



# Town of Duxbury Climate Change Vulnerability Assessment and Adaptation Planning

## MVP Action Grant – Final Public Meeting

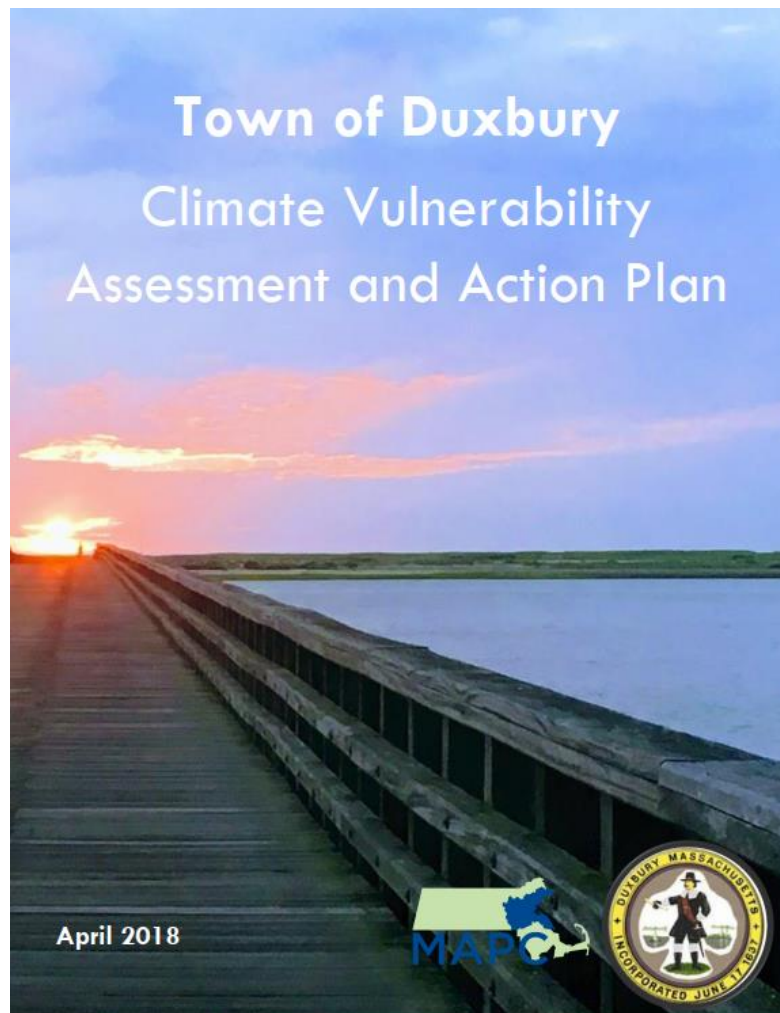
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Woods Hole Group

Project Team:  
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Senior Coastal Engineer  
Woods Hole Group

# Duxbury Climate Change Planning

*Climate Vulnerability Assessment and Action Plan (April 2018)*



- Hazards:
  - heat, drought, **sea level rise**, **storm surge**, precipitation
- Actions:
  - Engage in community **adaptation planning** process for the three (3) most vulnerable areas: Gurnet Road, **Snug Harbor**, and the Blue Fish River.
  - Collaborate with stakeholders in the most vulnerable areas to identify potential **zoning, regulatory, incentive mitigation and cooperative approaches** to deal with sea level rise.
  - Create a working group to inform **design standards for raising roads** and consider implications for commercial, industrial, and residential building egress
- MVP Certified Community

# Current Vulnerability to Coastal Flooding

*Impetus for MVP Action Grant*



Source: @Dux\_HM

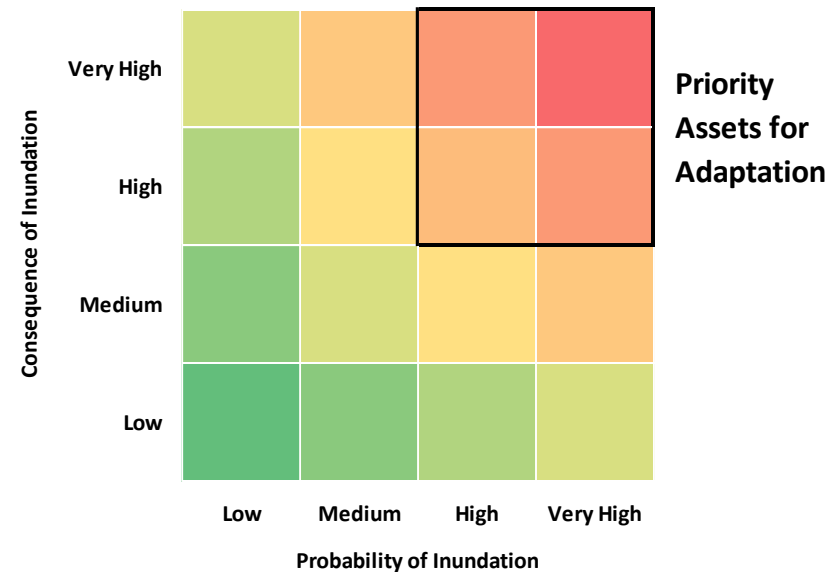


Source: Google

# Vulnerability Assessment and Adaptation Planning

## Project Approach

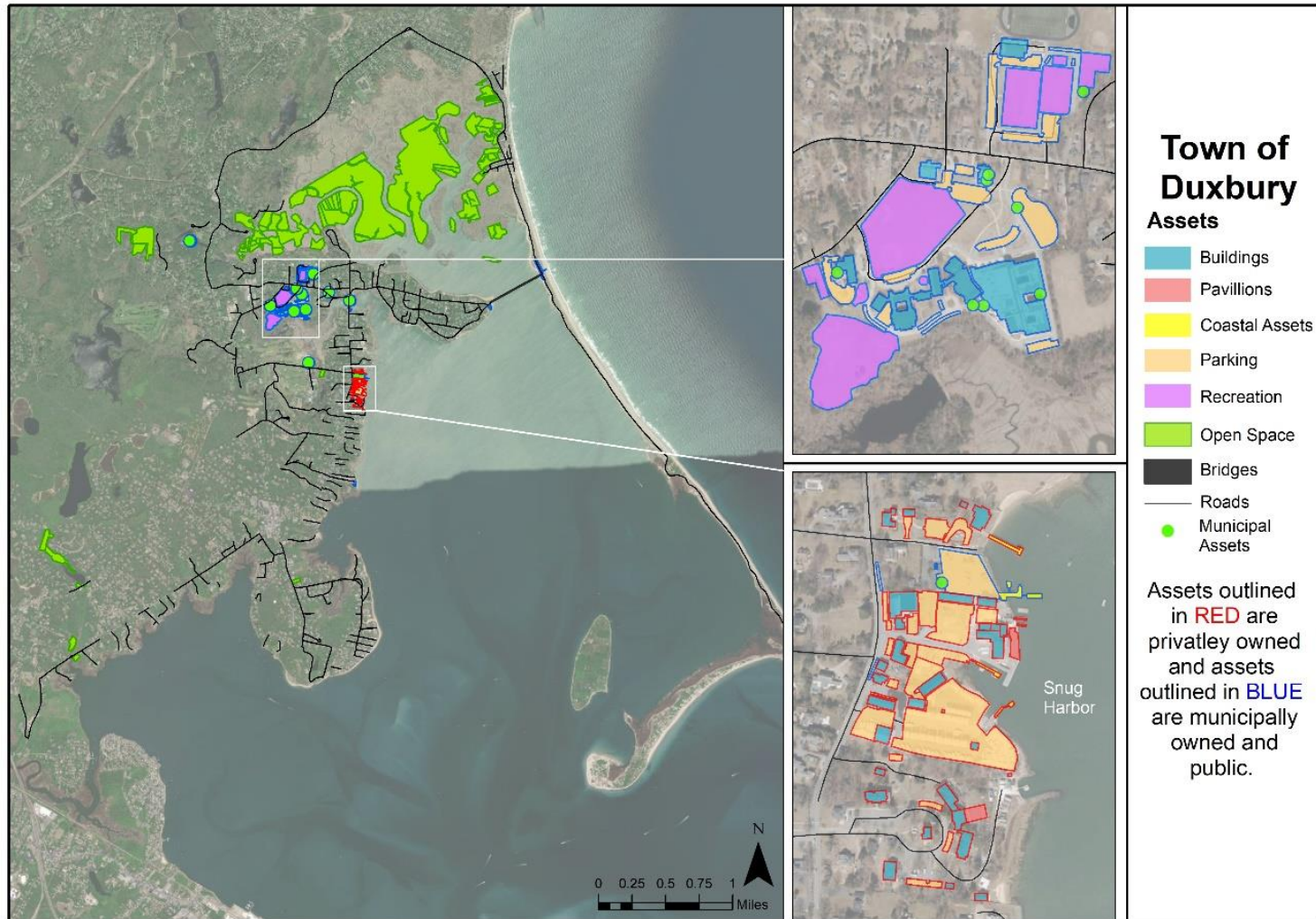
- Phase I
  - SLR / Storm Surge Projections
  - Scenario Development
  - Gather asset data
  - Determine Asset Critical Elevations
- Phase II
  - Score Asset Inundation Consequence
  - Map Inundation Probability
  - Map Natural Resource Changes
  - Vulnerability/Risk Assessment
    - Ⓢ *Risk = Probability \* Consequence*
- Phase III
  - Prioritize High Risk Assets
  - Adaptation Strategies for Priority Assets and Natural Resources





# Vulnerability Assessment and Adaptation Planning

## Phase I: Gather Asset Data



# Vulnerability Assessment and Adaptation Planning

## *Phase I: Gather Asset Data*

### ☑ Municipal Infrastructure

- Public roads (320 segments) and bridges (8)
- Municipal buildings (11)
- Municipal shared septic systems, generators, fuel tanks, and A/C units (14)
- Municipal parking lots (26)
- Municipal pier, dune walkover, and year-round floats (4)
- Municipal open space (71), playing fields/courts and playgrounds (9)

### ☑ Snug Harbor Commercial Infrastructure

- Buildings (34)
- Parking lots (20)
- Piers, year-round gangways and floats (6)
- Fuel tanks, A/C units, grease traps (3)
- pavilions (2)

# Asset Inundation Consequence Scoring

## *Municipal Assets*

Rating	Direct Impacts			Indirect Impacts		
	Service Loss Extent	Service Loss Duration	Cost of Damage	Public Safety & Emergency Services	Economic Activity	Public Health & Environment
4	Town	>30 d	>\$10M	Very High	Very High	Very High
3	Neighborhoods	15-30 d	\$1M-\$10M	High	High	High
2	Neighborhood	8-14 d	\$100K-\$1M	Moderate	Moderate	Moderate
1	Locality	1-7 d	\$10K-\$100K	Low	Low	Low
0	Property	<1 d	<\$10K	None	None	None



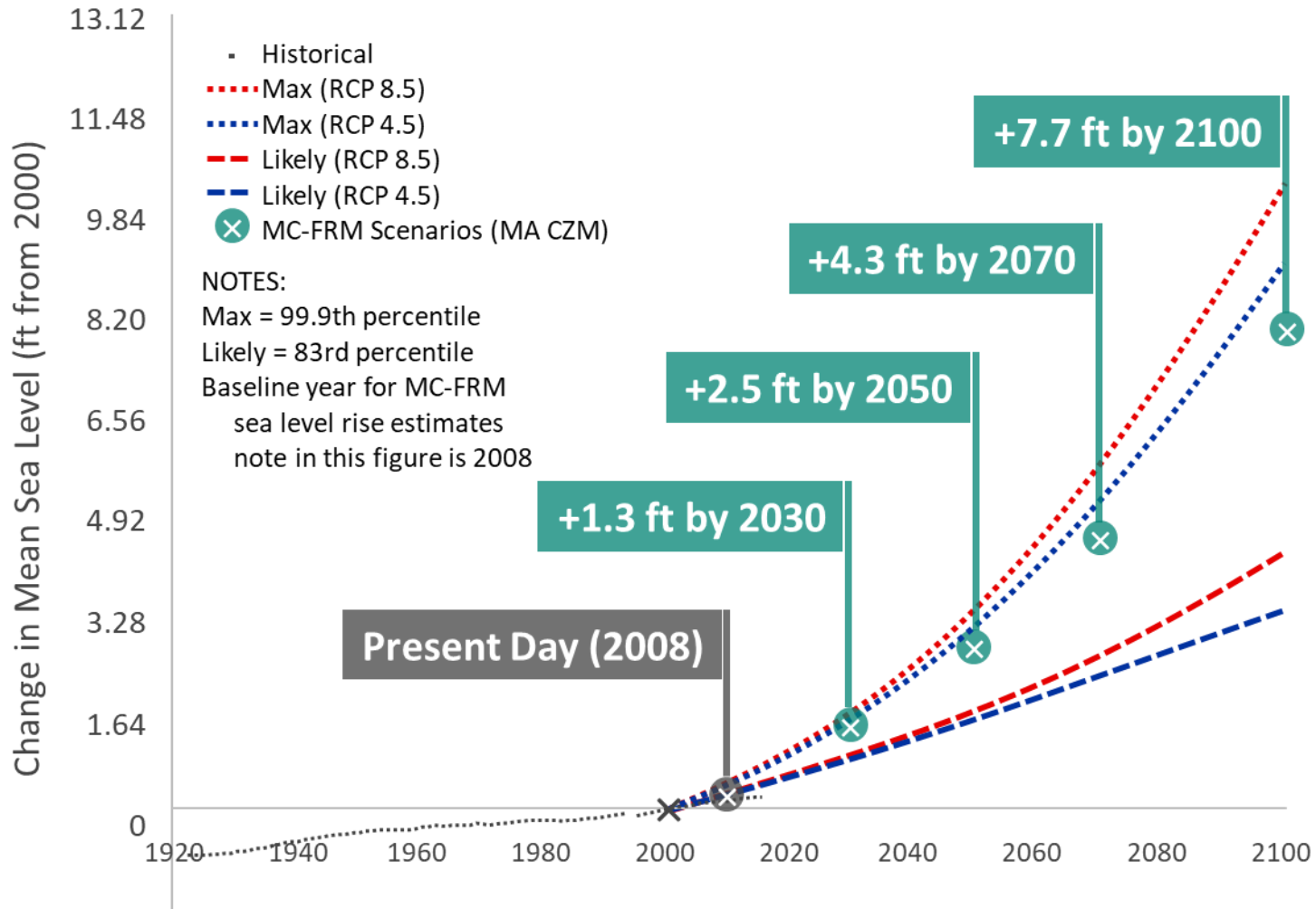
# Asset Inundation Consequence Scoring

## *Snug Harbor Private Assets*

Rating	Direct Impacts			Indirect Impacts		
	Service Loss Extent	Service Loss Duration	Cost of Damage	Economic Activity	Marketing & Outreach	Planning
4	Snug Harbor & Beyond	>30 d	>\$10M	Severe	Severe	Severe
3	Organization	15-30 d	\$1M-\$10M	High	High	High
2	Facility	8-14 d	\$150K-\$1M	Moderate	Moderate	Moderate
1	System	1-7 d	\$10K-\$150K	Low	Low	Low
0	Component	<1 d	<\$10K	None	None	None

# Sea Level Rise

## Probabilistic SLR Projections (Commonwealth of MA)





# Sea Level Rise

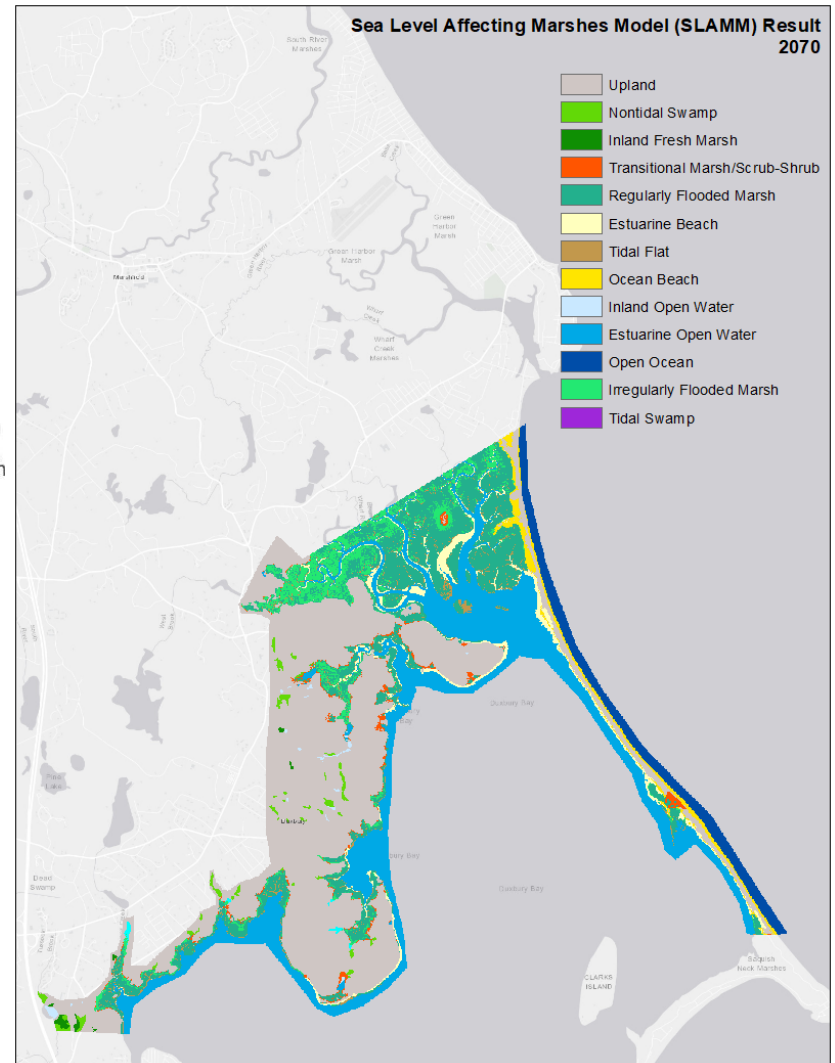
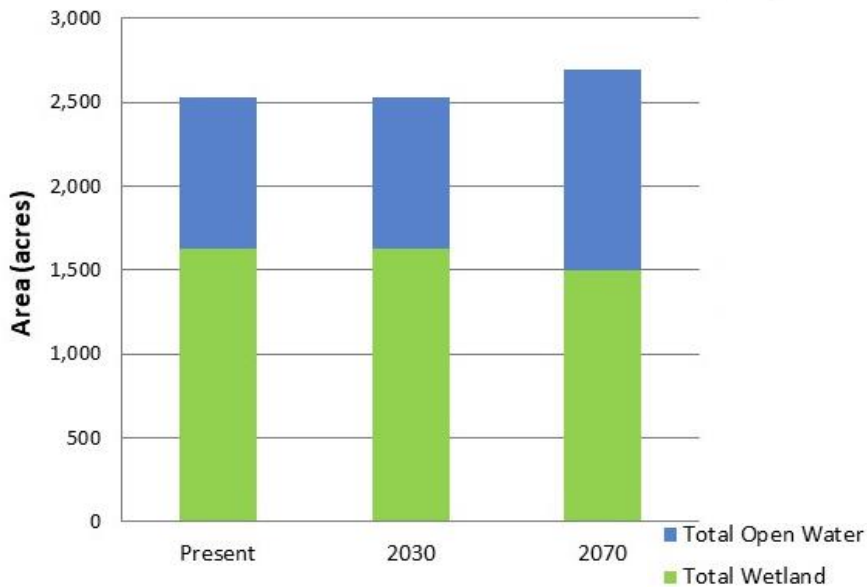
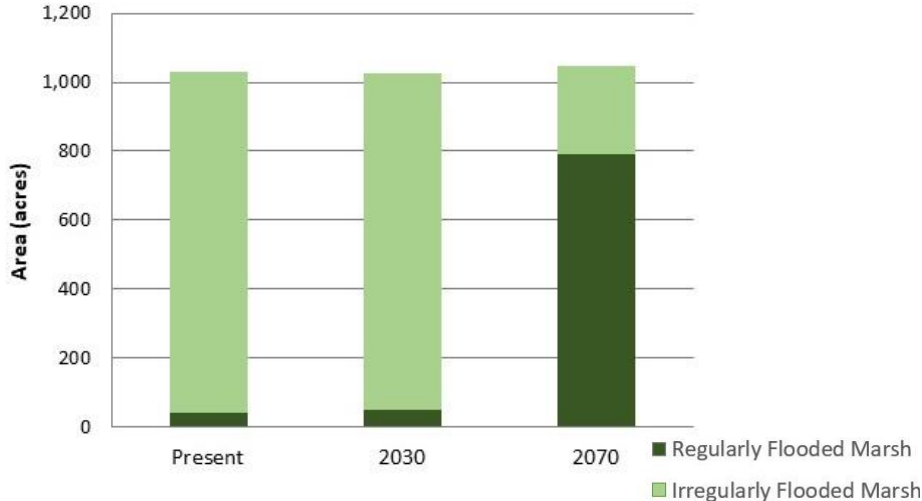
## Probabilistic MSL elevation projections (Commonwealth of MA) in feet NAVD88

Scenario	Cross-walked probabilistic projections	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83%) under RCP8.5	0.7	1.4	2.3	4.0
	<ul style="list-style-type: none"> <li>Extremely unlikely to exceed (95%) under RCP 4.5</li> <li>About as likely as not to exceed (50%) under RCP 4.5 when accounting for possible ice sheet instabilities</li> </ul>				
Intermediate-High	Extremely unlikely to exceed (95%) under RCP 8.5	0.8	1.7	2.9	5.0
	<ul style="list-style-type: none"> <li>Unlikely to exceed (83%) under RCP 4.5 when accounting for possible ice sheet instabilities</li> <li>About as likely as not to exceed (50%) under RCP 8.5 when accounting for possible ice sheet instabilities</li> </ul>				
High	Extremely unlikely to exceed (99.5%) under RCP 8.5	1.2	2.4	4.2	7.6
	<ul style="list-style-type: none"> <li>Unlikely to exceed (83%) under RCP 8.5 when accounting for possible ice sheet instabilities</li> <li>Extremely unlikely to exceed (95%) under RCP 4.5 when accounting for possible ice sheet instabilities</li> </ul>				
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9%) under RCP 8.5	1.4	3.1	5.4	10.2
	<ul style="list-style-type: none"> <li>Extremely unlikely to exceed (95%) under RCP8.5 when accounting for possible ice sheet instabilities</li> </ul>				
2008 (1999-2017 epoch) mean sea level at Boston tide gage was -0.09 feet (NAVD88)					

# Sea Level Rise and Habitat Change

*Projected conversion of ~75% of existing high marsh to low marsh*

*Projected 293 acre increase of open water (loss of wetlands and uplands)*



# Local Tidal Datum Projections

## MHHW Projections for Snug Harbor

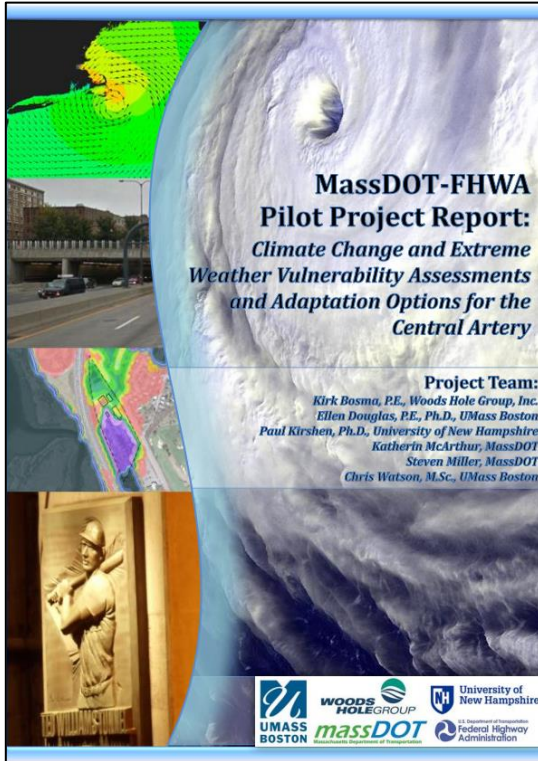
	Present	2030	2050	2070
MHW	4.8	6.1	7.4	9.3
MHHW	5.2	6.5	7.8	9.7





# SLR and Storm Surge Projections

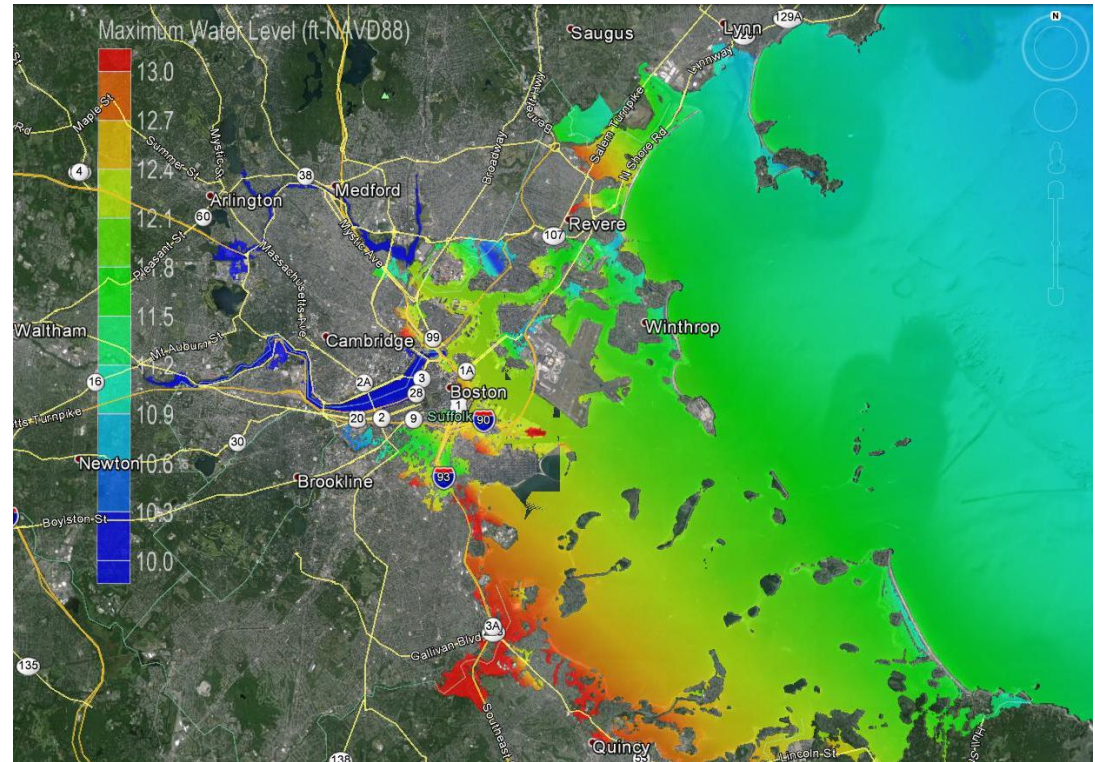
## *The case for hydrodynamic modeling*



**MassDOT-FHWA  
Pilot Project Report:  
Climate Change and Extreme  
Weather Vulnerability Assessments  
and Adaptation Options for the  
Central Artery**

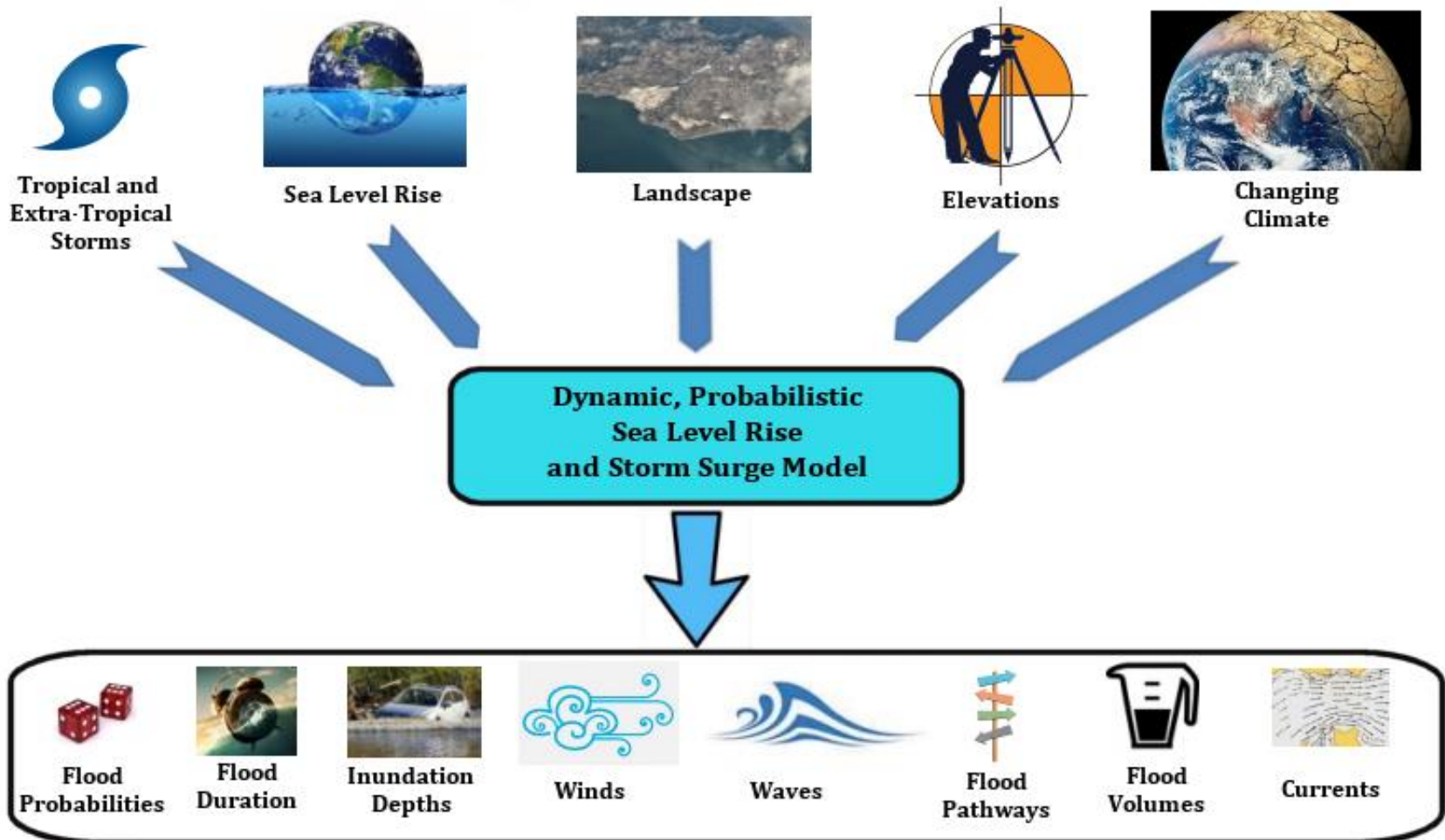
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UMASS BOSTON | WOODS HOLE GROUP | UNIVERSITY OF NEW HAMPSHIRE  
MASSDOT | U.S. DEPARTMENT OF TRANSPORTATION | FEDERAL HIGHWAY ADMINISTRATION



# SLR and Storm Surge Projections

## Massachusetts Coast Flood Risk Model (MC-FRM)



- Includes relevant physical processes (tides, storm surge, wind, waves, wave setup, river discharge, sea level rise, future climate scenarios)



# SLR and Storm Surge Projections

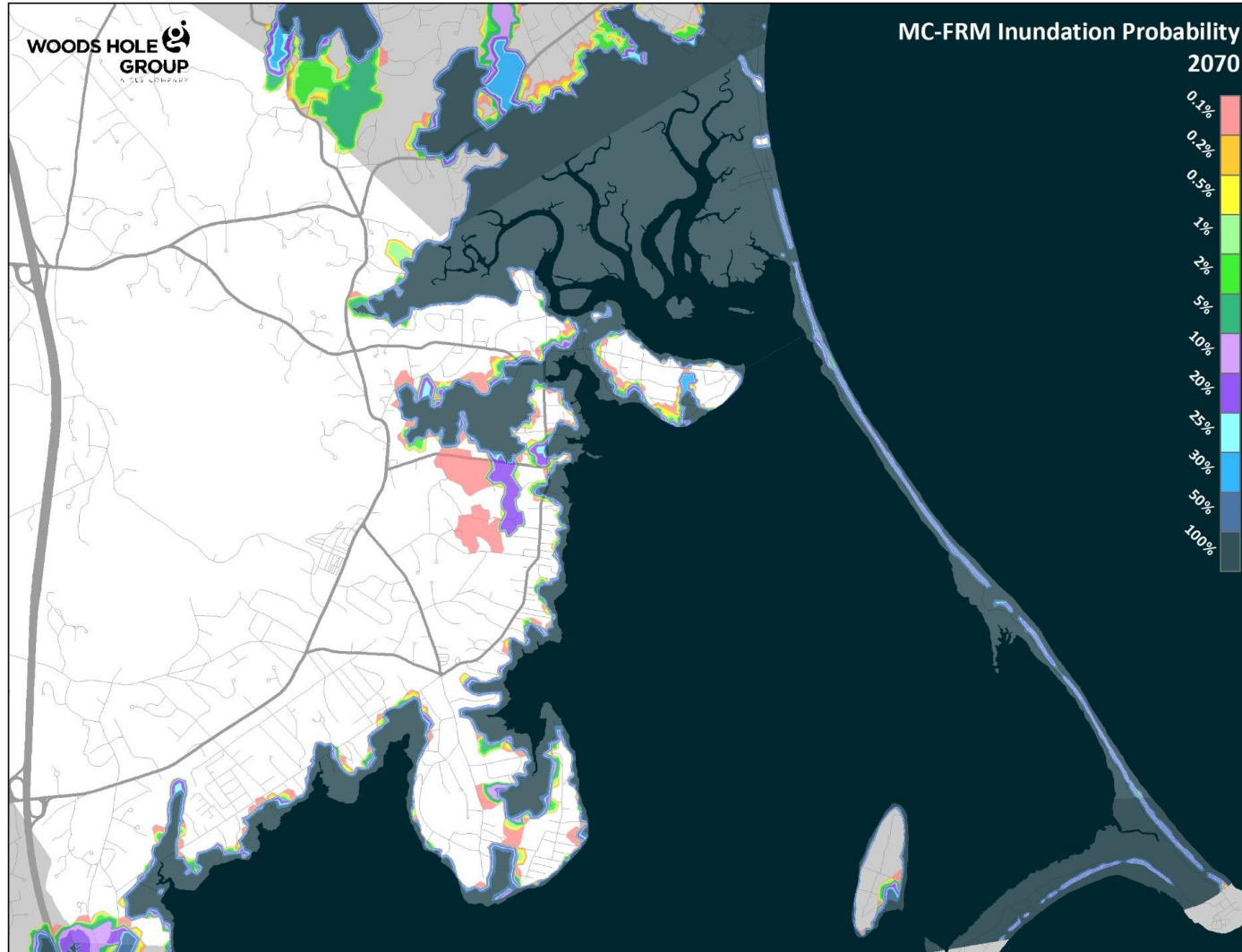
*MC-FRM Mesh in Duxbury*





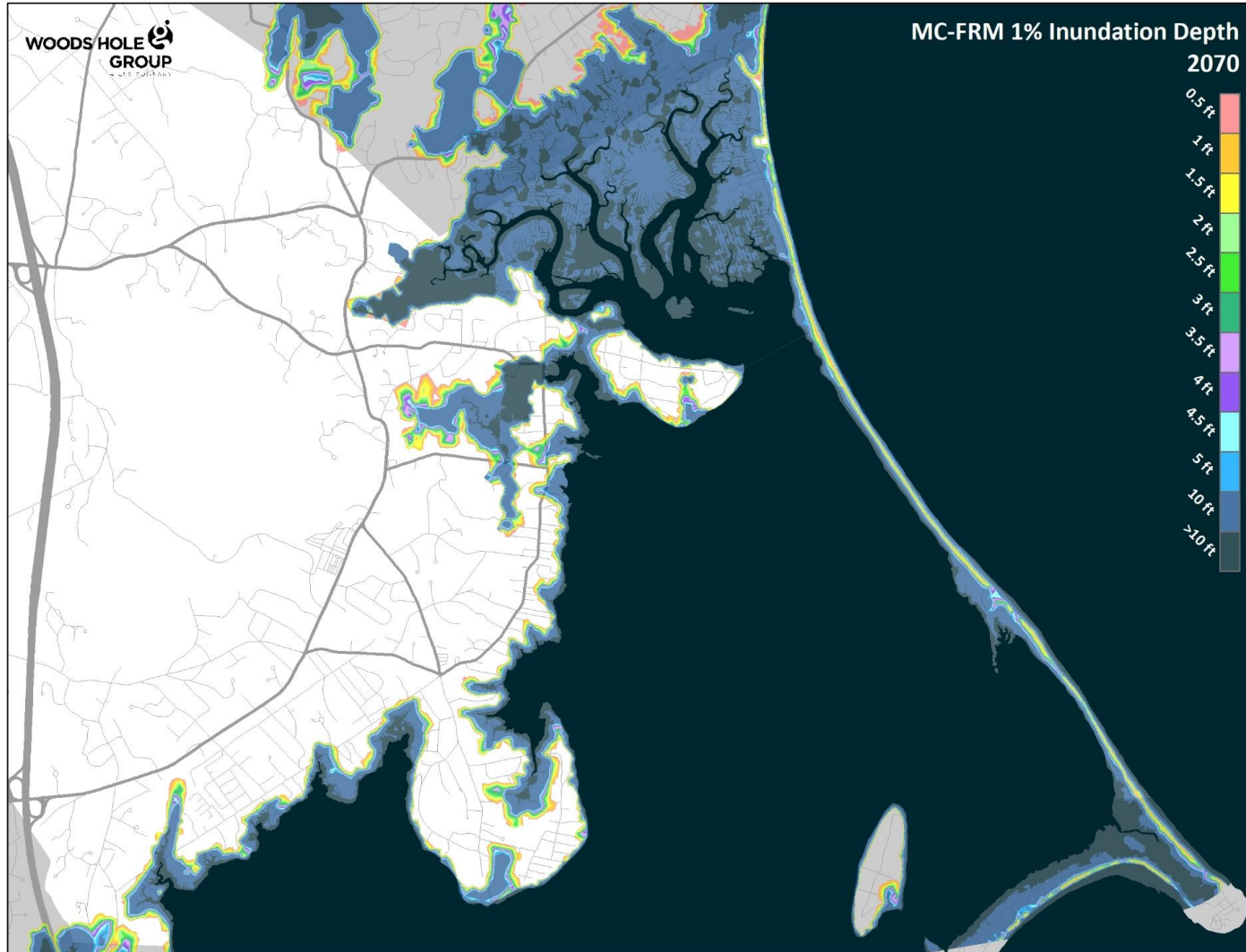
# SLR and Storm Surge Projections

*MC-FRM Results: Coastal Flood Exceedance Probability*



# SLR and Storm Surge Projections

*MC-FRM Results: Inundation Depth at 1% CFEP*



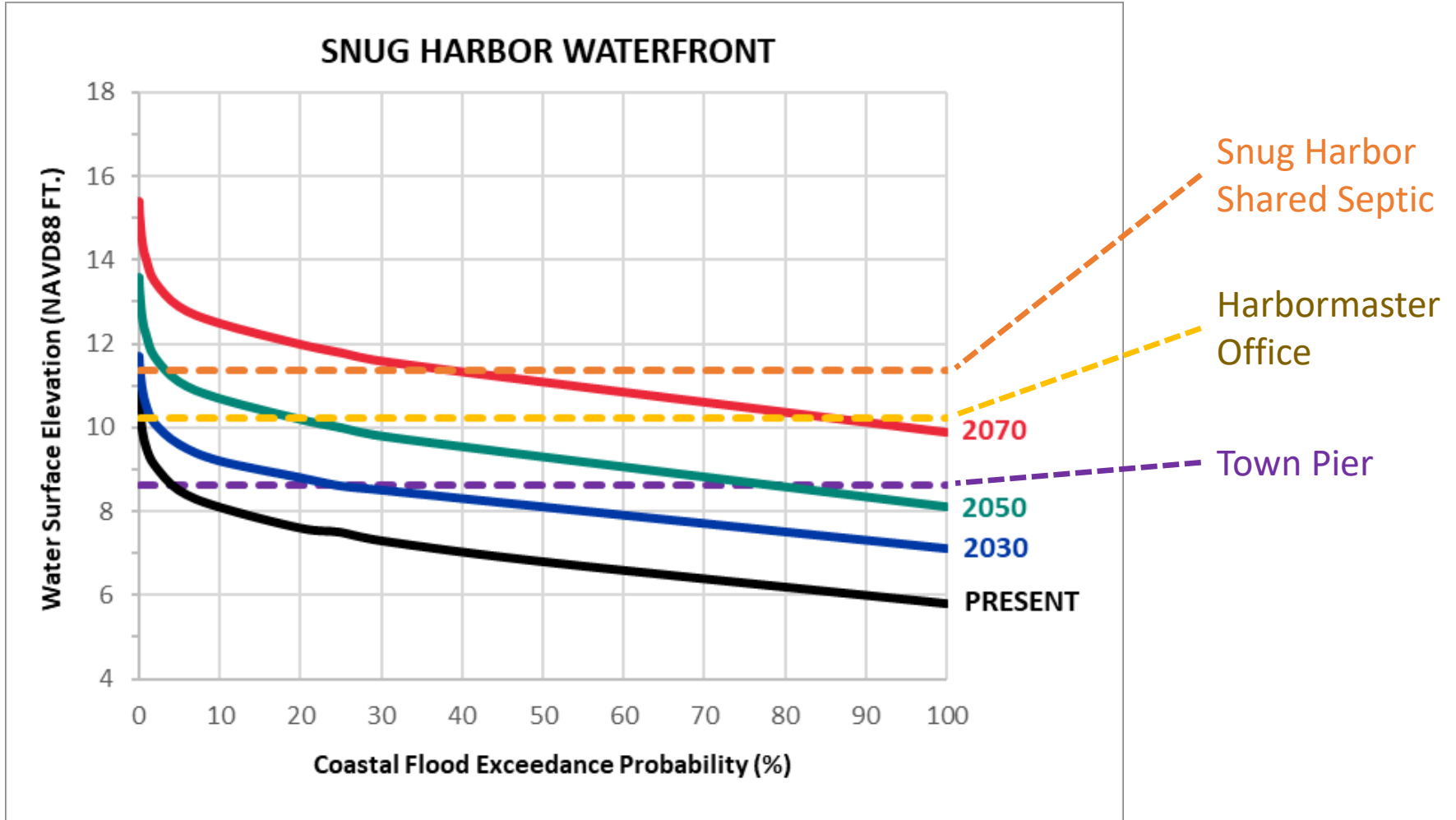
# SLR and Storm Surge Projections

## MC-FRM Town-wide Exposure Screening Profile

Potential vulnerability and exposure of structures and roadways in Duxbury	Present Day		2030		2050		2070	
	Quantity	Percent	Quantity	Percent	Quantity	Percent	Quantity	Percent
<b>Structures (Total 7341)</b>								
Nuisance Flooding (MHHW)	7	0.1%	20	0.3%	94	1.3%	274	3.7%
Storm Surge (10% Chance)	354	4.8%	526	7.2%	587	8.0%	715	9.7%
Storm Surge (1% Chance)	540	7.4%	602	8.2%	711	9.7%	807	11.0%
<b>Roadways (Total 183 miles)</b>								
Nuisance Flooding (MHHW)	0.39	0.2%	0.65	0.4%	2.73	1.5%	6.35	3.5%
Storm Surge (10% Chance)	7.31	4.0%	9.79	5.3%	11.1	6.1%	13.21	7.2%
Storm Surge (1% Chance)	10.13	5.5%	11.31	6.2%	13.3	7.3%	14.98	8.2%

# Vulnerability Assessment

## Probability of Exceeding Critical Elevation





# Vulnerability/Risk Assessment Results – Assets

## Asset Profiles – Town and Snug Harbor



### Harrison Bridge

Asset Type: Bridge

Critical Elevation (CE): 5.53 FT. NAVD88

Threshold Description:

Low chord elevation; Road surface 9.36 FT. NAVD88



Climate Vulnerability Assessment – Asset Profile

Probability of Exceedance Summary Table

Probability %	Present		2030		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.9	5.37	11.9	6.37	15.5	9.97
0.2	10.5	4.97	11.5	5.97	15.1	9.57
0.5	10	4.47	11	5.47	14.5	8.97
1	9.6	4.07	10.6	5.07	14.1	8.57
2	9.2	3.67	10.3	4.77	13.7	8.17
5	8.7	3.17	9.8	4.27	13.1	7.57
10	8.3	2.77	9.4	3.87	12.6	7.07
20	7.8	2.27	8.9	3.37	12.1	6.57
25	7.6	2.07	8.8	3.27	11.9	6.37
30	7.5	1.97	8.7	3.17	11.8	6.27
50	7	1.47	8.2	2.67	11.3	5.77
100	5.9	0.37	7.2	1.67	10.1	4.57

Consequence of Exceedance

	Direct Impacts			Indirect Impacts			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Safety & Emergency Services	Economic Activity	Public Health & Environment		
Scores	3	4	2	3	4	3	19	79

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	100	79	7900	1/35
2030	100	79	7900	1/35
2070	100	79	7900	3/35



### Joe's Building

Asset Type: Building

Critical Elevation (CE): 7.94 FT. NAVD88

Threshold Description:

Ground - from lidar

Climate Vulnerability Assessment – Asset Profile



Probability of Exceedance Summary Table

Probability %	Present		2030		2070	
	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE	Flood Elevation	Depth Over CE
	FT. NAVD88	FT.	FT. NAVD88	FT.	FT. NAVD88	FT.
0.1	10.8	2.86	11.7	3.76	15.4	7.46
0.2	10.4	2.46	11.4	3.46	15	7.06
0.5	9.9	1.96	10.9	2.96	14.4	6.46
1	9.5	1.56	10.5	2.56	14	6.06
2	9.1	1.16	10.1	2.16	13.5	5.56
5	8.5	0.56	9.6	1.66	12.9	4.96
10	8.1	0.16	9.2	1.26	12.5	4.56
20	7.6	-	8.8	0.86	12	4.06
25	7.5	-	8.6	0.66	11.8	3.86
30	7.3	-	8.5	0.56	11.6	3.66
50	6.8	-	8.1	0.16	11.1	3.16
100	5.8	-	7.1	-	9.9	1.96

Consequence of Exceedance

	Direct Impacts			Organizational Impacts			Sum	Consequence Score
	Service Loss Extent	Service Loss Duration	Cost of Damage	Economic Activity	Marketing & Outreach	Planning		
Scores	2	1	1	2	1	4	11	46

Risk of Exceedance

Time horizon	Probability of Exceedance	Consequence Score	Risk Score	Risk Rank
Present	10	46	460	1/14
2030	50	46	2300	1/14
2070	100	46	4600	2/14



# Municipal Risk Assessment Results – Assets (Top 25)

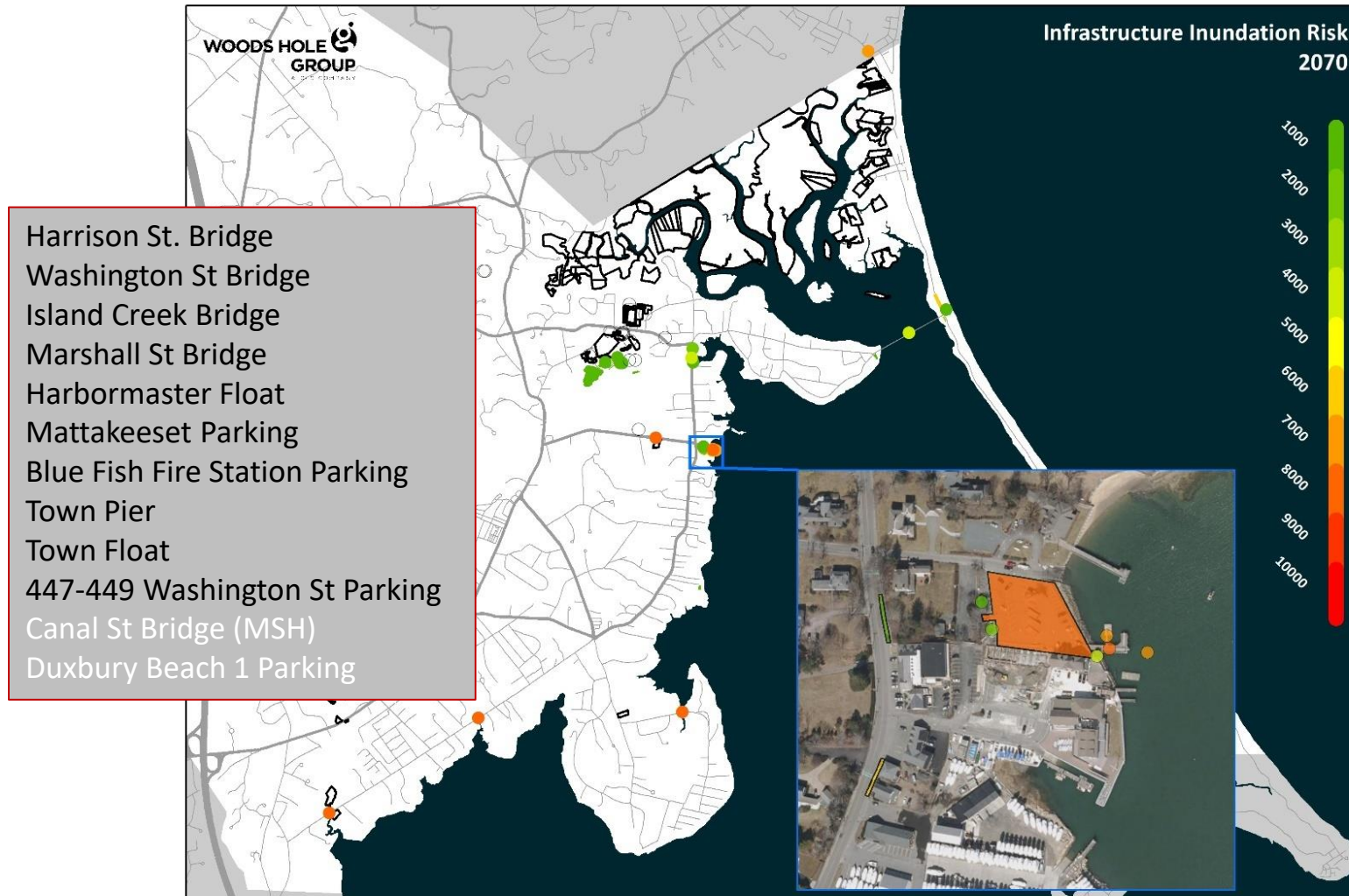
*Probability \* Consequence = Risk*

Asset Type	Asset Name	Critical Elevation (FT. NAVD88)	Consequence	Probability (%)			Risk		
				Present	2030	2070	Present	2030	2070
Bridges	Harrison St Bridge	5.53	79	100	100	100	7900	7900	7900
Bridges	Washington St Bridge	7.48	79	30	50	100	2370	3950	7900
Bridges	Island Creek Bridge	7.01	75	30	50	100	2250	3750	7500
Bridges	Marshall St Bridge	6.83	71	30	100	100	2130	7100	7100
Coastal	Harbormaster Float	6.88	67	30	100	100	2000	6667	6667
Parking	Mattakeeset	8.02	79	10	50	100	792	3958	7917
Parking	Blue Fish Fire Station	8.53	33	5	30	100	167	1000	3333
Coastal	Town Pier	8.62	79	2	25	100	158	1979	7917
Coastal	Town Float	8.62	67	2	25	100	133	1667	6667
Parking	447-449 Washington Street	8.54	54	2	25	100	108	1354	5417
Bridges	Canal St Bridge (MSH)	9.84	67	1	2	100	67	134	6700
Parking	Duxbury Beach 1	9.70	58	0.5	5	100	29	292	5833
Buildings	Harbormaster Office	10.21	71	0.2	1	50	14	71	3550
Assets	Blue Fish Shared Septic Pump	10.34	38	0.2	1	50	8	37	1875
Bridges	Powder Point Bridge	11.14	79	0	0.2	50	0	16	3950
Bridges	Beach St Bridge (MSH)	9.76	67	0	1	50	0	67	3350
Parking	Duxbury Beach 2	10.82	50	0	0.5	50	0	25	2500
Assets	Snug Harbor Shared Septic Pump	11.37	50	0	0.2	30	0	10	1500
Buildings	Blue Fish River Fire Station	11.78	33	0	0.1	30	0	3	990
Parking	Alden Elementary School 2	11.01	17	0	0.2	50	0	3	833
Parking	Duxbury Middle/High School 1	11.58	17	0	0.1	30	0	2	500
Parking	Alden Elementary School 3	11.92	17	0	0	20	0	0	333
Parking	479 Washington Street	12.67	54	0	0	5	0	0	271
Coastal	Duxbury Beach Walkover	12.88	50	0	0	2	0	0	100
Buildings	Alden Elementary School	14.03	75	0	0	1	0	0	75



# Vulnerability/Risk Assessment Results – Town Assets

*Probability \* Consequence = Risk*



# High Risk Town Assets at Mattakeeset

*2018 Winter Storm Riley*

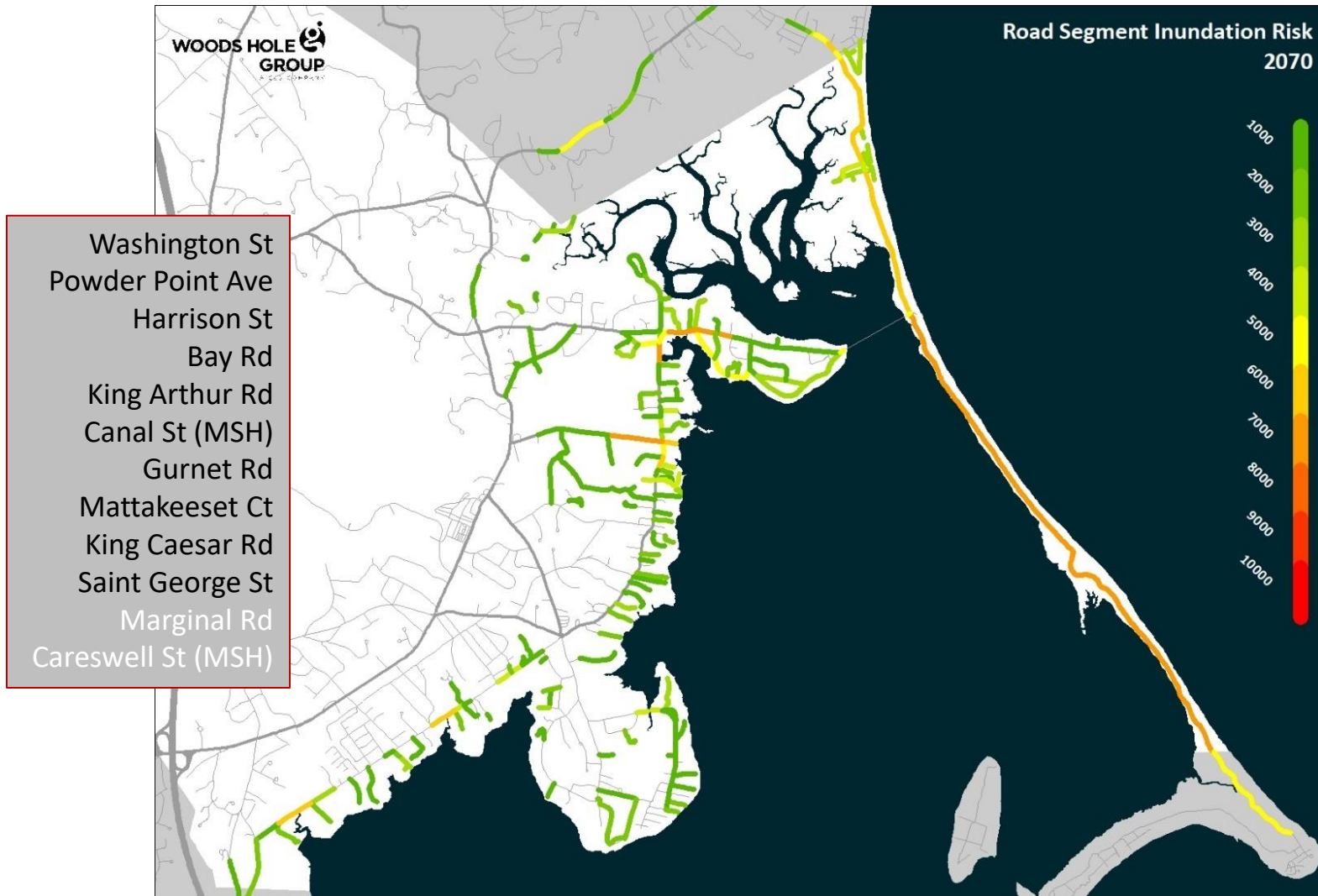


*Source: MAPC Snug Harbor Report*



# Vulnerability/Risk Assessment Results – Roads

*Probability \* Consequence = Risk*





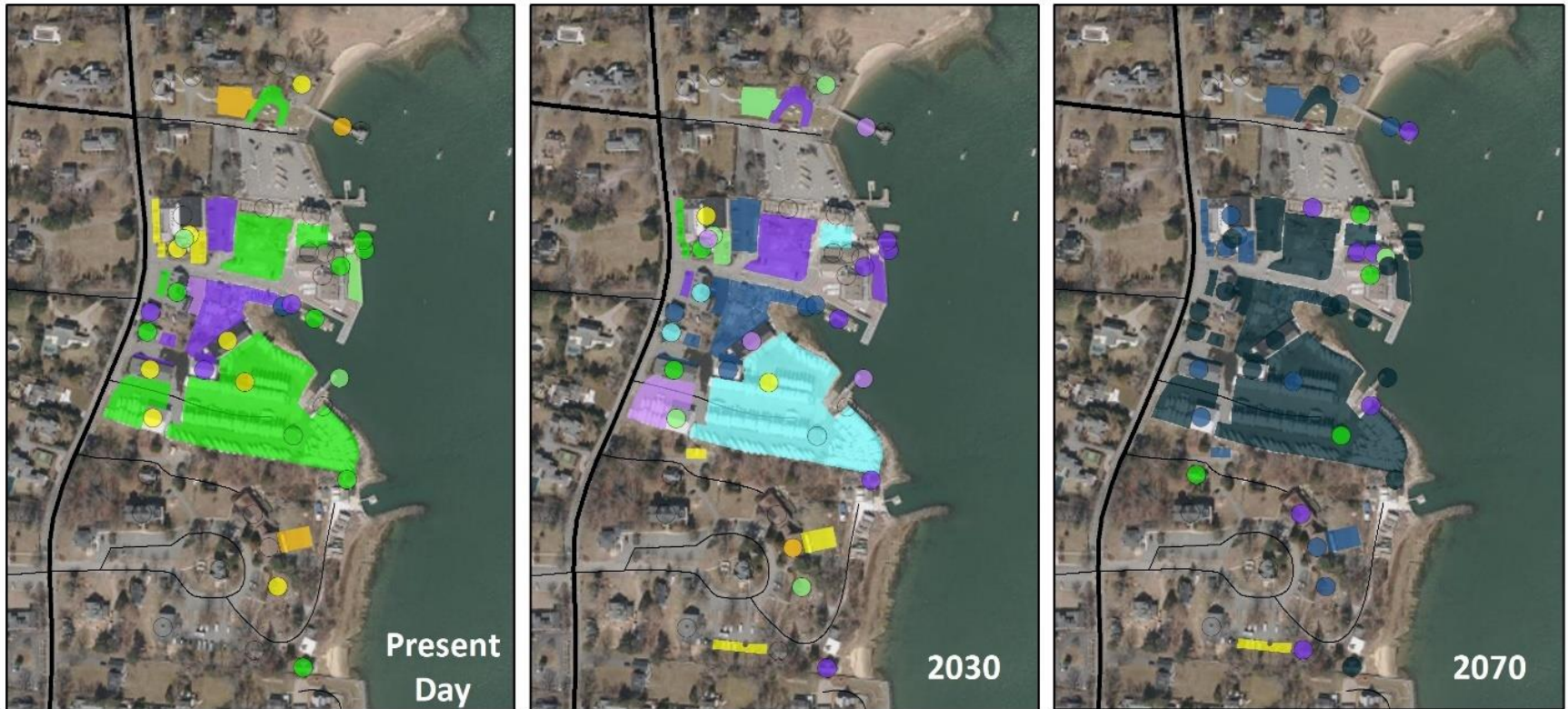
# High Risk Town Roads

*February 24, 2021 High Tide (10'0" at 08:51)  
Later that month, high tide was 1'8" higher*

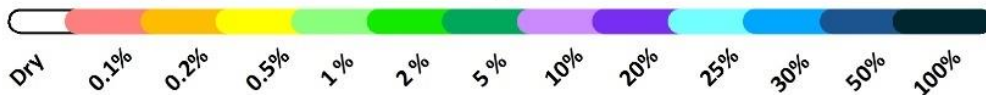


# Snug Harbor Vulnerability Assessment

## Probability of Inundation



Probability of Inundation- Snug Harbor



# Snug Harbor Risk Assessment

*Probability \* Consequence = Risk*

## Vulnerability

Rank	Asset Name	Owner
1	Gas Shed Building	DBMS
2	Guzzle Gangway	DBMS
3	Mattakeeset Parking Lot	Sweetsers
4	Joe's Building	Bayside
5	Bayside Marine 1 Parking Lot	Bayside
6	Talbots Rear Parking Lot	Bayside
7	Bayside Alley Parking Lot	Bayside
8	Duxbury Bay Maritime School 3 Parking Lot	DBMS
9	Pumphouse Building	ICO
10	Talbots Building	Bayside
11	Boathouse Building	ICO
12	Smith Building- Fire Sprinkler Room	DBMS
13	Guzzle Float	DBMS
14	Bayside Marine 3 Parking Lot	Bayside
15	Duxbury Yacht Club 3	DYC

## Risk

### Bayside

1. Joe's Building
2. Bayside Marine 1 Parking
3. Talbots Rear Parking
4. Bayside Alley Parking
5. Talbots Building

### DBMS

1. DBMS Gas Shed
2. Guzzle Gangway
3. DBMS 3 Parking
4. Smith Building-Fire Sprinkler Room
5. Guzzle Float

### DYC

1. Duxbury Yacht Club 3 Parking
2. Yacht Club Clubhouse
3. Yacht Club Pier
4. Duxbury Yacht Club 1 Parking
5. Yacht Club Pier Hut

### Island Creek

1. Pumphouse
2. Boathouse
3. Hatchery
4. ICO Patio
5. Admin Building

### Sweetser's

1. Mattakeeset Parking
2. Chiller AC Units and Crawl Space
3. Annex Building
4. Washington Parking
5. Annex Parking





# Vulnerability Assessment and Adaptation Planning

## Phase III: Develop Adaptation Strategies and Public Outreach

- Protection of natural resources
  - Opportunities for restoration and building ecosystem resilience
- Recommendations for changes to local policies and regulation to reduce vulnerability and enhance resilience
- Recommendations for adaption strategies
  - Asset/Site-specific with order-of-magnitude cost estimates
  - Possible regional solutions (conceptual level designs)



### Avoid

Identify future 'no-build areas' and use planning tools to prevent new development in areas at risk now or in future



### Protect

Use hard structures (eg sea walls) or soft solutions (eg dunes and vegetation) to protect land from the sea. May be prohibitively expensive, especially in the long term



### Accommodate

Continue to use the land but accommodate changes by building on piles, converting agriculture to fish farming or growing flood- or salt-tolerant crops



### Retreat

Withdraw, relocate or abandon assets that are at risk; ecosystems are allowed to retreat landward as sea levels rise

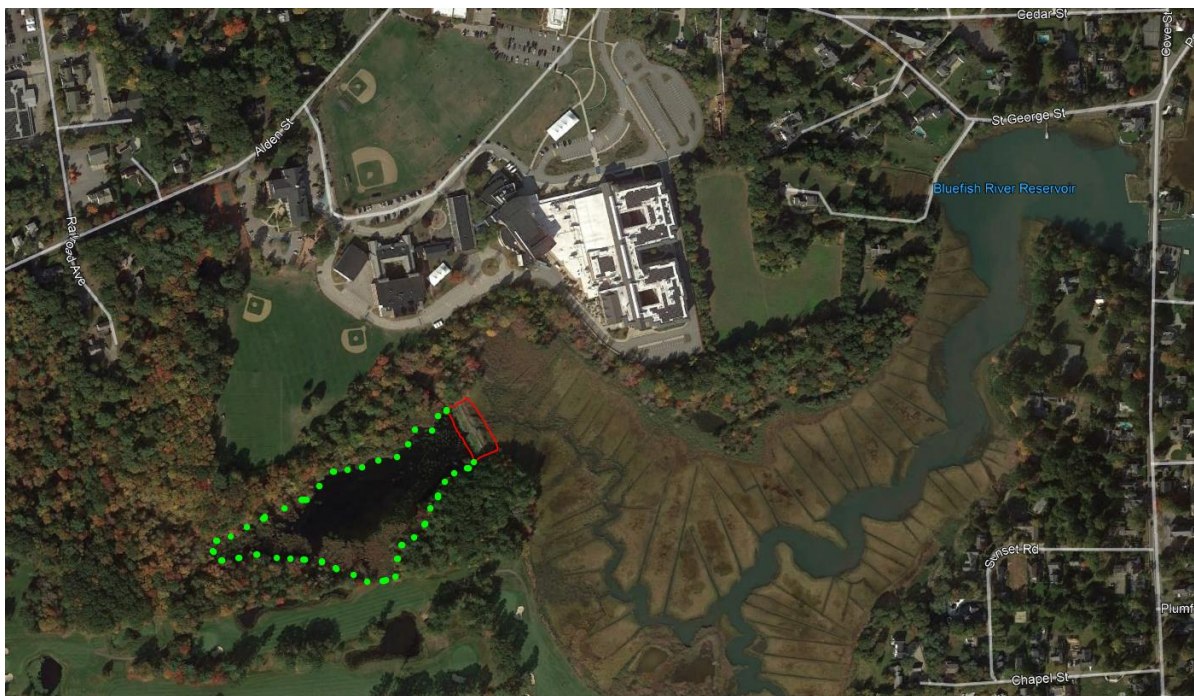


Source: NCCCARF, 2019

# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Natural Resources*

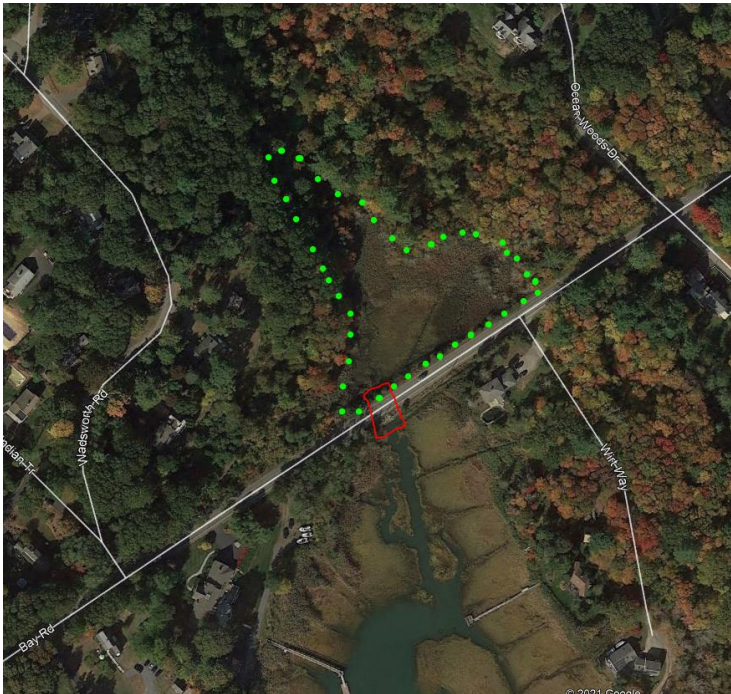
- Plan for **salt marsh migration** where possible
  - Bluefish River dam removal
  - Private land: Landing Road vicinity, Goose Point / Allens Pond area, Eagles Nest Point, Snug Harbor, Long Point Marine, Southern lobe of Powder Point neighborhood



# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Natural Resources*

- Address **tidal restrictions** at undersized culverts
  - Bay Road culvert near Wirt Way





# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Natural Resources

- Support **Duxbury Beach Reservation** ongoing resiliency efforts
  - FEMA (2007) declared Duxbury Beach ineligible for post-disaster restoration funding because it was deemed a “recreational resource” rather than a “shoreline protection resource”
  - MAPC (2018) recommends “collaborate with and provide financial support to the Duxbury Beach Reservation”

**Coastal Processes Study and Resiliency Recommendations for Duxbury Beach and Bay**

Duxbury Bay

Prepared by:  
Woods Hole Group, Inc.  
81 Technology Park Drive  
East Falmouth, MA 02536

Prepared for:  
The Duxbury Beach Reservation, Inc.  
Duxbury, MA 02332  
And  
The Town of Duxbury  
878 Tremont Street  
Duxbury, MA 02332

December 2017

WOODS HOLE GROUP

DUXBURY BEACH RESERVATION, INC.

Seal of the Commonwealth of Massachusetts

Duxbury Beach Reservation, Inc. is a 501(c)(3) non-profit organization

DUXBURY BEACH RESERVATION, INC.

### High Pines Dune Restoration

**Project Overview**

As landowners of Duxbury Beach, the Duxbury Beach Reservation, Inc. has implemented numerous restoration projects ranging from cobble berm creation to dune re-nourishment. This successful history has been reliant on undertaking projects both in response to storm impacts and proactively in vulnerable areas. High Pines, best known as the forested area midway down Duxbury Beach, is a critical geologic anchor point for the barrier beach. It connects the ribbons of sand to the north and south, forming a continuous barrier. The dunes on the Atlantic facing side of High Pines are experiencing ongoing erosion and must be actively maintained to ensure stability of this key anchor point. This work will strengthen the barrier beach and allow it to continue to protect the resources and communities behind it, particularly in the face of sea level rise and increased storm impacts.

**Project Benefits**

- **Maintain & Enhance** the High Pines anchor point by restoring the dune toe
- **Reinforce** the dune by planting beach grass and woody shrubs
- **Strengthen** the barrier beach by adding sand to the system
- **Shield** unique forested habitat for native wildlife and plants from flooding and storm impacts
- **Protect** the barrier beach in front of the High Pines salt marsh

**Project Costs**

Permitting and Construction Oversight	\$10,000
Finalize Survey and Plans	\$12,000
Equipment Mobilization & Demobilization	\$5,000
Sand Import	\$420,000*
Remove/Reset Fencing	\$8,400
Planting of Beach Grass and Shrubs	\$10,000
<b>Estimated Total Project Cost</b>	<b>\$465,400</b>

\*based on \$21.80 per ton delivered and installed

The Duxbury Beach back road is sheltered behind High Pines—here we see the back road today and the path that was traveled a century and more ago.

**Project Specs**

- 870 linear feet
- Elevation 16.5k NAVD88
- >15,000 culms American Beach Grass
- Exact sand volume to be determined through updated survey

Duxbury Beach has an extensive history. One hundred years ago the beach was purchased by a group of families to protect it from development. Four thousand years ago the barrier beach as we know it began to form. But to find the true beginning of Duxbury Beach we must look back 20,000 years.

This was the final stage of the last Ice Age. Known as the Wisconsin glaciation. As the glacier retreated north it left behind the three headlands that anchor Duxbury Beach, including High Pines.

Today High Pines is covered in trees and wind-blown sand dunes. However, the underlying layers are glacial till deposited 20,000 years ago. About 4,000 years ago, large deposits of glacial sediment began moving landward and sand spits protruded from the three headlands, eventually joining to form Duxbury Beach.

The beach has continued to change and migrate landward, but High Pines remains an important anchor point for the barrier beach.

**Restoration Steps**

- 1) Survey the project area
- 2) Design dune to regulations and to increase coastal resilience
- 3) Permit construction through appropriate agencies
- 4) Import & Grade compatible material
- 5) Install sand fencing and permanent symbolic fencing
- 6) Plant beach grass and woody shrubs
- 7) Monitor changes to the dune, vegetation, and sediment color

**Design Cross Section**

In order to maintain and enhance the High Pines dunes, the Woods Hole Group, an environmental engineering firm, recommended placing sand on the east side of the dune. This will widen the dune and enable it to better withstand future erosion and storm impacts.

(Figure created by Woods Hole Group)

A Look Back

# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Zoning Recommendations*

- Town of Duxbury Zoning Bylaws (amended through March ATM 2019\*)
  - Reference **future flood hazards** and require consideration in the design and approval of development proposals
  - Update and modify the **Flood Hazard Areas Overlay District** to account for future coastal flood risk and promote resiliency in future floodplain development
  - Update and modify the **Wetlands Protection Overlay District** to account for long-term sea level rise and promote ecological adaptation and resiliency

*\* Note that Town recently amended at 2021 ATM, generally consistent with Massachusetts 2020 Model Floodplain Bylaw. Generally, the above recommendations still apply. Report includes redline for both.*

# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Subdivision Recommendations*

- Town of Duxbury Planning Board Rules and Regulations Governing the Subdivision of Land (March 2005)
  - Reference **future flood hazards** in the text of the Rules and Regulations and require consideration in the design and approval of subdivision proposals
  - Require applicant to **supply information to assist Town staff and board members in their review** of subdivision proposals for **compliance with flood resistant design standards** of the State Building Code and proposed requirements of the FHAOD
  - Modify **drainage culvert and outfall design standards to prevent backflow** and ensure safe performance under future tidal and coastal storm flooding conditions
  - Modify references to **tidal wetland and vegetation protection buffer areas** to include areas of **potential wetland transition** or migration accounting for estimated long-term sea level rise.

# Vulnerability Assessment and Adaptation Planning

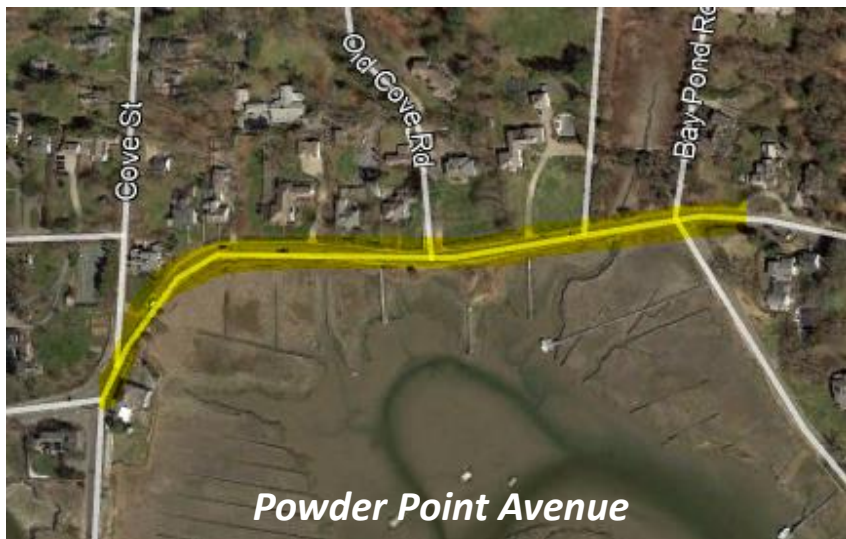
## *Adaptation Strategies – Wetlands Protection Bylaw Recommendations*

- Town of Duxbury Conservation Commission Wetlands Protection Bylaw, Chapter 9, Wetlands Regulations (adopted February 28, 2017)
  - Include **coastal resiliency as a wetland value** for Coastal Beach, Coastal Dune, Salt Marsh, and Land Subject to Coastal Storm Flowage
  - Modify definitions for Land Subject to Coastal Storm Flowage to distinguish **Coastal A Zones**.
  - Add **performance standards** to Vegetated Wetlands, Salt Marsh, and Land Subject Coastal Storm Flowage to consider the impacts of climate change on projects.
  - Create a subsection of Buffer Zone called **Special Transitional Areas** that calls for additional considerations to allow resource area migration



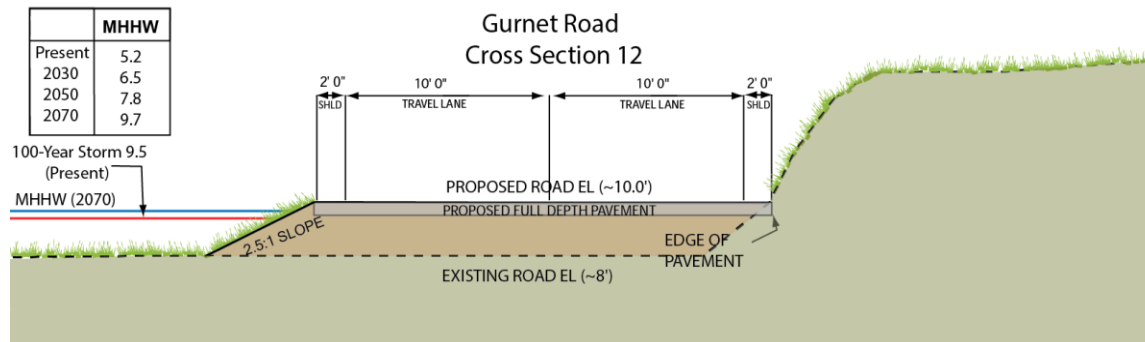
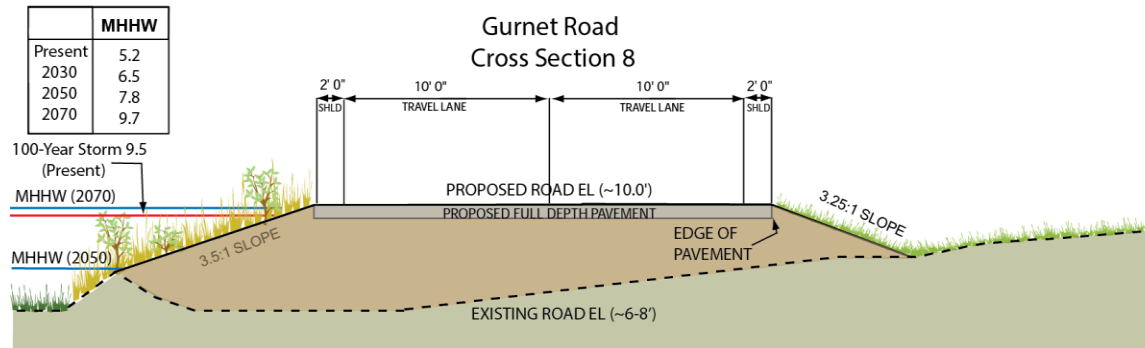
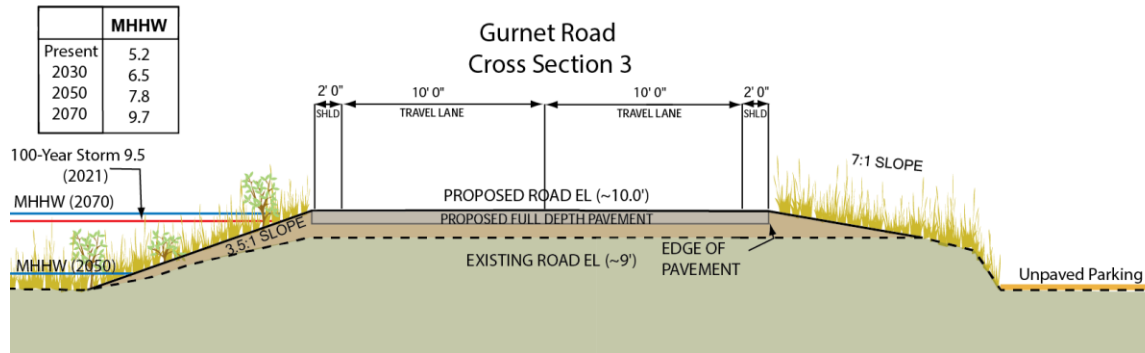
# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Duxbury Priority Assets



# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Gurnet Road



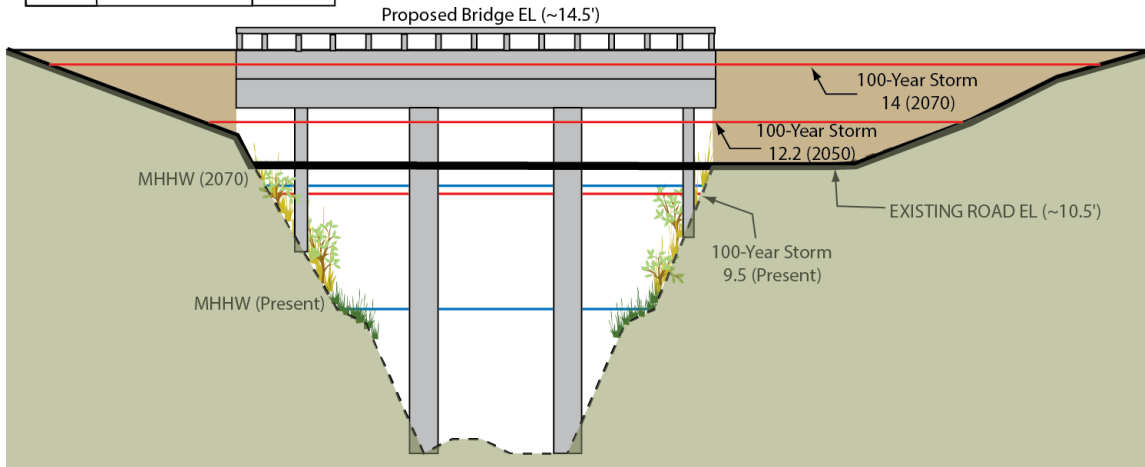
- 6,240 ft span
- Elevate to 10' NAVD88
  - Daily access
  - Reduced storm impacts
- Green infrastructure side slope treatments
- Preliminary opinion of probable cost:
  - ~\$1.2M

# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Marshall Street Bridge

	100 Year Storm	MHHW
Present	9.5	5.2
2030	10.5	6.5
2050	12.2	7.8
2070	14	9.7

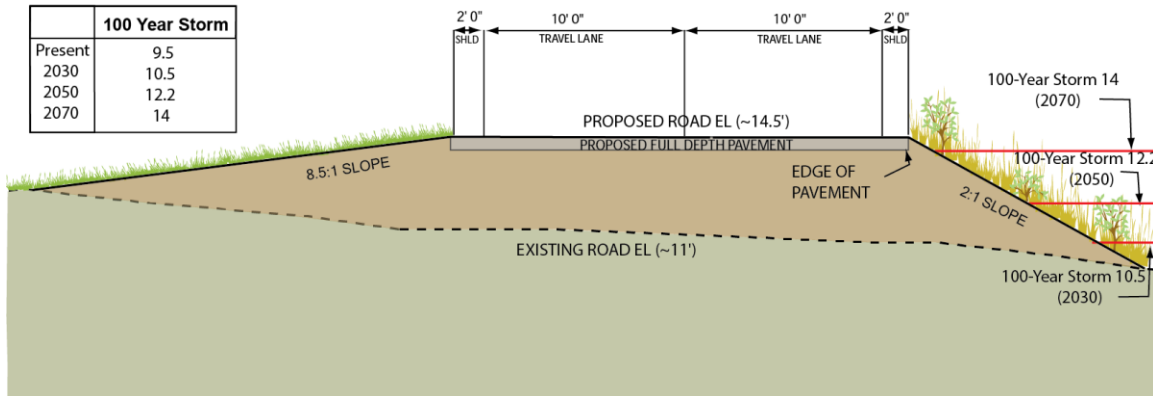
Marshal Street Bridge Profile



- Elevate bridge low chord > 10' NAVD88
  - Reduced storm impacts
- Green infrastructure side slope treatments on approaches
- Preliminary opinion of probable cost:
  - ~\$4.5M to ~\$8.7M

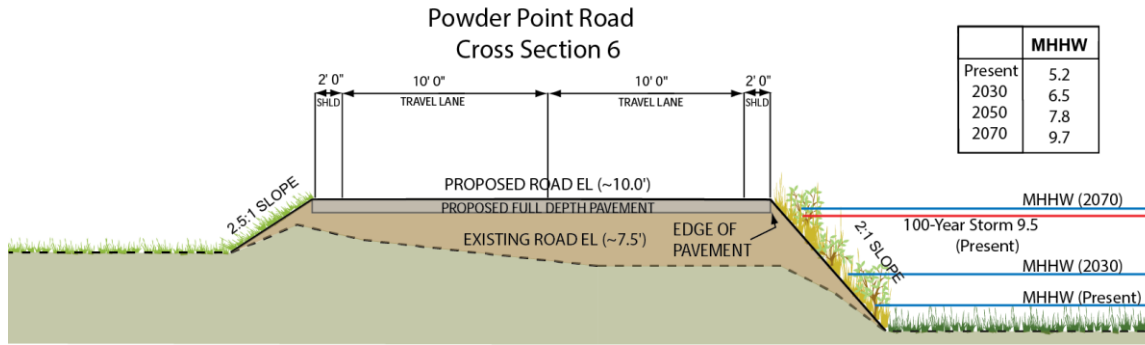
Marshal Street Bridge Cross Section 1

	100 Year Storm
Present	9.5
2030	10.5
2050	12.2
2070	14



# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Powder Point Avenue



- 1,660 ft span
- Elevate to 10' NAVD88
  - Daily access
  - Reduced storm impacts
- Green infrastructure side slope treatments
- Culvert replacement near Bay Pond Rd
- Preliminary opinion of probable cost:
  - ~\$1.0M



# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Snug Harbor Resilient Design Flood Elevations*

- Design Flood Elevation (DFE) is the anticipated flood elevation to which an asset should be designed in order to protect the asset from inundation
- Includes stillwater elevation and waves, but not freeboard
- Flexible values can be used if target DFEs are unreasonable to meet given surrounding infrastructure and conditions
- RMA/EEA developing DFE maps statewide using a statistical approach, so results may differ

Scenario	Stillwater Elevation (ft. NAVD88)	Approximate Wave Height (ft.)	Design Flood Elevation (ft. NAVD88) (no freeboard)
2070 1% (Target)	14.0	5.1	16.8
2050 1% (Flexible)	12.2	4.9	14.9

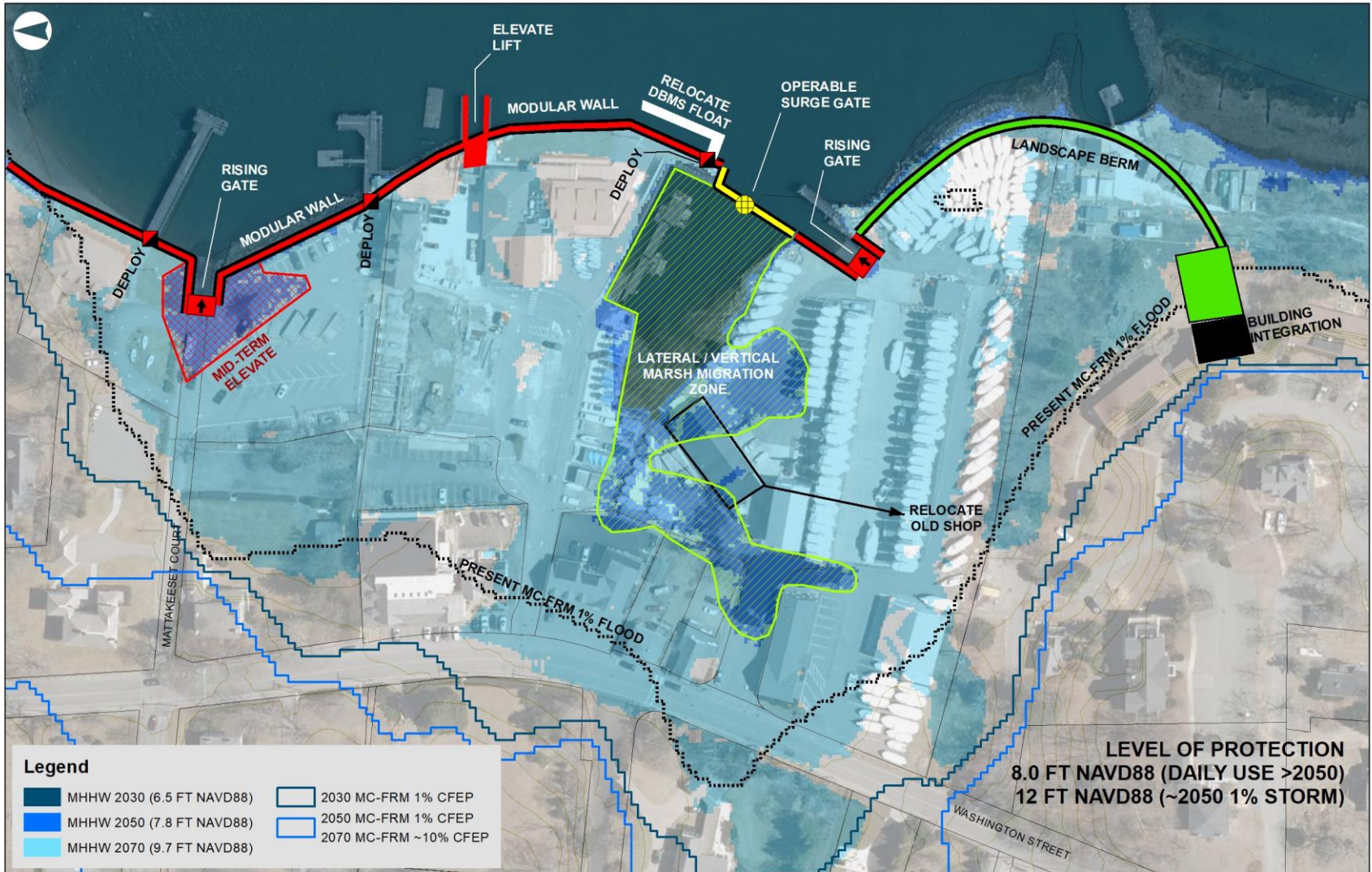
# Vulnerability Assessment and Adaptation Planning

## *Adaptation Strategies – Snug Harbor Asset Recommendations*

- Organization-specific property/asset-level recommendations sent for review
- Assumes no district-wide effort, or at least the need for intermediate adaptation while a district-level solution is pursued
- Generally, strategies include:
  - Building floodproofing such as deployable barriers
  - Raising mechanical equipment, seal or install waterproof systems
  - Raising buildings or interior floors
  - Site grading or modular walls
  - Building relocation
  - For unprotected assets that may flood, be sure to store materials higher than projected surge to reduce possibility of damage and/or release to environment
  - Pull back development to allow marsh migration vs. fill in low-lying operational areas
  - Coastal Flood Operations Plan

# Vulnerability Assessment and Adaptation Planning

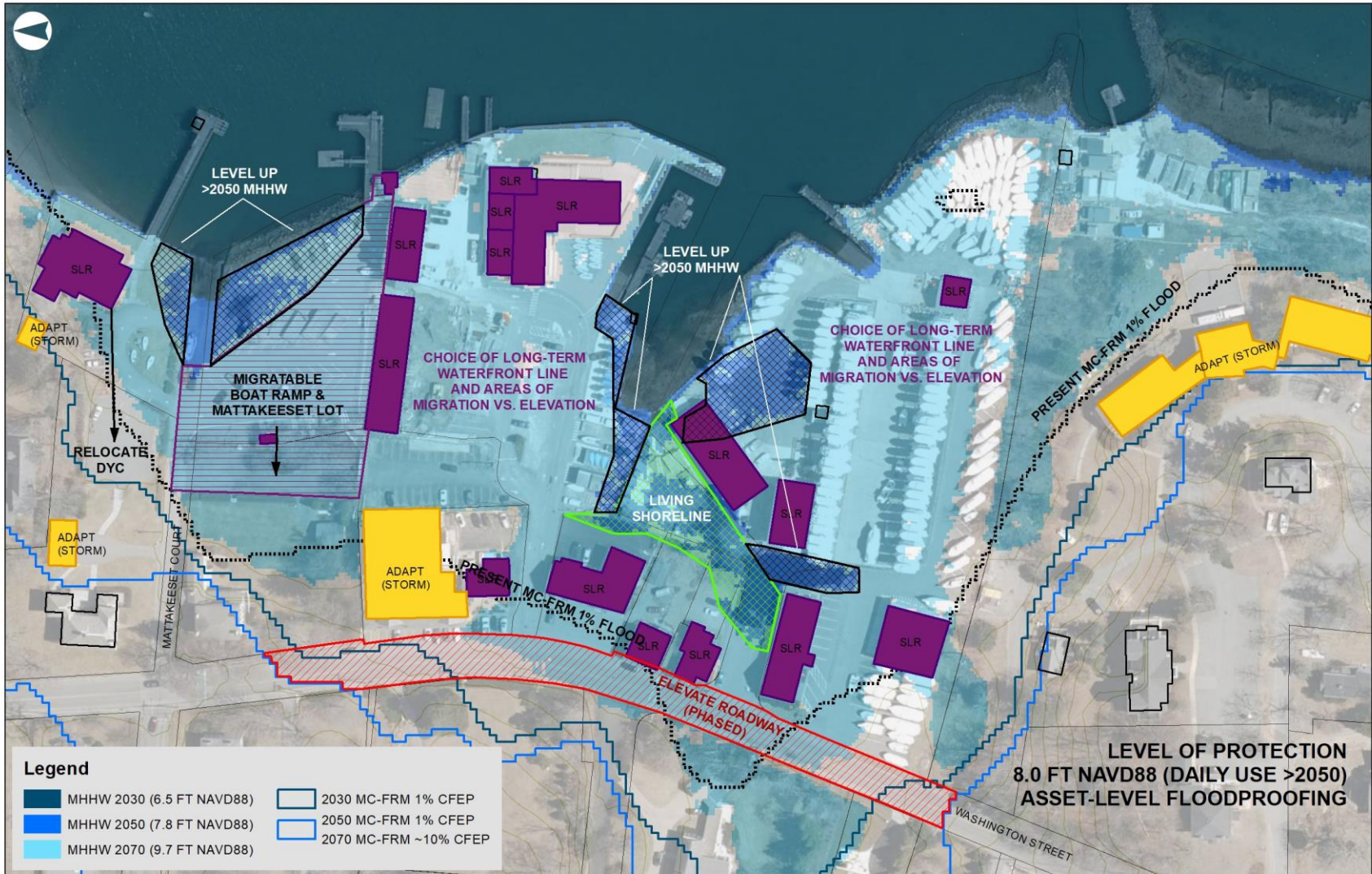
## Adaptation Strategies – Snug Harbor: Protect the Edge and Curate Marsh Migration





# Vulnerability Assessment and Adaptation Planning

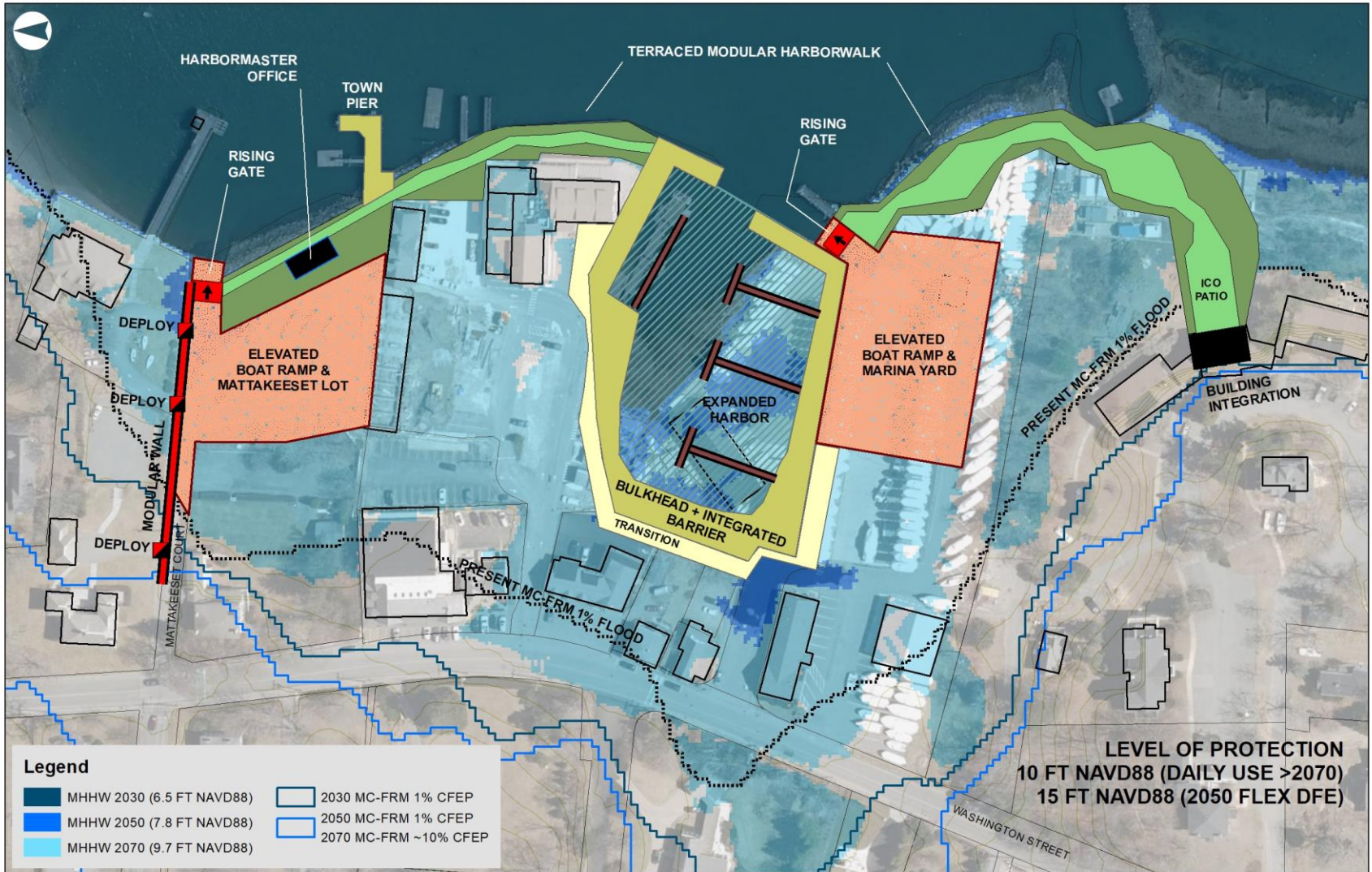
## Adaptation Strategies – Snug Harbor: Mid-Century Phased Migration





# Vulnerability Assessment and Adaptation Planning

## Adaptation Strategies – Snug Harbor: Transform



**Thank you!**  
**Questions and Discussion**

**Final Report available at:**  
**<https://www.town.duxbury.ma.us/planning-department/pages/climate-resiliency-and-sustainable-land-use>**

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