Town of Duxbury
Climate Change Vulnerability Assessment and Adaptation Planning

MVP Action Grant – Final Public Meeting

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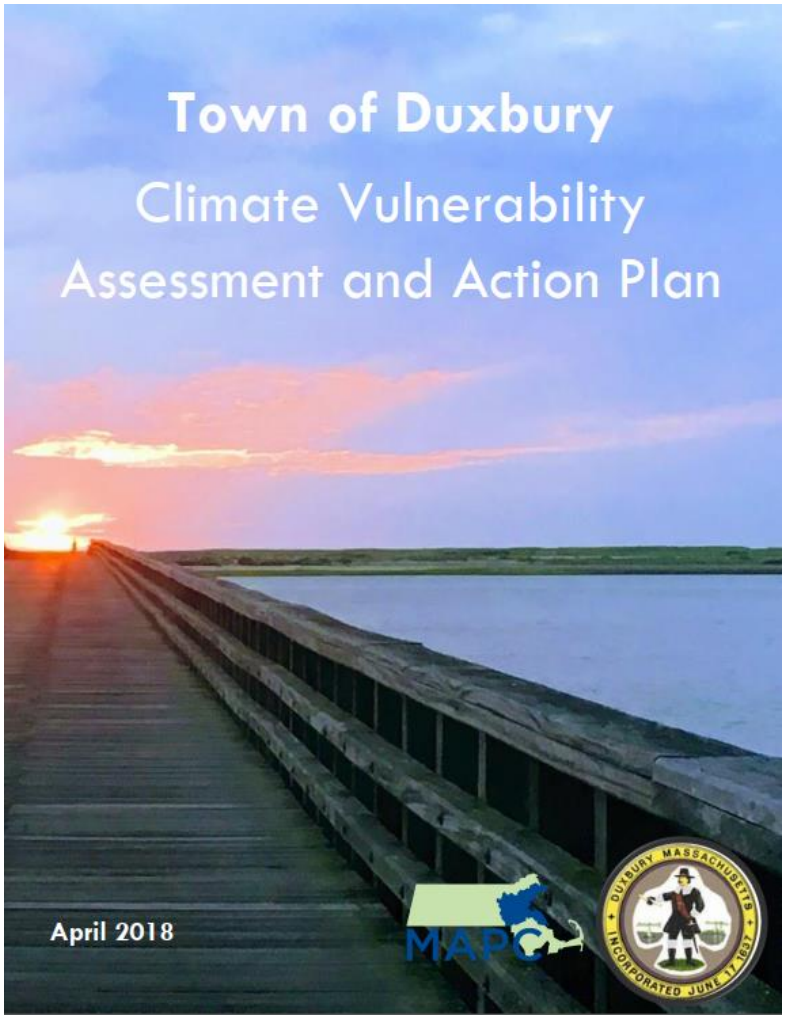
Duxbury Climate Change Planning

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

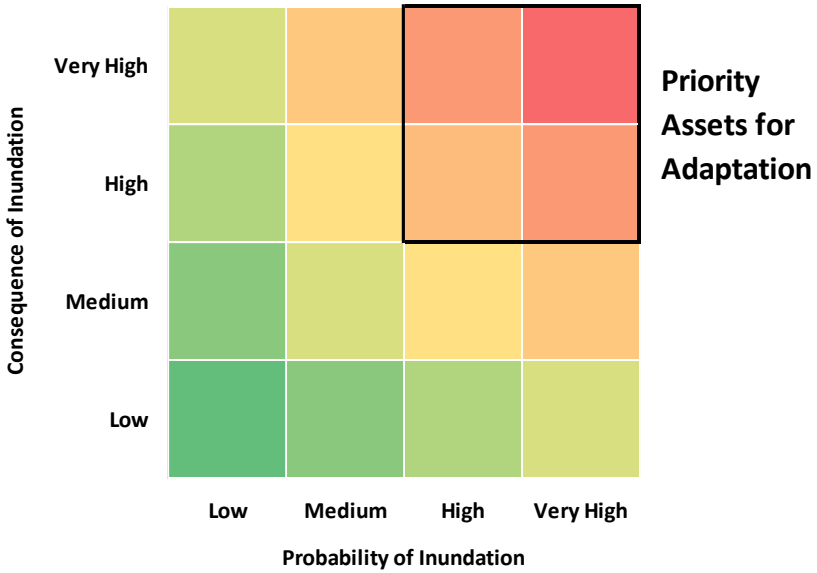
Source: @Dux_HM

Source: Google

Vulnerability Assessment and Adaptation Planning

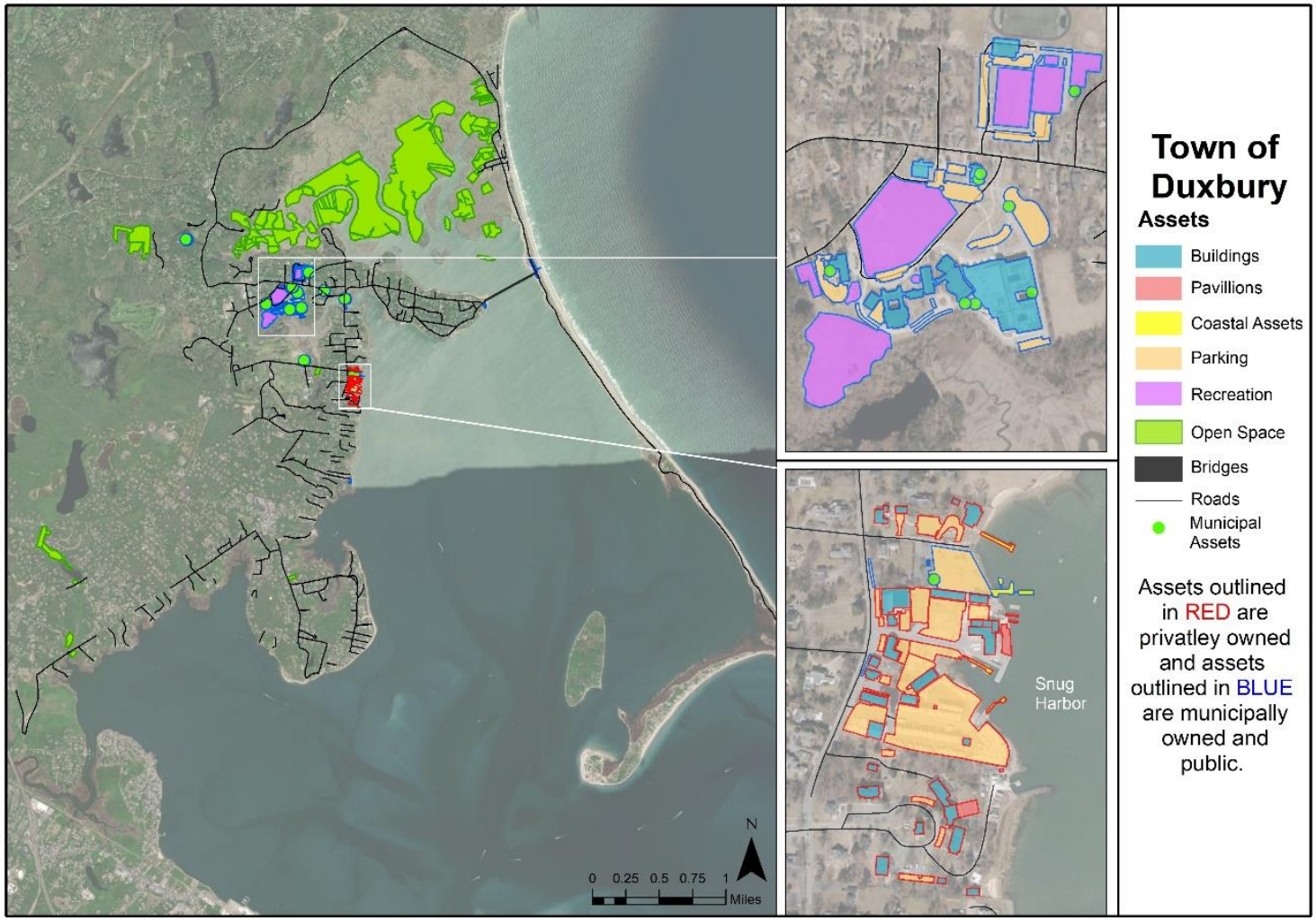
Project Approach

- 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

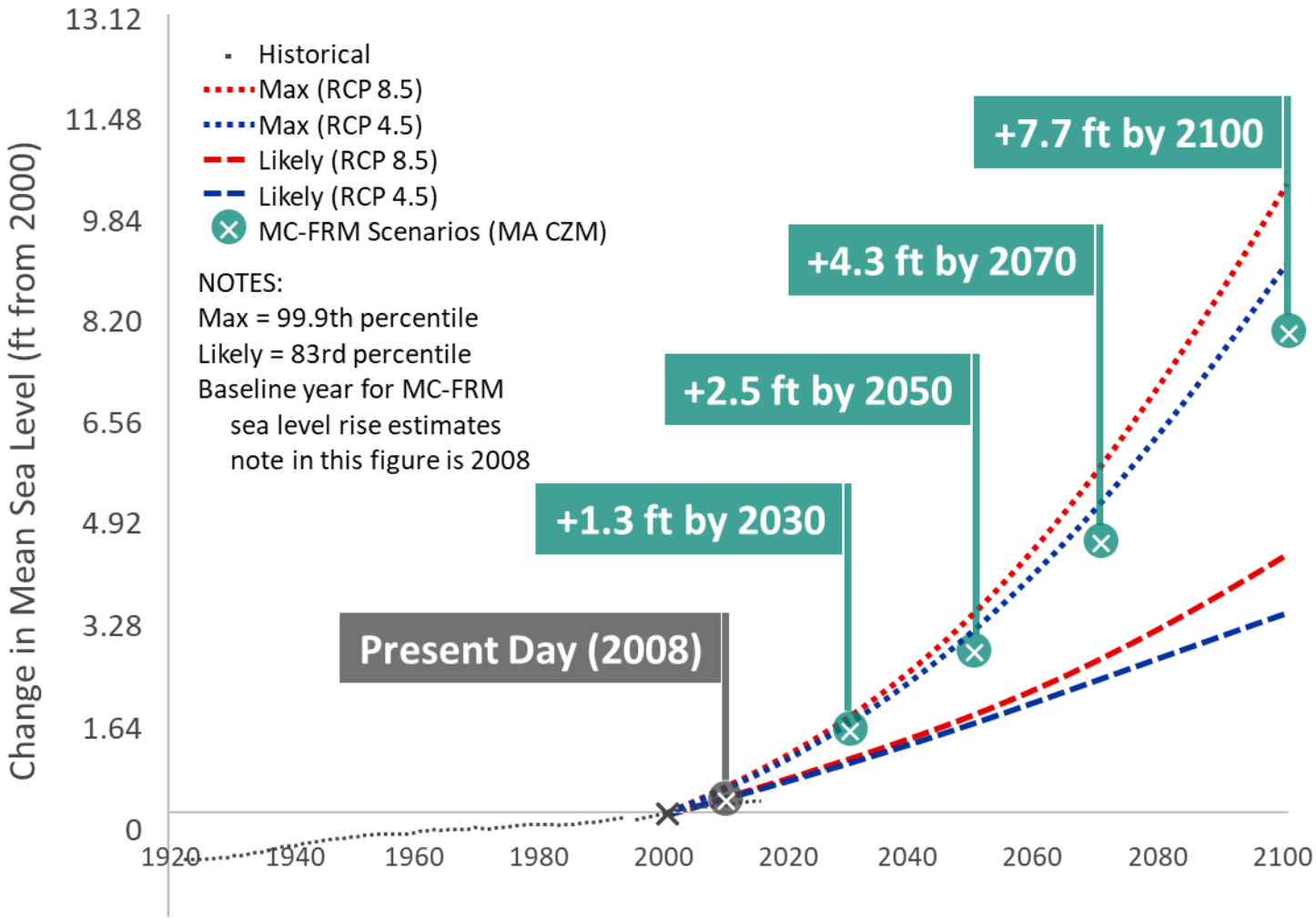
Asset Inundation Consequence Scoring

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

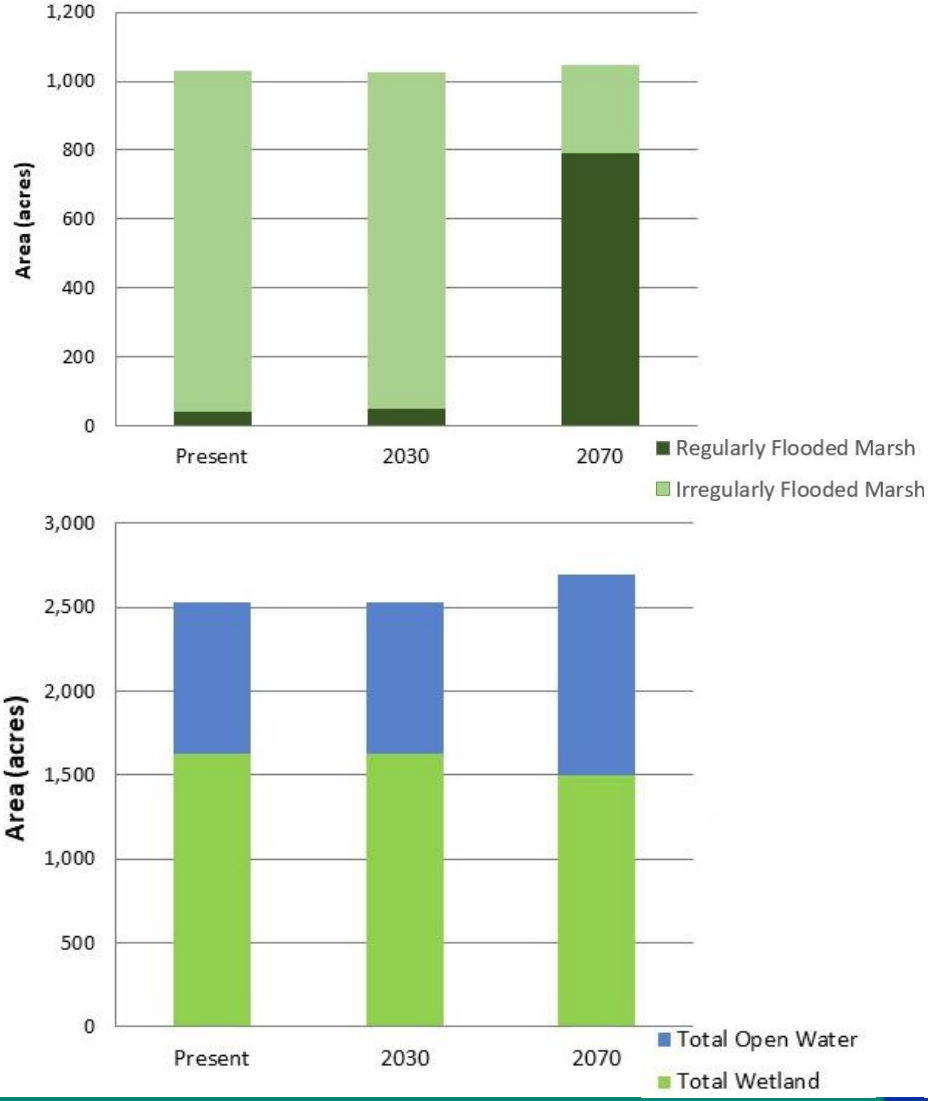
Probabilistic MSL elevation projections (Commonwealth of MA) in feet NAVD88

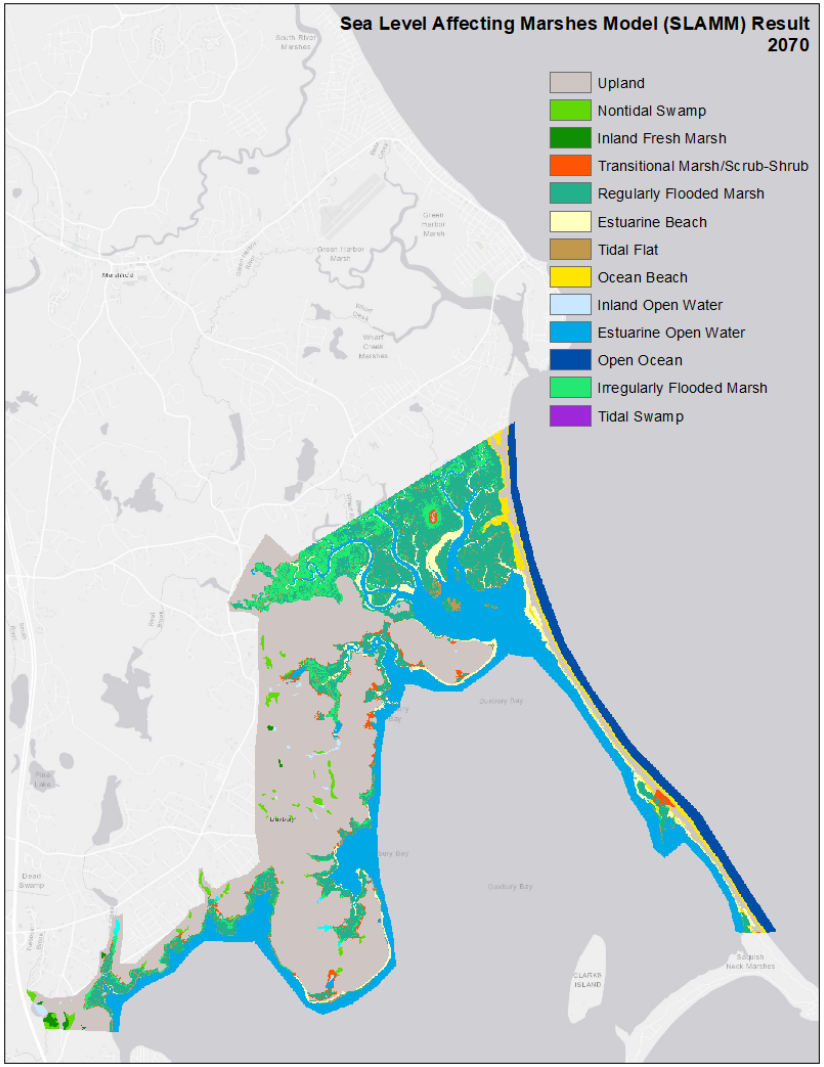
Scenario	Cross-walked probabilistic projections	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83%) under RCP8.5	0.7	1.4	2.3	4.0
	• Extremely unlikely to exceed (95%) under RCP 4.5 • About as likely as not to exceed (50%) under RCP 4.5 when accounting for possible ice sheet instabilities				
Intermediate-High	Extremely unlikely to exceed (95%) under RCP 8.5	0.8	1.7	2.9	5.0
	• Unlikely to exceed (83%) under RCP 4.5 when accounting for possible ice sheet instabilities • About as likely as not to exceed (50%) under RCP 8.5 when accounting for possible ice sheet instabilities				
High	Extremely unlikely to exceed (99.5%) under RCP 8.5	**1.2**	**2.4**	**4.2**	7.6
	• Unlikely to exceed (83%) under RCP 8.5 when accounting for possible ice sheet instabilities • Extremely unlikely to exceed (95%) under RCP 4.5 when accounting for possible ice sheet instabilities				
Extreme (Maximum physically plausible)	Exceptionally unlikely to exceed (99.9%) under RCP 8.5	1.4	3.1	5.4	10.2
	• Extremely unlikely to exceed (95%) under RCP8.5 when accounting for possible ice sheet instabilities				
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)





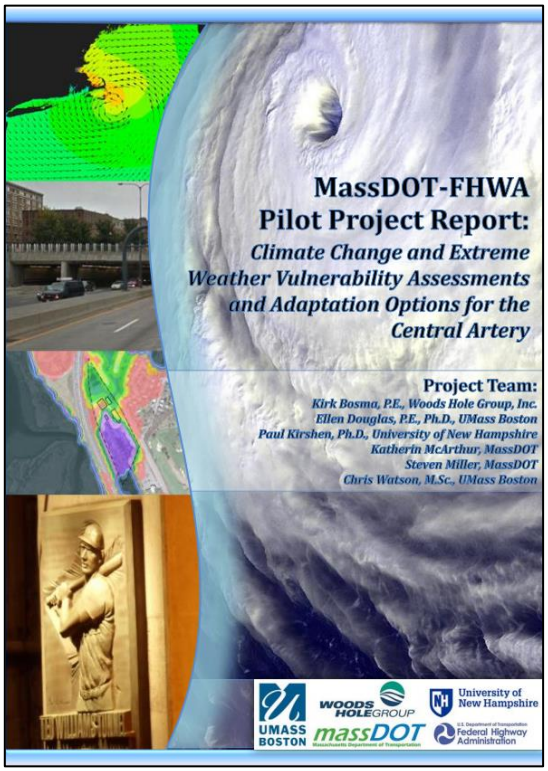
Local Tidal Datum Projections

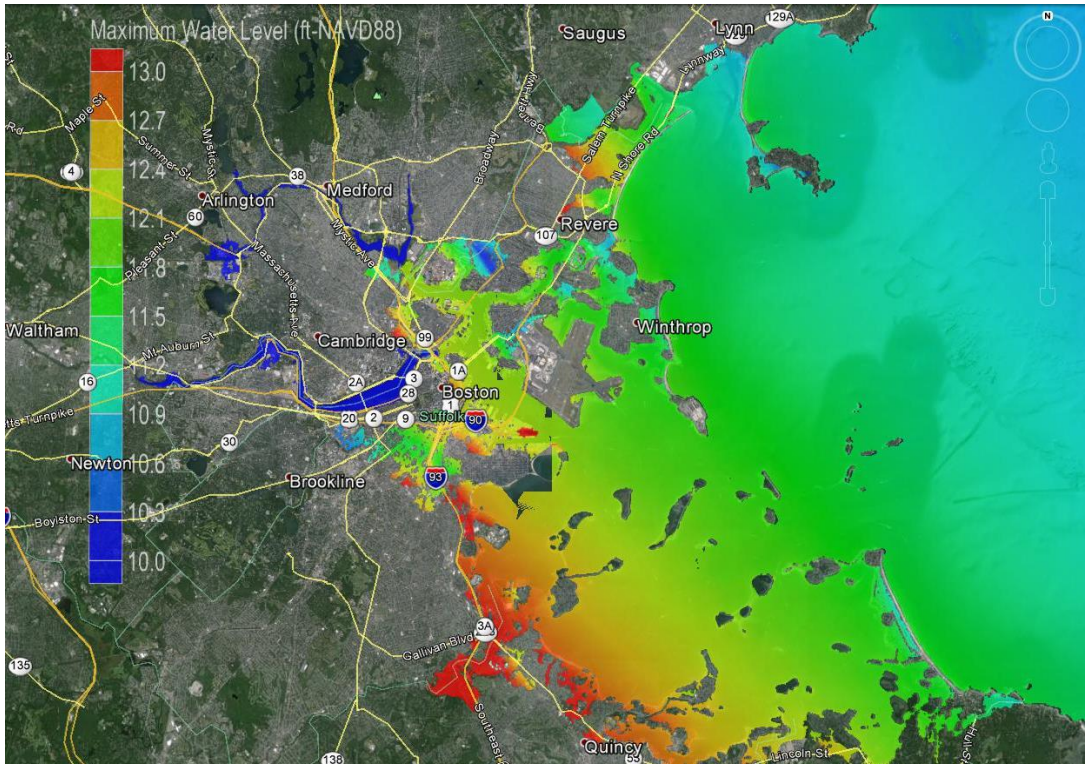
MHHW Projections for Snug Harbor

	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

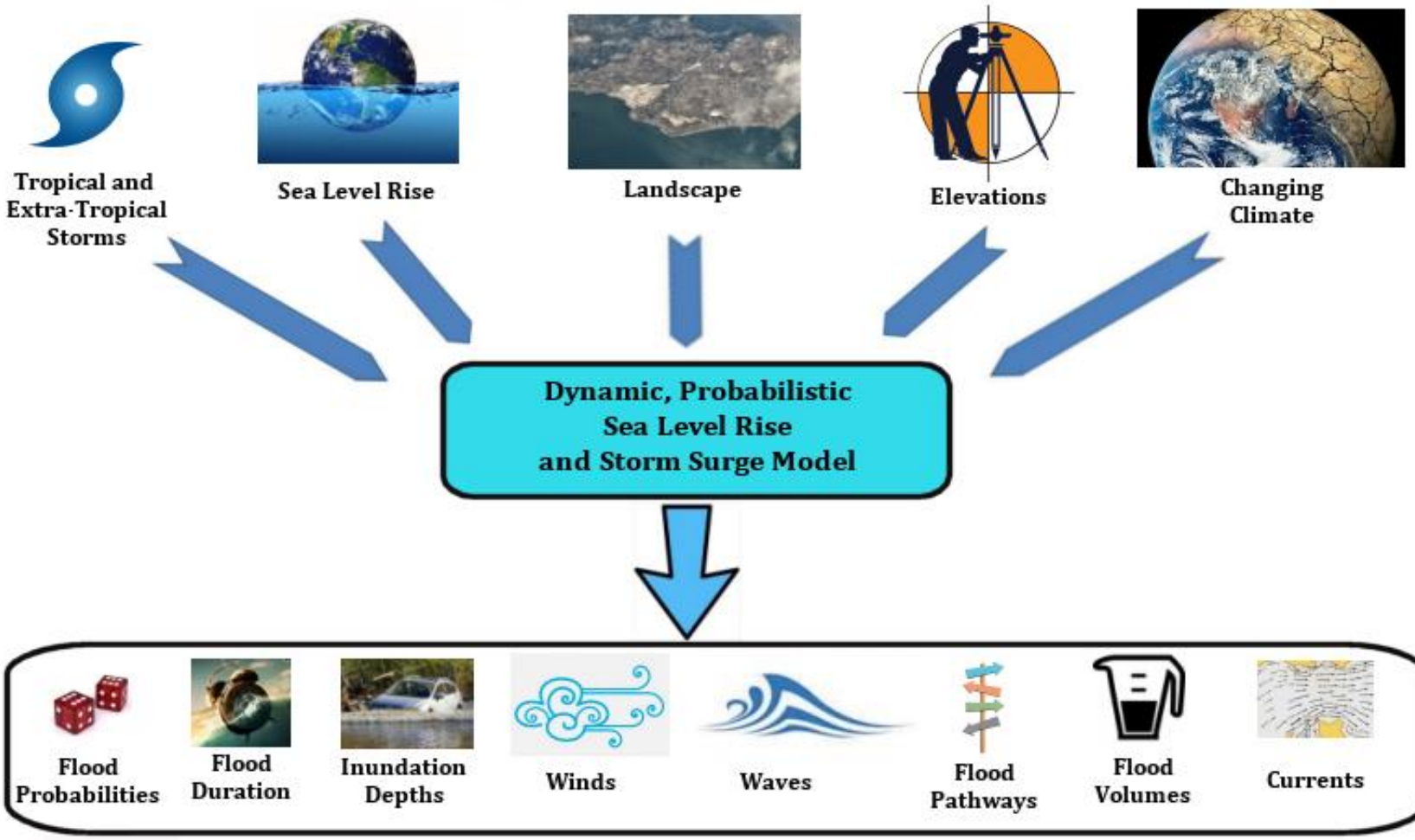
The case for hydrodynamic modeling





SLR and Storm Surge Projections

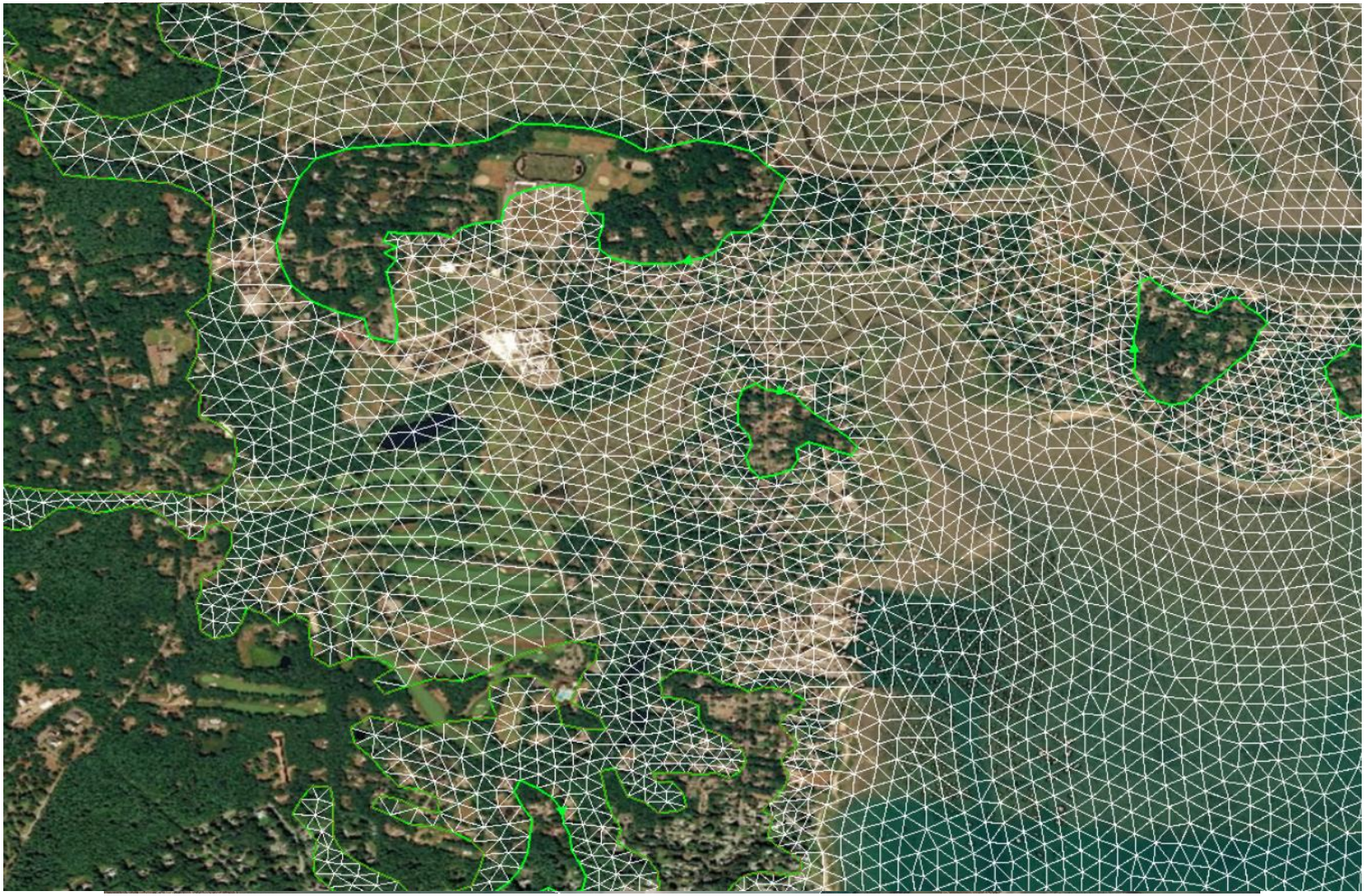
Massachusetts Coast Flood Risk Model (MC-FRM)



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

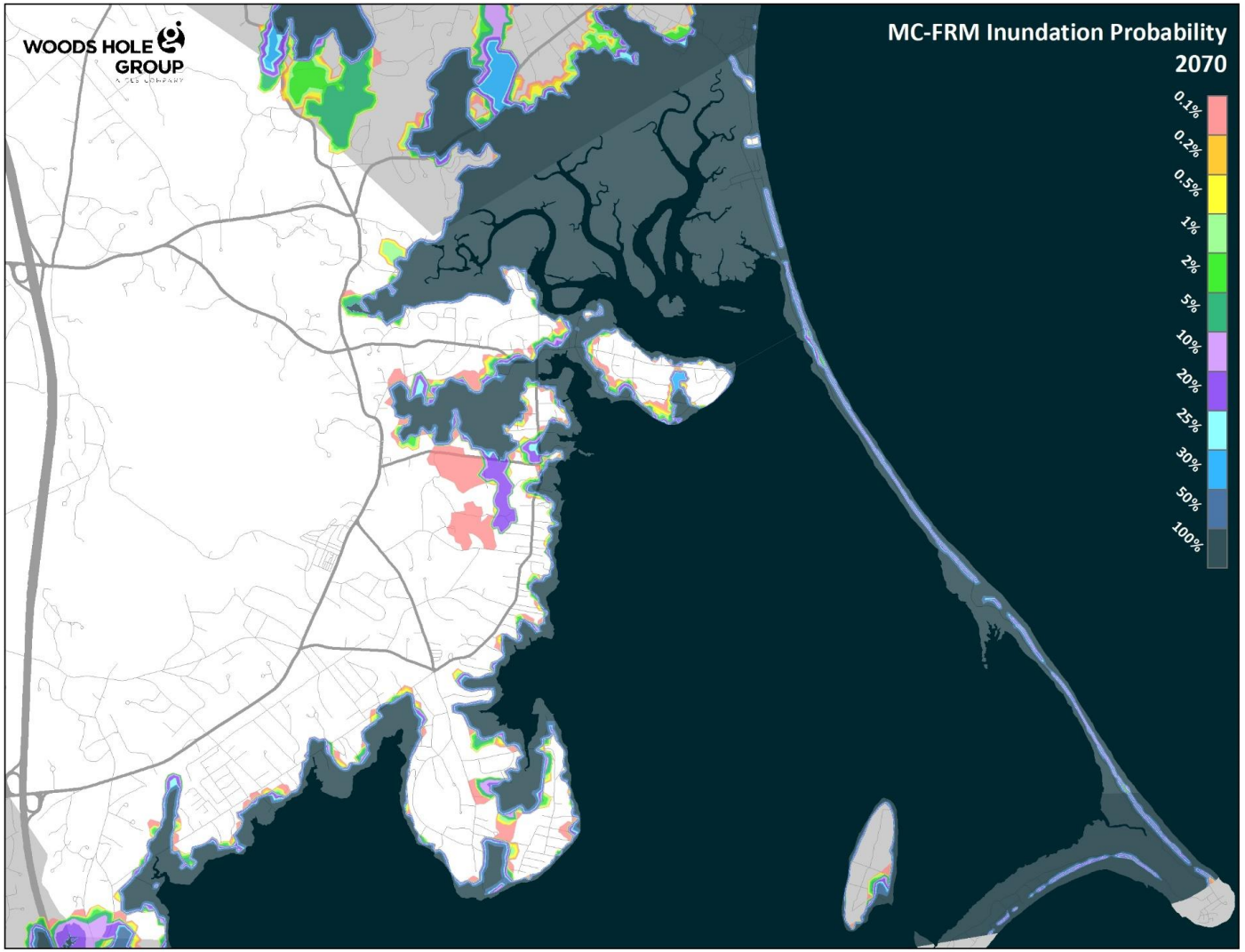
SLR and Storm Surge Projections

MC-FRM Mesh in Duxbury



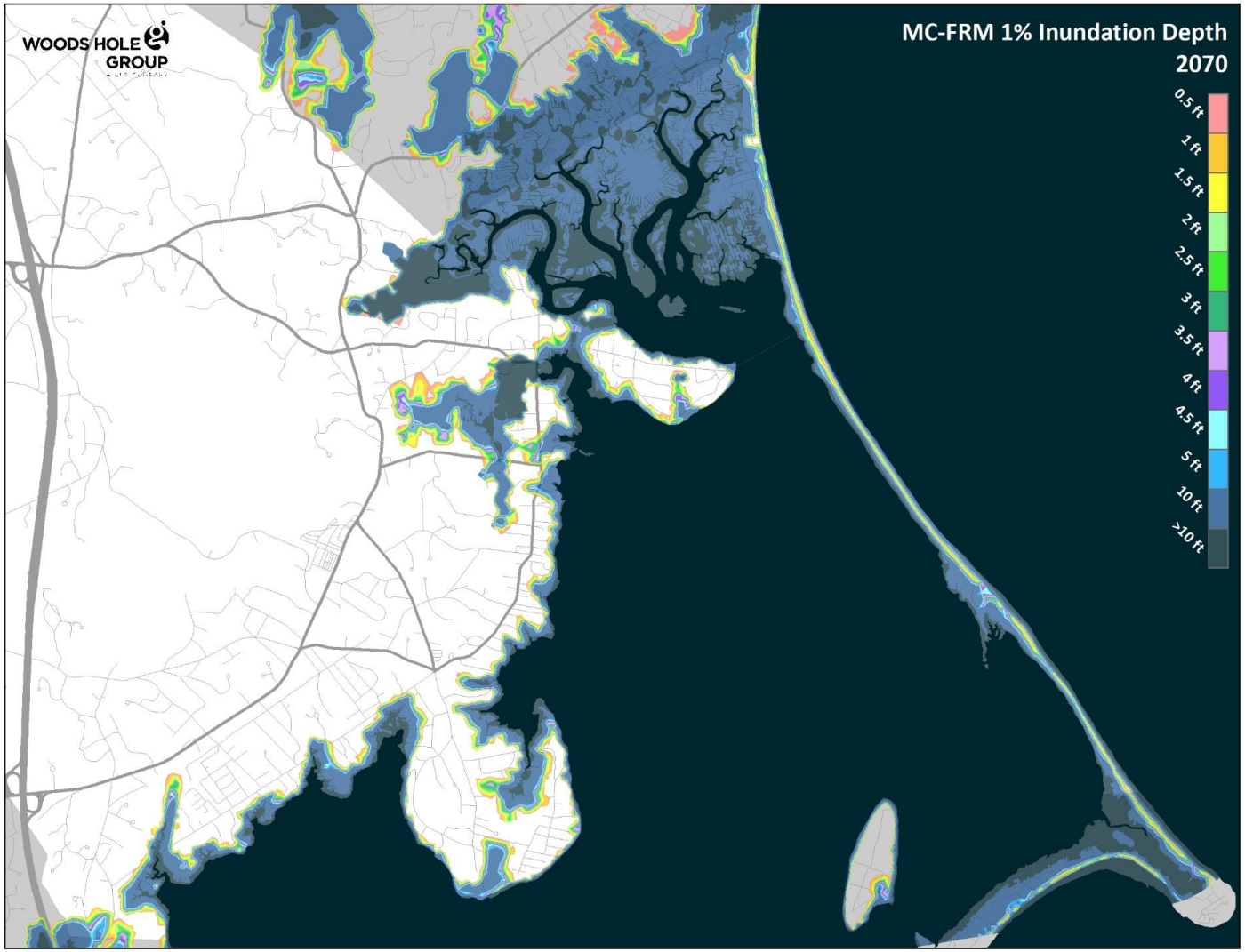
SLR and Storm Surge Projections

MC-FRM Results: Coastal Flood Exceedance Probability



SLR and Storm Surge Projections

MC-FRM Results: Inundation Depth at 1% CFEP



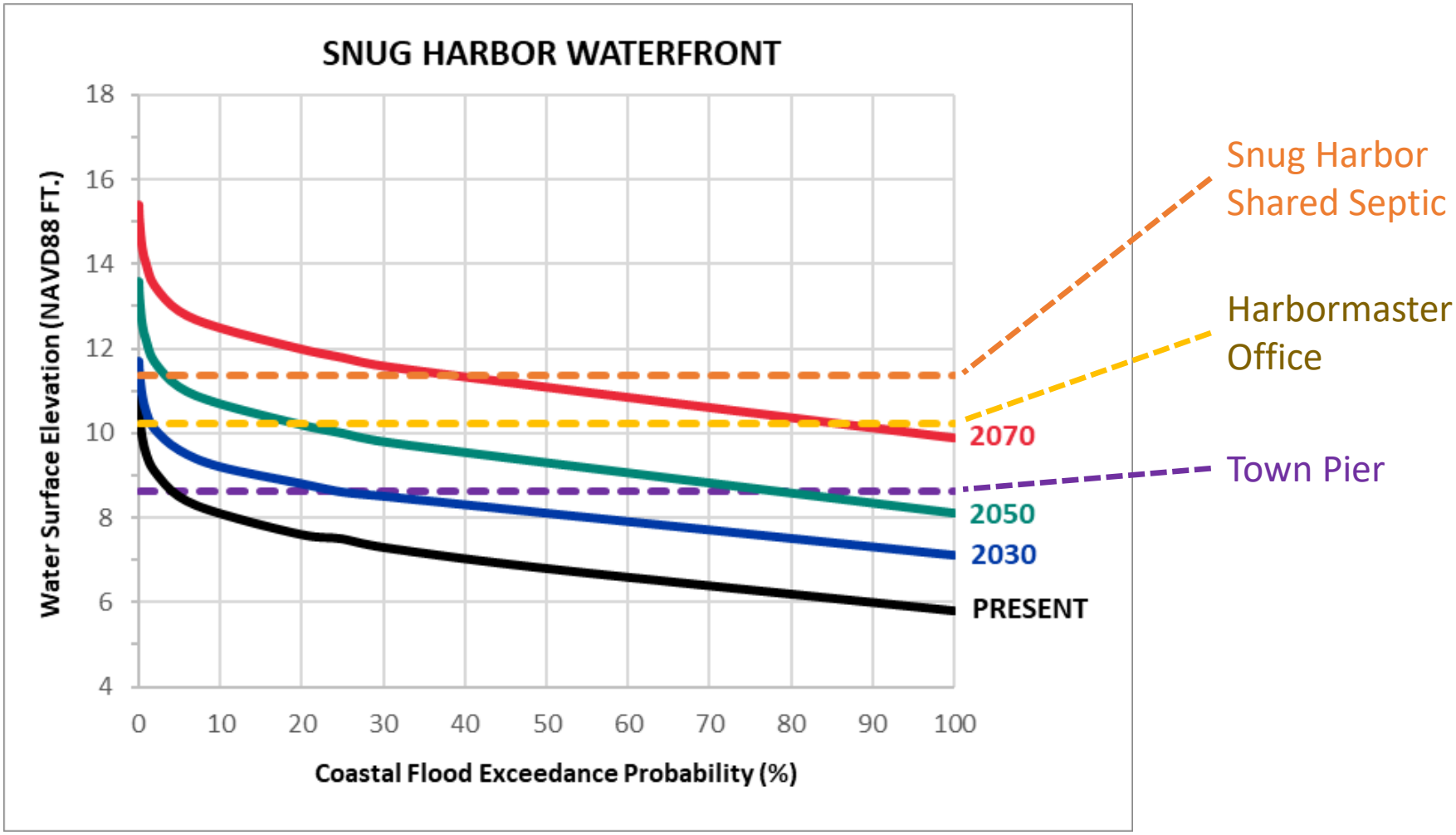
SLR and Storm Surge Projections

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
Structures (Total 7341)								
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%
Roadways (Total 183 miles)								
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

Climate Vulnerability Assessment – Asset Profile

Harrison Bridge

Asset Type: Bridge
Critical Elevation (CE): 5.53 FT. NAVD88
Threshold Description:
Low chord elevation; Road surface 9.36 FT. NAVD88

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				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Safety & Emergency Services	Economic Activity	Public Health & Environment	Sum	Consequence Score
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

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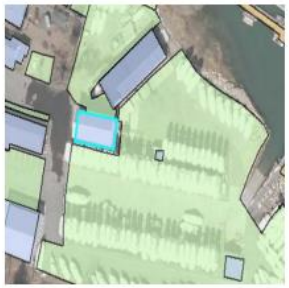
Climate Vulnerability Assessment – Asset Profile

Joe's Building

Asset Type: Building
Critical Elevation (CE): 7.94 FT. NAVD88
Threshold Description:
Ground - from lidar



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				
	Service Loss Extent	Service Loss Duration	Cost of Damage	Economic Activity	Marketing & Outreach	Planning	Sum	Consequence Score
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

WOODS HOLE GROUP

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

Harrison St. Bridge
Washington St Bridge
Island Creek Bridge
Marshall St Bridge
Harbormaster Float
Mattakeeset Parking
Blue Fish Fire Station Parking
Town Pier
Town Float
447-449 Washington St Parking
Canal St Bridge (MSH)
Duxbury Beach 1 Parking

High Risk Town Assets at Mattakeeset

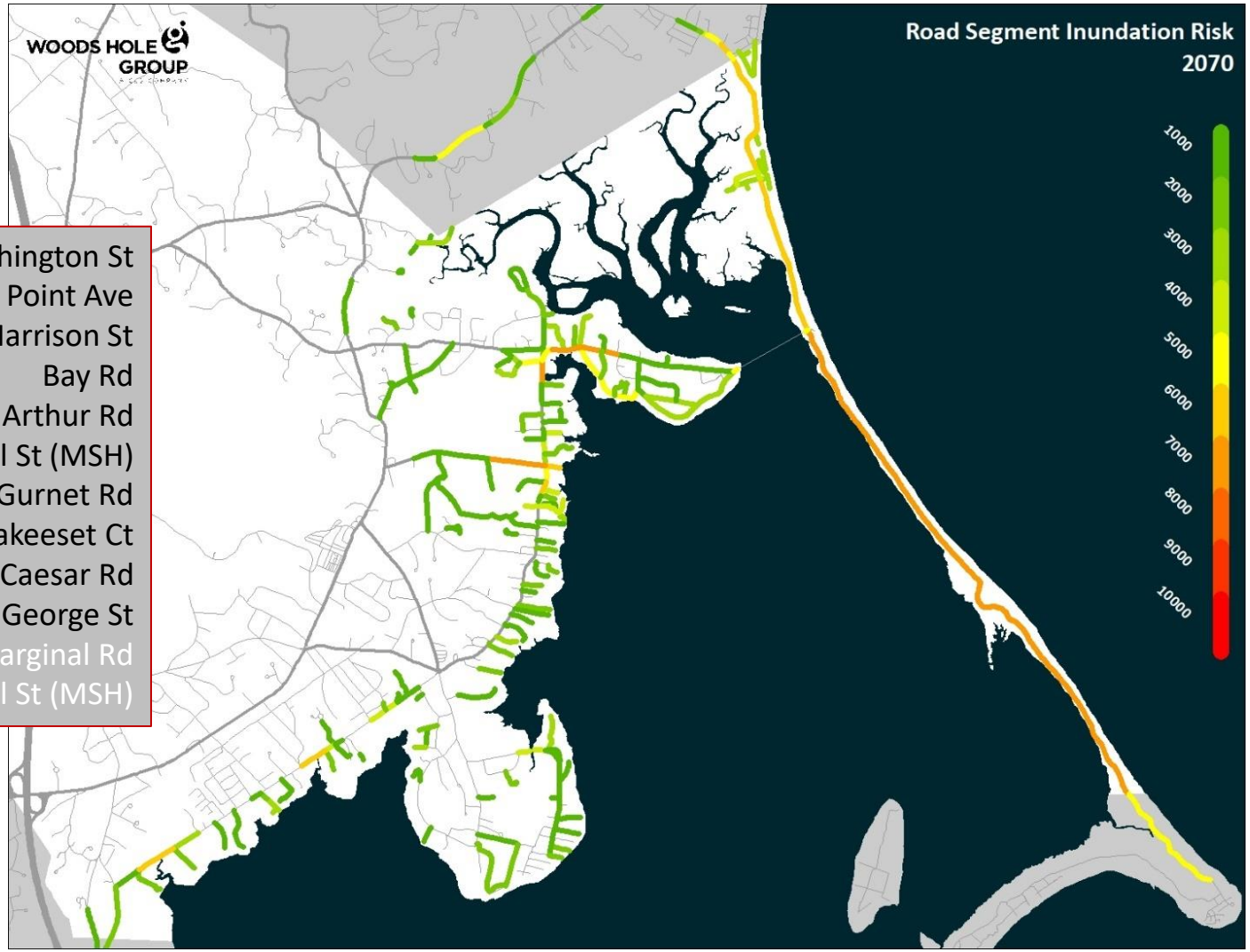
2018 Winter Storm Riley

Source: MAPC Snug Harbor Report

Vulnerability/Risk Assessment Results – Roads

Probability * Consequence = Risk

Washington St
Powder Point Ave
Harrison St
Bay Rd
King Arthur Rd
Canal St (MSH)
Gurnet Rd
Mattakeeset Ct
King Caesar Rd
Saint George St
Marginal Rd
Careswell St (MSH)

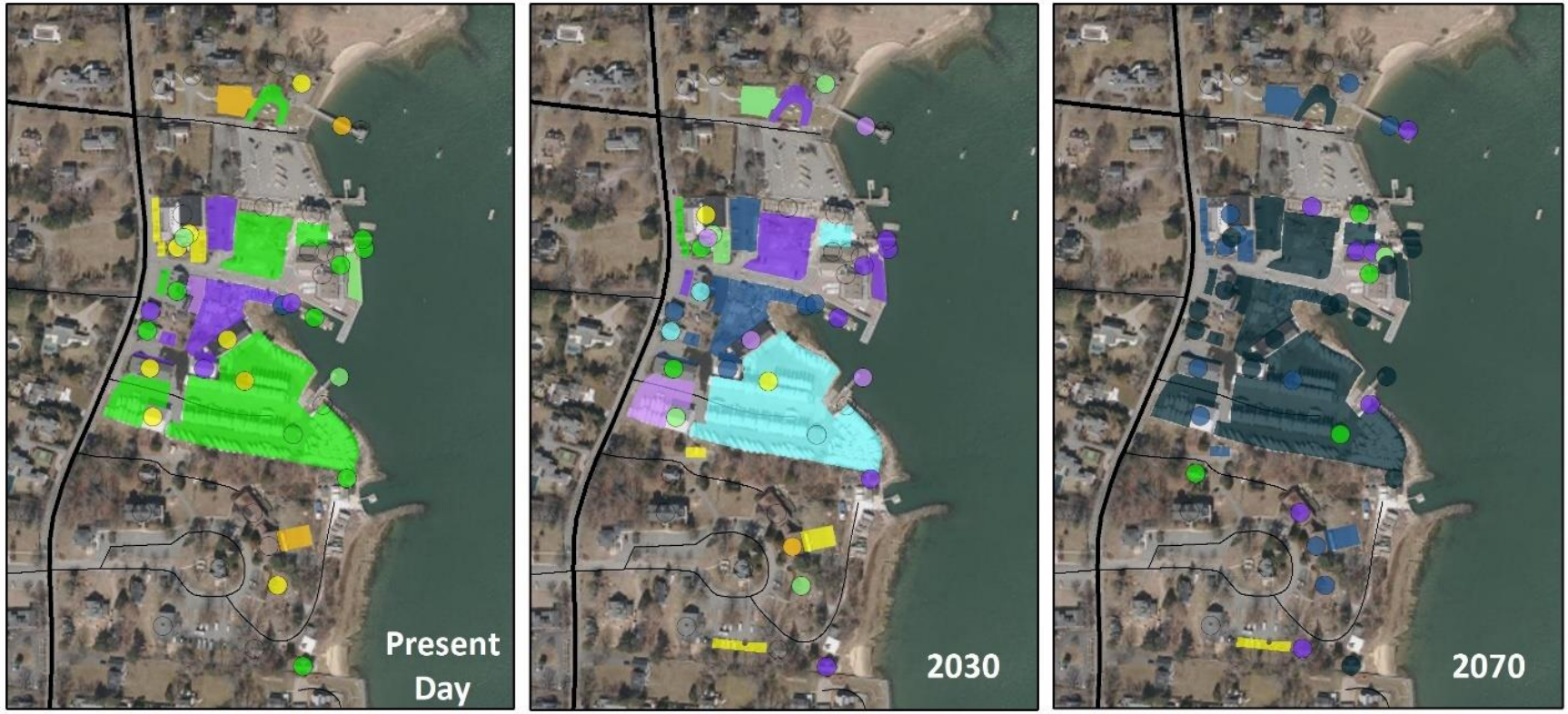


High Risk Town Roads

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



WOODS HOLE GROUP

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

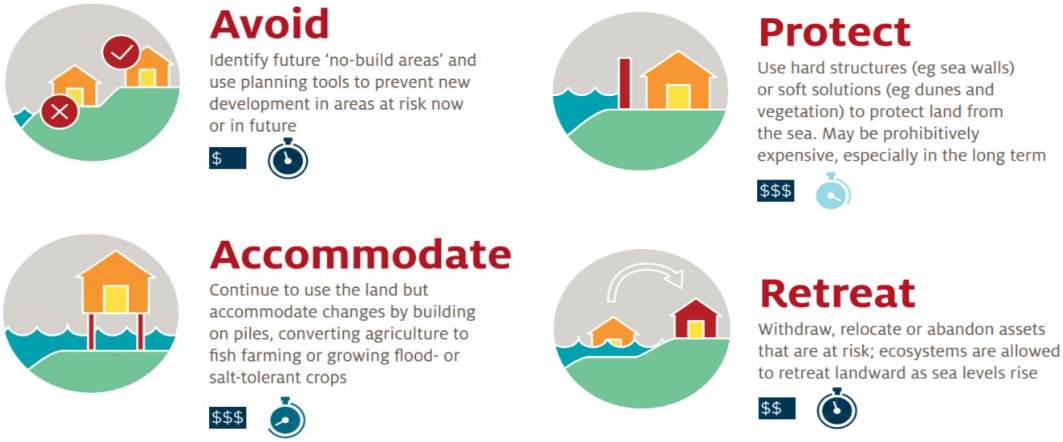
Sweetser's

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)

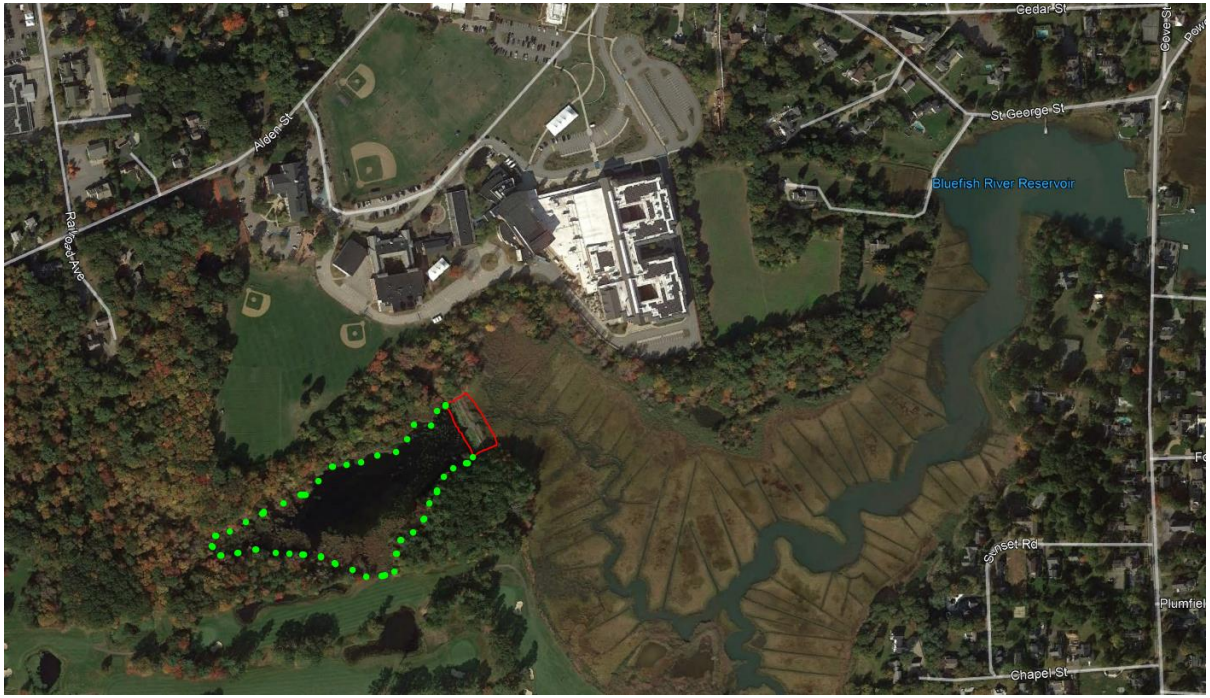


Source: NCCCARF, 2019

Vulnerability Assessment and Adaptation Planning

Adaptation Strategies – Natural Resources

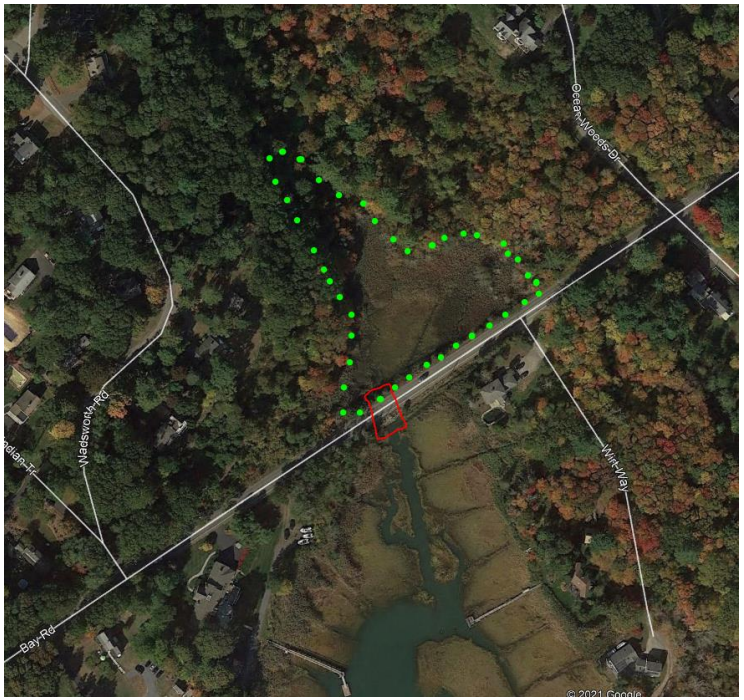
- Plan for salt marsh migration where possible
  - Bluefish River dam removal
  - Private land: Landing Road vicinity, Goose Point / Allens Pond area, Eagles Nest Point, Snug Harbor, Long Point Marine, Southern lobe of Powder Point neighborhood



Vulnerability Assessment and Adaptation Planning

Adaptation Strategies – Natural Resources

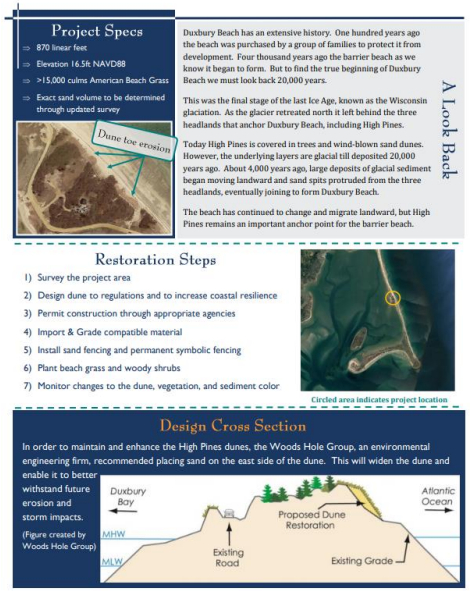
- Address tidal restrictions at undersized culverts
  - Bay Road culvert near Wirt Way



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”



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.

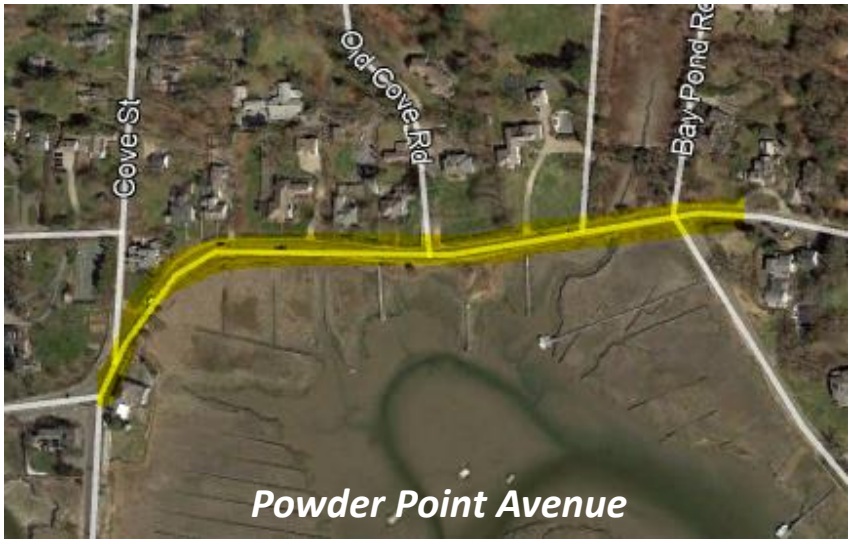
Vulnerability Assessment and Adaptation Planning

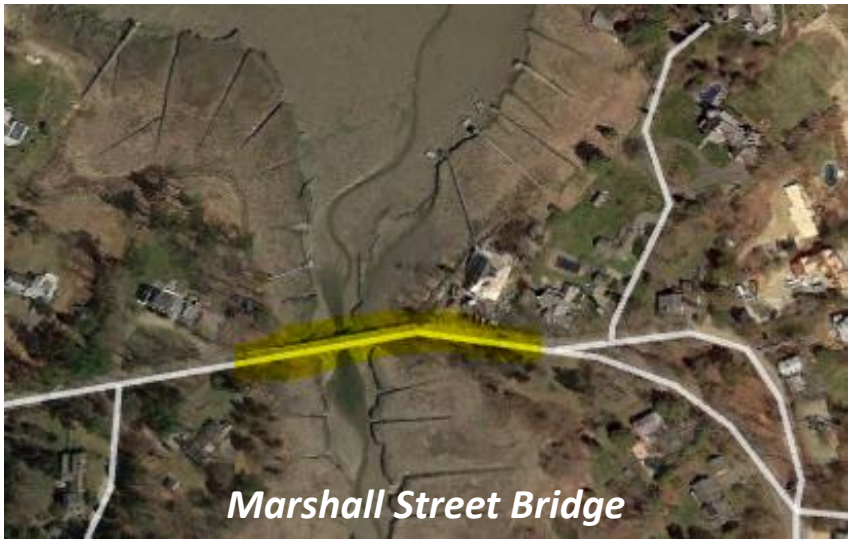
Adaptation Strategies – Wetlands Protection Bylaw Recommendations

- 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

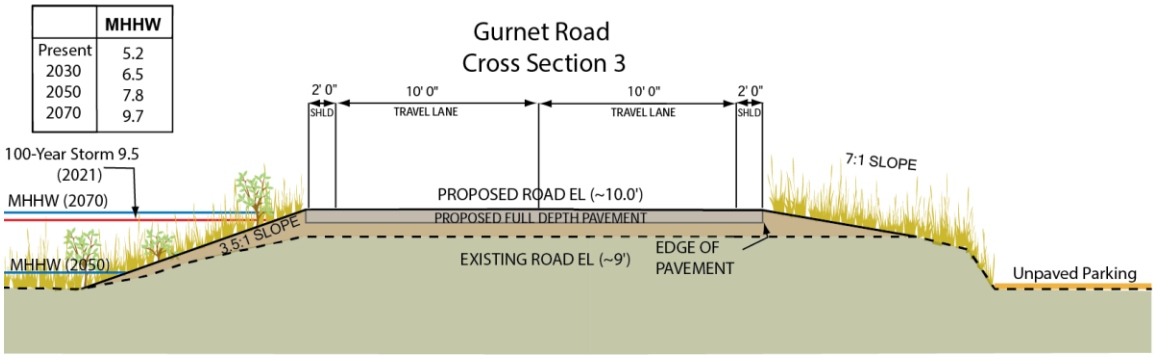
Adaptation Strategies – Duxbury Priority Assets

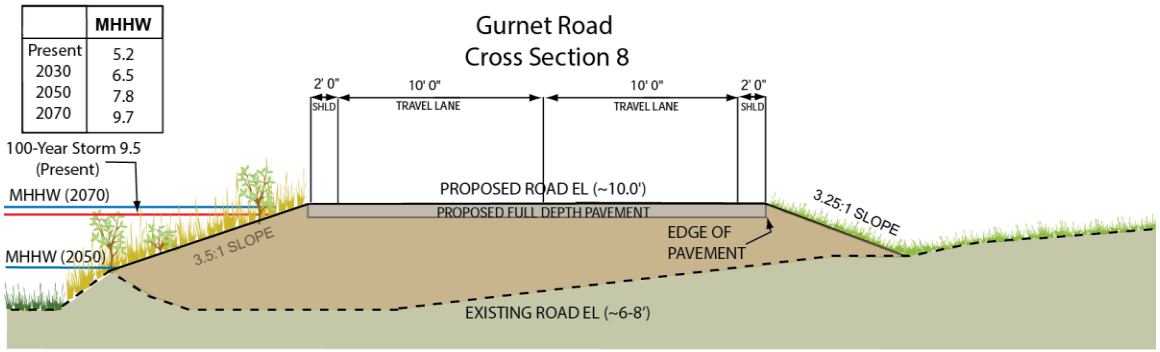


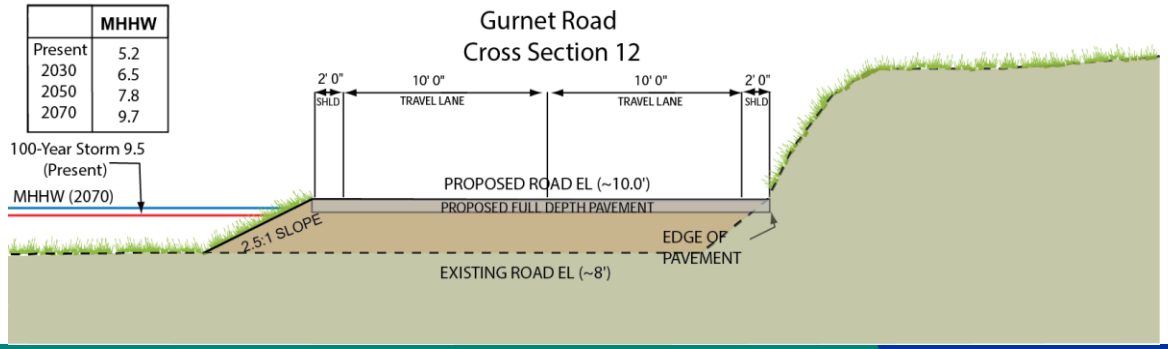


Vulnerability Assessment and Adaptation Planning

Adaptation Strategies – Gurnet Road





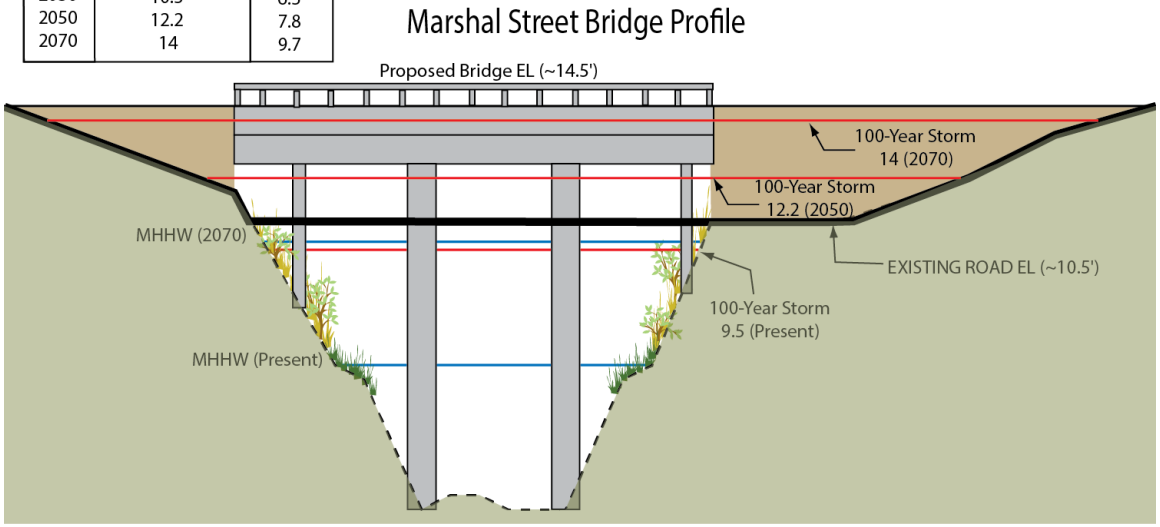


- 6,240 ft span
- Elevate to 10’ NAVD88
  - Daily access
  - Reduced storm impacts
- Green infrastructure side slope treatments
- Preliminary opinion of probable cost:
  - ~$1.2M

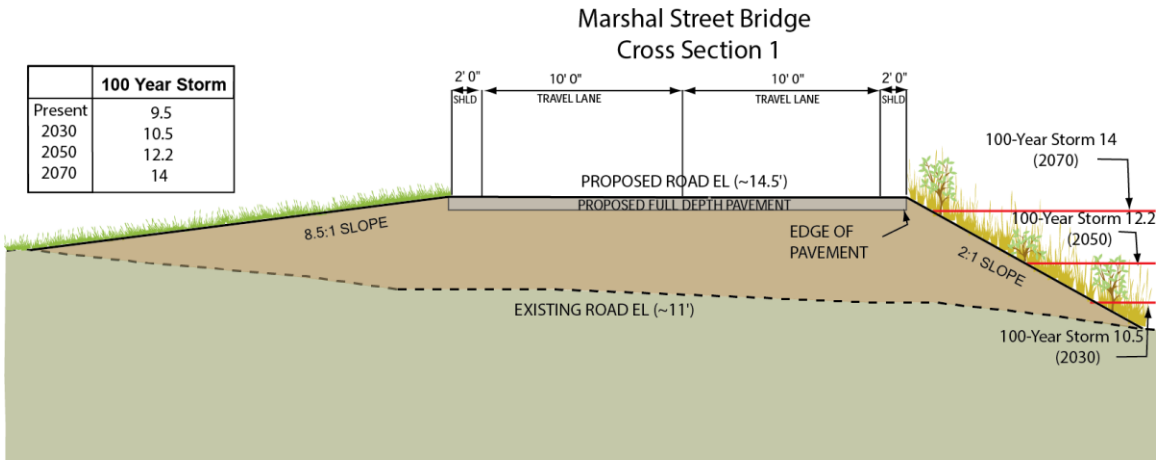
Vulnerability Assessment and Adaptation Planning

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



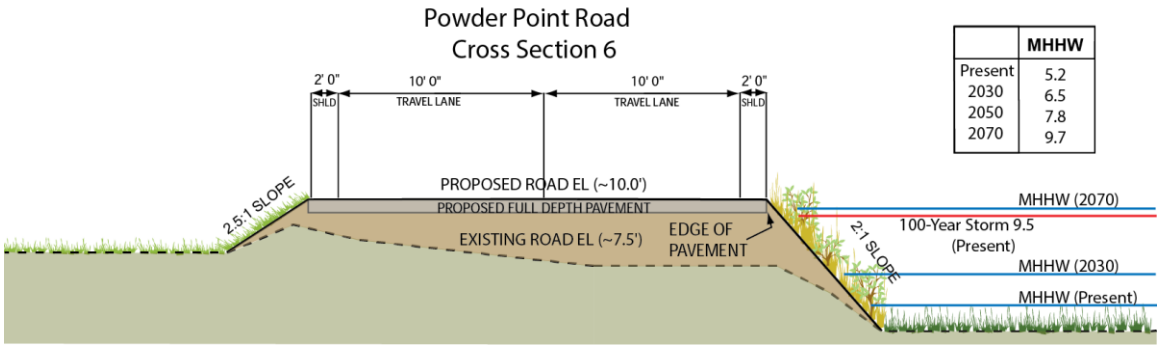
	100 Year Storm
Present	9.5
2030	10.5
2050	12.2
2070	14



- 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

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
- RMAT/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

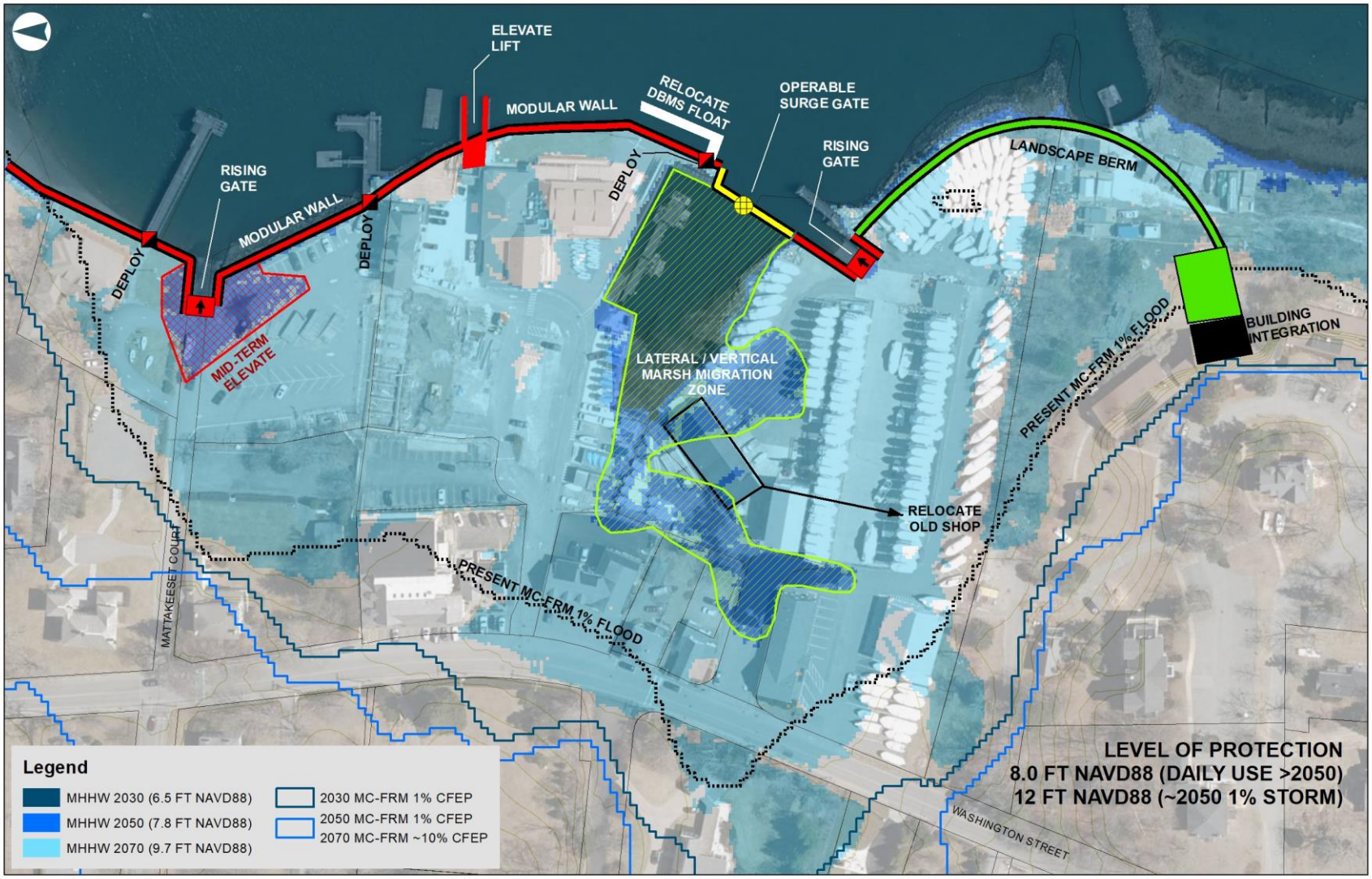
Vulnerability Assessment and Adaptation Planning

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

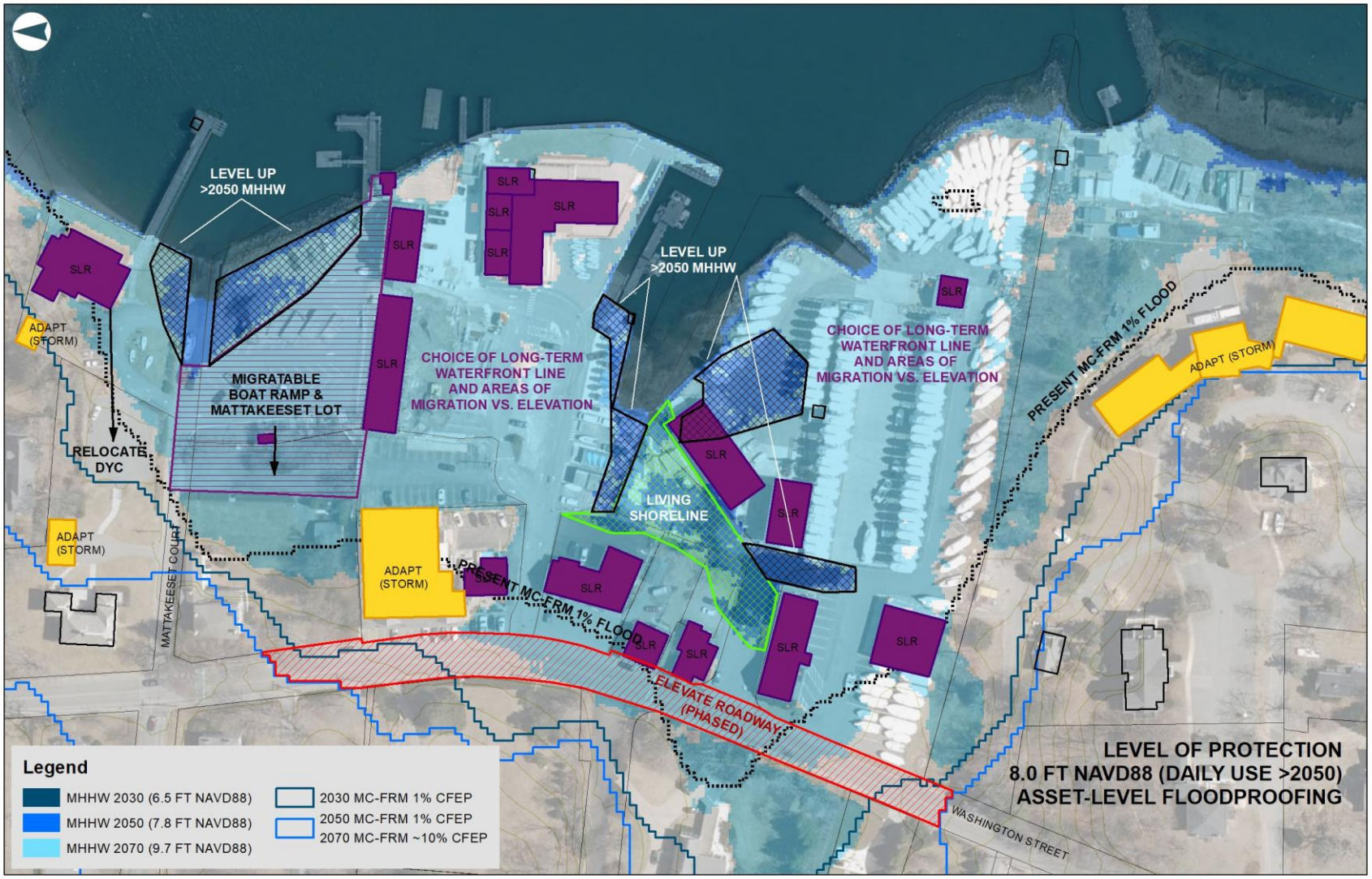
Vulnerability Assessment and Adaptation Planning

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



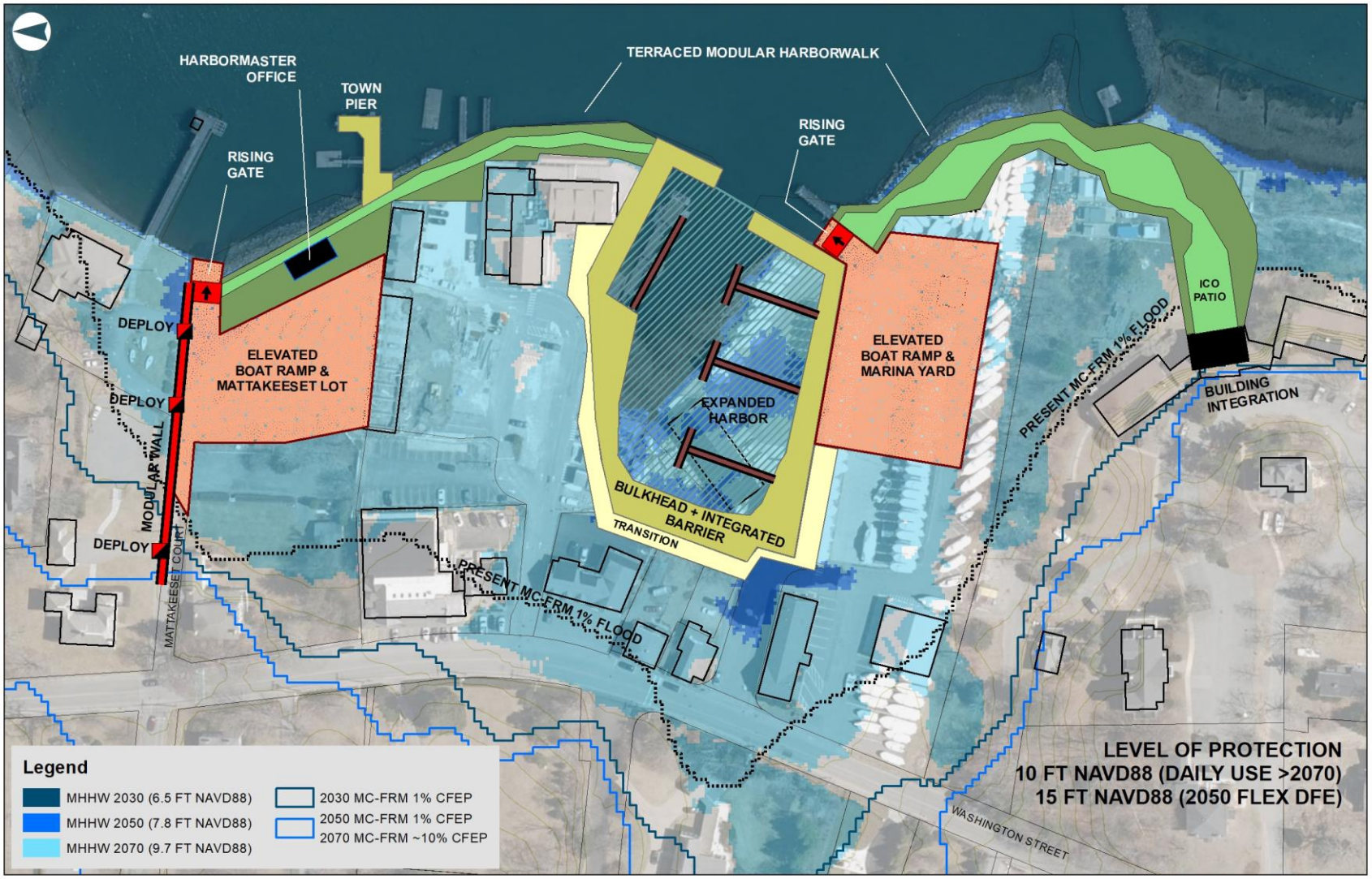
Vulnerability Assessment and Adaptation Planning

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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Source: @Dux_HM