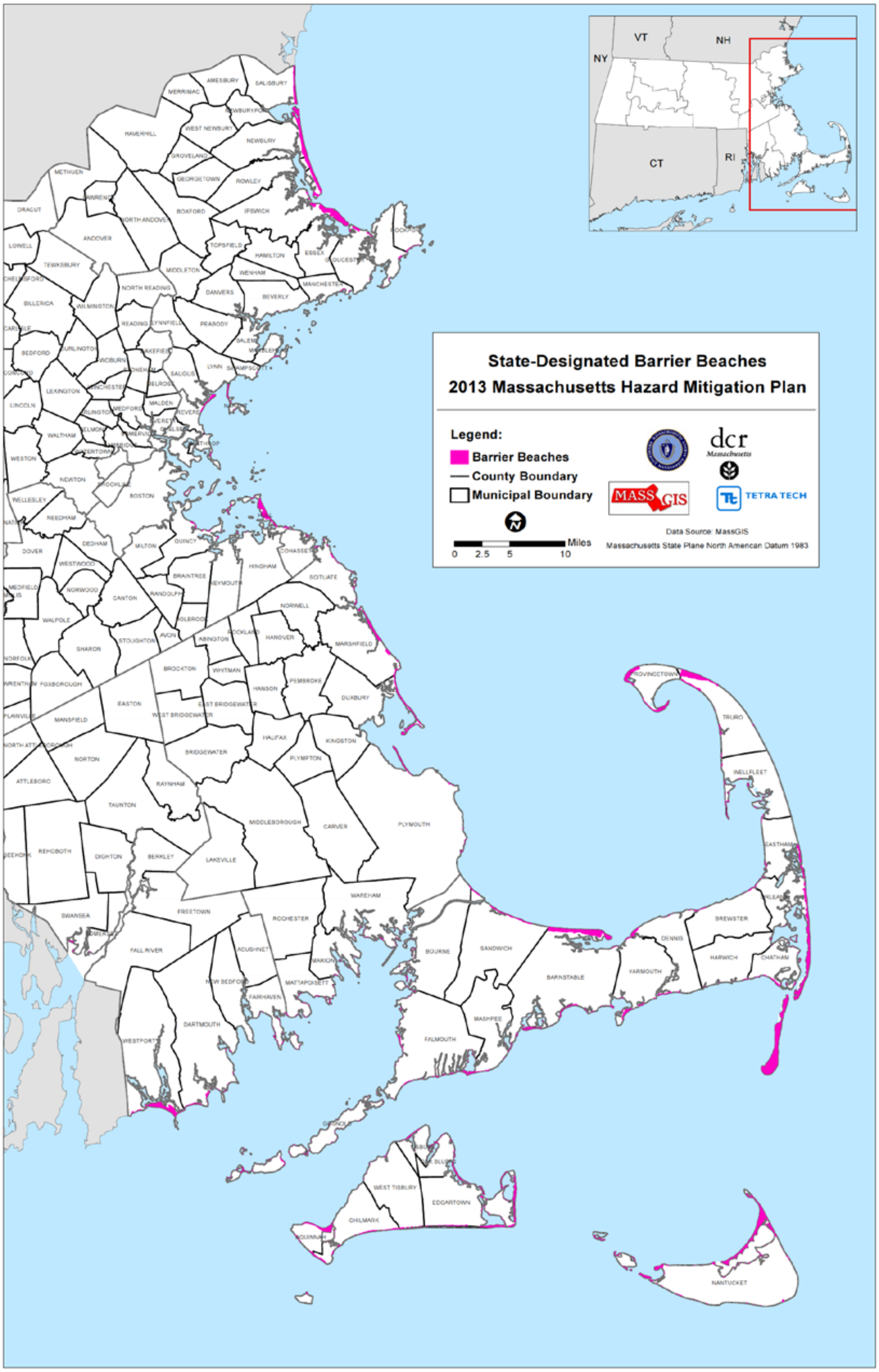

Figure 6-10. State-Designated Barrier Beaches

Source: MassGIS, 2012

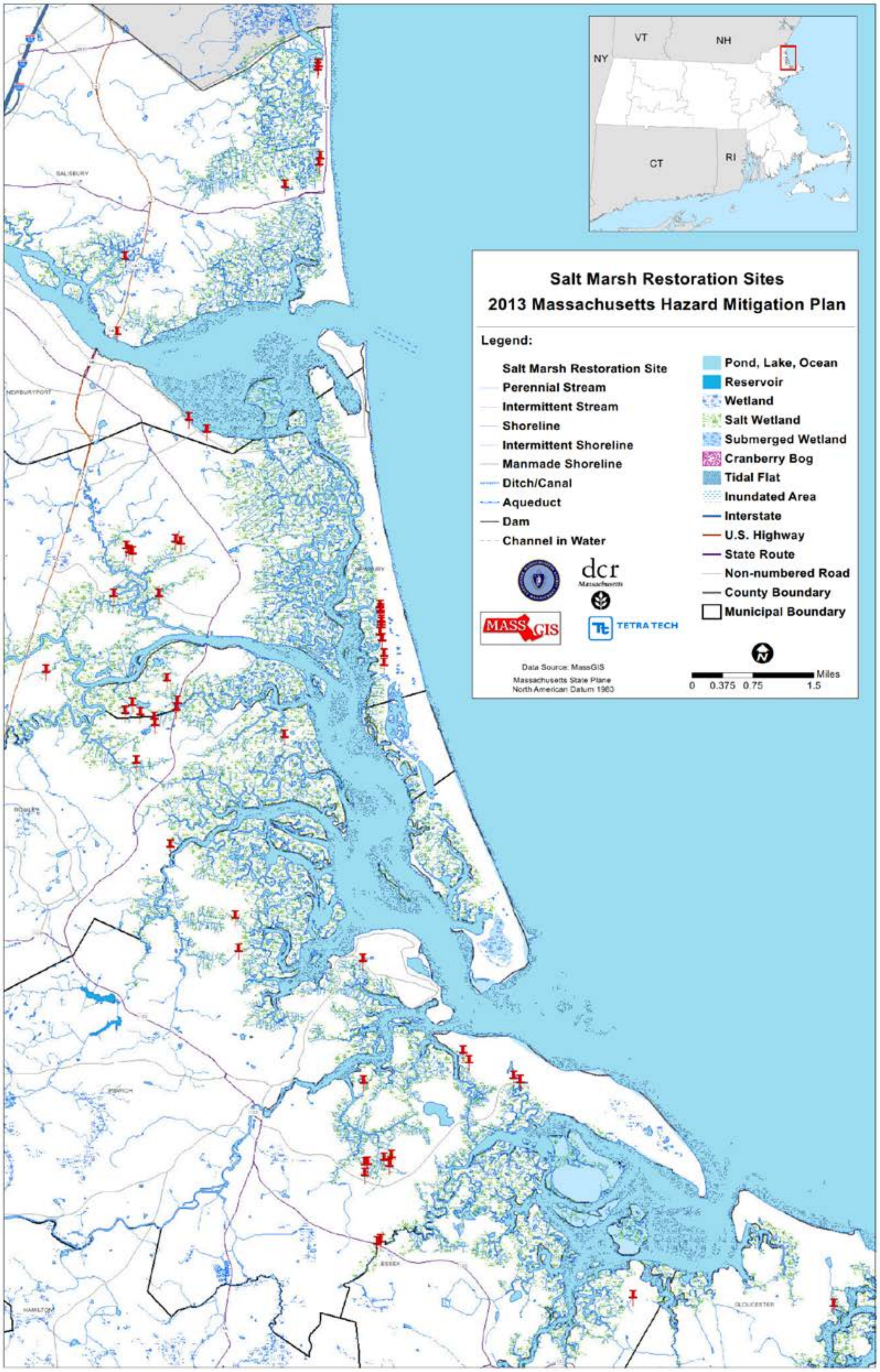

Figure 6-11. Salt Marsh Restoration Sites

6.5 VULNERABILITY

6.5.1 Population

Coastal erosion is not generally considered an imminent threat to public safety when the changes are gradual over many years. However, drastic changes to the shoreline may occur as a result of a single storm event which can threaten homes and public safety. The population exposed is also considered vulnerable to this hazard. Refer to Subsection 6.4.1.

6.5.2 State Facilities

To estimate the potential losses to state-owned and state-leased structures, the exposure analysis methodology was used. As discussed, there are 6,765 state-owned/leased structures in the Commonwealth and a total of 58 state-owned structures in the coastal resource area identified as vulnerable to coastal erosion. Table 6-6 identifies a total risk exposure of greater than $57 billion for state-owned and leased buildings in the Massachusetts coastal resource area. This figure assumes 100-percent loss to each structure and its contents. This estimate is considered high because coastal erosion generally occurs in increments of inches to feet per year along the coastline and would not occur across the entire coastal resource area at the same time from one event. Nonetheless, the total replacement cost value of state facilities within this area represents an estimated total loss value for facilities in the Massachusetts coastal resource area.

TABLE 6-6.
ESTIMATED REPLACEMENT COST VALUE OF STATE-OWNED AND STATE-LEASED BUILDINGS EXPOSED TO THE COASTAL EROSION HAZARD

County	Total Inventory Replacement Cost Value	Value Exposed			
		Own	Lease	Total	% of Inventory Total
Barnstable	$1,146,314,361	$15,263,116	—	$15,263,116	1.3
Berkshire	$1,852,000,832	—	—	—	—
Bristol	$3,012,210,350	$10,018,954	—	$10,018,954	0.3
Dukes	$16,224,048	—	—	—	—
Essex	$4,473,201,429	$24,660,411	—	$24,660,411	0.6
Franklin	$813,236,929	—	—	—	—
Hampden	$5,051,650,248	—	—	—	—
Hampshire	$4,687,387,853	—	—	—	—
Middlesex	$9,881,996,655	—	—	—	—
Nantucket	$31,381,244	—	—	—	—
Norfolk	$5,141,831,256	—	—	—	—
Plymouth	$3,182,404,153	$32,348,396	—	$32,348,396	1.0
Suffolk	$8,283,073,730	—	—	—	—
Worcester	$9,444,698,995	—	—	—	—
Total	**$57,017,612,082**	**$82,290,876**	**—**	**$82,290,876**	**0.1**

Source: DCAMM, 2012: MassGIS, 2012

Note: Building data are updated as agencies change or modify them. The state-owned building information is current as of October 3, 2012, and the state-leased building information is current as of October 10, 2010 with a total of 6,765 buildings.

6.5.3 Critical Facilities

Similar to the state facilities, to estimate potential losses to critical facilities and infrastructure, the exposure analysis methodology was used. The replacement cost values for critical facilities were not available for this planning effort. A total risk exposure would equal to the full replacement value of each critical facility exposed. As these data becomes available, the Commonwealth will update this section of the plan with new information. In terms of highway bridges, the Hazus-MH v. 2.1 default replacement cost value for the bridges estimated as exposed to coastal erosion is $308,051,240.

6.5.4 Economy

The Commonwealth's coastal resources are an enormous driver to the local economy and losses can greatly impact the Commonwealth's tax base and the local industries (i.e., tourism). Massachusetts' coastline and state ocean waters support 152,000 jobs and generate $4.3 billion in income each year, in addition to providing recreational opportunities (Durrant, 2008).

Building damage can impact a community's economy and tax base. To evaluate this impact, the building inventory estimated as exposed to coastal erosion was estimated using the Hazus-MH default general building stock inventory by 2000 U.S. Census block. The Census blocks with centroids in identified wetland types vulnerable to coastal erosion were determined. . Please note Census blocks do not follow the boundary of the wetland types and the results of this methodology should only be used as an estimate. Based on this estimate, there is $7 Billion of building (structure and content) replacement cost value exposed to the coastal erosion hazard, less than one-percent of the total in the Commonwealth. Table 6-7 summarizes the building inventory exposed to the coastal erosion hazard by County.

TABLE 6-7.
REPLACEMENT COST VALUE EXPOSED TO THE COASTAL EROSION HAZARD

County	Total Building and Content Replacement Cost Value	Replacement Cost Value in Coastal Zone	
		Value	% of Total
Barnstable	$47,450,250,000	$1,310,985,000	2.8
Berkshire	$20,566,219,000	—	—
Bristol	$74,946,506,000	$293,940,000	0.4
Dukes	$4,894,499,000	$64,469,000	1.3
Essex	$100,099,771,000	$1,697,707,000	1.7
Franklin	$10,130,548,000	—	—
Hampden	$67,212,508,000	—	—
Hampshire	$20,961,384,000	—	—
Middlesex	$244,161,008,000	—	—
Nantucket	$3,610,072,000	$55,594,000	1.5
Norfolk	$111,344,832,000	$609,038,000	0.5
Plymouth	$70,614,087,000	$2,460,079,000	3.5
Suffolk	$115,439,212,000	$764,897,000	0.7
Worcester	$112,858,251,000	—	—
Total	**$1,004,289,147,000**	**$7,256,709,000**	**0.7**

Source: Hazus-MH v. 2.1; MassGIS, 2012

Additional data is available to examine coastal vulnerability such as the USGS Open-File Report 99-593. However this study conducted an assessment on the national scale. The limitations of using results at this scale to identify more local vulnerabilities of the Commonwealth's shoreline are recognized. The Massachusetts Shoreline Change Project discussed earlier, which is currently being updated by USGS, is much more detailed. As noted, this report was not available in time for the 2013 planning effort and its results will be available for future plan updates.

Additional data on historical costs incurred to reconstruct buildings or infrastructure due to coastal erosion impacts would assist in estimating future losses. Studies addressing sea-level rise throughout the Commonwealth are summarized below.

The Boston Harbor Association examined Boston's vulnerability to coastal flooding for three scenarios (see Figure 6-12 through Figure 6-14):

- Mean higher high water (MHHW) + 2.5 feet (equal to an elevation of 7.3 feet in the North American Vertical Datum (NAVD))
- MHHW + 5 feet (9.8 feet NAVD)
- MHHW + 7.5 feet (12.3 feet NAVD).

The results probably underestimate the extent of flooding from higher sea levels because they do not include wave heights and other effects. For each coastal flooding scenario, the square footage of land affected by flooding was calculated, considering only parcel size and the amount of flooded area. Scenario 1 estimates flooding at the mid-day high tide on October 29, 2012 (5½ hours before Hurricane Sandy's maximum storm surge hit). No further vulnerability analysis was conducted. Scenario 2 estimates that 6.6 percent of Boston could be flooded, which approximates the current 100-year coastal storm surge at high tide. Scenario 2 estimates that more than 30 percent of Boston could be flooded. This approximates the 100-year coastal storm surge at high tide when sea levels are 2.5 feet higher, sometime after mid-century (The Boston Harbor Association, 2013). For more information, see: http://www.tbha.org/sites/tbha.org/files/documents/preparing_for_the_rising_tide_final.pdf.

According to the 2011 Massachusetts Climate Change Adaptation Plan, a sea level rise of 0.65 meters (26 inches) in Boston by 2050 could damage assets worth an estimated $463 billion (Lenton et al., 2009). Evacuation costs alone in the Northeast region resulting from sea level rise and storms during a single event could range between $2 billion and $6.5 billion (Ruth et al., 2007)

The Buzzards Bay Estuary Program and the CZM are expanding the existing FEMA 100-year floodplain using Flood Insurance Rate Map base flood elevations for Buzzards Bay municipalities (Fairhaven, Westport, Dartmouth, New Bedford, Mattapoisett, Marion, and Wareham) with 1-foot, 2-foot, and 4-foot increases in sea level. Using a recent assessor's data set, the number of buildings, their assessed values, and municipal structures are being enumerated within these various sea level rise expansion scenarios. For more detailed information on the study, the status of the reports and maps, see: http://buzzardsbay.org/floodzone-expansion-slr.html. This project has been listed in the Plan Maintenance section as one to potentially review in future plan updates.

A 2004 study conducted by Kirshen et al., examined impacts under two relative sea-level rise scenarios for 2100: 0.6 meters and 1.0 meters. The impacts for the period 2000 to 2100 were determined. Further details regarding the assumptions made and their methodology may be found in their 2004 paper in *Climatic Change*. Table 6-8 summarizes the estimated losses as a result of sea-level rise to property owners, and as a result of emergency and adaptation actions for the four modeled scenarios.

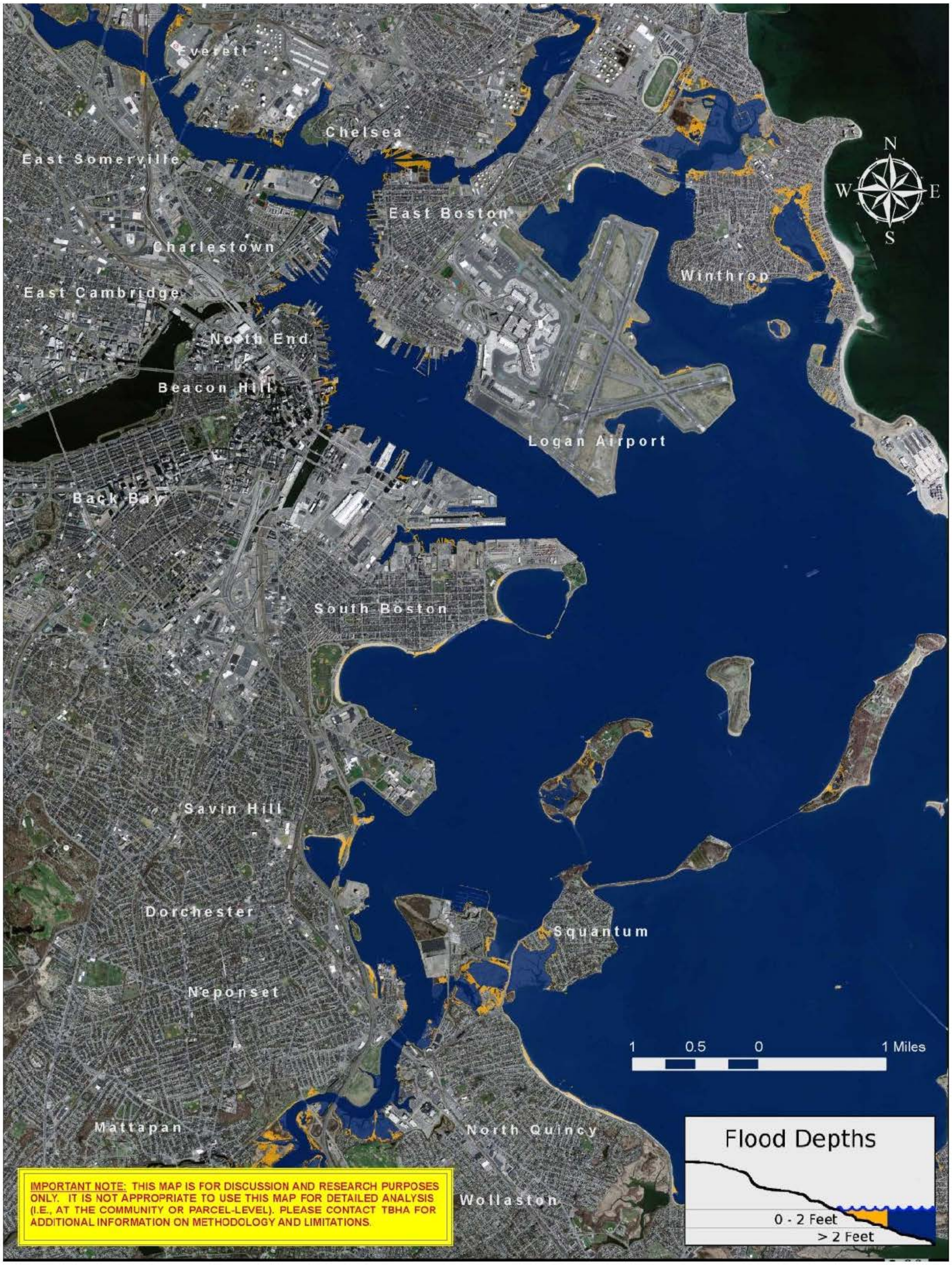

Figure 6-12. Estimated Flooding in Boston at MHHW + 2.5 feet/7.3 feet NAVD

Source: The Boston Harbor Association, 2013

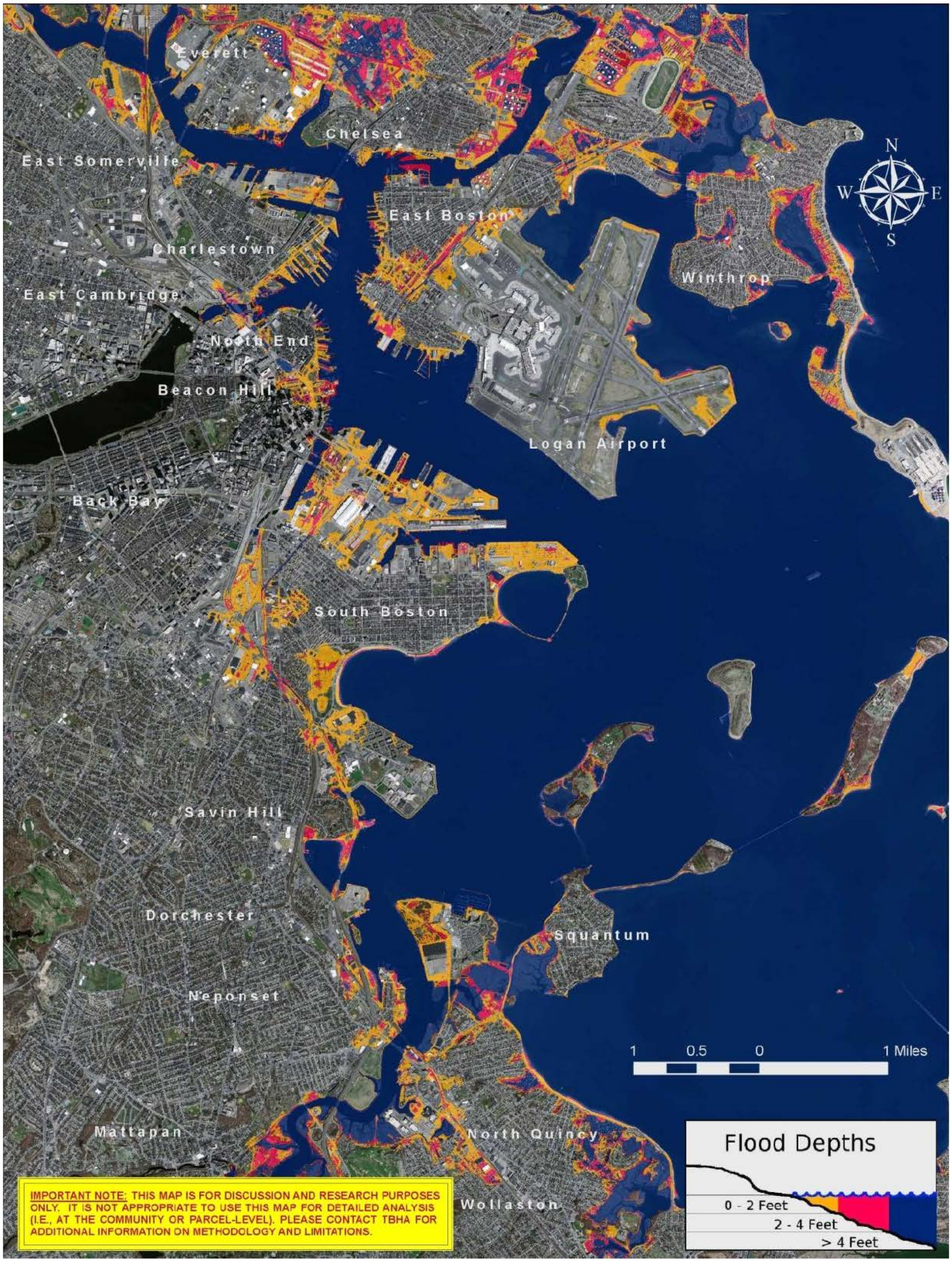

Figure 6-13. Estimated Flooding in Boston at MHHW + 5 feet/9.8 feet NAVD

Source: The Boston Harbor Association, 2013

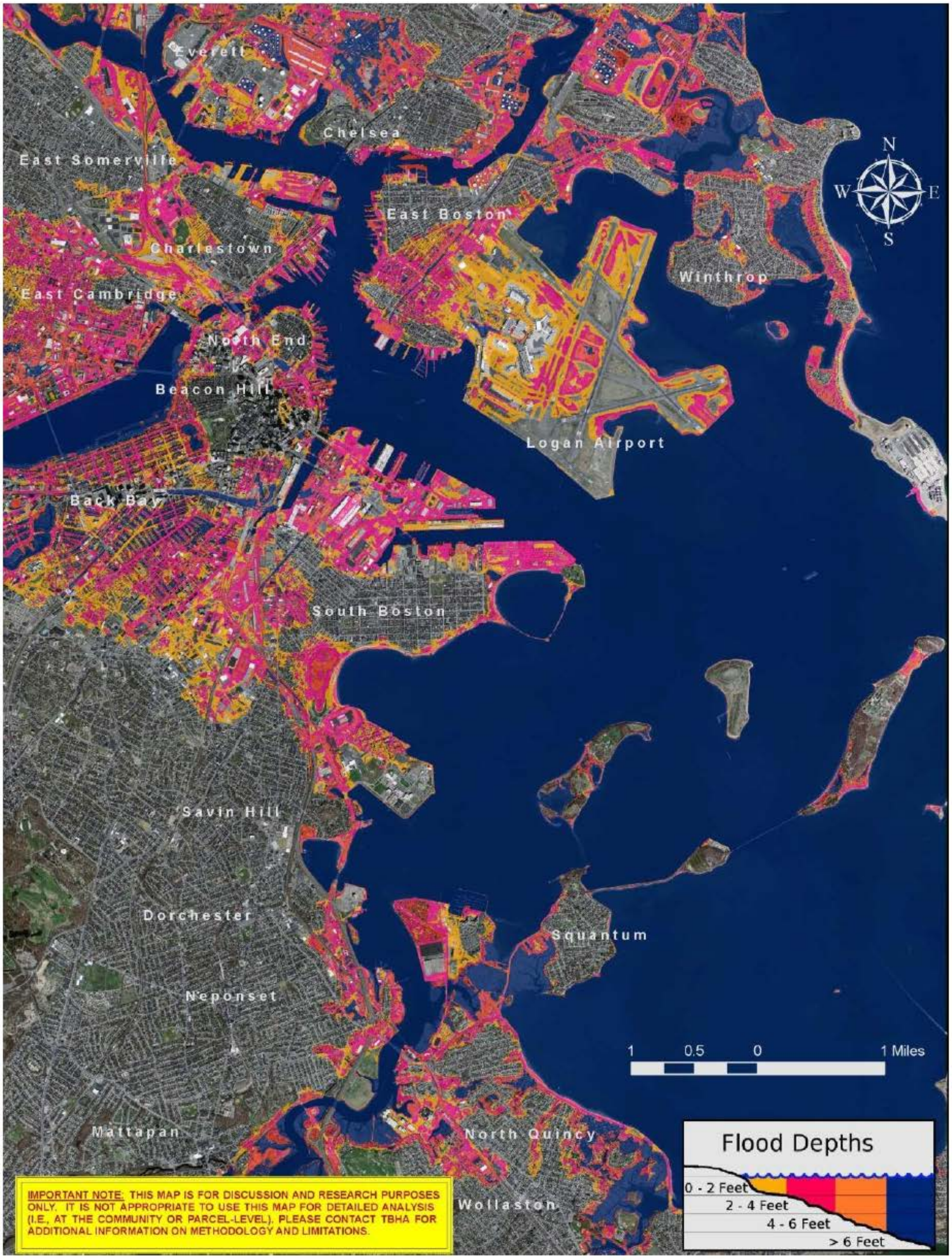

Figure 6-14. Estimated Flooding in Boston at a Sea-Level of MHHW + 7.5 feet/12.3 feet NAVD

TABLE 6-8.
ESTIMATED LOSSES FROM EACH SEA-LEVEL RISE SCENARIO ($ MILLIONS)

Model Run		Estimated Losses by Land Use				
		Residential	Commercial /Industrial	Emergency	Adaptation	**Total**
1	Baseline—no growth, one event	1,087	4,023	869	0	5,979
2	Baseline—no growth, three events	1,452	5,354	1,157	0	7,963
3	Baseline—growth, one event	1,205	4,305	937	0	6,447
4	Baseline—growth, three events	1,616	5,735	1,250	0	8,601
5	Ride-It-Out—0.6 m SLR, one event	3,563	13,525	2,905	0	19,993
6	Build-Your-Way-Out—0.6 m SLR, one event	1,091	3,984	863	3,462	9,400
7	Green—0.6 m SLR, one event	756	2,697	587	1,766	5,806
8	Retreat—0.6 m SLR, one event	5,093	9,142	2,420	500	17,155
9	Ride-It-Out—0.6 m SLR, three events	7,993	29,776	6,421	0	44,190
10	Build-Your-Way-Out—0.6 m SLR, three events	1,924	6,925	1,504	3,462	13,815
11	Green—0.6 m SLR, three events	1,649	5,945	1,291	3,391	12,276
12	Retreat—0.6 m SLR, three events	5,164	9,244	2,449	646	17,503
13	Ride-It-Out—1 m SLR, one event	6,131	25,014	5,295	0	36,440
14	Build-Your-Way-Out—1 m SLR, one event	969	3,613	779	3,462	8,823
15	Green—1 m SLR, one event	1,268	4,959	1,059	2,897	10,183
16	Retreat—1 m SLR, one event	5,564	9,632	2,583	546	18,325
17	Ride-It-Out—1 m SLR, three events	16,140	64,250	13,666	0	94,056
18	Build-Your-Way-Out—1 m SLR, three events	1,820	6,703	1,449	3,462	13,434
19	Green—1 m SLR, three events	3,272	12,760	2,726	6,798	25,556
20	Retreat—1 m SLR, three events	5,651	9,632	2,598	558	18,439

Source: Kirshen et al, 2004

Ride-It-Out: Assumes that existing buildings will be repaired to current conditions after each flood over the 100 year period with no additional flood-proofing. All growth in the present 100-year floodplain is flood-proofed 100-percent effectively so there is no damage to this property if flooded by any event. It is assumed that increased cost of flood-proofing new structures is insignificant compared to the total cost of new construction. There are no requirements for flood-proofing in the present 500 year floodplain.

Green: Requires that all growth in the current 100 and 500 year floodplains be flood-proofed at the time of construction and assume that flood-proofing new residential, commercial, and industrial structures only nominally adds to the cost of construction.

Build-Your-Way-Out: Unregulated growth is allowed in all floodplains because all current and future development is protected with retrofit or new coastal protection structures

Retreat: Assumes that no more residential, commercial, or industrial development is allowed in floodplains and that no rebuilding after flooded is permitted; there is no damage threshold below which an owner can repair instead of abandon. This scenario is distinctly different from the other scenarios because in this scenario property owners are forced to vacate the floodplain or not build in it. It is assumed that when a property is flooded, the owner loses the value of the building, contents, and the land.

In summary, this study estimates the cumulative 2000 to 2100 damage and adaptation costs of coastal flooding in metro Boston ranges from approximately $6 billion to $94 billion. These costs depend on numerous factors including the rate of sea-level rise, how quickly property owners rebuild after storms, and the adaptation scenario employed. In comparison, the cumulative costs for the present flood management strategy over that period but with subsidence only, no eustatic sea-level rise, is approximately $6 billion to $9 billion. It is noted that these costs do not include operation and maintenance costs, environmental costs or the distribution of costs among different socioeconomic groups (Kirshen, et al, 2004).