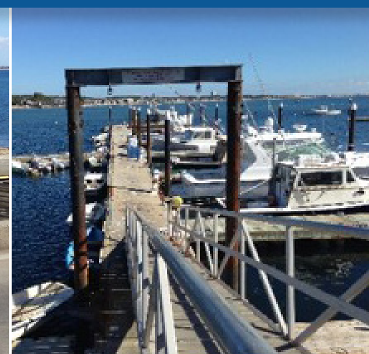
Town of Provincetown, MA



Increasing Coastal Resiliency and Reducing Infrastructure Vulnerability by Mapping Inundation Pathways

FINAL REPORT

Project funded in part by the Massachusetts Office of Coastal Zone Management Coastal Resilience Grant Program

Contact:
Richard J. Waldo, P.E.
Town of Provincetown
Department of Public Works - Director
2 Mayflower St. - Room 74.
Provincetown MA 02657
Phone 508-487-7060
Email : rwaldo@provincetown-ma.gov

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EXECUTIVE SUMMARY

The Town of Provincetown, Massachusetts (Town or Provincetown) is a coastal community located on a narrow peninsula at the tip of Cape Cod surrounded by Cape Cod Bay and the Atlantic Ocean. With the amount of ocean exposure, the community has significant vulnerabilities that exist for Provincetown due to natural hazards, major storm events and sea level rise. The community has been forward thinking about how it will be impacted and is utilizing resources such as Massachusetts Coastal Zone Management grants and other funding mechanisms, to advance plans and projects focused on helping the community increase its resiliency and mitigate potential impacts from storm events. In 2014, Provincetown was awarded a Coastal Zone Management grant to help identify and prepare mitigation actions for critical facilities and infrastructure in the community for a project called **"***Increasing Coastal Resiliency and Reducing Infrastructure Vulnerability by Mapping Inundation Pathways***."** The goal of the project was to identify the most critical facilities and infrastructure, conduct a detailed risk assessment, identify vulnerabilities and help prioritize mitigation projects and adaptation strategies for Provincetown. In addition, the study focused on preparing site-specific GPS surveys and exploring the horizontal extents of documented flood elevations associated with coastal inundation (referred to in this report as Storm Tide Pathways) to help minimize uncertainties associated with sea level rise projections. The project also included the installation of an interactive tide gauge and the production and installation of four 20-foot tide staffs. Each component of the project was designed with the overall intent of better informing public education and outreach efforts associated with the vulnerabilities of the community.

Project Phases

The project was executed in phases that included conducting a risk analysis, identifying storm tide pathways and developing recommendations for adaptive strategies. The risk assessment was prepared collaboratively with key stakeholders in Town to help Provincetown understand which of the Town's critical facilities and infrastructure are at the highest risk of being impacted by natural hazard events.

Risk assessment is a method for identifying system vulnerabilities, prioritizing mitigation projects, and optimizing mitigation budgets. Risk is the combination of how likely it is an asset could fail, and the resulting impact of failure. These concepts are represented in the risk analysis (**Section 3.0)** by Consequence of Failure (CoF), and Likelihood of Failure (LoF). The risk assessment considered the results of the Storm Tide Pathway assessment as one of the criteria.

Upon completion of the risk analysis work and Storm Tide Pathway identification, adaptive strategies were developed specifically to address some of the unique challenges in the community. Strategies considered FEMA floodplain maps, Storm Tide Pathways, information received from the Town (previous plans and reports), and research of other coastal communities and their adaptation efforts. **Table ES-1** identifies the critical facilities and infrastructure evaluated for this project and indicates which ones may be impacted directly by a Storm Tide Pathway.

Table ES-1: Critical Facilities & Infrastructure to Be Impacted by a Storm Tide Pathway

Mean Level Low Water (MLLW) Range	Critical Facility & Infrastructure to Be Impacted by a Storm Tide Pathway (STP) in this MLLW Range	Storm Tide Pathway(s) Impacting Critical Facilities & Infrastructure	Specific MLLW of the Storm Tide Pathway
< 12 feet	Provinceland Road Culvert	12-01	MLLW - 12.93
	Provincetown Airport	02-02 02-03	MLLW - 11.27 MLLW - 11.39
13.0 – 13.9 feet	Coast Guard Station	12-14 12-15	MLLW - 15.71 MLLW - 15.13

Mean Level Low Water (MLLW) Range	Critical Facility & Infrastructure to Be Impacted by a Storm Tide Pathway (STP) in this MLLW Range	Storm Tide Pathway(s) Impacting Critical Facilities & Infrastructure	Specific MLLW of the Storm Tide Pathway
		12-16	MLLW - 15.59
	Provincetown Town Hall	11-05 11-06	MLLW - 13.59 MLLW - 13.61
	Fire House #3	11-05 11-06	MLLW - 13.59 MLLW - 13.61
	Pump Station #8 - West End	12-05	MLLW - 13.25
14.0 – 14.9 feet	Fire Station #5	17-06	MLLW - 14.97
	Provincetown Public Television	11-07 11-08 11-12 11-11	MLLW – 14.51 MLLW - 14.75 MLLW - 15.77 MLLW - 15.5
	Fire Station #2	11-04	MLLW – 13.98
	Water Transmission Mains from Truro	11-05 11-06 22-01 22-02 17-06	MLLW - 13.59 MLLW - 13.61 MLLW - 14.83 MLLW - 14.43 MLLW - 14.97
	Pump Station #11 - Ice House Pump Station	17.06	MLLW - 14.97
	Pump Station #1 - Kendall Lane	17-06	MLLW - 14.97
	Pump Station #6 - Commodore Avenue	22-01 22-02	MLLW - 14.83 MLLW - 14.43
	Route 6A	11-05 11-06 22-01 22-02 17-06	MLLW - 13.59 MLLW - 13.61 MLLW - 14.83 MLLW - 14.43 MLLW - 14.97
	Stormwater Pumphouse	11-07 11-08	MLLW - 14.51 MLLW - 14.75
	Electrical Transmission Lines	22-01 22-02	MLLW - 14.83 MLLW - 14.43
	Route 6 Roadway	22-01 22-02	MLLW - 14.83 MLLW - 14.43
15.0 – 15.9 feet	Central Sewer Vacuum System	11-11	MLLW - 15.5
	Pump Station #7 - Thistlemore Road	16-03	MLLW - 15.43
	Pump Station #5 - Snail Road	16-04	MLLW - 15.02

Mean Level Low Water (MLLW) Range	Critical Facility & Infrastructure to Be Impacted by a Storm Tide Pathway (STP) in this MLLW Range	Storm Tide Pathway(s) Impacting Critical Facilities & Infrastructure	Specific MLLW of the Storm Tide Pathway
17.0 – 17.9 feet	Fire Station	07-04	MLLW - 17.29
	DPW Garage	07-04	MLLW - 17.29
	Pump Station #2 – Pleasant Street	07-04	MLLW - 17.29
	Provincetown Police Station	07-04	MLLW - 17.29
	Stop & Shop	07-04	MLLW - 17.29
	Pump Station #10 - Stop and Shop Pump Station	07-04	MLLW - 17.29
	Pump Station #9 - Shank Painter	07-04	MLLW - 17.29

The following critical facilities and infrastructure evaluated for this project were not found to be impacted by a Storm Tide Pathway, they include:

- Provincetown Public Library
- Telephone Station
- Fire Station #4
- Seashore Point
- Emergency Operations Center – Veterans
- Provincetown High School
- Maushope Senior Housing
- Housing Authority
- Outer Cape Health Services
- Wastewater Treatment Plant
- Winslow Water Tower
- Herring Cove Animal Hospital
- Pump Station #3 - Manor
- Pump Station #4 – Bayberry
- Mt. Gilboa Water Tower
- Power SubStation #1
- Power SubStation #2
- Transfer Station

Risk Results, Adaptive Strategies & Recommendations

The risk results from this project will serve as a tool for Provincetown to use for future planning efforts and capital improvement projects. Adaptive strategies and recommendations were detailed for the highest risk critical facilities and infrastructure which evaluated Consequence of Failure and Likelihood of Failure, they include:

- **Center of Provincetown's Downtown** – The risk assessment, which included evaluating the presence of Storm Tide Pathways, identified the central downtown area near Commercial Street at Ryder Street as an area with a number of critical facilities and infrastructure. Assets include the Town Hall, Fire House #3 and Bradford Street (sometimes referred to at 6A). Two Storm Tide Pathways were identified to impact this area.

Considerations to eliminate these storm tide pathways and the potential for floodwater damage include using natural feature enhancements or developing a sand bagging plan during storm threats.

- **Wastewater Pump Station Improvement –** Provincetown has 11 pump stations. A number of them received high risk scores due to their location and criticality to the community. Flooding and outages at pump stations could result in interrupted sewer service or sanitary sewer overflows, both of which could have an impact on public health and the environment. Protecting these stations from floodwaters may include solutions such as elevating or relocating equipment, developing standard operating procedures and ensuring generator capacity and availability.
- **Provincetown Municipal Airport –** The airport is an important economic and transportation service to the community and Cape Cod. Should the airport be impacted by a substantial natural hazard event, it could represent a major loss for Provincetown in terms of tourism and the economy. The airport is also in a floodplain and was found to be associated with two Storm Tide Pathways.
- **Shank Painter Road –** This area of Provincetown is of concern because there are several critical facilities and infrastructure located along this street including the police and fire stations. Shank Painter Road is in a floodplain and also associated with a Storm Tide Pathway.

The report includes 24 adaptive strategies and recommendations for Provincetown to consider to help protect existing critical facilities and infrastructure. The strategies range from integrating this project with other town efforts like the Capital Improvement Plan, Hazard Mitigation Plan, Emergency Response Plan and Community Rating System reporting to considering Storm Tide Pathways during project implementation and infrastructure upgrades to natural resource enhancement.

1. INTRODUCTION & BACKGROUND INFORMATION

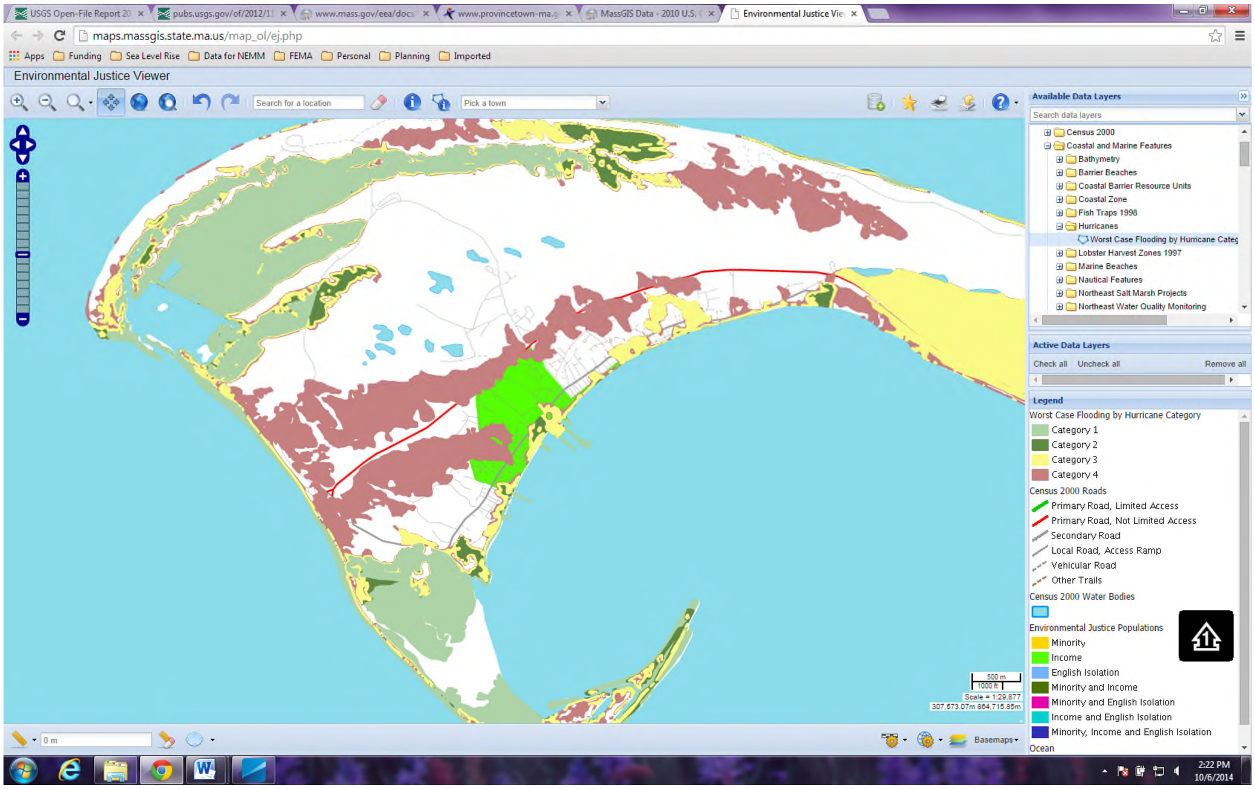
The Town of Provincetown, Massachusetts (the Town or Provincetown) is located on a narrow peninsula at the northern tip of Cape Cod surrounded by Cape Cod Bay to the west and north and the Atlantic Ocean to the east. The degree of ocean exposure presents a significant vulnerability for the Town to natural hazards, major storm events and future sea level rise. Provincetown has been forward thinking about managing these vulnerabilities, and was awarded a Coastal Zone Management (CZM) grant in 2014 to help identify and prepare mitigation actions for Town assets and infrastructure. The goal of the project was to identify the most critical facilities and infrastructure, conduct a detailed risk assessment, identify vulnerabilities and identify and prioritize mitigation projects and adaptation strategies.

The first phase of the project was to conduct a risk analysis, and provide the results to the Town. The risk assessment was performed in partnership between Woodard & Curran and the Provincetown Center for Coastal Studies (Coastal Studies). Coastal Studies contributed an assessment which used detailed survey information as well as aerial elevation data to pinpoint specific locations throughout the Town vulnerable to becoming inundated by a sea level rise which are referred to as Storm Tide Pathways. Coastal Studies surveyed points in a field survey to obtain increased vertical accuracy as compared to LiDAR data. When the water level reaches a Storm Tide Pathway level, it becomes active and water can flow inland and flood or inundate the associated area. The volume of inundation was not considered and the outlines associated with each Storm Tide Pathway are subjective to the length of time it remains active (i.e. the storm duration/length of flooding). Woodard & Curran performed the risk analysis using a combination of Coastal Studies results, Geographic Information Systems (GIS), background information gathered from previous reports and stakeholder interviews.

1.1 COMMUNITY INFORMATION

Provincetown is approximately 8.35 square miles of land area. A large portion of the Town's assessed property value is located in close proximity to Provincetown Harbor (over $2.9 billion). Over 75 percent of the land area in Provincetown is located within the Cape Cod National Seashore. Provincetown Harbor is home to a key transportation area for Cape Cod Bay and serves as a deep water port for marine traffic, including cruise ships. Within Provincetown Harbor are three piers (MacMillan, Fisherman's Wharf and the Coast Guard Pier) which are used by the commercial fishing and tourism industries producing millions in sales and hundreds of jobs. Provincetown has a designated Environmental Justice Area/Neighborhood based on income (see **Figure 1-1**) and this neighborhood is in an area which is susceptible to flooding from hurricanes (and other storm impacts) and sea level rise.

Figure 1-1: Provincetown Environmental Justice Area & Potential Hurricane Flooding



The entire Town is a designated as a Priority Habitat for Rare Species and an Estimated Habitat for Rare Wildlife (according to the Natural Heritage and Endangered Species Program (NHESP). The drivers for Provincetown to engage in climate action mitigation activities are social, economic, environmental and political.

1.2 NATURAL HAZARDS IMPACTING PROVINCETOWN

In 2015, Provincetown partnered with the Cape Cod Commission to update its local Hazard Mitigation Plan. The purpose of the planning effort was to help the community reduce loss to property and human life from natural hazard events. Provincetown's Hazard Mitigation Plan serves to educate the community about natural hazards and provide a foundation for creating a resilient community. Updating the Hazard Mitigation Plan involved reviewing the full range of natural hazards identified in the 2013 Massachusetts State Hazard Mitigation Plan and identified natural hazards that could impact Provincetown in the future or that have impacted Provincetown in the past. Impacts were evaluated using local expertise Town staff, input from the Barnstable County Regional Emergency Planning Committee, data from the 2013 Massachusetts State Hazard Mitigation Plan and other resources. Natural hazards that have or could impact the Town of Provincetown include the list below. The hazards identified for further risk assessment during the planning process are indicated in bold.

- **Coastal Erosion and Shoreline Change**
- Dam (Culvert) Failure
- Earthquake
- **Fire (Urban and Wildland)**
- **Flood**
- **Hurricane & Tropical Storms**
- Landslide

- **Nor'easter**
- **High Winds**
- Thunderstorms
- Extreme Temperatures
- Tornadoes
- Drought
- **Severe Winter Weather**
- Tsunami
- **Sea Level Rise**

During the hazard mitigation planning process, Provincetown determined that if the probability of a hazard was highly likely and if the public had experienced the hazard in the past, it was a hazard that most pertained to the community and was further evaluated in the risk assessment portion of the plan. The focus of this risk assessment is critical facilities and infrastructure. The recently updated local Hazard Mitigation Plan specifically identified potential impacts to buildings and infrastructure that could occur based on the type of natural hazard (see **Table 1-1**).

Table 1-1: Potential Impacts to Buildings & Infrastructure from Natural Hazards

Natural Hazard	Infrastructure Impacts	Building Impacts
Coastal Erosion & Shoreline Change	• Potential to expose septic systems or sewer pipes and risk contamination of natural resources. • Sand may block stormwater pipes and contribute to drainage issues. • Natural systems in Provincetown are vulnerable to coastal erosion where the natural process of erosion is altered (due to engineered structures to stabilize shorelines). The ability of natural resources to provide protection from storm damage and flooding can be diminished and increase the vulnerability of infrastructure.	• Public safety could be a concern when a building collapses or a water supply is contaminated due to erosion. • Roadway collapse could limit emergency response times.
Hurricane & Tropical Storms	• Damage to power lines and extended power outages. • Water/wastewater issues if there is power failure or structural damage. • The Hazard Mitigation Plan specifically noted in storm events where winds are sustained at over 50mph, docks in the harbor fail, boats break free from their moorings and there is the potential for Route 6 to be closed due to blowing sand and Route 6A to be closed due to flooding.	• Wind, rain, flood damage from debris or flying objects, or permanent collapse depending on the level of the storm.
Nor'easter	• Downed power lines, power outages and high winds can cause damage to coastal infrastructure.	• There has been damage in the past during a Nor'easter to roofs, windows and buildings including the roof of the Surfside Inn that blew off and damaged houses across the street.

Natural Hazard	Infrastructure Impacts	Building Impacts
Severe Winter Weather	• Ice and heavy snowfall can knock out heating, power, and communication services. • Pipes and water mains may break due to extremely cold temperatures. • Large sections of ice can cause damage to floating docks.	• Structural failure of buildings due to heavy snow loads; roof failure; structural damage to buildings because of high wind; damage to fishing vessels, recreational boats and kayaks because of ice floes and coastal flooding (Figure 2.26)
Sea Level Rise	• As this occurs, high water elevations will move landward, areas of coastal shorelines will retreat, and low-lying areas will be increasingly exposed to erosion, tidal inundation, and coastal storm flooding.	• Developed parts of the coast are especially vulnerable because of the presence of infrastructure, homes and businesses that can be damaged or destroyed by coastal storms. • Development often impedes the ability of natural coastal systems to buffer inland areas from storm damage.
Flood	• Debris or sediment may remain on and around town infrastructure and floods can damage gas lines, utility poles, water infrastructure and the wastewater treatment plant. • Damaged infrastructure can also cause secondary impacts to the local economy if severe enough.	• Buildings can be damaged or destroyed by floodwaters from the foundation level up and/or by floating objects caught in the floodwaters.

1.3 RESPONDING TO CLIMATE CHANGE AND SEA LEVEL RISE AT THE LOCAL LEVEL

Provincetown is forward thinking and proactive with regard to planning and preparing for potential natural hazard events. The Town has a documented history of flooding and erosion as a result of winter storms, hurricanes, and nor'easters. Flooding and coastal erosion are both hazards specifically identified and documented in the 2011 Hazard Mitigation Plan (HMP) as having the most damage potential to life and property and have also been highlighted in the updated HMP. The HMP has several related mitigation actions listed providing support for Provincetown's need to conduct this project and receive funding assistance. The following mitigation actions are related to this project and received the highest priority score rankings out of all of the mitigation projects listed in the plan, they include:

- Conduct an assessment of local infrastructure subject to damage from flooding or storm surge or that is likely to cause damage to surrounding areas should it fail or flood,
- Monitor beach conditions and evaluate all vulnerable shoreline areas for possible future nourishment and beach stabilization projects, and
- Conduct a thorough evaluation of the Town's most at-risk locations identified in the Vulnerability Analysis and evaluate the potential mitigation techniques for protecting each location to the maximum extent possible.

Under a separate Coastal Zone Management grant, Provincetown completed a strategic beach stabilization pilot project/analysis in June 2015. The report acknowledges the Town's proactive efforts towards coastal planning and documents the need for beach nourishment as a strategy for coastal resiliency. The project was a desktop study to identify shoreline areas vulnerable to or resilient to coastal erosion and inform more strategic resiliency planning.

Provincetown's Harbor Plan (recently updated in 2012) also identified increased protection and public access with beach nourishment as a primary tool to address sea level rise. It identified the need for a comprehensive sediment management plan including budgeted and periodic beach nourishment.

1.4 TIDE GUAGE INSTALLATION

As a part of the original grant application for this project, a 'web-accessible, tide gauge' was proposed to be installed near the Provincetown Harbormaster's office. After installation of the tide gauge, Provincetown was to be responsible for the care and maintenance of the tide gauge in perpetuity. Between when the funding for this project was awarded and its completion, Coastal Studies contacted the US Geological Survey's New England Water Science Center in Northborough, MA to explore potential interest in installing a real time tide gauge in Provincetown. After this contact, a meeting was arranged between Coastal Studies, USGS, the National Weather Service, the Massachusetts Office of Coastal Zone Management and the Provincetown Harbormaster to discuss potential tide gauge locations. The tide gauge was installed on December 31, 2014 and Coastal Studies continued to work with USGS staff to calibrate the tide gauge datum to the North American Datum of 1988 (NAVD88). The station is accessible at http://waterdata.usgs.gov/ma/nwis/uv/?site_no=420259070105600&PARAmeter_cd=00065,00060. The USGS will be responsible for all care and maintenance of the tide gauge going forward.

In addition to the tide gauge installation, Coastal Studies oversaw the production and installation of four custom-made 20-foot tide staffs, in lieu of the single tide staff that was originally envisioned. As opposed to traditional flat boards, tide staffs were produced in a half circle shape to increase visibility from multiple vantage points throughout the harbor. A prototype section was produced and used to evaluate potential installation locations. The tide staffs (datum referenced to NAVD88 and mean lower low water - local chart datum) were installed at 4 locations around the harbor as determined by the Provincetown Harbormaster in June 2016.

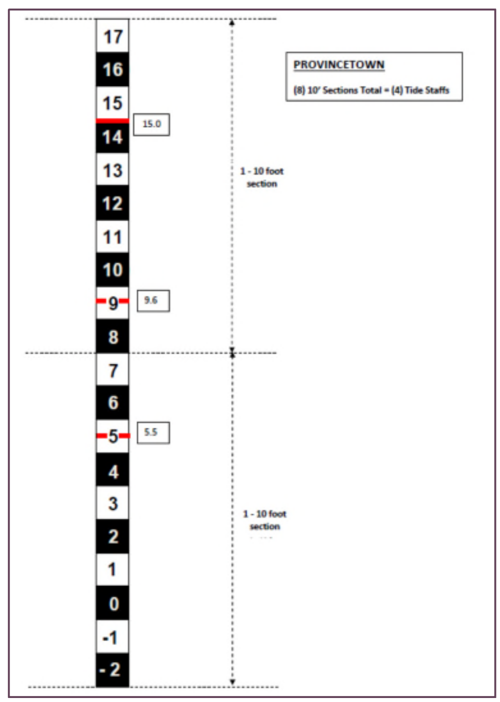


Photo: *Custom 20-Foot Tide Staff*

1.5 COMMUNITY OBSERVATIONS

The purpose of the critical facility and infrastructure evaluation associated with this planning project conducted in October 2015 was to gather more information from Town officials, which was used to categorize and assess risks to Provincetown's critical facilities and infrastructure being assessed for this project. The main goal was to better understand the role of Provincetown's critical infrastructure, how natural hazards have and may impact them and help the Town prioritize adaptive strategies to increase its resiliency, where possible.

One major component of the site visit was to meet with Richard Waldo, Director of the Department of Public Works to discuss the scoring of Consequence of Failure (CoF) for Provincetown's critical assets (see **Section 3.0**). Information was gathered to make a determination about the health and safety, financial, reputation, and environmental impacts the Town could face as a result of each asset's failure. In addition, a tour of critical infrastructure was conducted by Richard Waldo. Provincetown staff identified by Mr. Waldo were interviewed regarding critical infrastructure in the community and any past impacts from natural hazard events that have occurred. Major themes that resulted from the site visit are listed in **Table 1-2**.

Table 1-2: Site Visit Observations/Themes

Topic	Details
Severe Weather	Due to the geography of Provincetown and its location at the tip of Cape Cod with water on three sides, the community is at risk due to natural hazard events. Impacts can be severe due to high winds and wind exposure, flooding and blowing sand. All south blowing storms are of the greatest concern.
Sand Management	Moving, removing, replacing and managing sand is a big effort for the Department of Public Works and is a unique challenge to Provincetown.
Power/Electric Service	There are power issues in general in Provincetown. The main feed to the community is from the Town of Truro (Truro).
Emergency Shelter	Provincetown has a shelter, but most likely in a serious emergency event, it would not be able to evacuate, resulting in a shelter in place situation. Other communities in the area, like Truro, may also use the shelter.
Flooding	Flooding occurs in Provincetown due to natural hazard events, but also due to drainage issues.
Transmission Mains from Truro – Critical	All water delivered to Provincetown comes from Truro. Water transmission mains, under 6A near Shore Road, could be impacted and if something happens to that roadway or the pipes underneath, Provincetown loses access to water. The water tower would only buy a minimal amount of time. A Category 2 or 3 storm could impact Shore Road.

1.6 CRITICAL FACILITIES & INFRASTRUCTURE

Provincetown has numerous types of important resources, facilities and infrastructure it is responsible for managing and maintaining. For this project, it was necessary to identify and confirm the critical facilities and infrastructure being considered (see **Table 1-3**). The Critical Facilities & Infrastructure list was prepared by cross-referencing critical facilities identified in the 2008 Provincetown Hazard Mitigation Plan and the critical assets identified by the Cape Cod Commission for a project that addresses criticality and vulnerability of transportation assets in all of Barnstable County. The list was presented to the Director of the Department of Public Works who modified and finalized the list of Critical Facilities and Infrastructure for this project. **Table 1-3** lists the Critical Facilities & Infrastructure and **Figure 1-2** represents a map of each asset listed and indicates if the asset is in a flood zone.

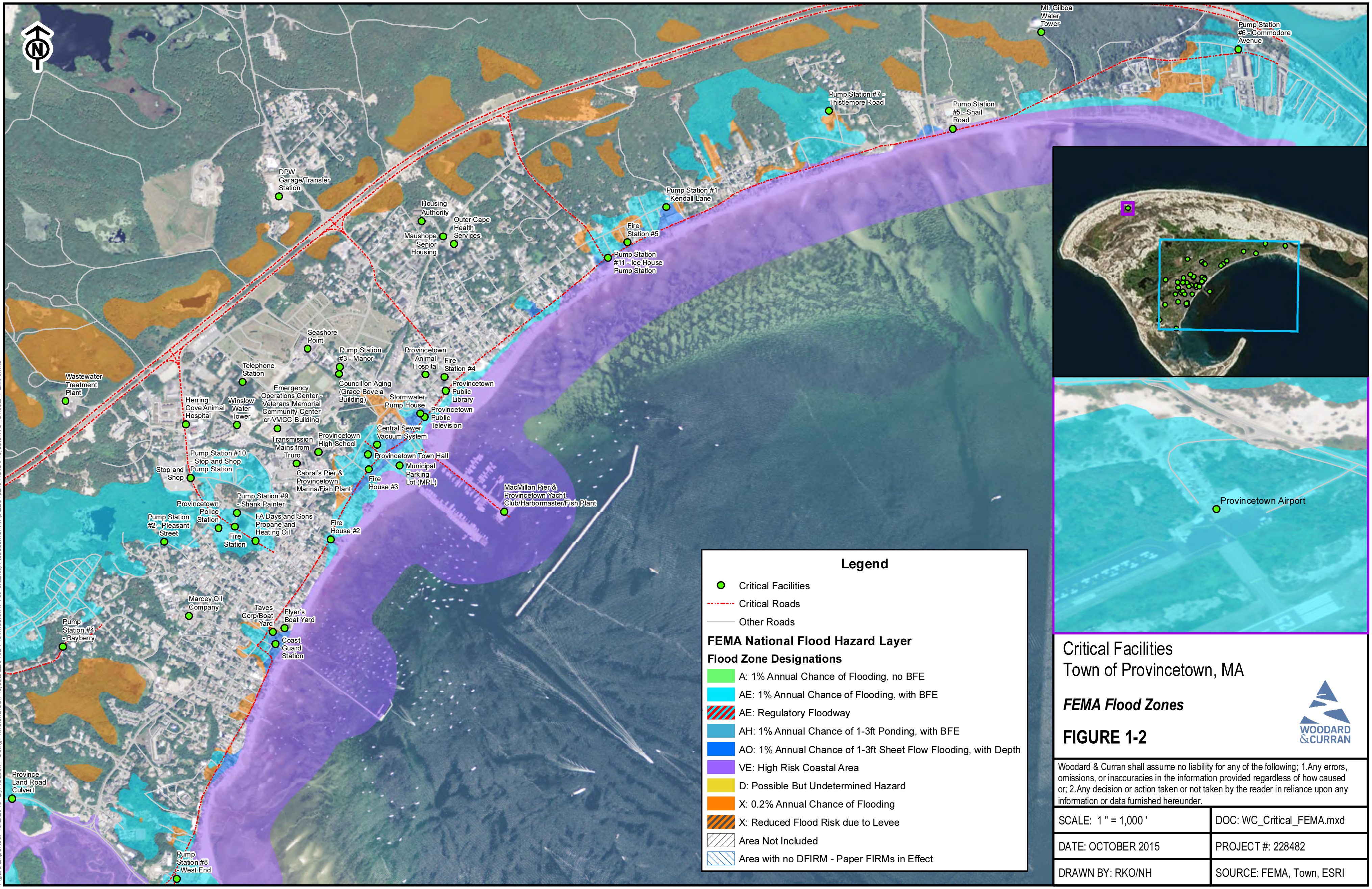
Table 1-3: Provincetown Critical Facilities & Infrastructure

Critical Facility/Infrastructure	Address	Listed in 2008 Hazard Mitigation Plan*	Listed by Cape Cod Commission**	Notes
Emergency Operations Center - Veterans Memorial Community Center or VMCC Building	2 Mayflower Lane	X		Noted in the HMP as the Veterans Memorial Elementary School
Provincetown High School	12 Winslow Street	X	X	
Provincetown Town Hall	260 Commercial Street	X	X	

Critical Facility/Infrastructure	Address	Listed in 2008 Hazard Mitigation Plan*	Listed by Cape Cod Commission**	Notes
Seashore Point	100 Alden Street	X		
MacMillan Pier & Harbormaster	MacMillan Wharf	X	X	
Provincetown Police Station	26 Shank Painter Road	X	X	
Fire Station	25 Shank Painter Road	X	X	
Fire House #2	189 Commercial Street			Public restrooms
Fire House #3	254 Commercial Street			Art commission storage area
Fire Station #4	4 Johnson Street	X	X	
Fire Station #5	514 Commercial Street	X	X	
Coast Guard Station	125 Commercial Street	X	X	
Telephone Station	38 Winslow Street	X	X	
Outer Cape Health Services	49 Harry Kemp Way	X	X	
Housing Authority	49 Harry Kemp Way	X	X	
Maushope Senior Housing	49 Harry Kemp Way	X		
Provincetown Public Library	356 Commercial Street	X	X	
DPW Garage	24 Race Point Road	X	X	
Transfer Station	90 Race Point Road			Added by DPW
Wastewater Treatment Plant	244 Route 6	X	X	
Herring Cove Animal Hospital	83 Shank Painter Road	X	X	
Central Sewer Vacuum System	5 Ryder Street	X	X	
Provincetown Airport	Race Point Road	X	X	
Province Land Road Culvert	125 Provinceland Road		X	
Water Transmission Mains - Truro	Route 6A			Added by DPW
Pump Station #1 – Kendall Lane	540-544 Commercial Street			Added by DPW
Pump Station #2 – Pleasant Street	61 Pleasant Street			Added by DPW
Pump Station #3 - Manor	26 Alden Street			Added by DPW
Pump Station #4 - Bayberry	74R Bayberry Avenue			Added by DPW
Pump Station #5 – Snail Road	698 Commercial Street			Added by DPW
Pump Station #6 – Commodore Avenue	50 Commodore Avenue			Added by DPW
Pump Station #7 – Thistlemore Road	324 Bradford Street			Added by DPW
Pump Station #8 – West End	1 Commercial Street			Added by DPW
Pump Station #9 – Shank Painter	25 Shank Painter Road			Added by DPW
Pump Station #10 – Stop and Shop Pump Station	56 Shank Painter Road			Added by DPW
Pump Station #11 – Ice House Pump Station	501 Commercial Street			Added by DPW
Route 6A Roadway	Route 6A			Other

Critical Facility/Infrastructure	Address	Listed in 2008 Hazard Mitigation Plan*	Listed by Cape Cod Commission**	Notes
Electric Transmission Lines	Route 6A			Other
Route 6 Roadway	Route 6			Other
Winslow Water Tower	7 Captain Bertie's Way			Added by DPW
Stormwater Pump House	Rear of 330 Commercial Street			Added by DPW
Mt. Gilboa Water Tower	120 Mt. Gilboa Road			Added by DPW
Provincetown Public Television	330 Commercial Street			Added by DPW
Power Substation #1	80 Shank Painter Road			Added by DPW
Power Substation #2	802 Commercial Street			Added by DPW
Stop & Shop	56 Shank Painter Road			Added by DPW

Note: *HMGP (Hazard Mitigation Plan); ** CCC (Cape Cod Commission) and refers to the work being done by the CCC for Barnstable County



Legend

- Critical Facilities
- Critical Roads
- Other Roads

FEMA National Flood Hazard Layer

Flood Zone Designations

- A: 1% Annual Chance of Flooding, no BFE
- AE: 1% Annual Chance of Flooding, with BFE
- AE: Regulatory Floodway
- AH: 1% Annual Chance of 1-3ft Ponding, with BFE
- AO: 1% Annual Chance of 1-3ft Sheet Flow Flooding, with Depth
- VE: High Risk Coastal Area
- D: Possible But Undetermined Hazard
- X: 0.2% Annual Chance of Flooding
- X: Reduced Flood Risk due to Levee
- Area Not Included
- Area with no DFIRM - Paper FIRMs in Effect

Critical Facilities
Town of Provincetown, MA

FEMA Flood Zones

FIGURE 1-2

WOODARD & CURRAN

SCALE: 1 " = 1,000 '	DOC: WC_Critical_FEMA.mxd
DATE: OCTOBER 2015	PROJECT #: 228482
DRAWN BY: RKO/NH	SOURCE: FEMA, Town, ESRI

Table 1-4 is a summary list of the Critical Facilities & Infrastructure and it indicates if its respective location is in a flood zone corresponding with **Figure 1-2** and if it will be impacted by a Storm Tide Pathway (**Section 4.3**).

Table 1-4: Provincetown Critical Facilities & Infrastructure Flood Zone & Storm Tide Pathway Status

Critical Facility/Infrastructure	Address	Impacted by a Storm Tide Pathway?	FEMA Flood Zone?	FEMA Zone*
Emergency Operations Center - Veterans Memorial Community Center or VMCC Building	2 Mayflower Lane	No	No	N/A
Provincetown High School	12 Winslow Street	No	No	N/A
Provincetown Town Hall	260 Commercial Street	Yes	Yes	AE
Seashore Point	100 Alden Street	No	No	N/A
MacMillan Pier & Harbormaster	MacMillan Wharf	Yes	Yes	VE
Provincetown Police Station	26 Shank Painter Road	Yes	Yes	AE
Fire Station	25 Shank Painter Road	Yes	Yes	AE
Fire House #2	189 Commercial Street	No	Yes	VE
Fire House #3	254 Commercial Street	Yes	Yes	AE
Fire Station #4	4 Johnson Street	No	No	N/A
Fire Station #5	514 Commercial Street	No	Yes	AO
Coast Guard Station	125 Commercial Street	Yes	Yes	AO
Telephone Station	38 Winslow Street	No	No	N/A
Outer Cape Health Services	49 Harry Kemp Way	No	No	N/A
Housing Authority	49 Harry Kemp Way	No	No	N/A
Maushope Senior Housing	49 Harry Kemp Way	No	No	N/A
Provincetown Public Library	356 Commercial Street	No	No	N/A
DPW Garage	24 Race Point Road	No	No	N/A
Transfer Station	90 Race Point Road	No	No	N/A
Wastewater Treatment Plant	244 Route 6	No	No	N/A
Herring Cove Animal Hospital	83 Shank Painter Road	No	No	N/A
Central Sewer Vacuum System	5 Ryder Street	Yes	Yes	AE
Provincetown Airport	Race Point Road	Yes	Yes	AE
Province Land Road Culvert	125 Provinceland Road	Yes	Yes	AE
Water Transmission Mains – Truro	Route 6A	Yes	Yes	VE
Pump Station #1 – Kendall Lane	540-544 Commercial Street	Yes	Yes	AO
Pump Station #2 – Pleasant Street	61 Pleasant Street	No	No	N/A
Pump Station #3 - Manor	26 Alden Street	No	No	N/A
Pump Station #4 - Bayberry	74R Bayberry Avenue	No	No	N/A
Pump Station #5 – Snail Road	698 Commercial Street	Yes	Yes	VE
Pump Station #6 – Commodore Avenue	50 Commodore Avenue	Yes	Yes	AE

Critical Facility/Infrastructure	Address	Impacted by a Storm Tide Pathway?	FEMA Flood Zone?	FEMA Zone*
Pump Station #7 – Thistlemore Road	324 Bradford Street	Yes	Yes	AE
Pump Station #8 – West End	1 Commercial Street	Yes	Yes	AE
Pump Station #9 – Shank Painter	25 Shank Painter Road	Yes	Yes	AE
Pump Station #10 – Stop and Shop Pump Station	56 Shank Painter Road	Yes	No	N/A
Pump Station #11 – Ice House Pump Station	501 Commercial Street	Yes	Yes	VE
Route 6A Roadway	Route 6A	Yes	Yes	VE
Electric Transmission Lines	Route 6A	Yes	Yes	AE
Route 6 Roadway	Route 6	Yes	Yes	AE
Winslow Water Tower	7 Captain Bertie's Way	No	No	N/A
Stormwater Pump House	Rear of 330 Commercial Street	Yes	Yes	AE
Mt. Gilboa Water Tower	120 Mt. Gilboa Road	No	No	N/A
Provincetown Public Television	330 Commercial Street	Yes	Yes	AO
Power Substation #1	80 Shank Painter Road	No	No	N/A
Power Substation #2	802 Commercial Street	No	No	N/A
Stop & Shop	56 Shank Painter Road	Yes	Yes	AE

*** FEMA Zone Definitions:**

VE – (High Velocity Zone) Areas subject to inundation by the 1-percent-annual-chance flood event with additional hazards due to storm-induced velocity wave action.

AE - Areas subject to inundation by the 1-percent-annual-chance flood event.

AO - Areas subject to inundation by 1-percent-annual-chance shallow flooding (usually sheet flow on sloping terrain) where average depths are between one and three feet.

Table 1-5 includes a detailed summary of the Standby Generators that Provincetown has available for various critical facilities and infrastructure.

Table 1-5: Provincetown Inventory of Standby Generators (January 2016)

Location	Department	kW	Phase	Voltage	Fuel Type	Year	Manufacturer	Model No.	Serial No.
3 Phase, 480V Generators									
South Hollow	Water	300	3	480/277VAC	Diesel	2004	Caterpillar	SR4B	8ER04151
Wastewater Treatment Plant	**Wastewater**	***265***	***3***	***480/277VAC***	***Diesel***	***2001***	***Kohler***	**250REOZD**	
Central Vacuum Station (CVS)	**Wastewater**	***160***	***3***	***480/277VAC***	***Diesel***	***2001***	***Kohler***	**150REOZJB**	
North Union Field	Water	115	3	480/277VAC	Propane	2013			
Knowles Crossing (Surplus Generator)	Water	100	3	480/277VAC	Diesel	2009 (?)	Caterpillar	D100P1	OLY00000CN PS01568
Shank Painter Pump Station	**Wastewater**	***80***	***3***	***480/277VAC***	***Propane***	***2007***	***Kohler***	**8DRZG**	
Thistlemore Pump Station	**Wastewater**	***44***	***3***	***480/277VAC***	***Propane***	***2011***	***Baldor***	***IGLC45-2GU***	
Kendall Lane Pump Station	**Wastewater**	***32***	***3***	***480/277VAC***	***Propane***	***2011***	***Baldor***	***IGLC35-2GU***	
3 Phase, 208V Generators									
Town Hall	**Town**	**140**	**3**	**208/120VAC**	**Propane**	**2010**	**Cummins**	**GGLB-2089029**	**L090079237**
VMCC (Elementary School)	**Town**	**130**	**3**	**208/120VAC**	**Diesel**	**2002**	**Generac**	**2894560100**	**2070907**
Fire Station	**Town**	**125**	**3**	**208/120VAC**	**Propane**	**(?)**	**Kohler**	**125R0ZJ81**	**327068**
Freeman Street Pumps	**Town**	**40**	**3**	**208/120VAC**	**Diesel**	**1990**	**Kohler**	**0R0ZJ81**	**189201-81**
Highway Garage	**Town**	**30**	**3**	**208/120VAC**	**Propane**	**(?)**	**Kohler**	**HC144G**	**04149/04**

Location	Department	kW	Phase	Voltage	Fuel Type	Year	Manufacturer	Model No.	Serial No.
Commodore Pump Station	**Wastewater**	***32***	***3***	***208/120VAC***	***Propane***	***2011***	***Baldor***	***IGLC35-2GU***	
Snail Pump Station	**Wastewater**	***32***	***3***	***208/120VAC***	***Propane***	***2011***	***Baldor***	***IGLC35-2GU***	
1 Phase Generators									
Police Department	**Town**	**40**	**1**	**240/120VAC**	**Propane**	**2001**	**Generac**	**43730**	**3533193**
West End Pump Station	**Wastewater**	***40***	***1***	***240/120VAC***	***Diesel***	***2001***	***Katolight***	**SED40FGJ4 CSA LR32481**	
3 Phase, 480V Generators									
South Hollow	Water	300	3	480/277VAC	Diesel	2004	Caterpillar	SR4B	8ER04151
Wastewater Treatment Plant	**Wastewater**	***265***	***3***	***480/277VAC***	***Diesel***	***2001***	***Kohler***	**250REOZD**	

In addition to the generators listed in **Table 1-5**, the Town also has a towable spare Kohler generator (Model No. 150REOZT) that was purchased new in 2015. The generator is trailer mounted, towable and available as an emergency backup generator for all town facilities.

2. STORM TIDE PATHWAYS – METHODS & RESULTS

The Provincetown Center for Coastal Studies (Coastal Studies) developed and conducted the Storm Tide Pathways process associated with this project. **Section 2.1** includes a general summation of their methodology and results. The full report from Coastal Studies is included in **Appendix A**. For reference, the mean tidal range for Provincetown is 9.3 feet (see **Figure 2-1**) and a summary of key water elevation and tidal datum is shown in **Table 2-1**. A tidal datum is a standard elevation defined by a certain phase of the tide.

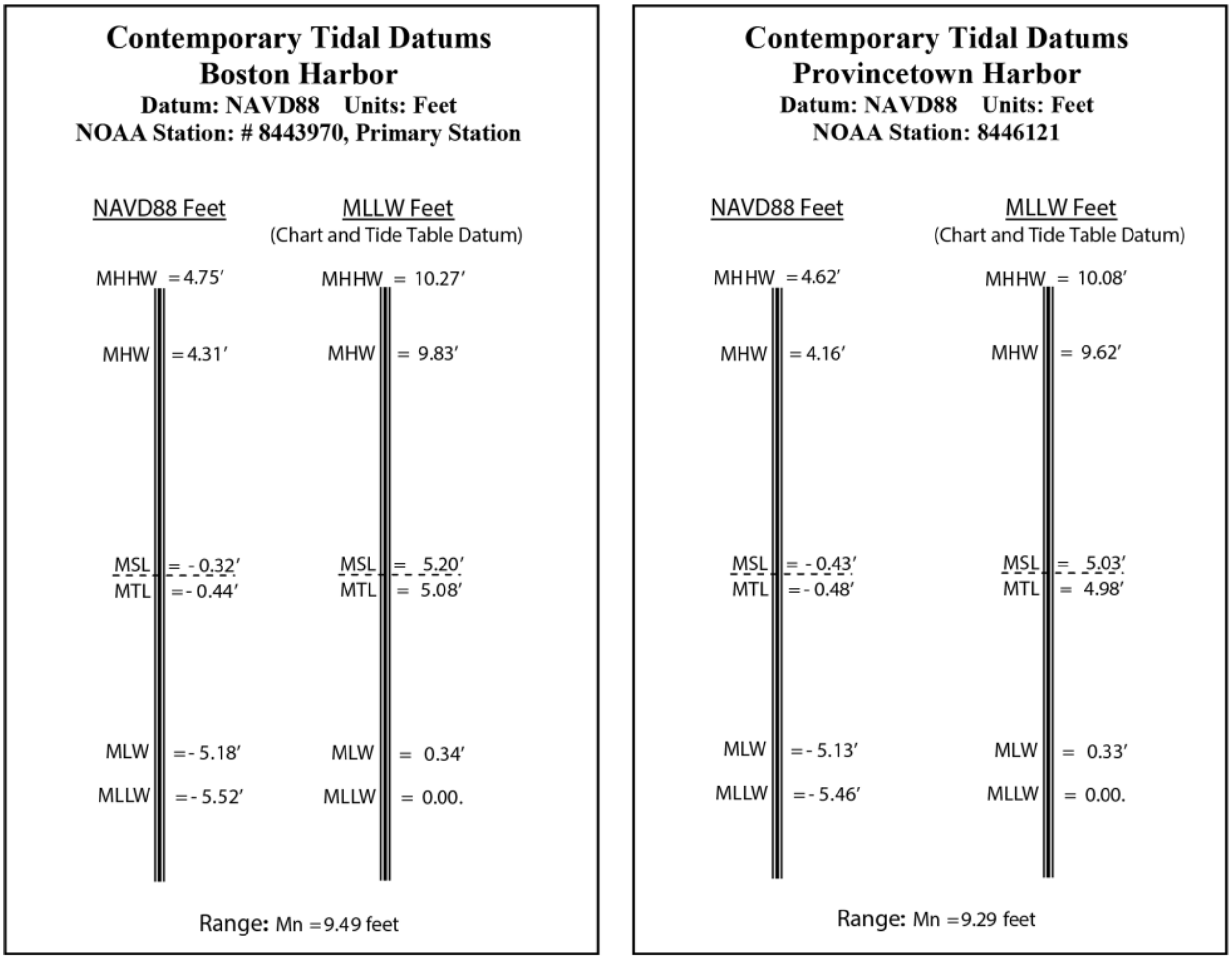
Table 2-1: Key Water Elevation and Tidal Datum

	Still Water Elevation in Feet (MLLW)
100 Year Return Still Water Level	13.95
50 Year Return Still Water Level	13.55
10 Year Return Still Water Level	13.35
High Tide Level	11.57
Mean Higher High Water	9.75
Mean High Water	**9.29**
NAVD88	4.95
NGVD29	4.10
Mean Low Water	0.00
Mean Lower Low Water	-0.33
Lowest Predicted	-2.43

2.1 METHODS

Identifying existing storm-tide pathways (STP) in a dynamic coastal environment is a multi-step process. First, a datum referenced tidal profile is established for the local area. For Provincetown Harbor, existing benchmarks for NOAA CO-OPS tidal station # 8446121 were recovered, occupied by the Center's Real-Time-Kinematic Global Positioning System (RTK GPS) and referenced vertically to the North American Vertical Datum of 1988 (NAVD88). Tidal station # 8446121 was established in Provincetown Harbor on March 5, 2010 and tidal datum referenced to the station datum, and reported on the NOAA CO-OPS website [tidesandcurrents.noaa.gov], were then converted to NAVD88 for reference throughout the project. **Figure 2-1** shows the contemporary tidal datum for Provincetown Tidal Station # 8446121 referenced to NAVD88 and Mean Lower Low Water (MLLW). As shown in **Figure 2-1**, this tidal profile is extremely similar to Boston Harbor.

Figure 2-1: Tidal Datum Profiles for Boston and Provincetown



Having established a datum referenced tidal profile, historical coastal storms were researched to determine significant storm tide (storm surge + astronomical tide) events occurring since 1921, the beginning of the continuous tidal record for Boston Harbor. Based on a Provincetown Harbor tidal characterization, the STP analysis proceeds with the identification of potential STPs in the lab using a rigorous desktop analysis of existing elevation Light Detection and Ranging (LiDAR) data.

An extensive fieldwork assessment program to locate, identify and verify the presence or absence of an existing STP in locations discovered in the desktop exercise was completed. This fieldwork is critical due to the following:

- LiDAR collected via low flying aerial surveys and the post-processing involved introduces uncertainties that can exaggerate or diminish features in three dimensional data and obscure or conflate the presence and scale of a storm-tide pathway. This has been shown to be particularly evident in cases of ‘bare earth’ models where elevations tend to be “pulled up” in areas adjacent to where buildings are removed and “pulled down” in areas of bridges or where roads cross streams.
- The use of an RTK-GPS instrument provides the best possible accuracy for acquiring and verifying 3-dimensional positional data. The GPS data can corroborate, or refute the presence of STPs identified from the desktop LiDAR analysis.

- Due to the dynamic nature of coastal geography only through this type of field work can potential STPs be discovered that were not seen in the desktop analysis of the LiDAR data.
- Even the most current LiDAR is rapidly out of date in certain areas. Consequently, GPS fieldwork is critical to identify those STPs that appeared in the LiDAR but no longer exist due to changes in landform.

2.1.1 Desktop Analysis

Potential STPs begins with the desktop analysis of the best available synoptic elevation data for the study area. The latest LiDAR data were downloaded from the NOAA website (https://coast.noaa.gov/digitalcoast/). The website has default settings for horizontal and vertical reference datum, spheroid and projection as well as units (metric vs standard). For the purposes of this study, the default download parameters were altered for ease of use within several software packages. Regardless of the spatial parameters, the positional information within the LiDAR are not altered. The final data are reported within the MLLW datum for Provincetown Harbor, to simplify use at the local level.

The data are downloaded in a raster format and brought into ESRI's ArcGIS software where the raster is divided into smaller tiles. The LiDAR tiles are brought into QPS's Fledermaus data visualization software. While acquired by CCS as an integral component of its Seafloor Mapping Program, the Fledermaus software package has proven to be an ideal platform for the initial desktop identification of STPs with the accuracy of the initial analysis limited primarily by the uncertainty and resolution of the LiDAR itself.

The power of Fledermaus lies in its ability to work with very large data files quickly. Individual files can be multiple GBs in size, yet Fledermaus can very rapidly, almost instantly, move through the data for visual inspection, 'fly-throughs' and similar functions. A horizontal plane, representing a specific STP elevation can be added to a Fledermaus project or 'scene' and that plane can be changed to simulate the increase or decrease in water level (**Figure 2-2**).

Figure 2-2: Downtown Provincetown, Draped Aerial Photograph Over LiDAR Surface

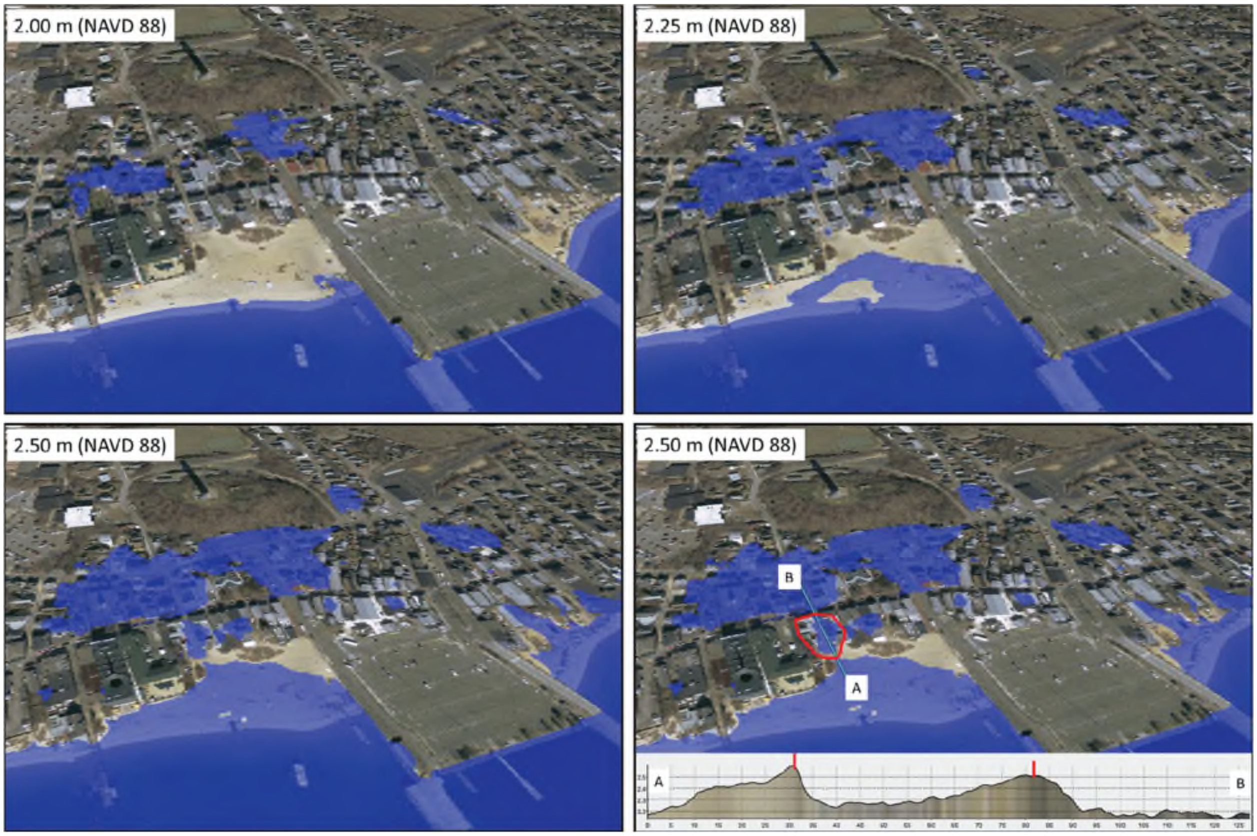


Figure 2-2. *Downtown Provincetown, draped aerial photograph over Lidar surface. Blue areas are horizontal plane created in Fledermaus at increasing elevation. Lower left is example of a storm-tide pathway with accompanying profile. These images were generated before field work.*

Another invaluable feature of the data visualization software is the ability to drape a two dimensional data, set such a vertical aerial photograph, over a 3D dataset (LiDAR). This allows better documentation of the STP and the ability to gain valuable information as to the substrate the STP is located in and its landscape setting. For example, an STP found on or near a naturally evolving coastal feature such as a beach or dune, would be characterized differently than one atop a concrete wall or other relatively static structure. This is important not only for a final assessment of the most appropriate way to address a STP in a critical area but also serves to closely examine naturally evolving areas and to understand STPs in close proximity to the identified point but not present in the LiDAR.

In the Spring of 2011, the Natural Resource Conservation Services (NRCS) collected terrestrial LiDAR data for Barnstable County. These data were used to provide an accurate synoptic elevation dataset. Metadata for these data indicate horizontal and vertical accuracies of +/- 1.0 m and +/- 0.15 m respectively, previous LiDAR for the area had double the vertical uncertainty.

2.1.2 Field Work

At the completion of the desktop analysis, potential STPs were compiled into a database with x, y, z coordinates and uploaded into the GPS. Field work occurred over several days using the GPS instrument to navigate to the location of a potential STP and determine its presence or absence or if an alternative location is more appropriate. Many coastal sites have very low relief (relatively flat) and determining whether a STP exists and its exact location and direction of water flow is facilitated with the professional judgment and experience in the principles and practices of land surveying fieldwork as well as a thorough knowledge of coastal processes.

2.1.3 Data Processing

After the field work has been completed, data collected is processed to determine the refined STPs. Points that were determined not be STPs are eliminated and new STPs that were identified and documented in the field are added and labeled with position, elevation, substrate and other pertinent information. This information is included in a comprehensive database that can be brought into the project GIS. Particular attention is focused on those areas when the LiDAR was found to correlate poorly with current conditions or real-world positions as determined by the GPS surveys and professional judgment applied to accurately represent the STP.

With the compilation of the comprehensive STP database, the file is brought into ESRI's ArcGIS to visualize STP locations and provide a working tool to: 1) proactively address STPs prior to storm events; 2) prepare for approaching storms; and 3) to plan for longer-term improvements to mitigate other STPs. Recognizing that accurate field delineation of the extent of inundation for each STP is beyond the scope of the project, the LiDAR data was used in two interactive ways to visualize STP inundation levels. The first depiction is referred to as the Pathway Activation Level (PAL). The PAL is the elevation at which water begins to flow over a STP, the extent of which is delineated as a continuous contour using elevation from the LiDAR. For example, based on the GPS fieldwork, a STP with a PAL of 13.6 MLLW indicates that the moment the water reaches 13.6 MLLW water will begin to flow inland over the STP. Using the data visualization software, a water elevation of 13.6 MLLW was used to demarcate the area that would hypothetically be inundated (assuming storm tide water levels are maintained long enough for the area to become flooded). If a storm tide recedes after reaching the PAL, then the depiction can be viewed as a "best" case scenario for impacts associated with a specific storm tide. If water levels were to continue to rise above the PAL, higher that 13.6, more area would be inundated leading to the need for a second way to visualize STPs.

To increase the utility of the STP data and to make visualizations more user friendly, Inundation Ranges (IRs) were developed for the entire study area rather than creating PALs for every STP and all elevations of potential flooding. Based on a series iterations depicting potential inundation scenarios, including nuisance flooding, it was determined that the lowest value IR range would begin at the highest Spring tide of the year. The elevations were incrementally raised to the elevation of the Storm of Record for the area and three more elevations were added (Storm of Record +1ft; Storm of Record +2ft; and Storm of Record +3ft) to represent future sea level rise.

3. RISK ASSESSMENT

3.1 METHODOLOGY

Improving the resiliency and preparedness of Provincetown for impacts related to natural hazards, begins with understanding which of the Town's assets and infrastructure are at the highest risk. Understanding the risk presented to an asset in the system, allows the Town to make informed decisions about improvements and helps optimize the value of mitigation projects. To conduct the risk assessment, Woodard & Curran worked collaboratively with key stakeholders in Town to perform a risk analysis which identifies the criticality of the Town's assets (buildings, facilities, resources, etc.), and helps prioritize assets for possible risk mitigation projects.

Risk assessment is a method for identifying system vulnerabilities, prioritizing mitigation projects, and optimizing mitigation budgets. Risk is the combination of how likely it is an asset could fail, and the resulting impact of that failure. These concepts are represented in the risk analysis by Consequence of Failure (CoF), and Likelihood of Failure (LoF). This section describes the basis for identifying critical assets throughout the system and the risk assessment process. The results of this analysis were utilized to identify mitigation strategies and will be available during future planning efforts such as the recently updated Provincetown Hazard Mitigation Plan.

3.1.1 Scope of Assessment and Data Gathering

In order to delineate set of assets for the assessment, Woodard & Curran worked collaboratively with the Town to define a "Critical Facilities & Infrastructure" list. The assets included were selected based on a high-level assessment of criticality to the Town. The critical assets include infrastructure, facilities, public services resources, and commercial properties. The process was outlined in **Section 1.6**, and the list is shown in **Table 1-3**.

Woodard & Curran worked closely with Town stakeholders during the preliminary stages of the project to identify the data needed to complete the risk assessment. Woodard & Curran issued a data request to the Town to obtain information during the preliminary stages of the project. The resources used for the assessment included Town GIS and parcel maps, online data viewers, annual reports, and land use/zoning. Additionally, inundation pathway data generated by Coastal Studies was used as a component of the LoF assessment.

3.1.2 Consequence of Failure Assessment

The Consequence of Failure (CoF) assessment focused on how important the assets are to the Town, and the resulting impact in the case the asset was no longer functional. The CoF was evaluated based on the impact if the asset had been damaged to the point it was non-functional.

The CoF for each asset was scored based on the impact its failure could have to the following four categories:

- **Public Health and Safety:** This category focused on the likelihood a failure of each asset could cause injuries or deaths. It was assumed the impacts could be caused directly by the actual failure of the structure, or indirectly by failing to provide critical services (such as nursing homes, medical facilities, etc.).
- **Community Image:** This category concerned how the failure of an asset could affect the reputation of the Town. This includes media coverage, service interruptions, and generally how and asset's failure could affect the ability of the Town to achieve its desired levels of service.
- **Financial:** This category was based on the direct financial replacement value of the asset, using the scale shown in **Table 3-1**. This is a community financial impact and includes private and public cost implications. The costs were based on Town Assessor's data where it was available, and was estimated based on Woodard & Curran's knowledge of infrastructure costs where it was not available. The results from this section are

provided for high level, planning purposes only. Some specific assumptions made for assets during the scoring for this category include:

- For many of the assets, assessors building values were used for the scoring. However, for some examples it was apparent the assessed building value did not include the value of the equipment and vehicles on site. For these assets, an equipment and vehicles value was added to the building value during the scoring.
- Non-point location infrastructure (roadways, sewer system, distribution mains etc.): For these assets, because they span large areas and are not located at one site, it was not assumed failure would result in a total replacement. Instead, the financial impact was assumed to reflect the approximate cost of a major repair or rehabilitation.
- For wastewater pump stations, the financial impact was assumed based on the capacity of the station. Stations with a capacity of greater than 300 gallons per minute (gpm) were given a higher score than those less than 300 gpm.
- For several assets, including the water towers, public television station, and electrical substations, there was not enough information to assume approximate replacement values. For these assets, Woodard & Curran used our best professional judgement to approximate the score.

- **Environmental Damage:** In many cases, the failure of an asset may result in environmental contamination. Environmental damage may have an impact from a regulatory perspective. However, Provincetown is a community whose tourism revenue relies heavily on the attraction of healthy shore land ecosystems such as beaches, natural dunes, wetlands and other geological features.

The assets were scored for each category on a numeric scale of 1-5, where 5 is a major impact, and 1 is a negligible impact. The scoring methodology is illustrated in detail in **Table 3-1**.

Table 3-1: CoF Scoring Matrix

Health & Safety	Community Image	Financial	Environmental Damage
5. Significant risk of injury or death 4. Significant risk of major injury 3. Low risk of major injury 2. Low risk of injury 1. No Risk of Injury	5. Major service interruption, reputation impact and/or national media coverage. 4. Intermittent services, reputation impact and local or regional media attention. 3. Minor service and reputation impacts, no media. 2. No media and reputation impacts, minor intermittent service impacts. 1. No media, reputation or reputation impacts.	5. Greater than $5 million 4. $1 million to $ 5million 3. $100k to $1 million 2. $10,000 to $100k 1. Less than $10,000	5. Significant environmental damages. 4. Localized environmental damage. 3. Possible environmental damage. 2. Possible minor or eventual environmental damage. 1. No environmental damage

Woodard & Curran developed CoF scoring based on our industry knowledge as well as through interviews with key stakeholders. These interviews took place during the site visit, and included discussions designed to further assess the criticality of key assets, identify vulnerabilities and incorporate stakeholder knowledge into the desktop CoF assessment. Using the information gathered during the stakeholders' meetings, the CoF scores for each asset were developed and/or adjusted accordingly. The results of the CoF assessment are included in **Appendix A**.

3.1.3 Likelihood of Failure Assessment

The Likelihood of Failure (LoF) assessment gauges the probability of a failure taking place. The failure modes for this assessment included the most probable hazards for a community highly exposed to open ocean. These include sea level rise, storm surge, and flooding. Failure as a result of these hazards could occur at varying degrees and in this assessment sea level inundation was assumed to be a failure. It was not within the scope of this project to include a determination on the varying degrees to which hazards could affect the condition of individual assets.

The first step in the LoF assessment was to spatially locate the assets on the critical infrastructure list using a GIS database. Each of the scoring categories for this analysis were based on GIS layers, which show the areas in the Town that could be affected by different climatological hazards. Each category is described below:

- **Coastal Studies Inundation Pathways:** As part of the project, Coastal Studies conducted an analysis that used detailed on the ground surveys to accurately represent the most probably pathways storm surge could enter the Town, and the most likely area that could be inundated. The pathways are each designated with an elevation of water above sea level that could result in the inundation pathway becoming active. The resulting flooded areas were represented as a shape file in GIS, and any assets within those areas were scored according to the elevation needed to inundate the specific flood area, using the criteria shown in **Table 3-2**.

- **Hurricane Surge Inundation Zones:** The hurricane surge category is based on the Sea Lake and Overland Surges from Hurricanes (SLOSH) model developed by the National Weather Service for the purposes of estimating storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The model takes into account the atmospheric pressure, size, and forward speed, and tracks data in order to model the wind field, which drives the storm surge. The GIS layers for this model were acquired from the Cape Cod Commission. Similar to the previous category, assets were scored based on whether they fell into a SLOSH surge zone based on the category of hurricane.

- **FEMA FIRM National Flood Hazard Maps:** "FIRM is an official map of a community that displays the floodplains, more explicitly Special Flood Hazard Areas (SFHA) and Coastal High Hazard Areas (CHHA), as delineated by FEMA. Both areas are subject to inundation by 1-percent-annual chance flood."[1] The scoring for this category was based on whether an asset fell into one of these areas. **Figure 3-1** illustrates as an example, the location of several Town assets in the FEMA designated floodplain.

[1] Cape Cod Sea Level Rise Viewer. http://gis-services.capecodcommission.org/apps/public/SeaLevelRise/SeaLevelRise.html#MoreInfo Cape Cod Commission 2015. Accessed October 2015.

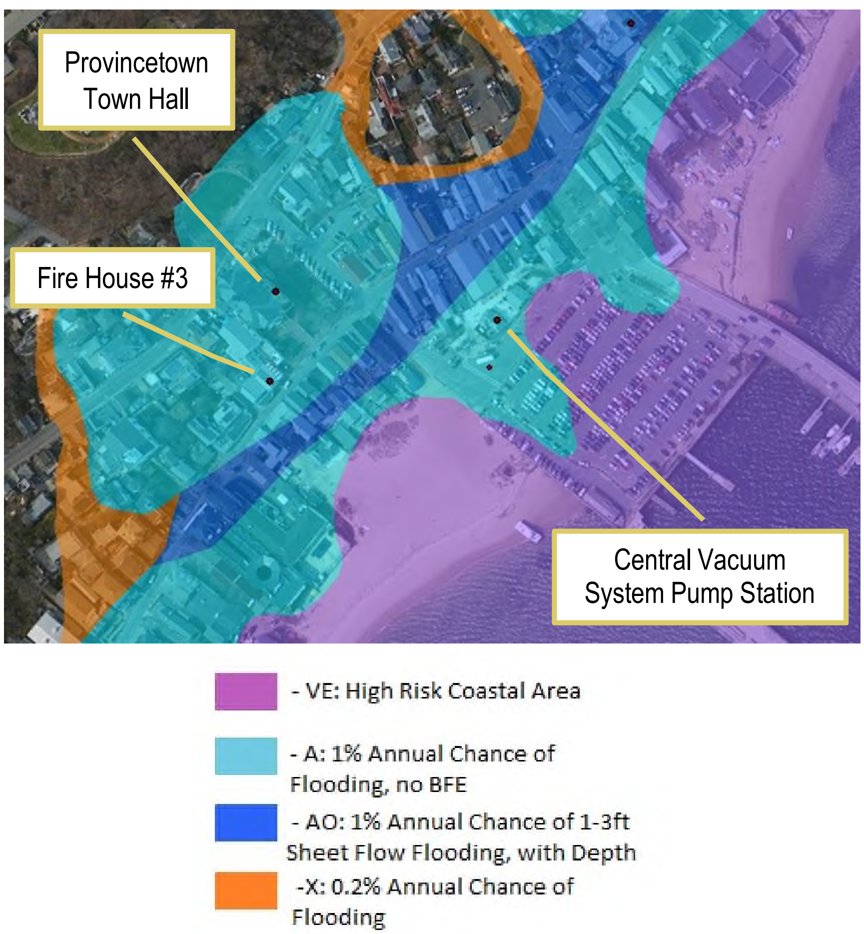
Table 3-2: LoF Scoring Matrix

Coastal Studies Inundation Pathway	Hurricane Surge Inundation Zones	FEMA FIRM National Flood Hazard Maps	Sea Level Rise
5: Inundation within less than 2 meters 4: Inundation between 2 and 3 meters 3: Inundation between 3 and 4 meters *2: Not Used* 1: Not within Inundation Area	5: Category 1 Hurricane 4: Category 2 Hurricane 3: Category 3-4 Hurricane *2: Not Used* 1: Not within a SLOSH surge area	5: Coastal High Hazard Areas 4: Special Flood Hazard Areas *3: Not Used* *2: Not Used* 1: Not within a FIRM area	5: Affected by 3-ft. SLR 4: Affected by 4-ft. SLR 3: Affected by 5-ft. SLR 2: Affected by 6-ft. SLR 1: Not affected by 6-ft. SLR

LoF Assessment Assumptions:

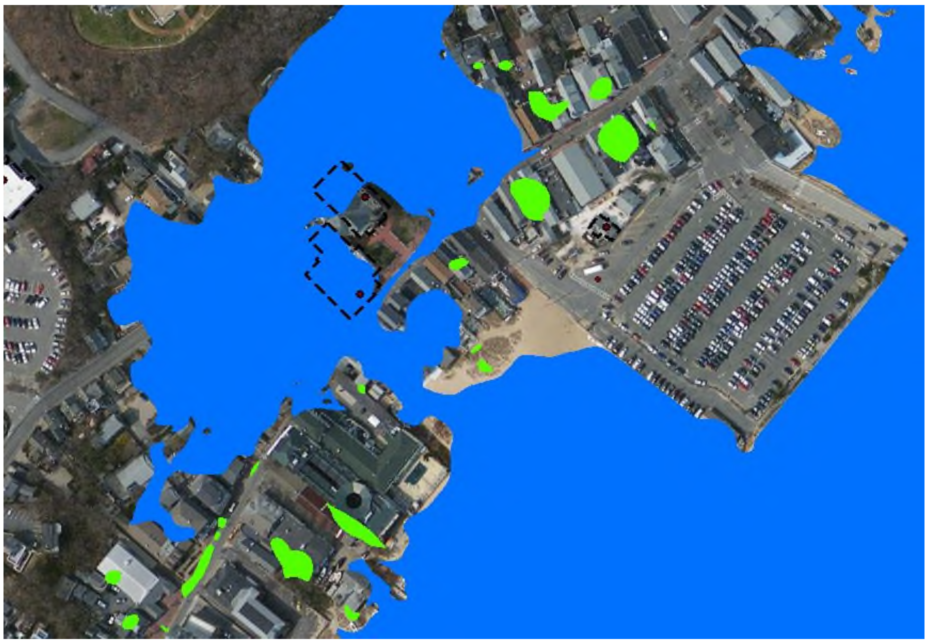
- *Central Vacuum System*: For the LoF assessment, the Central Vacuum System was included only as the Central Vacuum Pump Station, and did not include the entire vacuum collection system.
- *MacMillian Pier & Harbormaster:* Storm Tide Pathways data did not extend beyond the coastline to the location of the pier. As a result, the LoF score for this asset was comprised of the Hurricane Surge Index Zones, FEMA FIRM Maps, and Sea Level Rise scores.

Figure 3-1: FEMA FIRM Map - Town Assets Within Floodplain Zones



- **Sea Level Rise:** The Sea Level Rise layers were acquired from the Cape Cod Commission's website, and were derived from "classified Digital Elevation Model (DEM) data collected through Light Detection and Ranging (LiDAR) in 2011 by USGS." The impacted areas were based on land elevations relative to the Mean Higher High Water (MHHW) using NOAA software[1]. **Figure 3-2** shows the projected impacts of Sea Level Rise on the center of Provincetown with 4 feet of Sea Level Rise.

Figure 3-2: Projected Impacts of Sea Level Rise (SLR) With 4-ft. of SLR



3.2 RISK ANALYSIS INTERPRETATION & RESULTS

Based on the LoF and CoF assessments, the risk scores were determined for each asset as shown in **Table 3-3.** The risk evaluation was completed using the results of the CoF and LoF analyses. Risk is the product of the numerical metrics of LoF and CoF (Risk = CoF x LoF). As a result, the risk scores are on a scale of 1-25.

Table 3-3: Asset Criticality Ranking

ASSET ID	Name	LoF	CoF	RISK
1	Provincetown Airport	4.67	4.00	**18.7**
2	Provincetown Town Hall	4.17	4.00	**16.7**
3	MacMillan Pier & Harbormaster*	4.00	4.00	**16.0**
4	Coast Guard Station	4.34	3.50	**15.2**
5	Route 6A	3.84	3.75	**14.4**
6	Electrical Transmission Lines	3.84	3.75	**14.4**
7	Route 6 Roadway	3.84	3.75	**14.4**
8	Water Transmission Mains from Truro	3.84	3.50	**13.4**
9	Pump Station #8 - West End	4.00	3.00	**12.0**
10	Central Sewer Vacuum System*	3.17	3.75	**11.9**
11	Province Land Road Culvert	4.50	2.50	**11.3**
12	Fire Station	3.17	3.50	**11.1**
13	Provincetown Police Station	3.17	3.50	**11.1**

ASSET ID	Name	LoF	CoF	RISK
14	Stop and Shop	3.17	3.50	**11.1**
15	Pump Station #1 - Kendall Lane	3.67	3.00	**11.0**
16	Pump Station #6 - Commodore Avenue	3.67	3.00	**11.0**
17	Stormwater Pumphouse	3.67	3.00	**11.0**
18	Fire Station #5	3.34	3.25	**10.8**
19	DPW Garage	2.67	4.00	**10.7**
20	Pump Station #11 - Ice House Pump Station	3.84	2.75	**10.6**
21	Pump Station #7 - Thistlemore Road	3.50	3.00	**10.5**
22	Pump Station #9 - Shank Painter	3.17	3.25	**10.3**
23	Provincetown Public Television	3.34	3.00	**10.0**
24	Pump Station #5 - Snail Road	3.34	3.00	**10.0**
25	Fire House #3	4.17	2.00	**8.3**
26	Pump Station #2 - Pleasant Street	2.67	3.00	**8.0**
27	Fire House #2	3.34	2.00	**6.7**
28	Wastewater Treatment Plant	1.17	4.50	**5.3**
29	Emergency Operations Center - VMCC	1.17	4.25	**5.0**
30	Outer Cape Health Services	1.17	4.00	**4.7**
31	Pump Station #10 - Stop and Shop P.S.	2.00	2.25	**4.5**
32	Seashore Point	1.17	3.75	**4.4**
33	Transfer Station	1.17	3.75	**4.4**
34	Provincetown High School	1.17	3.50	**4.1**
35	Pump Station #4 - Bayberry	1.17	3.50	**4.1**
36	Provincetown Public Library	1.17	3.25	**3.8**
37	Fire Station #4	1.17	3.25	**3.8**
38	Maushope Senior Housing	1.17	3.00	**3.5**
39	Pump Station #3 - Manor	1.17	3.00	**3.5**
40	Power SubStation #1	1.00	3.50	**3.5**
41	Power SubStation #2	1.00	3.50	**3.5**
42	Winslow Water Tower	1.17	2.75	**3.2**
43	Mt. Gilboa Water Tower	1.17	2.75	**3.2**
44	Housing Authority	1.17	2.50	**2.9**
45	Herring Cove Animal Hospital	1.17	2.50	**2.9**
46	Telephone Station	1.17	2.25	**2.6**

**See assumptions listed in Section 3.1.3 above.*

The assets' risk scores are an effective tool for prioritizing hazard mitigation projects. However, developing effective projects requires a deeper look at the results from the risk assessment. In addition to risk, it is important to consider the individual LoF and CoF scores when deciding the appropriate response strategy for a high-risk asset.

3.3 RISK INTERPRETATION FOR HIGHEST RISK SCORES OR "CRITICAL" TO THE COMMUNITY

The risk results are a tool for the Town to use for future planning efforts. In the sections below, more detailed assessment results and implications have been provided for several assets having the highest risk scores, or identified as critical to the community for economic, cultural and public safety reasons. This assessment does not include assessing how a natural hazard event would specifically affect each asset and considers a 'failure' when an asset becomes inundated with water from sea level rise, storm surge, flooding, or any combination of those hazards. The assessment does not estimate the actual damage that could be caused by inundation as a separate more detailed engineering analysis for each individual asset would be required.

3.3.1 Municipal Airport

Provincetown Municipal Airport provides an important economic and transportation service to the community. During the high tourism season, there is very high usage of the facility. The CoF score for this asset was driven primarily by the community image and financial impact scores. It could be a major loss for Provincetown if the airport were to be significantly impacted by a natural hazard event.

Coupled with the high CoF score, the Airport is also within a floodplain. Our assessment shows it is currently at risk of inundation from sea level rise, storm surge and flooding. The Town previously installed a dike to protect the airport from flooding, however, the inundation pathways information shows the dike may not provide enough protection, and it could be easily overcome during a certain type of major weather event.

3.3.2 Police Department

Although the Police Department did not score in the top five of the risk assessment, it is discussed in this section because it was recognized by Town stakeholders as critical for ensuring public safety. Due to its current location (in a FEMA floodplain) it has been the subject of numerous recent discussions and planning efforts. The risk assessment resulted in a CoF and LoF score of 3.5 each for the Police Station.

The LoF score for the Police Station is driven by the fact that the location of the station on Shank Painter Road is in a depression and at a low elevation. As a result, the Police Station is at risk for flooding due to precipitation. However, the detailed Storm Tide Pathways analysis shows storm surge and sea level rise are not a great concern for this location. The storm tide pathway from which seawater could reach the Police Station is about a mile away along the eastern shore, making it unlikely that storm surge would reach this location.

Photo: *Provincetown Police Station (December 2015)*

3.3.3 Town Hall

Provincetown's Town Hall is one of the most important and critical of the Town's assets, and it received one of the highest CoF scores (4.0) in the risk assessment. It is an important civic and cultural landmark and many of the Town's public services are managed from within the building. Town Hall serves as the central hub for the community and in addition to conducting Town business there; Provincetown uses the building as an entertainment venue and meeting/rental space giving it additional economic value. The Town's active servers are located on the basement floor of the building and could be exposed to potential flood damage.

Photo: *Provincetown Town Hall (December 2015)*

Photo: *Provincetown Town Hall – Basement Entry (December 2015)*

3.3.4 Next Steps

The results from this risk analysis provide Provincetown with a tool for making informed decisions about how best to prioritize capital projects and mitigation actions. In the following sections, these risk results were used to develop recommendations for adaptive strategies that align well with the recently updated Provincetown Hazard Mitigation Plan.

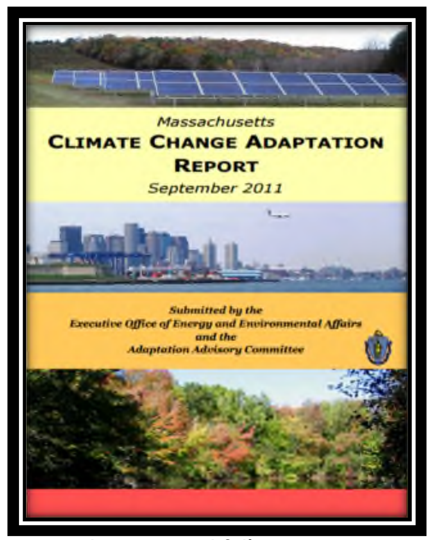
4. RECOMMENDATIONS FOR ADAPTIVE STRATEGIES

Upon the completion of the risk assessment, recommendations for adaptive strategies for high-risk critical facilities and infrastructure were prepared. The strategies considered the inundation pathways and areas at risk for flooding. The recently updated Provincetown Hazard Mitigation Plan was also referenced due to the relevant recommendations and strategies pertaining to some of the critical facilities evaluated. Recommendations developed considered the following:

- Statewide policy recommendations applicable to all infrastructure (areas of policy that may be incorporated into future facility planning studies),
- Site-specific recommendations for short and long term physical and operational measures that can be incorporated into the infrastructure systems, and
- Recommendations for long-term physical and operational systems alterations, including possible relocation of components (if applicable).

Initial considerations for adaptation strategies included infrastructure capital upgrades (like relocating and/or upgrading culverts, elevating sensitive equipment, manholes, strengthening/hardening structures, etc.) and soft infrastructure upgrades (such as beach nourishment, increasing buffer zones, etc.).

4.1 MASSACHUSETTS CLIMATE CHANGE ADAPTATION REPORT



The Massachusetts Climate Change Adaptation Report (2011), prepared by the Executive Office of Environmental Affairs, was developed specifically to review strategies to help the state become more resilient and ready to adapt to climate change. The report notes that climate change has the potential to have huge impacts on the state's economy, public health, water resources, infrastructure, coastal resources, energy demand, natural features and recreation. Infrastructure is a specific sector discussed in the report along with and acknowledgement of significant development occurring along the coastline and in floodplains. General adaptation strategies from the report relevant to Provincetown include:

- Strengthen infrastructure resources, where possible, for future climate change impacts through principles of conservation, efficiency and reuse (i.e. drinking water conservation, stormwater management and flood-proofing structures during upgrades or routine maintenance). Ensuring there is capacity to manage and withstand climate change impacts will be critical to minimizing infrastructure damage and failure.
- Consider land use, design, site selection and building standard modifications to include climate change impacts.
- Focus on protecting and enhancing natural systems like wetlands, coastal features and areas that serve as flood storage capacity and provide protection and resilience to infrastructure.
- When considering infrastructure maintenance, replacement and rehabilitation, provide proper lead time so that an adaptation strategy can be included in the overall assessment of the critical facility. The amount of time to repair, improve, permit, or move a facility will vary greatly depending on what it is, so planning early is key.

Transportation - Provincetown has identified Route 6, Route 6A, MacMillan Pier and the Provincetown Airport as critical facilities. The state Climate Change Adaptation Report acknowledges coastal transportation infrastructure is vulnerable to sea level rise and extreme weather. This is specifically relevant to Provincetown because of its local airport, high temperatures or dense air conditions that may result in longer runway requirements. Provincetown is somewhat isolated from a transportation perspective and there are not any alternative modes or routes available to enter or exit the community via vehicle. Transportation strategies from the state report to be considered include:

- Continued maintenance of existing infrastructure to minimize damage from natural hazard events.
- Formulate risk-based methods to evaluate service life of infrastructure assets against adverse climate change.
- Include climate changes impacts with standard maintenance and inspection procedures and increase the frequency of routine inspections of coastal zone and inland drainage structures.
- Initiate comprehensive community asset damage inventories after major storm events.
- The Provincetown Airport should consider how it can use and implement new technology for navigation aids and airfield lighting systems to function better during a natural hazard event.

Water Resources – Provincetown identified a wide range of water resource facilities as critical. Water resources strategies from the state report to be considered include:

- Focus on natural systems to help absorb or redirect inflow from stormwater collection systems into natural systems or those that use LID technology. Keeping stormwater flow contained helps to increase capacity for other systems (wastewater, water) and groundwater recharge.
- Expand water conservation and reuse of drinking water and reduce wastewater discharge and stormwater runoff.
- Educate the community and relevant staff on the vulnerabilities of its assets or individual facility to climate change impacts, where appropriate.

Built Infrastructure & Buildings – Provincetown included a number of buildings and built infrastructure on its critical facilities list. Built Infrastructure & Buildings strategies from the state report to be considered include:

- Use the permitting process to recommend new construction and renovation projects consider potential climate change impacts, where appropriate. Requiring protection of basements and first floor levels or enhancing site work to include natural systems for surface runoff could improve their ability to withstand a natural hazard event.
- Consider climate change impacts and develop design guidelines for new construction and renovation projects.

4.2 RELEVANT ACTION ITEMS FROM OTHER PROVINCETOWN PLANNING PROJECTS

Provincetown has undertaken a number of recent broad ranging planning projects. To acknowledge those efforts and consider relevant information from these projects, including areas where there could be potential integration, this section highlights action items from the following plans and how they are relevant to the identification of adaptive strategies to increase coastal resiliency.

- 2016 - Provincetown Hazard Mitigation Plan Update
- 2012 - Provincetown Harbor Plan
- 2015 - Strategic Beach Stabilization Pilot Project/Analysis (funded by Coastal Zone Management)

4.2.1 Provincetown Hazard Mitigation Plan Update

The Provincetown Hazard Mitigation Plan, was updated by the Cape Cod Commission, and completed in 2016.The Plan notes specific actions the Town can take to reduce or eliminate long term risk from natural hazards. The actions most relevant to the identification of adaptive strategies to increase coastal resiliency are listed in **Table 4-1**.

Table 4-1: Relevant Action Items from Provincetown Hazard Mitigation Plan (2016)

Action	Status
Review and revise the Town's Floodplain District Zoning Bylaw to ensure it incorporates up to date floodplain science, policy, and legislation as well as cumulative substantial damage or improvement requirements.	At Town Meeting in April 2014, voters amended the Provincetown Zoning Bylaw to make it consistent with the newly updated Flood Insurance Rate Maps (FIRMs) for Barnstable County.
Relevance to Adaptation Strategies Project: Some of Provincetown's Critical Facilities and Infrastructure are located in a floodplain. Any recommendations or adaptation strategies should consider and reference the Provincetown Zoning Bylaw for consistency with the regulations.	
Conduct an assessment of local infrastructure subject to damage from flooding or storm surge or that is likely to cause damage to surrounding areas should it fail or flood.	Town Hall Staff, Department of Public Works and the Harbormaster continuously assess infrastructure vulnerable to flooding and storm surge. The Town received funding for two separate projects: one grant was used to assess how shoreline change will impact coastal infrastructure and the other was used to conduct a town-wide vulnerability assessment of Critical Facilities.
Relevance to Adaptation Strategies Project: The Adaptation Strategies project is the second project noted in the status column and serves to conduct the town-wide vulnerability assessment of Critical Facilities.	
Develop, prioritize and seek funding for a list of needed infrastructure improvement projects.	The Town actively seeks funding from state and federal agencies.
Relevance to Adaptation Strategies Project: The Adaptation Strategies project is an example of how the Town of Provincetown sought out, applied for and was awarded grant funding from the Massachusetts Office of Coastal Zone Management.	
Conduct a thorough evaluation of the Town's most at-risk locations identified in the Vulnerability Analysis, and evaluate the potential mitigation techniques for protecting each location to the maximum extent possible.	In 2014, The Department of Public Works received funding from the Massachusetts Office of Coastal Zone Management to identify vulnerable areas and assets in town. Specifically, this project will identify and map low-lying areas that provide a direct pathway for floodwaters to reach inland areas and install a tide gauge to provide real time water level data. The goal of the project is to assess potential flood impacts to critical public infrastructure and recommend short- and long-term strategies for future protection of high-risk assets.

Action	Status
Relevance to Adaptation Strategies Project: The Adaptation Strategies project is the result of the action noted above.	
Flood proofing structures and elevating utilities in town buildings such as Town Hall, Freeman Street Building, and businesses on the south side of Commercial Street from the east end of Town through the west.	Building files and art were moved to the second floor of publicly owned buildings.
Relevance to Adaptation Strategies Project: This action is relevant to some of the recommendations being made for the Adaptive Strategies project, particularly in reference to critical infrastructure such as the Town Hall. Additional modifications such as moving critical paper and electronic files and associated hardware needs to be planned.	
Utilities servicing critical structures require flood proofing and elevating to secure them against storm surge and flooding.	While the Town recognizes the need to elevate structures to secure them from surge and flooding, a more detailed risk assessment needs to be performed so money is allocated to higher priority projects. Currently, the Department of Public Works is working with a private consultant on a risk assessment for critical facilities in Provincetown.
• **Relevance to Adaptation Strategies Project:** The Adaptation Strategies project looked at critical facilities and has prioritized projects based on a risk assessment and analysis.	

4.2.2 Strategic Beach Stabilization Pilot Project

Under a separate Coastal Zone Management grant, Provincetown completed a strategic beach stabilization pilot project/analysis in June 2015. The report acknowledges the Town's proactive efforts towards coastal planning and documents the need for beach nourishment as a tool for coastal resiliency. The project was a desktop study to identify shoreline areas vulnerable to or resilient to coastal erosion and inform more strategic resiliency planning. The plan acknowledges beach nourishment is a tool key to coastal resiliency in Provincetown. The Beach Stabilization Pilot Project focused on the following goals:

- Complete the sediment budget to identify shoreline areas vulnerable to or resilient to coastal erosion and to inform more strategic resiliency planning.
- Utilize the sediment budget to better understand sediment transport and the amount of material available for beach nourishment at a town-wide scale.
- Conduct community outreach, including workshops, to inform the public of sediment transport processes and to help identify priority areas for restoration/enhancement.
- Select and evaluate a beach nourishment pilot project site and complete design plans, profiles, sections, details and local permitting to demonstrate the benefits of beaches and dunes in providing storm damage protection to the Provincetown coastline; and
- Use scientific analysis of shoreline sediment dynamics to inform a future comprehensive beach management plan.

4.2.3 Provincetown Harbor Plan

The Provincetown Harbor Plan (2012) serves as a planning tool to consider and consolidate the interests and needs of private property owners, and public recreational and commercial uses with regulatory and planning agencies. With a Harbor Plan in place, Provincetown is able to access grant funds for improvements and protection of the harbor, provides guidance to MADEP and support Chapter 91 licensing.

For example, MacMillan Pier was identified in this project as a critical facility due in part to its supporting role for the Provincetown economy and its identity as a recreational and commercial mainstay. The Harbor Plan specifically discusses FEMA high velocity zones (MacMillan Pier is located in one) and the need to understand and undertake measures to reduce storm damage risks and investigate the potential for mitigation.

4.3 ADAPTIVE STRATEGIES

The adaptive strategies identified for Provincetown were developed specifically to address some of the unique challenges in the community. Strategies considered FEMA floodplain maps, Storm Tide Pathways information received from the Town and research of other coastal communities and their adaptation efforts. **Table 4-2** identifies the critical facilities and infrastructure that will be impacted directly by a Storm Tide Pathway at specified water levels.

Table 4-2: Critical Facilities & Infrastructure to Be Impacted by a Storm Tide Pathway

Mean Level Low Water (MLLW) Range	Critical Facility & Infrastructure to Be Impacted by a Storm Tide Pathway (STP) in this MLLW Range	Storm Tide Pathway(s) Impacting Critical Facilities & Infrastructure	Specific MLLW of the Storm Tide Pathway
< 12 feet	Provinceland Road Culvert	12-01	MLLW - 12.93
	Provincetown Airport	02-02 02-03	MLLW - 11.27 MLLW - 11.39
13.0 – 13.9 feet	Coast Guard Station	12-14 12-15 12-16	MLLW - 15.71 MLLW - 15.13 MLLW - 15.59
	Provincetown Town Hall	11-05 11-06	MLLW - 13.59 MLLW - 13.61
	Fire House #3	11-05 11-06	MLLW - 13.59 MLLW - 13.61
	Pump Station #8 - West End	12-05	MLLW - 13.25
14.0 – 14.9 feet	Fire Station #5	17-06	MLLW - 14.97
	Provincetown Public Television	11-07 11-08 11-12 11-11	MLLW – 14.51 MLLW - 14.75 MLLW - 15.77 MLLW - 15.5
	Fire Station #2	11-04	MLLW – 13.98

Mean Level Low Water (MLLW) Range	Critical Facility & Infrastructure to Be Impacted by a Storm Tide Pathway (STP) in this MLLW Range	Storm Tide Pathway(s) Impacting Critical Facilities & Infrastructure	Specific MLLW of the Storm Tide Pathway
	Water Transmission Mains from Truro	11-05 11-06 22-01 22-02 17-06	MLLW - 13.59 MLLW - 13.61 MLLW - 14.83 MLLW - 14.43 MLLW - 14.97
	Pump Station #11 - Ice House Pump Station	17.06	MLLW - 14.97
	Pump Station #1 - Kendall Lane	17-06	MLLW - 14.97
14.0 – 14.9 feet (continued)	Pump Station #6 - Commodore Avenue	22-01 22-02	MLLW - 14.83 MLLW - 14.43
	Route 6A	11-05 11-06 22-01 22-02 17-06	MLLW - 13.59 MLLW - 13.61 MLLW - 14.83 MLLW - 14.43 MLLW - 14.97
	Stormwater Pumphouse	11-07 11-08	MLLW - 14.51 MLLW - 14.75
	Electrical Transmission Lines	22-01 22-02	MLLW - 14.83 MLLW - 14.43
	Route 6 Roadway	22-01 22-02	MLLW - 14.83 MLLW - 14.43
15.0 – 15.9 feet	Central Sewer Vacuum System	11-11	MLLW - 15.5
	Pump Station #7 - Thistlemore Road	16-03	MLLW - 15.43
	Pump Station #5 - Snail Road	16-04	MLLW - 15.02
17.0 – 17.9 feet	Fire Station	07-04	MLLW - 17.29
	DPW Garage	07-04	MLLW - 17.29
	Pump Station #2 – Pleasant Street	07-04	MLLW - 17.29
	Provincetown Police Station	07-04	MLLW - 17.29
	Stop & Shop	07-04	MLLW - 17.29
	Pump Station #10 - Stop and Shop Pump Station	07-04	MLLW - 17.29
	Pump Station #9 - Shank Painter	07-04	MLLW - 17.29

The following critical facilities and infrastructure evaluated for this project were not found to be impacted by a Storm Tide Pathway, they include:

- Provincetown Public Library

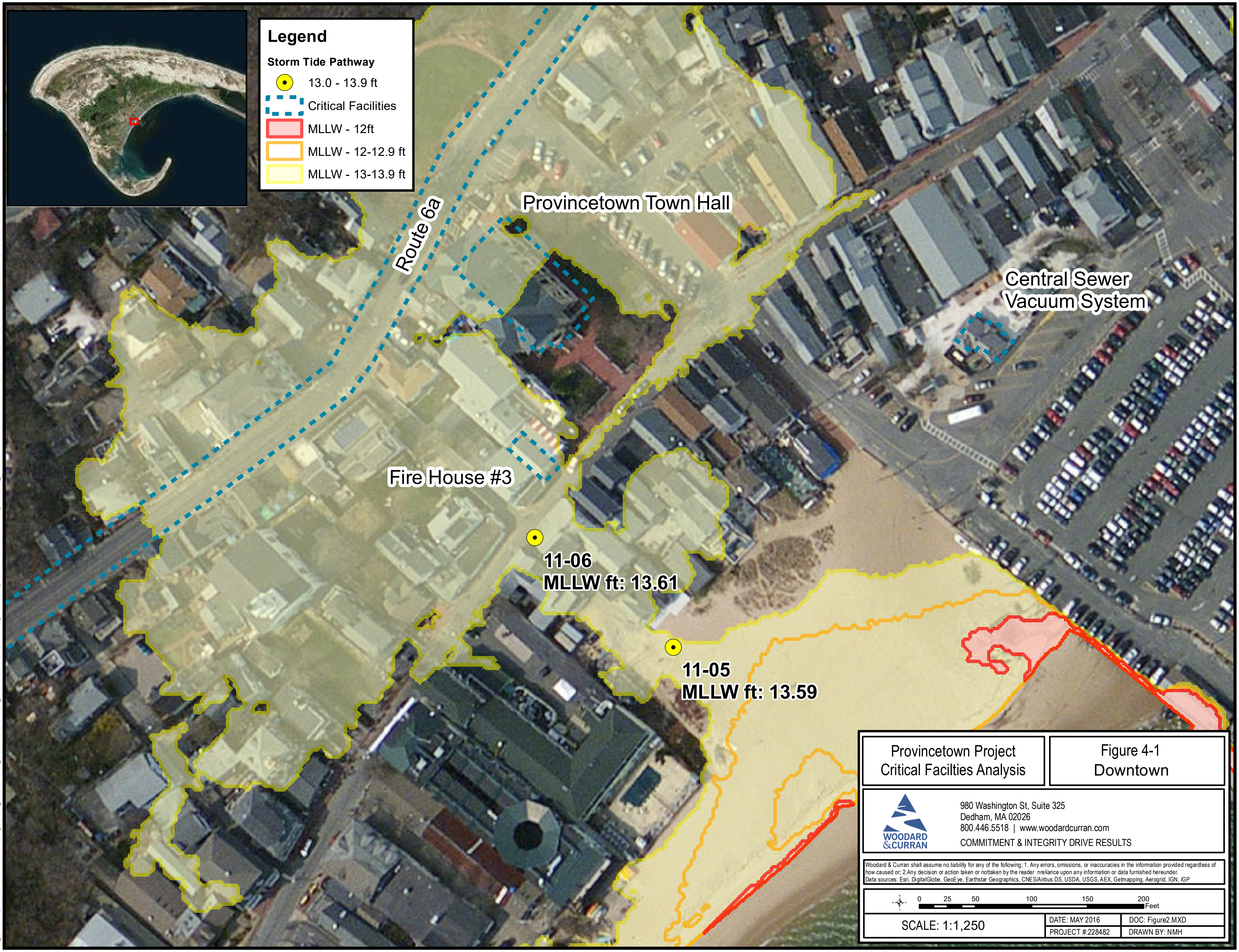
- Telephone Station
- Fire Station #4
- Seashore Point
- Emergency Operations Center – Veterans
- Provincetown High School
- Maushope Senior Housing
- Housing Authority
- Outer Cape Health Services
- Wastewater Treatment Plant
- Winslow Water Tower
- Herring Cove Animal Hospital
- Pump Station #3 - Manor
- Pump Station #4 – Bayberry
- Mt. Gilboa Water Tower
- Power SubStation #1
- Power SubStation #2
- Transfer Station

A specific inundation pathway was not identified for the MacMillan Pier & Harbormaster since this area is adjacent to the ocean and would be directly impacted.

4.3.1 Adaptive Strategies for Highest Risk Critical Facilities & Infrastructure

Detailed below are adaptive strategies and recommendations for the highest risk critical facilities and infrastructure.

- **Center of Provincetown's Downtown**: According to the STP results, the central downtown area near Commercial Street at Ryder Street presents a significant risk to the community for flooding hazards during major storm events (see **Figure 4-1**). This area is also confirmed to be a flood zone by the FEMA and SLOSH models. The STP and respective flood contour within this area affect several critical assets including the Town Hall, Fire House #3 and Bradford Street. In addition to the critical facilities, it also affects an important area of town with many commercial businesses driving the Town's economy. Woodard & Curran recommends the Town eliminate the STP which affects this area. The site of the specific STP will need to be investigated to determine the most effective strategy for eliminating the STP. There are a number of ways these pathways could be eliminated, including:
  - Developing a plan to sand bag the STP during storm threats,
  - Inserting a flood gate at a key location,
  - Using natural feature enhancements, such as plantings or beach restoration, to provide more of a natural buffer, and
  - Constructing a structural berm (or temporary berm that could be put in place) to block the STP.



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- **Wastewater Pump Station Improvements**: A number of the pump stations received high risk scores due to their spatial locations and criticality to the Town. By their nature, pump stations tend to be located at geographic low points and as a result many of the Town's stations are located within higher probability flood areas. It was also noted by Provincetown staff that emergency generators are not available to power all of the Town's wastewater pump stations during an outage. Flooding and outages at stations could result in interrupted sewer services or sanitary sewer overflows (SSO), both of which have a significant public health, and environmental impact. **Table 4-3** summarizes the risk scores for each pump station, as well as additional information collected during the site visit relevant to the recommendations.
    - Four of the Town's wastewater pump stations are located within areas identified to be inundated at a sea water elevation of 15-ft. above MLLW. Additionally, over half of the stations would be affected by 3-ft. of Sea Level Rise. Woodard & Curran recommends the Town incorporates projects to protect these pump stations into their capital plans. The town will need to assess the most cost effective strategy for protecting these stations from flood waters; some possible solutions may include:
        - Adding risers to wet well hatches to prevent flood waters from entering,
        - Relocating sensitive electronic equipment (control panels, generators, etc.), to higher elevations.
        - Building protections such as hurricane proof doors.
        - Wet well hatches, and any sensitive electrical equipment are raised above a high risk elevation.
    - In order to prevent SSO's during storm events, it's important the Town is prepared to provide emergency power to each of the pump stations during an outage. The Town should develop a Standard Operating Procedure (SOP) for providing emergency power to the pump stations using the portable generators, and add it to the Town's Emergency Response Plan.

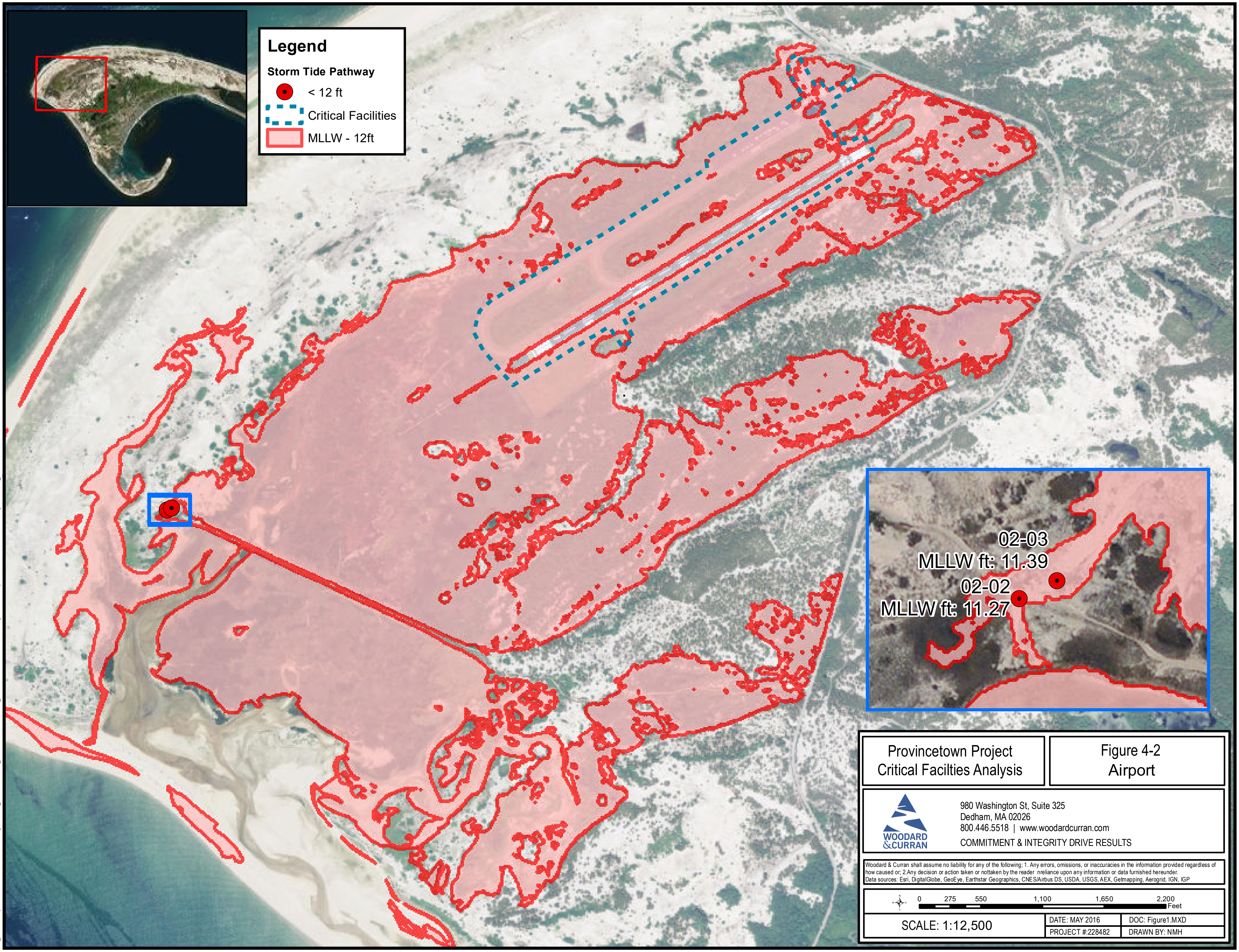
Table 4-3: Provincetown Pump Stations

Pump Station	Risk Score	Located in an Inundation Pathway?	Elevation of Inundation Pathway (ft above MLLW	FEMA Flood Zone	FEMA Zone	SLR Level	Emergency Generator?
Pump Station #8 – West End	11.5	Yes	13.0 - 13.9ft	Yes	AE	4-ft.	yes
Central Sewer Vacuum System Pump Station	11.3	Yes	15.0 - 15.9ft	Yes	AE	3-ft.	yes
Pump Station #1 – Kendall Lane	10.5	Yes	14.0 - 14.9ft	Yes	AO	3-ft.	yes
Pump Station #6 – Commodore Avenue	10.5	Yes	14.0 - 14.9ft	Yes	AE	3-ft.	yes
Pump Station #11 – Ice House Pump Station	10.1	Yes	14.0 - 14.9ft	Yes	VE	3-ft.	no

Pump Station	Risk Score	Located in an Inundation Pathway?	Elevation of Inundation Pathway (ft above MLLW	FEMA Flood Zone	FEMA Zone	SLR Level	Emergency Generator?
Pump Station #7 – Thistlemore Road	10	Yes	15.0 - 15.9ft	Yes	AE	3-ft.	yes
Pump Station #9 – Shank Painter	9.8	Yes	17.0 - 17.9ft	Yes	AE	N/A	yes
Pump Station #5 – Snail Road	9.5	Yes	15.0 - 15.9ft	Yes	VE	3-ft.	yes
Pump Station #2 – Pleasant Street	7.5	No	N/A	No	N/A	N/A	no
Pump Station #10 – Stop and Shop Pump Station	4.1	Yes	17.0 - 17.9ft	No	N/A	N/A	no
Pump Station #4 - Bayberry	3.5	No	N/A	No	N/A	N/A	no
Pump Station #3 - Manor	3	No	N/A	No	N/A	N/A	no

- **Provincetown Airport**: Provincetown Municipal Airport provides an important economic and transportation service to the community. During the high tourism season, there is very high usage of the facility. The CoF score for this asset was driven primarily by the community image and financial impact scores. If the airport were to be significantly impacted by a natural hazard event, it could represent a major loss for Provincetown. Coupled with the high CoF score, the Airport is also within a floodplain and our assessment shows it is currently at risk of inundation from sea level rise, storm surge and flooding (see **Figure 4-2**). The Town previously installed a dike to protect the airport from flooding, however, inundation pathways information shows the dike may not provide enough protection, and could be easily overcome during a certain type of major weather event.

  There are several STPs located along the existing dike, which extends between the Airport and the coastline. Provincetown should consider increasing the length and height of the dike in order to eliminate the STPs identified.



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- **Shank Painter Road**: This area is of interest to town stakeholders because several critical assets, including the police and fire stations, are located along Shank Painter Road. It was mentioned specifically by the Board of Selectmen during the preliminary presentation for this project in December 2015 as an area of concern. Shank Painter Road is indicated to be a flood risk in the FEMA flood maps and inundation pathways. The STP by which flood waters would reach this area of town is more than a mile away at the end of the peninsula, indicating it would be challenging for storm surge flood waters to reach this location. The scope of this project did not encompass analyzing the effects of groundwater surcharge on flooding. Woodard & Curran recommends the Town perform a groundwater analysis in order to gather data which could be joined with the results of this analysis to better understand the flood risk in this area (see **Figure 4-3**).
- **Capital Improvement and Maintenance Planning**: The risk analysis should be used to inform future capital improvement and maintenance planning efforts. As an example, it would be advisable to focus stormwater pipe improvements, inspections, and cleanings on areas of town that affect critical assets, and are shown to be at high risk for flooding. In this way, the Town will increase the value it receives from CIP and Maintenance budgets.

Table 4-4 includes additional recommendations for Provincetown to consider in terms of adaptive strategies to best protect existing critical facilities and infrastructure.

Other Storm Tide Pathway results for the rest of the top 20 ranked critical facilities and infrastructure identified in **Table 3-3** are presented in **Figure 4-4** to **Figure 4-10**.

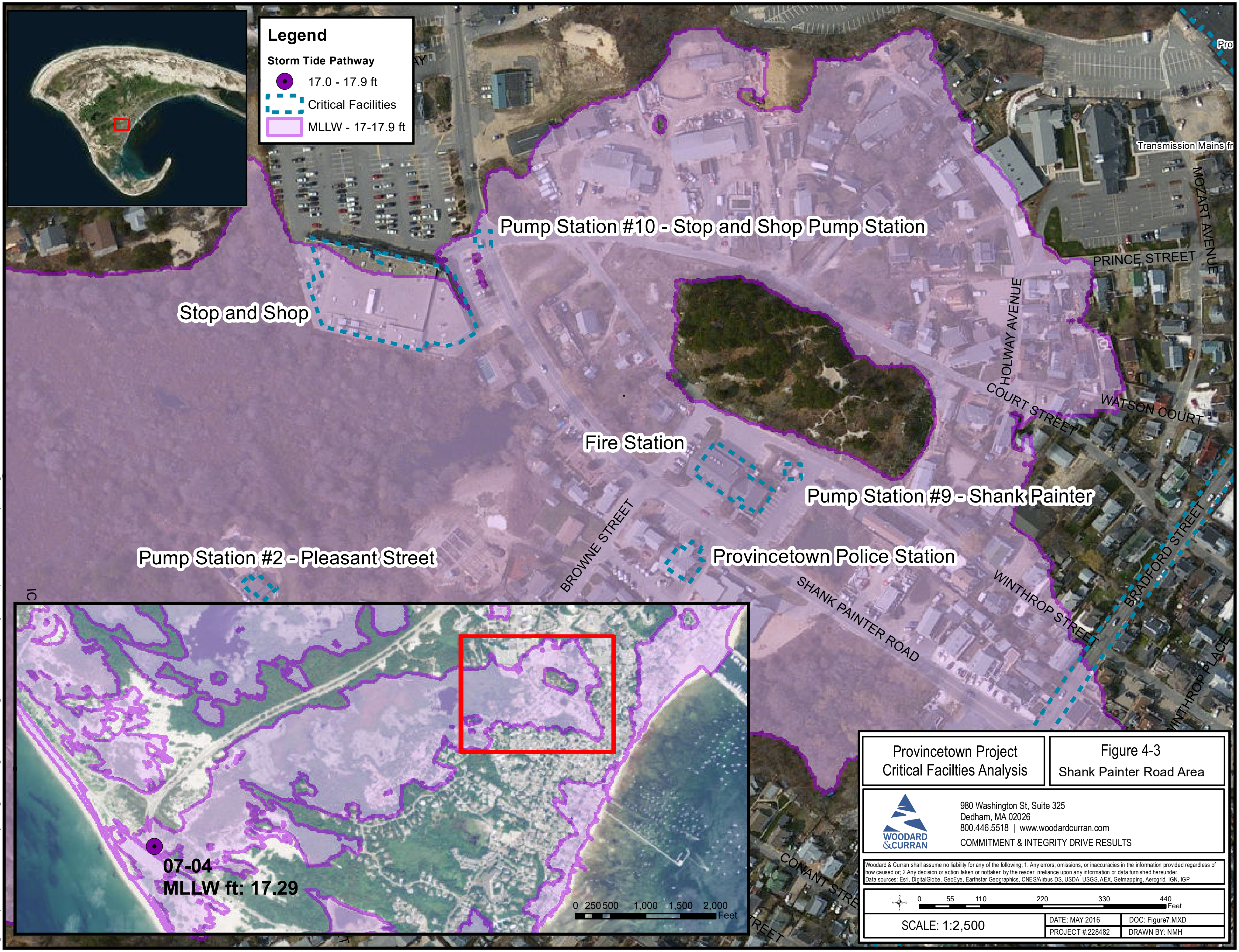

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Table 4-4: Provincetown Adaptation Strategies & Recommendations

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Natural Resource Areas	Conduct a beach nourishment project at Ryder Street Beach to enhance natural storm damage protection and coastal resilience.	Short	$200,000	The Ryder Street Beach Nourishment Project is a non-structural measure that will help increase natural storm damage protection, flood and erosion control, and community resilience.
Multiple Assets	Integrate the recently updated Hazard Mitigation Plan and completed Critical Facility/Infrastructure Adaptation Study into the Capital Improvement Planning process.	Short	Town Staff	The focus of this recommendation is the implementation of the Hazard Mitigation Plan to coordinate with and support the Capital Improvement Planning process.
Multiple Assets	During the Capital Improvement Planning process, when working on the actual projects, consider Storm Tide Pathways.	Ongoing	Town Staff	When Provincetown is working on CIP projects and there is a storm tide pathway associated with the area or site, being aware of and considering even a small project change, if appropriate, to minimize potential impacts associated with the storm tide pathway.
Multiple Assets	Review this project and associated strategies and recommendations to determine if credit can be given to Provincetown (a participant in the Community Rating System program) and potentially improve the overall CRS score of 9.0.	Short	Town Staff	Provincetown may be able to earn additional credit by providing information about areas (not mapped on the FIRM) predicted to be susceptible to flooding in the future because of climate change or sea level rise.

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Emergency Operations Center - Veterans Memorial Community Center or VMCC Building	Replace the existing generator and power feed lines.	Short	Funding is in place for the project and the project is underway.	This building functions as the emergency shelter (for Provincetown and Truro) as well as the DPW Department. The roof was recently replaced with USDA funding and a Town appropriation. Wind exposure remains high in this area of town and during storm events. The generator and the power feed that comes into the facility is not in good condition. There is funding in place to replace the generator.
Emergency Operations Center - Veterans Memorial Community Center or VMCC Building	Install a vegetative buffer along the roadway to limit snow drifting.	Short	$20,000	In the past, it has been hard to access this location in the winter. This building is also home to the DPW Department. During winter storm events, including high wind, there are huge snow drifts blocking Winslow Street. Road access can be limited. Installing a vegetative buffer along the roadway will help to limit large snow drifts.
Water Transmission Mains – Truro	Add redundant water transmission main lines from Truro.	Medium	$5M - $7M	The water transmission main lines that run along Route 6A from Truro to Provincetown are critical to the community. Provincetown receives its water from Truro and the roadway these lines are underneath is inundated by sea water at times. If Provincetown loses Route 6A and the pipes underneath are impacted, the community will quickly be out of water – even after they use the water tower (this might last two days in the summer and one week in the winter). Another issue with Route 6A is it is an evacuation route. Electric power comes in through 6A as well.

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Town Hall	Conduct a drainage study for the area around Town Hall and/or perform a groundwater study/modeling analysis.	Short	$50,000	Town Hall has been flooded in the past and continues to see flooding occurrences due in part to drainage issues in the area. The main servers for Town Hall are located in the basement area and these assets need to be relocated. In 2016, Provincetown approved funding to relocate the servers to the DPW office location.
Multiple Assets	Conduct a drainage study for the area around Shank Painter and/or perform a groundwater study/modeling analysis.	Short	$40,000	The Police Station and Fire Station, the Herring Cover Animal Hospital, two pump stations and a power substation are located on Shank Painter Road. The Police Station has flooded in the past and Provincetown is concerned about whether or not they need to prepare for coastal flooding impacts on Shank Painter and/or invest in a new Police Station facility at a different location (this process has been ongoing for several years).
Multiple Assets	Conduct a study to identify an Operations & Maintenance strategy for CCTV work.	Short	$25,000	The purpose of identifying an Operations & Maintenance strategy for CCTV work is to help understand and assess pipe conditions and be able to fix or clean pipes where needed to ensure they are able to properly move water flow.
Multiple Assets	Update the Emergency Response Plan.	Short	Town Staff	Update the local Emergency Response Plan and educate staff and the community about its contents. Ensure lessons learned from past events are reflected in the document.

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Provincetown Airport	Conduct an assessment at the Provincetown Airport to determine the most cost effective solution for mitigating risk.	Medium	$60,000	The assessment should consider capital projects including making improvements to the existing dike to eliminate the storm tide pathways and/or projects to limit damage if the airport does become inundated during a storm event. The assessment may also consider procedural preventative activities such as sandbagging, planting sea grass or monitoring periodic changes in the dunes to determine how that might impact risk to the Airport. Cape Air flies year round.
Provincetown Airport	The Provincetown Airport should consider how it can use and implement new technology for navigation aids and airfield lighting systems to function better during a natural hazard event.	Short	TBD	This strategy is based on the Massachusetts Climate Change report as a transportation for airports, particularly in vulnerable areas to consider.
MacMillan Pier	The Ryder Street outfall is in close proximity to MacMillan Pier. The DPW Director articulated the desire to remove and relocate the Ryder Street outfall and return the area back to its natural state.	Medium	$2M	MacMillan Pier and the surrounding area is home to 400 private moorings, 60 recreational boat slips, 220 rental moorings, 60-70 commercial fishing boats and 12 excursion boats/vessels. Approximately 100,000 passengers use the ferries at this location on an annual basis. MacMillan Pier is critical to the local economy and an important piece of infrastructure in the community due to the transportation amenities it provides and the economic impact it has due to job creation and revenue generation.

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Pump Stations Elevation	For pump stations that have a wet well below ground, particularly if there is an exposed hatch and if the pump station may be impacted by an inundation pathway, add risers around submersible pump station wet wells to increase elevations out of the floodplain.	Short	$2,500 - $5,000 per pump station	All but two of the Town's eleven pump stations are located within STP inundation pathway areas.
Pump Stations	Develop a Standard Operating Procedure to provide emergency power to all wastewater pump stations in Town during power outages. Focus on the highest flow pump stations first which are Bayberry (#4) and Shank Painter (#9).	Short	$2,500 - $30,000 depending on what is needed for each pump station.	Ensure the Public Works Department has equipment needed for the SOP. Include emergency SOP in the Town Emergency Response Plan
Pump Stations	Perform an evaluation of pump stations with a high LoF to determine if raising sensitive critical electrical equipment could better protect the stations during a flooding/high water event. For pump stations with above ground electrical equipment, consider raising sensitive electrical and controls information.	Short	TBD	Pump Station #8 West End – LoF 4.0 Pump Station #1 Kendall Lane – LoF 3.67 Pump Station #6 Commodore Avenue – LoF 3.67 Pump Station #11 Ice House Pump Station – LoF 3.84 Pump Station #7 Thistlemore Road – LoF 3.50 Pump Station #9 Shank Painter – LoF 3.17 Pump Station #5 Snail Road – 3.34 Pump Station #2 Pleasant Street – 2.67 Pump Station #10 Stop and Shop – 2.00 Pump Station #4 Bayberry – 1.17 Pump Station #3 Manor – 1.17

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Central Vac Station	Secure a backup generator for the Central Vac Station to be utilized when the existing generator does not operate properly.	Short	$0 - $60,000 depending on the solution identified.	The Central Vac Station takes on all of the commercial flow in the area. There is a need to secure a backup generator for the existing generator at this facility. In the winter of 2014-2015 there was an issue with the existing generator not performing, so a backup is needed. **Table 1-5** highlights all of the generators Provincetown currently has the generator at the Central Vac Station is from 2001.
MacMillan Pier	Wave Attenuator to Replace/Protect Finger Piers or, Install Floating Docks	Medium	$3M - $5M	During a south wind there can be pier damage. In addition, public water servicing the pier during storm events is frequently damaged. A tow behind generator was recently replaced and is ready for use when needed.
Provincetown Public Library	Investigate the potential for a generator to be installed at the library	Medium	$40,000	The public library houses an important art collection and book collection. It also provides internet services for the community and is a place where people gather. Currently, it does not have its own generator.
Multiple Assets	Develop a formal beach management plan.	Short	$100,000	Sand accretion is a concern for Provincetown, particularly when it blows during storms and makes roads impassable.
DPW Garage	Consider design/facility enhancements to ensure a fully functioning DPW garage during storm events.	Medium	$60,000	This facility was built in the 1950s and is a critical building for operations and houses equipment and machines. There is high groundwater and wetlands (there is not good drainage) and it is in a FEMA SLOSH zone. Equipment for the harbormaster is stored here and it is a fueling station for public vehicles. If something happened to the building it would have a community impact.

Critical Facility or Infrastructure	Recommendation	Short: 0 to 5 years Medium: 5-10 years Long: 10+ years	Cost Range	Notes
Wastewater Treatment Plant	Conduct a study to evaluate capacity issues and plan for necessary critical upgrades.	Short	$60,000	Half the town is connected to the wastewater treatment plant for sewer service. The need for additional capacity for Provincetown and potentially serving parts of Truro have been discussed along with taking Title V septage.
Multiple Assets	Site any new (or existing that needs to be relocated) critical facility or infrastructure outside of both a FEMA flood zone and an inundation pathway.	Ongoing	TBD	This recommendation could pertain to a new Police Station or pump station relocation.
Natural Resource Areas	Ensure management plans for existing natural resources include a focus on reducing climate impacts. Focused efforts on natural resource areas will help to lessen the impact of natural hazard events on Provincetown's critical facilities and infrastructure.	Ongoing	TBD	Ways to reduce climate impacts of natural resources may include mapping and developing a plan to control invasive species, details for regular debris management and removal (particularly in flood prone areas) and pursuit of additional land acquisition that would be complementary to the natural resource.

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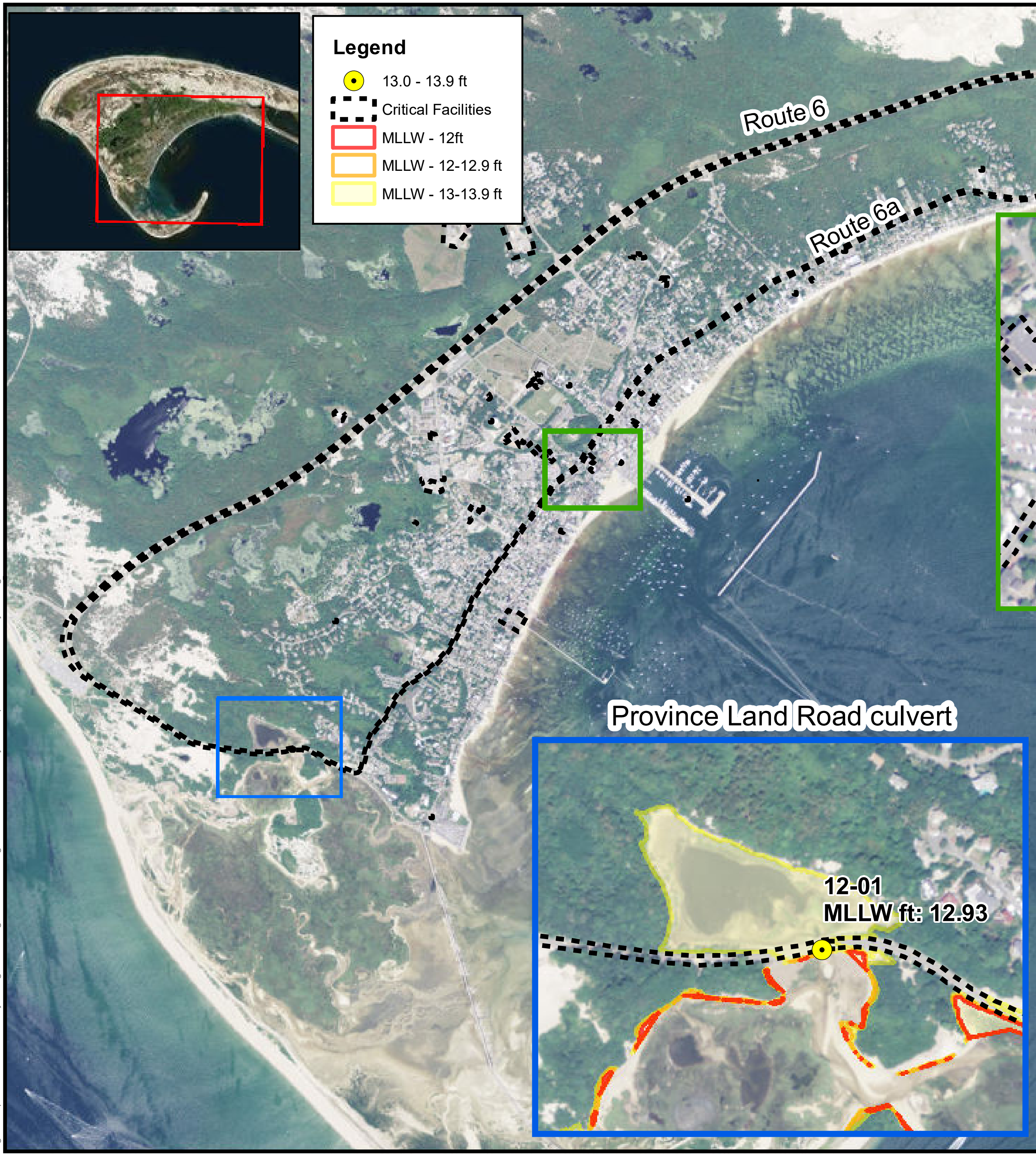


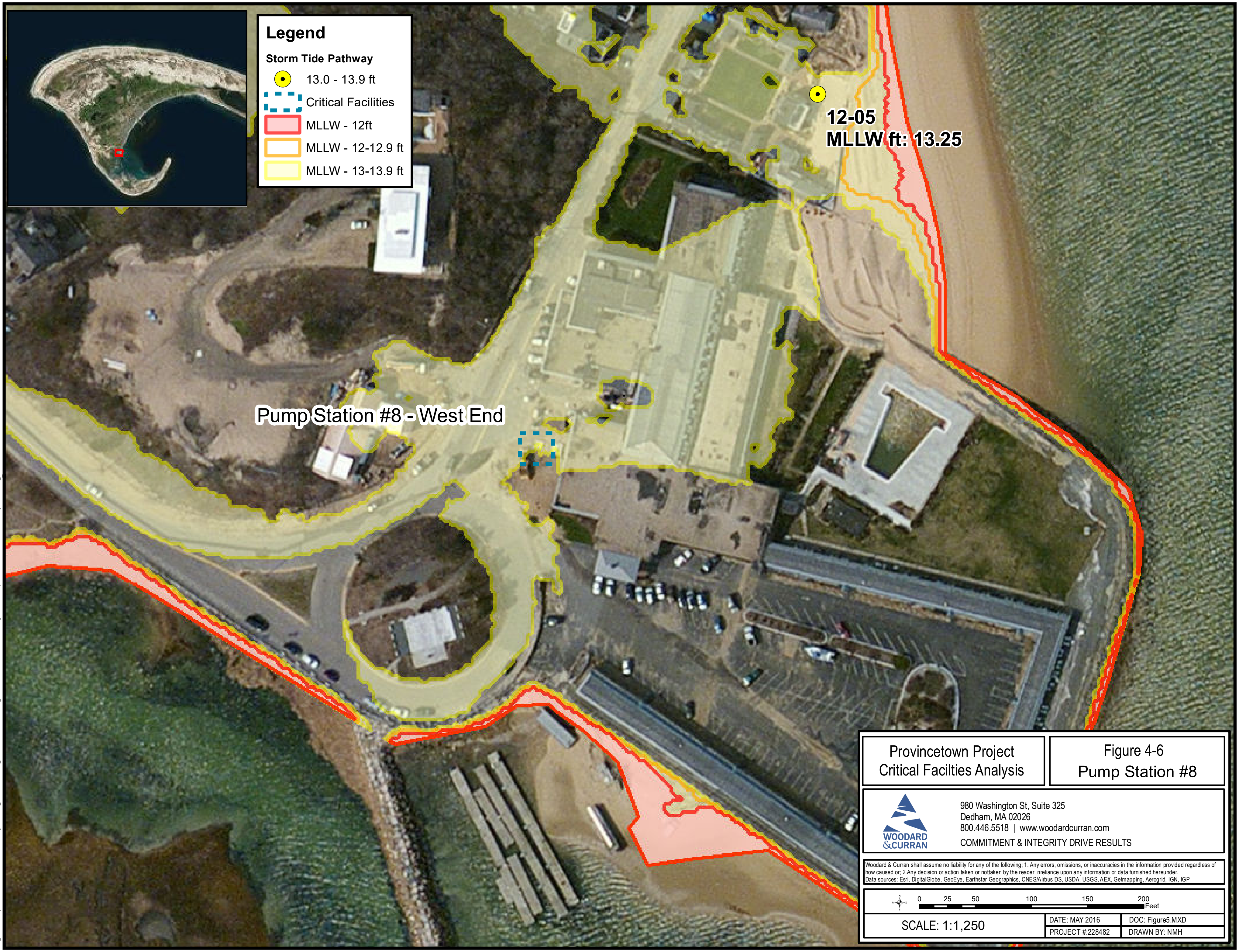
Provincetown Project
Critical Facilties Analysis

Figure 4-5
Route 6-6a

WOODARD & CURRAN
980 Washington St, Suite 325
Dedham, MA 02026
800.446.5518 | www.woodardcurran.com
COMMITMENT & INTEGRITY DRIVE RESULTS

SCALE: 1:24,000

DATE: MAY 2016 | DOC: Figures 4.MXD
PROJECT #:228482 | DRAWN BY: NMH



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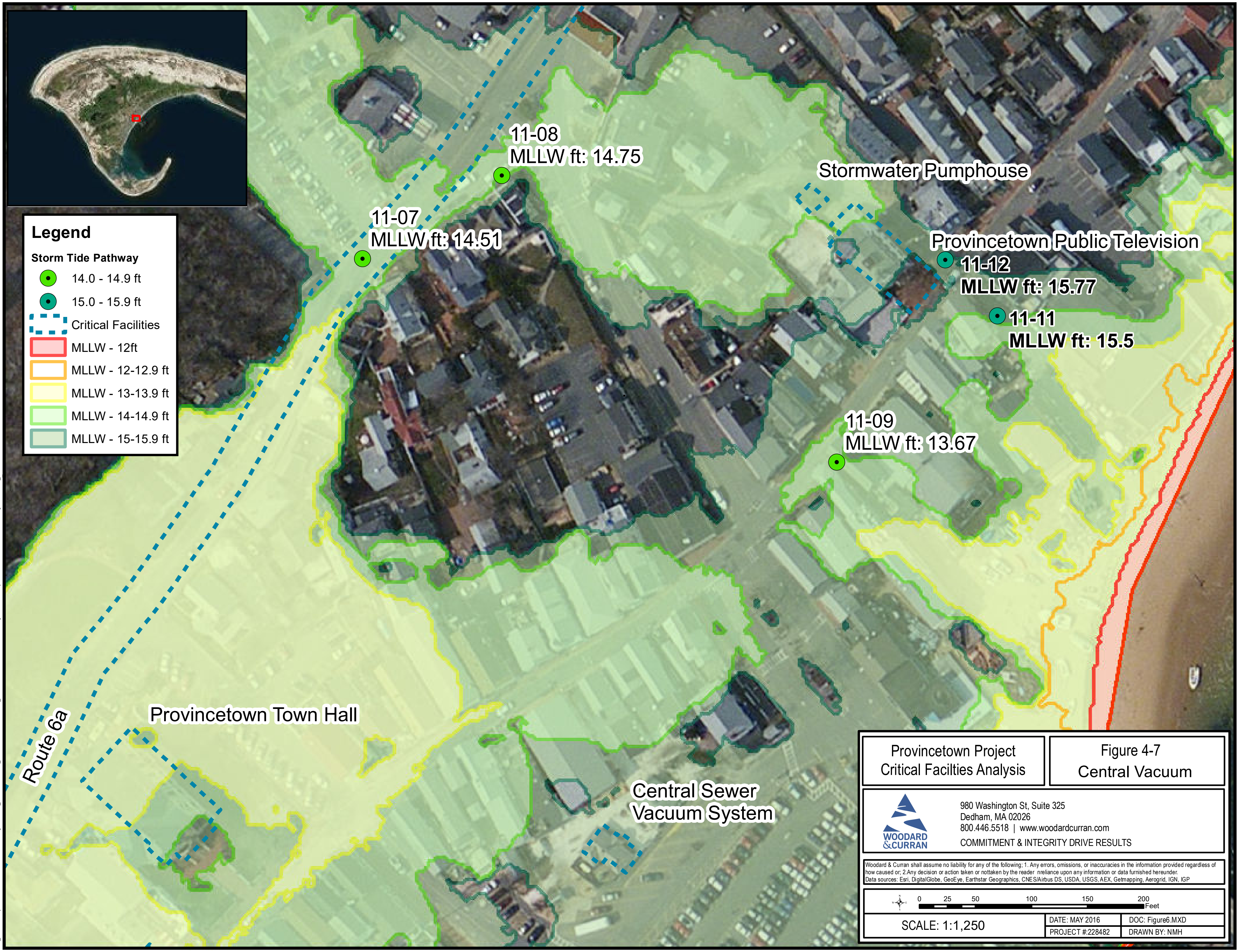

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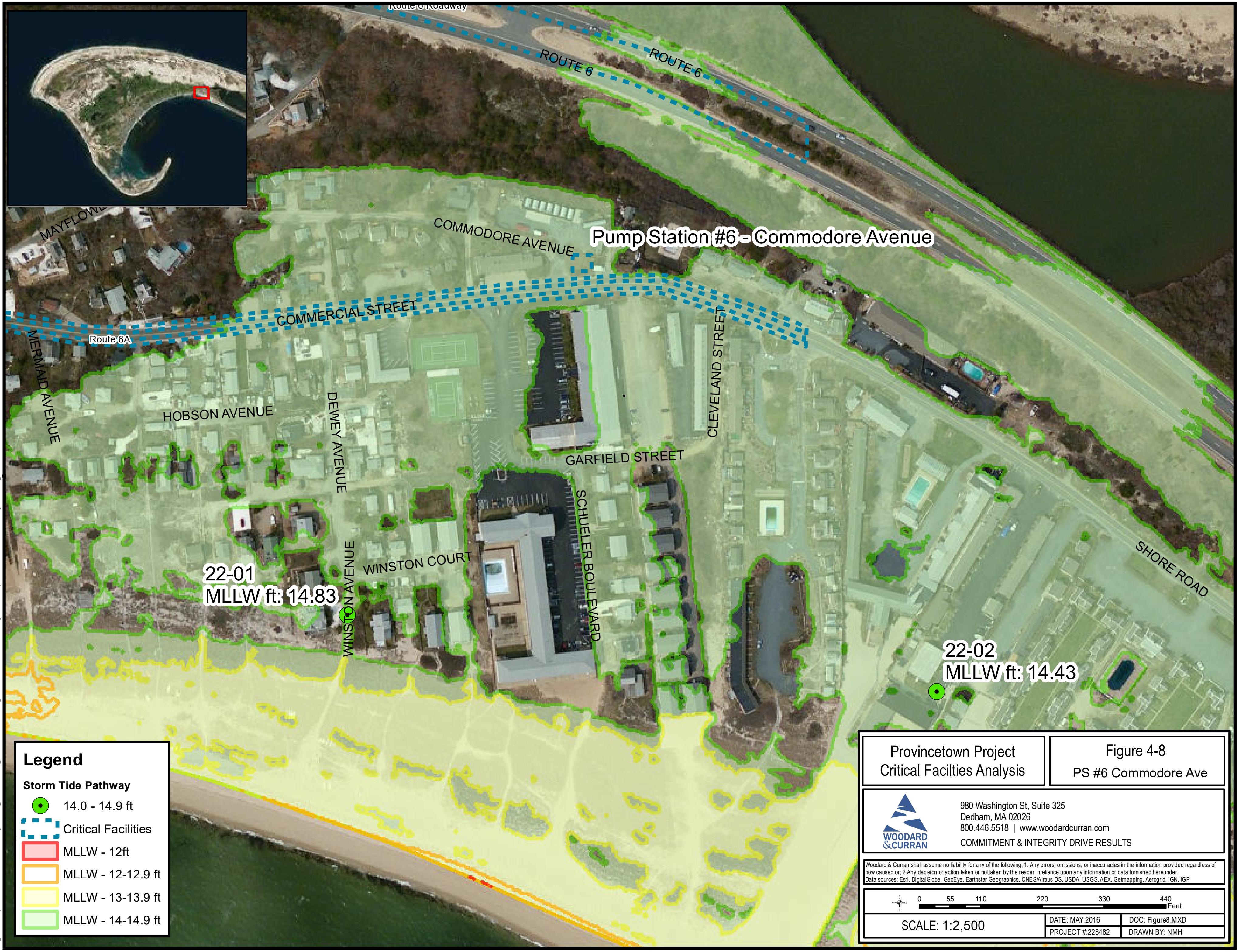

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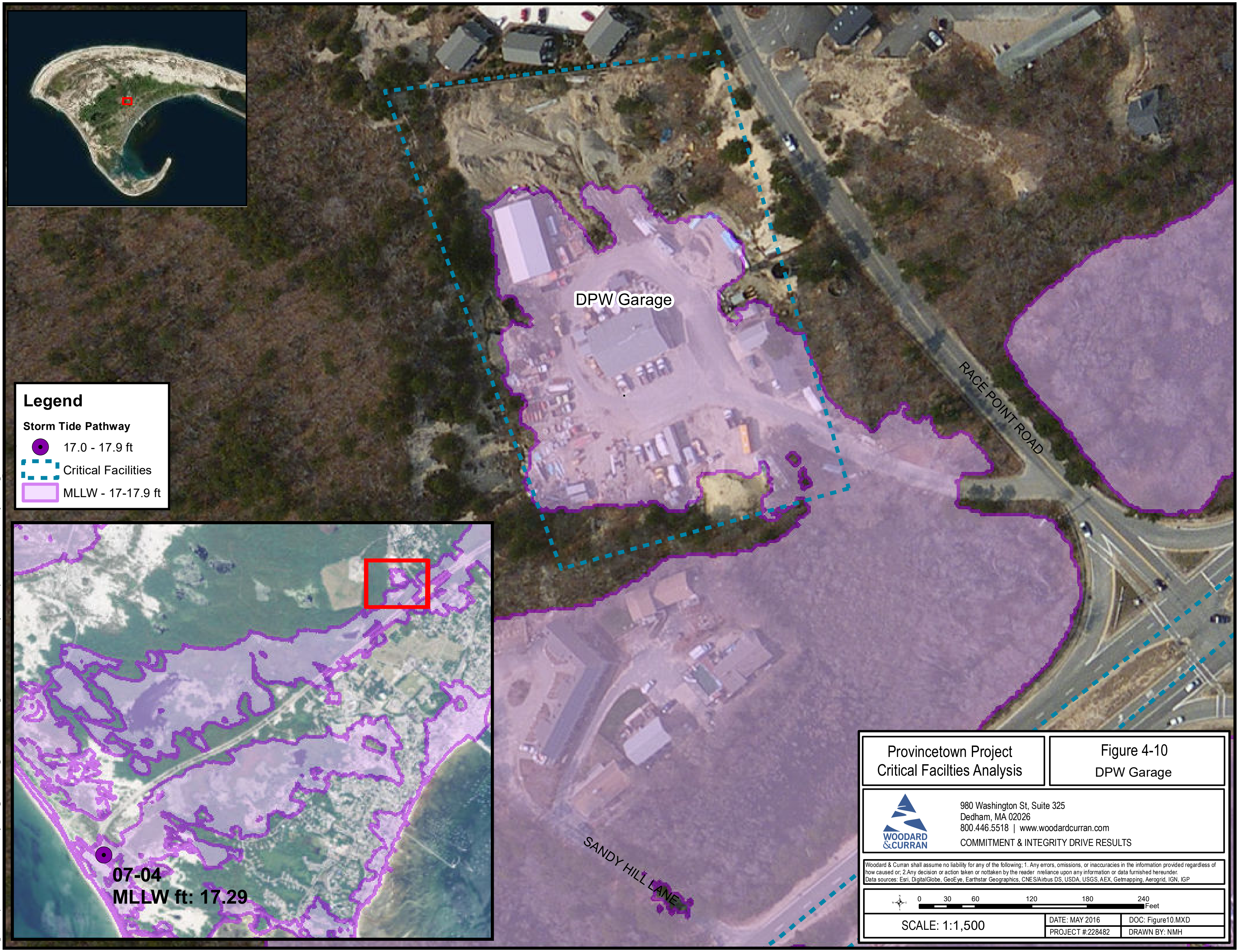

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4.4 SUMMARY

The Town of Provincetown, by conducting a vulnerability assessment and risk analysis and determining key inundation pathways, has developed critical information for the community, to continue to be progressive in managing risk and damage from natural hazard events. The methodology for this work allows the Town to prepare specific mitigation actions that Provincetown can implement in the future. Due to competing needs for funding in the community, this plan will serve as a tool so that prioritization of actions and projects can be conducted.

This project is an example of a successful partnership that has resulted in real, community specific information that will serve to inform future decisions by Provincetown during Capital Improvement Planning, stormwater mitigation measures, emergency management planning, regulatory changes and other activities. Completing this project also continues Provincetown along its progression of having a strong understanding of climate change impacts to the community such that it can transition to the implementation of mitigation actions.

APPENDIX A: CENTER FOR COASTAL STUDIES REPORT

PROJECT BACKGROUND AND OVERVIEW

The impacts of coastal inundation have historically confronted coastal managers dealing with vulnerabilities to existing infrastructure and planning for future infrastructure improvements. Occurring on multiple temporal and spatial scales, impacts range from the chronic encroachment of tides to the more episodic destruction associated with coastal storms and flooding. As evidenced by recent storms such as Katrina and Sandy, management challenges are becoming more acute as current climate conditions appear to be producing higher intensity storms accompanied by large storm surges, resulting in more significant coastal flooding events.

Within this context, much attention has been focused on the subjects of climate change and sea level rise. With regard to the latter, many scientists have concluded that sea levels are not only rising, but at an increasing rate. As shown in Figure 1, projections vary from a low of 0.15 meters (0.5 feet) to a high of 2 meters (>6 feet) by the end of this century. Such a broad range creates significant issues for coastal managers faced with identifying potential hazards to, and vulnerabilities of property and infrastructure, prioritizing response actions, and demonstrating to local governments the need to undertake actions in spite of the unavoidable uncertainties inherent in century-scale sea level rise projection scenarios. Traditionally (and necessarily) shorter planning horizons are not easily defined within the context of sea level rise discussions and effective response actions, implementable at the local level are difficult to identify.

In addition to the issue of defining a suitable planning horizon, the ability of coastal managers to effectively and efficiently recognize potential vulnerabilities and to educate residents and community leaders about the threats associated with storm tides and flooding has been severely limited by the lack of regional-scale, accurate elevation data. For example, Flood Insurance Rate Maps (FIRMS), produced by the Federal Emergency Management Agency (FEMA), have long been standard resources for coastal communities, however, these maps were intended to facilitate the determination of flood insurance rates and lack the topographic detail necessary for focused planning efforts. Until recently the accuracy of relatively low cost elevation data has been appropriate only for general planning at regional scales and not appropriate for identifying storm tide and flooding impacts over timeframes that meet the needs and budgets of most municipalities. Numerical modeling of storm surge, sea level rise, waves, or sediment transport (coastal erosion) can be effective for regional efforts to understand coastal evolution, but can also be cost prohibitive. Furthermore, these models are typically too coarsely-scaled to inform local decisions, appropriately-scaled studies are critical for coastal managers and municipalities.

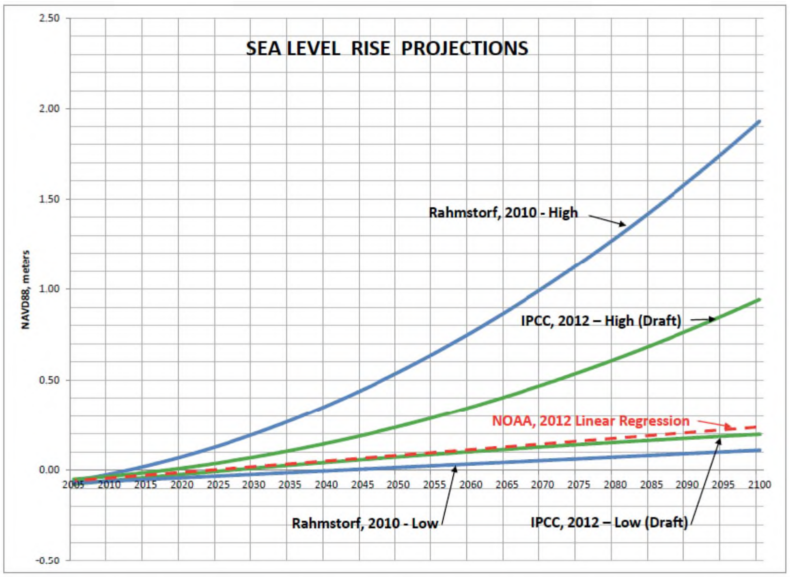

Figure 1. Projection of global sea level rise.

Based on the long range projections of sea level rise and the catastrophic damages associated with recent coastal storms such as Sandy and Katrina much attention has been placed on long term strategies to reverse current climate trends and slow or reverse the rate of sea level rise. Strategies to reduce Green House Gas (GHG) emissions, promote green energy, and deal with rising temperatures, glacial ice melt, and thermal expansion of sea water over the next hundreds of years are being discussed and debated at the international, national, and state levels. Clearly the planning and costs to confront these issues are long term, and capital intensive. Lost in these discussions are viable hazard planning strategies that can be adopted and implemented at the local level within the shorter planning horizons and financial means of local municipalities.

Reflective of the limited financial and technical resources of coastal communities and their unique geography, local responses and strategies to sea level rise and climate change will be more successful particularly in the context of short-term planning horizons and frequently changing leadership. Specifically, the short term planning should identify actions or responses that are:

1) Achievable within an appropriate time frame (e.g., 30 years)
2) Implementable with current technology
3) Financially feasible
4) Politically viable (i.e., not extreme – e.g., wholesale retreat)
5) Adaptable to future scenarios
6) Focused on both infrastructure and natural resources

While sea level rise projections are clearly relevant for planning considerations, particularly for large scale efforts, actual storm tide elevations may provide a more effective means of characterizing coastal hazard vulnerability for local planning actions. Figure 2 depicts estimates of various historical storm tide elevations for the Boston area (an easterly facing shore) from various sources for the 17^{th} - 21^{st} centuries. The current projections for the highest sea level rise scenario and the NOAA regression rate scenario based on current tide gauge data obtained from the Boston tide gauge are shown through the year 2100.

Not surprisingly, the graph illustrates that in recent history the storm of record for Boston and areas to the north of Cape Cod was the “Blizzard of ‘78”. Significantly, this plot indicates that the storm tides and associated flooding for Boston reached an elevation of approximately 1 meter (~3 feet) above that of the highest sea level rise projection for the year 2100. The plot further reveals that earlier estimates of storm tide heights have probably equaled or exceeded the 1978 maximum numerous times since the 17^{th} century.

Using historical data to identify accurately the potential height of storm tides, the extent of coastal flooding, and areas of potential vulnerability provides important, high certainty planning information to local communities with several benefits. First, using historical storm tides to identify coastal hazard vulnerabilities removes sea level rise and the disparity of projections (Figure 1) from the discussion of the most appropriate sea level rise elevation to use to develop short term planning responses. Sea level rise notwithstanding, storm tides of these magnitudes

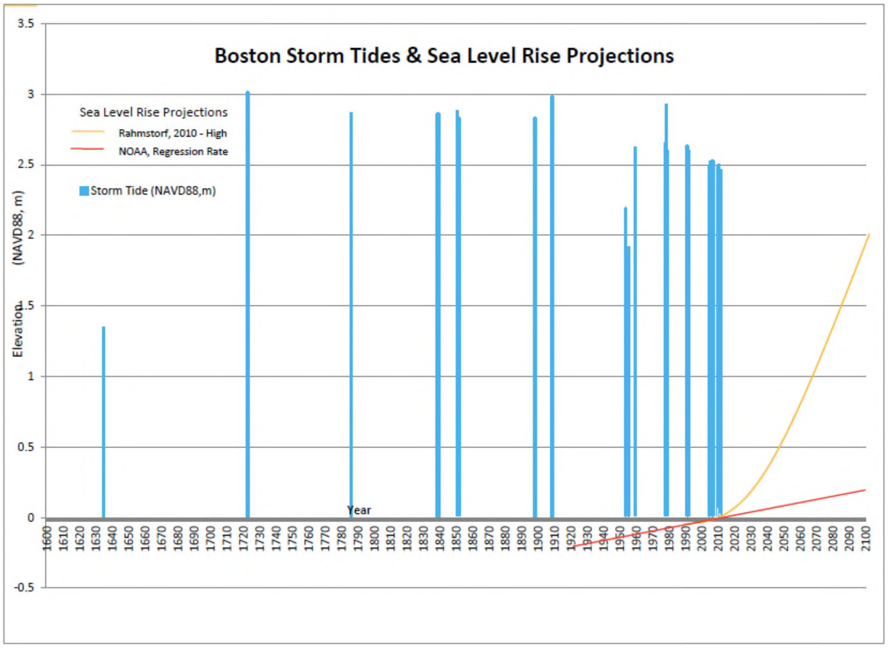

Figure 2. Historical Storm tides and sea level rise.

have been experienced and are likely to be experienced again in the future. Second, storms of record provide an accurate, actual (i.e., indisputable) reference elevation that towns can plan for when history repeats itself. Finally, as discussed below, using emerging data gathering technologies to identify storm tide impacts, will yield valuable information that can be used by coastal communities to plan and implement ground level strategy in response to sea level rise.

Accurate Elevation Data, Record Storm Tides and Potential Pathways

Over the past ten years, **li**ght **d**etection **a**nd **r**anging (lidar) surveys have emerged as a cost-effective source of coastal elevation data. Covering broad geographic areas with horizontal accuracies on the order of 3 meters (~10 feet) and vertical accuracies on the order of 15-30 cm (0.5-1.0 feet), this relatively high resolution topographic information can be used by coastal managers as the initial basis for developing inundation scenarios which can be used to begin to communicate threats associated with coastal storms. Despite improvements in vertical accuracy, the use of lidar alone to map areas of storm vulnerability and to develop community response strategies remains limited. Recognizing these limitations, current guidelines for inundation modeling using lidar elevation data sets with vertical accuracies of 15 cm (0.5 feet) recommend analyses be performed at increments of 58.8 cm (~2.0 feet), a resolution clearly too coarse for the development of local action items. This base level information, however, when supplemented with area-specific high resolution elevation data, can be used to accurately identify and prioritize potential coastal hazards at the local level in a cost effective manner.

In 2011, the Natural Resource Conservation Service, United States Department of Agriculture (NRCS) completed terrestrial lidar surveys of Barnstable County, Massachusetts. The horizontal and vertical accuracies of this free contemporary elevation data provide a reliable base map and can be used as the foundation for local action planning.

This study maps the precise locations through which inundation of seawater flows into and through Provincetown Massachusetts. These locations are referred to herein as 'storm tide' pathways. The term 'storm tide' refers to the rise in water level experienced during a storm event resulting from the combination of storm surge and the astronomical (predicted) tide level. Storm tides are referenced to datums, either to geodetic datums (e.g., NAVD88 or NGVD29) or to local tidal datums (e.g., mean lower low water (MLLW)). Storm surge refers to the increase in water level associated with the presence of a coastal storm. As the difference between the actual level of the storm tide and the predicted tide height, storm surges are not referenced to a datum.

Generally, storm tide pathways, by virtue of their elevation relative to the elevation of the storm tide, provide a direct hydraulic connection between coastal waters and low lying inland areas. Examples of pathways that may serve as direct hydraulic connections include: low spots in built environment (e.g., roads, walkways, dikes, seawalls, etc.); low lying infrastructure that can serve as unintended conduits (e.g., storm water system, sanitary sewers, electrical/utility conduits); and low spots in natural topography (e.g. low lying earthen berms, barrier beaches, and dune systems susceptible to erosion and breaching).

As discussed above, to minimize the uncertainties associated with sea level rise projections and to provide information that is reliable within a 30 year planning horizon, the study used recorded flood elevations associated with actual coastal storm tides. As discussed below, research of available records and studies indicates that, as for Boston, the best approximation of the storm of record for Provincetown would appear to be storm tide elevation of the Blizzard of '78. This storm tide was recorded by Dr. Graham S. Giese of the Center for Coastal Studies in Provincetown at 9.36 feet (2.85 meters) NAVD88. This elevation represents an actual storm tide elevation that is approximately 5 feet above contemporary mean higher high water (MHHW) and approximately 11 feet above contemporary mean sea level (MSL).

METHODS

Datums: Definition and Uses

A datum is a reference point, line, or plane from which linear measurements are made. Horizontal datums (*e.g.*, the North American Datum of 1983 (NAD83)) provide a common reference system in the x,y-dimension from which a point's position on the earth's surface can be reported (*e.g.*, latitude and longitude). Similarly, vertical datums provide a common reference system in the z-direction from which heights (elevation) and depths (soundings) can be measured. For many marine and coastal applications, the vertical datum is the height of a specified sea or water surface, mathematically defined by averaging the observed values of a particular stage or phase of the tide, and is known as a tidal datum (Hicks, 1985).[1] It is important to note that as local phenomena, the heights of tidal datums can vary significantly from one area to another in response to local topographic and hydrographic characteristics such as the geometry of the landmass, the depth of nearshore waters, and the distance of a location from the open ocean (Cole, 1997).[2]

As almost every coastal resident knows, tides are a daily occurrence along the Massachusetts coast. Produced largely in response to the gravitational attraction between the earth, moon and sun, the tides of Massachusetts are semi-diurnal - *i.e.*, two high tides and two low tides each tidal

[1] The definition of a tidal datum, a method definition, generally specifies the mean of a particular tidal phase(s) calculated from a series of tide readings observed over a specified length of time (Hicks, 1985). Tidal phase or stage refers to those recurring aspects of the tide (a periodic phenomenon) such as high and low water.
[2] For example, the relative elevation of MHW in Massachusetts Bay is on the order of 2.8 feet higher than that encountered on Nantucket Sound and 3.75 feet higher than that of Buzzards Bay.

day.[3] Although comparable in height, generally one daily tide is slightly higher than the other hand, correspondingly, one low tide is lower than the other. Tidal heights vary throughout the month with the phases of the moon with the highest and lowest tides (referred to as spring tides) occurring at the new and full moons. Neap tides occur approximately halfway between the times of the new and full moons exhibiting tidal ranges 10 to 30 percent less than the mean tidal range (NOAA, 2000a.)

Tidal heights also vary over longer periods of time due to the non-coincident orbital paths of the earth and moon about the sun. This variation in the path of the moon about the sun introduces significant variation into the amplitude of the annual mean tide range and has a period of approximately 18.6 years (a Metonic cycle), which forms the basis for the definition of a tidal epoch (NOAA, 2000a). In addition to the long-term astronomical effects related to the Metonic cycle, the heights of tides also vary in response to relatively short-term seasonal and meteorological effects. To account for both meteorological and astronomical effects and to provide closure on a calendar year, tidal datums are typically computed by taking the average of the height of a specific tidal phase over a 19-year period referred to as a National Tidal Datum Epoch (NTDE) (Marmer, 1951). The present NTDE, published in April 2003, is for the period 1983-2001 superseding previous NTDEs for the years 1960-1978, 1941-1959, 1924-1942 and 1960-1978 (NOAA, 2000a).

[3] A tidal day is the time or rotation of the earth with respect to the moon, and is approximately equal to 24.84 hours (NOAA, 2000a). Consequently, the times of high and low tides increase by approximately 50 minutes from calendar day to calendar day.

Tidal Datum	Abbreviation	Definition
Mean Higher High Water	MHHW	Average of the highest high water (or single high water) of each tidal day observed at a specific location over the NTDE*
Mean High Water	MHW	Average of all high water heights observed at a specific location over the NTDE*
Mean Sea Level	MSL	Arithmetic mean of hourly tidal heights for a specific location observed over the NTDE*
Mean Tide Level	MTL	Arithmetic mean of mean high and mean low water calculated for a specific location
Mean Low Water	MLW	Average of all low water heights observed at a specific location over the NTDE"
Mean Lower Low Water	MLLW	Average of the lowest low water (or single low water) of each tidal day observed at a specific location over the NTDE*

Table 1. Common Tidal Datums (Source: NOAA, 2000b).

Identifying existing storm-tide pathways (STP) in a dynamic coastal environment is a multi-step process. First, a datum referenced tidal profile is established for the local area. For Provincetown Harbor, existing benchmarks for NOAA CO-OPS tidal station # 8446121 were recovered, occupied by the Center's Real-Time-Kinematic Global Positioning System (RTK GPS) and referenced vertically to the North American Vertical Datum of 1988 (NAVD88). Tidal station # 8446121 was established in Provincetown Harbor on March 5, 2010 and tidal datums referenced to the station datum, and reported on the NOAA CO-OPS website [tidesandcurrents.noaa.gov], were then converted to NAVD88 for reference throughout the project. Figure 3 shows the contemporary tidal datums for Provincetown Tidal Station # 8446121 referenced to NAVD88 and Mean Lower Low Water (MLLW). As shown in Figure 3, this tidal profile is extremely similar to that for Boston Harbor.

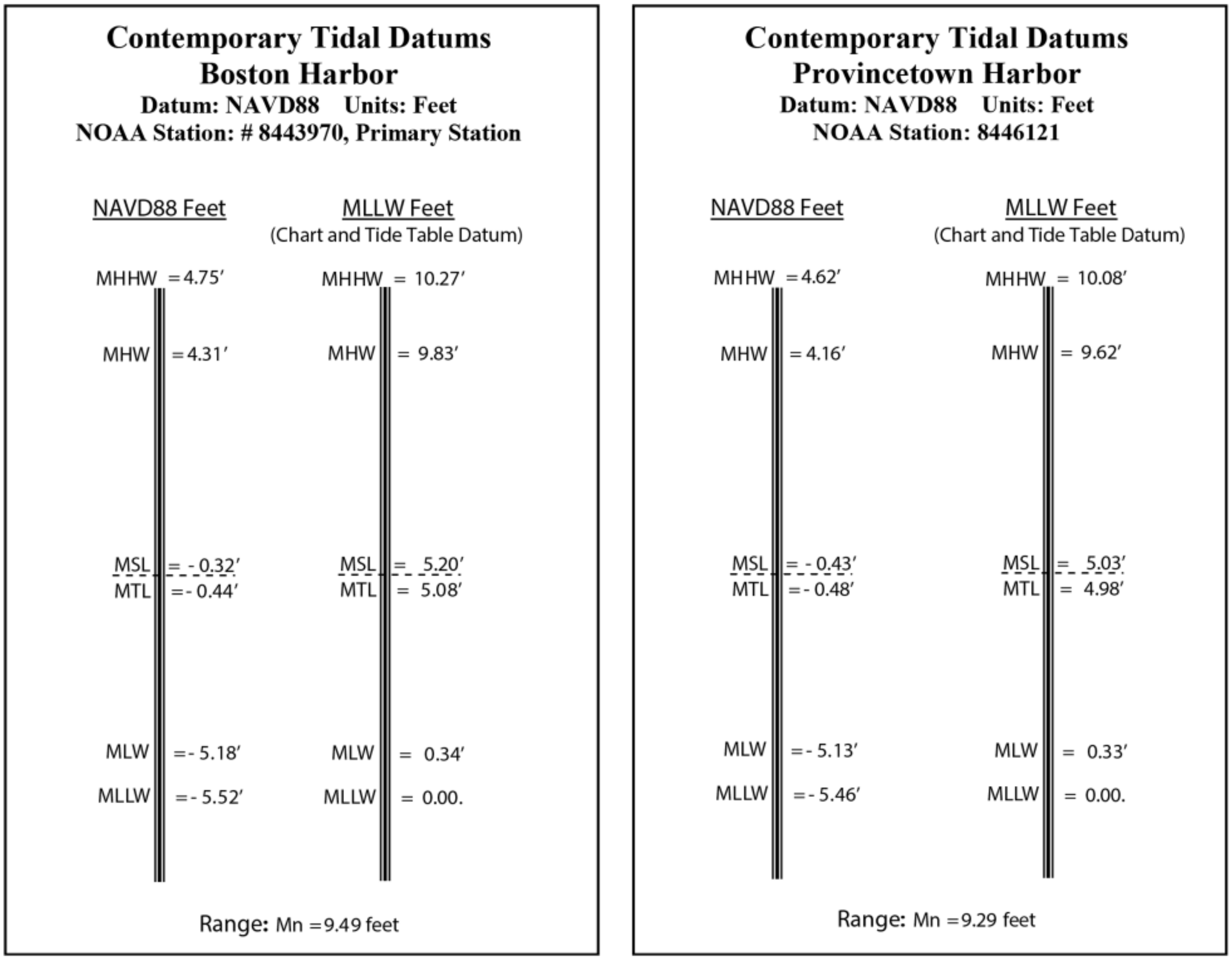

Figure 3. Tidal datum profiles for Boston and Provincetown.

Having established a datum referenced tidal profile, historical coastal storms were then researched to determine significant storm tide (storm surge + astronomical tide) events that have occurred since 1921, the beginning of the continuous tidal record for Boston Harbor.

In addition to the major inundation that often accompanies coastal storms, many coastal communities are also beginning to experience occasional minor flooding during spring tides as relative sea level continues to rise. Often referred to as nuisance flooding since it is rarely associated with dramatic building and property damage, this type of minor flooding is becoming more common with chronic impacts that include overwhelmed drainage systems, frequent road closures, and the general deterioration of infrastructure not designed to withstand saltwater immersion (NOAA, 2014).

Spatial Analysis

Based on a Provincetown Harbor tidal characterization discussed below the STP analysis proceeds with the identification of potential STPs in the lab using a rigorous desktop analysis of existing elevation (lidar) data. This is then followed up by an extensive fieldwork assessment program to locate, identify and verify the presence or absence of an existing STP in locations discovered in the desktop exercise. This fieldwork is a critical step for several reasons. First, lidar collected via low flying aerial surveys and the post-processing involved introduce uncertainties that can exaggerate or diminish features in three dimensional data that could obscure or conflate the presence and scale of a storm-tide pathway. This has been shown to be particularly evident in cases of 'bare earth' models where elevations tend to be "pulled up" in areas adjacent to where buildings are removed and "pulled down" in areas of bridges or where roads cross streams. Second, the use of an RTK-GPS instrument provides the best possible accuracy for acquiring and verifying 3-dimensional positional data. Thus the GPS data can corroborate, or refute the presence of STPs identified from the desktop lidar analysis. Further, due to the dynamic nature of coastal geography only through this type of field work can potential STPs be discovered that were not seen in the desktop analysis of the lidar data. Lastly, and also related to the ephemeral characteristics of the areas proximate to the shoreline, even the most current lidar is rapidly out of date in certain areas. Consequently, GPS fieldwork is critical to identify those STPs that appeared in the lidar but no longer exist due to changes in landform.

A list of potential STPs begins with the desktop analysis of the best available synoptic elevation data for the study area. The latest lidar data were downloaded from the NOAA website (https://coast.noaa.gov/digitalcoast/). The website has default settings for horizontal and vertical reference datums, spheroid and projection as well as units (metric vs standard). For the purposes of this study Center staff alters the default download parameters for ease of use within several software packages. Regardless of the spatial parameters, the positional information within the lidar are not altered. The final data products at the conclusion of the project, will be reported within the MLLW datum for Provincetown Harbor, to simplify use at the local level. The data are downloaded in a raster format and brought into ESRI's ArcGIS software where the raster is divided into smaller tiles. These lidar tiles are then brought into QPS's Fledermaus data visualization software. While acquired by CCS as an integral component of its Seafloor Mapping Program, the Fledermaus software package has proven to be an ideal platform for the initial desktop identification of STPs with the accuracy of the initial analysis limited primarily by the uncertainty and resolution of the lidar itself.

The power of Fledermaus lies in its ability to work with very large data files quickly. Individual files can be multiple GBs in size, yet Fledermaus can very rapidly, almost instantly, move through the data for visual inspection, ‘fly-throughs’ and similar functions. A horizontal plane, representing a specific STP elevation can be added to a Fledermaus project or ‘scene’ and that plane can be changed to simulate the increase or decrease in water level (Figure 4).

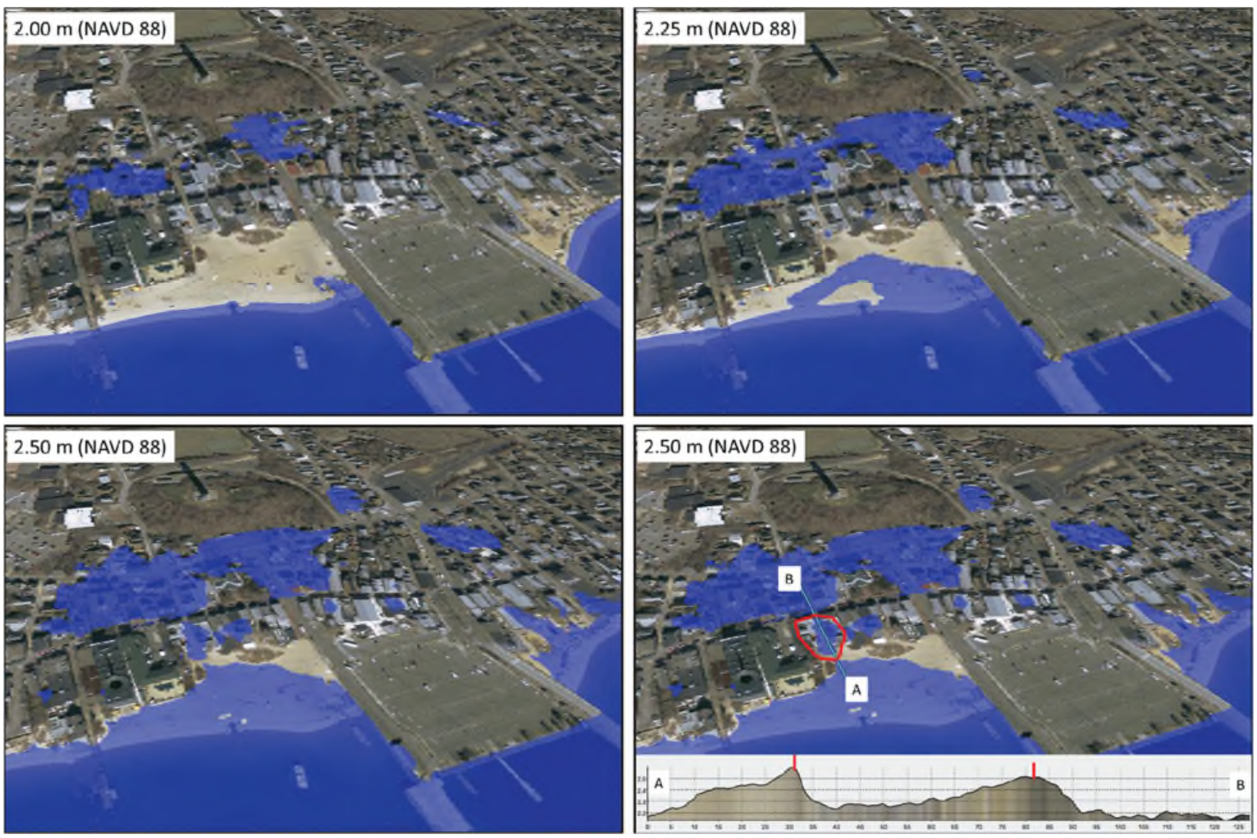

Figure 4. Downtown Provincetown, draped aerial photograph over Lidar surface. Blue areas are horizontal plane created in Fledermaus at increasing elevation. Lower left is example of a storm-tide pathway with accompanying profile. These images were generated before field work.

Another invaluable feature of the data visualization software is the ability to drape a 2 dimensional data set such a vertical aerial photograph over a 3D dataset (lidar). This allows the analyst to better document the STP and also to gain valuable information as to the substrate the STP is located in and its landscape setting. For example, an STP found on or near a naturally evolving coastal feature such as a beach or dune would be characterized differently than one atop a concrete wall or other relatively static structure. This is important not only for a final assessment of the most appropriate way to address an STP in a critical area but also serves to inform the field team to more closely examine areas that are naturally evolving and to be vigilant for other to potential STPs in close proximity to the identified point but not present in the lidar.

In the Spring of 2011, the Natural Resource Conservation Services (NRCS) collected terrestrial lidar data for Barnstable County. These data were used in phase one and provide an accurate synoptic elevation dataset. Metadata for these data indicate horizontal and vertical accuracies of +/- 1.0 m and +/- 0.15 m respectively, previous lidar for the area had double the vertical uncertainty.

Field Work

At the completion of the desktop analysis, all potential STPs are compiled into a database with x, y, z coordinates and uploaded into the Center's GPS. Each potential STP location was inspected by a 3-person team. The field team incorporated the lidar data via a laptop in the field in real-time while RTK-GPS data were collected at each location. This served three purposes, the first was to map the real-world location of the STP that was found during the analysis of the lidar data and the second was to increase the positional accuracy of the STP itself and lastly it served as a check on the positional accuracy of the lidar data.

The field crew used the GPS instrument to navigate to the location of a potential STP and determine its presence or absence and with further investigation if an alternative location is more appropriate. Many coastal sites have very low relief (relatively flat) and determining whether an STP exists, its exact location and direction of water flow is facilitated with the professional judgment and experience in the principles and practices of land surveying fieldwork as well as a thorough knowledge of coastal processes.

A Trimble® R8 GNSS receiver utilizing Real-Time-Kinematic GPS (RTK-GPS) is used for positioning and tide correction. The Center subscribes to a proprietary Virtual Reference Station (VRS) network (KeyNetGPS) that provides virtual base stations via cellphone from Southern Maine to Virginia. This allows the Center to collect RTK-GPS without the need to setup a terrestrial base station or post-process the GPS data in any way, reducing mobilization and demobilization costs, streamlining the field effort, and maximizing vessel-based survey time.

The Center undertook a rigorous analysis of this system to quantify the accuracy of this network (Mague and Borrelli, in prep). Over 25 National Geodetic Survey (NGS) and Massachusetts Department of Transportation (DOT) survey control points, with published state plane coordinate values relating to the Massachusetts Coordinate System, Mainland Zone (horizontal: NAD83; vertical NAVD88), were occupied. Control points were distributed over a wide geographic area up to 50 km away from the Center.

Multiple observation sessions, or occupations, were conducted at each control point with occupations of 1 second, 90 seconds, and 15 minutes. To minimize potential initialization error, the unit was shut down at the end of each session and re-initialized prior to the beginning of the next session. The results of each session (i.e., 1 second, 90 second, and 15 minute occupations) were averaged to obtain final x, y, and z values to further evaluate the accuracy of short-term occupation. Survey results from each station for each respective time period were then compared with published NGS and DOT values and the differences (error) used to assess and quantify uncertainty. Significantly, there was little difference between the error obtained for the 1 second, 90 second, and 15 minute occupations. The overall uncertainty analysis for these data yielded an average error of 0.008 m in the horizontal (H) and 0.006 m in the vertical (V). An RMSE of 0.0280 m (H) and 0.0247 m (V) and a National Standard for Spatial Data Accuracy (95%) of 0.0484 m (H) and 0.0483 m (V).

After the field work has been completed the team returns to the lab and culls points that were determined not be STPs, adds new STPs that were identified and documented in the field and labels all STPs with regards to position, elevation, substrate and other pertinent information for inclusion into a comprehensive database that can be brought into the project GIS. Particular attention must be focused on those areas when the lidar was found to correlate poorly with current conditions or real-world positions as determined by the GPS surveys and professional judgment applied to accurately represent the STP.

With the compilation of the comprehensive STP database, the file is brought into ESRI's ArcGIS to visualize STP locations and provide a working tool for local managers to: 1) proactively address STPs prior to storm events; 2) prepare for approaching storms; and 3) to plan for longer-term improvements to mitigate other STPs. Recognizing that accurate field delineation of the extent of inundation for each STP is beyond the scope of the project, the lidar data was used in 2 interactive ways to visualize STP inundation levels. The first depiction is referred to as the Pathway Activation Level (PAL). The PAL is the elevation at which water begins to flow over an STP the extent of which is delineated as a continuous contour using elevation from the lidar. For example, based on the GPS fieldwork, an STP with a PAL of 13.6 MLLW indicates that the moment the water reaches 13.6 MLLW water will begin to flow inland over the STP. Using the data visualization software, a water elevation of 13.6 MLLW is then used to demarcate the area that would hypothetically be inundated (assuming storm tide water levels are maintained long enough for the entire area to become flooded). If a storm tide recedes after reaching the PAL then this depiction can be viewed perhaps as a "best" case scenario for impacts associated with a specific storm tide. If water levels were to continue to rise above the PAL, higher that 13.6, however, obviously more area would be inundated leading to the need for a second way to visualize STPs.

To increase the utility of the STP data and to make visualizations more user friendly for local mangers, Inundation Ranges (IRs) were developed for the entire study area rather than creating PALs for every STP and all elevations of potential flooding. Based on a series iterations depicting potential inundation scenarios, including nuisance flooding, it was decided that the lowest value IR range would begin at the highest Spring tide of the year. The elevations were then incrementally raised in 1 foot intervals to the elevation of the Storm of Record for the area. After which we add three more elevations: Storm of Record +1ft; Storm of Record +2ft; and Storm of Record +3ft. We believe this is a useful representation of future sea level rise with practical implications for local managers.

RESULTS AND DISCUSSION

Provincetown Harbor Tidal Profile

As noted in the Methods section, in order to document STPs the development of an elevation profile for the community of interest that characterizes both storm tides and nuisance flooding is needed. In addition to the more common tidal datums of mean high water springs (MHWS), mean higher high water (MHHW), mean high water (MHW), and mean sea level (MSL) this tidal profile should include datum referenced storm tides of the past, including the elevation of the maximum storm tide experienced (i.e., the storm of record), and an estimate of potential future storm tides by adding three feet to the storm of record.

The storm of record for the Boston Tide Gauge (#8443970) occurred on February 7, 1978 with a maximum storm tide elevation of 9.59' NAVD88. Occurring at approximately the time of the predicted or astronomical high tide, the storm surge was approximately 3.5 feet. By comparison, the maximum storm tide elevation experienced during the blizzard of January 27, 2015 was 8.16' NAVD88. Occurring shortly after the astronomical high tide, this elevation resulted from the combination of an astronomical tide height of 4.79' NAVD88 and a storm surge of 3.37 feet. Significantly the maximum storm surge for this event was observed to be 4.5 feet, however, because it occurred close to the time of the astronomical low water the corresponding storm tide elevation was only -1.1' NAVD88. Had the maximum storm surge occurred approximately 6 hours earlier at the time of the astronomical high tide, the resulting storm tide elevation would have been 9.2' NAVD88, approximately 5 inches below the elevation of the storm of record. Recognizing the significance of not only the magnitude of the predicted storm but the time it will occur relative to the stage of the tide, the National Weather Service in Boston, MA maintains an informative website that estimates storm surge and total water level at various stations (http://www.weather.gov/box/coastal) as coastal storms approach New England.

The affects of storm tides on coastal communities are dependent on many factors. These include coastal orientation (e.g., east facing v. south facing shores); the elevations of astronomical tides (e.g., the elevation of mean high water in Boston Harbor is 4.31 feet NAVD88 v. the elevation of mean high water for Woods Hole is 0.56' NAVD88); general characteristics of astronomical tides (e.g., the average range – MHW minus MLW – of Boston tides is 9.49 feet while that of Woods Hole tides is only 1.79 feet); topography (e.g., the elevation of the land relative to the community tidal profile); nearshore bathymetry (e.g., the deeper the water relative to shore, the greater the potential wave energy); topographic relief (i.e., a measure of the flatness or steepness of the land with flatter areas more sensitive to small changes in water levels); the nature of coastal landforms (e.g., the rock shorelines of the North shore v. the dynamic sandy shorelines of Cape Cod); and the vertical relationship between historical community development and adjacent water levels (e.g., development in Boston began in the early 17th century with the water levels at that time influencing the elevation of not only pile supported structures but large scale landmaking – filling – efforts). With such variation in physical characteristics, the initial step in the identification of storm tide pathways for a community is the development of a datum-referenced tidal profile.

On December 31, 2014, the U.S. Geological Survey (USGS) Water Resources installed a datum-referenced (NAVD88, feet) station in Provincetown Harbor. This station now provides a real-time source of 15-minute water level observations for north Cape Cod Bay. The gage is accessible at the following website: http://waterdata.usgs.gov/ma/nwis/uv/?site_no=420259070105600&PARAmeter_cd=00065,00060.

Prior to 2015, tidal and water level information for Provincetown Harbor was established based on a secondary NOAA tide station (#8446121) established within the Harbor on March 5, 2010 and water level observations recorded for a period of four months from April to July, 2010. The gage was referenced to a station datum memorialized with four benchmarks established around the harbor. Tide station #8443970, the primary tide station for Boston Harbor and the longest continuously operating station in Massachusetts (since 1921) was used as the control station to publish local tidal datum elevations. These datums represent mean tidal elevations for the 1983 to 2001 National Tidal Datum Epoch (NTDE). Information on the NOAA tide station #8446121 can be found at http://tidesandcurrents.noaa.gov/datums.html?id=8446121.

Recognizing that tidal heights vary with location, the published tidal datums were converted to NAVD88 for reference throughout the project area and for direct comparison with the tidal profiles of other areas. To accurately convert elevations from the Station Datum to NAVD88, the four benchmarks for tidal station # 8446121 were recovered and occupied by the Center's RTK GPS for 15 minutes to obtain benchmark elevations referenced vertically to NAVD88. Since each benchmark is also referenced to the station datum the published tidal information for # 8446121 can be converted to NAVD88. Figure 3 depicts contemporary tidal datums for Provincetown Harbor referenced to NAVD88 and mean lower low water (MLLW), the local tidal or chart datum.

As noted above, NOAA tide station #8443970 located in Boston Harbor is a primary tide station and has been used historically as the control station for published tide information in Cape Cod Bay. Figure 3 depicts the tidal profile for Boston Harbor referenced to NAVD88 and MLLW. Referencing tidal heights to NAVD88 allows for Provincetown and Boston Harbors to be compared directly and as shown in Figure 3 the tidal profiles for the two harbors is very close.

The Provincetown tidal profile was completed with historical research of significant coastal storms to determine, where possible, the elevation of the associated storm tide (astronomical tide + storm surge). APPENDIX A includes a list of references summarizing major coastal storm events and associated storm tide elevations.

With similar tidal profiles, Boston Harbor was used as a proxy for Provincetown Harbor. Table 1 summarizes the highest water levels for Boston Harbor since May 3, 1921 when tidal station #8443970 was installed. Since this time, the maximum water level for Boston Harbor was observed to be 9.59' NAVD88 on February 7, 1978 during the "Blizzard of '78".

While no tide station was available at this time in Provincetown Harbor, Dr. Graham S. Giese, co-founder of the Center for Coastal Studies, was on scene at MacMillan Wharf to record observations of water height during the Blizzard. Significantly, Dr. Giese referenced the water readings to a 1933 NOAA tidal benchmark, which was recovered as part of this project and occupied with the Center's RTK GPS instrument to convert water level readings to NAVD88.

Based on this work, the elevation of the Blizzard of ’78 storm tide for Provincetown Harbor was determined to be 9.36’ NAVD88. Interestingly, this was found to be 0.71 feet above the maximum water level of 8.65’ NAVD88 measured by CCS during the January 27, 2015 blizzard.

Boston Harbor (Station #8443970)
Highest Recorded Water Levels

Rank	Date	NAVD88 (Ft.)	MLLW (Ft.)
1	2/7/1978	9.59	15.11
2	1/2/1987	8.69	14.21
3	10/30/1991	8.66	14.18
4	1/25/1979	8.53	14.05
5	12/12/1992	8.52	14.04
6	12/29/1959	8.49	14.01
7	4/18/2007	8.29	13.81
8	5/25/2005	8.27	13.79
9	2/19/1972	8.19	13.71
10	12/27/2010	8.19	13.71
11	5/26/2005	8.16	13.68
12	1/27/2015	8.13	13.65
13	5/26/1967	8.11	13.63
14	6/5/2012	8.07	13.59
15	3/4/1931	7.97	13.49
16	11/30/1944	7.87	13.39
17	1/20/1961	7.85	13.37
18	4/21/1940	7.83	13.35

Table 2. Historical storm-tides recorded at the Bostin Harbor water levelsStation. Modified after Mague and Foster (2008).

Table 3 represents the resulting tidal profile constructed for Provincetown Harbor for use in screening potential STPs. As shown by the table, the maximum storm tide elevation considered in this analysis was the storm tide of record plus 3 feet (12.36’ NAVD88). To evaluate potential nuisance flooding associated with more frequent non-storm tidal events, the lowest elevation considered in the STP analysis was that of the maximum predicted high tide for 2015 (6.44’ NAVD88). A review of the NOAA tide charts for Provincetown Harbor indicated that the maximum astronomical high water predicted for 2015 was 6.44’ NAVD88.

Provincetown Harbor Tidal Profile Station: 8446121			
	NAVD88 (FT)	**MLLW (FT)**	**Comments**
Storm of Record plus 3 Feet	**12.36**	**17.82**	**Upper Limit of Storm Tide Pathway Analysis**
Blizzard of '15 if max storm surge occurred at Max Predicted High For Year	10.74	16.20	Max. Storm Surge = 4.30' occurred at approx. low tide
Blizzard of 1978 Maximum Storm Tide	**9.36**	**14.82**	**Storm of Record Based on CCS Observations**
Blizzard of '15 if max storm surge had occurred at Predicted High	9.19	14.65	Max. Storm Surge = 4.30' occurred at approx. low tide
Blizzard of 2015 Maximum Storm Tide	8.65	14.11	Based on CCS Observations Storm Surge = 3.65', Predicted High Tide El. = 5.00' NAVD88 at 0430 hrs
Maximum 2015 Predicted High	6.44	11.90	From 2015 NOAA Tide Predictions
MHWS	5.54	11.00	NOAA Tide Station #8446121
MHHW	4.62	10.08	NOAA Tide Station #8446121
MHW	4.16	9.62	NOAA Tide Station #8446121
MSL	-0.43	5.03	NOAA Tide Station #8446121
MTL	-0.48	4.98	NOAA Tide Station #8446121
MLW	-5.13	0.33	NOAA Tide Station #8446121
MLLW	-5.46	0.00	NOAA Tide Station #8446121

Table 3. The Provincetown Tidal Profile

STORM TIDE PATHWAYS

Analysis of the lidar data in phase one yielded 81 potential STPs throughout the study area. Each location was inspected by the 3-person field team. The team incorporated the lidar data via a laptop in the field in real-time while RTK-GPS data were collected at each location. Many times in the field the STP was moved when the team determined the 2011 lidar was not representative of the real-world terrain in 2015.

map the real-world location of the STP that was found during the analysis of the lidar data and increase the positional accuracy of the STP itself and lastly it served as a check on the positional accuracy of the lidar data.

The final dataset contains 72 storm-tide pathways. There are several types of STPs included in

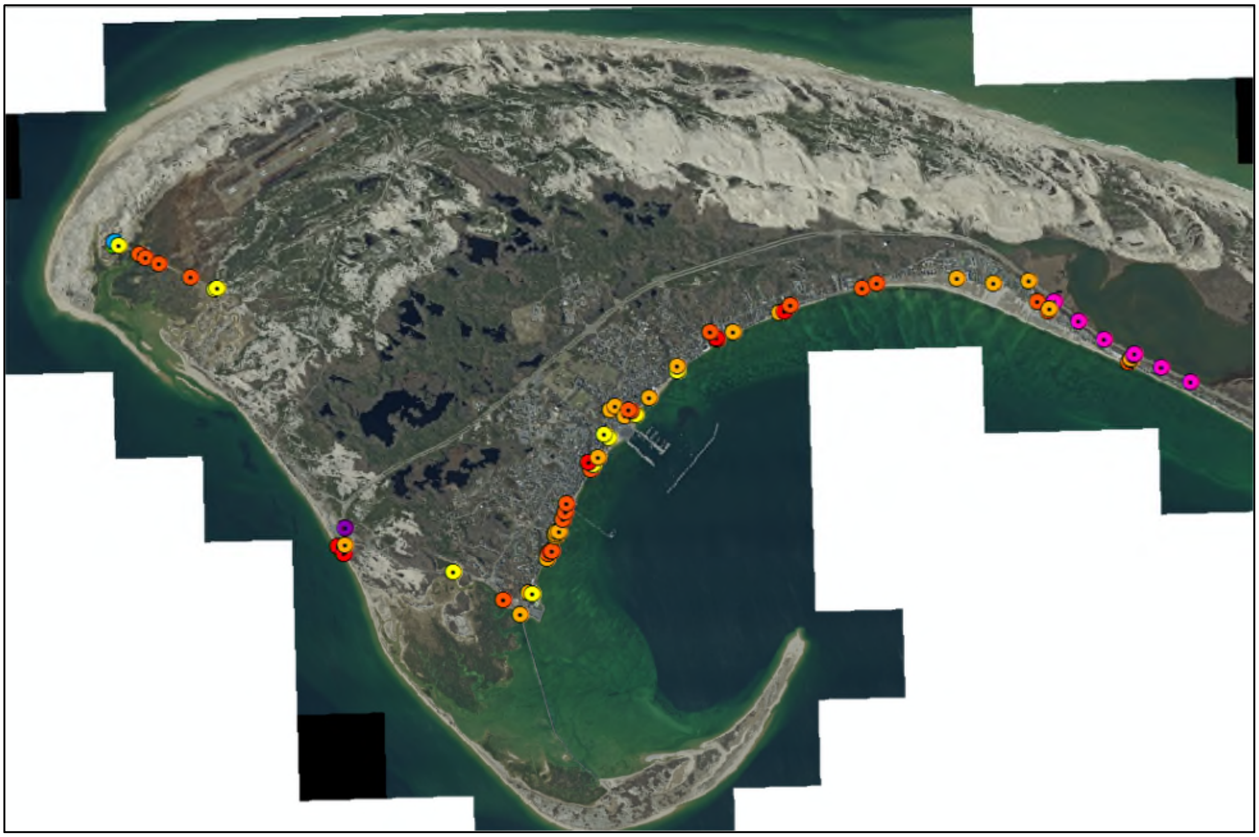

Figure 5. Color-coded Storm Tide Pathways (n = 72) ranging from <12ft -18 ft (MLLW).

this dataset: the standard Storm Tide Pathway (STP) as discussed above, the 'spillway' (STP-S); the 'roadway' (STP-R); and the unverified (STP-U) (Table 4). The sub-types were developed to reflect different on-the-ground morphologies and techniques needed to identify and/or address potential inundation at these locations.

Table 4. Breakdown of Storm Tide Pathways

Pathways	Standard (STP)	Spillway (STP-S)	Roadway (STP-R)	Unverified (STP-U)
72	43	15	9	5

The ‘standard’ pathway was a relatively narrow low-lying area where flowing water would be directed to by the natural topography (Figure 6).

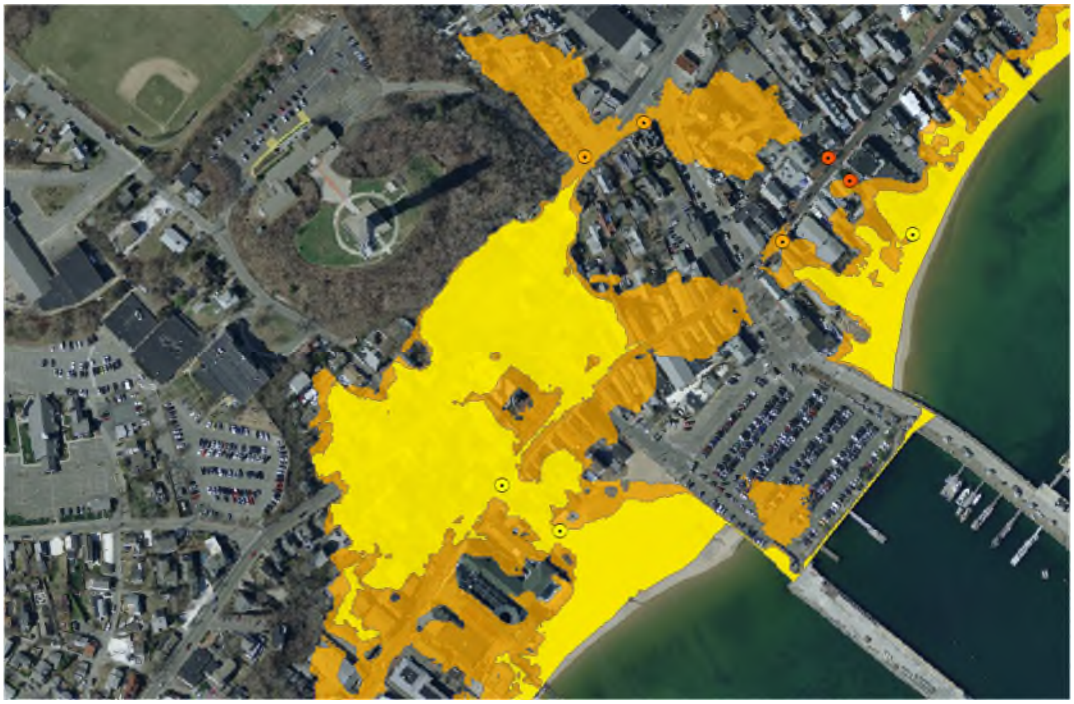

Figure 6. Examples of STPs and potential extent of flooding. The points are STPs over which water will flow when it reaches the elevation of the STP.

The term ‘spillway’ was intended to reflect the low relief (little change in elevation) of the area. The STP-S are situated in very flat areas that will require a broad space to be considered in order to prevent flooding during future events. While difficult to visualize these areas may be of great concern precisely because of the characteristic that makes them a spillway, a broad flat area of inundation with no clear, narrow pathway for flood waters to enter.

The roadway STP (STP-R) was delineated as it provides a pathway for water flowage that only effects a roadway and no other resource that would necessarily need protection from inundation. All nine STP-Rs found in the study were located along Route 6, near East Harbor (Pilgrim Lake). These STP-Rs are relatively low lying (12.2 – 14.2 ft), but the path water would need to take would be circuitous and would likely only happen if storm surge and winds prevented water from draining over many tidal cycles. As mentioned above this study does not quantify the probability of flooding events, but only the location of inundation and area effected. These STP-

Rs would see water flowing from Cape Cod Bay, flooding the gully directly south of Route 6 and then flowing over the road and into East Harbor. This gully is deep but could fill during certain types of storms. The only hazard for these STP-Rs is water flowing over the road, if the water continued into an area where resources was flooded then it would not be a STP-R, but simply an STP. Therefore, an STP could flood a road, but an STP-R 'only' floods a road.

An unverified STP (STP-U) are STPs that were found during the lidar analysis, but were unable to be occupied by the field team. The lidar used for this study is a 'bare earth' lidar data set, which is the industry standard for these kinds of analyses (REF). Simply put, during the processing of these data the vegetation, (tress, bushes, beach grass, salt marsh, etc.) and structures (houses, buildings, etc.) are removed from the data, hence the 'bare earth' name. Therefore, certain low spots found in the lidar analysis could not be accessed or were otherwise inaccessible (private property) (STP-U figure).

Figure 7. Example of an STP-U. This was an unverified STP as the field team could not lawfully gain access to the exact location of the STP.

The 5 STP-Us found in this study are in low areas that will experience water flowage but the precise location of the STP is unknown. With further analysis the precise location of the STP may be ascertained, but remains beyond the scope of this study.

This study is deterministic rather than probabilistic, the focus was on creating a high-resolution map of *where* inundation would occur and *when*, or at what water level, inundation would begin. The uncertainties associated with quantifying the *how and why* of coastal flooding, the modelling of storm surge, sea level rise, waves, etc. are prohibitive when dealing with inundation events at the local level by coastal managers. These uncertainties and others are largely removed by the ‘where and when’ of mapping storm tide pathways.

APPENDIX B: CONSEQUENCE OF FAILURE ASSESSMENT & RESULTS

Provincetown CoF Worksheet

Category		Consequence of Failure Score: Health & Safety	Community Image	Financial	Environmental Damage
		5. Significant Risk of Injury or Death 4. Significant risk of major injury 3. Low risk of major injury 2. Low risk of injury 1. No Risk of Injury	5. Major service interruption, reputation impact and/or national media coverage. 4. Intermittent services, reputation impact and local or regional media attention. 3. Minor service and reputation impacts, no media. 2. No Media and reputation impacts, minor intermittent service impacts. 1. No media, reputation or reputation impacts.	5. Greater than $5 million 4. $1 million to $ 5million 3. $100k to $1 million 2. $10,000 to $100k 1. Less than $10,000 * Used Assessors information where applicable, industry knowledge of infrastructure/vehicle/equipment costs.	5. Significant environmental damages. 4. Localized environmental damage. 3. Possible environmental damage. 2. Possible Minor or eventual environmental damage. 1. No environmental damage

Name of Critical Asset*	Comments	Health and Safety Score	Community Image	Financial Score	Environmental Damage Score	Max Value	Average Value
Emergency Operations -VMCC	Houses the DPW offices, also the shelter; wind exposure here is high; existing generator outdated, funding is in place for a new one.	5 *Emergency Operations run out of this building as well as the community center. This makes the risk of H&S impacts significant.*	5	5 *Both schools were included on the same assessors summary report, and were valued as a total at approximately $19M. We have assumed that both structures individually would have $5M or greater replacement costs.*	2	5	4.25
Provincetown High School	A nonessential building, there is no generator and it is not a shelter. It is a big financial asset and currently serves as the elementary school.	3	4	5 *Both schools were included on the same assessors summary report, and were valued as a total at approximately $19M. We have assumed that both structures individually would have $5M or greater replacement costs.*	2 *Chemistry Lab/cleaning chemicals, kitchens, etc.*	5	3.5
Provincetown Town Hall	Historic building and center of the community, servers stored here.	4	5 *Eliminates town services, puts records and servers at risk. Holds the main servers, the central hub for town.*	5 *The Town Hall is the center of the Town's civic function. It is a historical building and has a high value to the community.*	2	5	4
Seashore Point	Retirement Community	5 *Due to the high quantity of senior citizens, this could be a serious H&S Risk.*	3	5 *Includes a number of individually assessed condo's for people aged 55+. Collectively this is a major financial asset.*	2	5	3.75
MacMillan Pier & Harbormaster	Harbor master office, dock space for large vessels, local fishing boats.	4	5 *Yacht Club, Harbor Master, and fish plant services would be suspended in the case of failure.*	4 *The Pier is a very important economic asset for the City for tourism, ferry travel, and commercial fishing.*	3	5	4
Provincetown Police Station	Emergency services	4	4 *Police services are critical during emergencies. The loss of this facility could have a major impact.*	4 *Also takes into consideration vehicles and equipment that might be stationed there.*	2	4	3.5
Fire Station	Emergency services	4 *This asset would very likely be in use in case of a major weather event.*	4 *Fire services are critical during emergencies. The loss of this facility could have a major impact.*	4 *Also takes into consideration vehicles and equipment that might be stationed there.*	2	4	3.5
Fire House #2	This station is no longer used for fire services, and are used for some basic city services such as storage and for public restrooms.	2	2	3	1	3	2
Fire House #3	These assets are no longer used for fire services, and are used for some basic city services such as storage and for public restrooms.	2	2	3	1	3	2
Fire Station #4	Sattelite Fire Station in use.	3	4 *Fire services are critical during emergencies. The loss of this facility could have a major impact.*	4 *Also takes into consideration vehicles and equipment that might be stationed there.*	2	4	3.25
Fire Station #5	Sattelite Fire Station in use.	3	4 *Fire services are critical during emergencies. The loss of this facility could have a major impact.*	4 *Also takes into consideration vehicles and equipment that might be stationed there.*	2	4	3.25

Provincetown Risk Assessment

Category		Consequence of Failure Score			
		Health & Safety	Community Image	Financial	Environmental Damage
		5. Significant Risk of Injury or Death 4. Significant risk of major injury 3. Low risk of major injury 2. Low risk of injury 1. No Risk of Injury	5. Major service interruption, reputation impact and/or national media coverage. 4. Intermittent services, reputation impact and local or regional media attention. 3. Minor service and reputation impacts, no media. 2. No Media and reputation impacts, minor intermittent service impacts. 1. No media, reputation or reputation impacts.	5. Greater than $5 million 4. $1 million to $ 5million 3. $100k to $1 million 2. $10,000 to $100k 1. Less than $10,000 * Used Assessors information where applicable, industry knowledge of infrastructure/vehicle/equipment costs.	5. Significant environmental damages. 4. Localized environmental damage. 3. Possible environmental damage. 2. Possible Minor or eventual environmental damage. 1. No environmental damage

Name of Critical Asset*	Comments	Health and Safety Score	Community Image	Financial Score	Environmental Damage Score	Max Value	Average Value
Coast Guard Station	Very active community partner. Important regional base.	3 *This asset would very likely be evacuated, and crew members prepared in the case of a major weather event.*	4 *Coast Guard Services could provide significant value during an emergency.*	4	3 *There may be fuel, ammunition, chemicals, etc. Stored at these bases which could provide environmental damage.*	4	3.5
Telephone Station		2 *This asset would very likely be evacuated in the case of a major weather event.*	2 *Telephone service interruptions.*	3	2	3	2.25
Outer Cape Health Services	The primary healthcare facility in the area. Medical supplies and expertise are sourced to this facility.	5 *Only healthcare provider in the town.*	4	4	3	5	4
Housing Authority		2	3	4 *Located within the same building as Outer Cape Health Services, assumed same assessed value.*	1	4	2.5
Maushope Senior Housing	We have assumed that there are senior citizens living at this facility.	4 *Due to the high quantity of senior citizens, this could be a serious H&S Risk.*	3 *Depending on the severity, this could range from a minor impact to a large impact.*	4 *Located within the same building as Outer Cape Health Services, assumed same assessed value.*	1	4	3
Provincetown Public Library	Historic building with valuable art/literature collections. There is no generator.	2 *This asset would very likely be evacuated in the case of a major weather event.*	4 *Loss of library services, media impact.*	5 *Takes into consideration artwork collection and other assets.*	2	5	3.25
DPW Garage		3	5 *Provides services critical for managing emergencies such as plowing, disposal, sewer maint. Etc.*	4 *Also takes into consideration vehicles and equipment that might be stationed there.*	4 *Hydrocarbons from fueling station.*	5	4
Wastewater Treatment Plant		4 *Environmental contamination and lack of sewer services could provide a direct threat to public health.*	4 *If the WWTF was shut down, it would be a major service impact and would draw media attention due to compliance violations.*	5	5 *A WWTF failure would result in major environmental contamination.*	5	4.5
Provincetown Animal Hospital		2	3	3	2	3	2.5
Central Sewer Vacuum System	Sewer system for the downtown which services the most densely populated and financially critical area of the City.	3	4 *Lack of sewer service for heavily populated area in the Town*	3 *Assuming that a failure would not be a total loss, and that the financial impact would include major rehabilitation work.*	5 *Would likely result in a major SSO.*	5	3.75
Provincetown Airport	Big asset to the town and local economy.	3	5 *This would be a major service and reputation impact.*	4 *Includes assessed value of structures as well as runway, paving etc.*	4 *Assuming potential fuel storage leaks*	5	4
Province Land Road Culvert	Failure would result in significant environmental damage to an important marsh.	2	2	2	4	4	2.5
Water Transmission Mains from Truro	Only source of water for Provincetown. They do have a water tower, but any issue with these transmission mains is a major emergency.	4 *Lack of potable water could be a major health risk.*	5 *Water service could interrupted.*	3 *Assuming that a failure would not be a total loss, and that the financial impact would include major rehabilitation work.*	2 *Possible issues with wastewater and other systems if there is no power. (Not all Pump stations have emergency power.).*	5	3.5
Pump Station #1 – Kendall Lane (540-544 Commercial Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3	3 *Would likely result in a significant SSO.*	3	3

Provincetown Risk Assessment

Category		Consequence of Failure Score: Health & Safety	Consequence of Failure Score: Community Image	Consequence of Failure Score: Financial	Consequence of Failure Score: Environmental Damage
		5. Significant Risk of Injury or Death 4. Significant risk of major injury 3. Low risk of major injury 2. Low risk of injury 1. No Risk of Injury	5. Major service interruption, reputation impact and/or national media coverage. 4. Intermittent services, reputation impact and local or regional media attention. 3. Minor service and reputation impacts, no media. 2. No Media and reputation impacts, minor intermittent service impacts. 1. No media, reputation or reputation impacts.	5. Greater than $5 million 4. $1 million to $ 5million 3. $100k to $1 million 2. $10,000 to $100k 1. Less than $10,000 * Used Assessors information where applicable, industry knowledge of infrastructure/vehicle/equipment costs.	5. Significant environmental damages. 4. Localized environmental damage. 3. Possible environmental damage. 2. Possible Minor or eventual environmental damage. 1. No environmental damage

Name of Critical Asset*	Comments	Health and Safety Score	Community Image	Financial Score	Environmental Damage Score	Max Value	Average Value
Pump Station #2 – Pleasant Street (61 Pleasant Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #3 - Manor (26 Alden Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #4 - Bayberry (74R Bayberry Ave)	Has a generator.	3	4 *Would result in SSO, possible sewer backups, etc. Over 300gpm*	3 *Could be expensive repair depending on extent of damage*	4 *Would likely result in a significant SSO. Over 300gpm*	4	3.5
Pump Station #5 – Snail Road (698 Commercial Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #6 – Commodore Avenue (50 Commodore Avenue)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #7 – Thistlemore Road (324 Bradford Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #8 – West End (1 Commercial Street)	Has a generator.	3	3 *Would result in SSO, possible sewer backups, etc.*	3 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	3
Pump Station #9 – Shank Painter (25 Shank Painter Road)	Has a generator.	3	4 *Would result in SSO, possible sewer backups, etc.*	2 *Could be expensive repair depending on extent of damage*	4 *Would likely result in a significant SSO. Over 300gpm*	4	3.25
Pump Station #10 – Stop and Shop Pump Station (56 Shank Painter Road)	Has a generator.	2	3 *Would result in SSO, possible sewer backups, etc.*	2 *Could be expensive repair depending on extent of damage*	2 *Very small station*	3	2.25
Pump Station #11 – Ice House Pump Station (501 Commercial Street)		3	3 *Would result in SSO, possible sewer backups, etc.*	2 *Could be expensive repair depending on extent of damage*	3 *Would likely result in a significant SSO.*	3	2.75
Route 6A Roadway	This is an evacuation route.	4 *This could affect drivers on the road, people attempting to cross flood waters, preventing people from leaving, etc.*	5 *One of the two means of egress from the town.*	4 *Cost of rehabilitating or replacing a major road would be high.*	2	5	3.75
Winslow Water Tower		2	4 *Water service may be interrupted.*	3 *Assumption of rehabilitation cost.*	2	4	2.75
Mt. Gilboa Water Tower		2 *Very Low risk of injury*	4 *Water service may be interrupted.*	3 *Assumption of rehabilitation cost.*	2	4	2.75
Provincetown Public Television		3	4 *Local Television service would be interrupted.*	4 *Building and contents are valuable.*	1	4	3
Stop & Shop	Primary food source in town.	4 *Primary food source in town.*	4	4	2	4	3.5
Power SubStation #2	Required to maintain electrical Service in Town.	3 *Outage could result in injuries or health issues.*	4 *Eliminating electrical services*	4 *Assumption of rehabilitation cost.*	3 *Would force wastewater treatment plant and pump stations to rely on generators.*	4	3.5
Power SubStation #2	Required to maintain electrical Service in Town.	3 *Outage could result in injuries or health issues.*	4 *Eliminating electrical services*	4 *Assumption of rehabilitation cost.*	3 *Would force wastewater treatment plant and pump stations to rely on generators.*	4	3.5

Provincetown Risk Assessment

Category		Consequence of Failure Score			
		Health & Safety	Community Image	Financial	Environmental Damage
		5. Significant Risk of Injury or Death 4. Significant risk of major injury 3. Low risk of major injury 2. Low risk of injury 1. No Risk of Injury	5. Major service interruption, reputation impact and/or national media coverage. 4. Intermittent services, reputation impact and local or regional media attention. 3. Minor service and reputation impacts, no media. 2. No Media and reputation impacts, minor intermittent service impacts. 1. No media, reputation or reputation impacts.	5. Greater than $5 million 4. $1 million to $ 5million 3. $100k to $1 million 2. $10,000 to $100k 1. Less than $10,000 * Used Assessors information where applicable, industry knowledge of infrastructure/vehicle/equipment costs.	5. Significant environmental damages. 4. Localized environmental damage. 3. Possible environmental damage. 2. Possible Minor or eventual environmental damage. 1. No environmental damage

Name of Critical Asset*	Comments	Health and Safety Score	Community Image	Financial Score	Environmental Damage Score	Max Value	Average Value
Stormwater Pumphouse	Could help mitigate flooding in downtown.	3	3 *Would likely worsen flooding issues. Although in a flooding scenario, this station would likely be overwhelmed anyway.*	3	3	3	3
Transfer Station	90 Race Point Road, Solar Array on Site.	3	4 *Solar array on site*	4 *Also takes into consideration vehicles and equipment that might be stationed there. Solar Array on Site*	4 *Hydrocarbons from fueling station.*	4	3.75
Electrical Transmission Lines	Only source of electricity to Provivincetown.	4 *Would result in health issues at senior homes, health services, etc.*	5 *Only source of electricity to Provivincetown.*	3 *Assuming that a failure would not be a total loss, and that the financial impact would include major rehabilitation work.*	3 *Issues with wastewater treatment likely, and other waste disposal services.*	5	3.75
Route 6 Roadway	This is an evacuation route.	4 *This could affect drivers on the road, people attempting to cross flood waters, preventing people from leaving, etc.*	5 *One of the two means of egress from the town.*	4 *Cost of rehabilitating or replacing a major road would be high.*	2	5	3.75

****Woodard & Curran comments based on data gathering, interviews with key stakeholders and the October 2015 site visit are noted in italics.**

APPENDIX C: LIKELIHOOD OF FAILURE SUMMARY

Likelihood of Failure Scoring Criteria

		Weight	Scoring: 5	4	3	2	1
Coastal Studies Inundation Pathway	Coastal Studies, as a component of this project developed a detailed review of the most likely flood water inundation pathways in Provincetown. Values are feet above Mean Lower Low Water (MLLW), which is the average height of the lowest tide recorded for a tidal station.	50%	<12ft	12-14ft	14-16ft	16-18ft	Not within an inundation contour
Hurricane Surge Inundation Zones	Information gathered from the Cape Cod Commission's GIS Viewer. "*The SLOSH model is a computerized numerical model developed by the National Weather Service (NWS) to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account the atmospheric pressure, size, forward speed, and track data. These parameters are used to create a model of the wind field which drives the storm surge.* " -From Cape Cod Commission	16.7%	Category 1	Category 2	Categories 3-4	---	Not Within Surge Zone
FEMA FIRM National Flood Hazard Maps	Information gathered from the Cape Cod Commission's GIS Viewer. " *FIRM is an official map of a community that displays the floodplains, more explicitly Special Flood Hazard Areas (SFHA) and Coastal High Hazard Areas (CHHA), as delineated by FEMA. Both areas are subject to inundation by 1-percent-annual chance flood* ." -From Cape Cod Commission.	16.7%	VE	AE or AO	---	---	Not within FIRM Layers
Sea Level Rise	Information gathered from the Cape Cod Commission's GIS Viewer. "*The Sea Level Rise data was derived from classified Digital Elevation Model (DEM) data collected through Light Detection and Ranging (LiDAR) in 2011 by the USGS. The Sea Level Rise is shown as a simple representation of a change in elevation, commonly referred to as a "Bathtub" model.* " - From Cape Cod Commission	16.7%	<3ft	3-4ft	4-5ft	5-6ft	Not inundated within 6-ft

**Actual Scoring of Assets for LoF was completed in GIS. The results are shown in the Risk Results pdf.

APPENDIX D: RISK RESULTS SUMMARY

Provincetown Risk Assessment

Name	LoF	CoF	RISK	Risk Rank
Provincetown Airport	4.67	4.00	18.7	1
Provincetown Town Hall	4.17	4.00	16.7	2
MacMillan Pier & Harbormaster	4.00	4.00	16.0	3
Coast Guard Station	4.34	3.50	15.2	4
Route 6A	3.84	3.75	14.4	5
Electrical Transmission Lines	3.84	3.75	14.4	5
Route 6 Roadway	3.84	3.75	14.4	5
Water Transmission Mains from Truro	3.84	3.50	13.4	8
Pump Station #8 - West End	4.00	3.00	12.0	9
Central Sewer Vacuum System	3.17	3.75	11.9	10
Province Land Road Culvert	4.50	2.50	11.3	11
Fire Station	3.17	3.50	11.1	12
Provincetown Police Station	3.17	3.50	11.1	12
Stop and Shop	3.17	3.50	11.1	12
Pump Station #1 - Kendall Lane	3.67	3.00	11.0	15
Pump Station #6 - Commodore Avenue	3.67	3.00	11.0	15
Stormwater Pumphouse	3.67	3.00	11.0	15
Fire Station #5	3.34	3.25	10.8	18
DPW Garage	2.67	4.00	10.7	19
Pump Station #11 - Ice House Pump Station	3.84	2.75	10.6	20
Pump Station #7 - Thistlemore Road	3.50	3.00	10.5	21
Pump Station #9 - Shank Painter	3.17	3.25	10.3	22
Provincetown Public Television	3.34	3.00	10.0	23
Pump Station #5 - Snail Road	3.34	3.00	10.0	23
Fire House #3	4.17	2.00	8.3	25
Pump Station #2 - Pleasant Street	2.67	3.00	8.0	26
Fire House #2	3.34	2.00	6.7	27
Wastewater Treatment Plant	1.17	4.50	5.3	28
Emergency Operations Center - VMCC	1.17	4.25	5.0	29
Outer Cape Health Services	1.17	4.00	4.7	30
Pump Station #10 - Stop and Shop P.S.	2.00	2.25	4.5	31
Seashore Point	1.17	3.75	4.4	32
Transfer Station	1.17	3.75	4.4	32
Provincetown High School	1.17	3.50	4.1	34
Pump Station #4 - Bayberry	1.17	3.50	4.1	34
Provincetown Public Library	1.17	3.25	3.8	36
Fire Station #4	1.17	3.25	3.8	36
Maushope Senior Housing	1.17	3.00	3.5	38
Pump Station #3 - Manor	1.17	3.00	3.5	38
Power SubStation #1	1.00	3.50	3.5	40
Power SubStation #2	1.00	3.50	3.5	40
Winslow Water Tower	1.17	2.75	3.2	42
Mt. Gilboa Water Tower	1.17	2.75	3.2	42
Housing Authority	1.17	2.50	2.9	44
Herring Cove Animal Hospital	1.17	2.50	2.9	44
Telephone Station	1.17	2.25	2.6	46

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