



Cape Cod Bridges Program

Bourne, Massachusetts

Appendix 4.22
Climate Change Adaptation and Resiliency Technical Report

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Acronyms and Abbreviations

Acronym/Abbreviation	Definition
DEIR	Draft Environmental Impact Report
EOP	edge of pavement
FEIR	Final Environmental Impact Report
FEMA	Federal Emergency Management Agency
FFRMS	Federal Flood Risk Management Standard
FHWA	Federal Highway Administration
FIS	Flood Insurance Study
HEC	Hydraulic Engineering Circular
LST	land surface temperature
MA EEA	Massachusetts Executive Office of Energy and Environmental Affairs
MassDOT	Massachusetts Department of Transportation
MC-FRM	Massachusetts Coast Flood Risk Model
MHHW	mean higher high water
MHW	mean high water
MLLW	mean lower low water
MRER/EA	Major Rehabilitation Evaluation Report/Environmental Assessment
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
Program	Cape Cod Bridges Program
ResilientMass	ResilientMass Maps and Data Center
RMAT	Resilient Massachusetts Action Team
RSLR	relative sea level rise
RWDI	Rowan Williams Davies & Irwin Incorporation
SCM	Stormwater Control Measures
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	sea level rise
SS	storm surge
TBD	to be determined
USACE	U.S. Army Corps of Engineers

1 Introduction

This Climate Change Adaptation and Resiliency Technical Report has been prepared in support of the Draft Environmental Impact Report (DEIR) for the Cape Cod Bridges Program (Program), in accordance with federal and state statutes, regulations, and guidance. This report assesses the potential risks relative to climate change and extreme weather events for the following current and future conditions:

- Sea Level Rise
- Extreme Precipitation
- Extreme Heat
- Winter Weather
- Extreme Winds

1.1 Regulatory Framework

This section was prepared using federal regulatory directives and guidance, including the following:

- Establishing a risk management plan under 23 Code of Federal Regulations (CFR) Section 515.7(c)(1) (i.e., risk to bridges on the National Highway System from current and future conditions)
- 33 CFR 207.2: Navigation Regulations, Cape Cod Canal, Massachusetts; Use, Administrative and Navigation
- 23 CFR Part 650(A): Location and Hydraulic Design of Encroachments on Flood Plains
- 23 U.S. Code 176: Promoting Resilient Operations for Transformative, Efficient, and Cost-Savings Transportation Program
- Federal Highway Administration (FHWA) Hydraulic Engineering Circular Number 25 (HEC-25) Highways in the Coastal Environment, Third Edition (2020).
- FHWA HEC-18 Evaluating Scour at Bridges, Fifth Edition (2012).

There are several Massachusetts regulatory directives and guidance that informed the preparation of this section, including the following:

- Massachusetts Environmental Policy Act Interim Protocol on Climate Change Adaptation and Resiliency (2021)
- Certificate of the Secretary of the Office of Energy and Environmental Affairs on the Environmental Notification Form for the Cape Cod Bridges Program (2023).

1.2 Study Areas

For the purposes of assessing the impacts of climate change adaptation and resiliency, the Study Areas consist of the construction Project Limit and a 500-foot buffer from Sagamore Bridge and Bourne Bridge (**Figure 2-1**).

2 Methodology

To ensure consistency with standardized statewide data used in Massachusetts and data used by the U.S. Army Corps of Engineers (USACE) in previous assessments that supported analyses for the replacement bridges, the methodology relies on existing data and climate projections; no new data or downscaled climate projections were developed.

The methodology consisted of reviewing published studies, climate data, and future projections, and the Resilient Massachusetts Action Team (RMAT) Tool. Each climate risk assessed included an evaluation of observed or modeled historical data and available projections, which were used in conjunction with the affected environment to inform the recommendations for data and methods to assess the impact on the No Build Alternative and Build Alternative.

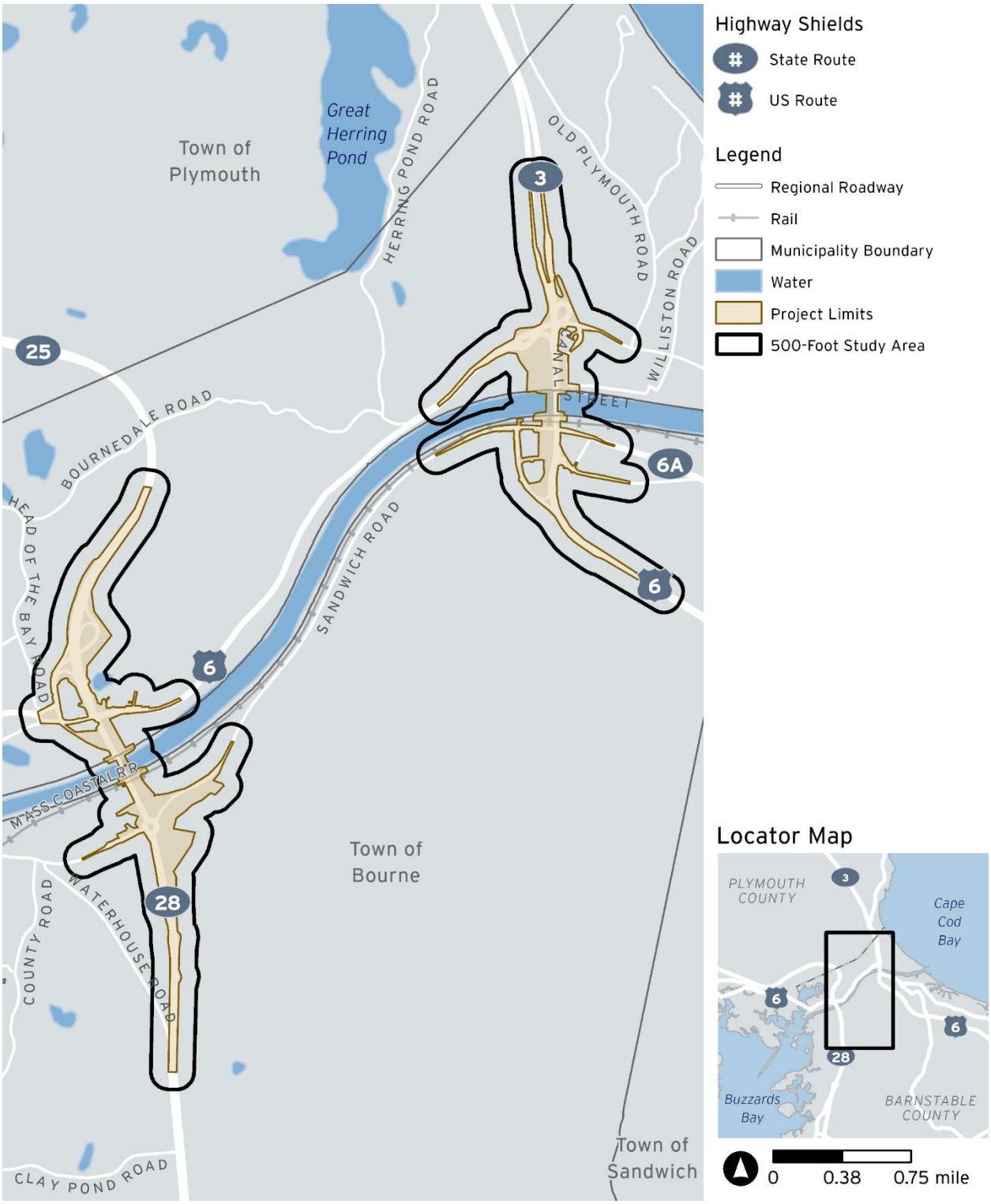
2.1 Published Studies, Climate Data, and Future Projections

The Massachusetts Department of Transportation (MassDOT) referenced the following published resources for climate projections:

- Cornell University for Massachusetts Executive Office of Energy and Environmental Affairs (MA EEA), Massachusetts Climate and Hydrologic Risk Project for the Northeast United States – Intensity Duration Frequency Curves Precipitation Methodology (December 2021)[1]
- MA EEA, Massachusetts Climate Change Assessment (2022)[2]
- MA EEA, Massachusetts Climate Change Projections (2018)[3]
- USACE, Major Rehabilitation Evaluation Report/Environmental Assessment (MRER/EA)
- ResilientMass Maps and Data Center (ResilientMass)[4]

[1] https://www.mass.gov/doc/eea-climate-and-hydrologic-risk-idf-curves-technical-document/download
[2] https://www.mass.gov/info-details/massachusetts-climate-change-assessment#read-the-report-
[3] https://eea-nescaum-dataservices-assets-prd.s3.us-east-1.amazonaws.com/resources/production/MA%20Statewide%20and%20MajorBasins%20Climate%20Projections_Guidebook%20Supplement_March2018.pdf
[4] https://resilientma-mapcenter-mass-eoeea.hub.arcgis.com/

Figure 2-1. Study Area for Climate Change Adaptation and Resiliency Evaluation



Source: Massachusetts Department of Transportation, 2024

MassDOT referenced the following published resources for additional climate data and flood maps:

- Federal Emergency Management Agency (FEMA), Flood Insurance Study (FIS) Number 25001CV000B, Effective July 7, 2021.[5]
- FEMA Policy: Federal Flood Risk Management Standard (FFRMS), Effective September 9, 2024.[6]
- Dangendorf, S. (2024). Kalman Smoother Sea Level Reconstruction [Data set]. Zenodo.[7]
- National Oceanic and Atmospheric Administration (NOAA), Precipitation-Frequency Atlas of the United States, Northeastern states - Atlas 14, Volume 10 (2019).[8]
- NOAA, Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model, (Version 3 – June 2022)[9]

The following additional published studies and plans were reviewed to evaluate impacts on the affected environment:

- USACE, Massachusetts Hurricane Evacuation Study Technical Data Report, Chapter 2 Hazards Analyses (2016)[10]
- USACE, New England Hurricane Evacuation Study Technical Data Report (June 2016)[11]
- Massachusetts Emergency Management Agency, Cape Cod Emergency Traffic Plan (2018)[12]

2.2 Massachusetts Climate Resilience Design Standards Tool

The 2021 Massachusetts Environmental Policy Act Interim Protocol on Climate Change Adaptation and Resiliency (2021 Interim Protocol) requires that all new project filings attach an output report from the RMAT Climate Resilience Design Standards Tool (RMAT Tool) and encourages use of recommended design standard outputs. The RMAT Tool is intended to provide a basis-of-discussion and point of reference for planning, early design, and evaluation that is standardized across the Commonwealth. The RMAT Tool provides a preliminary climate change exposure and risk rating for projects and recommended climate resilience design standards for physical assets based on user provided information, project location, and existing statewide climate data for sea level rise (SLR)/storm

[5] https://map1.msc.fema.gov/data/25/S/PDF/25001CV000B.pdf?LOC=51a412c9cdcc22ab0113e2e0169d67bd
[6] https://www.federalregister.gov/documents/2024/07/11/2024-15170/fema-policy-federal-flood-risk-management-standard-ffrms
[7] https://doi.org/10.5281/zenodo.10621070
[8] https://www.weather.gov/media/owp/hdsc_documents/Atlas14_Volume10.pdf
[9] https://gis.data.mass.gov/maps/a9e9d37e363f434f84b28e791b23398b/about
[10] https://www.nae.usace.army.mil/Portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/MA_Ch%202_Hazards%20Analysis.pdf
[11] https://www.nae.usace.army.mil/portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/New%20England%20Hurricane%20Evacuation%20Study.pdf
[12] https://www.mass.gov/doc/cape-cod-emergency-traffic-plan/download

surge (SS), precipitation, and temperature.[13] **Attachments 1 and 2**, contain the RMAT Tool output reports for the Sagamore and Bourne Bridges, respectively.

2.2.1 Exposure Rating

The Project Limits and associated bridges, interchanges, and stormwater control measures were input to the RMAT Tool, Version 1.2.[14] The RMAT Tool identified preliminary high exposure and risk ratings for SLR/coastal SS, urban/riverine flooding, and extreme heat.[15] **Table 2-1** summarizes the scoring rationale for the exposure ratings for the bridges' Project Limits from the RMAT Tool. In addition to the climate parameters in the RMAT Tool, MassDOT also evaluated winter weather and wind as they affect bridge design and stability.

Table 2-1. RMAT Tool Exposure Scores and Rational (Sagamore Bridge and Bourne Bridge)

Climate Parameter	Scoring Rationale – Project Exposure Score	
	Sagamore Bridge	**Bourne Bridge**
Sea Level Rise/Storm Surge	High Exposure: • Located within the predicted mean high water shoreline by 2030 • Exposed to the 1% annual coastal flood event as early as 2030 • Located within the 0.1% annual coastal flood event within the project's useful life	High Exposure: • Located within the predicted mean high water shoreline by 2030 • Exposed to the 1% annual coastal flood event as early as 2030 • Located within the 0.1% annual coastal flood event within the project's useful life
Extreme Precipitation - Urban Flooding	High Exposure: • Increased impervious area • No historical flooding at project site • Maximum annual daily rainfall exceeds 10 inches within the overall project's useful life • Existing impervious area of the project site is between 10% and 50%	High Exposure: • Increased impervious area • No historical flooding at project site • Maximum annual daily rainfall exceeds 10 inches within the overall project's useful life • Existing impervious area of the project site is between 10% and 50%

[13] The Resilient Massachusetts Action Team (RMAT) Tool does not replace location-specific engineering calculations and analyses, existing code and regulatory requirements, risk and vulnerability assessments, or cost-benefit analyses.

[14] https://resilient.mass.gov/rmat_home/designstandards/

[15] Projects that receive a High Exposure score to a climate hazard will always receive a High Risk Rating for that hazard for all building/facility and infrastructure assets based on the relationships underlying the Resilient Massachusetts Action Team (RMAT) Tool.

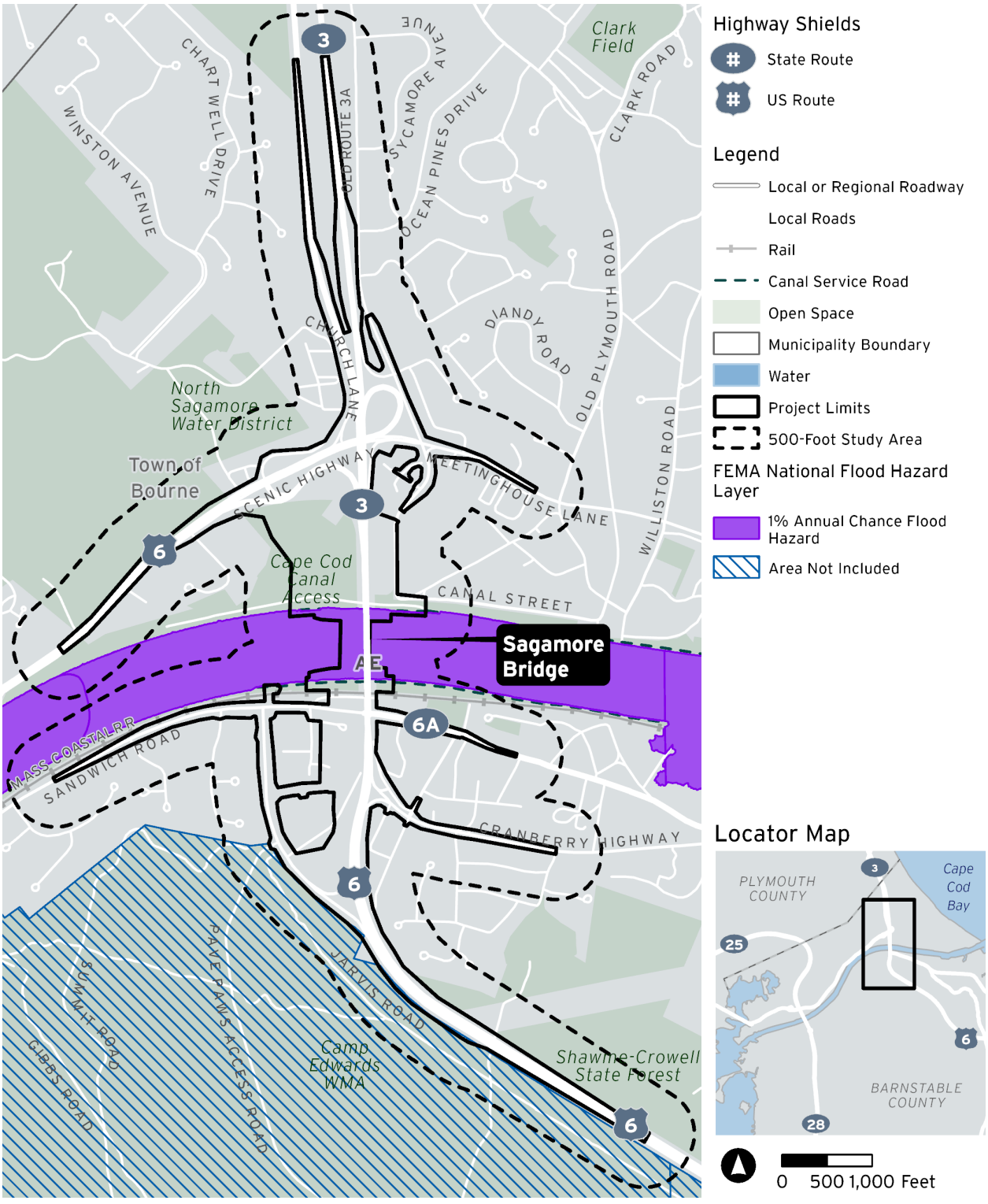
Climate Parameter	Scoring Rationale – Project Exposure Score	
	Sagamore Bridge	**Bourne Bridge**
Extreme Precipitation - Riverine Flooding	High Exposure: • Part of the project is within a mapped Federal Emergency Management Agency (FEMA) floodplain, outside of the Massachusetts Coast Flood Risk Model (MC-FRM) • Part of the project is within 100 feet of a waterbody • Project is potentially susceptible to riverine erosion • No historical riverine flooding at project site	High Exposure: • Part of the project is within a mapped FEMA floodplain, outside of the MC-FRM • Part of the project is within 100 feet of a waterbody • Project is potentially susceptible to riverine erosion • No historical riverine flooding at project site
Extreme Heat	High Exposure: • Increased impervious area • Existing trees are being removed as part of the proposed project • Existing impervious area of the project site is between 10% and 50% • Located within 100 ft of existing water body • 10 to 30 day increase in days over 90° Fahrenheit within project's useful life	High Exposure: • Increased impervious area • Existing trees are being removed as part of the proposed project • Existing impervious area of the project site is between 10% and 50% • Located within 100 ft of existing water body • 10 to 30 day increase in days over 90° Fahrenheit within project's useful life

Source: RMAT Tool Project Report for Sagamore Bridge, created November 21, 2024, and Bourne Bridge, created January 22, 2025.

2.2.2 Riverine Flooding Exposure Review

Exposure inherently varies geographically, and exposure outputs do not necessarily apply to the entire Project Limits or all Program elements, or over the entire useful life of Program elements. In reviewing published data with the RMAT Tool outputs for the project sites, it was determined that Riverine Flooding exposure is erroneous; the Cape Cod Canal connects two bays: Cape Cod Bay and Buzzards Bay. The Project Limits include areas within a mapped FEMA floodplain, outside of the Massachusetts Coast Flood Risk Model (MC-FRM); FEMA floodplains do not distinguish between inland and coastal floodplains, and the extent of the FEMA floodplain within the Project Limits originates from the tidal canal (**Figure 2-2** and **Figure 2-3**).

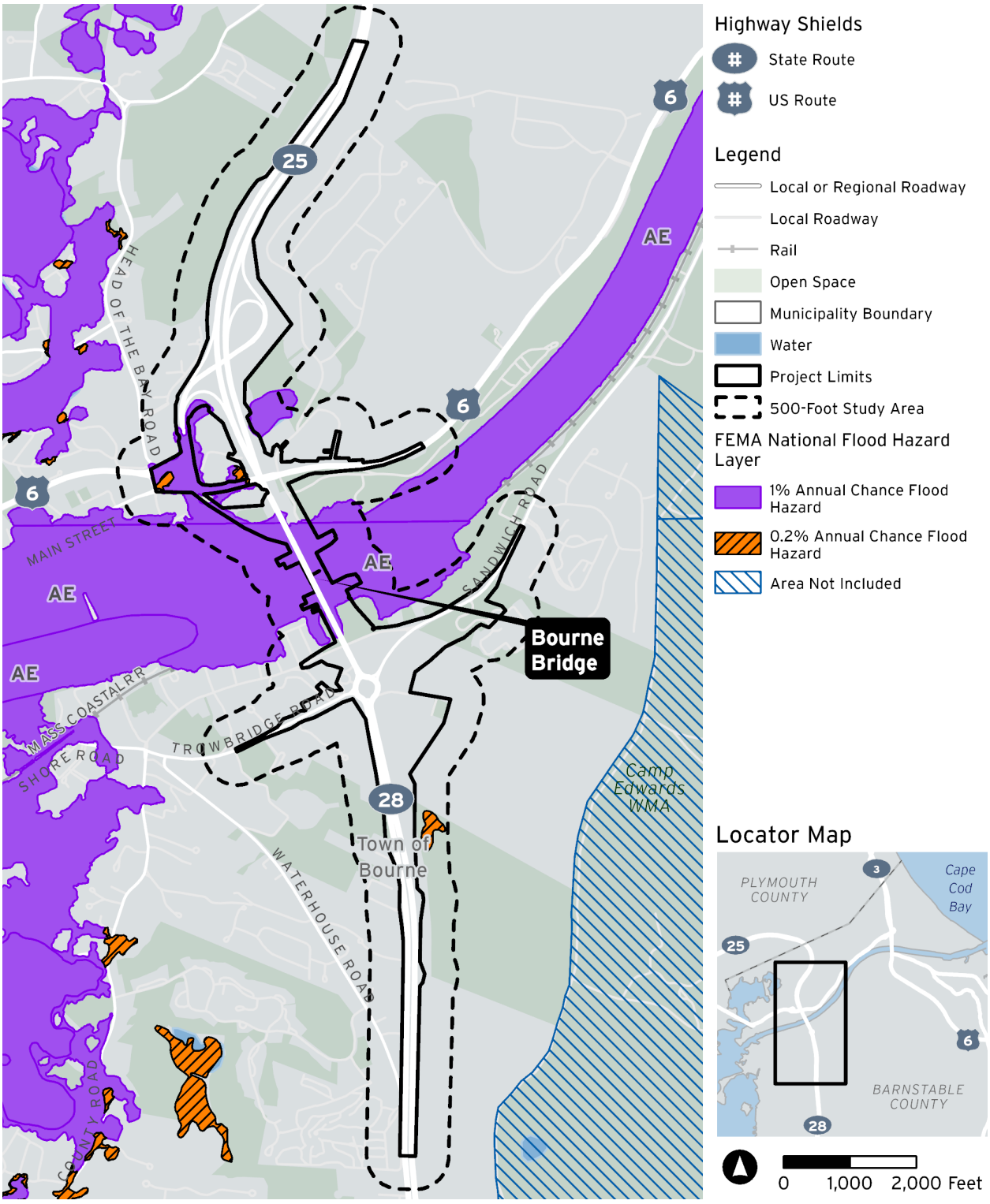
Figure 2-2. FEMA Floodplain Limits (Sagamore Bridge)



Source: Massachusetts Department of Transportation, 2024

FEMA = Federal Emergency Management Agency

Figure 2-3. FEMA Floodplain Limits (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

FEMA = Federal Emergency Management Agency

2.2.3 Environmental Justice Considerations

In accordance with the Final Massachusetts Environmental Policy Act Interim Protocol for Analysis of Project Impacts on Environmental Justice Populations, this report also considers whether the Build Alternative will increase or reduce the impacts of climate change on identified Environmental Justice populations. Refer to **Section 4.9** of the DEIR for identification of Environmental Justice populations and an assessment of whether these populations would experience disproportionately high and adverse construction-related or operational impacts due to the Build Alternative. As described herein, the project is not anticipated to increase the impacts of climate change.

2.2.4 Integration of RMAT Tool Outputs

Table 2-2 summarizes the RMAT Tool outputs associated with Sea Level Rise/Storm Surge, Extreme Precipitation – Urban Flooding, and Extreme Heat and discussed in the following respective sections, including if and how they were considered to evaluate the effect on the No Build Alternative and Build Alternative.

Table 2-2. RMAT Tool Outputs and Applicability to Assessment

Applicable Design Criteria	Values Provided	Methodology Discussed Herein	Affected Environment
Projected Tidal Datum	No	Section 2.3.2 Tides	Canal, Bridge, Stormwater Control Measures (SCM), Transportation, Mobility
Projected Water Surface Elevation	Yes	Section 2.3.3 Storm Surge and Coastal Inundation	SCMs, Land Cover, Transportation, Mobility
Projected Wave Action Water Elevation	Yes	Section 2.3.4 Wave Hazards	Not Applicable
Projected Wave Heights	Yes	Section 2.3.4 Wave Hazards	Not Applicable
Projected Duration of Flooding	No	Section 2.3.3 Storm Surge and Coastal Inundation	Not Applicable
Projected Design Flood Velocity	No	Section 2.3.5 Scour	Bridge
Projected Scour and Erosion	No	Section 2.3.5 Scour	Bridge
Projected Total Precipitation Depth and Peak Intensity for 24-hr Design Storms	Yes	Section 2.4.1 24-hour Rainfall Depth	SCMs, Land Cover, Transportation, Mobility
Projected Riverine Peak Discharge and Peak Flood Elevation	No	Not included in assessment – Not exposed to riverine environment	Not applicable

Applicable Design Criteria	Values Provided	Methodology Discussed Herein	Affected Environment
Projected Annual/Summer/Winter Average Temperatures	No	Not included in assessment – No affected environment to analyze	Not applicable
Projected Heat Index	No	Not included in assessment – No affected environment to analyze	Not applicable
Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F	No	• Section 2.5 Extreme Heat • Section 2.6 Winter Weather	Bridge, Transportation, Mobility
Projected Number of Heat Waves Per Year and Average Heat Wave Duration	No	Not included in assessment – No affected environment to analyze	Not applicable

Table 2-3 summarizes the recommendations taken from the RMAT Tool and integrated into the methodology to assess the impacts of the No Build Alternative and Build Alternative on the affected environment and to inform mitigation plans.

Table 2-3. Impacts Assessed using RMAT Tool Recommendations

RMAT Tool Output	Recommendation	Affected Environment (Impact)	Useful Life	Assessed
Projected Temperatures	2090, 90th Percentile	Bridge (Expansion Joints)	100 years	Likelihood of temperatures greater than 120°F
Projected Total Precipitation Depth and Peak Intensity for 24-hr Design Storms	2070, 100-year event	Stormwater Control Measures (Infiltration Basins)	50 years	Sizing and performance under recommended event
Projected Total Precipitation Depth and Peak Intensity for 24-hr Design Storms	2070, 100-year event	• Land Cover • Transportation • Mobility	• Not applicable • 50 years • 30 years	Localized Stormwater Flooding under recommended event
Projected Days Per Year With Max Temp >90°F	2050, 90th Percentile	Transportation (Pavement)	25 years (Pavement)	Increased days above 90°F
Projected Days Per Year With Max Temp >90°F	2050, 90th Percentile	Mobility (Active Transportation Use)	30 years	Increased days above 90°F

RMAT Tool Output	Recommendation	Affected Environment (Impact)	Useful Life	Assessed
Projected Days Per Year With Max Temp <32°F	2050, 90th Percentile	Transportation (Snow and Ice on Roadways)	25 years (Pavement)	Days below 32°F

MassDOT did not ultimately use the projected water surface elevation values from the RMAT Tool to assess impacts due to near-term projections from the RMAT Tool being less conservative than other methods to establish horizontal and vertical floodplain extents (refer to **Section 2.3.3**).

MassDOT did not ultimately use the projected wave heights and wave action water surface elevation values from the RMAT Tool to assess impacts due to lack of affected environment in the No Build Alternative and Build Alternative. **Section 2.3.4** discusses this further.

2.3 Sea Level Rise/Storm Surge

2.3.1 Sea Levels

Global sea level trends and relative sea level trends are different measurements.[16] Relative sea levels are measured by tide gauges (height of the sea relative to land) and satellite altimetry (sea surface heights) for a specific location. Relative sea levels fluctuate throughout the year due to tides and changes in seasons, and the movement of nearby land; some years sea level may be higher than others due to natural fluctuations and climate cycles, such as El Niño.

2.3.1.1 Observations

The closest tide station to the Program Limits is the Woods Hole tide station (NOAA Gage: 8447930). **Figure 2-4** depicts measured changes in sea level over the past 50 years at Woods Hole tide station overlaid with reconstructed sea levels and a trajectory trend line.[17] According to data made available through the Global Sea Level Change Website developed by NASA in collaboration with the United States Department of Defense, United States Department of State, and the World Bank using authoritative data from satellites, tide gauges, and the Intergovernmental Panel on Climate Change 6th Assessment Report, relative sea level rose approximately 0.9 inch (0.08 feet) from 1993 to 2000 and 4.5 inches (0.38 feet) from 2000 to present day at the Woods Hole tide station.[18]

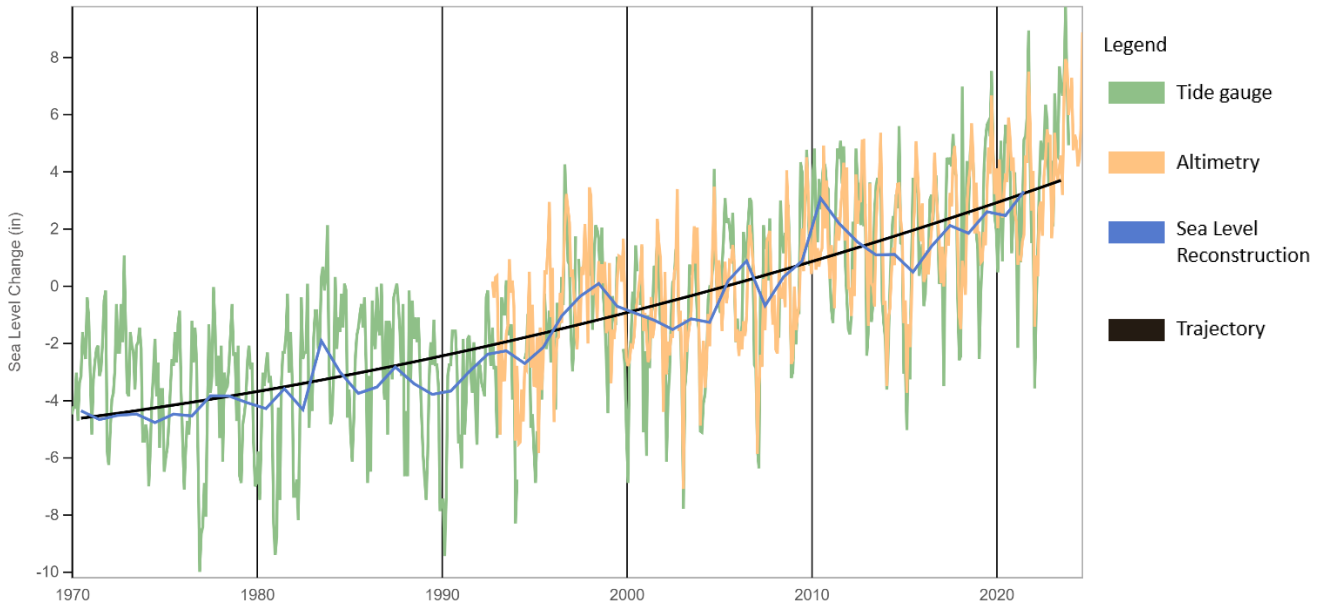
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[16] On average, sea level is rising around the globe. However, sea level is changing at different rates in different coastal regions as a result of many interacting processes. https://oceanservice.noaa.gov/facts/sealevel-global-local.html

[17] Sea Level reconstruction based on Dangendorf, S. (2024). Kalman Smoother Sea Level Reconstruction [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10621070

[18] The data, curated and processed by the NASA Sea Level Change Team, were obtained from the Global Sea Level website at earth.gov/sealevel on December 5, 2024.

Figure 2-4. Satellite Altimetry and Tide Gauge Measurements (Woods Hole, MA)



Source: Global Sea Level website at earth.gov/sealevel

Note: The satellite record started in 1993. The data are curated and processed by the NASA Sea Level Change Team.

2.3.1.2 Projections

Future SLR projections are inherently uncertain due to complex processes, including human response and actions. MassDOT conducted an analysis of best available data to evaluate the Program's vulnerability to SLR. Future relative sea level rise (RSLR) projections were taken from the Commonwealth's "ResilientMass Maps and Data Center,"[19] (ResilientMass), which references the Massachusetts Climate Change Projections published by MA EEA in 2018 and the USACE scenario-based sensitivity analysis published in the Cape Cod Canal Highway Bridges MRER/EA in 2020.[20] Future RSLR projections are based on historical rates of SLR, as well as increased rates of SLR based on varying emissions scenarios, and estimated for future time periods (or planning horizons).

Table 2-4 lists the RSLR values for Woods Hole tide station provided by ResilientMass;[21] these values reference a tidal epoch centered on the year 2000 and are relative to the North American Vertical

[19] https://resilientma-mapcenter-mass-eoeea.hub.arcgis.com/#ClimateDashboard

[20] The 2022 National Oceanic and Atmospheric Administration sea level rise projections for Woods Hole Stations were also reviewed. The values are generally lower than the values being used by ResilientMass (with the exception of 7.87 feet of relative sea level rise by 2100). Given the uncertainty of relative sea level rise projections, a value of 7.7 feet was used to remain consistent with ResilientMass data.

[21] Massachusetts Executive Office of Energy and Environmental Affairs. 2018. Massachusetts Climate Change Projections. March. p. 16. https://eea-nescaum-dataservices-assets-prd.s3.us-east-1.amazonaws.com/resources/production/MA%20Statewide%20and%20MajorBasins%20Climate%20Projections_Guidebook%20Supplement_March2018.pdf.

Datum of 1988 (NAVD88).[22] The RMAT Tool references SLR data associated with the High Scenario, which is extremely unlikely to exceed (99.5%).

Table 2-4. Relative Mean Sea Level Rise (feet NAVD88) for Woods Hole, MA

Scenario	Probabilistic Projections Given a High Emissions Pathway	2030	2050	2070	2100
Intermediate	Unlikely to exceed (83% probability)	0.6	1.3	2.3	4.0
Intermediate – High	Extremely unlikely to exceed (95% probability)	0.8	1.7	2.9	5.1
High	Extremely unlikely to exceed (99.5% probability) – used by the Resilient Massachusetts Action Team (RMAT) Tool	1.1	2.4	4.2	7.7
Extreme (Maximum Physically Plausible)	Exceptionally unlikely to exceed (99.9% probability)	1.3	3.1	5.4	10.3

Source: Massachusetts Executive Office of Energy and Environmental Affairs. 2018. Massachusetts Climate Change Projections. March. p. 16. https://eea-nescaum-dataservices-assets-prd.s3.us-east-1.amazonaws.com/resources/production/MA%20State wide%20and%20MajorBasins%20Climate%20Projections_Guidebook%20Supplement_March2018.pdf.

NAVD88 = North American Vertical Datum of 1988

Table 2-5 lists the RSLR values for the Woods Hole tide station provided in the USACE MRER/EA;[23] these values reference a tidal epoch centered on the year 1992 and are relative to local mean sea level. The sea level change rates required by USACE for scenario-based sensitivity analysis consider a project start in 2025 with future conditions through 2125. Through 2075, the historical rate of SLR (low) would result in 0.78-foot increase, while the intermediate and high rates would cause increases of 1.40 feet and 3.34 feet, respectively. Through 2125, the historical rate of SLR results in a rise of 1.26 feet; the intermediate and high rates would increase sea levels 2.83 feet and 7.82 feet, respectively, within that same time period.

[22] A tidal epoch is a 19-year period of time over which tide observations are taken and reduced to obtain values for tidal datums. The present national tidal datum epoch (NTDE) is 1983 through 2001.

[23] U.S. Army Corps of Engineers (USACE). 2020. Cape Cod Canal Highway Bridges, Bourne, Massachusetts. Major Rehabilitation Evaluation Report and Environmental Assessment. March. p. 65. https://www.nae.usace.army.mil/Portals/74/docs/Topics/Cape%20Cod%20Canal%20Bridges/Reports/FinalMRERDocument.pdf.

Table 2-5. Relative Sea Level Change Predictions (feet relative to local mean sea level) for Woods Hole, MA

Value	Relative Sea Level Rise Rate/Year												
	2000	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100	2110	2120
USACE Low	0.08	0.17	0.27	0.36	0.45	0.55	0.64	0.74	0.83	0.93	1.02	1.12	1.21
USACE Intermediate	0.08	0.20	0.33	0.49	0.66	0.85	1.05	1.28	1.52	1.78	2.06	2.35	2.67
USACE High	0.10	0.29	0.56	0.89	1.31	1.80	2.36	2.99	3.70	4.49	5.35	6.28	7.28

Source: U.S. Army Corps of Engineers (USACE). 2020. Cape Cod Canal Highway Bridges, Bourne, Massachusetts. Major Rehabilitation Evaluation Report and Environmental Assessment. March. p. 65. https://www.nae.usace.army.mil/Portals/74/docs/Topics/Cape%20Cod%20Canal%20Bridges/Reports/FinalMRERDocument.pdf.

2.3.1.3 Recommended Data and Methodology

The impacts of RSLR vary based on the affected environment, and the RSLR rates considered for the Program and associated improvements were determined based on:

- Useful life or year through which the infrastructure is expected to last
- The functional requirements through the infrastructure's useful life
- Estimated adaptive capacity at the end of the infrastructure's useful life
- Past published USACE assessments of construction costs and impacts

Table 2-6 summarizes the RSLR scenarios considered for assessing future conditions for the No Build Alternative and Build Alternative.

Table 2-6. Relative Sea Level Rise Recommended for Methodology

Affected Environment	Useful Life (if any)	Impact	Recommended Relative Sea Level Rise to Assess Impacts	ResilientMass Time Horizon	USACE Time Horizon
Canal	NA	Navigational Clearance	3 feet	Between 2050[1] and 2070[2]	Between 2070[3] and 2125[4]
Bridge	100 years	Pier Scour	7.7 feet	2100[5]	Between 2120[3] and 2125[3]
Stormwater Control Measures	• NA • 50 years	• Outfall • Infiltration Basins	1.1, 2.4, and 4.2 feet*	2030[5], 2050[5], 2070[5]	2035[3], 2060[3], and 2085[3]

Affected Environment	Useful Life (if any)	Impact	Recommended Relative Sea Level Rise to Assess Impacts	ResilientMass Time Horizon	USACE Time Horizon
Land Cover	NA	Floodplain Function	4.2 feet	2070[5]	2085[3]
Transportation	50 years	Roadways and Evacuation Route Flooding	4.2 feet	2070[5]	2085[3]
Mobility	30 years	Shared-use Path Flooding	4.2 feet	2070[5]	2085[3]

Notes:
[1] ResilientMass Extreme scenario
[2] ResilientMass Intermediate-High scenario
[3] U.S. Army Corps of Engineers (USACE) High Rate
[4] U.S. Army Corps of Engineers (USACE) Intermediate Rate
[5] ResilientMass High Scenario (used in the Resilient Massachusetts Action Team [RMAT] Tool)
* Multiple relative sea level rises were recommended for evaluating the effect of relative sea level rise on existing outfalls that are part of the stormwater system.

The following subsections in **Section 2.3** incorporate the recommended RSLR values to assess impact on tides, SS and coastal inundation, wave hazards, and scour on the affected environment by the No Build Alternative and Build Alternative. The respective sections present the specific methodologies.

2.3.2 Tides

The range of tides and associated elevations observed over the National Tidal Datum Epoch are known as a tidal datum.[24] **Table 2-7** provides the phases of tides for a tidal datum as defined by NOAA.

Table 2-7. Tidal Datums

Tidal Datum	Definition
Mean Higher High Water (MHHW)	The average of the higher high-water height of each tidal day observed over the National Tidal Datum Epoch.
Mean High Water (MHW)	The average of all the high water heights observed over the National Tidal Datum Epoch.
Mean Sea Level (MSL)	The arithmetic mean of hourly heights observed over the National Tidal Datum Epoch.
Mean Tide Level (MTL)	The arithmetic mean of mean high water and mean low water.

[24] Tidal datum is a standard vertical elevation reference defined by certain phases of the tide. The datum is unique to each station, which has a fixed base elevation at a tide station to which all water level measurements are referred. The National Tidal Datum Epoch is the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values for tidal datums.

Tidal Datum	Definition
Mean Low Water (MLW)	The average of all the low water heights observed over the National Tidal Datum Epoch.
Mean Lower Low Water (MLLW)	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch.

Source: National Oceanic and Atmospheric Administration Tidal Datums. https://tidesandcurrents.noaa.gov/datum_options.html

2.3.2.1 Observations

Available tidal datums for the existing bridges that cross the canal were published in the USACE MRER/EA and reflect a tidal epoch centered on 1992. ResilientMass RSLR projections reference a tidal epoch centered on the year 2000. A value of 0.9 inch was added to the tidal datum for each bridge to account for the RSLR that occurred from 1993 to 2000 as measured by the NOAA Sea Level Change Team to provide a consistent temporal reference for analyses. The resulting tidal datums were transformed using NOAA's Datum to provide elevations in NAVD88 as a common geodetic datum for analysis.[25]

2.3.2.2 Projections

Projected tidal datums are not available through the RMAT Tool for Cape Cod Canal.[26] Projected RSLR values from ResilientMass were added to the tidal datums, which are summarized in **Table 2-8** and **Table 2-9** for Sagamore Bridge and Bourne Bridge, respectively.

Table 2-8. Tidal Datums and Relative Sea Level Rise (Sagamore Bridge)

Tidal Datums[1,3] (NAVD88)		Adjusted for Relative Sea Level Rise (NAVD88)				
		+ 1.1 feet (2030)	+ 2.4 feet (2050)	+ 3.0 feet[2]	+ 4.2 feet (2070)	+7.7 feet (2100)
Mean Higher High Water (MHHW)	3.45	4.55	5.85	6.37	7.65	11.15
Mean High Water (MHW)	3.08	4.18	5.48	6.00	7.28	10.78
Mean Sea Level (MSL)	-0.49	0.62	1.92	2.44	3.72	7.22

[25] https://vdatum.noaa.gov/vdatumweb/

[26] The Resilient Massachusetts Action Team (RMAT) Tool had the following output for projected tidal datums for both bridges, "This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale." The Cape Cod Canal is a manmade feature.

Tidal Datums[1,3] (NAVD88)		Adjusted for Relative Sea Level Rise (NAVD88)				
		+ 1.1 feet (2030)	+ 2.4 feet (2050)	+ 3.0 feet[2]	+ 4.2 feet (2070)	+7.7 feet (2100)
Mean Tide Level (MTL)	-0.66	0.45	1.75	2.27	3.55	7.05
Mean Low Water (MLW)	-4.38	-3.28	-1.98	-1.45	-0.18	3.33
Mean Lower Low Water (MLLW)	-4.69	-3.59	-2.29	-1.76	-0.48	3.02

Notes:

[1] Based on tidal datums reported for the bridge in the U.S. Army Corps of Engineers (USACE) Major Rehabilitation Evaluation Report/Environmental Assessment, adjusted for relative sea level rise (RSLR) between 1993 and 2000 (0.9 inch), and then converted to North American Vertical Datum of 1988 (NAVD88).

[2] The RSLR of 3 feet informs navigational clearance considerations and is based on a tidal epoch centered on the year 1992, so it is inclusive of the 0.9 inch of RSLR.

[3] Values shown for tidal datums are rounded to the nearest hundredths decimal.

Table 2-9. Tidal Datums and Relative Sea Level Rise (Bourne Bridge)

Tidal Datums[1,3] (NAVD88)		Adjusted for Relative Sea Level Rise (NAVD88)				
		+ 1.1 ft. (2030)	+ 2.4 ft. (2050)	+ 3.0 ft.[2]	+ 4.2 ft. (2070)	+7.7 ft. (2100)
Mean Higher High Water (MHHW)	2.03	3.13	4.43	4.95	6.23	9.73
Mean High Water (MHW)	1.65	2.75	4.05	4.57	5.85	9.35
Mean Sea Level (MSL)	-0.50	0.61	1.91	2.43	3.71	7.21
Mean Tide Level (MTL)	-0.60	0.51	1.81	2.33	3.61	7.11
Mean Low Water (MLW)	-2.84	-1.74	-0.44	0.09	1.37	4.87
Mean Lower Low Water (MLLW)	-3.12	-2.02	-0.72	-0.19	1.09	4.59

Notes:

[1] Based on tidal datums reported for the bridge in the U.S. Army Corps of Engineers' Major Rehabilitation Evaluation Report, adjusted for relative sea level rise (RSLR) between 1993 and 2000 (0.9 inch), and then converted to North American Vertical Datum of 1988 (NAVD88).

[2] The RSLR of 3 feet informs navigational clearance considerations and is based on a tidal epoch centered on the year 1992, so it is inclusive of the 0.9 inch of RSLR.

[3] Values shown for tidal datums are rounded to the nearest hundredths decimal.

2.3.2.3 Recommended Data and Methodology

The impacts of tides vary based on the affected environment. **Table 2-10** summarizes the tidal datums and associated RSLR considered for assessing future conditions for the No Build Alternative and Build Alternative. Associated elevations of tidal datums for the replacement bridges are summarized in **Table 2-8** and **Table 2-9.** MassDOT used mean higher high water (MHHW) as the primary tidal datum to assess impacts, with the exception of Storm Control Measures (SCM), which considers the full range.

Table 2-10. Tidal Datums Recommended for Analyses

Affected Environment	Impact from Relative Sea Level Rise	Recommended Relative Sea Level Rise for Effect	Tidal Datum
Canal	Navigational Clearance (135 feet)	3 feet	Mean Higher High Water
Stormwater Control Measures	• Submerged or partially submerged outfalls • Infiltration Basin Flooding	1.1, 2.4, and 4.2 feet	• Mean High Water • Mean Sea Level • Mean Tide Level • Mean Low Water • Mean Lower Low Water

MassDOT used the following methods with the recommended data to assess the impacts of the No Build Alternative and the Build Alternative on the affected environment:

- To evaluate the effect on navigational clearance, MassDOT subtracted the existing vertical clearance of 135 feet from the bridges' low chord elevations. If the MHHW elevation was greater than resulting elevation, it was assumed to be affected. If affected, additional tidal datums were assessed to estimate the percentage likelihood of being impacted over a tide cycle.
- To evaluate the effect on stormwater outfalls, the tidal datums were compared with the outfall invert and crown elevations. If the tidal datum exceeded the outfall invert elevation, it was assumed to be partially submerged, with potential backflow through the system. If the tidal datum exceeded the outfall crown elevation, it was assumed to be fully submerged, with potential backflow through the system.
- To evaluate the effect on stormwater infiltration basins, the tidal datums were compared with the proposed basin bottom and top elevations. Once the overflow outlet structures are designed for the infiltration basins, the outlet elevation should also be considered. If the tidal datum exceeded the proposed basin bottom elevation, the basin was assumed to have reduced infiltration capacity due to groundwater rise. If the tidal datum exceeds the proposed overflow structure's outlet elevation, the basin will be assumed to be partially full to the elevation of the tide. If the tidal

datum exceeded the proposed basin top elevation, it was assumed that the tides overtopped the basin and resulted in localized flooding.

2.3.3 Storm Surge and Coastal Inundation

Storm surge is the abnormal rise in water level over and above typical tides caused by extreme wind and pressure forces. Storm surge is an important coastal process to consider during the design of infrastructure in coastal zones because it increases the design stillwater level, which allows floodwaters and waves to reach higher elevations. Three major hurricanes have affected Cape Cod to date: Hurricane Carol and Hurricane Edna in 1954, and Hurricane Bob in 1991. No records of water elevation were available for these storms within the Cape Cod Canal. However, at the NOAA Woods Hole Station, a peak storm surge elevation for Hurricane Bob was recorded at 5.8 feet (mean sea level datum) on August 19, 1991. Given there were no available observations or records on extents and elevations of historical coastal events in Cape Cod Canal, existing models that assessed SS and coastal inundation were used.

2.3.3.1 Modeled Historical

The datasets that describe current SS conditions for the Program Limits include the following:

- SLOSH model developed by the National Weather Service
- FIS prepared by FEMA

Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model

The SLOSH numerical SS model calculates potential surge heights from hurricanes and simulates the routing of SS into sounds, bays, estuaries, and coastal river basins.[27] The SLOSH model depicts areas of possible surge flooding from the maximum of maximum event of a hurricane during a high tide landfall.[28] The SLOSH model does not reference a specific likelihood of occurrence (e.g., 1% annual or 100-year flood event). Additional heights of waves generated on top of the stillwater SS are not captured in the SLOSH model.[29] **Figure 2-5** and **Figure 2-6** show the inundation zones for the Study Areas for Sagamore Bridge and Bourne Bridge, respectively, based on the SLOSH model 2022, Version 3, downloaded by the Massachusetts Office of Coastal Zone Management on February 21, 2024.[30]

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[27] Massachusetts Hurricane Evacuation Study Technical Data Report p 2-5

[28] The MOM event represents the worst-case scenario for storm surge inundation during a landfall, specifically when the hurricane hits at high tide, considering all possible combinations of storm characteristics like forward speed, trajectory, and intensity, essentially representing the highest potential storm surge height for a given location under ideal conditions for maximum surge generation. Hurricanes are categorized on a scale from one to five, with five being the most extreme event. In Massachusetts, hurricanes are categorized only from one to four.

[29] Massachusetts Hurricane Evacuation Study Technical Data Report p. 2-4

[30] National Oceanic and Atmospheric Administration (NOAA) National Hurricane Center (NHC) Storm Surge Unit, SLOSH (Sea, Lake, and Overland Surges from Hurricanes) Model 2022 (Tile Service), accessed from MassGIS on December 6, 2024. https://gis.data.mass.gov/maps/a9e9d37e363f434f84b28e791b23398b/about

In addition to the inundation maps, MassDOT downloaded SLOSH model hydrographs to support scour analyses, which included the peak water surface elevation associated with Category 1 through Category 4 hurricanes (**Table 2-11**).

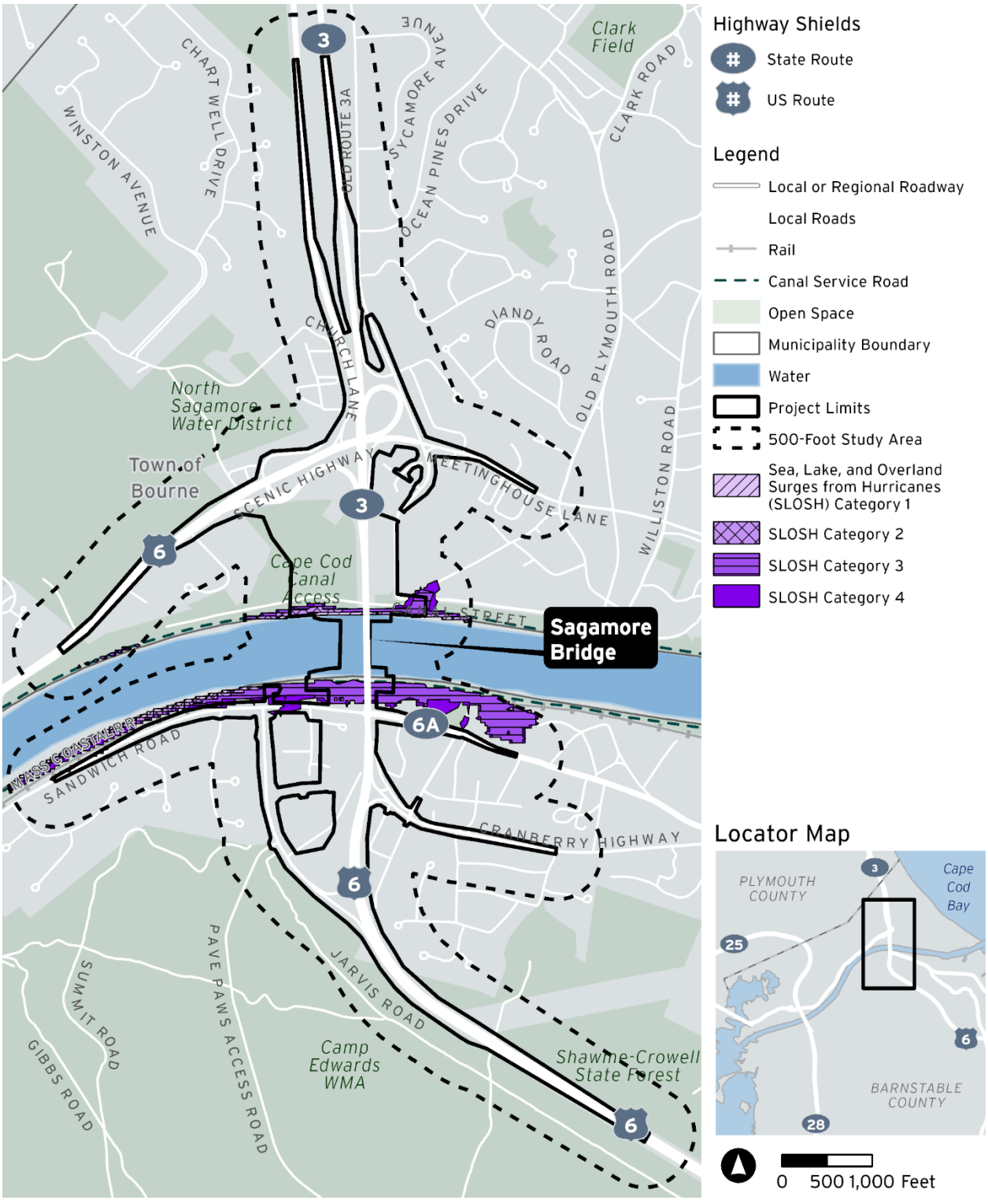
Table 2-11. Maximum Water Surface Elevation from SLOSH Model Hydrographs

Hurricane Category	Water Surface Elevation (feet-NAVD88)[1]
1	9.9
2	16.3
3	22.4
4	28.2

[1] Water surface elevations provided by the SLOSH model hydrographs do not account for additional height generated by waves, including wave action or wave run-up.

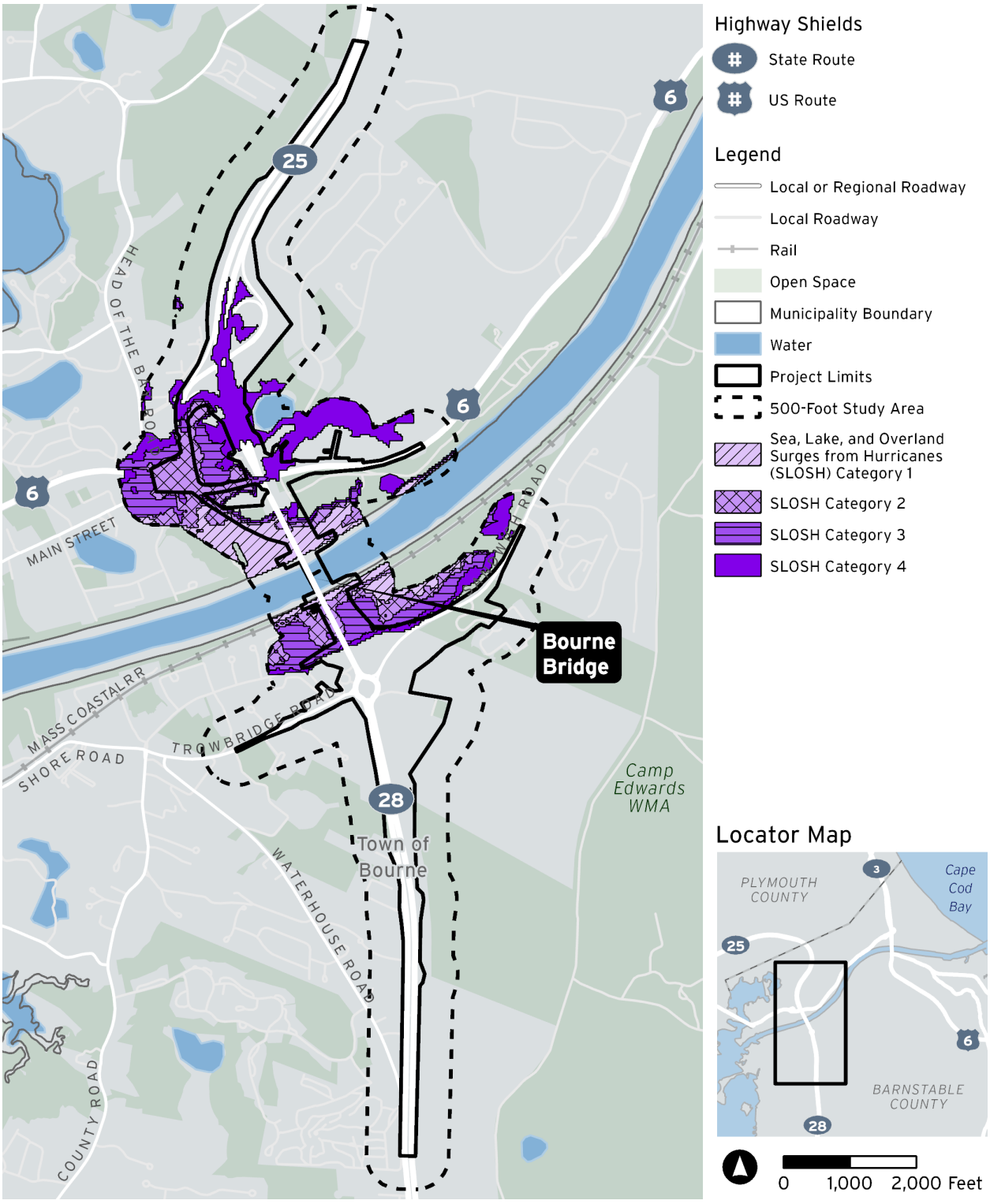
NAVD88 = North American Vertical Datum of 1988, SLOSH = Sea, Lake, and Overland Surges from Hurricanes

Figure 2-5. SLOSH Model Inundation Map (Sagamore Bridge)



Source: Massachusetts Department of Transportation, 2024

Figure 2-6. SLOSH Model Inundation Map (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

FEMA Flood Insurance Study

Cape Cod—including the Cape Cod Canal, Buzzards Bay, and Cape Cod Bay—were studied and detailed in the FEMA FIS Report for Barnstable County, MA, effective date July 6, 2021. The FIS Report lists the stillwater elevations along the shoreline of Buzzards Bay and Cape Cod Bay at transects for the 10-, 50-, 100-, and 500-year storm events.[31] As part of the Program's scour hydraulic analyses, stage hydrographs for the 2-, 10-, 25-, 50-, 100-, 200-, and 500-year storm events were developed for each bridge using the FIS Stillwater Elevations and SLOSH model hydrographs. **Table 2-12** summarizes the maximum water surface elevations and associated likelihoods developed for and from 2D hydraulic analyses to evaluate scour depth.

Table 2-12. Stillwater Elevations

Design Storm Event (annual likelihood)	Water Surface Elevation (feet-NAVD88)			
	Cape Cod Bay[1]	Buzzards Bay[1]	Sagamore Bridge[2]	Bourne Bridge[2]
2-year (50%)	7.5*	5.4*	6.9	To be determined
10-year (10%)	8.4	8.7	8.4	To be determined
25-year (4%)	8.9*	10.8*	9.2	To be determined
50-year (2%)	9.4	12.3	9.9	To be determined
100-year (1%)	9.6	13.9	10.4	To be determined
200-year (0.5%)	10.1*	15.2*	11.0	To be determined
500-year (0.2%)	10.7	17.0	11.2	To be determined

* Estimated by extrapolating or interpolating data.

[1] Source is the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) Report for Barnstable County, Massachusetts, effective date July 6, 2021; FIS water surface elevations and associated hydrographs were used as inputs for the 2D hydraulic model.

[2] Source is maximum water surface elevation output from the 2D hydraulic model developed for scour analyses. Analyses not yet performed for Bourne Bridge (as of January 1, 2025).

NAVD88 = North American Vertical Datum of 1988

2.3.3.2 Projections

The MC-FRM is a physics-based approach to water level increases, wave dynamics, and flooding progression using ResilientMass RSLR projections for 2030, 2050, and 2070 planning horizons. The model dynamically includes the impacts of tides, waves, wave set-up, wave run-up and overtopping, SS, winds, and currents over a range of storm conditions. The MC-FRM is the result of over 1,000 simulations of storms, including both extra-tropical (i.e., nor'easters) and tropical (i.e., hurricanes) cyclones, and was calibrated to historical and contemporary storm events. This statistically robust approach provides information corresponding to an annual exceedance probability, such as the 1% or

[31] There are no coastal transects in Cape Cod Canal. Coastal transect 5 was used for Cape Cod Bay; coastal transect 200 was used for Buzzards Bay.

100-year return period. The landscape of the model is based on topography and bathymetry conditions at the time of model mesh creation (2016-2017).[32]

The MC-FRM flood extents from the 1% annual exceedance probability for 2030, 2050, and 2070 are shown in **Figure 2-7** and **Figure 2-8** for Sagamore Bridge and Bourne Bridge, respectively.[33] Note, the extent of flooding at Sagamore Bridge does not change with RSLR, which is likely due to the existing topography of the Study Area.

The RMAT Tool provides projected water surface elevations based on the MC-FRM Level 2 outputs as of September 13, 2021.[34] Through manipulating the useful life of the replacement bridges in the RMAT Tool, MassDOT was able to gather the 100-year, 500-year, and 1,000-year projected water surface elevations for 2030, 2050, and 2070. MassDOT plotted this data to extrapolate/interpolate projected water surface elevations for other return periods. **Table 2-13** and **Table 2-14** summarize the projected water surface elevations for Sagamore Bridge and Bourne Bridge based on the MC-FRM.

Table 2-13. Massachusetts Coast Flood Risk Model Projected Water Surface Elevations (Sagamore Bridge)

Return Period (Annual Exceedance Probability)	2030	2050	2070
2-year (50%)	5.9*	7.8*	9.5*
10-year (10%)	6.9*	9.1*	10.8*
25-year (4%)	7.5*	9.9*	11.6*
50-year (2%)	7.9*	10.4*	12.1*
100-year (1%)	8.4	11	12.7
200-year (0.5%)	8.8*	11.6*	13.3*
500-year (0.2%)	9.4	12.4	14.1
1,000-year (0.1%)	9.9	12.9	14.6

Note: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team (RMAT) Tool.

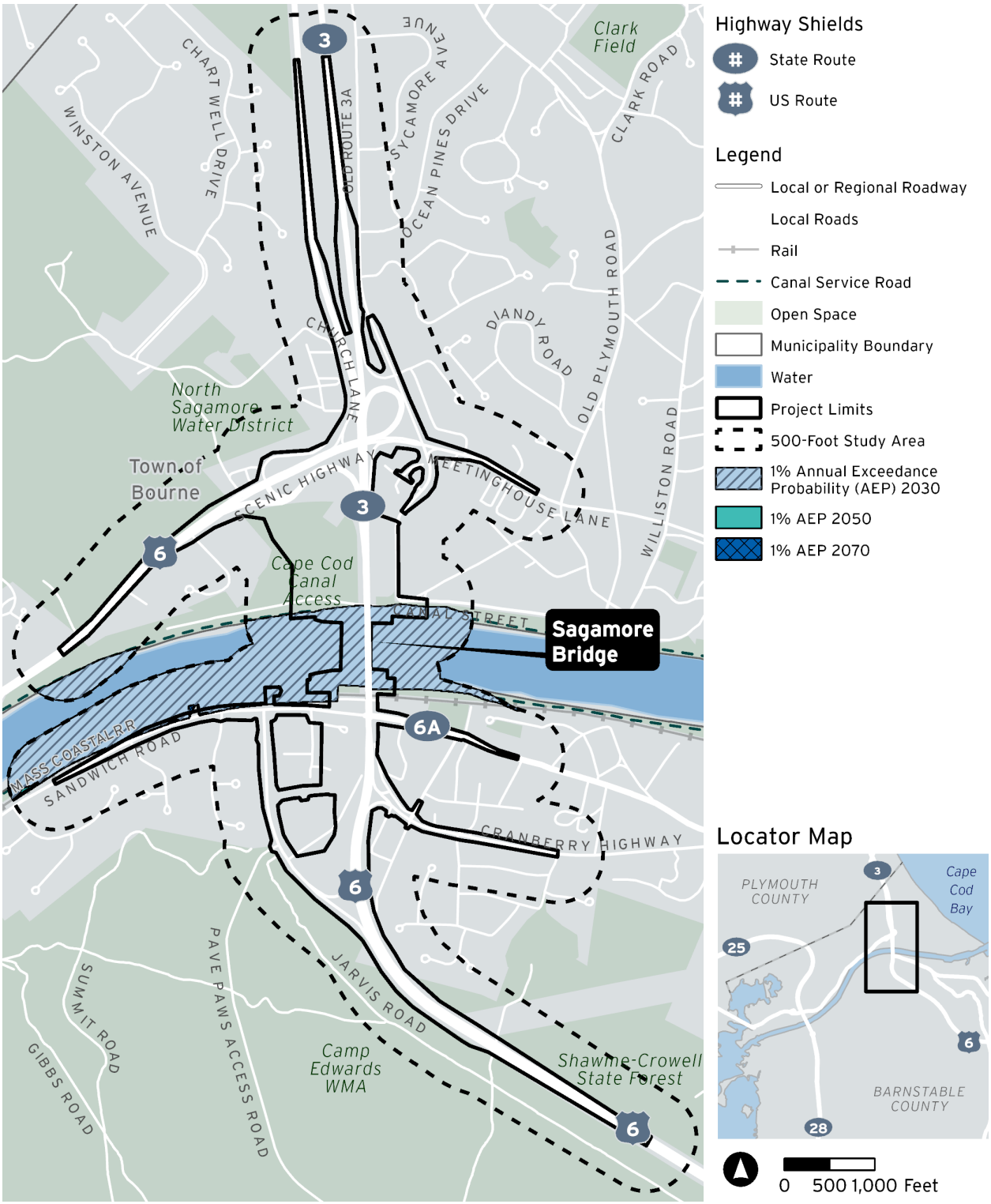
* Indicates value that was extrapolated or interpolated by trend lines. Extrapolated/interpolated data have coefficients of determination (R-squared values) of 0.998 and 0.999 for Sagamore Bridge and Bourne Bridge, respectively.

[32] Resilient Massachusetts Action Team (RMAT). 2022. Climate Resilience Design Standards and Guidance – Section 3: Preliminary Climate Exposure & Risk Screening, Version 1.2, July. p. 9

[33] Extents for the Massachusetts Coast Flood Risk Model (MC-FRM) 1% annual exceedance probability were taken from the ResilientMass Maps and Data Center (MC-FRM 1pct 2030, 2050, and 2070) accessed on December 6, 2024. https://resilientma-mapcenter-mass-eoeea.hub.arcgis.com/search?groupIds=332fcfe6cb494b2884d79eda182f12a1&tags=massachusetts%2520coast%2520flood%2520risk%2520model

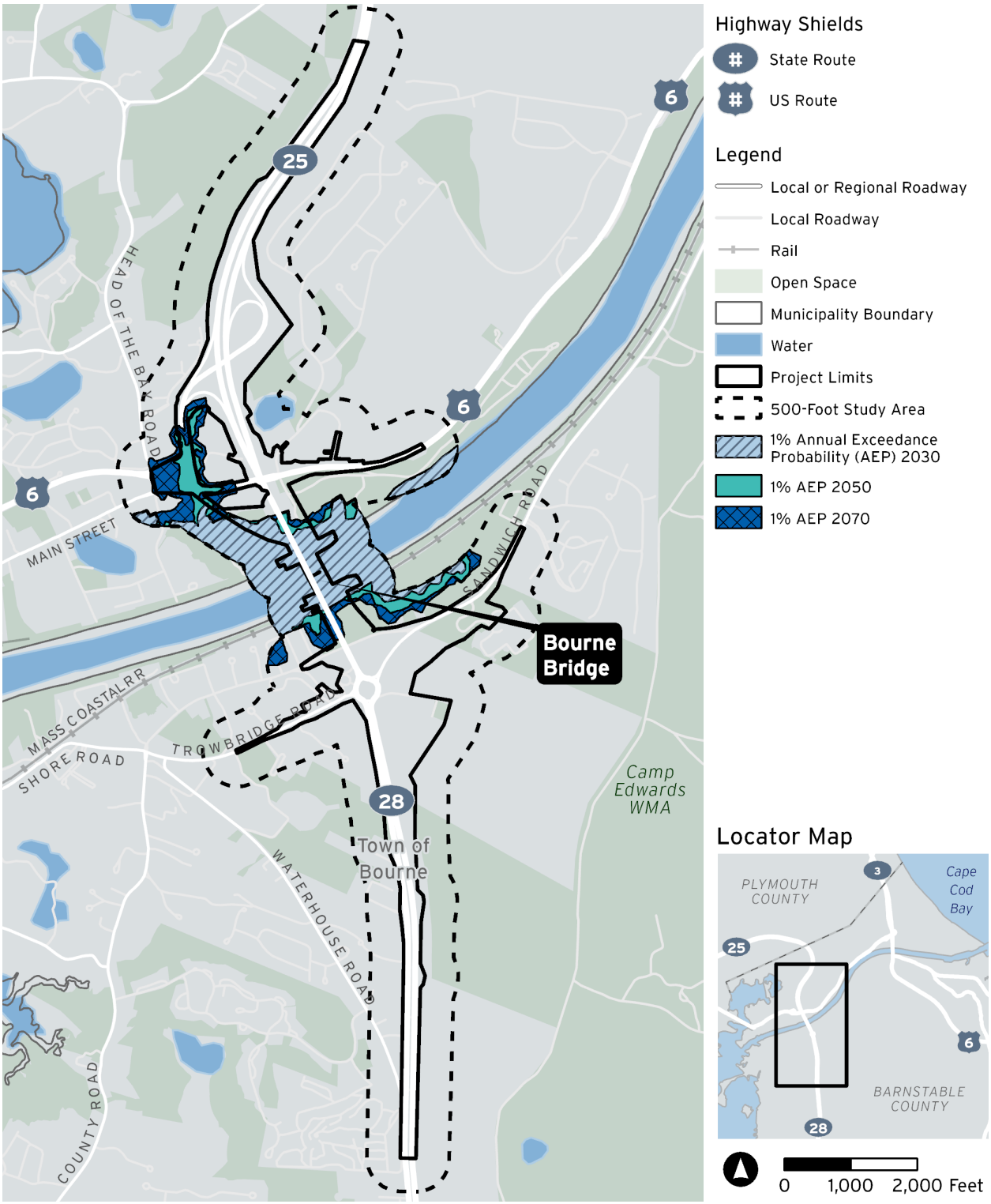
[34] RMAT. 2022. Climate Resilience Design Standards and Guidance – Section 4: Climate Resilience Design Standards, Version 1.2, July. P. 8

Figure 2-7. Composite Massachusetts Coast Flood Risk Model 1% Annual Exceedance Probability Inundation Map for 2030, 2050, and 2070 (Sagamore Bridge)



Source: Massachusetts Department of Transportation, 2024

Figure 2-8. Composite Massachusetts Coast Flood Risk Model 1% Annual Exceedance Probability Inundation Map for 2030, 2050, and 2070 (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

Table 2-14. Massachusetts Coast Flood Risk Model Projected Water Surface Elevations (Bourne Bridge)

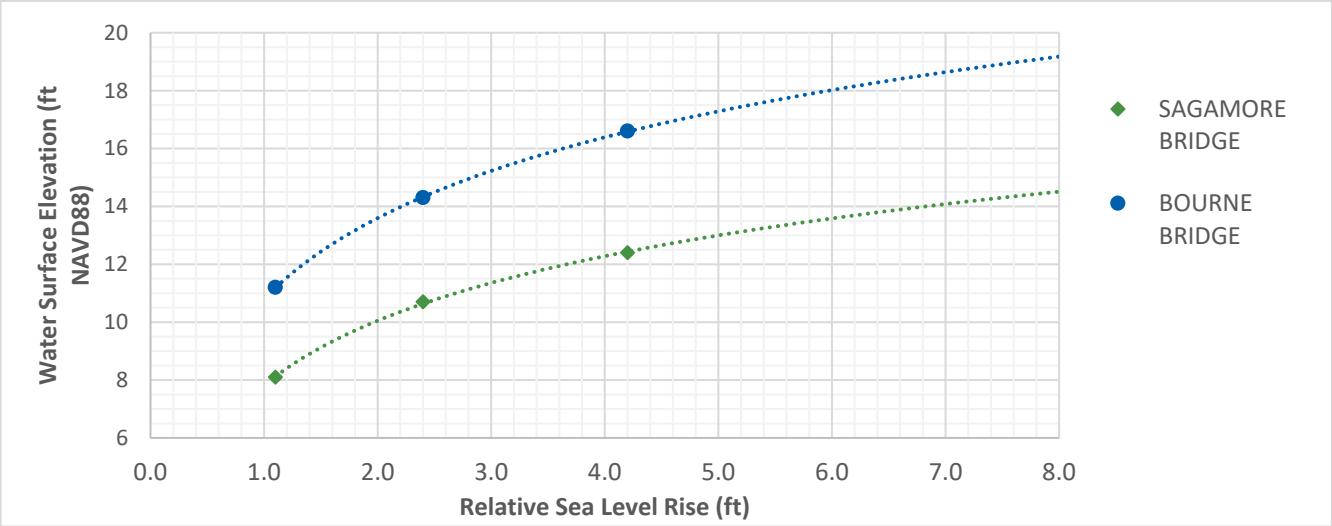
Return Period (Annual Exceedance Probability)	2030	2050	2070
2-year (50%)	6.6*	8.1*	10.2*
10-year (10%)	8.5*	10.7*	12.9*
25-year (4%)	9.6*	12.2*	14.5*
50-year (2%)	10.5*	13.3*	15.6*
100-year (1%)	11.3	14.5	16.8
200-year (0.5%)	12.1*	15.6*	18.0*
500-year (0.2%)	13.2	17.1	19.6
1,000-year (0.1%)	14.1	18.2	20.8

Notes: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team Tool.

* Indicates value that was extrapolated or interpolated by trend lines. Extrapolated/interpolated data have coefficients of determination (R-squared values) of 0.998 and 0.999 for Sagamore Bridge and Bourne Bridge, respectively.

MassDOT also used the MC-FRM data to assess the non-linear effect that RSLR has on SS elevation for the replacement bridges. **Figure 2-9** illustrates the trends for a 1% annual exceedance event (100-year storm) for both bridges; based on extrapolation, the projected 1% water surface elevation with 7.7 feet of RSLR would be El. 14.4 feet and El. 19.0 feet NAVD88 for Sagamore Bridge and Bourne Bridge, respectively.

Figure 2-9. Effect of Relative Sea Level Rise on Storm Surge based on Massachusetts Coast Flood Risk Model Projected Water Surface Elevations (Sagamore Bridge and Bourne Bridge)



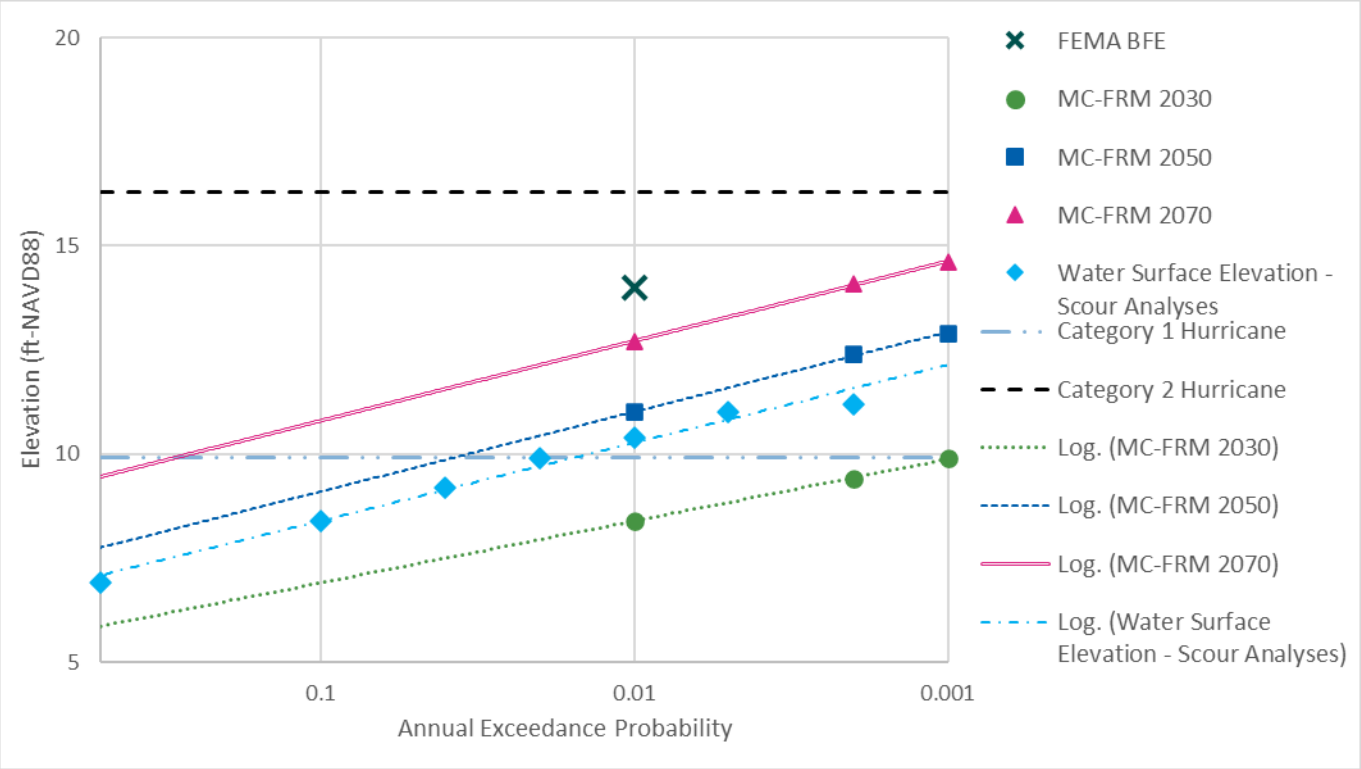
Source: Massachusetts Coast Flood Risk Model (MC-FRM) minimum projected water surface elevations for the 1% annual exceedance event (or 100-year storm) from the Resilient Massachusetts Action Team Tool outputs for 2030 (1.1 feet relative sea level rise [RSLR]), 2050 (2.4 feet RSLR), and 2070 (4.2 feet RSLR).

NAVD88 = North American Vertical Datum of 1988

2.3.3.3 Recommended Data and Methodology

Figure 2-10 and **Figure 2-11** summarize the SS water surface elevations reviewed for the replacement Sagamore Bridge and Bourne Bridge, respectively, including maximum water surface elevations from the 2D hydraulic model developed for scour analyses (if available).

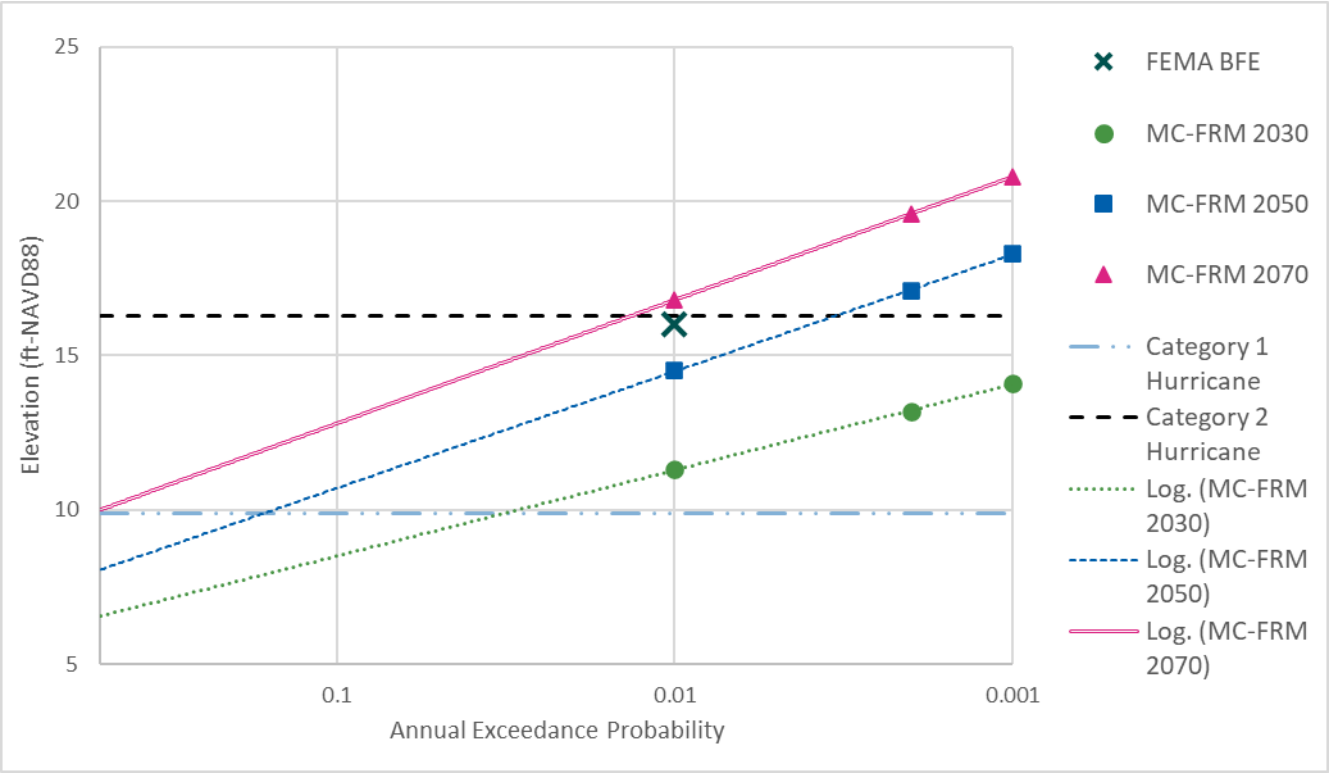
Figure 2-10. Storm Surge Water Surface Elevations Reviewed (Sagamore Bridge)



Source: FEMA Flood Insurance Rate Map 25001C0318K, effective July 6, 2021; MC-FRM Resilient Massachusetts Action Team Tool area weighted average values for the Study Area; Outputs from 2D hydraulic model created for scour analyses; Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model Hydrographs (no probability associated).

BFE = base flood elevation, FEMA = Federal Emergency Management Agency, Log = Logarithmic Scale, MC-FRM = Massachusetts Coast Flood Risk Model, NAVD88 = North American Vertical Datum of 1988

Figure 2-11. Storm Surge Water Surface Elevations Reviewed (Bourne Bridge)



Source: FEMA Flood Insurance Rate Map 25001C0502J, effective July 16, 2014, and 25001C0313K, effective July 6, 2021; MC-FRM Resilient Massachusetts Action Team (RMAT) Tool area weighted average values for Study Area; Sea, Lake, and Overland Surges from Hurricanes (SLOSH) Model Hydrographs (no probability associated).

BFE = base flood elevation, FEMA = Federal Emergency Management Agency, Log = Logarithmic Scale, MC-FRM = Massachusetts Coast Flood Risk Model, NAVD88 = North American Vertical Datum of 1988

The methods used to produce FEMA Flood Insurance Rate Maps and establish base flood elevations are substantially different than the MC-FRM, as is the purpose of each source; it is not recommended to compare MC-FRM and FEMA maps and data.[35] In general, while the MC-FRM accounts for RSLR, it appears to underpredict other SS models that do not account for RSLR as illustrated in **Figure 2-10** and **Figure 2-11**.

The RMAT Tool references the MC-FRM data. While the RMAT Tool recommends the 2070, 1,000-year (0.1%) event for both replacement bridges, at Sagamore Bridge, that event is only 0.6 foot higher than the existing FEMA 100-year event. At Bourne Bridge, the 2070, 1,000-year event is 4.7 feet higher than the existing FEMA 100-year event. There is a significant discrepancy between historical 100-year events and future 1,000-year events with RSLR across the two Study Areas.

[35] The Massachusetts Coast Flood Risk Model Frequently Asked Questions, Dated 4_06_22. Pg. 3 https://eea-nescaum-dataservices-assets-prd.s3.amazonaws.com/cms/GUIDELINES/MC-FRM_FAQ_04-06-22.pdf

Effective September 9, 2024, FEMA's Federal Flood Risk Management Standard (FFRMS) policy provides three methods to establish appropriate vertical flood elevation and corresponding horizontal FFRMS floodplain for Actions Subject to the FFRMS:

- Climate Informed Science Approach
- Freeboard Value Approach
- 0.2 Percent Annual Chance Flood Approach (0.2PFA)

This policy instructs FEMA to determine the FFRMS elevation and extent for critical actions using the area that would be inundated by the higher of the Climate Informed Science Approach, 0.2PFA, or +3 feet Freeboard Value Approach.[36] While this Program is not subject to the FFRMS, this resource and approach was considered to inform the methodology for future floodplain extents.

To provide a consistent methodology for both replacement bridges given the available SS data and FFRMS guidance, MassDOT used SLOSH data for a Category 2 hurricane with a freeboard of 3 feet to account for uncertainty, including RSLR and potential height generated by waves, to assess SS inundation extents and elevations. **Table 2-15** summarizes the elevations. This elevation is greater than the 2070, 200-year events (provided in **Table 2-13** and **Table 2-14**) and greater than the extrapolated 2100, 100-year event (7.7 feet RSLR) (refer to **Figure 2-9**) based on the MC-FRM data for both sites.

Table 2-15. Storm Surge Elevations to Assess Overland Coastal Inundation (Sagamore Bridge and Bourne Bridge Study Areas)

Storm Surge Parameter	Water Surface Elevation (feet-NAVD88)	
	Sagamore Bridge	Bourne Bridge
Federal Emergency Management Agency (FEMA) 100-year (1%) Flood[1]	14.0	16.0
Bridge – Resilient Massachusetts Action Team (RMAT) Tool: 2070, 1,000-year (0.1%)	14.6	20.8
Roadways – RMAT Tool: 2070, 500-year (0.2%)	14.1	19.6
Shared-Use Paths – RMAT Tool: 2050, 100-year (1%)	11.0	14.5
Storm Control Measures – RMAT Tool: 2070, 50-year (2%)	12.1	15.6
Category 2 Hurricane + 3 feet Freeboard[2]	19.3	19.3

Sources:

[1] FEMA Base Flood Elevation from Flood Insurance Rate Maps 25001C0318K and 25001C0313K, effective July 6, 2021.

[2] Water surface elevation for Category 2 Hurricane from the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model hydrograph, plus 3 feet freeboard.

NAVD88 = North American Vertical Datum of 1988

[36] FEMA (Federal Emergency Management Agency) Policy: Federal Flood Risk Management Standard (FFRMS). https://www.federalregister.gov/documents/2024/07/11/2024-15170/fema-policy-federal-flood-risk-management-standard-ffrms

Table 2-16 summarizes the SS events and associated RSLR considered for assessing the No Build Alternative and Build Alternative.

Table 2-16. Inundation Scenarios Recommended for Analyses

Affected Environment	Impact from Relative Sea Level Rise/Storm Surge	Recommended Relative Sea Level Rise for Effect	Inundation Scenario	Design Criteria
Stormwater Control Measures	• Submerged or partially submerged outfalls • Infiltration Basin Flooding	NA*	• Federal Emergency Management Agency (FEMA) 100-year • Category 2 + 3 feet	Storm Surge Inundation Extent and Elevations
Land Cover	Floodplain Function	NA*	• FEMA 100-year • Category 2 + 3 feet	Storm Surge Inundation Extent and Elevations
Highway Transportation Traffic and Safety	Evacuation Route Flooding	NA*	• FEMA 100-year • Category 2 + 3 feet	Storm Surge Inundation Extent and Elevations
Mobility	Shared-use Path Flooding	NA*	• FEMA 100-year • Category 2 + 3 feet	Storm Surge Inundation Extent and Elevations

* Not applicable due to lower values from the Massachusetts Coast Flood Risk Model (MC-FRM). Freeboard value approach recommended in conjunction with the Category 2 Hurricane surge elevation to provide a consistent standard to assess inundation within the Study Areas.

The following methods were used with the recommended data to assess impacts on the affected environment by the No Build and Build Alternatives.

- To evaluate the effect on stormwater outfalls, the SS elevations were compared with the outfall invert and crown elevations. If the elevation exceeded the outfall invert elevation, it was assumed to be partially submerged, with potential backflow through the system. If the elevation exceeded the outfall crown elevation, it was assumed to be fully submerged, with potential backflow through the system.
- To evaluate the effect on stormwater infiltration basins, the SS elevations were compared with the proposed basin elevations. Once the overflow outlet structures are designed for the infiltration basins, the outlet elevation should be considered. If the SS elevation exceeds the proposed overflow structure's outlet elevation, the basin will be assumed to be partially full to the elevation of the SS. If the elevation exceeded the proposed basin top elevation, it was assumed to overtop the basin and resulted in localized flooding. The extent of overland SS inundation was overlaid with

locations of proposed stormwater infiltration basins. If the elevation exceeded the top of the stormwater basin, it was assumed to be flooded.

- To evaluate the impact on the floodplain, the extent of overland SS inundation was overlaid with existing and proposed grades. Areas with lower elevation were assumed to be where coastal waters flooded first, which informed flood pathways. Grades that exceeded the SS elevation were assumed to not be flooded. Cross-sections were evaluated for potential channelization of flow and increased velocities based on grading and land cover surface type.
- To evaluate the impact on roadways and active transportation, the extent of overland SS inundation was overlaid with roadways, sidewalks, and SUPs. If those routes were within the extent of inundation, they were assumed to be affected.

2.3.4 Wave Hazards

Waves can generate large forces and can result in damages when they are riding on top of SS and able to strike roads and bridges not designed for those forces.[37] There were no available observations or records on extents and elevations of past wave action, so historical modeled results were reviewed.

2.3.4.1 Modeled Historical

FEMA designates existing areas with expected wave heights greater than 3 feet as "Zone VE, a Coastal High Hazard Area, where waves and fast-moving water can cause extensive damage during the 1-percent-annual chance flood."[38] Both the proposed replacement bridges and areas in the FEMA floodplain within the Study Areas are outside of the Limit of Moderate Wave Action,[39] which is a line on FEMA flood maps that shows the inland boundary of the area where waves can reach 1.5 feet or higher during a flood event.

2.3.4.2 Projections

The MC-FRM Level 2 outputs available in the RMAT Tool include projected wave heights that MassDOT statistically calculated using the significant wave height outputs from the MC-FRM. The projected Wave height represents the wave height statistic that is slightly higher than the average of the highest 1% of wave heights.[40] **Table 2-17** and **Table 2-18** summarize the projected wave heights available through the RMAT Tool. **Table 2-19** and **Table 2-20** summarize the projected wave action water surface elevations available through the RMAT Tool.

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[37] Federal Highway Administration Hydraulic Engineering Circular (HEC) 25, "Highways in the Coastal Environment, 3rd Edition", published January 2020, pg. 22.

[38] ResilientMass Action Team (RMAT) Tool

[39] Closest Limit of Moderate Wave Action is shown on Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps 25001C0319J and 25001C0501J, effective July 16, 2014, for Sagamore Bridge and Bourne Bridge, respectively.

[40] ResilientMass Action Team (RMAT). 2022. Climate Resilience Design Standards and Guidance – Section 4-D: Design Criteria Guidance, Version 1.2, July. p. 5

Table 2-17. Massachusetts Coast Flood Risk Model Projected Wave Heights (feet) (Sagamore Bridge)

Return Period (Annual Exceedance Probability)	2050	2070
100-year (1%)	5.0 (0 to 12.5)	5.1 (0 to 12.5)
500-year (0.2%)	5.9 (0 to 15)	6.0 (0 to 16)
1,000-year (0.1%)	6.2 (0 to 16)	6.4 (0 to 16)

Notes: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team (RMAT) Tool. Values in parentheses represent minimum to maximum values for the design storm event from the RMAT Tool.

Table 2-18. Massachusetts Coast Flood Risk Model Projected Wave Heights (feet) (Bourne Bridge)

Return Period (Annual Exceedance Probability)	2050	2070
100-year (1%)	2.5 (0 to 6.5)	2.5 (0 to 7.0)
500-year (0.2%)	2.8 (0 to 7.5)	3.1 (0 to 8.0)
1,000-year (0.1%)	2.9 (0 to 8.0)	3.2 (0 to 8.5)

Notes: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team (RMAT) Tool. Values in parentheses represent minimum to maximum values for the design storm event from the RMAT Tool.

Table 2-19. Massachusetts Coast Flood Risk Model Projected Wave Action Water Elevation (feet-NAVD88) (Sagamore Bridge)

Return Period (Annual Exceedance Probability)	2050	2070
100-year (1%)	12.8 (10.7 to 16.0)	14.5 (12.4 to 17.7)
500-year (0.2%)	14.4 (11.8 to 18.6)	16.2 (13.4 to 20.2)
1,000-year (0.1%)	15.1 (12.2 to 19.3)	16.9 (13.9 to 21.1)

Notes: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team (RMAT) Tool. Values in parentheses represent minimum to maximum values for the design storm event from the RMAT Tool.

NAVD88 = North American Vertical Datum of 1988

Table 2-20. Massachusetts Coast Flood Risk Model Projected Wave Action Water Elevation (feet-NAVD88) (Bourne Bridge)

Return Period (Annual Exceedance Probability)	2050	2070
100-year (1%)	15.9 (14.3 to 18.9)	18.4 (16.6 to 21.2)
500-year (0.2%)	18.8 (16.9 to 22.3)	21.5 (19.1 to 24.9)
1,000-year (0.1%)	20 (17.7 to 23.7)	22.8 (20.3 to 26.5)

Notes: Values represent area weighted averages for the design storm event from the Resilient Massachusetts Action Team (RMAT) Tool. Values in parentheses represent minimum to maximum values for the design storm event from the RMAT Tool.

NAVD88 = North American Vertical Datum of 1988

2.3.4.3 Recommended Data and Methodology

Given the extent of the Study Area, proposed replacement bridges' deck height and location of piers/abutments, land use and development between the shoreline and proposed land-based infrastructure (roadways, ramps, and SCMs), and lack of structures proposed along the shoreline that could reflect waves, wave heights and associated wave action water surface elevations with RSLR were not formally assessed in this study due to lack to affected environment.

2.3.5 Scour

At the time of this report, only hydraulic analyses to study scour for the proposed Sagamore Bridge have been performed. This will be updated once the hydraulic analyses to study scour for the proposed Bourne Bridge are available.

2.3.5.1 Observations

Observed erosion and scour were evaluated following guidelines from FHWA Item 61 - Channel and Channel Protection as part of the bridges' recent inspection reports. No scour was noted on the land side of the piers at low tide.

2.3.5.2 Modeled Historical

The maximum velocity and maximum storm tide elevation typically occur at different times in a coastal environment, and maximal coastal scour formation conditions generally occur when the velocity is the greatest value.[41] A two-dimensional hydraulic analysis was performed using the U.S. Department of the Interior, Bureau of Reclamation's SRH-2D computer model (Version 3.0) built into Aquaveo's

[41] Federal Highway Administration Hydraulic Engineering Circular 25, "Design of Highways in the Coastal Environment," published January 2020. P. 241.

SMS 13.2.10 modeling program. The 2D model was run for seven storm events under current sea level conditions, which were based on SLOSH hydrographs and FIS Stillwater Elevations for Buzzards Bay and Cape Cod Bay, and the proposed bridge piers.[42] **Table 2-21** summarizes the hydraulic conditions for the proposed conditions at Sagamore Bridge.

Table 2-21. Hydraulic Analysis Summary, Proposed Conditions (Sagamore Bridge)

Return Period (Annual Exceedance Probability)	Water Surface Elevation (feet-NAVD88)	Velocity (feet per second)
2-year (50%)	6.44	2.56
10-year (10%)	8.09	1.45
25-year (4%)	8.37	1.83
50-year (2%)	8.92	2.86
100-year (1%)	9.32	4.14
200-year (0.5%)	9.05	5.25
500-year (0.2%)	10.34	5.20

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

NAVD88 = North American Vertical Datum of 1988

MassDOT calculated the estimated scour depths for the 200-year and 500-year studied events following the equations listed in the FHWA HEC-18, "Evaluating Scour at Bridges, Fifth Edition," dated April 2012. **Table 2-22** summarizes the parameters used to calculate scour depth, and **Table 2-23** summarizes the calculated scour depths.

Table 2-22. Scour Calculations Input Variables, Proposed Conditions (Sagamore Bridge)

Return Period	Location	Average Local Velocity (feet per second)	Average Local Water Depth (feet)	Flow Angle of Attack (degrees)	Area within Channel (feet^2)	Flow within Channel (cubic feet per second)
200-year	Approach Section	4.97	50.48	NA	39,624	196,845
200-year	Upstream Bridge Face Section	5.10	58.21	NA	37,943	193,641

[42] Since reuse of the existing structures is not proposed, only a proposed conditions model was developed for the Sagamore Bridge replacement.

Return Period	Location	Average Local Velocity (feet per second)	Average Local Water Depth (feet)	Flow Angle of Attack (degrees)	Area within Channel (feet^2)	Flow within Channel (cubic feet per second)
200-year	Northern Canal Pier	2.55	7.96	9.30	NA	NA
200-year	Southern Canal Pier	2.93	7.69	5.68	NA	NA
500-year	Approach Section	5.93	50.31	NA	39,497	234,151
500-year	Upstream Bridge Face Section	6.07	58.10	NA	37,789	229,402
500-year	Northern Canal Pier	2.89	7.79	9.78	NA	NA
500-year	Southern Canal Pier	3.24	7.43	5.69	NA	NA

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

Table 2-23. Calculated Scour Depths, Proposed Conditions (Sagamore Bridge)

Return Period	Location	Total Scour (feet)	Ground Elevation (feet-NAVD88)	Scour Bottom Elevation (feet-NAVD88)
200-year	Northern Canal Pier	37.96	-2.00	-39.96
200-year	Southern Canal Pier	33.71	-2.00	-35.71
500-year	Northern Canal Pier	41.76	-2.00	-43.76
500-year	Southern Canal Pier	35.88	-2.00	-37.88

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

NAVD88 = North American Vertical Datum of 1988

2.3.5.3 Projections

The same 2D model was also run for seven storm events under future sea level conditions, which were adjusted for RSLR by adding 7.7 feet to FIS Stillwater Elevations for Cape Cod Bay and Buzzards Bay. **Table 2-24** summarizes the hydraulic conditions for the proposed conditions at Sagamore Bridge.

Table 2-24. Hydraulic Analysis Summary, Proposed Conditions with 7.7 feet Relative Sea Level Rise (Sagamore Bridge)

Return Period	Relative Sea Level Rise (feet)	Water Surface Elevation (feet-NAVD88)	Velocity (feet per second)
2-year (50%)	7.7	12.00	1.61
10-year (10%)	7.7	15.81	1.52
25-year (4%)	7.7	16.36	0.44
50-year (2%)	7.7	16.97	1.58
100-year (1%)	7.7	17.50	3.03
200-year (0.5%)	7.7	17.32	3.64
500-year (0.2%)	7.7	18.32	3.37

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

NAVD88 = North American Vertical Datum of 1988

Estimated scour depths were calculated for the 200-year and 500-year studied events in accordance with FHWA HEC-18. **Table 2-25** summarizes the parameters used to calculate scour depth, and **Table 2-26** summarizes the calculated scour depths.

Table 2-25. Scour Calculations Input Variables, Proposed Conditions with 7.7 feet Relative Sea Level Rise (Sagamore Bridge)

Return Period + 7.7 feet Relative Sea Level Rise	Location	Average Local Velocity (feet per second)	Average Local Water Depth (feet)	Flow Angle of Attack (degrees)	Area within Channel (feet^2)	Flow within Channel (cubic feet per second)
200-year	Approach Section	3.79	55.82	NA	41,726	157,272
200-year	Upstream Bridge Face Section	3.39	68.45	NA	44,174	149,844
200-year	Northern Canal Pier	2.21	16.18	6.47	NA	NA
200-year	Southern Canal Pier	2.41	16.02	11.19	NA	NA
500-year	Approach Section	5.16	54.87	NA	40,861	210,590

Return Period + 7.7 feet Relative Sea Level Rise	Location	Average Local Velocity (feet per second)	Average Local Water Depth (feet)	Flow Angle of Attack (degrees)	Area within Channel (feet^2)	Flow within Channel (cubic feet per second)
500-year	Upstream Bridge Face Section	4.66	65.66	NA	43,322	202,024
500-year	Northern Canal Pier	3.60	15.14	5.64	NA	NA
500-year	Southern Canal Pier	3.95	14.92	6.59	NA	NA

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

Table 2-26. Calculated Scour Depths, Proposed Conditions with 7.7 feet Relative Sea Level Rise (Sagamore Bridge)

Return Period + 7.7 feet Relative Sea Level Rise	Location	Total Scour (feet)	Ground Elevation (feet-NAVD88)	Scour Bottom Elevation (feet-NAVD88)
200-year	Northern Canal Pier	24.64	-2.00	-26.64
200-year	Southern Canal Pier	35.58	-2.00	-37.58
500-year	Northern Canal Pier	34.22	-2.00	-33.22
500-year	Southern Canal Pier	39.07	-2.00	-41.07

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

NAVD88 = North American Vertical Datum of 1988

2.3.5.4 Recommended Data and Methodology

Since reuse of the existing structures is not proposed, no methodology is proposed to assess scour on the No Build Alternative. The maximum scour depth should be used for bridge pier design considerations. **Table 2-27** summarizes the scour events and associated RSLR considered for assessing future conditions for Sagamore Bridge and Bourne Bridge.

Table 2-27. Scour Scenarios Recommended for Analyses (Sagamore Bridge and Bourne Bridge)

Affected Environment	Impact from Relative Seal Level Rise	Recommended Relative Seal Level Rise for Effect	Scour Event	Design Criteria
Bridge	Pier Scour	7.7 feet	• 200-year (Design Storm) • 500-year (Check Storm)	Maximum scour depth

The following methods were used with the recommended data to assess impacts on the affected environment by the Build Alternative:

- To evaluate the effect on bridge pier scour, the 2D Hydraulic analysis should be run with and without 7.7 feet RSLR. The maximum scour depth generated should be used to assess impacts and design foundations.

2.4 Extreme Precipitation

2.4.1 24-Hour Rainfall Depth

Total Precipitation Depth is often used to inform design of green and grey infrastructure solutions to manage stormwater. MassDOT did not review historical rainfall records but instead assessed modeled historical rainfall data.

2.4.1.1 Modeled Historical

NOAA Atlas 14 Volume 10 provides spatially independent precipitation frequency estimates and accompanying lower and upper bounds of the 90% confidence interval for Massachusetts that are used in design practices. The methods used to create NOAA Atlas 14 are based on the assumption of stationary annual maximum series.[43] NOAA is in the process of updating precipitation frequency estimates to be published in two volumes of NOAA Atlas 15:

- Volume 1 will provide precipitation frequency estimates that account for non-stationarity and temporal trends in historical observations.
- Volume 2 will provide precipitation frequency estimates projected into the future based on climate model projections.[44]

MassDEP is in the process of updating the Stormwater Handbook, which references TP-40 for rainfall depths to attenuate, infiltrate, and treat stormwater. MassDEP is proposing to use a scaling factor of 0.9 to the upper bound of the 90% confidence interval for precipitation frequency estimates for 2-year, 10-year, and 100-year events in NOAA Atlas 14, also known as NOAA Atlas 14 Plus (NA14+), for the design of SCMs.[45]

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[43] Perica, S. et al. 2015, revised 2019. NOAA (National Oceanic and Atmospheric Administration) Atlas 14 Volume 10 Version 3, Precipitation-Frequency Atlas of the United States, Northeastern States. April. p. 20. https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

[44] Perica, S. et al. 2024. NOAA (National Oceanic and Atmospheric Administration) Atlas 15 Pilot Technical Report. NOAA Office of Water Prediction. September. p. 5. https://www.weather.gov/media/owp/precip-frequency/noaa_atlas15_pilot_technical_report.pdf

[45] DRAFT Massachusetts Stormwater Management Handbook, December 2023, p. 2-5 https://www.mass.gov/doc/massachusetts-stormwater-management-handbook/download

2.4.1.2 Projections

Projected extreme precipitation estimates and Intensity Duration Frequency curves are published through ResilientMass, which is maintained by MA EEA.[46] These values were generated by Cornell University through the Massachusetts Climate and Hydrologic Risk project conducted by MA EEA. The methodology includes scaling design storms at sub-daily to daily time scales from NOAA Atlas 14 at the theoretical (Clausius-Clapeyron) rate of 7% per degree Celsius, which is the rate at which the moisture-holding capacity of the atmosphere increases with warming.[47] The Intensity Duration Frequency curves published for future time periods are based on the associated warming for that period from an ensemble of climate model projections.[48]

Table 2-28 and **Table 2-29** summarize historical and future projected 24-hour rainfall depths considered for Sagamore Bridge and Bourne Bridge, respectively. The projected 24-hour rainfall depth for the 2070, 100-year event is consistent with the RMAT Tool output for the replacement bridges.

Table 2-28. 24-Hour Rainfall Depths (inches) (Sagamore Bridge Study Area)

Design Storm (Annual Probability)	Historic National Oceanic and Atmospheric Administration (NOAA) Atlas 14		Future Projections ResilientMass Intensity Duration Frequency Site 7446[1]			
	Precipitation Frequency Estimates	NOAA Atlas 14 Plus	2030	2050	2070	2090
2-year (50%)	3.41	3.64	3.90	4.20	4.5	4.8
10-year (10%)	4.98	5.34	5.70	6.10	6.5	7.0
100-year (1%)	7.47	8.59	8.50	9.10	9.8	10.5

[1] The data were obtained through the Massachusetts Climate Change Projections Dashboard (https://mass-EEA.maps.arcgis.com/apps/dashboards/2e8534bc2a7849b0aa6f64d0f79a8937), accessed on December 5, 2024 for Intensity Duration Frequency Site 7446, which is the closest site to Sagamore Bridge.

[46] The data were obtained through the Massachusetts Climate Change Projections Dashboard: https://mass-eoeea.maps.arcgis.com/apps/dashboards/2e8534bc2a7849b0aa6f64d0f79a8937, accessed on December 5, 2024.

[47] Steinschneider, S., & Najibi, N. 2022. Observed and Projected Scaling of Daily Extreme Precipitation with Dew Point Temperature at Annual and Seasonal Scales across the Northeastern United States, Journal of Hydrometeorology, 23(3), 403-419. https://journals.ametsoc.org/view/journals/hydr/23/3/JHM-D-21-0183.1.xml

[48] ResilientMass Action Team. 2022. Climate Resilience Design Standards & Guidance, Section 4: Climate Resilience Design Standards, Attachment 4-B. July. p. 4B-5. https://www.mass.gov/doc/climate-resilience-design-standards/download

Table 2-29. 24-Hour Rainfall Depths (inches) (Bourne Bridge Study Area)

Design Storm (Annual Probability)	Historic National Oceanic and Atmospheric Administration (NOAA) Atlas 14		Future Projections ResilientMass Intensity Duration Frequency Site 7558[1]			
	Precipitation Frequency Estimates	NOAA Atlas 14 Plus	2030	2050	2070	2090
2-year (50%)	3.43	3.65	3.90	4.20	4.5	4.8
10-year (10%)	5.01	5.36	5.70	6.10	6.6	7.0
100-year (1%)	7.51	8.60	8.60	9.20	9.9	10.5

[1] The data were obtained through the Massachusetts Climate Change Projections Dashboard (https://mass-EEA.maps.arcgis.com/apps/dashboards/2e8534bc2a7849b0aa6f64d0f79a8937), accessed on December 5, 2024, for Intensity Duration Frequency Site 7558, which is the closest site to Bourne Bridge.

2.4.1.3 Recommended Data and Methodology

The RMAT Tool recommends different extreme precipitation events for each asset (**Table 2-30**).

Table 2-30. Recommended Extreme Precipitation Events from the Resilient Massachusetts Action Team (RMAT) Tool (Sagamore Bridge and Bourne Bridge)

Asset	Target Planning Horizon	Return Period	Projected 24-hr Total Rainfall Depth (inches)	
			Sagamore Bridge	Bourne Bridge
Replacement Bridge	2070	100-year (1%)	9.8	9.9
Highways/Roadways	2070	50-year (2%)	8.8	8.8
Storm Control Measures – Infiltration Basins	2070	10-year (10%)	6.5	6.6
Shared-Use Paths	2050	10-year (10%)	6.1	6.1

To analyze the combined impacts of increased extreme rainfall and SLR, four combination scenarios for Sagamore Bridge and Bourne Bridge are recommended. **Table 2-31** and **Table 2-32** summarize these scenarios, respectively. These scenarios were chosen to be able to:

- Reflect near-term extreme events that are likely to be experienced given infrastructure useful life and projected climate changes.
- Assess the impact of SLR and timing of tides on the same extreme rainfall event.
- Represent more frequent conditions expected near the end of useful life for SCMs.

The impacts of extreme precipitation vary based on the affected environment but are typically mitigated through SCMs and site-civil practices. **Table 2-33** summarizes the precipitation events and associated coastal boundary conditions considered for assessing the No Build Alternative and Build Alternative.

Table 2-31. Combination Sea Level Rise and Extreme Rainfall Events Recommended for Sagamore Bridge

Combination Event Scenarios	Water Surface (feet-NAVD88)	24-hour rainfall (inches)
2030 Mean High Water and 100-year	4.18	8.5
2050 Mean Low Water and 100-year	-1.98	9.1
2050 Mean Higher High Water and 100-year	5.85	9.1
2070 Mean Higher High Water and 10-year	7.65	6.5

Source: Tidal Datums and ResilientMass Intensity Duration Frequency curves.

NAVD88 = North American Vertical Datum of 1988

Table 2-32. Combination Sea Level Rise and Extreme Rainfall Events Recommended for Bourne Bridge

Combination Event Scenarios	Water Surface (feet-NAVD88)	24-hour rainfall (inches)
2030 Mean High Water and 100-year	2.75	8.6
2050 Mean Low Water and 100-year	-0.44	9.2
2050 Mean Higher High Water and 100-year	4.43	9.2
2070 Mean Higher High Water and 10-year	6.23	6.6

Source: Tidal Datums and ResilientMass Intensity Duration Frequency curves.

NAVD88 = North American Vertical Datum of 1988

Table 2-33. Extreme Precipitation Scenarios Recommended for Analyses

Affected Environment	Useful life (if any)	Impact from Extreme Precipitation	Rainfall Scenario	Assessed Impact
Stormwater Control Measures	50 years	Infiltration Basins	2070, 100-year, 24-hour	Sizing of infiltration basin
			• 2030 Mean High Water and 100-year, 24-hour • 2050 Mean Low Water and 100-year, 24-hour • 2050 Mean Higher High Water and 100-year, 24-hour • 2070 Mean Higher High Water and 10-year, 24-hour	Performance of stormwater control measures over time
Land cover; Transportation; Mobility	30 to 50 years	Localized Flooding	2070, 100-year, 24-hour	Capacity of storm control measures to manage stormwater volumes

Section 4.11, Water Quality and Stormwater, of the DEIR discusses the methods used with the recommended data to assess impact on the affected environment by the No Build Alternative and Build Alternative.

2.5 Extreme Heat

Extreme heat considerations are a function of land cover characteristics and temperatures. The methodology considered land cover (modeled land surface temperatures and percentage of impervious surfaces), observed temperatures, and projected temperatures.

2.5.1 Land Cover Characteristics

2.5.1.1 Land Surface Temperature Index

Land surface temperature (LST) for the Study Area was assessed using the Land Surface Temperature Index data layer developed by the Metropolitan Area Planning Council and made available by ResilientMass.[49] The LST Index values were created for each regional planning agency area by combining estimates of surface temperature where the maximum daily air temperature exceeded 70 Fahrenheit (F) from days in 2018, 2019, and 2020. Single-day estimates of surface temperatures were normalized on a scale of 0 to 1, with 0 as the coolest grid cell and 1 as the warmest. A composite index was generated by averaging the normalized single-day estimates. According to the data layer metadata, the resolution of the raster data is 30 meters, and areas with LST Index values below 0.5 tend to be cooler, while areas greater than 0.5 tend to be warmer.[50] In general, the LST within the Study Areas is on average with or cooler than the area served by the Cape Cod Commission. **Figure 2-12** and **Figure 2-13** illustrate the LST Index values for the Sagamore Bridge and Bourne Bridge Study Areas, respectively.

2.5.1.2 Impervious Surface Area

According to the RMAT Tool preliminary exposure ratings for the replacement bridges, existing impervious area of the project site is between 10% and 50%. Excluding the interactions of tree canopy cover, the percentage coverage of impervious surfaces and air temperature generally has a linear relationship that is amplified at larger scales, with 50% representing the tipping point for temperature anomalies.[51] As such, MassDOT used the tipping point of 50% in the RMAT Tool as a threshold for impacts.

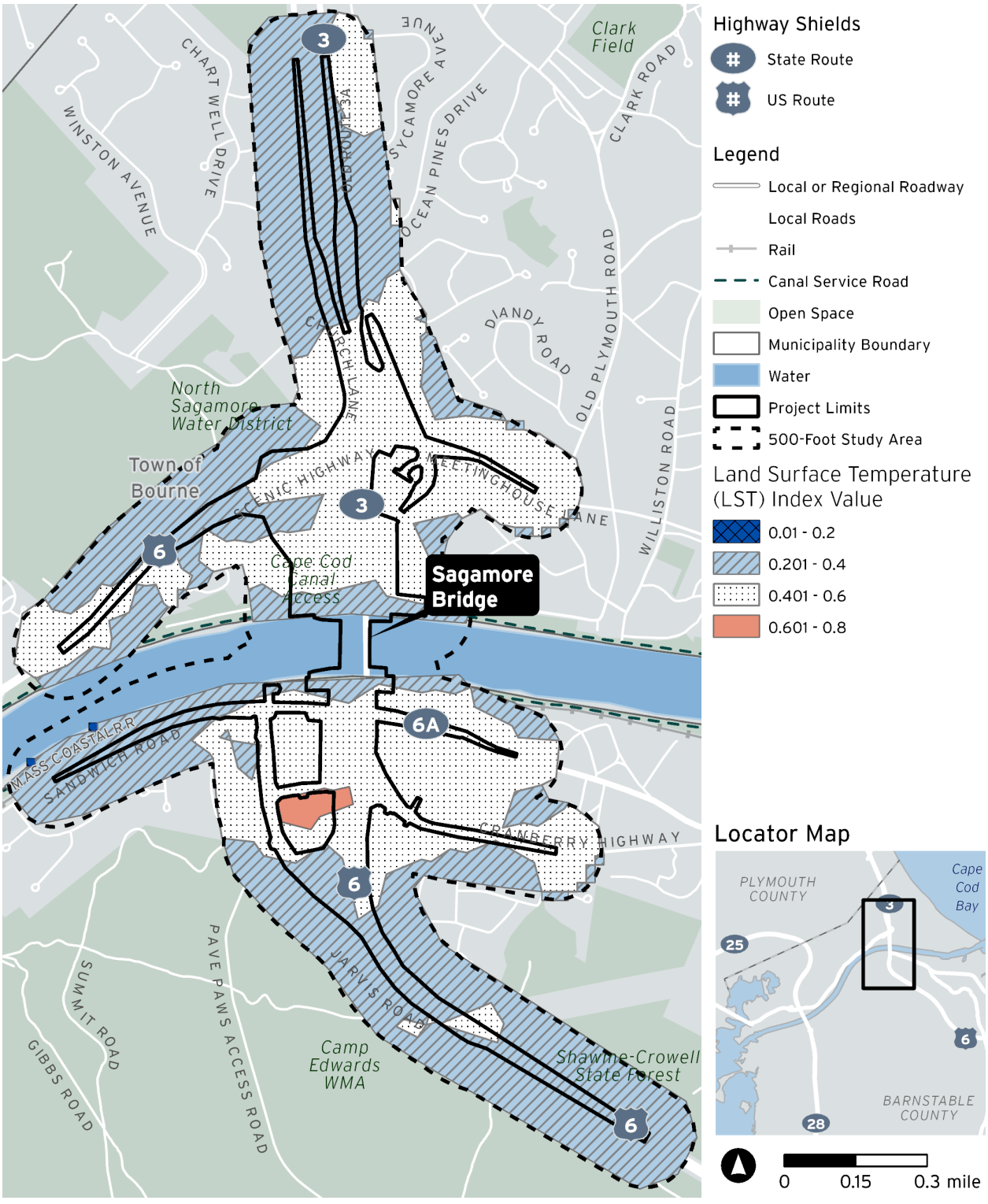
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[49] https://tiles.arcgis.com/tiles/7iJyYTjCtKsZS1LR/arcgis/rest/services/Land_Surface_Temperature_Index_CCC_SP/MapServer

[50] https://tiles.arcgis.com/tiles/7iJyYTjCtKsZS1LR/arcgis/rest/services/Land_Surface_Temperature_Index_CCC_SP/MapServer

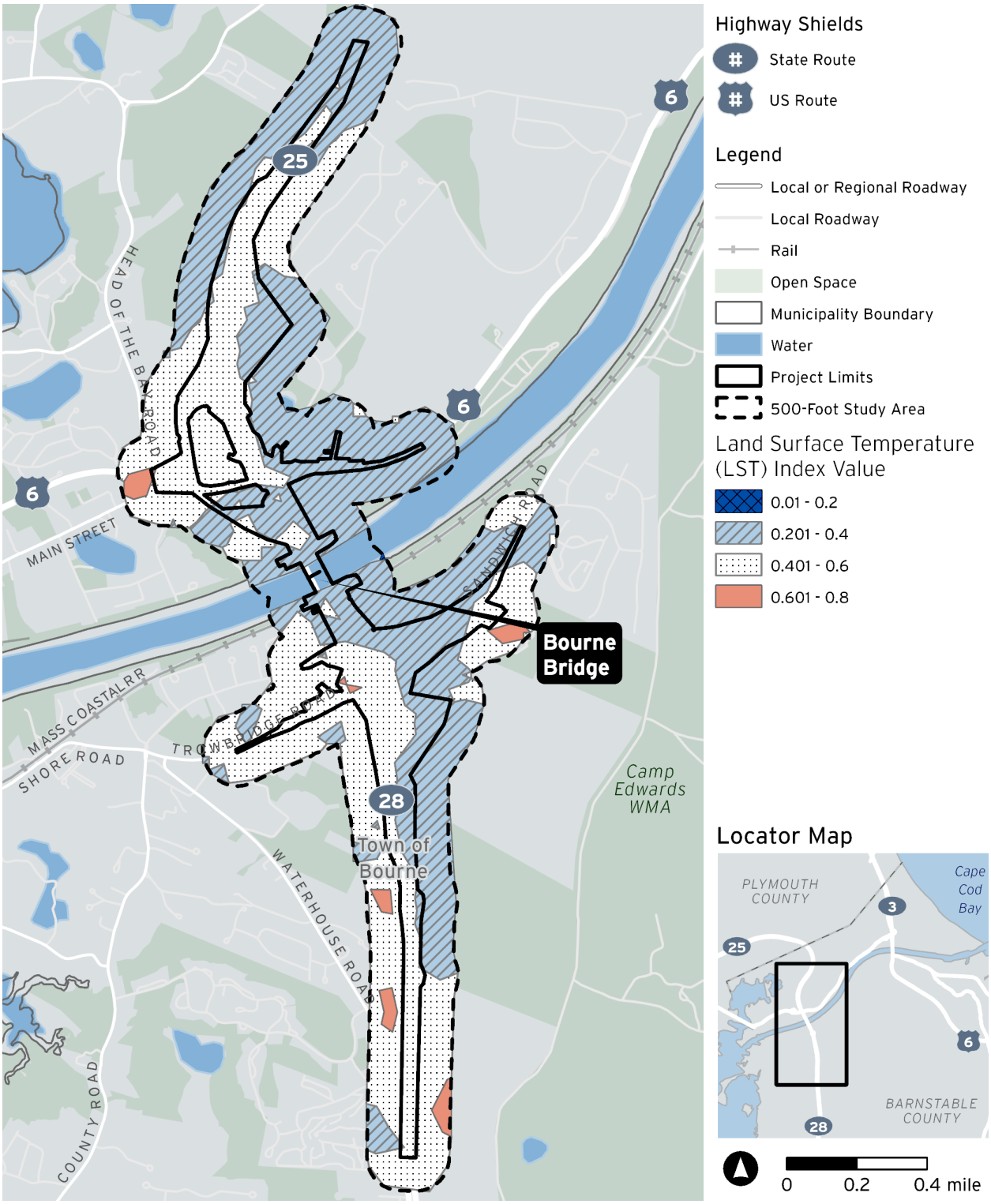
[51] Ziter, C.D., E.J. Pedersen, C.J. Kucharik, M.G. Turner. 2019. "Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer," Proc. Natl. Acad. Sci. U.S.A. 116 (15) 7575-7580, https://doi.org/10.1073/pnas.1817561116

Figure 2-12. Land Surface Temperature Index Values (Sagamore Bridge)



Source: Massachusetts Department of Transportation, 2024

Figure 2-13. Land Surface Temperature Index Values (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

2.5.2 Observations

The East Wareham and East Sandwich Stations are the closest stations to the Study Area for NOAA Online Weather data, which include calendar day summaries for each day of the year with daily high maximum and minimum temperatures. **Table 2-34** summarizes how many days equaled or exceeded 90 F per year over the past 20 years of reported station data.

Table 2-34. Days with Maximum Temperature Exceeding or Equal to 90° Fahrenheit since 2004

Year of Record	East Wareham Station	East Sandwich Station
2004	0	No Data Reported
2005	3	No Data Reported
2006	4	No Data Reported
2007	1	No Data Reported
2008	4	No Data Reported
2009	2	No Data Reported
2010	9	0
2011	2	1
2012	8	0
2013	7	0
2014	0	0
2015	7	0
2016	No Data Reported	0
2017	No Data Reported	0*
2018	No Data Reported	0*
2019	No Data Reported	0
2020	12	1
2021	5	0
2022	25	0
2023	7	0

"No Data Reported" = Data were significantly missing or not available for the year of record.

* Approximately 18 to 20 days with no records for daily temperatures. Data were obtained through National Oceanic and Atmospheric Administration (NOAA) Online Weather Data (https://www.weather.gov/wrh/Climate?wfo=box), accessed on December 11, 2024.

2.5.3 Projections

Projected extreme heat temperature data and trends are published through ResilientMass, which is maintained by MA EEA. **Table 2-35** provides the baseline values and projected increases for extreme heat. The RMAT Tool recommends using the 90th percentile for the bridge and highway assets, and as such, MassDOT applied for all affected environment considerations for consistency.

Table 2-35. Extreme Heat Projections (Town of Bourne, MA)

Climate Metric	Baseline	2030	2050	2070	2090
Max Temperature (degrees Fahrenheit)	84.8	+3.6 (+1.8 to + 4.5)	+5.4 (+3.6 to +7.2)	+7.2 (+5.4 to +9.9)	+9.0 (+6.3 to +11.7)
Days above 90° Fahrenheit	1	+4 (+1 to +6)	+9 (+4 to +16)	+16 (+9 to +33)	+27 (+12 to +48)
Days above 95° Fahrenheit	0	+1 (0 to +1)	+2 (+1 to +3)	+3 (+2 to +8)	+6 (+2 to +15)

Source: These annual values were taken from the ResilientMass Climate Change Projections Dashboard, accessed on December 6, 2024, for town of Bourne. The values displayed are the median value; the values in the parentheses represent the 10th and 90th percentile range. The Resilient Massachusetts Action Team (RMAT) Tool recommends evaluating the upper 90th percentile for new construction. The climate metrics presented are expressed as absolute change relative to baseline values calculated based on the median value across the 50 model ensemble members associated with the 0° Celsius temperature change scenario derived from observational data.

2.5.4 Recommended Data and Methodology

The impacts of extreme heat vary based on the affected environment. **Table 2-36** summarizes the extreme heat parameters that MassDOT considered for assessing future conditions for the No Build Alternative and Build Alternative.

MassDOT used the following methods with the recommended data to assess heat impacts on the affected environment by the No Build Alternative and Build Alternative:

- To evaluate the effect on the bridge joint expansion, the likelihood of maximum temperatures greater than 120°F was assessed. The design temperature of steel structures ranges from -30°F to 120°F.[52] If the maximum temperature exceeded 120°F, it was assumed to be affected because it is beyond the design range.
- To evaluate the effect on the LST, the percentage of impervious area within the Study Areas was assessed in line with the metrics used by the RMAT Tool for exposure rating. If the percentage was less than 10%, it was assumed to reduce LST. If the percentage was between 10% and 50%, it was assumed to have a negligible impact on LST. If the percentage was greater than 50%, it was assumed to affect land surface temperature and increase heat risk.

[52] Massachusetts Departments of Transportation (MassDOT) Bridge Manual – Part I – Hundredth Anniversary Edition, Section 3.1.8. Temperature, p – 3-7.

- To evaluate the effect on pavement performance, the number of days greater than 90°F was assessed. Increases in days over 90°F were assumed to affect pavement performance.
- To evaluate the effect of increased temperatures on pedestrian use and SUPs, the number of days greater than 90°F was assessed. An increase in days over 90°F were assumed to affect active transportation use.

Table 2-36. Extreme Heat Parameters Recommended for Analyses

Affected Environment	Impact from Extreme Heat	Recommended Planning Horizon	Extreme Heat Characteristic	Criteria
Bridge	Bridge Joint Expansion	2090, 90th percentile	Max Temperature	Greater than 120° Fahrenheit
Land Cover	Surface temperature	NA*	Impervious Surface Area	• Less than 10% • Between 10% and 50% • Greater than 50%
Transportation	Pavement Performance	2050, 90th percentile	Days over 90° Fahrenheit	Increase
Mobility	Active Transportation Use	2050, 90th percentile	Days over 90°Fahrenheit	Increase

* Not applicable due to data type.

2.6 Winter Weather

Winter weather considerations are a function of snow and ice events, which are possible with freezing temperatures. MassDOT evaluated observations, modeled historical events, and projections.

2.6.1 Observations

MassDOT reviewed days with freezing temperatures (below 32°F) using NOWData products for East Wareham and East Sandwich Station, similar to extreme heat. **Table 2-37** summarizes how many days experienced temperatures below 32°F per year over the past 20 years of reported station data.

Table 2-37. Days with Minimum Temperatures Below 32° Fahrenheit since 2004

Year of Record	East Wareham Station	East Sandwich Station
2004	110	No Data Reported
2005	119	No Data Reported
2006	94	No Data Reported
2007	113	No Data Reported

Year of Record	East Wareham Station	East Sandwich Station
2008	114	No Data Reported
2009	104	No Data Reported
2010	105	116
2011	112	119
2012	89	108
2013	115	116
2014	105	120
2015	108	111
2016	No Data Reported	108
2017	No Data Reported	102*
2018	No Data Reported	112*
2019	No Data Reported	125
2020	96	99
2021	114	106
2022	115	105
2023	111	88

No Data Reported = Data were significantly missing or not available for the year of record.

* Approximately 18 to 20 days with no records for daily temperatures. Data were obtained through NOAA (National Oceanic and Atmospheric Administration) Online Weather Data (https://www.weather.gov/wrh/Climate?wfo=box), accessed on December 11, 2024.

2.6.2 Modeled Historical

MassDOT assessed the frequency and quantity of ice and wet snow events to inform design considerations for the replacement bridges. This assessment was based on historical meteorological data obtained from Cape Cod Gateway Airport from 1997 to 2021. MassDOT characterized freezing rain and wet snow events using daily and hourly precipitation amounts and flags, with hourly temperatures, wind speeds, and directions. Each ice and wet snow accretion event was tracked so that the maximum thicknesses could be subject to extreme value analysis.

2.6.3 Projections

Projected changes in temperatures are published through ResilientMass, which is maintained by MA EEA. **Table 2-38** provides the baseline values and projected increases for days below 32°F.

Table 2-38. Cold Weather Projections (Town of Bourne, MA)

Climate Metric	Baseline	2030	2050	2070	2090
Days below 32° Fahrenheit	106	-28 (-14 to -35)	-40 (-28 to -51)	-51 (-40 to -64)	-60 (-46 to -71)

Source: These annual values were taken from the ResilientMass Climate Change Projections Dashboard, accessed on December 6, 2024, for the town of Bourne. The values displayed are the median value; the values in the parentheses represent the 10th and 90th percentile range. The climate metrics presented are expressed as absolute change relative to baseline values calculated based on the median value across the 50 model ensemble members associated with the 0° Celsius temperature change scenario derived from observational data.

2.6.4 Recommended Data and Methodology

The impacts of winter weather vary based on the affected environment. **Table 2-39** summarizes the winter weather parameters considered for assessing the No Build Alternative and Build Alternative.

Table 2-39. Winter Weather Parameters Recommended for Analyses

Affected Environment	Impact from Winter Weather	Recommended Event	Winter Weather Characteristic	Criteria
Bridge	Icing on Cables	500-year	Combined Ice and Wet Snow	Thickness (inches)
Transportation	Snow and ice on roadways	2050, 90th percentile	Freezing temperatures	Days below 32° Fahrenheit

MassDOT used the following methods with the recommended data to assess winter weather impacts on the No Build Alternative and Build Alternative affected environments:

- To evaluate the effect of icing on bridge cables, the thickness of combined ice and wet snow was assessed. An extreme value analysis of maximum thicknesses was performed, which resulted in a 500-year combined ice and wet snow thickness of 1 inch. This is consistent with the ice thickness value specified in American Society of Civil Engineers/Structural Engineering Institute (ASCE/SEI) 7-22 for the Program Limits.
- To evaluate the effect on highway transportation from snow and ice, the number of days below 32 F was assessed. If there were still days below 32°F, it was assumed to affect the Program Limits.

2.7 Extreme Wind

The Saffir/Simpson Hurricane Scale (**Table 2-40**) is used to categorize hurricanes based their sustained wind speeds.

Table 2-40. Saffir/Simpson Hurricane Damage Scale

Category Hurricane	Wind speeds (miles per hour)	Damage Potential
1	74 to 95	Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96 to 110	Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.
3	111 to 129	Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4	130 to 156	Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5	Greater than 157	Catastrophic damage will occur: A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

Source: National Oceanic and Atmospheric Administration. National Hurricane Center and Central Pacific Hurricane Center. https://www.nhc.noaa.gov/aboutsshws.php

MassDOT evaluated modeled historical events to assess design wind speeds, aerodynamic stability wind speeds, and potential for vehicle rollover.

2.7.1 Modeled Historical

MassDOT performed a wind climate analysis for the proposed replacement bridges' design wind speeds and flutter verification, which included a Monte Carlo simulation of tropical cyclone and hurricane wind speeds. Wind tunnel testing of the proposed bridges and a buffeting analysis were conducted to determine the wind force impacts on structures. The relationship between wind speed

and return period was assessed using an extreme value analyses model with exposure corrected historical wind records. The directionality of extreme winds was assessed using a Weibull model.

2.7.2 Projections

Massachusetts does not have published projections for wind speeds related to climate change.

2.7.3 Recommended Data and Methodology

Table 2-41 summarizes the wind parameters considered for assessing the No Build Alternative and Build Alternative.

Table 2-41. Wind Parameters Recommended for Analyses

Affected Environment	Impact from Extreme Wind	Recommended Event	Extreme Heat Characteristic	Assessed Impact
Bridge	Design	• 97-year (construction) • 1,400-year (completed)	1-hour Mean Wind Speed	Mean Wind Speed (miles per hour)
Bridge	Aerodynamic Stability	• 1,000-year (construction) • 10,000-year (completed)	10-minute wind speeds/ 3 second gusts	Mean Wind Speed (miles per hour)
Highway Transportation Traffic and Safety	Vehicle Rollover	NA*	3-second wind gusts	Likelihood of gusts greater than 50 miles per hour

Note: The likelihood of the event was assessed, so there is no recommended event.

The extreme wind conditions are agnostic to the No Build Alternative and Build Alternative. MassDOT used the following methods with the recommended data to assess the wind impact on the affected environment, which aligns with American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Design Factor 10th Edition and AASHTO Guide Specifications for Wind Loads on Bridges During Construction return-period recommendations:

- To evaluate the effect of wind on bridge design, mean wind speed at deck level for 1 hour was modeled to produce the worst-case loading conditions.
- To evaluate the effect of wind on aerodynamic stability, extreme wind speeds associated with less frequent return periods (10-minute mean wind speeds associated with a 1,000-year return period for construction and 10,000-year return period for completed bridge) were analyzed.
- To evaluate the effect of potential vehicle rollover, the likelihood of wind gust speeds greater than 50 miles per hour at deck level was assessed.

3 Existing Conditions

Table 3-1 summarizes the affected environments within the Program Limits and Study Areas and the primary climate risks assessed in the No Build Alternative and Build Alternative. The affected environment briefly describes the relevant components within the affected environment with respect to these climate risks, and more information on the overall affected environment can be found in their associated chapters.

Table 3-1. Affected Environment and Potential Impacts

Affected Environment	Related Draft Environmental Impact Report Section	Sea Level Rise/Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Wind
Cape Cod Canal	Section 4.4, Maritime Transportation, Traffic, and Safety	Navigational Clearance	NA	NA	NA	NA
Bridge	Chapter 3, Proposed Action and Alternatives	Pier Scour	NA	Joint Expansion	Icing on Cables	Design and Aerodynamic Stability
Stormwater Control Measures	Section 4.11, Water Quality and Stormwater	• Submerged Outfalls* • Infiltration Basin Flooding	Infiltration Basin Performance	NA	NA	NA
Land Cover	• Section 4.10, Wetlands and Floodplains • Section 4.11, Water Quality and Stormwater • Section 4.6, Land Use, Zoning, and Community Cohesion	Floodplain Function	Localized Flooding	Surface temperature	NA	NA
Transportation	Section 4.2, Transportation, Traffic, and Safety	Roadways Evacuation Route Flooding	Localized Flooding	Pavement Performance	Snow and ice on roadways	Vehicle Rollover
Mobility	Section 4.3, Pedestrian and Bicycle Facilities	Shared-use Path Flooding	Localized Flooding	Active Transportation Use	NA	NA

NA = Not assessed for affected environment.

* Outfalls are within the Study Area shown in **Figure 2-1** but would not be part of the Build Alternative; they were assessed due to their impact on stormwater systems (flooding and performance) within the Study Area.

3.1 Cape Cod Canal

Section 4.4, Maritime Transportation, Traffic, and Safety, of the DEIR identifies the affected environment for navigation.

3.1.1 Sea Level Rise and Storm Surge

Cape Cod Canal is a navigational channel with an existing vertical clearance of 135 feet. The existing and replacement bridges are and would be fixed structures, so SLR/SS affects the ability to maintain the required vertical clearance.

3.2 Bridge

Chapter 3, Proposed Action and Alternatives, of the DEIR describes the existing and replacement bridges.

3.2.1 Sea Level Rise and Storm Surge

The existing and replacement bridge piers are and would be along the canal banks and subject to coastal processes, including inundation and scour. SLR/SS affects the coastal processes and may affect water levels, by increasing velocities and flows, while also affecting attack angles related to flow directions that impact scour potential.

3.2.2 Extreme Heat

The existing and replacement bridges' expansion joints are and would be thermally sensitive to extreme temperatures. Temperatures below or exceeding design threshold of -30 F to +120 F may affect the performance of the expansion joints.

3.2.3 Winter Weather

Ice accretion affects static loads and wind drag, which may affect the aerodynamic stability of the bridge. Icing on bridge structures above the bridge deck (i.e., cables or overhead cross-members) poses a risk to safety, including traffic below, when the accumulated ice or snow sheds off the bridge members and falls down on the bridge deck.[53]

3.2.4 Extreme Wind

Wind causes static loads on a bridge and also results in a special dynamic behavior that affects aerodynamic stability.[54]

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[53] Lubomir M., C.T. Georgakis. 2022. "A review of ice and snow risk mitigation and control measures for bridge cables," Cold Regions Science and Technology, Volume 193, 103429, ISSN 0165-232X, https://doi.org/10.1016/j.coldregions.2021.103429.

[54] Federal Highway Administration 2011. "Framework for Improving Resilience of Bridge Design." Publication No. FHWA-IF-11-016. January. Pg. 56. https://www.fhwa.dot.gov/bridge/pubs/hif11016/hif11016.pdf

3.3 Stormwater Control Measures

Section 4.11, Water Quality and Stormwater, of the DEIR describes the SCMs.

3.3.1 Sea Level Rise and Storm Surge

Stormwater is ultimately discharged into the canal through outfalls by gravity flow, and SLR/SS affect the ability of the existing outfalls to discharge flow freely (without submerged or partially submerged conditions). **Table 3-2** summarizes the outfalls and associated elevations that discharge into Cape Cod Canal.

Table 3-2. Stormwater Outfalls that Discharge into Cape Cod Canal

Outfall Location (quadrant)	Description	Invert Elevation (feet-NAVD88)	Crown Elevation (feet-NAVD88)
Sagamore North	24-inch reinforced concrete pipe	5.15	7.15
Sagamore South – West	36-inch cast iron	4.43	7.43
Sagamore South – East	36-inch cast iron	7.5	10.5
Bourne North*	43-inch by 68-inch concrete	0.46	4.04
Bourne North*	43-inch by 68-inch concrete	0.36	3.94
Bourne South	24-inch reinforced concrete pipe	4.67	6.67

Note: * Twin elliptical culverts

NAVD88 = North American Vertical Datum of 1988

The existing outfalls do not have gates or backflow preventers and modifications to the outfall structures are not proposed as part of the program. If tides exceed the invert elevations, flow inundates the system and may prevent stormwater from discharging during rain events. This can cause flooding from either SLR/SS or precipitation events. Inundation from SLR/SS also reduces the ability of the infiltration basins to manage stormwater generated by rainfall events.

3.3.2 Extreme Precipitation

Extreme precipitation combined with SLR/SS affects the performance of the overall system—from managing stormwater quality and quantity, to discharging into Cape Cod Canal. Extreme precipitation events also affect the size of the stormwater basin needed to manage rainfall quality and quantity.

3.4 Land Cover

Land cover is described several sections, including **Section 4.10, Wetlands and Floodplains; Section 4.11, Water Quality and Stormwater;** and **Section 4.6, Land Use, Zoning, and Community Cohesion,** of the DEIR, which address resource areas, impervious surfaces, and land clearing.

3.4.1 Sea Level Rise and Storm Surge

Figure 2-2 and **Figure 2-3** show the floodplain, which is considered a previously developed area within Minimal Wave Action Zone of Land Subject to Coastal Storm Flowage (LSCSF) as described in **Section 4.10, Wetlands and Floodplains** of the DEIR. LSCSF is presumed to be significant to storm damage prevention and flood control based on its following abilities:

- Dissipate wave energy and decrease the velocity of moving water.
- Receive coastal floodwaters that spread laterally and landward and infiltrate.
- Allow water to flow across the landform without redirecting or channeling the flow or increasing the velocity of flood waters.
- Slow moving water, thereby reducing erosion.
- Store floodwaters until they can return to the ocean or infiltrate into the ground.

SLR/SS increases the horizontal and vertical extent of LSCSF—even if it does not affect the regulatory boundary.

3.4.2 Extreme Precipitation and Extreme Heat

Impervious surfaces exacerbate localized flooding caused by extreme precipitation and also increase surface temperatures. Vegetative cover improves infiltration and slows moving water.

3.5 Transportation

Section 4.2, Transportation, Traffic, and Safety, of the DEIR identifies the affected environment for transportation, traffic, and safety for the Program, including the Cape Cod Emergency Traffic Plan and Traffic Operations Annex, which identifies traffic control points along major routes to facilitate/ expedite off-Cape traffic flow.[55]

3.5.1 Sea Level Rise and Storm Surge

Coastal inundation from SS may affect the likelihood of flooding on formal emergency evacuation routes and roadways. It is not safe to drive into flooded areas; 6 inches of water will reach the bottom of most passenger cars, which can cause loss of control and possible stalling.[56] During flood events, most casualties are caused by vehicles when drivers attempt to drive along flooded roads.[57] Coastal flooding from SS events may result in damage to existing roadways, particularly in areas of channelized flow. SLR/SS increases the horizontal and vertical extent of the inundated area.

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[55] Commonwealth of Massachusetts. 2018. Cape Cod Emergency Traffic Plan. July. https://www.mass.gov/doc/cape-cod-emergency-traffic-plan/download

[56] Commonwealth of Massachusetts. n.d. Flood Safety Tips. https://www.mass.gov/info-details/flood-safety-tips

[57] Commonwealth of Massachusetts. n.d. Flood Safety Tips. https://www.mass.gov/info-details/flood-safety-tips

3.5.2 Extreme Precipitation

High-intensity, short-duration events that exceed design criteria can overwhelm drainage infrastructure and result in localized flooding. The hazard of low-water depths is usually underestimated because it can be perceived as less threatening to drivers.[58] These events can also reduce pavement strength and result in roadway washouts of varying magnitudes.

3.5.3 Extreme Heat

Warmer temperatures lead to higher asphalt-concrete pavement temperatures, which affect materials durability distress and fatigue cracking.[59] Extreme heat may reduce material stability, particularly pavement that softens and expands when exposed to extreme heat over long periods of time. This can cause buckling, rutting, and potholes. Combined with heavy precipitation events, this can lead to increased ponding on roadways and/or lead to failures that increase the frequency of repairs and replacements.

3.5.4 Winter Weather

Winter weather (including snow and ice) can cause slower speeds, reduce roadway capacity, increase travel-time delay, and increase crash risk as a result of reduced pavement friction, visibility, and vehicle maneuverability. Average arterial speeds decline by 30% to 40% on snowy or slushy pavement, and highway speeds are reduced by up to 13% in light snow and up to 40% in heavy snow. Winter weather events also increase road maintenance costs, including salt management and costs to repair infrastructure damaged by snow and ice.[60]

3.5.5 Wind

Vehicles are more sensitive to wind while passing over long-span bridges compared to ground-level roads given the higher road elevations, exposure, and possible speed-up impacts.[61]

3.6 Mobility

Section 4.3, Pedestrian and Bicycle Facilities, of the DEIR identifies the affected environment for pedestrian and bicycle facilities.

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[58] Commonwealth of Massachusetts. n.d. Flood Safety Tipshttps://hntb.sharepoint.com/sites/dp_70095_CCBPcollab/CCBP_DEIR_D2/04.22_Climate_Change_Adaptation_and_Resiliency/Flood Safety Tips. https://www.mass.gov/info-details/flood-safety-tips

[59] Federal Highway Administration. 2029. FHWA-HRT-16-084: Impact of Environmental Factors on Pavement Performance in the Absence of Heavy Loads. March. p. 222. https://www.fhwa.dot.gov/publications/research/infrastructure/pavements/16084/16084.pdf

[60] Federal Highway Administration. 2024. n.d. Snow and Ice. September. https://ops.fhwa.dot.gov/weather/weather_events/snow_ice.htm

[61] Rowan Williams Davies & Irwin Incorporation (RWDI). n.d. "Study of vehicle roll-over stability in strong winds," Long Span Bridges. https://rwdi.com/en_ca/projects/vehicle-roll-over-stability-in-strong-winds-on-long-span-bridges/

3.6.1 Sea Level Rise and Storm Surge

Coastal inundation from SS may affect the likelihood of flooding on shared-use paths and sidewalks. It is not safe for pedestrians or bicyclists to travel into flooded areas; 6 inches of fast-moving water can knock over an adult.[62] Coastal inundation can also reduce pavement strength and result in washouts of varying magnitudes. SLR/SS increases the horizontal and vertical extent of the inundated area.

3.6.2 Extreme Precipitation

High-intensity, short-duration events that exceed design criteria can overwhelm drainage infrastructure and result in localized flooding. It is not safe for pedestrians or bicyclists to travel into flooded areas; 6 inches of fast-moving water can knock over an adult.[63] These events can also reduce pavement strength and result in washouts of varying magnitudes.

3.6.3 Extreme Heat

People using alternative modes of transportation (such as bus, bicycle, and walk) are more vulnerable to extreme heat; under extreme heat, the use of shared-use paths and alternative modes of transportation is likely to be lower.[64] Extreme heat may reduce material stability, particularly pavement that softens and expands when exposed to extreme heat over long periods of time. This can cause buckling, rutting, and potholes that affect accessibility of active transportation networks and increase the frequency of maintenance.

4 No Build Alternative

This section reflects No Build impacts with current and future conditions based on methodology and affected area described in previous sections. Assessed impacts are negative, unless otherwise noted.

4.1 Cape Cod Canal

For the No Build Alternative, Cape Cod Canal and Sagamore Bridge and Bourne Bridge would remain as-is, but the navigational clearance would be affected.

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[62] Commonwealth of Massachusetts. n.d. Flood Safety Tips. https://www.mass.gov/info-details/flood-safety-tips

[63] Commonwealth of Massachusetts. n.d. Flood Safety Tips. https://www.mass.gov/info-details/flood-safety-tips

[64] Batur, I., V.O. Alhassan, M.V. Chester, S.E. Polzin, C. Chen, C.R. Bhat, R.M. Pendyala. 2024. Understanding how extreme heat impacts human activity-mobility and time use patterns, Transportation Research Part D: Transport and Environment, Volume 136, 2024,104431, ISSN 1361-9209. November. https://doi.org/10.1016/j.trd.2024.104431

4.1.1 Navigational Clearance and Sea Level Rise

For the No Build Alternative, RSLR would affect the ability to maintain the existing 135-foot vertical navigational operational clearance through Cape Cod Canal.[65] The approximate low chord elevations are El. 140.5 feet-NAVD88 and EL. 139.0 feet-NAVD88 for Sagamore Bridge and Bourne Bridge, respectively, which would provide an approximate 137-foot clearance for both structures under existing MHHW for each structure. If MHHW increases 3 feet due to RSLR, the existing clearance would be maintained approximately 71% of the time, making the canal unnavigable during high tides.

4.2 Bridge

For the No Build Alternative, the Sagamore Bridge and Bourne Bridge decks, superstructures, and substructures would remain as-is.

4.2.1 Bridge Pier Scour and Sea Level Rise

Since reuse of the existing structures is not proposed, only a Build Alternative model was developed for the Sagamore Bridge replacement to assess scour.

4.2.2 Bridge Joint Expansion and Extreme Heat

Design practices and standards for extreme heat have changed since construction of the existing structures, but the steel is likely to have the same sensitivity to heat. There are no projected maximum annual temperatures over 120°F, so extreme heat is unlikely to affect the No Build Alternative.

4.2.3 Icing and Winter Weather

Design practices and standards for winter weather have changed since construction of the existing structures, including the link slabs and slab-over-backwall details to reduce risk of winter deicing treatment infiltrating into superstructure and substructure elements. Icing of the cross-members pose a risk to the existing structures as well. Since there are projected days below 32°F, the No Build Alternative is likely to remain vulnerable to winter weather, including snow and ice.

4.2.4 Aerodynamic Stability and Extreme Wind

Design practices and standards for extreme wind have changed since construction of the existing structures. The Sagamore Bridge and Bourne Bridge were designed in the 1930s and are composed of steel trusses forming continuous spans, with spans over Cape Cod Canal that are 616 feet in length. Truss bridges tend to be more vulnerable to progressive collapse due to lack of redundancy in design,

[65] There is a third crossing over the Cape Cod Canal, the Railroad Bridge, which is west of Bourne Bridge. The Railroad Bridge crossing has not been evaluated for its impacts to navigational clearance since it is outside the Study Area and the scope for proposed improvements.

and generally longer spans (i.e., greater than 300 feet) have issues related to deflections due to wind.[66] The No Build Alternative is vulnerable to extreme wind given the bridges' age and truss structure.

4.3 Stormwater Control Measures

For the No Build Alternative, the SCMs, including existing SCMs, piped infrastructure, and outfalls, would remain as-is.

4.3.1 Submerged and Partially Submerged Outfalls and Sea Level Rise

There are no tide gates or backflow preventers on the outfalls that discharge stormwater to the canal. The No Build Alternative would enable future high tides and SSs to back flow through the storm drain system, which may result in localized flooding from tides and/or the inability to convey stormwater runoff to the canal. All of the outfalls within the Study Area are vulnerable to rising sea levels. **Table 4-1** summarizes the projected tidal datums where the inverts and/or crown elevations are exceeded.

Table 4-1. Partially and Fully Submerged Outfalls Based on Projected Tidal Datums **Relative Sea Level Rise**

Outfall Location	Invert Elevation Exceeded (Partially Submerged)	Crown Elevation Exceeded (Fully Submerged)
Sagamore North	• 2050 (2.4 feet RSLR) – MHW • 2070 (4.2 feet RSLR) – MHW	• 2070 (4.2 feet RSLR) - MHW
Sagamore South – West	• 2030 (1.2 feet RSLR) – MHHW • 2050 (2.4 feet RSLR) – MHW • 2070 (4.2 feet RSLR) – MHW	• 2070 (4.2 feet RSLR) - MHHW
Sagamore South – East	• 2070 (4.2 feet RSLR) – MHHW	• MLLW would not exceed crown by 2070
Bourne North (twin elliptical culverts)	• 2000 – MHW • 2030 (1.1 feet RSLR) – MTL • 2050 (2.4 feet RSLR) – MTL • 2070 (4.2 feet RSLR) – MLLW	• 2050 (2.4 feet RSLR) – MHW • 2070 (4.2 feet RSLR) – MHW
Bourne North (twin elliptical culverts)	• 2000 – MHW • 2030 (1.1 feet RSLR) – MTL • 2050 (2.4 feet RSLR) – MTL • 2070 (4.2 feet RSLR) – MLLW	• 2050 (2.4 feet RSLR) – MHW • 2070 (4.2 feet RSLR) – MHW

[66] Federal Highway Administration. 2011. "Framework for Improving Resilience of Bridge Design." Publication No. FHWA-IF-11-016. January. Pg. 25. https://www.fhwa.dot.gov/bridge/pubs/hif11016/hif11016.pdf

Outfall Location	Invert Elevation Exceeded (Partially Submerged)	Crown Elevation Exceeded (Fully Submerged)
Bourne South	• 2070 (4.2 feet RSLR) – MHW	• MLLW would not exceed crown by 2070

MHHW = mean higher high water; MHW = mean high water; MLLW = mean lower low water; MTL = mean tide level; RSLR = relative sea level rise

The Bourne North quadrant outfall structure is very vulnerable to RSLR. Current tidal datums restrict flow during high tide with the outfall approximately 50% submerged. Under 2050 RSLR conditions, the Bourne North quadrant outfall would be fully submerged during high tides and free flow only during low tides. By 2070, there would be partial submerged tailwater conditions even at low tide.

4.3.2 Stormwater Control Measure Performance and Extreme Precipitation

Section 4.11, Water Quality and Stormwater, of the DEIR discusses impacts to SCMs from extreme precipitation for the No Build Alternative.

4.4 Land Cover

For the No Build Alternative, the land cover, including impervious surfaces and land surface temperatures, would remain as-is.

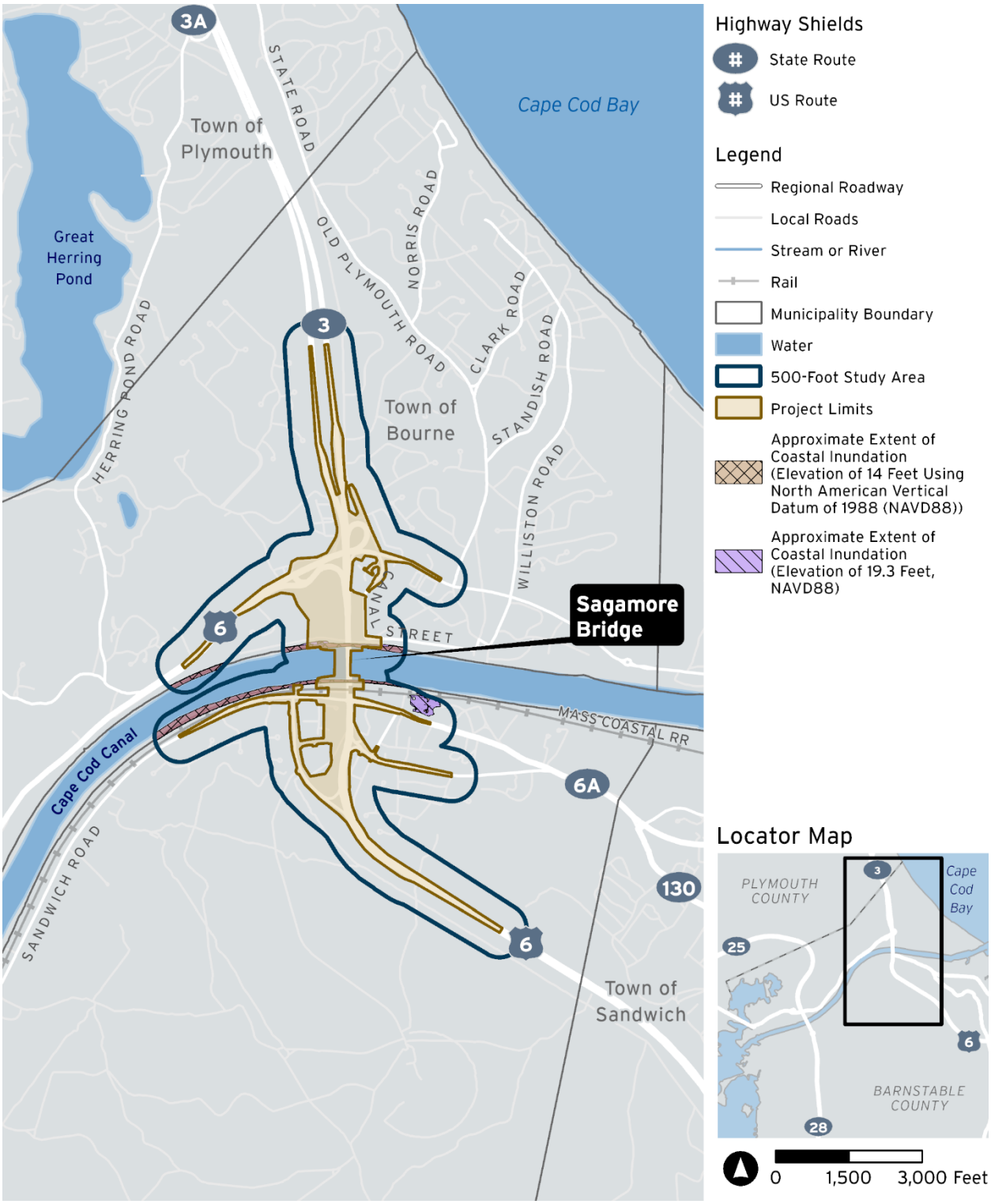
4.4.1 Floodplain Function and Sea Level Rise/Storm Surge

Figure 4-1 and **Figure 4-2**, respectively, show the extent of overland coastal surge for the No Build Alternative for the Sagamore Bridge and Bourne Bridge Study Areas. **Figure 4-3** illustrates the flood pathways at the Bourne North quadrant near Belmont Circle. There would be no changes to the land cover that would affect the floodplain, and the vertical and horizontal extent of inundations would change slightly between the FEMA 100-year event and a Category 2 hurricane with 3 feet freeboard. **Section 4.10, Wetlands and Floodplains,** of the DEIR discusses additional impacts to floodplains from the No Build Alternative.

4.4.2 Localized Stormwater Flooding and Extreme Precipitation

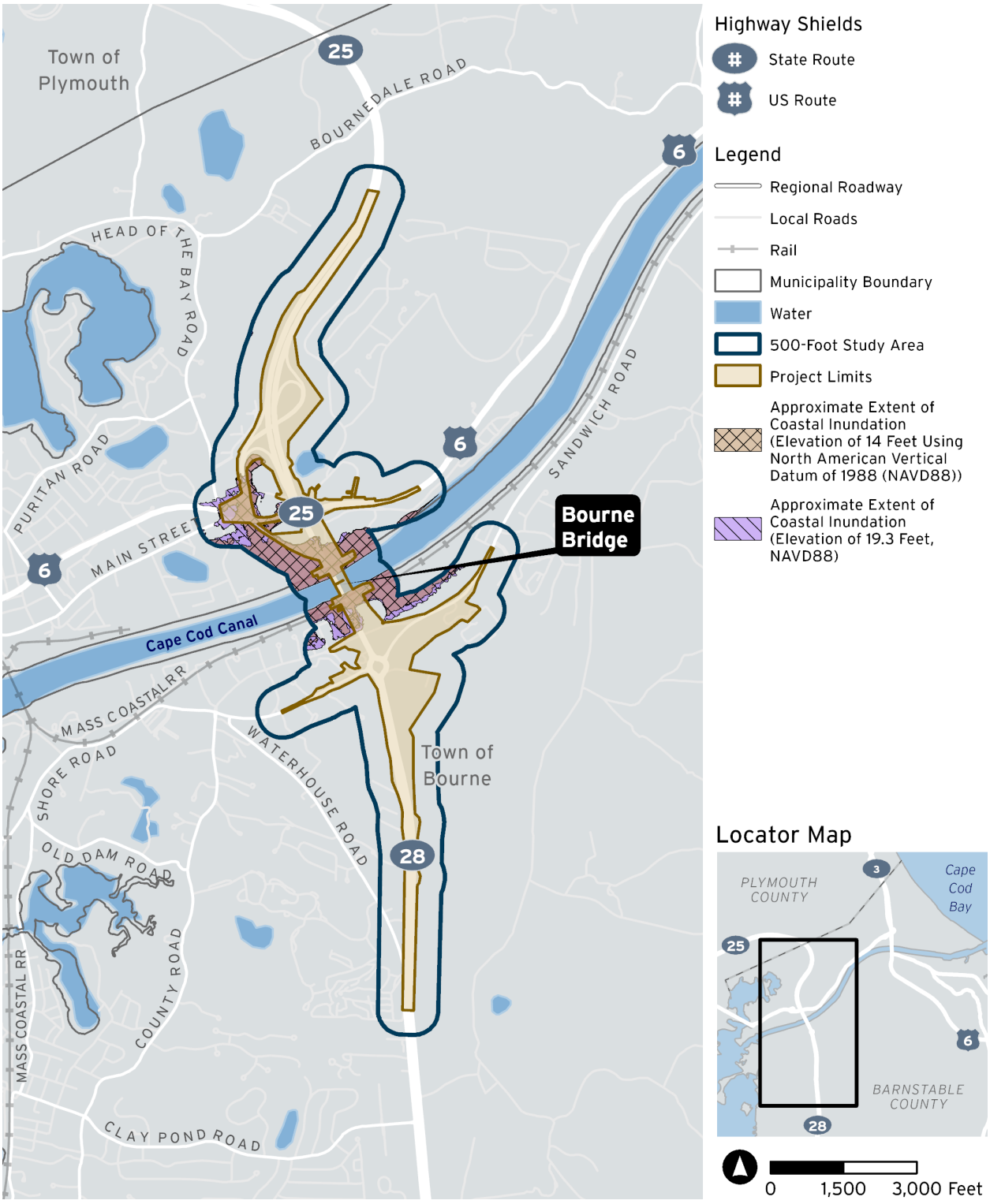
Section 4.11, Water Quality and Stormwater, of the DEIR discusses impacts to localized flooding from impervious surfaces and extreme precipitation for the No Build Alternative.

Figure 4-1. No Build Alternative: Coastal Surge Flood Extents (Sagamore Bridge Study Area)



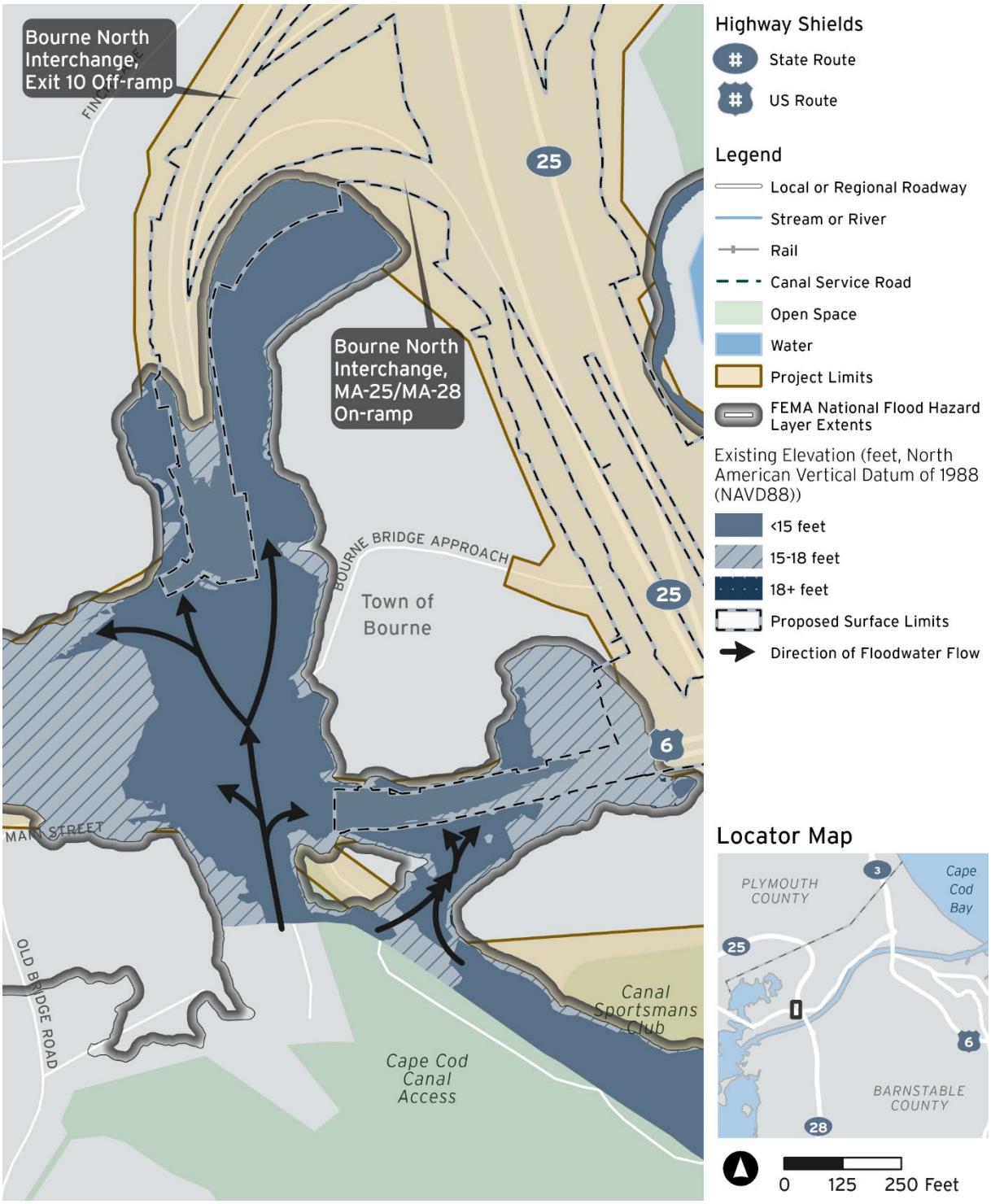
Source: Massachusetts Department of Transportation, 2024

Figure 4-2. No Build Alternative: Coastal Surge Flood Extents (Bourne Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

Figure 4-3. No Build Alternative: Existing Grading and Flood Pathways (Bourne North Quadrant)



Source: Massachusetts Department of Transportation, 2024

4.4.3 Surface Temperatures and Extreme Heat

For the No Build Alternative, the land cover (impervious surfaces) would remain as-is. **Figure 4-4** and **Figure 4-5** illustrate the existing impervious surfaces within the Study Areas based on the 2016 land cover dataset hosted on ResilientMass Climate and Hazards Viewer. **Table 4-2** summarizes the impervious surface area with the Sagamore Bridge and Bourne Bridge Study Areas shown in **Figure 4-4** and **Figure 4-5**.

Table 4-2. Impervious Area within Sagamore Bridge and Bourne Bridge Study Areas

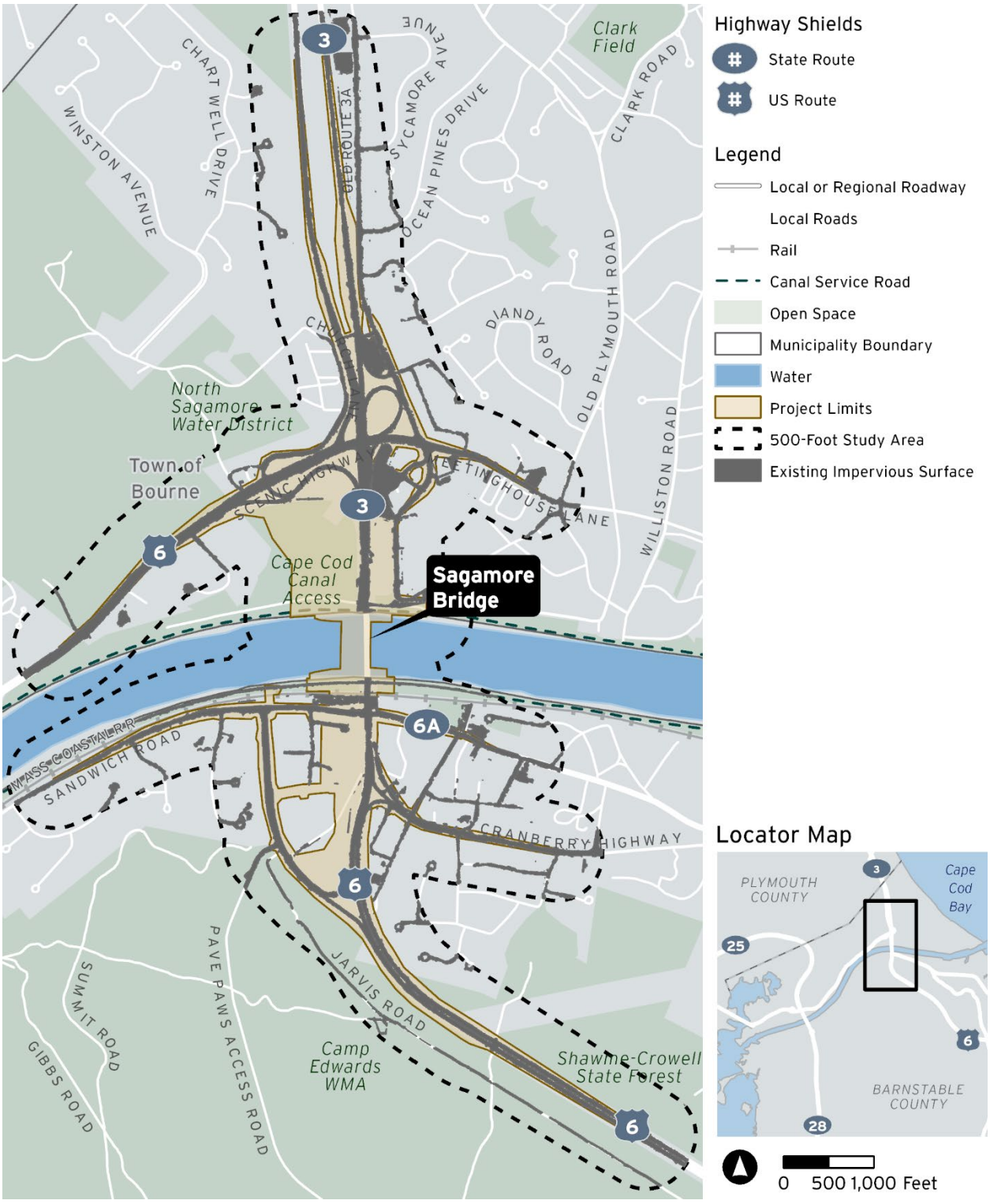
Study Area	Project Limits (acres)	Roadway Surface Area (acres)[1]	Total Impervious Surface within Project Limits (acres)[2]	No Build Alternative Percentage Impervious
Sagamore Bridge	201.7	42.9	73.5	36.4%
Bourne Bridge	273.7	44.0	80.9	29.5%

[1] The existing roadway surface area based on survey measurements for north and south quadrants of each Study Area as presented in **Section 4.11, Water Quality and Stormwater.**

[2] Impervious surface areas are based off Massachusetts Department of Transportation (MassDOT) Land Cover Land Use Data, filtered to right-of-way and other impervious and encompasses more than roadway surfaces.

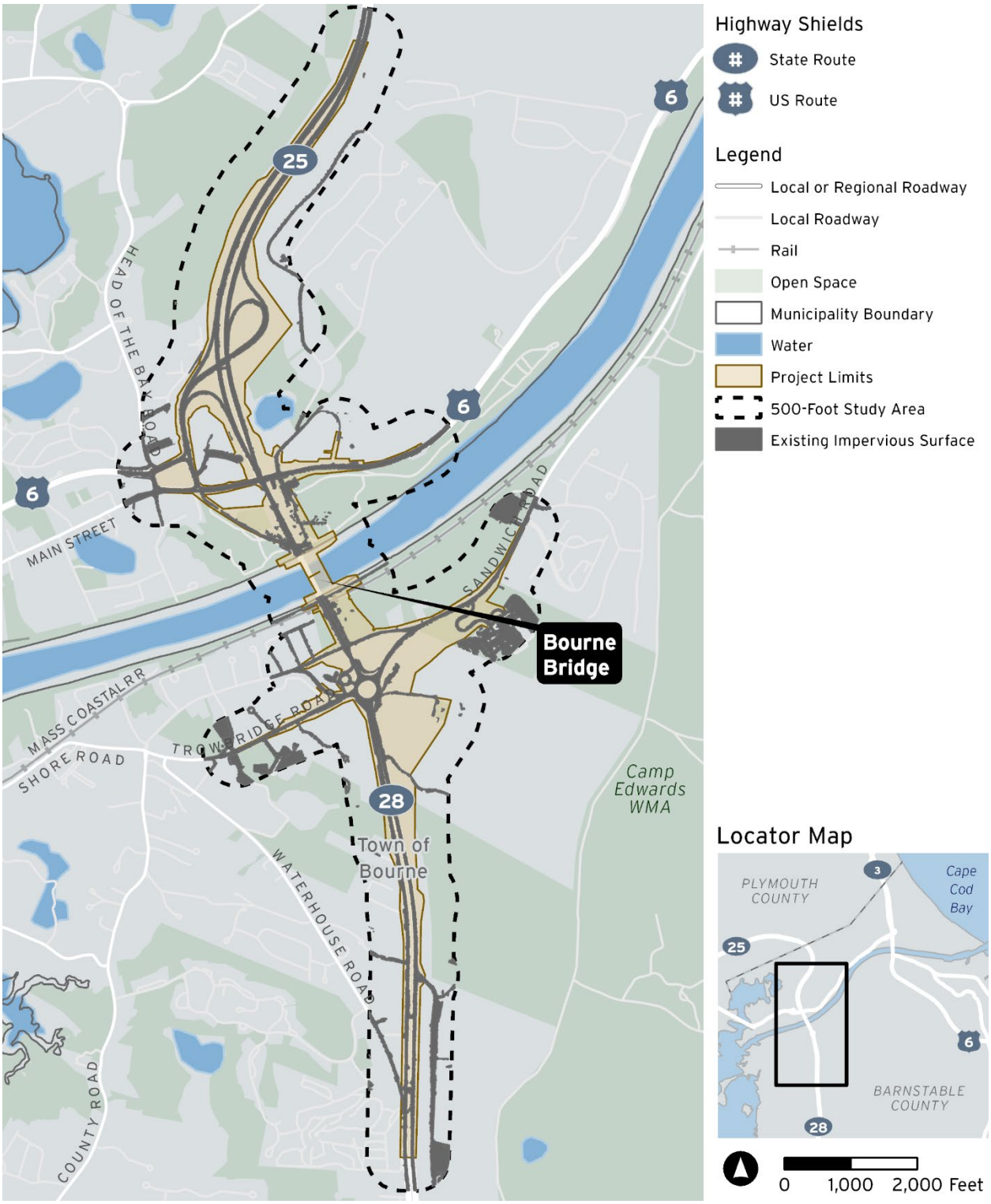
Surface temperature is a function of impervious surfaces, so the No Build Alternative is not assumed to be affected.

Figure 4-4. No Build Alternative: Land Cover – Impervious Surfaces (Sagamore Bridge)



Source: Massachusetts Department of Transportation, 2024

Figure 4-5. No Build Alternative: Land Cover – Impervious Surfaces (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

4.5 Transportation

For the No Build Alternative, the highway transportation routes would remain as-is.

4.5.1 Flooded Roadways and Evacuation Routes and Sea Level Rise/Storm Surge

The roadways within the Bourne North quadrant Study Area, in particular, those that travel through Belmont Circle, are vulnerable to coastal inundation; there is at least a 1% annual likelihood (or 1-in-4 chance over the next 30 years) for a coastal flood event. In the No Build Alternative, the likelihood of flooding and existing conditions remains the same, with heavy traffic volumes exiting to Belmont Circle and merging from the entrance ramp from Belmont Circle. Flooding may cause roadway closures, increase traffic delays, and affect emergency services.

The Cape Cod Emergency Traffic Plan, which facilitates the egress of a high volume of traffic from Cape Cod in the event of a hurricane or other potential or actual hazard, particularly during peak tourist season, includes traffic operations that reduce traffic flow to Belmont Circle, including restricting access to State Routes 28/25 via Scenic Highway and closing Exit 10 (formerly Exit 3) that leads to U.S. Route 6 from State Route 25W.[67] Even with this plan, flooding of Belmont Circle is likely to affect traffic plans and operations in emergency recovery and for events that do not trigger plan implementation.

4.5.2 Localized Stormwater Flooding and Extreme Precipitation

Section 4.11, Water Quality and Stormwater, of the DEIR discusses impacts to localized flooding from extreme precipitation for the No Build Alternative.

4.5.3 Pavement Performance and Extreme Heat

It is likely that the performance of the existing pavement will be affected with increases in days over 90°F for the No Build Alternative, such as increased prevalence of buckling, rutting, and potholes.

4.5.4 Snow and Ice on Roadways and Winter Weather

Winter weather conditions that generate snow and ice on roadways are likely to affect the No Build Alternative traffic and safety conditions.

4.5.5 Vehicle Rollover Potential and Extreme Wind

Based on analyses by Rowan Williams Davies & Irwin Incorporation (RWDI), 3-second wind gust speeds that can increase the likelihood of vehicle rollover occur 0.2% of the time (or an average of roughly 20 hours per year) at Sagamore Bridge, and 0.55% of the time (or an average of roughly 50 hours per year) at Bourne Bridge. This is irrespective of the No Build Alternative or Build Alternative.

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[67] Commonwealth of Massachusetts. 2018. Cape Cod Emergency Traffic Plan. July. https://www.mass.gov/doc/cape-cod-emergency-traffic-plan/download

4.6 Mobility

For the No Build Alternative, the alternative modes of transportation, such as bus, bicycle, and walk, would remain as-is.

4.6.1 Flooded Shared-Use Paths and Sea Level Rise/Storm Surge

Alternative modes of transportation within the Bourne North quadrant Study Area, in particular, travel through Belmont Circle, are vulnerable to coastal inundation. In the No Build Alternative, existing conditions and likelihood of flooding would remain the same (at least a 1% annual likelihood or 1-in-4 chance over the next 30 years).

4.6.2 Localized Stormwater Flooding and Extreme Precipitation

Section 4.11, Water Quality and Stormwater, of the DEIR discusses impacts to localized flooding from extreme precipitation for the No Build Alternative.

4.6.3 Active Transportation Use and Extreme Heat

In addition to affected pavement performance, it is likely that extreme heat events will impact the use of alternative modes of travel in the No Build Alternative. Increases in days over 90°F may increase the risk of heat stress for pedestrians and bicyclists.

5 Program Impacts

This section reflects Build Alternative impacts with current and future conditions based on methodology and affected area described in previous sections.

5.1 Cape Cod Canal

For the Build Alternative, Cape Cod Canal would remain as-is, but the Sagamore Bridge and Bourne Bridge low chords would be elevated to reduce the impact on navigational clearance.

5.1.1 Navigational Clearance and Sea Level Rise

The Build Alternative would raise the low chord elevation of the replacement bridges to establish a vertical clearance of 138.3 feet compared to the existing MHHW. If MHHW is 3 feet higher[68], the replacement bridges would maintain the existing navigational clearance of 135 feet for the range of

[68] Three feet of relative sea level rise corresponds with the planning horizons between 2050 and 2070 (ResilientMass) and between 2070 and 2125 (.S. Army Corps of Engineers) as presented in **Table 2-6**.

tidal datums assessed.[69] The replacement bridges would also meet the preliminary vertical clearance determined by the U.S. Coast Guard.[70]

5.2 Bridge

For the Build Alternative the existing bridges would be replaced with network tied-arch structures with piers along riprap armored banks. A network tied-arch structure is a highly redundant in that it can lose any two cables without compromising stability.

5.2.1 Bridge Pier Scour and Sea Level Rise

MassDOT performed preliminary hydraulics and scour analyses to assess maximum scour depth with and without RSLR for Sagamore Bridge.[71]

In general, RSLR of 7.7 feet for the scour events modeled would result in changes in average local velocity between approximately -1.7 and +0.7 feet per second and changes in average local water depth would increase between approximately 4.6 feet and 10.2 feet. The RSLR of 7.7 feet would also affect the flow angle of attack for the canal piers, increase the area within Cape Cod Canal, and decrease the flow volume in the canal. The scour depth for the northern canal pier would be greater without 7.7 feet RSLR, and the scour depth for the southern canal pier would be greater with 7.7 feet RSLR.

Maximum scour depths for design and check events (200-year and 500-year, respectively, in accordance with FHWA HEC-18) at the proposed northern canal pier were identified under current sea level conditions, while RSLR of 7.7 feet would lead to the maximum scour depths at the proposed southern canal pier. **Table 5-1** summarizes the maximum scour depths for Sagamore Bridge piers based on 2D hydraulic analyses.

The foundations of the Build Alternative would be designed to remain stable during the maximum scour design and check events, so the Build Alternative for Sagamore Bridge is unlikely to be affected by scour. This assessment will be updated in the Final Environmental Impact Report (FEIR) once Bourne Bridge is analyzed.

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[69] Notwithstanding the navigational limitations from the aforementioned railroad bridge that crosses Cape Cod Canal to the west of Bourne Bridge.

[70] The First Coast Guard District issued a Preliminary Navigation Clearance Determination dated March 11, 2025, to the Massachusetts Department of Transportation (MassDOT) and the U.S. Army Corps of Engineers (USACE). The determination stated that the replacement Sagamore and Bourne Bridges should provide at least 138.3 feet of vertical clearance and at least 500 feet of horizontal clearance to not unreasonably obstruct the free navigation of the waters over which the bridge is constructed.

[71] Scour analyses for Bourne Bridge are in progress (as of December 13, 2024).

Table 5-1. Maximum Calculated Scour Depths (Sagamore Bridge)

Return Period	Location	Total Scour (feet)	Ground Elevation (feet-NAVD88)	Scour Bottom Elevation (feet-NAVD88)
200-year	Northern Canal Pier	37.96	-2.00	-39.96
200-year + 7.7 feet RSLR	Southern Canal Pier	35.58	-2.00	-37.58
500-year	Northern Canal Pier	41.76	-2.00	-43.76
500-year + 7.7 feet RSLR	Southern Canal Pier	39.07	-2.00	-41.07

Source: Preliminary Hydraulics and Scour Analyses Report for the Cape Cod Canal, Sagamore Bridge Replacement Project, prepared by HNTB, dated November 2024.

NAVD88 = North American Vertical Datum of 1988, RSLR = relative sea level rise

5.2.2 Bridge Joint Expansion and Extreme Heat

Design practices and standards for new bridges include limiting the number of bridge expansion joints and assuming a range of -30°F to 120°F. Bridge joints in the Build Alternative are unlikely to be affected by extreme heat.

5.2.3 Icing and Winter Weather

Icing on bridge cables of network tied-arch structures poses a risk to safety, including traffic below. The Build Alternative would be designed for a 1-inch combined ice and wet snow thickness, which is a 500-year event as identified by RWDI, through mitigation measures as described in **Section 6**.

Design practices and standards for new bridges include limiting the number of bridge expansion joints to reduce risk of winter deicing treatment infiltrating into superstructure and substructure elements. While there are projected days below 32°F, the replacement bridges would unlikely be affected by snow and ice events.

5.2.4 Aerodynamic Stability and Extreme Wind

Network tied-arch bridges have better resistance against wind-induced vibrations and deformation. The Build Alternative would be designed to remain stable during the extreme wind conditions modeled by RWDI; the replacement bridges are unlikely to be affected by extreme wind events.

5.3 Stormwater Control Measures

For the Build Alternative, new infiltrations basins are proposed, with overflow outlet structures that connect to the existing stormwater system. Existing piped infrastructure and outfalls would remain as-is.

5.3.1 Submerged and Partially Submerged Outfalls and Sea Level Rise

Because there are no tide gates or backflow preventers on the outfalls that discharge stormwater to the canal, the Build Alternative would experience the same impacts as the No Build Alternative. Refer to **Section 4.3.1**.

5.3.2 Infiltration Basins and Sea Level Rise/Storm Surge

The Build Alternative would include new infiltration basins to manage stormwater quality and volumes. Of the 24 infiltration basins proposed in the Build Alternative, five were identified as potentially vulnerable to rising sea levels and storm surge. **Table 5-2** summarizes the Build Alternative infiltration basins where the basin elevations would be exceeded. Once the overflow outlet structures are designed for the infiltration basins, the outlet elevation for each vulnerable basin will be considered in this table as well.

Table 5-2. Potentially Affected Infiltration Basins

Infiltration Basins	Basin Bottom Elevation (feet-NAVD88)	Overflow Outlet Elevation (feet-NAVD88)	Basin Top Elevation (feet-NAVD88)	Potential Inundation Scenario Impact
SCM-SS01	13	TBD	21	• Federal Emergency Management Agency (FEMA) 100-year (Elevation [El.] 14): Exceeds bottom of basin • Top of basin not exceeded
SCM-BN10	12	TBD	18	• FEMA 100-year (El. 16): Exceeds bottom of basin • Category 2 + 3 feet (El. 19.3): Exceeds top of basin
SCM-BN07	7.5	TBD	17.5	• FEMA 100-year (El. 16): Exceeds bottom of basin • Category 2 + 3 feet (El. 19.3): Exceeds top of basin
SCM-BN08	13.25	TBD	21	• FEMA 100-year (El. 16): Exceeds bottom of basin • Top of basin not exceeded
SCM-BSO1A	14.5 to 15	TBD	18	• FEMA 100-year (El. 16): Exceeds bottom of basin • Category 2 + 3 feet (El. 19.3): Exceeds top of basin

Note: The elevations of the proposed overflow outlets are to be determined (TBD). They are between the bottom and top of the basins.

NAVD88 = North American Vertical Datum of 1988

Without mechanisms to prevent backflow into infiltration basins, coastal inundation would affect the basins when floodwater elevations exceed the overflow structure's outlet elevation, causing the structure to surcharge. Those events would affect infiltration basins within the extent of coastal inundation with an overflow structure outlet elevation lower than the elevation of the SS.

5.3.3 Stormwater Control Measure Performance and Extreme Precipitation

As described in **Section 4.11, Water Quality and Stormwater**, of the DEIR, the SCMs would function as intended with the projected 2070, 100-year 24-hour rainfall event for the Build Alternative. The infiltration basins' performance may be altered under scenarios where tidal datums would exceed the outfall invert elevation (refer to **Table 4-1**). In these scenarios, a basin's ability to discharge would be reduced, which may result in the infiltration basin temporarily acting as a retention basin. The basins would provide peak-flow attenuation and storage until the stormwater captured in the basins are able to infiltrate or discharge through the outfall. As such, the SCMs are unlikely to be affected by the four combined extreme rainfall and SLR events assessed.

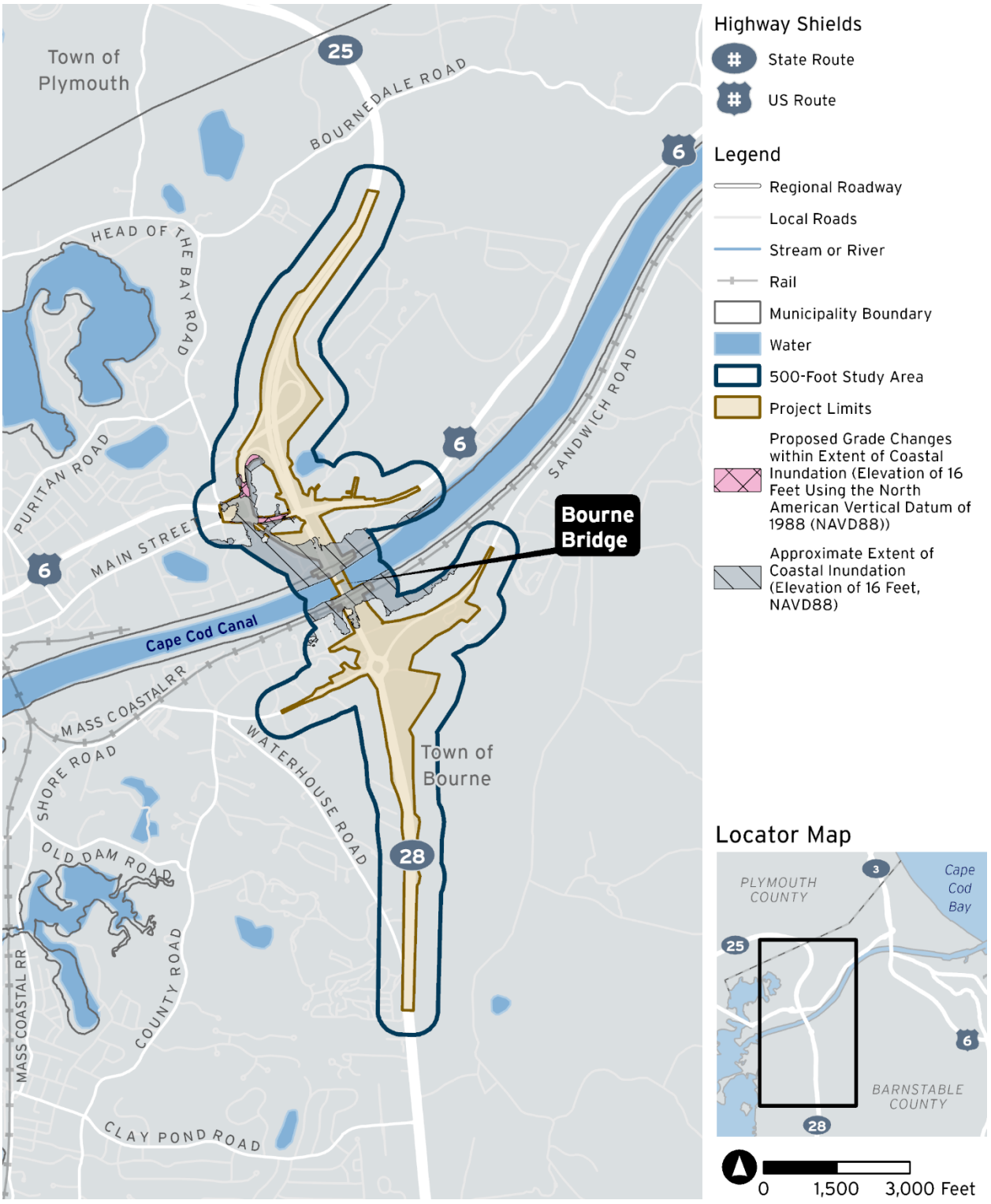
5.4 Land Cover

For the Build Alternative, the land cover, resource areas, and land use would change as described in **Section 4.10, Wetlands and Floodplains**, and **Section 4.6, Land Use, Zoning, and Community Cohesion.**

5.4.1 Floodplain Function and Sea Level Rise/Storm Surge

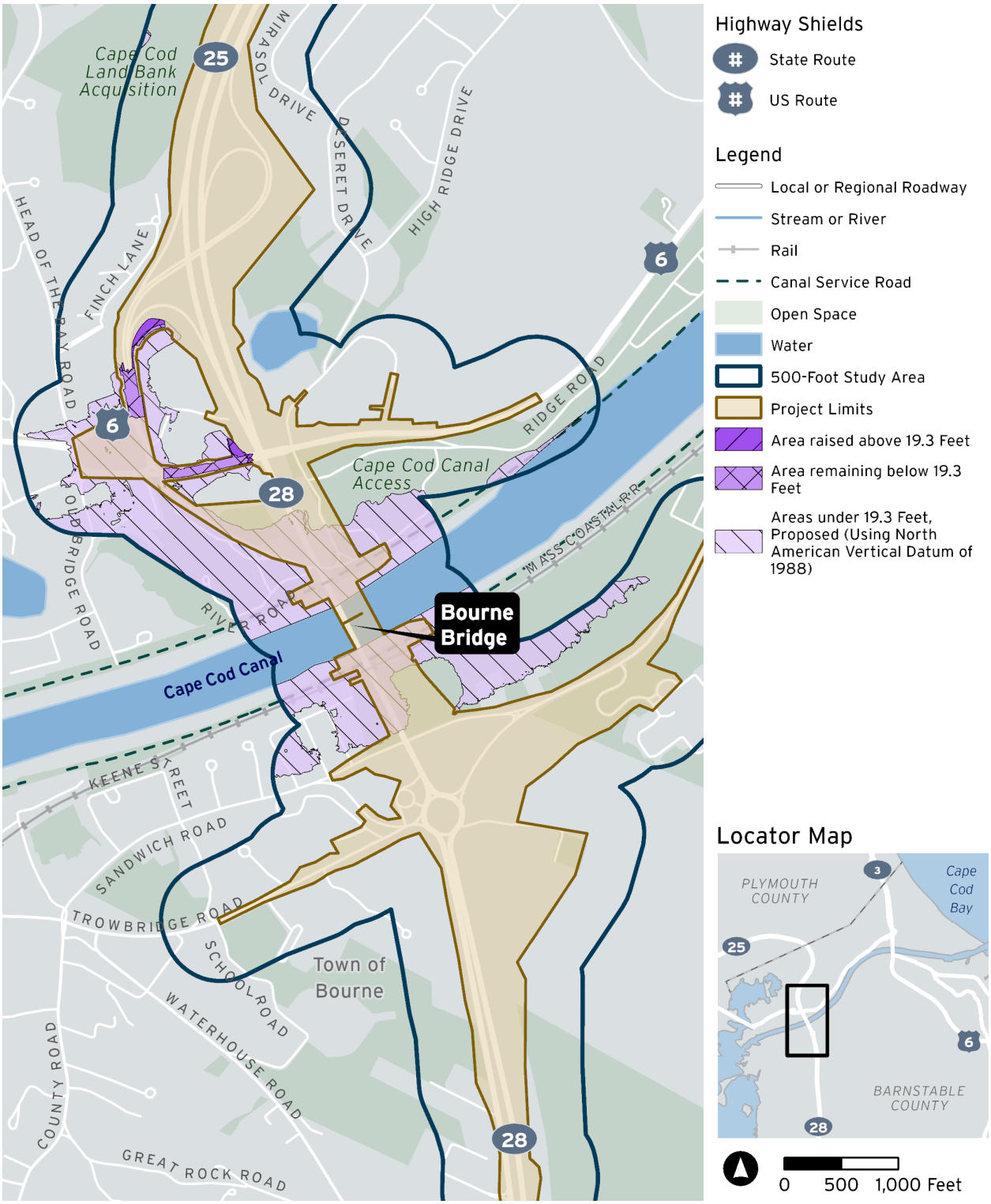
Figure 5-1 and **Figure 5-2** show the extent of overland coastal surge for the Build Alternative for the FEMA floodplain and coastal inundation associated with the Category 2 hurricane plus 3 feet freeboard. These figures also identify areas where changes to site grading and topography are proposed below the associated SS elevations. The extent of overland coastal surge for the Build Alternative for Sagamore Bridge would be the same as the No Build Alternative (**Figure 4-1**) because there are no proposed changes to grading within the flood extents. The extent of overland coastal surge for Bourne Bridge for the Build Alternative (**Figure 5-1** and **Figure 5-2)** would be the same as the No Build Alternative (**Figure 4-2**), with the exception of the Bourne North quadrant, where there are proposed grade changes near Belmont Circle to accommodate the higher bridge deck elevation spanning Cape Cod Canal to maintain navigational clearance and connect to existing grades. **Figure 5-3** shows the proposed grade changes and corresponding flood pathways in the Bourne North quadrant. These grade changes would slightly reduce the extent of coastal inundation at the edge of the floodplain, but would not affect the flood pathways compared to the No Build Alternative (**Figure 4-3**).

Figure 5-1. Build Alternative: Coastal Surge Flood Extents –Existing 100-year Floodplain (Bourne Bridge)



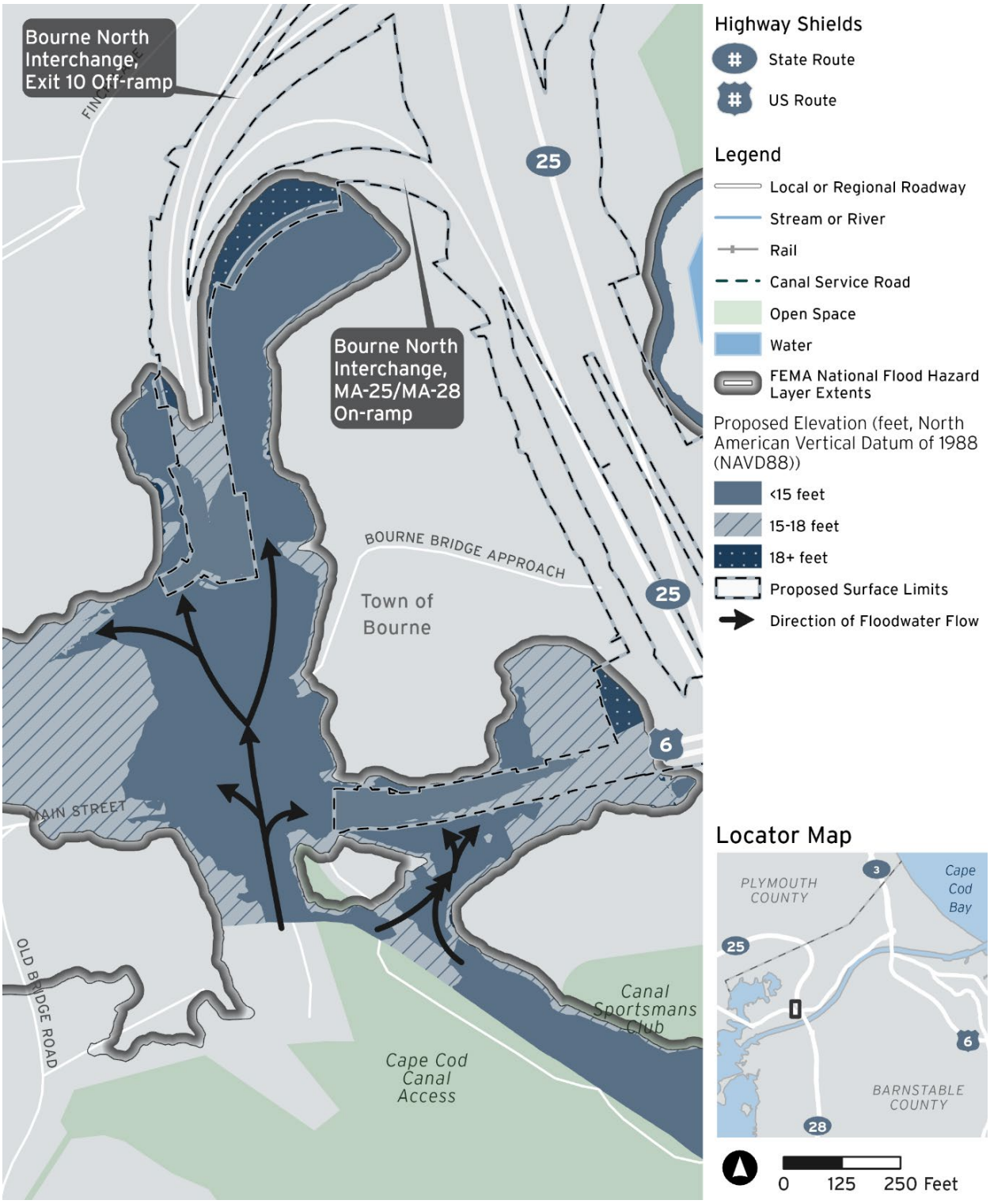
Source: Massachusetts Department of Transportation, 2024

Figure 5-2. Build Alternative: Coastal Surge Flood Extents –Category 2 Hurricane + 3 feet Freeboard (Bourne Bridge)



Source: Massachusetts Department of Transportation, 2024

Figure 5-3. Build Alternative: Proposed Grading and Flood Pathways (Bourne North Quadrant)



Source: Massachusetts Department of Transportation, 2024

Five cross-sections were taken where grade changes are proposed on the ramps and along U.S. Route 6 (**Figure 5-4**) to assess potential impediments to flow. The cross-sections are represented in **Figure 5-5** through **Figure 5-9**, and depict the following:

- Existing grade (Dashed Lines - No Build Alternative) and proposed topography (Solid Lines - Build Alternative)
- Proposed roadway surfaces, including shared-use paths (SUP) and shoulders (SHLD)
- Existing edge of pavement (EOP), right-of-way (ROW), and driveways (DWY) to adjacent parcels
- Coastal surge flood elevations El. 16 (FEMA 100-year) and El. 19.3 (Category 2 hurricane + 3 feet freeboard)

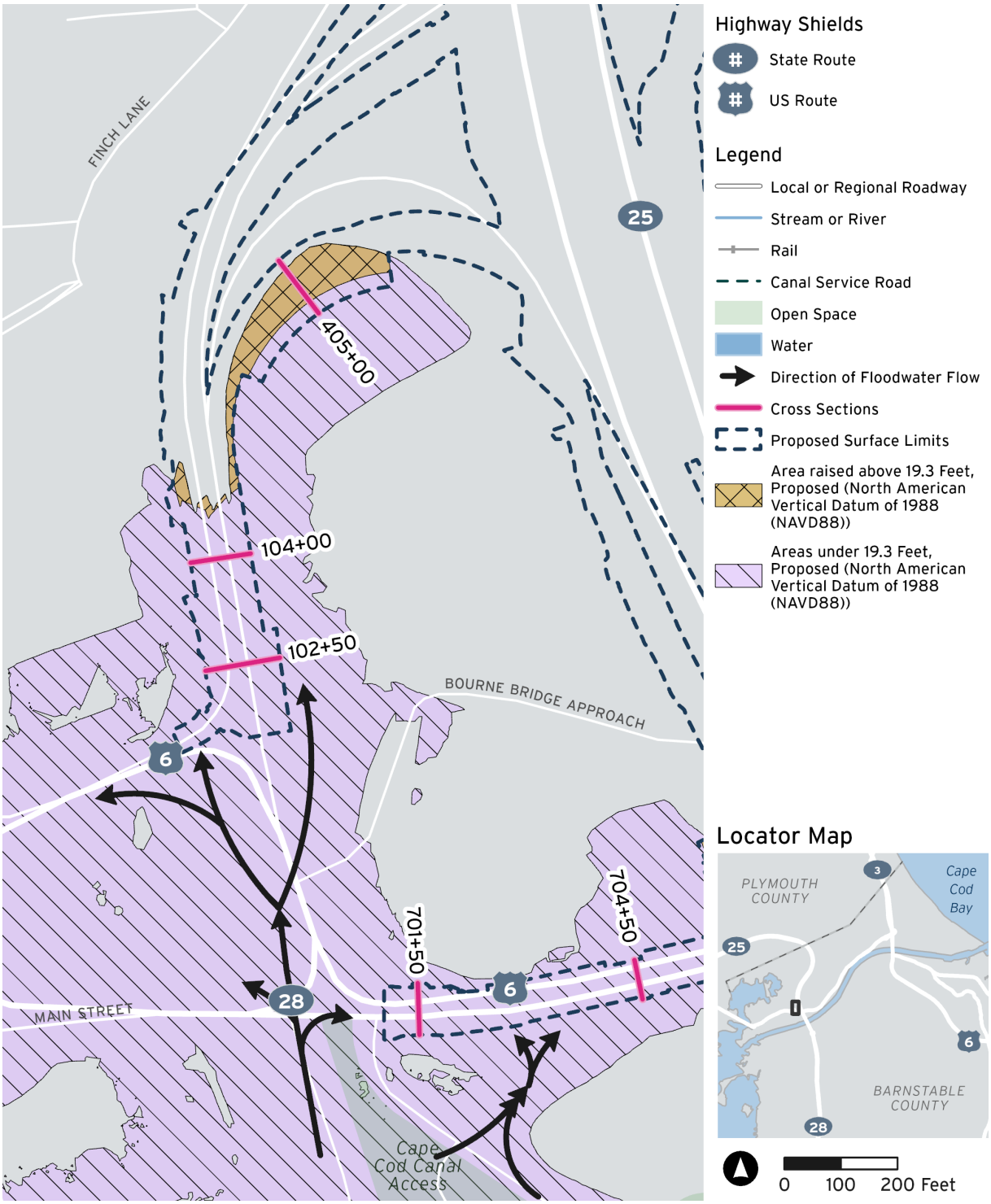
The cross-sections on U.S. Route 6 at 701+50 (**Figure 5-5**) and 704+50 (**Figure 5-6**) are subject to perpendicular and parallel flood pathways; when subject to perpendicular flows, the water travels right to left. The cross-sections on the westbound ramps at 102+50 (**Figure 5-7**) and 104+00 (**Figure 5-8**) are subject to parallel flood pathways, and the cross-section on the eastbound ramp at 405+00 (**Figure 5-9**) is subject to perpendicular flows where the water travels right to left.

These cross-sections illustrate that the Build Alternative for U.S. Route 6, including changes to landcover and grading, is not likely to create channelized flow conditions within the extent of mapped inundation. The proposed changes to the westbound ramps for the Build Alternative would include the installation of retaining walls to increase grades, while reducing the impact on nearby wetlands. These cross-sections would be at the edge of the floodplain and would receive flow from pathways that have already crossed developed areas with existing impervious surfaces and vertical impediments, such as curbs and structures. The areas farther inland from these cross-sections are low lying wetlands; therefore, the changes to land cover from the westbound ramps are not anticipated to have an impact on the land subject to coastal floodplain functions. The proposed changes to the eastbound ramps for the Build Alternative would include creating an embankment (2H:1V) to raise grades up to 28 feet at the edge of the floodplain, and would receive flow from pathways that have already crossed developed areas and the existing wetland; therefore, the changes to land cover from the eastbound ramp is not anticipated to have an impact on the land subject to coastal floodplain functions.

5.4.2 Localized Stormwater Flooding and Extreme Precipitation

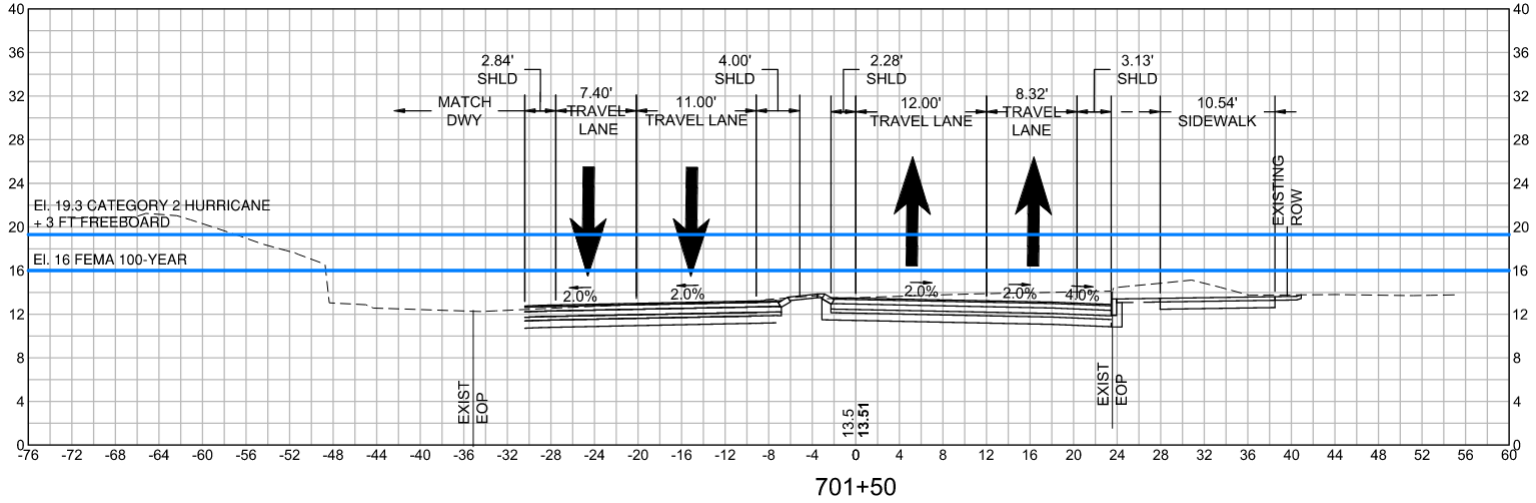
SCMs would function as intended with the projected 2070, 100-year 24-hour rainfall event for the Build Alternative; as such, the SCMs presented in **Section 4.11, Water Quality and Stormwater,** of the DEIR will mitigate localized flooding resulting from impervious surfaces and extreme precipitation.

Figure 5-4. Build Alternative: Cross-Section Reference for Bourne North Quadrant Grading Plan



Source: Massachusetts Department of Transportation, 2024

Figure 5-5. Build Alternative: Cross-Section U.S. Route 6: 701+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)

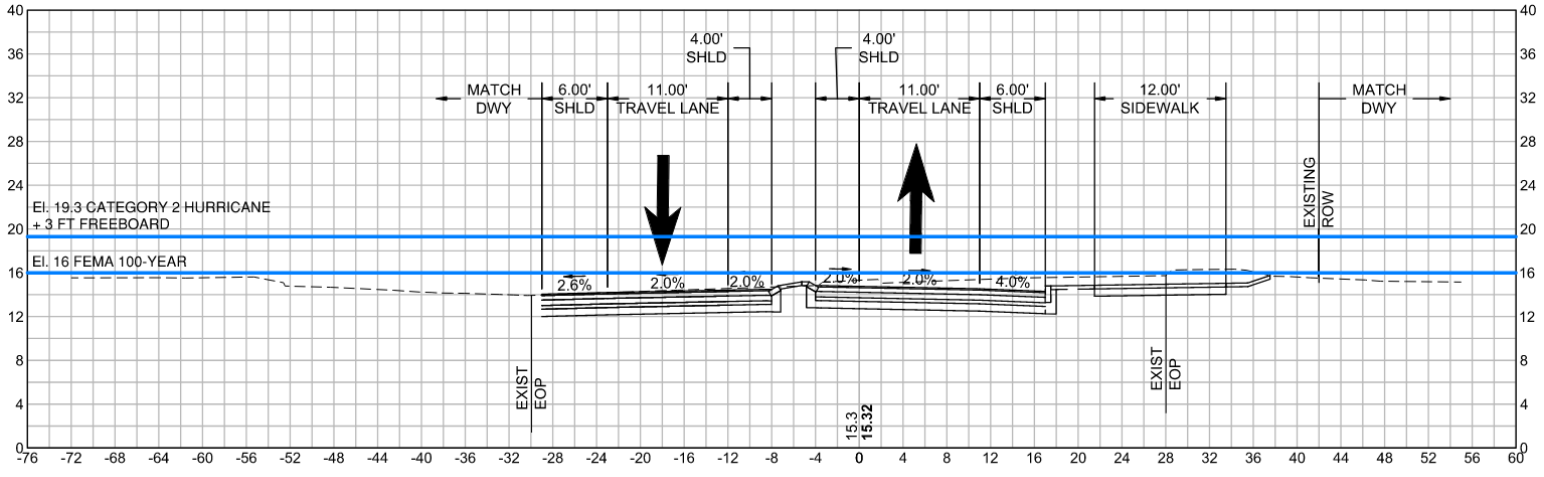


Source: Massachusetts Department of Transportation, 2024

Note: Cross-section subject to parallel and perpendicular flows; when subject to perpendicular flows, water travels right to left.

DWY = driveway, EOP = edge of pavement, ROW = right=of-way, SHLD = shoulder

Figure 5-6. Build Alternative: Cross-Section U.S. Route 6: 704+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)

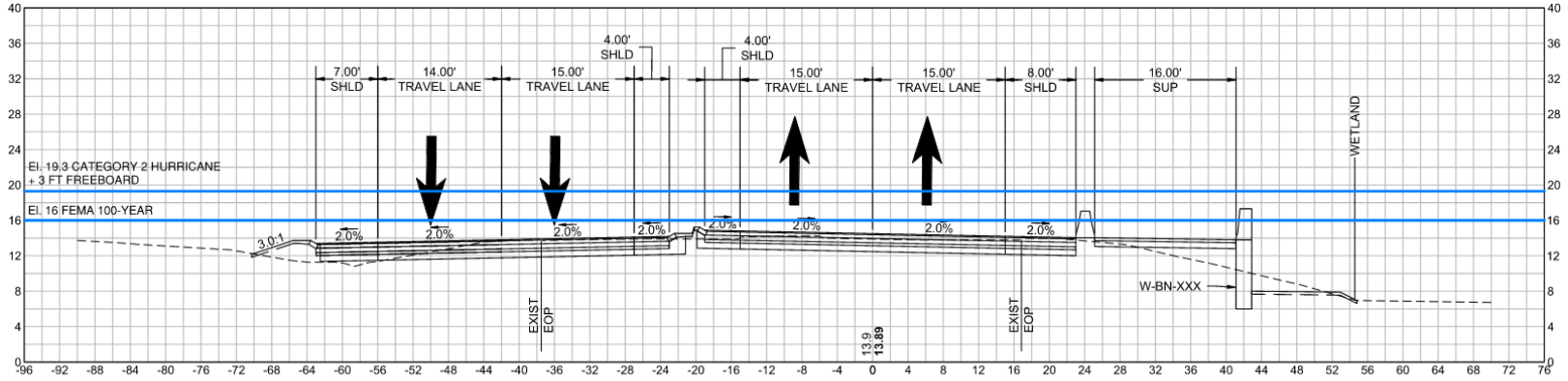


Source: Massachusetts Department of Transportation, 2024

Note: Cross-section subject to parallel and perpendicular flows; when subject to perpendicular flows, water travels right to left.

DWY = driveway, EOP = edge of pavement, ROW = right=of-way, SHLD = shoulder

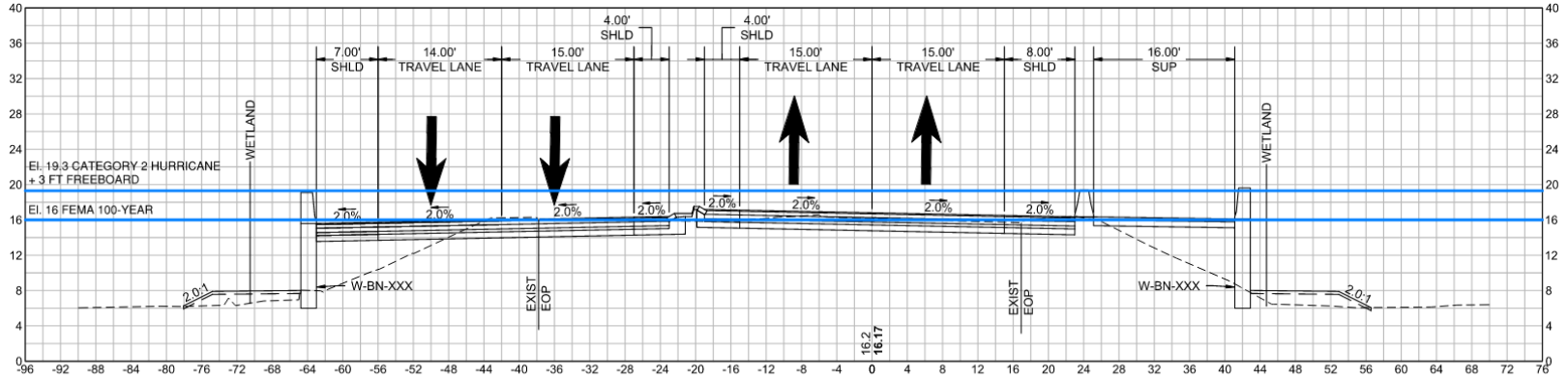
Figure 5-7. Build Alternative: Cross-Section Westbound On- and Off-Ramps: 102+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



102+50

Source: Massachusetts Department of Transportation, 2024
Note: Cross-section subject to parallel flows.
EOP = edge of pavement, SHLD = shoulder, SUP = shared-use path

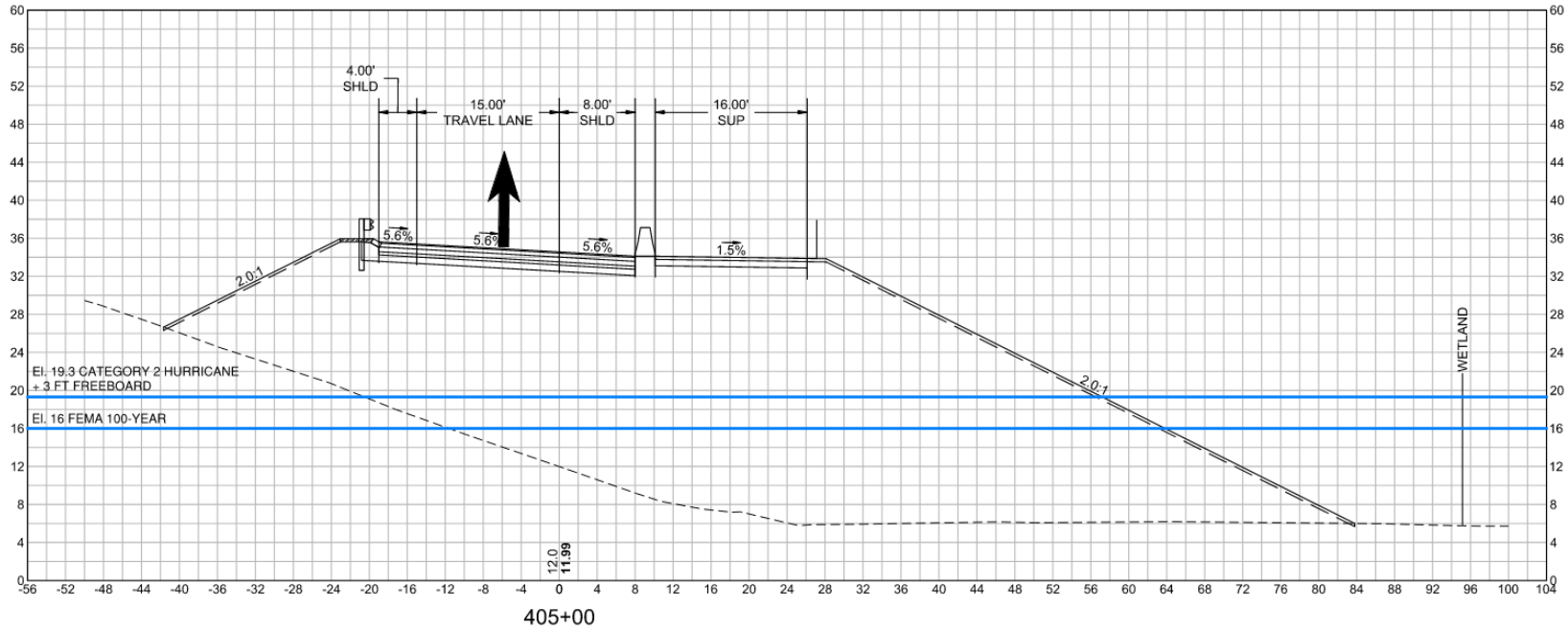
Figure 5-8. Build Alternative: Cross-Section Westbound On- and Off-Ramps: 104+00, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



104+00

Source: Massachusetts Department of Transportation, 2024
Note: Cross-section subject to parallel flows.
EOP = edge of pavement, SHLD = shoulder, SUP = shared-use path

Figure 5-9. Build Alternative: Cross-Section Eastbound On-Ramp: 405+00, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



Source: Massachusetts Department of Transportation, 2024

Note: Cross-section subject to perpendicular flow; water travels right to left.

SHLD = shoulder, SUP = shared-use path

5.4.3 Surface Temperatures and Extreme Heat

The Build Alternative would result in a 50.9-acre increase in impervious area across Project Limits, and therefore an increase in level of stormwater treatment required, compared to existing conditions as described **Section 4.11, Water Quality and Stormwater,** of the DEIR. The increase in impervious areas would increase the total impervious surface (**Table 5-3**). Because the final percentage of impervious surface would be less than 50%, the Build Alternative would not change the exposure rating or rationale in the RMAT Tool.

Table 5-3. Build Alternative: Impervious Surface (Sagamore Bridge and Bourne Bridge Study Areas)

Study Areas	Impervious Surface Area Increase (acres) (percentage)[1]	Build Alternative Percentage Impervious for Project Limits
Sagamore Bridge	+ 25.3 (+ 12.6%)	49%
Bourne Bridge	+ 25.6 (+ 9.5%)	39%

[1] Increase in impervious surface area is based on increase from No Build Alternative conditions of 36.4% (Sagamore Bridge) and 29.5% (Bourne Bridge) from **Section 4.11, Water Quality and Stormwater**, of the Draft Environmental Impact Report.

Landscaping plans are in development, as described in the mitigation section. Refer to **Section 5.6.3** for additional information on impervious surfaces and heat.

5.5 Transportation

For the Build Alternative, the highway transportation routes and traffic would change as described in **Section 4.2, Transportation, Traffic, and Safety**, of the DEIR.

5.5.1 Flooded Roadways and Evacuation Routes and Sea Level Rise/Storm Surge

In the Build Alternative, the combination of new direct connection ramps between State Route 25 and U.S. Route 6 (Scenic Highway) in the Bourne North quadrant would allow vehicles to bypass Belmont Circle and reduce travel in the existing floodplain and mapped areas of coastal inundation.[72] The Build Alternative would facilitate emergency egress of high traffic volumes from Cape Cod in the event of a hurricane or other potential hazards through replacement of Bourne Rotary with a grade-separated diamond interchange and the construction of a new flyover ramp connection from Scenic Highway to State Route 25 westbound. Construction of two separate deck structures for the replacement bridges for the Build Alternative would provide additional service redundancy in case of an emergency evacuation or a compromising event that would affect a single bridge structure. Cross-canal pedestrian and bicycle lanes would also improve hurricane evacuation ability for all road users.

[72] Regionally these changes would result in a reduction of 1.7% in vehicle-miles traveled and 8% in vehicle-hours traveled from the No Build Alternative to the Build Alternative.

While flooding of Belmont Circle has at least a 1% annual likelihood or (a 1-in-4 chance of flooding over 30 years), the Build Alternative would increase the adaptive capacity of the network to reduce vulnerability to coastal inundation. Changes to traffic patterns associated with the Build Alternative should be updated for construction phases and completion of the Program within the Cape Cod Emergency Traffic Plan.

5.5.2 Localized Stormwater Flooding and Extreme Precipitation

SCMs would function as intended with the projected 2070, 100-year 24-hour rainfall event for the Build Alternative; as such, the SCMs presented in **Section 4.11, Water Quality and Stormwater,** of the DEIR will mitigate localized flooding resulting from impervious surfaces and extreme precipitation.

5.5.3 Pavement Performance and Extreme Heat

MassDOT's Transportation Asset Management Plan includes best practices that have been incorporated into MassDOT standards to increase the resilience of Highway Division assets, including modifying pavement mixtures to provide additional stability in high temperatures and incorporating balanced mixture design methods to reduce mixture cracking and moisture damage. It is likely that extreme heat events would still affect the performance of the pavement for the Build Alternative but to a lesser degree than the No Build Alternative.

5.5.4 Snow and Ice on Roadways and Winter Weather

The Build Alternative would be designed to meet existing performance standards, which account for winter weather operational needs, such as plowing and road treatments. Winter weather conditions that generate snow and ice on roadways are still likely to affect the Build Alternative traffic and safety conditions but to a lesser degree than the No Build Alternative.

5.5.5 Vehicle Rollover Potential and Extreme Wind

Based on analyses by MassDOT, 3-second wind gust speeds that can increase the likelihood of vehicle rollover occur 0.2% of the time (or an average of roughly 20 hours per year) at Sagamore Bridge, and 0.55% of the time (or an average of roughly 50 hours per year) at Bourne Bridge. This is irrespective of the No Build Alternative or Build Alternative.

5.6 Mobility

For the Build Alternative, the alternative modes of transportation, such as bus, bicycle, and walk, would change as described in **Section 4.3, Pedestrian and Bicycle Facilities**, of the DEIR.

5.6.1 Flooded Shared-Use Paths and Sea Level Rise/Storm Surge

Alternative modes of transportation within the Bourne North quadrant, particularly those within Belmont Circle, are vulnerable to coastal inundation with a likelihood of flooding of at least a 1% annual likelihood (or 1-in-4 chance over the next 30 years). The Build Alternative would improve mobility within this area but would also significantly improve mobility outside of this area. Cross-canal

pedestrian and bicycle lanes proposed in the Build Alternative would improve hurricane evacuation ability for all road users and would reduce travel within the extent of inundation.

5.6.2 Localized Stormwater Flooding and Extreme Precipitation

SCMs would function as intended with 2070, 100-year 24-hour rainfall events for the Build Alternative; as such, SCMs presented in **Section 4.11, Water Quality and Stormwater,** of the DEIR will mitigate localized flooding resulting from impervious surfaces and extreme precipitation.

5.6.3 Active Transportation Use and Extreme Heat

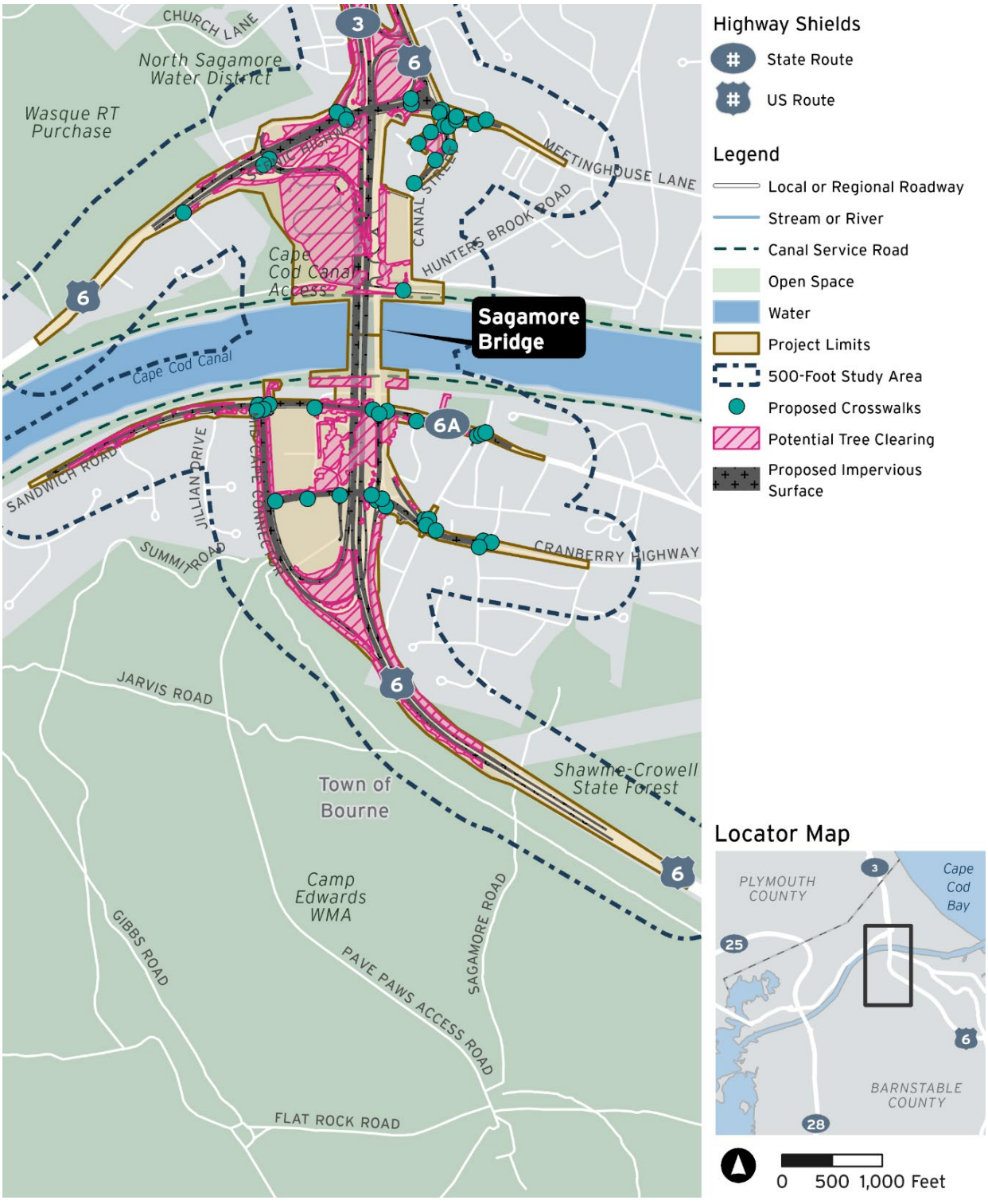
Increases in days over 90°F may impact the use of alternative modes of travel in the No Build Alternative. Extreme heat events and lack of shade are likely to affect pedestrians and bicyclists. These impacts may be more pronounced in areas where tree clearing is required, new impervious surfaces are being proposed, and there are proposed crosswalks where pedestrians have prolonged exposure while waiting to cross.

For Sagamore Bridge, these locations are likely to include the SUPs from Scenic Highway to Canal Service Road, and cross connections from Cranberry Highway, Sandwich Road (6A) (**Figure 5-10**). For Bourne Bridge, these locations are generally in the area of the replacement of Bourne Rotary with a grade-separated diamond interchange and the construction of a new flyover ramp connection from Scenic Highway to State Route 25 westbound (**Figure 5-11**).

5.7 Summary of Impacts from the Build Alternative

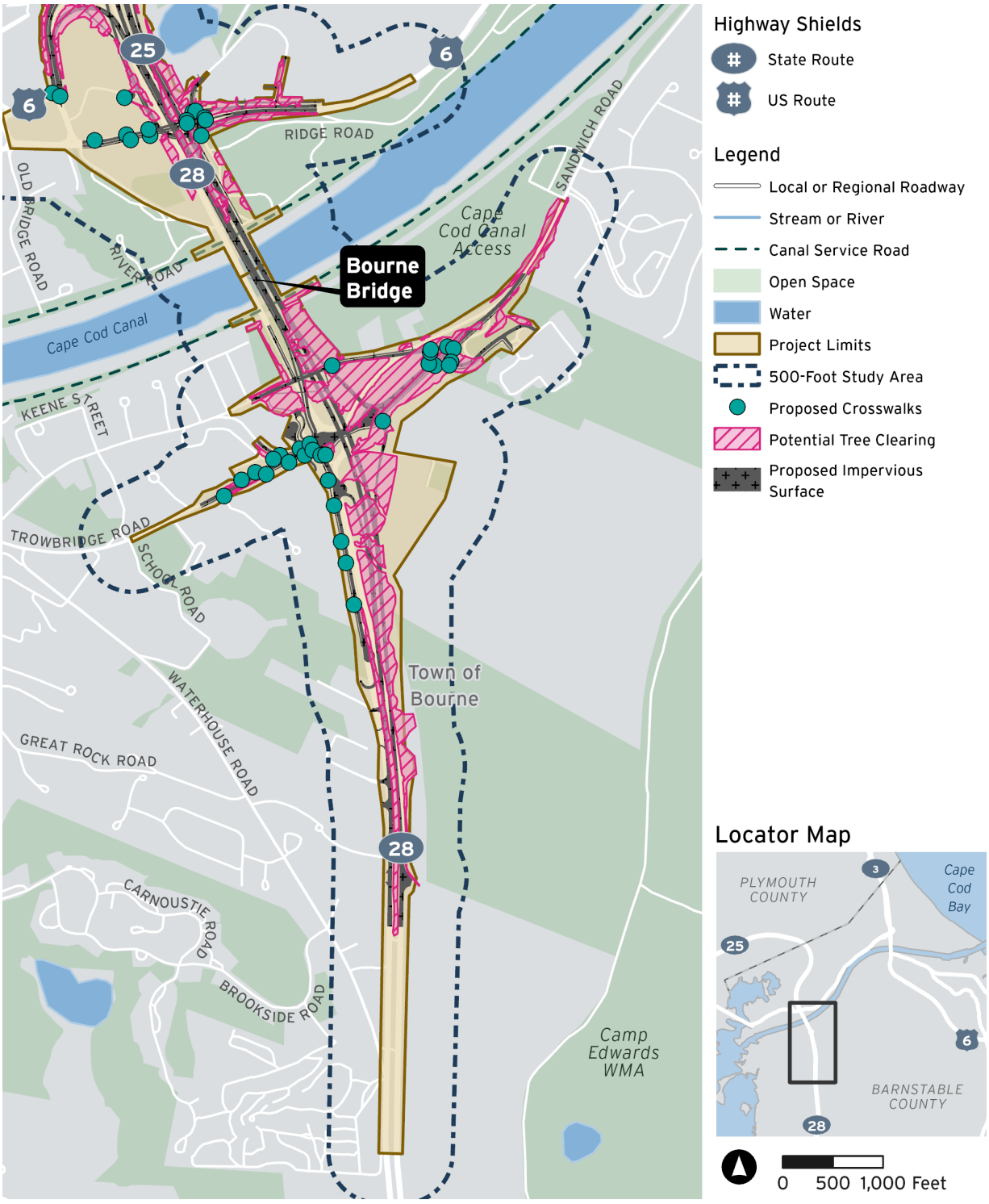
Table 5-4 summarizes the impacts on affected environments within the Program Limits and Study Areas from the Build Alternative that may benefit from mitigation beyond standard design best practices.

Figure 5-10. Build Alternative: Proposed Impervious Surfaces, Tree Clearing, and Crosswalks (Sagamore Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

Figure 5-11. Build Alternative: Proposed Impervious Surfaces, Tree Clearing, and Crosswalks (Bourne Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

Table 5-4. Build Alternative: Impacts to be Addressed with Mitigation Beyond Standard Design Best Practices

Affected Environment	Related Draft Environmental Impact Report Section	Sea Level Rise/Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
Cape Cod Canal	Section 4.4, Maritime Transportation, Traffic, and Safety	No impact	NA	NA	NA	NA
Bridge	Chapter 3, Proposed Action and Alternatives	No impact*	NA	No impact	Reduced Impact	No impact
Stormwater Control Measures	Section 4.11, Water Quality and Stormwater	• Submerged/ partially submerged outfalls** • Infiltration basin flooding	No impact	NA	NA	NA
Land Cover	Section 4.10, Wetlands and Floodplains	No impact	No impact	Surface temperature	NA	NA
Transportation	Section 4.2, Transportation, Traffic, and Safety	Reduced impact	No impact	Reduced impact	Reduced impact	Vehicle Rollover
Mobility	Section 4.3, Pedestrian and Bicycle Facilities	Reduced impact	No impact	Active Transportation Use	NA	NA

NA indicates not assessed for affected environment. Reduced impact is in comparison to the No Build Alternative.

* Only for Sagamore Bridge at this time.

** Outfalls are within the Study Area shown in **Figure 2-1**, but are not part of the Cape Cod Bridges Program; they were assessed due to their impact on stormwater systems (flooding and performance) within the Study Area.

6 Mitigation

This section discusses proposed measures to increase the resilience of the Build Alternative to mitigate impacts on affected environments.

6.1 Cape Cod Canal

6.1.1 Navigational Clearance and Sea Level Rise

The Build Alternative would be designed to maintain the existing navigational clearance of 135 feet (measured from the low chord elevation) with sea levels 3 feet higher than the existing MHHW. No additional mitigation measures will be required.

6.2 Bridge

6.2.1 Bridge Pier Scour and Sea Level Rise

The pier foundations for the Sagamore Bridge Build Alternative would be designed to maximum scour depths in accordance with FHWA HEC-18, and no additional mitigation measures will be required. Since the Bourne Bridge scour analyses have not yet been performed, the need for mitigation has not been assessed. If required, the mitigation measures will be described in the FEIR.

6.2.2 Icing and Winter Weather

Deicing measures for bridge cables include a variety of passive mitigation measures, such as modifying the cable surface to reduce size and mass of shed ice fragments or laying heating cables or exchange pipes inside the bridge deck. These measures will be detailed as designs advance, where appropriate, in accordance with best practices.

6.2.3 Aerodynamic Stability and Extreme Wind

The proposed network tied-arch bridges have better resistance against wind-induced vibrations and deformation. The Build Alternative would be designed to remain stable during the extreme wind conditions identified in the wind climate analysis. No additional mitigation measures will be required.

6.3 Stormwater Control Measures

Section 4.11, Water Quality and Stormwater, of the DEIR describes the proposed stormwater mitigation measures, which are based on designing to the 2070, 100-year 24-hour rainfall event recommended through the RMAT Tool and the four combination tidal and rainfall events described in the methodology.

6.3.1 Submerged and Partially Submerged Outfalls and Sea Level Rise

Improvements to the existing outfalls are not part of the Build Alternative, but to reduce the risk of backflow into new SCMs from increased sea levels, MassDOT will consider backflow preventers or in-pipe tide gates, where appropriate, to reduce backflow into infiltration basins. MassDOT is developing this mitigation measure and will provide more information in the FEIR.

6.3.2 Infiltration Basins and Sea Level Rise

The siting and elevations (bottom, overflow, and top) of stormwater infiltration basins proposed for water quality and stormwater mitigation in **Section 4.11, Water Quality and Stormwater,** of the DEIR will be informed by the projected tidal datums and water surface elevations and the combination events to reduce risk of inundation through piped infrastructure and from overland flows. MassDOT is developing this mitigation measure and will provide more information in the FEIR.

6.3.3 Stormwater Control Measure Performance and Extreme Precipitation

Section 4.11, Water Quality and Stormwater, of the DEIR describes the proposed stormwater mitigation measures, which were designed to ensure performance under the recommended extreme rainfall event (2070, 100-year, 24-hour). No additional mitigation measures will be required.

6.4 Land Cover

Section 4.10, Wetlands and Floodplains, and **Section 4.6, Land Use, Zoning, and Community Cohesion,** of the DEIR describe the proposed land cover mitigation measures.

6.4.1 Floodplain Function and Sea Level Rise/Storm Surge

The Build Alternative would not increase the velocity of moving water, redirect, or channelize flow, and would allow water to spread laterally and landward. **Section 4.11, Water Quality and Stormwater,** and **Section 4.10, Wetlands and Floodplains**, of the DEIR describe the strategies that will mitigate the impacts of impervious surface on infiltration.

6.4.2 Localized Stormwater Flooding and Extreme Precipitation

No mitigation will be required beyond what is proposed in **Section 4.11.7, Water Quality and Stormwater,** of the DEIR to manage the projected 2070, 100-year, 24-hour rainfall event.

6.4.3 Surface Temperatures and Extreme Heat

Mitigation measures to address potential increases in surface temperature due to increased impervious surfaces and tree clearing include a comprehensive landscape and vegetation plan. MassDOT is developing the landscape plan and will provide more information in the FEIR.

6.5 Transportation

Section 4.2, Transportation, Traffic, and Safety, of the DEIR describes the proposed highway transportation, traffic, and safety mitigation measures.

6.5.1 Flooded Roadways and Evacuation Routes and Sea Level Rise/Storm Surge

While the Build Alternative would reduce the impact of flooded roadways and evacuation routes compared to the No Build Alternative, the new traffic patterns should be reviewed and Cape Cod Emergency Traffic Plan updated as necessary to reflect construction and proposed configurations and flows, as well as remaining flood risk at Belmont Circle. This may include signage and public notices when storms are forecast, as appropriate.

6.5.2 Localized Stormwater Flooding and Extreme Precipitation

No mitigation will be required beyond what is proposed in **Section 4.11.7, Water Quality and Stormwater,** of the DEIR to manage the projected 2070, 100-year, 24-hour rainfall event.

6.5.3 Pavement Performance and Extreme Heat

MassDOT is considering mitigation measures—such as modifying pavement mixtures to provide additional stability in high temperatures and incorporated balanced mixture design methods to reduce mixture cracking and moisture damage—and will provide more information in the FEIR.

6.5.4 Snow and Ice on Roadways and Winter Weather

MassDOT is considering mitigation measures—such as updated snow and salt management plans for the Program—and will provide more information in the FEIR.

6.5.5 Vehicle Rollover Potential and Extreme Wind

MassDOT is considering mitigation measures—such as installing wind anemometers to measure and report actual wind speeds to Highway Operations, notify road users of potential for vehicle rollover, or close the replacement bridges—and will provide more information in the FEIR.

6.6 Mobility

Section 4.3, Pedestrian and Bicycle Facilities, of the DEIR describes the mitigation measures for pedestrian and bicycle facilities.

6.6.1 Flooded Shared-Use Paths and Sea Level Rise/Storm Surge

While the Build Alternative would reduce the impact of flooded SUPs and sidewalks, compared to the No Build Alternative, the remaining flood risk in the Bourne North quadrant at Belmont Circle should be communicated to the public. This may include National Weather Service safety signage, such as “Turn around, don’t drown,” and public notices when storms are forecast, as appropriate.

6.6.2 Localized Stormwater Flooding and Extreme Precipitation

No mitigation will be required beyond what is proposed in **Section 4.11.7, Water Quality and Stormwater,** of the DEIR to manage the projected 2070, 100-year, 24-hour rainfall event.

6.6.3 Active Transportation Use and Extreme Heat

In addition to identifying opportunities for green infrastructure that will mitigate both extreme precipitation and heat impacts, there may be opportunities to integrate shading features into the bridge fence design that abuts the pedestrian path or shaded areas for rest within the approach and arch span cross-sections. Lighter-colored surface materials are recommended to be considered in areas where glare will not impact road user safety. MassDOT is considering these strategies in conjunction with land use mitigation strategies (for example, landscaping plans) and will provide more information in the FEIR.

7 Attachments

Attachment 1. Resilient Massachusetts Action (RMAT) Tool Output Report: Sagamore Bridge

Attachment 2. RMAT Tool Output Report: Bourne Bridge

Attachment 1 – RMAT Output Report: Sagamore Bridge

Climate Resilience Design Standards Tool Project Report

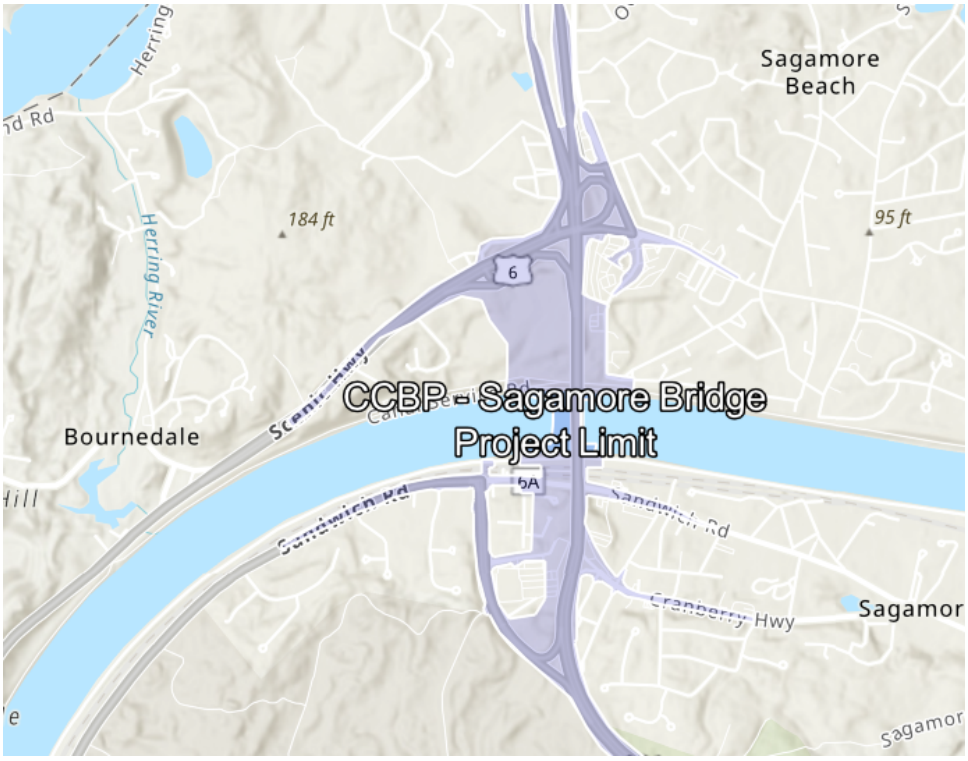
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Date Created: 11/21/2024 4:08:46 PM
Created By: julieeatonernst
Date Report Generated: 1/29/2025 8:55:52 PM
Tool Version: Version 1.2
Project Contact Information: Julie Eaton Ernst (jeatonernst@hntb.com)

Project Summary

Link to Project

Estimated Capital Cost: $3975000000.00
End of Useful Life Year: 2128
Project within mapped Environmental Justice neighborhood: Yes

Ecosystem Service Benefits	Scores
Project Score	Moderate
Exposure	**Scores**
Sea Level Rise/Storm Surge	High Exposure
Extreme Precipitation - Urban Flooding	High Exposure
Extreme Precipitation - Riverine Flooding	High Exposure
Extreme Heat	High Exposure



Asset Preliminary Climate Risk Rating Summary

Number of Assets: 4

Asset Risk	Sea Level Rise/Storm Surge	Extreme Precipitation - Urban Flooding	Extreme Precipitation - Riverine Flooding	Extreme Heat
Sagamore Bridge	High Risk	High Risk	High Risk	High Risk
SCMs - Infiltration Basins	High Risk	High Risk	High Risk	High Risk
Shared Use Paths (Active Transportation)	High Risk	High Risk	High Risk	High Risk
Highway	High Risk	High Risk	High Risk	High Risk

Climate Resilience Design Standards Summary

	Target Planning Horizon	Intermediate Planning Horizon	Percentile	Return Period	Tier
Sea Level Rise/Storm Surge					
Sagamore Bridge	2070	2050		1000-yr (0.1%)	
SCMs - Infiltration Basins	2070	2050		50-yr (2%)	
Shared Use Paths (Active Transportation)	2050			100-yr (1%)	
Highway	2070	2050		500-yr (0.2%)	
Extreme Precipitation					
Sagamore Bridge	2070			100-yr (1%)	Tier 3
SCMs - Infiltration Basins	2070			10-yr (10%)	Tier 2
Shared Use Paths (Active Transportation)	2050			10-yr (10%)	Tier 2

Highway	2070		50-yr (2%)	Tier 3
Extreme Heat				
Sagamore Bridge	2070	90th		Tier 3
SCMs - Infiltration Basins	2070	50th		Tier 2
Shared Use Paths (Active Transportation)	2050	50th		Tier 2
Highway	2070	90th		Tier 3

Scoring Rationale - Project Exposure Score

The purpose of the Exposure Score output is to provide a preliminary assessment of whether the overall project site and subsequent assets are exposed to impacts of natural hazard events and/or future impacts of climate change. For each climate parameter, the Tool will calculate one of the following exposure ratings: Not Exposed, Low Exposure, Moderate Exposure, or High Exposure. The rationale behind the exposure rating is provided below.

Sea Level Rise/Storm Surge

This project received a "High Exposure" because of the following:

- Located within the predicted mean high water shoreline by 2030
- Exposed to the 1% annual coastal flood event as early as 2030
- Located within the 0.1% annual coastal flood event within the project's useful life

Extreme Precipitation - Urban Flooding

This project received a "High Exposure" because of the following:

- Increased impervious area
- Maximum annual daily rainfall exceeds 10 inches within the overall project's useful life
- No historic flooding at project site
- Existing impervious area of the project site is between 10% and 50%

Extreme Precipitation - Riverine Flooding

This project received a "High Exposure" because of the following:

- Part of the project is within a mapped FEMA floodplain, outside of the Massachusetts Coast Flood Risk Model (MC-FRM)
- Part of the project is within 100ft of a waterbody
- Project is potentially susceptible to riverine erosion
- No historic riverine flooding at project site

Extreme Heat

This project received a "High Exposure" because of the following:

- Increased impervious area
- Existing trees are being removed as part of the proposed project
- Existing impervious area of the project site is between 10% and 50%
- 10 to 30 day increase in days over 90 deg. F within project's useful life
- Located within 100 ft of existing water body

Scoring Rationale - Asset Preliminary Climate Risk Rating

A Preliminary Climate Risk Rating is determined for each infrastructure and building asset by considering the overall project Exposure Score and responses to Step 4 questions provided by the user in the Tool. Natural Resource assets do not receive a risk rating. The following factors are what influenced the risk ratings for each asset.

Asset - Sagamore Bridge
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event
- Greater than 100,000 people would be directly affected by the loss/inoperability of the asset

- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Infrastructure functions as an evacuation route during emergencies
- Cost to replace is greater than $100 million
- There are no hazardous materials in the asset

Asset - SCMs - Infiltration Basins
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable for more than a day but less than a week after natural hazard event
- Loss/inoperability of the asset would have impacts limited to the location of infrastructure only
- Inoperability of the asset would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
- Cost to replace is between $10 million and $30 million
- Impact on natural resources will require remediation/rehabilitation with the inoperability of the asset

Asset - Shared Use Paths (Active Transportation)
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable for more than a day but less than a week after natural hazard event
- Less than 100,000 people would be directly affected by the loss/inoperability of the asset
- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Inoperability of the asset would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
- Cost to replace is between $10 million and $30 million
- There are no hazardous materials in the asset

Asset - Highway
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event
- Greater than 100,000 people would be directly affected by the loss/inoperability of the asset
- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Infrastructure functions as an evacuation route during emergencies
- Cost to replace is greater than $100 million
- There are no hazardous materials in the asset

Project Climate Resilience Design Standards Output

Climate Resilience Design Standards and Guidance are recommended for each asset and climate parameter. The Design Standards for each climate parameter include the following: recommended planning horizon (target and/or intermediate), recommended return period (Sea Level Rise/Storm Surge and Precipitation) or percentile (Heat), and a list of applicable design criteria that are likely to be affected by climate change. Some design criteria have numerical values associated with the recommended return period and planning horizon, while others have tiered methodologies with step-by-step instructions on how to estimate design values given the other recommended design standards.

Asset: Sagamore Bridge — Infrastructure

Sea Level Rise/Storm Surge — High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 1000-yr (0.1%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Sagamore Bridge	2050	0.1% (1000-Year)	15.3	12.1	12.9
	2070		17.0	13.9	14.6

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Sagamore Bridge	2050	0.1% (1000-Year)	19.3	12.2	15.1
	2070		21.1	13.9	16.9

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Sagamore Bridge	2050	0.1% (1000-Year)	16.0	0.0	6.2
	2070		16.0	0.0	6.4

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE

Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 100-yr (1%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Sagamore Bridge	2070	100-Year (1%)	9.8	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Extreme Heat High Risk

Target Planning Horizon: 2070
Percentile: 90th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Sea Level Rise/Storm Surge High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 50-yr (2%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

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Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
SCMs - Infiltration Basins	2050	2% (50-Year)	11.4	10.2	10.4
	2070		13.2	11.9	12.1

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
SCMs - Infiltration Basins	2050	2% (50-Year)	15.1	10.2	12.0
	2070		16.9	11.9	13.8

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
SCMs - Infiltration Basins	2050	2% (50-Year)	11.5	0.0	4.6
	2070		11.5	0.0	4.7

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 10-yr (10%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic

Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
SCMs - Infiltration Basins	2070	10-Year (10%)	6.5	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Extreme Heat — High Risk

Target Planning Horizon: 2070
Percentile: 50th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Asset: Shared Use Paths (Active Transportation) — Infrastructure

Sea Level Rise/Storm Surge — High Risk

Target Planning Horizon: 2050
Intermediate Planning Horizon: Not Applicable
Return Period: 100-yr (1%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based

on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	12.3	10.7	11.0

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	16.0	10.7	12.8

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	12.5	0.0	5.0

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2050
Return Period: 10-yr (10%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Shared Use Paths (Active Transportation)	2050	10-Year (10%)	6.1	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Extreme Heat High Risk

Target Planning Horizon: 2050
Percentile: 50th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Asset: Highway Infrastructure

Sea Level Rise/Storm Surge High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 500-yr (0.2%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

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Applicable Design Criteria

Projected Tidal Datums: APPLICABLE

This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Highway	2050	0.2% (500-Year)	14.4	11.7	12.4
	2070		16.1	13.4	14.1

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Highway	2050	0.2% (500-Year)	18.6	11.8	14.4
	2070		20.2	13.4	16.2

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Highway	2050	0.2% (500-Year)	15.0	0.0	5.9
	2070		15.0	0.0	6.0

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 50-yr (2%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Highway	2070	50-Year (2%)	8.8	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Extreme Heat High Risk

Target Planning Horizon: 2070
Percentile: 90th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Sea Level Rise/Storm Surge Project Maps

The following three maps illustrate the Projected Water Surface Elevation for the 2030, 2050, and 2070 planning horizons corresponding to the lowest return period (largest design storm) recommended across the assets identified for this project in the Tool. For projects that only have Natural Resource assets, the maps will show the Projected Water Surface Elevations corresponding to the 5% (20-year) return period. Refer to the Climate Resilience Design Standards Output - Sea Level Rise/Storm Surge Section for additional values associated with other assets. The maps include the project area as drawn by the user with a 0.1 mile minimum buffer, but do not reflect the location of specific assets on the site.

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values and maps provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

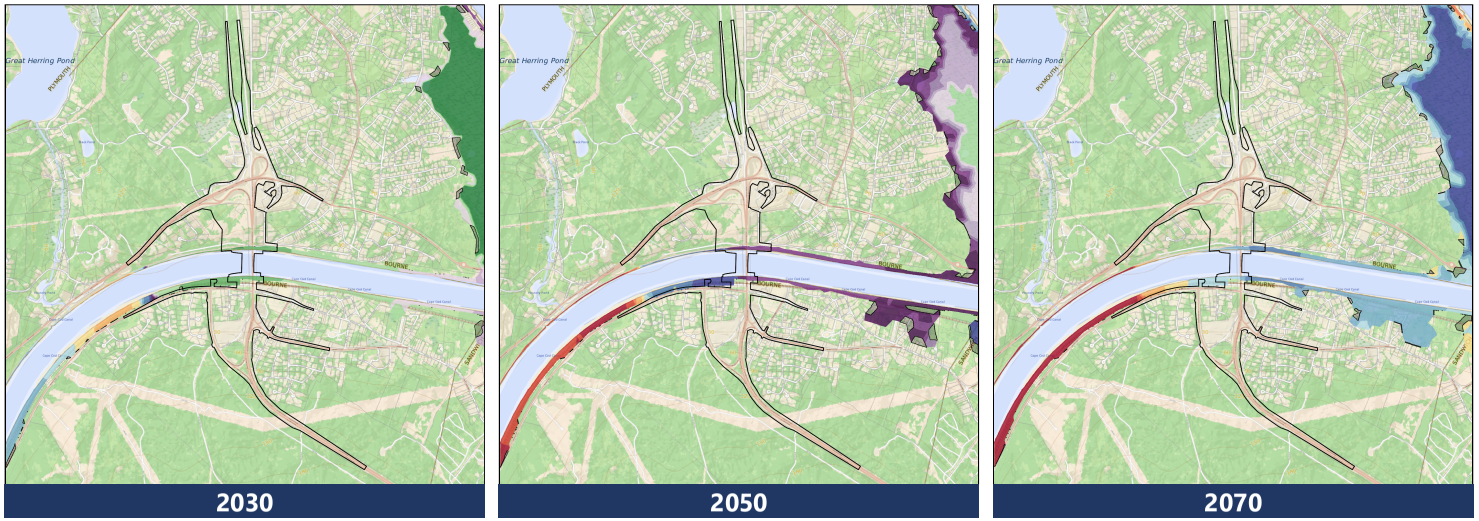
The projected values, maps, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Legend

- Project Boundary
- Low probability flooding zone

Projected Water Surface Elevation (ft-NAVD88)

- ≤ 9.7
- 9.7 - 10.0
- 10.0 - 10.5
- 10.5 - 11.0
- 11.0 - 11.5
- 11.5 - 12.0
- 12.0 - 12.5
- 12.5 - 13.0
- 13.0 - 13.5
- 13.5 - 14.0
- 14.0 - 14.5
- 14.5 - 15.0
- 15.0 - 15.5
- 15.5 - 16.0
- 16.0 - 16.5
- 16.5 - 17.0
- ≥ 17.0



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 0.1% (1000-yr)

Project Name: CCBP - Sagamore Bridge Project
Limit
Location (Town): Bourne

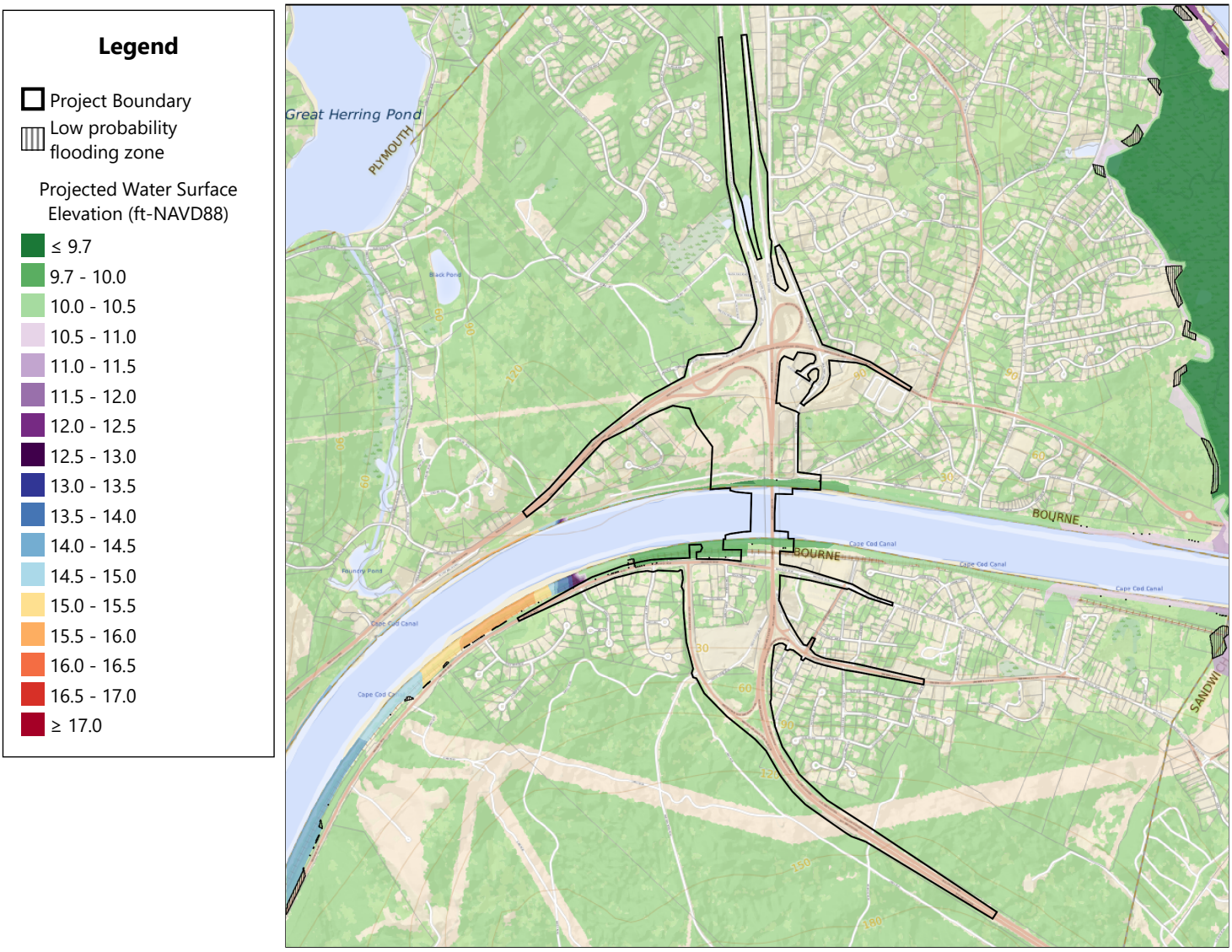
0.25 0.5 1.0 Miles

Created by: julieeatonernst
Date Created: 11/21/2024
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Sagamore Bridge	2030	0.1% (1000-yr)	13.5	9.7	9.9
	2050	0.1% (1000-yr)	15.3	12.1	12.9
	2070	0.1% (1000-yr)	17.0	13.9	14.6

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2030, 0.1% (1000-yr)

Project Name: CCBP - Sagamore Bridge Project Limit
Location (Town): Bourne

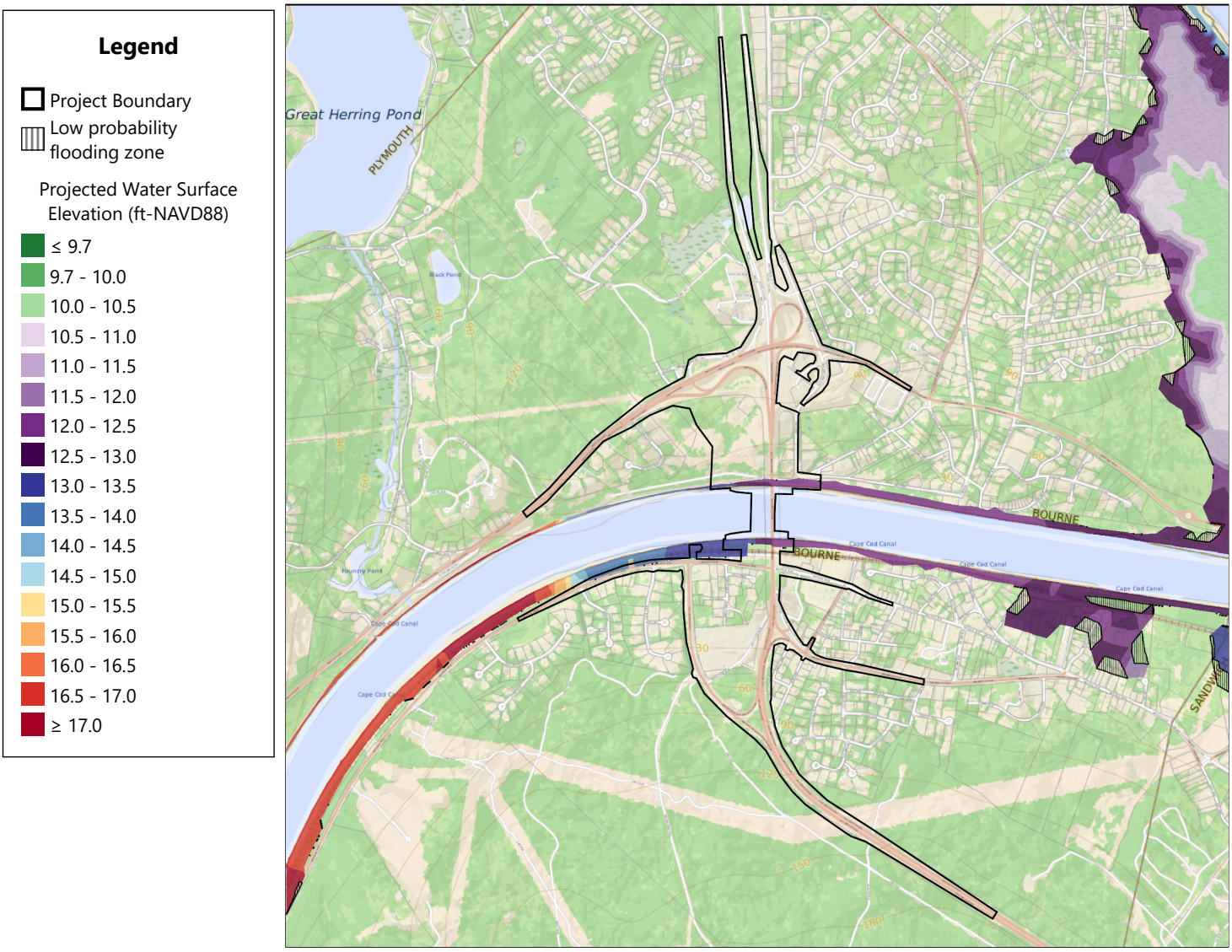
0.05 0.1 0.25 Miles

Created by: julieeatonernst
Date Created: 11/21/2024
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Sagamore Bridge	2030	0.1% (1000-yr)	13.5	9.7	9.9

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2050, 0.1% (1000-yr)

Project Name: CCBP - Sagamore Bridge Project Limit
Location (Town): Bourne

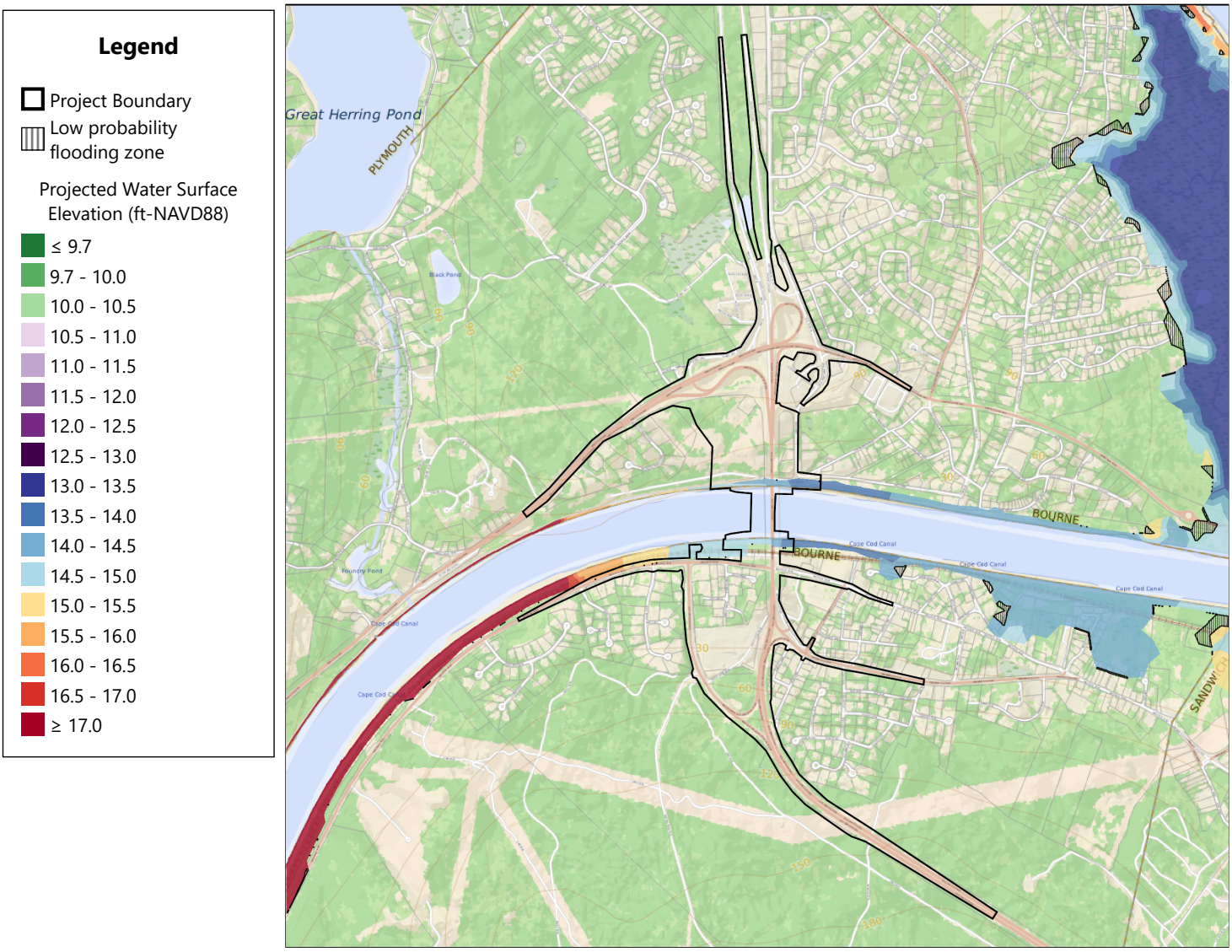
0.05 0.1 0.25 Miles

Created by: julieeatonernst
Date Created: 11/21/2024
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Sagamore Bridge	2050	0.1% (1000-yr)	15.3	12.1	12.9

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2070, 0.1% (1000-yr)

Project Name: CCBP - Sagamore Bridge Project Limit
Location (Town): Bourne

0.05 0.1 0.25 Miles

Created by: julieeatonernst
Date Created: 11/21/2024
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Sagamore Bridge	2070	0.1% (1000-yr)	17.0	13.9	14.6

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.

Project Inputs

Core Project Information

Name:	CCBP - Sagamore Bridge Project Limit
Given the expected useful life of the project, through what year do you estimate the project to last (i.e. before a major reconstruction/renovation)?	2128
Location of Project:	Bourne
Estimated Capital Cost:	$3,975,000,000
Who is the Submitting Entity?	State Agency Massachusetts Department of Transportation / Department of Transportation Julie Eaton Ernst (jeatonernst@hntb.com)
Is this project identified as an agency priority project, such as in the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP)?	No
Is this project being submitted as part of a state grant application?	No
Which grant program?	
What stage are you in your project lifecycle?	Design
Is climate resiliency a core objective of this project?	Yes
Is this project being submitted as part of the state capital planning process?	Yes
Is this project being submitted as part of a regulatory review process or permitting?	Yes
Brief Project Description:	The preliminary purpose of the Cape Cod Bridges Program (CCBP) is to improve cross-canal mobility and accessibility between Cape Cod and mainland MA for all road users and to address the increasing maintenance needs and functional obsolescence of the aging Cape Cod Canal highway bridges. The program will improve traffic operations and multimodal accommodations to facilitate the dependable and efficient movement of people, goods, and services across the Cape Cod Canal. MassDOT has identified program goals, which include improving traffic operations and safety within the Cape Cod Canal area roadway system, improving/expanding options for non-motorists, avoiding/minimizing/mitigating impacts to adjacent residences, businesses, natural resources, open space, historic/archaeological resources, and ensuring climate resilient infrastructure design.

Project Submission Comments:

Project Ecosystem Service Benefits

Factors Influencing Output

- ✓ Project provides flood protection through nature-based solutions
- ✓ Project reduces storm damage
- ✓ Project promotes decarbonization
- ✓ Project filters stormwater using green infrastructure

Factors to Improve Output

- ✓ Protect public water supply by reducing the risk of contamination, pollution, and/or runoff of surface and groundwater sources used for human consumption
- ✓ Incorporate green infrastructure or nature-based solutions that recharge groundwater
- ✓ Incorporate nature-based solutions that improve water quality
- ✓ Increase biodiversity, protect critical habitat for species, manage invasive populations, and/or provide connectivity to other habitats
- ✓ Preserve, enhance, and/or restore coastal shellfish habitats
- ✓ Provide opportunities for passive and/or active recreation through open space
- ✓ Mitigate atmospheric greenhouse gas concentrations and other toxic air pollutants through nature-based solutions
- ✓ Incorporate education and/or protect cultural resources as part of your project

Is the primary purpose of this project ecological restoration?

No

Project Benefits

Provides flood protection through nature-based solutions	Yes
Reduces storm damage	Yes
Recharges groundwater	Maybe
Protects public water supply	Maybe
Filters stormwater using green infrastructure	Yes
Improves water quality	Maybe
Promotes decarbonization	Yes
Enables carbon sequestration	No

Provides oxygen production	No
Improves air quality	Maybe
Prevents pollution	No
Remediates existing sources of pollution	No
Protects fisheries, wildlife, and plant habitat	Maybe
Protects land containing shellfish	Maybe
Provides pollinator habitat	No
Provides recreation	Maybe
Provides cultural resources/education	Maybe

Project Climate Exposure

Is the primary purpose of this project ecological restoration?	No
Does the project site have a history of coastal flooding?	No
Does the project site have a history of flooding during extreme precipitation events (unrelated to water/sewer damages)?	Unsure
Does the project site have a history of riverine flooding?	No
Does the project result in a net increase in impervious area of the site?	Yes
Are existing trees being removed as part of the proposed project?	Yes

Project Assets

Asset: Sagamore Bridge
Asset Type: Transportation
Asset Sub-Type: Bridge
Construction Type: New Construction
Construction Year: 2028
Useful Life: 100

Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event.

Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts would be regional (more than one municipality and/or surrounding region)

Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Greater than 100,000 people

Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

Will the infrastructure reduce the risk of flooding?
No

If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would not be expected to result in injuries

If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Debilitating – Inoperability will result in cascading impacts that will render other assets inoperable and/or prevent the functionality of major regional or statewide infrastructure or delivery of critical services

If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Greater than or equal to $100 million

Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
Yes

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
No impact on surrounding natural resources is expected

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure may reduce the ability to maintain some government services, while a majority of services will still exist

What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Loss of confidence in government agency

Asset: SCMs - Infiltration Basins
Asset Type: Utility Infrastructure
Asset Sub-Type: Stormwater utility infrastructure
Construction Type: New Construction
Construction Year: 2028
Useful Life: 50

Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable for more than a day, but less than a week after natural hazard without consequences.

Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts limited to location of infrastructure only
Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Less than 5,000 people
Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure does not provide services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
Will the infrastructure reduce the risk of flooding?
Yes
If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Moderate – Inoperability may impact other facilities, assets, or buildings, but cascading impacts do not affect the ability of other facilities, assets, or buildings to operate
If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Between $10 million and $30 million
Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
No
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
Impact on natural resources will require remediation/rehabilitation
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure is not expected to reduce the ability to maintain government services
What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Reduced morale and public support
Asset: Shared Use Paths (Active Transportation)
Asset Type: Transportation
Asset Sub-Type: Pedestrian ways and bikeways
Construction Type: Major Repair/Retrofit
Construction Year: 2028
Useful Life: 30
Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable for more than a day, but less than a week after natural hazard without consequences.
Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts would be limited to local area and/or municipality
Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Less than 100,000 people
Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
Will the infrastructure reduce the risk of flooding?
No
If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Moderate – Inoperability may impact other facilities, assets, or buildings, but cascading impacts do not affect the ability of other facilities, assets, or buildings to operate
If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Between $10 million and $30 million
Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
No
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
No impact on surrounding natural resources is expected

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure is not expected to reduce the ability to maintain government services
What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Reduced morale and public support
Asset: Highway
Asset Type: Transportation
Asset Sub-Type: Roads (highway)
Construction Type: Major Repair/Retrofit
Construction Year: 2028
Useful Life: 50
Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event.
Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts would be regional (more than one municipality and/or surrounding region)
Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Greater than 100,000 people
Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
Will the infrastructure reduce the risk of flooding?
No
If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Significant – Inoperability is likely to impact other facilities, assets, or buildings and result in cascading impacts that will likely affect their ability to operate
If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Greater than or equal to $100 million
Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
Yes
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
No impact on surrounding natural resources is expected
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure may reduce the ability to maintain some government services, while a majority of services will still exist
What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Reduced morale and public support

Report Comments

N/A

Attachment 2 – RMAT Output Report: Bourne Bridge

Climate Resilience Design Standards Tool Project Report

CCBP_BourneBridgeProjectLimit
Date Created: 1/22/2025 2:44:02 PM
Date Report Generated: 1/22/2025 8:18:38 PM
Project Contact Information: Julie Eaton Ernst (jeatonernst@hntb.com)

Created By: Julieeatonernst
Tool Version: Version 1.2

Project Summary

Link to Project

Estimated Capital Cost: $3975000000.00
End of Useful Life Year: 2128
Project within mapped Environmental Justice neighborhood: No

Ecosystem Service Benefits	Scores
Project Score	Moderate
Exposure	**Scores**
Sea Level Rise/Storm Surge	High Exposure
Extreme Precipitation - Urban Flooding	High Exposure
Extreme Precipitation - Riverine Flooding	High Exposure
Extreme Heat	High Exposure



Asset Preliminary Climate Risk Rating Summary

Number of Assets: 4

Asset Risk	Sea Level Rise/Storm Surge	Extreme Precipitation - Urban Flooding	Extreme Precipitation - Riverine Flooding	Extreme Heat
Bourne Bridge	High Risk	High Risk	High Risk	High Risk
Infiltration Basins	High Risk	High Risk	High Risk	High Risk
Shared Use Paths (Active Transportation)	High Risk	High Risk	High Risk	High Risk
Highway	High Risk	High Risk	High Risk	High Risk

Climate Resilience Design Standards Summary

	Target Planning Horizon	Intermediate Planning Horizon	Percentile	Return Period	Tier
Sea Level Rise/Storm Surge					
Bourne Bridge	2070	2050		1000-yr (0.1%)	
Infiltration Basins	2070	2050		50-yr (2%)	
Shared Use Paths (Active Transportation)	2050			100-yr (1%)	
Highway	2070	2050		500-yr (0.2%)	
Extreme Precipitation					
Bourne Bridge	2070			100-yr (1%)	Tier 3
Infiltration Basins	2070			10-yr (10%)	Tier 2
Shared Use Paths (Active Transportation)	2050			10-yr (10%)	Tier 2

Highway	2070		50-yr (2%)	Tier 3
Extreme Heat				
Bourne Bridge	2070	90th		Tier 3
Infiltration Basins	2070	50th		Tier 2
Shared Use Paths (Active Transportation)	2050	50th		Tier 2
Highway	2070	90th		Tier 3

Scoring Rationale - Project Exposure Score

The purpose of the Exposure Score output is to provide a preliminary assessment of whether the overall project site and subsequent assets are exposed to impacts of natural hazard events and/or future impacts of climate change. For each climate parameter, the Tool will calculate one of the following exposure ratings: Not Exposed, Low Exposure, Moderate Exposure, or High Exposure. The rationale behind the exposure rating is provided below.

Sea Level Rise/Storm Surge

This project received a "High Exposure" because of the following:

- Located within the predicted mean high water shoreline by 2030
- Exposed to the 1% annual coastal flood event as early as 2030
- Located within the 0.1% annual coastal flood event within the project's useful life

Extreme Precipitation - Urban Flooding

This project received a "High Exposure" because of the following:

- Increased impervious area
- Maximum annual daily rainfall exceeds 10 inches within the overall project's useful life
- No historic flooding at project site
- Existing impervious area of the project site is between 10% and 50%

Extreme Precipitation - Riverine Flooding

This project received a "High Exposure" because of the following:

- Part of the project is within a mapped FEMA floodplain, outside of the Massachusetts Coast Flood Risk Model (MC-FRM)
- Part of the project is within 100ft of a waterbody
- Project is potentially susceptible to riverine erosion
- No historic riverine flooding at project site

Extreme Heat

This project received a "High Exposure" because of the following:

- Increased impervious area
- Existing trees are being removed as part of the proposed project
- Existing impervious area of the project site is between 10% and 50%
- 10 to 30 day increase in days over 90 deg. F within project's useful life
- Located within 100 ft of existing water body

Scoring Rationale - Asset Preliminary Climate Risk Rating

A Preliminary Climate Risk Rating is determined for each infrastructure and building asset by considering the overall project Exposure Score and responses to Step 4 questions provided by the user in the Tool. Natural Resource assets do not receive a risk rating. The following factors are what influenced the risk ratings for each asset.

Asset - Bourne Bridge
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event
- Greater than 100,000 people would be directly affected by the loss/inoperability of the asset

- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Infrastructure functions as an evacuation route during emergencies
- Cost to replace is greater than $100 million
- There are no hazardous materials in the asset

Asset - Infiltration Basins
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable for more than a day but less than a week after natural hazard event
- Loss/inoperability of the asset would have impacts limited to the location of infrastructure only
- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Inoperability of the asset would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
- Cost to replace is between $10 million and $30 million
- Impact on natural resources will require remediation/rehabilitation with the inoperability of the asset

Asset - Shared Use Paths (Active Transportation)
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable for more than a day but less than a week after natural hazard event
- Less than 100,000 people would be directly affected by the loss/inoperability of the asset
- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Inoperability of the asset would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
- Cost to replace is between $10 million and $30 million
- There are no hazardous materials in the asset

Asset - Highway
Primary asset criticality factors influencing risk ratings for this asset:

- Asset may inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event
- Greater than 100,000 people would be directly affected by the loss/inoperability of the asset
- The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
- Infrastructure functions as an evacuation route during emergencies
- Cost to replace is greater than $100 million
- There are no hazardous materials in the asset

Project Climate Resilience Design Standards Output

Climate Resilience Design Standards and Guidance are recommended for each asset and climate parameter. The Design Standards for each climate parameter include the following: recommended planning horizon (target and/or intermediate), recommended return period (Sea Level Rise/Storm Surge and Precipitation) or percentile (Heat), and a list of applicable design criteria that are likely to be affected by climate change. Some design criteria have numerical values associated with the recommended return period and planning horizon, while others have tiered methodologies with step-by-step instructions on how to estimate design values given the other recommended design standards.

Asset: Bourne Bridge — Infrastructure

Sea Level Rise/Storm Surge — High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 1000-yr (0.1%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Bourne Bridge	2050	0.1% (1000-Year)	18.8	17.7	18.3
	2070		21.1	20.3	20.8

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Bourne Bridge	2050	0.1% (1000-Year)	23.7	17.7	20.0
	2070		26.5	20.3	22.8

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Bourne Bridge	2050	0.1% (1000-Year)	8.0	0.0	2.9
	2070		8.5	0.0	3.2

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE

Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 100-yr (1%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

The projected values, standards, and guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence

Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Bourne Bridge	2070	100-Year (1%)	9.9	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Extreme Heat High Risk

Target Planning Horizon: 2070
Percentile: 90th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Sea Level Rise/Storm Surge High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 50-yr (2%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.

Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Infiltration Basins	2050	2% (50-Year)	13.5	13.1	13.3
	2070		15.9	15.4	15.6

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Infiltration Basins	2050	2% (50-Year)	17.3	13.2	14.7
	2070		19.6	15.4	17.1

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Infiltration Basins	2050	2% (50-Year)	6.0	0.0	2.5
	2070		6.0	0.0	2.4

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 10-yr (10%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic

Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Infiltration Basins	2070	10-Year (10%)	6.6	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Extreme Heat — High Risk

Target Planning Horizon: 2070
Percentile: 50th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Asset: Shared Use Paths (Active Transportation) — Infrastructure

Sea Level Rise/Storm Surge — High Risk

Target Planning Horizon: 2050
Intermediate Planning Horizon: Not Applicable
Return Period: 100-yr (1%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based

on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

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Applicable Design Criteria

Projected Tidal Datums: APPLICABLE
This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	14.7	14.3	14.5

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	18.9	14.3	15.9

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Shared Use Paths (Active Transportation)	2050	1% (100-Year)	6.5	0.0	2.5

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2050
Return Period: 10-yr (10%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

The projected values, standards, and guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence

Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Shared Use Paths (Active Transportation)	2050	10-Year (10%)	6.1	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Extreme Heat High Risk

Target Planning Horizon: 2050
Percentile: 50th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 2

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 2

Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

Asset: Highway Infrastructure

Sea Level Rise/Storm Surge High Risk

Target Planning Horizon: 2070
Intermediate Planning Horizon: 2050
Return Period: 500-yr (0.2%)

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

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Applicable Design Criteria

Projected Tidal Datums: APPLICABLE

This project is located in an area with uncertainty for future tidal datums. These uncertain zones are either dynamic in terms of geomorphology or are restricted by manmade features (i.e., culverts, tide gates, etc.) that should be evaluated in more detail at the site-scale.

Projected Water Surface Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Highway	2050	0.2% (500-Year)	17.6	16.9	17.2
	2070		19.9	19.1	19.6

Projected Wave Action Water Elevation: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(ft - NAVD88)		
Highway	2050	0.2% (500-Year)	22.3	16.9	18.8
	2070		24.9	19.1	21.5

Projected Wave Heights: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period	Max	Min	Area Weighted Average
			(Feet)		
Highway	2050	0.2% (500-Year)	7.5	0.0	2.8
	2070		8.0	0.0	3.1

Projected Duration of Flooding: APPLICABLE
Methodology to Estimate Projected Values

Projected Design Flood Velocity: APPLICABLE
Methodology to Estimate Projected Values

Projected Scour & Erosion: APPLICABLE
Methodology to Estimate Projected Values

Extreme Precipitation High Risk

Target Planning Horizon: 2070
Return Period: 50-yr (2%)

LIMITATIONS: The recommended Standards for Total Precipitation Depth & Peak Intensity are determined by the user drawn polygon and relationships as defined in the Supporting Documents. The projected Total Precipitation Depth values provided through the Tool are based on the climate projections developed by Cornell University as part of EEA's Massachusetts Climate and Hydrologic Risk Project, GIS-based data as of 10/15/21. For additional information on the methodology of these precipitation outputs, see Supporting Documents.

While Total Precipitation Depth & Peak Intensity for 24-hour Design Storms are useful to inform planning and design, it is recommended to also consider additional longer- and shorter-duration precipitation events and intensities in accordance with best practices. Longer-duration, lower-intensity storms allow time for infiltration and reduce the load on infrastructure over the duration of the storm. Shorter-duration, higher-intensity storms often have higher runoff volumes because the water does not have enough time to infiltrate infrastructure systems (e.g., catch basins) and may overflow or back up during such storms, resulting in flooding. In the Northeast, short-duration high intensity rain events are becoming more frequent, and there is often little early warning for these events, making it difficult to plan operationally. While the Tool does not provide recommended design standards for these scenarios, users should still consider both short- and long-duration precipitation events and how they may impact the asset.

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Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Total Precipitation Depth & Peak Intensity for 24-hr Design Storms: APPLICABLE

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity

Asset Name	Recommended Planning Horizon	Recommended Return Period (Design Storm)	Projected 24-hr Total Precipitation Depth (inches)	Step-by-Step Methodology for Peak Intensity
Highway	2070	50-Year (2%)	8.8	Downloadable Methodology PDF

Projected Riverine Peak Discharge & Peak Flood Elevation: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Extreme Heat High Risk

Target Planning Horizon: 2070
Percentile: 90th Percentile

Applicable Design Criteria

Tiered Methodology: Tier 3

Projected Annual/Summer/Winter Average Temperatures: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Heat Index: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Growing Degree Days: NOT APPLICABLE

Projected Days Per Year With Max Temp > 95°F, >90°F, <32°F: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

Projected Number of Heat Waves Per Year & Average Heat Wave Duration: APPLICABLE
Methodology to Estimate Projected Values : Tier 3

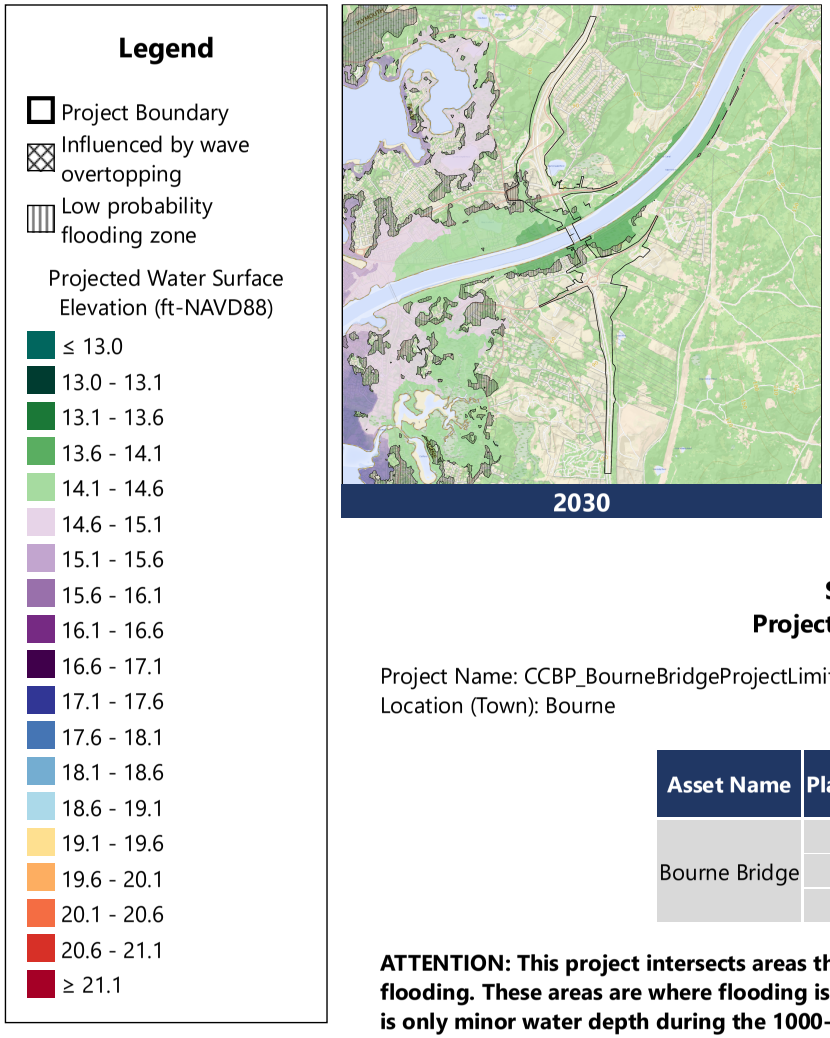
Projected Cooling Degree Days & Heating Degree Days (base = 65°F): NOT APPLICABLE

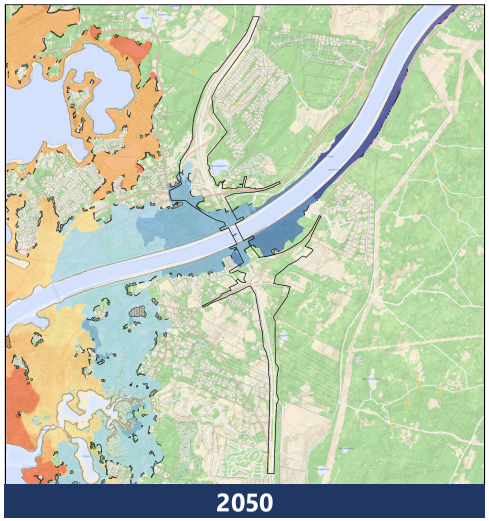
Sea Level Rise/Storm Surge Project Maps

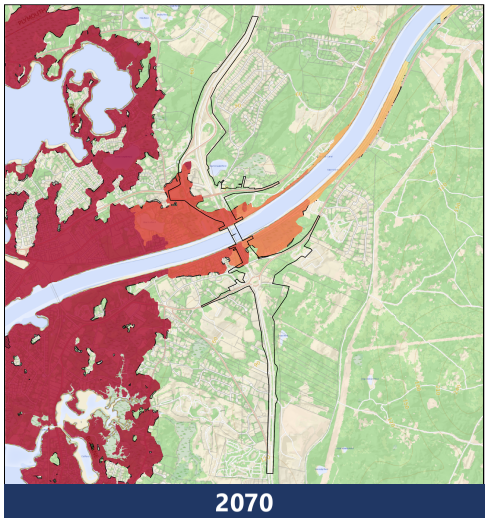
The following three maps illustrate the Projected Water Surface Elevation for the 2030, 2050, and 2070 planning horizons corresponding to the lowest return period (largest design storm) recommended across the assets identified for this project in the Tool. For projects that only have Natural Resource assets, the maps will show the Projected Water Surface Elevations corresponding to the 5% (20-year) return period. Refer to the Climate Resilience Design Standards Output - Sea Level Rise/Storm Surge Section for additional values associated with other assets. The maps include the project area as drawn by the user with a 0.1 mile minimum buffer, but do not reflect the location of specific assets on the site.

LIMITATIONS: The recommended Climate Resilience Design Standards for the Sea Level Rise / Storm Surge Design Criteria are based on the user drawn polygon and relationships as defined in the Supporting Documents. The projected values and maps provided through the Tool are based on the Massachusetts Coast Flood Risk Model (MC-FRM) outputs as of 9/13/2021, which included GIS-based data for three planning horizons (2030, 2050, 2070) and six return periods (0.1%, 0.2%, 0.5%, 1%, 2%, 5%). These values are projections based on assumptions as defined in the model and the LiDAR used at the time. For additional information on the MC-FRM, review the additional resources provided on the Start Here page.

The projected values, maps, Standards, and Guidance provided within this Tool may be used to inform plans and designs, but they do not provide guarantees for future conditions or resilience. The projected values are not to be considered final or appropriate for construction documents without supporting engineering analyses. The guidance provided within this Tool is intended to be general and users are encouraged to do their own due diligence.







Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 0.1% (1000-yr)

Project Name: CCBP_BourneBridgeProjectLimit
Location (Town): Bourne

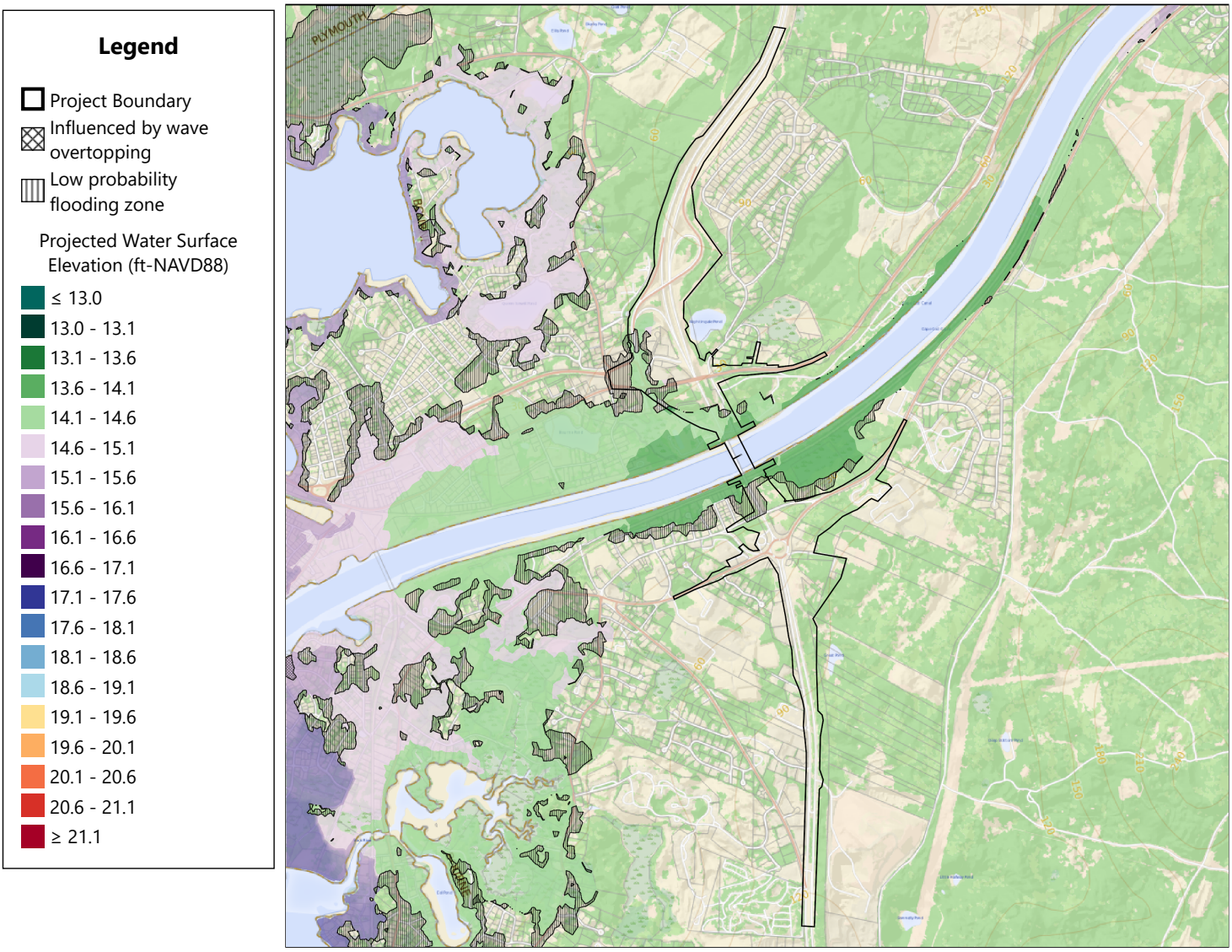
0.25 0.5 1.0 Miles

Created by: Julieeatonernst
Date Created: 1/22/2025
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Bourne Bridge	2030	0.1% (1000-yr)	14.7	13.0	14.1
	2050	0.1% (1000-yr)	18.8	17.7	18.3
	2070	0.1% (1000-yr)	21.1	20.3	20.8

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2030, 0.1% (1000-yr)

Project Name: CCBP_BourneBridgeProjectLimit
Location (Town): Bourne

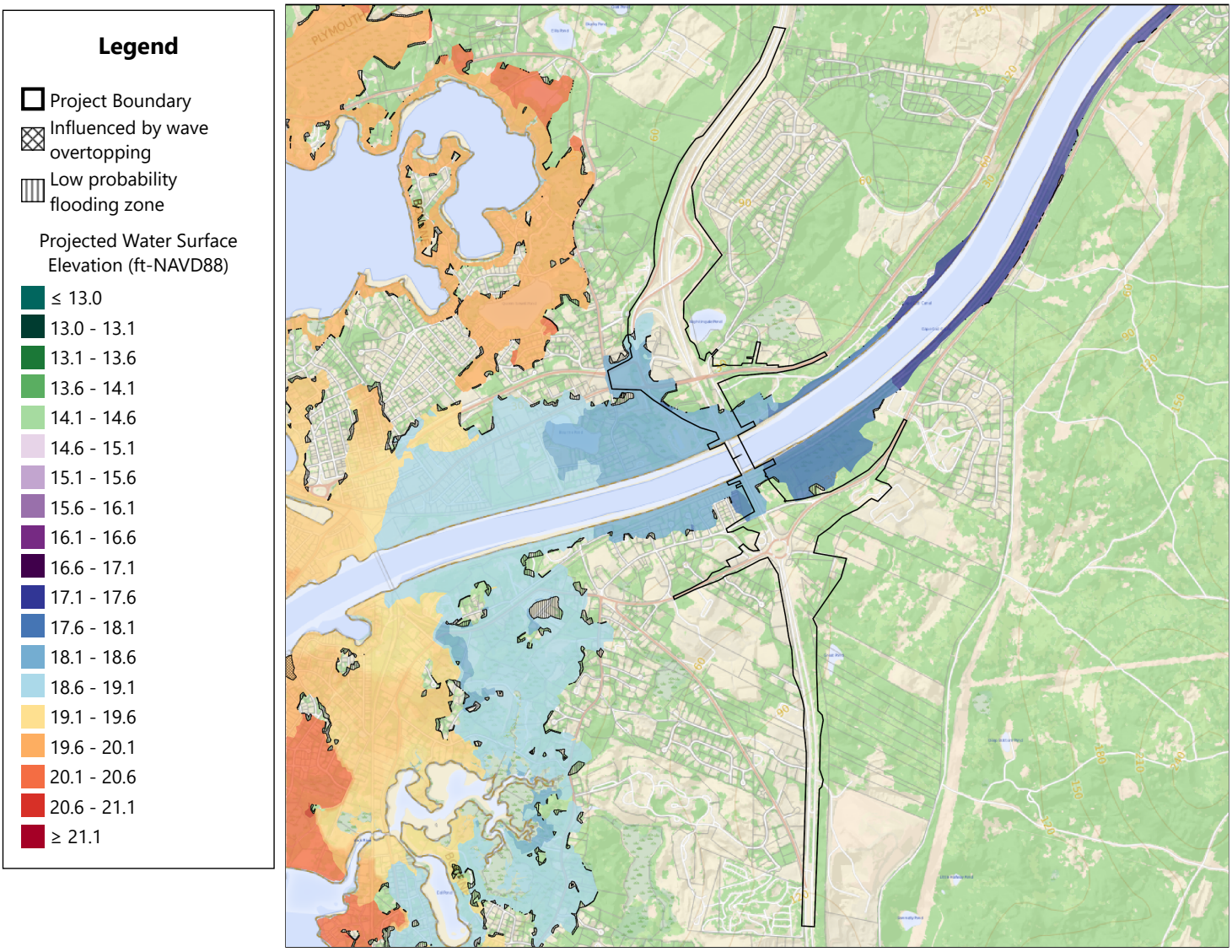
0.05 0.1 0.25 Miles

Created by: Julieeatonernst
Date Created: 1/22/2025
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Bourne Bridge	2030	0.1% (1000-yr)	14.7	13.0	14.1

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2050, 0.1% (1000-yr)

Project Name: CCBP_BourneBridgeProjectLimit
Location (Town): Bourne

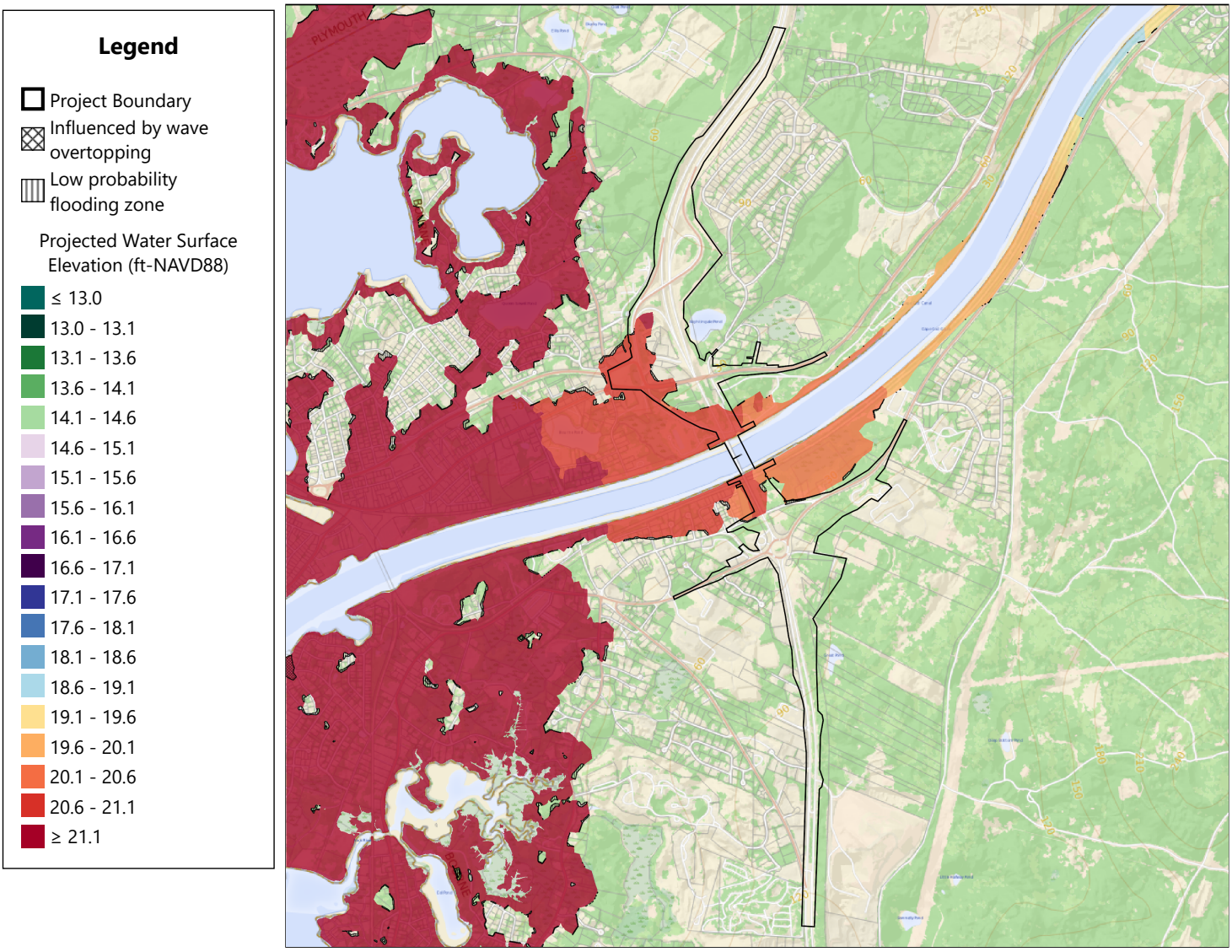
0.05 0.1 0.25 Miles

Created by: Julieeatonernst
Date Created: 1/22/2025
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Bourne Bridge	2050	0.1% (1000-yr)	18.8	17.7	18.3

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.



Climate Resilience Design Standards Tool:
Sea Level Rise/Storm Surge Design Criteria
Projected Water Surface Elevation Map: 2070, 0.1% (1000-yr)

Project Name: CCBP_BourneBridgeProjectLimit
Location (Town): Bourne

0.05 0.1 0.25 Miles

Created by: Julieeatonernst
Date Created: 1/22/2025
Tool Version: 1.3

N

Asset Name	Planning Horizon	Return Period	Max	Min	Area Weighted Average (ft-NAVD88)
Bourne Bridge	2070	0.1% (1000-yr)	21.1	20.3	20.8

ATTENTION: This project intersects areas that are low probability flooding zones with minimal flood risk and small depth of flooding. These areas are where flooding is expected during the most extreme storm events (>1000-yr return period) or where there is only minor water depth during the 1000-yr return period. Additional site analyses are recommended to establish design values associated with design criteria.

Project Inputs

Core Project Information

Name:	CCBP_BourneBridgeProjectLimit
Given the expected useful life of the project, through what year do you estimate the project to last (i.e. before a major reconstruction/renovation)?	2128
Location of Project:	Bourne
Estimated Capital Cost:	$3,975,000,000
Who is the Submitting Entity?	State Agency Massachusetts Department of Transportation Julie Eaton Ernst (jeatonernst@hntb.com)
Is this project identified as an agency priority project, such as in the State Hazard Mitigation and Climate Adaptation Plan (SHMCAP)?	No
Is this project being submitted as part of a state grant application?	No
Which grant program?	
What stage are you in your project lifecycle?	Design
Is climate resiliency a core objective of this project?	Yes
Is this project being submitted as part of the state capital planning process?	Yes
Is this project being submitted as part of a regulatory review process or permitting?	Yes
Brief Project Description:	The preliminary purpose of the Cape Cod Bridges Program (CCBP) is to improve cross-canal mobility and accessibility between Cape Cod and mainland MA for all road users and to address the increasing maintenance needs and functional obsolescence of the aging Cape Cod Canal highway bridges. The program will improve traffic operations and multimodal accommodations to facilitate the dependable and efficient movement of people, goods, and services across the Cape Cod Canal. MassDOT has identified program goals, which include improving traffic operations and safety within the Cape Cod Canal area roadway system, improving/expanding options for non-motorists, avoiding/minimizing/mitigating impacts to adjacent residences, businesses, natural resources, open space, historic/archaeological resources, and ensuring climate resilient infrastructure design.
Project Submission Comments:	

Project Ecosystem Service Benefits

Factors Influencing Output

- ✓ Project provides flood protection through nature-based solutions
- ✓ Project reduces storm damage
- ✓ Project promotes decarbonization
- ✓ Project filters stormwater using green infrastructure

Factors to Improve Output

- ✓ Protect public water supply by reducing the risk of contamination, pollution, and/or runoff of surface and groundwater sources used for human consumption
- ✓ Incorporate green infrastructure or nature-based solutions that recharge groundwater
- ✓ Incorporate nature-based solutions that improve water quality
- ✓ Increase biodiversity, protect critical habitat for species, manage invasive populations, and/or provide connectivity to other habitats
- ✓ Preserve, enhance, and/or restore coastal shellfish habitats
- ✓ Provide opportunities for passive and/or active recreation through open space
- ✓ Mitigate atmospheric greenhouse gas concentrations and other toxic air pollutants through nature-based solutions
- ✓ Incorporate education and/or protect cultural resources as part of your project

Is the primary purpose of this project ecological restoration?

No

Project Benefits

Provides flood protection through nature-based solutions	Yes
Reduces storm damage	Yes
Recharges groundwater	Maybe
Protects public water supply	Maybe
Filters stormwater using green infrastructure	Yes
Improves water quality	Maybe
Promotes decarbonization	Yes
Enables carbon sequestration	No
Provides oxygen production	No

Improves air quality	Maybe
Prevents pollution	No
Remediates existing sources of pollution	No
Protects fisheries, wildlife, and plant habitat	Maybe
Protects land containing shellfish	Maybe
Provides pollinator habitat	No
Provides recreation	Maybe
Provides cultural resources/education	Maybe

Project Climate Exposure

Is the primary purpose of this project ecological restoration?	No
Does the project site have a history of coastal flooding?	No
Does the project site have a history of flooding during extreme precipitation events (unrelated to water/sewer damages)?	Unsure
Does the project site have a history of riverine flooding?	No
Does the project result in a net increase in impervious area of the site?	Yes
Are existing trees being removed as part of the proposed project?	Yes

Project Assets

Asset: Bourne Bridge
Asset Type: Transportation
Asset Sub-Type: Bridge
Construction Type: New Construction
Construction Year: 2028
Useful Life: 100

Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event.

Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts would be regional (more than one municipality and/or surrounding region)

Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Greater than 100,000 people

Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

Will the infrastructure reduce the risk of flooding?
No

If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would not be expected to result in injuries

If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Debilitating – Inoperability will result in cascading impacts that will render other assets inoperable and/or prevent the functionality of major regional or statewide infrastructure or delivery of critical services

If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Greater than or equal to $100 million

Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
Yes

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
No impact on surrounding natural resources is expected

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure may reduce the ability to maintain some government services, while a majority of services will still exist

What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Loss of confidence in government agency

Asset: Infiltration Basins
Asset Type: Utility Infrastructure
Asset Sub-Type: Stormwater utility infrastructure
Construction Type: New Construction
Construction Year: 2028
Useful Life: 50

Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable for more than a day, but less than a week after natural hazard without consequences.

Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.

Impacts limited to location of infrastructure only
Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Less than 5,000 people
Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
Will the infrastructure reduce the risk of flooding?
Yes
If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Moderate – Inoperability may impact other facilities, assets, or buildings, but cascading impacts do not affect the ability of other facilities, assets, or buildings to operate
If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Between $10 million and $30 million
Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
No
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
Impact on natural resources will require remediation/rehabilitation
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?
Loss of infrastructure is not expected to reduce the ability to maintain government services
What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?
Reduced morale and public support
Asset: Shared Use Paths (Active Transportation)
Asset Type: Transportation
Asset Sub-Type: Pedestrian ways and bikeways
Construction Type: Major Repair/Retrofit
Construction Year: 2028
Useful Life: 30
Identify the length of time the asset can be inaccessible/inoperable without significant consequences.
Infrastructure may be inaccessible/inoperable for more than a day, but less than a week after natural hazard without consequences.
Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.
Impacts would be limited to local area and/or municipality
Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.
Less than 100,000 people
Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.
Will the infrastructure reduce the risk of flooding?
No
If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?
Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses
If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?
There are no hazardous materials in the infrastructure
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?
Moderate – Inoperability may impact other facilities, assets, or buildings, but cascading impacts do not affect the ability of other facilities, assets, or buildings to operate
If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?
Between $10 million and $30 million
Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.
No
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?
No impact on surrounding natural resources is expected
If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?

Loss of infrastructure is not expected to reduce the ability to maintain government services

What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?

Reduced morale and public support

Asset: Highway
Asset Type: Transportation
Asset Sub-Type: Roads (highway)
Construction Type: Major Repair/Retrofit
Construction Year: 2028
Useful Life: 50

Identify the length of time the asset can be inaccessible/inoperable without significant consequences.

Infrastructure may be inaccessible/inoperable during natural hazard event, but must be accessible/operable within one day after natural hazard event.

Identify the geographic area directly affected by permanent loss or significant inoperability of the infrastructure.

Impacts would be regional (more than one municipality and/or surrounding region)

Identify the population directly served that would be affected by the permanent loss or significant inoperability of the infrastructure.

Greater than 100,000 people

Identify if the infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

The infrastructure provides services to populations that reside within Environmental Justice neighborhoods or climate vulnerable populations.

Will the infrastructure reduce the risk of flooding?

No

If the infrastructure became inoperable for longer than acceptable in Question 1, how, if at all, would it be expected to impact people's health and safety?

Inoperability of the infrastructure would be expected to result in minor impacts to people's health, including minor injuries or minor impacts to chronic illnesses

If there are hazardous materials in your infrastructure, what are the extents of impacts related to spills/releases of these materials?

There are no hazardous materials in the infrastructure

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts on other facilities, assets, and/or infrastructure?

Significant – Inoperability is likely to impact other facilities, assets, or buildings and result in cascading impacts that will likely affect their ability to operate

If the infrastructure was damaged beyond repair, how much would it approximately cost to replace?

Greater than or equal to $100 million

Does the infrastructure function as an evacuation route during emergencies? This question only applies to roadway projects.

Yes

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the environmental impacts related to natural resources?

No impact on surrounding natural resources is expected

If the infrastructure became inoperable for longer than acceptable in Question 1, what are the impacts to government services (i.e. the infrastructure is not able to serve or operate its intended users or function)?

Loss of infrastructure may reduce the ability to maintain some government services, while a majority of services will still exist

What are the impacts to loss of confidence in government resulting from loss of infrastructure functionality (i.e. the infrastructure asset is not able to serve or operate its intended users or function)?

Reduced morale and public support

Report Comments

N/A