4 Affected Environment, Environmental Consequences, and Mitigation

4.21 Adaptation and Resiliency

4.21.1 Introduction

This section assesses the potential extreme weather risks to the No Build Alternative and Build Alternative under various conditions related to:

- Sea levels and storm surge
- Extreme precipitation
- Extreme heat
- Winter weather
- Extreme wind

This section evaluates potential risks to the following affected environments referenced in other Draft Environmental Impact Statement sections:

- Cape Cod Canal operations
- Bridge infrastructure
- Stormwater control measures
- Land cover
- Highway-traffic operations and safety
- Mobility and accessibility for all road users

In addition to assessing extreme weather risk from the No Build Alternative and Build Alternative, this section also discusses potential mitigation strategies that the Massachusetts Department of Transportation (MassDOT) is considering to increase resilience. **Table 4.21-1** summarizes the affected environments within the Project Limits and Study Areas and the primary risks assessed.

4.21.1.1 Regulatory Context

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

- 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 USC 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).

4.21.1.2 Study Areas

For the purposes of assessing the impacts of extreme weather, the Study Areas consist of the construction project limit and a 500-foot buffer for Sagamore Bridge and Bourne Bridge (**Figure 4.21-1**).

4.21.1.3 Methodology

Past observations and/or modeled conditions were used in conjunction with the affected environment to inform the recommendations for data and methods to assess the impact on the No Build and Build Alternatives. The methodology consisted of reviewing published studies and environmental data, including:

- Federal Emergency Management Agency (FEMA), Flood Insurance Study Number 25001CV000B, Effective July 7, 2021[1]
- FEMA Policy: Federal Flood Risk Management Standard, Effective September 9, 2024[2]
- Dangendorf, S. (2024). Kalman Smoother Sea Level Reconstruction [Data set]. Zenodo[3]
- National Oceanic and Atmospheric Administration (NOAA), Precipitation-Frequency Atlas of the United States, Northeastern states - Atlas 14, Volume 10 (2018)[4]
- NOAA Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (Version 3 – June 2022)[5]

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

- U.S. Army Corps of Engineers (USACE), Massachusetts Hurricane Evacuation Study Technical Data Report, Chapter 2 Hazards Analyses (2016)[6]
- USACE, New England Hurricane Evacuation Study Technical Data Report (June 2016)[7]
- Massachusetts Emergency Management Agency, Cape Cod Emergency Traffic Plan (2018)[8]

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[1] https://map1.msc.fema.gov/data/25/S/PDF/25001CV000B.pdf?LOC=51a412c9cdcc22ab0113e2e0169d67bd

[2] https://www.federalregister.gov/documents/2024/07/11/2024-15170/fema-policy-federal-flood-risk-management-standard-ffrms

[3] https://doi.org/10.5281/zenodo.10621070

[4] https://www.weather.gov/media/owp/oh/hdsc/docs/Atlas14_Volume10.pdf

[5] https://gis.data.mass.gov/maps/a9e9d37e363f434f84b28e791b23398b/about

[6] https://www.nae.usace.army.mil/Portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/MA_Ch%202_Hazards%20Analysis.pdf

[7] https://www.nae.usace.army.mil/portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/New%20England%20Hurricane%20Evacuation%20Study.pdf

[8] https://www.mass.gov/doc/cape-cod-emergency-traffic-plan/download

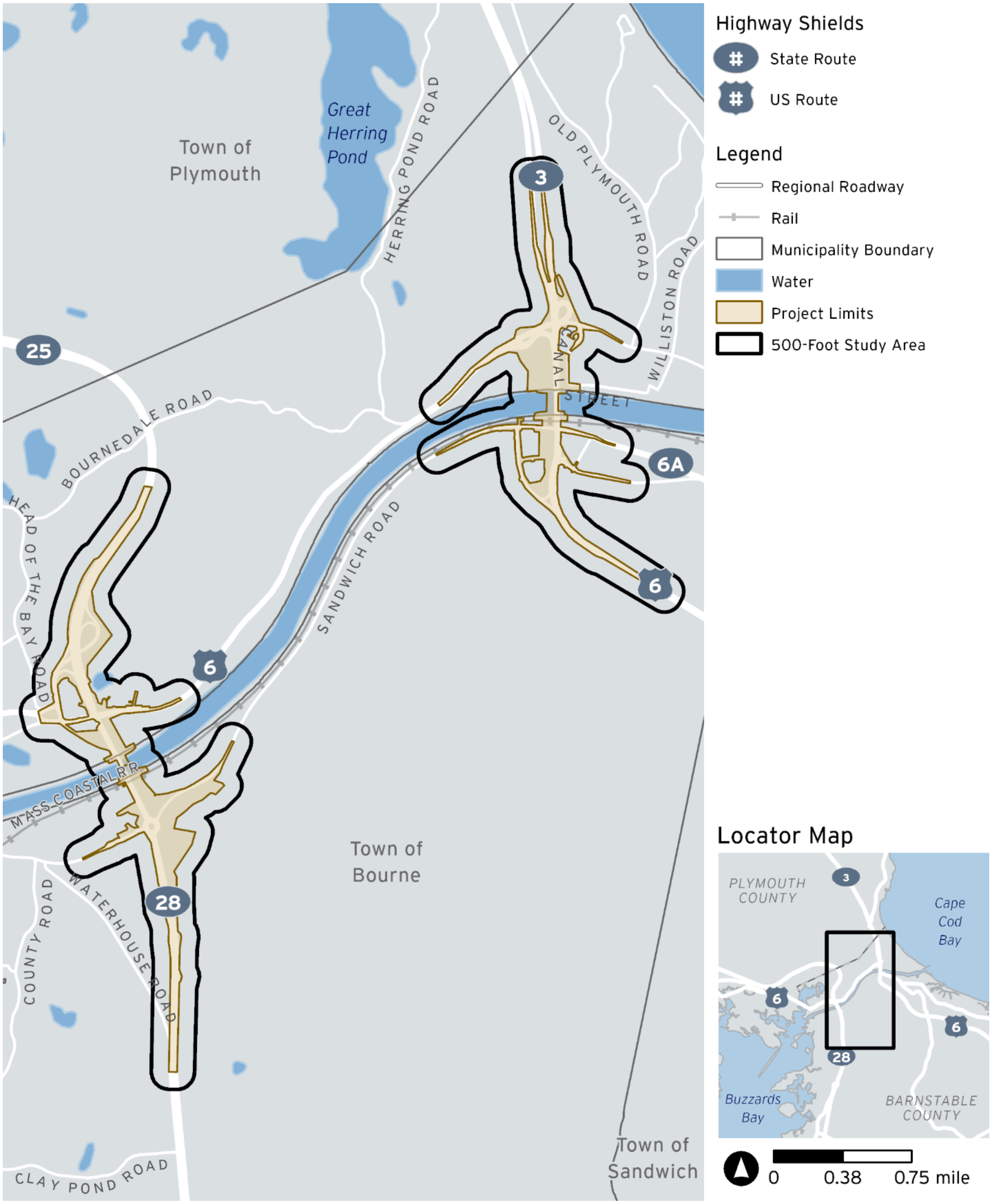
Table 4.21-1. Adaptation and Resiliency Affected Environment

Affected Environment	Related Draft Environmental Impact Statement Section	Impacts Assessed				
		Sea Levels and Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
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 4.10, Water Quality and Stormwater**	Submerged Outfalls* Infiltration Basin Flooding	Infiltration Basin Performance	NA	NA	NA
Land Cover	**Section 4.6, Land Use, Zoning, and Community Cohesion** **Section 4.9, Wetlands and Floodplains** **Section 4.10, Water Quality and Stormwater**	Floodplain Function	Localized Flooding	Surface temperature	NA	NA
Transportation	**Section 4.2, Transportation, Traffic, and Safety**	Roadways and 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

Notes: NA = Not assessed for affected environment.

* Outfalls are within the Study Areas are shown in **Figure 4.21-1**, but are not part of the Program; they were assessed due to their impact on stormwater systems (flooding and performance) within the Study Areas.

Figure 4.21-1. Study Areas for Adaptation and Resiliency Evaluation



Source: Massachusetts Department of Transportation, 2024

Sea Levels and Storm Surge Methodology

The methodology included reviewing published observed sea level data from the closest tide gauge (Woods Hole, MA - NOAA Station ID: 8447930), SLOSH models, and FEMA maps and studies. **Table 4.21-2** and **Table 4.21-3** include summaries of sea level and storm surge design criteria used to assess the affected environment, impacts assessed, and methodology.

Table 4.21-2. Affected Environment and Impacts Assessed: Inundation, Sea Level, and Storm Surge

Design Criteria	Affected Environment	Impact	Inundation Scenario Assessed
Tidal Datums	Canal	Navigational clearance	Mean Higher High Water (MHHW)
	Stormwater Control Measures	• Submerged or partially submerged outfalls • Infiltration Basin Flooding and Performance	MHHW
Storm Surge and Coastal Inundation	Stormwater Control Measures	• Submerged or partially submerged outfalls • Infiltration Basin Flooding	• Federal Emergency Management Agency (FEMA) 100-year • Category 2 + 3 feet
	Land Cover	Floodplain Function	• FEMA 100-year • Category 2 + 3 feet
	Transportation	Roadways and Evacuation Route Flooding	• FEMA 100-year • Category 2 + 3 feet
	Mobility	Shared-Use Path Flooding	• FEMA 100-year • Category 2 + 3 feet
Wave Hazards	None[1]	None	None
Scour	Bridge	Pier Scour	• 200-year (Design Storm) • 500-year (Check Storm)

Notes: Given the extent of the Study Areas, FEMA special flood hazard area designations, 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 stormwater control measures), and lack of structures proposed along the shoreline that could reflect waves, wave hazards were not formally assessed in this study due to the lack of an affected environment.

Table 4.21-3. Affected Environment and Methodology: Sea Levels and Storm Surge

Design Criteria	Affected Environment	Methodology
Tidal Datums	Canal	To evaluate the effect of tidal datums on navigational clearance, the required vertical clearance determined by the United States Coast Guard was subtracted from the bridges' low chord elevation. If the Mean Higher High Water (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 affected over a tide cycle.
	Stormwater Control Measures	To evaluate the effect of tidal datums on outfalls associated with the stormwater control measures, the Massachusetts Department of Transportation (MassDOT) compared tidal datums to outfall invert and crown elevations. If the tidal datum exceeded the outfall invert elevation, MassDOT was assumed it to be partially submerged, with potential backflow through the system. If the tidal datum exceeded the outfall crown elevation, MassDOT was assumed it to be fully submerged, with potential backflow through the system. MassDOT applied similar comparisons to the infiltration basins, with bottom of basin and top of basin elevations.[1] If the tidal datum exceeded the proposed basin bottom elevation, MassDOT assumed the basin to have reduced infiltration capacity due to groundwater rise. If the tidal datum exceeds the proposed overflow structure's outlet elevation, MassDOT assumed the basin to be partially full to the elevation of the tide. If the tidal datum exceeded the proposed basin top elevation, MassDOT assumed that the tides overtopped the basin and resulted in localized flooding.
Storm Surge and Coastal Inundation	Stormwater Control Measures	To evaluate the effect of storm surge on the stormwater control measures, MassDOT compared storm surge elevations associated with the Federal Emergency Management Agency (FEMA) 100-year base flood elevation and a Category 2 Hurricane with 3-foot freeboard with the elevations of the outfalls and infiltration basins, in a similar fashion to the tidal datum methodology. In addition, the extent of storm surge inundation was overlaid with proposed basins to identify potential for overland flooding.
	Land Cover	To evaluate the impact on land subject to coastal storm flowage, MassDOT overlaid the extent of overland storm surge inundation 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 storm surge elevation were assumed to not be flooded. MassDOT evaluated cross-sections for potential channelization of flow and increased velocities based on grading and land cover surface type.
	Transportation Mobility	To evaluate the impact on roadways and active transportation, MassDOT overlaid the extent of overland storm surge inundation with roadways, sidewalks, and shared-use paths. If those routes were within the extent of inundation, MassDOT assumed them to be affected.

Design Criteria	Affected Environment	Methodology
Scour	Bridge	To evaluate the effect on bridge pier scour, MassDOT analyzed a 2D Hydraulic Model.[2] The maximum scour depth generated should be used to assess impact and design foundations.

[1] Overflow outlet structure elevations are to be determined and should be assessed once known in accordance with this methodology.

[2] Only for Sagamore Bridge. MassDOT is developing the Bourne Bridge 2D model, which will be updated in the Final Environmental Impact Statement.

Extreme Precipitation

The methodology included MassDOT reviewing published NOAA rainfall precipitation frequency estimates, as well as past observations, for 24-hour rainfall depths for Massachusetts. **Table 4.21-4** summarizes the extreme precipitation design criteria used to assess affected environment and impacts. **Section 4.10, Water Quality and Stormwater,** discusses the methodology used to assess the No Build Alternative and Build Alternative impacts on the affected environment. **Table 4.21-3** provides the methodology for combined impacts with tidal datums.

Table 4.21-4. Affected Environment and Impacts Assessed: Extreme Precipitation

Design Criteria	Affected Environment	Impact	Extreme Precipitation Scenario Assessed
Rainfall Depths	Stormwater Control Measures	Sizing of Infiltration Basins	500-year, 24-hour event
	Land Cover; Transportation, Mobility	Localized flooding from capacity of drainage infrastructure	500-year, 24-hour event
Rainfall Depths and Tidal Datums	Stormwater Control Measures	Performance of stormwater control measures with submerged or partially submerged outfalls	Varying tidal datums and 500-year, 24-hour event

Extreme Heat

The methodology included reviewing land cover characteristics and observations of days over 90 degrees Fahrenheit (F). **Table 4.21-5** and **Table 4.21-6** summarize how extreme heat was used to assess the affected environment.

Table 4.21-5. Affected Environment and Impacts Assessed: Extreme Heat

Design Criteria	Affected Environment	Impact	Extreme Heat Scenario Assessed
Max Temperatures	Bridge	Bridge joint expansion	Temperature exceeding 120 degrees Fahrenheit
Days above 90 degrees Fahrenheit	Transportation	Pavement performance	Days above 90 degrees Fahrenheit
	Mobility	Active transportation use	Days above 90 degrees Fahrenheit
Impervious surface area	Land cover	Surface temperatures	• Percentage area – Less than 10% – Between 10% and 50% – Greater than 50%

Table 4.21-6. Affected Environment and Methodology: Extreme Heat

Design Criteria	Affected Environment	Methodology
Max Temperatures	Bridge	To evaluate the effect on the bridge joint expansion, the Massachusetts Department of Transportation (MassDOT) assessed maximum temperatures greater than 120 degrees Fahrenheit (F). The design temperature of steel structures ranges from -30 to 120 degrees F. If the maximum temperature exceeded 120 degrees F, it was assumed to be affected because it is beyond the design range.
Days Above 90 degrees F	Transportation	To evaluate the effect on pavement performance, MassDOT assessed the number of days greater than 90 degrees F; days over 90 degrees F were assumed to affect pavement performance.
	Mobility	To evaluate the effect on use of pedestrian and shared-use paths, MassDOT assessed the number of days greater than 90 degrees F; days over 90 degrees F were assumed to affect active transportation use.
Impervious surface area	Land cover	To evaluate the effect on the land surface temperature, MassDOT assessed the percentage of impervious area within the Study Areas. If the percentage was less than 10%, it was assumed to reduce land surface temperature. If the percentage was between 10% to 50%, it was assumed to have a negligible effect on land surface temperatures. If the percentage was greater than 50%, it was assumed to affect land surface temperature and increase heat severity.

Winter Weather

The methodology included reviewing results from an extreme value analysis to assess maximum thicknesses for combined snow and ice and observations of days below 32 degrees F. Table 4.21-7 and Table 4.21-8 summarize how MassDOT used winter weather to assess the affected environment.

Table 4.21-7. Affected Environment and Impacts Assessed: Winter Weather

Design Criteria	Affected Environment	Impact	Winter Weather Scenario Assessed
Combined Ice and Wet Snow Thickness	Bridge	Icing on cables and members	500-year (0.2%) thickness (inches)
Freezing temperatures	Transportation	Potential for snow and ice on roadways	Days below 32 degrees Fahrenheit

Table 4.21-8. Affected Environment and Methodology: Winter Weather

Design Criteria	Affected Environment	Methodology
Combined Ice and Wet Snow Thickness	Bridge	To evaluate the effect of icing on bridge members/cables, the Massachusetts Department of Transportation (MassDOT) assessed the maximum thickness of combined ice and wet snow using extreme value analysis and comparing with the values specified in American Society of Civil Engineers/Structural Engineering Institute 7-22 for the project location.
Freezing temperatures	Transportation	To evaluate the effect on highway transportation from snow and ice, MassDOT assessed the number of days below 32 degrees Fahrenheit (F); days below 32 degrees F were assumed to create conditions where snow and ice are possible.

Extreme Wind

The methodology included reviewing wind climate analysis for the replacement bridges' design wind speeds and flutter verification, which included a Monte Carlo simulation of tropical cyclone and hurricane wind speeds. **Table 4.21-9** and **Table 4.21-10** summarize how extreme winds were used to assess the affected environment.

Table 4.21-9. Affected Environment and Impacts Assessed: Extreme Winds

Design Criteria	Affected Environment	Impact	Extreme Wind Scenario Assessed
1-hour Mean Wind Speed	Bridge	Design	• 97-year (construction) • 1,400-year (completed)
10-minute wind speeds/ 3-second wind gusts	Bridge	Aerodynamic Stability	• 1,000-year (construction) • 10,000-year (completed)
3-second wind gusts	Transportation	Vehicle Rollover	Gusts greater than 50 miles per hour

Table 4.21-10. Affected Environment and Methodology: Extreme Winds

Design Criteria	Affected Environment	Methodology[1]
1-hr Mean Wind Speed	Bridge	To evaluate wind loads for bridge design, the Massachusetts Department of Transportation (MassDOT) modeled the mean wind speed at deck level for 1 hour to produce the worst-case loading conditions.
10-minute wind speeds/ 3-second wind gusts	Bridge	To evaluate aerodynamic stability, MassDOT analyzed 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).
3-second wind gusts	Transportation	To evaluate potential vehicle rollover, MassDOT analyzed the likelihood of wind gust speeds greater than 50 miles per hour at deck level.

[1] Methodology aligns with American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Design Factor Bridge Design Specifications (10th edition) and AASHTO Guide Specifications for Wind Loads on Bridges During Construction (GSWLB-1) return-period recommendations. A specialized wind subconsultant conducted wind tunnel testing of the replacement bridges and a buffeting analysis to determine the wind force effects on structures.

4.21.2 Affected Environment

4.21.2.1 Cape Cod Canal

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

Sea Levels and Storm Surge

Cape Cod Canal is a navigational channel that requires a vertical clearance of 138.3 feet[9]. The existing and replacement bridges are and would be fixed structures, so fluctuations in sea level elevation and storm surge affect the ability to maintain the required vertical clearance.

[9] The First Coast Guard District issued a Preliminary Navigation Clearance Determination dated March 11, 2025, to MassDOT and the U.S. Army Corps of Engineers (USACE). The determination stated the replacement Bourne and Sagamore 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.

4.21.2.2 Bridge

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

Sea Levels and Storm Surge

The existing and replacement bridge piers are and would be along the Cape Cod Canal banks and subject to coastal processes, including inundation and scour. Fluctuations in sea level elevation and storm surge affect 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.

Extreme Heat

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

Winter Weather

Ice accretion affects static loads and wind drag, which may affect aerodynamic stability of the replacement bridges. 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.[10]

Extreme Wind

Wind causes static loads on a bridge and also results in a special dynamic behavior that affects aerodynamic stability.[11]

4.21.2.3 Stormwater Control Measures

Section 4.10 Water Quality and Stormwater, discusses stormwater control measures.

Sea Levels and Storm Surge

Stormwater is ultimately discharged into Cape Cod Canal through outfalls by gravity flow, and fluctuations in sea level elevation and storm surge affect the ability of the existing outfalls to discharge flow freely (without submerged or partially submerged conditions). **Table 4.21-11** summarizes the outfalls and associated elevations.

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[10] Lubomir, M. and 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. January. https://doi.org/10.1016/j.coldregions.2021.103429

[11] 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

Table 4.21-11. Existing 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	7.50	10.50
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

NAVD88 = North American Vertical Datum of 1988

Note: * Twin elliptical culverts

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 coastal or precipitation events. Coastal inundation also reduces the ability of the infiltration basins to manage stormwater generated by rainfall events.

Extreme Precipitation

Extreme precipitation combined with fluctuations in sea level elevations 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.

4.21.2.4 Land Cover

Land cover is described several sections, including **Section 4.9, Wetlands and Floodplains**, **Section 4.10, Water Quality and Stormwater**, and **Section 4.6, Land Use, Zoning, and Community Cohesion,** which address resource areas, impervious surfaces, and land clearing.

Sea Levels and Storm Surge

Section 4.9, Wetlands and Floodplains, describes the floodplain within the study areas, which is considered a previously developed area within Minimal Wave Action Zone of Land Subject to Coastal Storm Flowage (LSCSF). 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.

Fluctuations in sea levels and storm surge may affect the horizontal and vertical extent of coastal inundation—even if it does not affect the LSCSF regulatory boundary.

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.

4.21.2.5 Transportation

Section 4.2, Transportation, Traffic, and Safety, identifies the affected environment for transportation, traffic, and safety, 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.[12]

Sea Levels and Storm Surge

Coastal inundation from storm surge 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, and cars can be swept away in only two feet of moving water.[13] During flood events, most casualties are caused by vehicles when drivers attempt to drive along flooded roads. Coastal flooding from storm surge events may result in damage to existing roadways, particularly in areas of channelized flow. Elevated sea levels increase the horizontal and vertical extent of the inundated area.

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. These events can also reduce pavement strength and result in roadway washouts of varying magnitudes.

Extreme Heat

Warmer temperatures lead to higher asphalt-concrete pavement temperatures, which affect materials durability distress and fatigue cracking.[14] 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.

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

[13] https://www.mass.gov/info-details/flood-safety-tips

[14] 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

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.[15]

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 effects.[16]

4.21.2.6 Mobility

Section 4.3, Pedestrian and Bicycle Facilities, identifies the affected environment for pedestrian and bicycles facilities.

Sea Levels and Storm Surge

Coastal inundation from storm surge 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.[17] Coastal inundation can also reduce pavement strength and result in washouts of varying magnitudes. Elevated sea levels increase the horizontal and vertical extent of the inundated area.

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.[18] These events can also reduce pavement strength and result in washouts of varying magnitudes.

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.[19] Extreme heat may reduce material stability, particularly

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

[16] 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/

[17] https://www.mass.gov/info-details/flood-safety-tips

[18] https://www.mass.gov/info-details/flood-safety-tips

[19] 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

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.

4.21.3 No Build Alternative

This section reflects No Build Alternative impacts with current and future conditions based on methodology and affected area described in previous sections. **Table 4.21-12** summarizes the No Build Alternative impacts on the affected environment.

Table 4.21-12. No Build Alternative Impacts

Affected Environment	Sea Levels and Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
Canal	Navigational clearance	NA	NA	NA	NA
Bridge	NA	NA	No Impact	Icing on Members	Aerodynamic Stability
Stormwater Control Measures	Submerged/partially submerged outfalls*	Refer to **Section 4.10, Water Quality and Stormwater**	NA	NA	NA
Land Cover	No impact to floodplain function	NA. Refer to **Section 4.10, Water Quality and Stormwater**	No Impact	NA	NA
Transportation	Roadways and evacuation route flooding	NA. Refer to **Section 4.10, Water Quality and Stormwater**	Pavement performance	Snow and Ice	Vehicle Rollover
Mobility	Shared-use path flooding	NA. Refer to **Section 4.10, Water Quality and Stormwater**	Active Transportation Use	NA	NA

NA = not assessed for affected environment.

* Outfalls are within the Study Areas shown in **Figure 4.21-1**, but are not part of the Program; they were assessed due to their impact on stormwater systems (flooding and performance) within the Study Areas.

4.21.3.1 Cape Cod Canal

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

Sea Levels and Navigational Clearance

Under the No Build Alternative, fluctuations in sea level elevation would affect the ability to meet the required 138.3-foot vertical navigational operational clearance through Cape Cod Canal.[20] The approximate low chord elevations would provide an approximate 137-foot clearance for both structures with existing MHHW.

4.21.3.2 Bridge

Under the No Build Alternative, the bridges' decks, superstructures, and substructures would remain as-is.

Sea Levels and Bridge Pier Scour

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

Extreme Heat and Bridge Joint Expansion

The highest recorded temperature over the past 100 years at the East Wareham Weather Station was 100 degrees F (1948, 1949, 1975, and 2006). 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. The No Build Alternative is unlikely to be affected by extreme heat.

Winter Weather and Icing

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. The No Build Alternative is likely to remain vulnerable to winter weather, including snow and ice.

Extreme Wind and Aerodynamic Stability

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

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[20] There is a third crossing over 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 Areas and the scope for proposed improvements.

spans (i.e. greater than 300 feet) have issues related to deflections due to wind.[21] The No Build Alternative is vulnerable to extreme wind given the bridges' age and truss structure.

4.21.3.3 Stormwater Control Measures

Under the No Build Alternative, the stormwater control measures, including existing infiltration basins, piped infrastructure, and outfalls, would remain as-is.

Sea Levels and Submerged and Partially Submerged Outfalls

There are no tide gates or backflow preventers on the outfalls that discharge stormwater to Cape Cod Canal. The No Build Alternative would enable high tides and storm surges 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. The Bourne North quadrant outfall structure is very vulnerable to fluctuating sea level elevations. Current tidal datums restrict flow during high tide with the outfall approximately 50% submerged.

Stormwater Control Measure Performance and Extreme Precipitation

Section 4.10, Water Quality and Stormwater, discusses impacts to stormwater control measures from extreme precipitation under the No Build Alternative.

4.21.3.4 Land Cover

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

Storm Surge and Land Subject to Coastal Storm Flowage Function

Figure 4.21-2 and **Figure 4.21-3**, respectively, show the extent of overland coastal surge for the No Build Alternative for the Sagamore Bridge and Bourne Bridge Study Areas. **Figure 4.21-4** illustrates the existing flood pathways at the Bourne North quadrant near Belmont Circle. The vertical and horizontal extent of inundations changes slightly between the FEMA 100-year event and a Category 2 Hurricane with 3 feet freeboard. **Section 4.9, Wetlands and Floodplains**, discusses additional discussions of impacts to floodplains from the No Build Alternative.

Extreme Precipitation and Localized Stormwater Flooding

Section 4.10, Water Quality and Stormwater, discusses impacts to localized flooding from impervious surfaces and extreme precipitation under the No Build Alternative.

Extreme Heat and Surface Temperatures

Under the No Build Alternative, the land cover (impervious surfaces) would remain as-is. **Figure 4.21-5** and **Figure 4.21-6** illustrate the existing impervious surfaces within the Study Areas based on the 2016 land cover dataset hosted by the Massachusetts Office of Energy and Environmental Affairs.

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

Table 4.21-13 summarizes the impervious surface area with the Sagamore Bridge and Bourne Bridge Study Areas.

Table 4.21-13. No Build Alternative: Impervious Area within Sagamore Bridge and Bourne Bridge Study Areas

Study Area	Project Limits (acres)	Roadway Surface Area (acres)[1]	Total Impervious Surface (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%

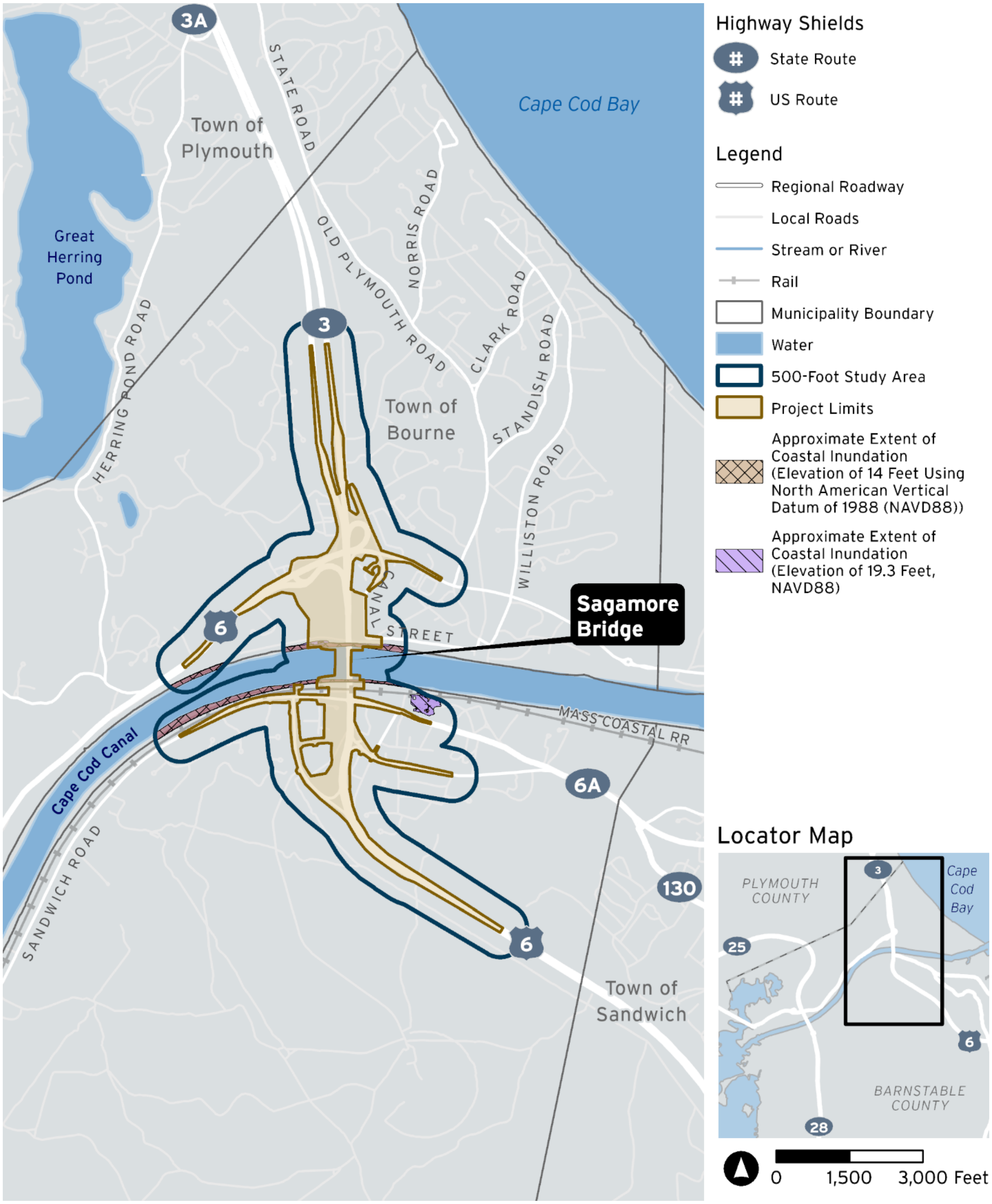
Notes:

[1] The existing roadway surface area based on survey measurements for north and south quadrants of each Study Area as presented in **Section 4.10, 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.

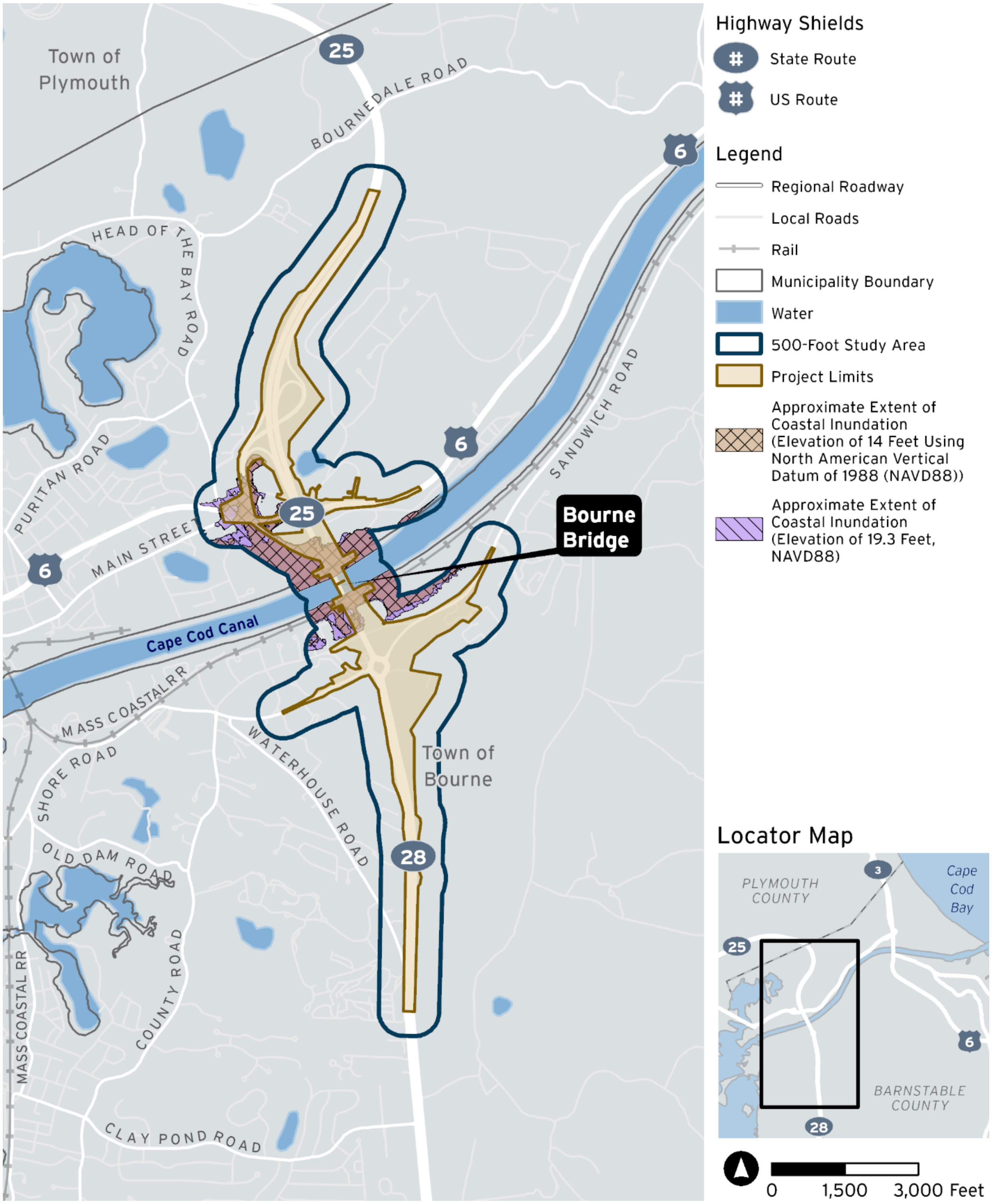
Surface temperature is a function of impervious surfaces, so the No Build Alternative is not assumed to be affected.

Figure 4.21-2. No Build Alternative: Coastal Surge Flood Extents (Sagamore Bridge Study Area)



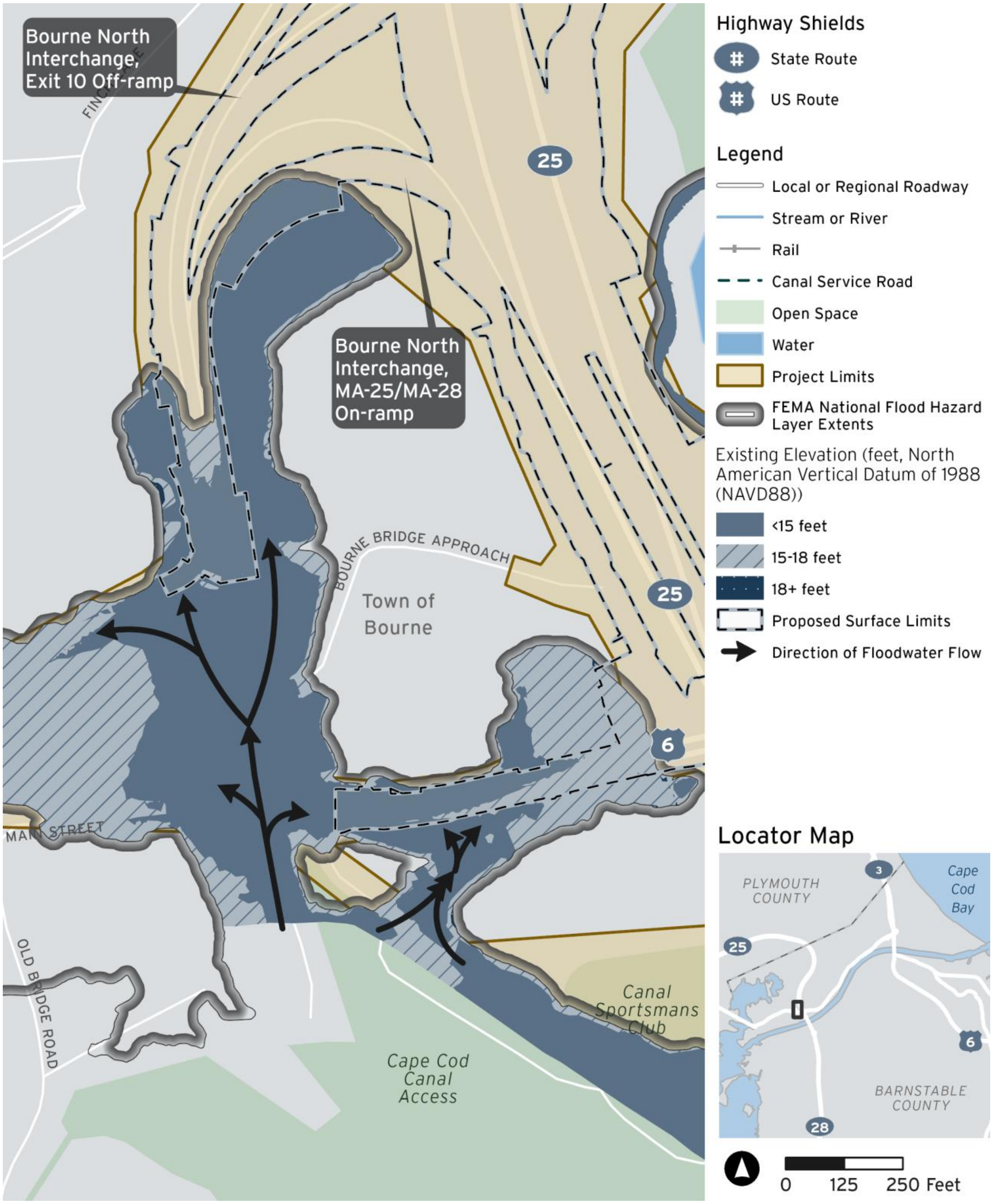
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-3. No Build Alternative: Coastal Surge Flood Extents (Bourne Bridge Study Area)



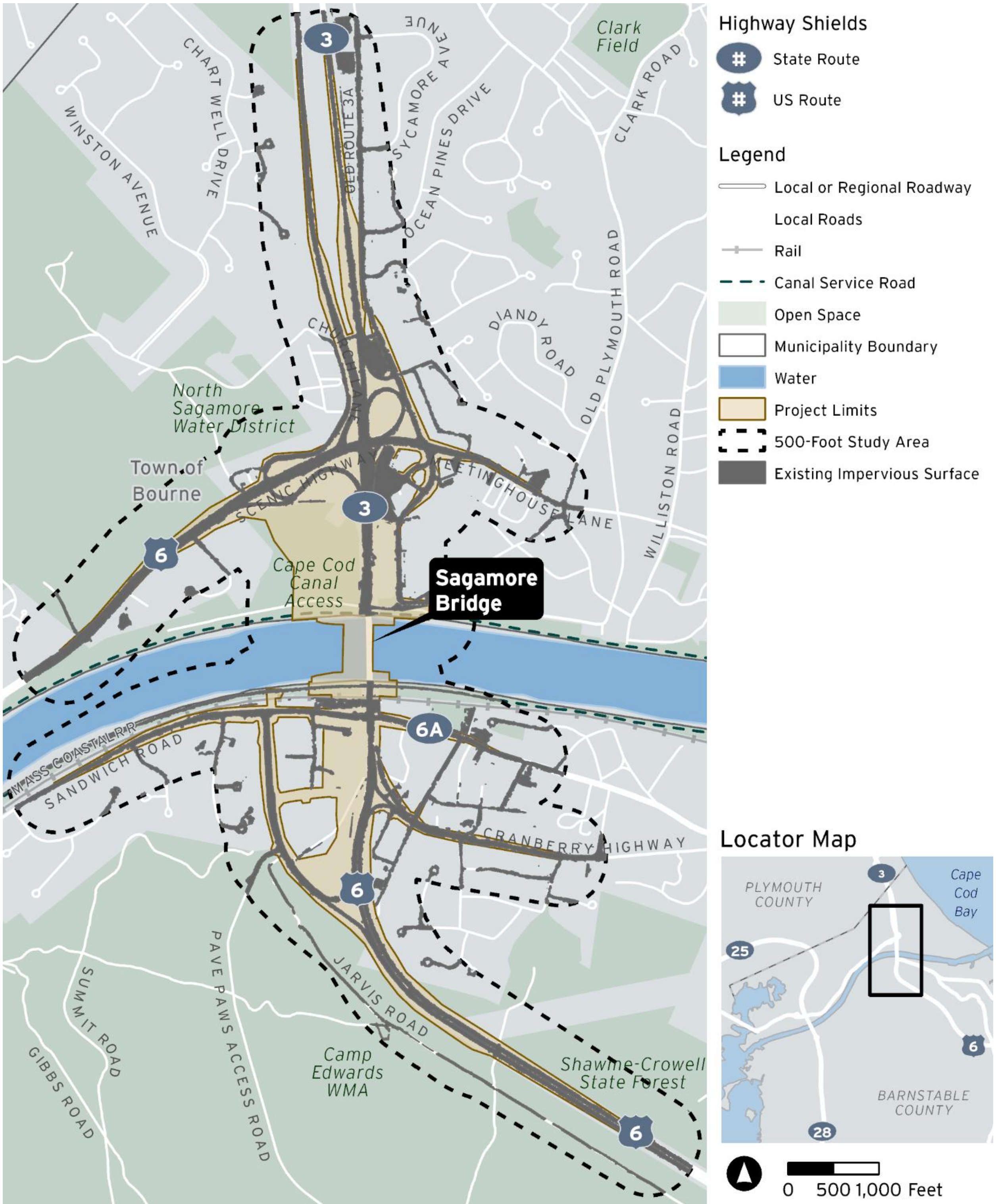
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-4. No Build Alternative: Existing Grading and Flood Pathways (Bourne North Quadrant)



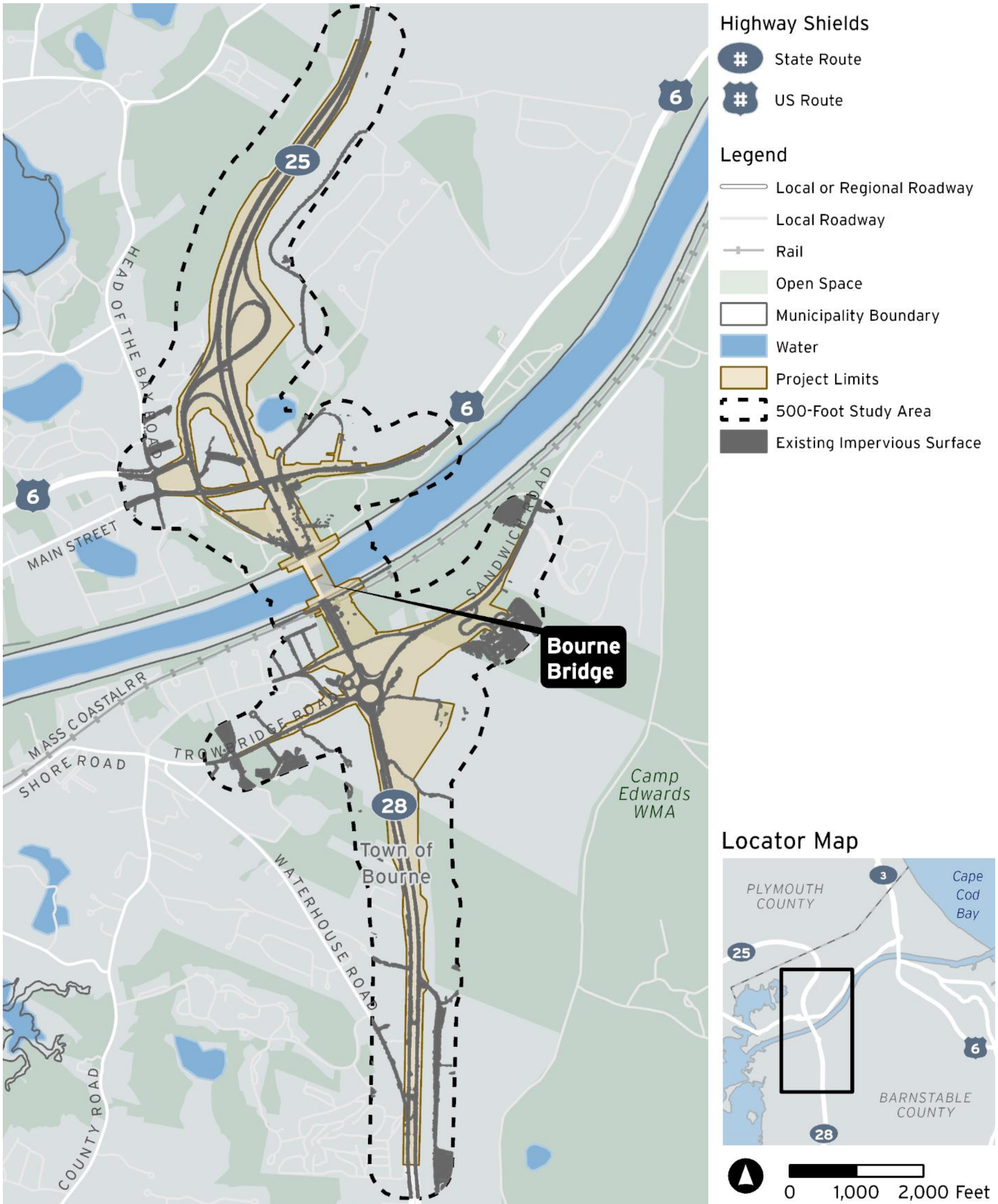
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-5. No Build Alternative: Land Cover – Impervious Surfaces (Sagamore Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

Figure 4.21-6. No Build Alternative: Land Cover – Impervious Surfaces (Bourne Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

4.21.3.5 Transportation

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

Storm Surge and Flooded Roadways and Evacuation Routes

The roadways within the Bourne North quadrant, 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. For the No Build Alternative, the likelihood of flooding and existing conditions would remain 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.[22] Even with this plan, flooding of Belmont Circle would likely affect traffic plans and operations in emergency recovery and for events that do not trigger plan implementation.

Extreme Precipitation and Localized Stormwater Flooding

Section 4.10, Water Quality and Stormwater, discusses impacts to localized flooding from extreme precipitation for the No Build Alternative.

Extreme Heat and Pavement Performance

For the No Build Alternative, it is likely that the performance of the existing pavement would be affected by extreme heat, such as increased prevalence of buckling, rutting, and /or potholes.

Winter Weather and Snow and Ice on Roadways

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

Extreme Wind and Vehicle Rollover Potential

Based on wind climate analysis results, 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.

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

4.21.3.6 Mobility

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

Storm Surge and Flooded Shared-Use Paths

Alternative modes of transportation within the Bourne North quadrant, 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).

Extreme Precipitation and Localized Stormwater Flooding

Section 4.10, Water Quality and Stormwater, discusses impacts to localized flooding from extreme precipitation for the No Build Alternative.

Extreme Heat and Active Transportation Use

In addition to affected pavement performance, it is likely that extreme heat events will affect people who use alternative modes of travel in the No Build Alternative.

4.21.4 Build Alternative

This section reflects Build Alternative impacts with current and future conditions based on the methodology and the affected area described in previous sections. **Table 4.21-14** summarizes the Build Alternative impacts on the affected environment.

Table 4.21-14. Build Alternative Impacts

Affected Environment	Sea Levels and Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
Canal	No impact	NA	NA	NA	NA
Bridge	No impact*	NA	No impact	Reduced Impact	No impact
Stormwater Control Measures	Submerged/ partially submerged outfalls** Infiltration basin flooding	No impact. Refer to **Section 4.10, Water Quality and Stormwater**.	NA	NA	NA
Land Cover	No impact	No impact. Refer to **Section 4.10, Water Quality and Stormwater**.	Surface temperature	NA	NA

Affected Environment	Sea Levels and Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
Transportation	Reduced impact – flooding	No impact. Refer to **Section 4.10, Water Quality and Stormwater**.	Reduced impact	Reduced impact	Vehicle Rollover
Mobility	Reduced impact - Flooding	No impact. Refer to **Section 4.10, Water Quality and Stormwater**.	Active Transportation Use	NA	NA

Notes:

NA = 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 Areas shown in **Figure 4.21-1**, but are not part of the Program; they were assessed due to their impact on stormwater systems (flooding and performance) within the Study Area.

4.21.4.1 Cape Cod Canal

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

Sea Levels and Navigational Clearance

The Build Alternative would raise the elevation of the replacement bridges to establish a vertical clearance of 138.3 feet under existing MHHW; therefore, the Build Alternative would be unlikely to affect navigational clearance.

4.21.4.2 Bridge

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

Sea Levels and Bridge Pier Scour

MassDOT calculated maximum scour depths for design and check events (200-year and 500-year, respectively, in accordance with FHWA HEC-18). The foundations of the Build Alternative would be designed to remain stable during the maximum scour design and check events; therefore, the Build Alternative for Sagamore Bridge would unlikely be affected by scour. This assessment will be updated in the Final Environmental Impact Statement (FEIS) once Bourne Bridge is analyzed.

Extreme Heat and Bridge Joint Expansion

Design practices and standards for new bridges include limiting the number of bridge expansion joints. Extreme heat is unlikely to affect the bridge joints in the Build Alternative.

Winter Weather and Icing

The Build Alternative would be designed for a 1-inch combined ice and wet snow thickness, which corresponds with a 500-year event, using mitigation measures as described in **Section 4.21.5.**

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

Extreme Wind and Aerodynamic Stability

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; as such, extreme wind events would unlikely affect the replacement bridges.

4.21.4.3 Stormwater Control Measures

Under the Build Alternative, new infiltrations basins are proposed, including piped infrastructure to connect to the existing stormwater system. Existing piped infrastructure and outfalls would remain as-is.

Sea Levels and Submerged and Partially Submerged Outfalls

Because there are no tide gates or backflow preventers on the outfalls that discharge stormwater to the canal, the impacts of the Build Alternative would be the same as the No Build Alternative. Refer to **Section 4.21.3.3**.

Storm Surge and Infiltration Basins

The Build Alternative would include 24 new infiltration basins to manage stormwater quality and volumes; five were identified as potentially vulnerable to storm surge. **Table 4.21-15** summarizes the Build Alternative infiltration basins where the basin elevations would be exceeded by storm events. Refer to **Section 4.10, Water Quality and Stormwater (Figures 4-10.9 through 4-10.12),** for locations of the infiltration basins.

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

Table 4.21-15. Build Alternative: Potentially Affected Infiltration Basins

Infiltration Basin ID	Basin Bottom (feet-NAVD88)	Overflow Outlet (feet-NAVD88)	Basin Top (feet-NAVD88)	Potential Inundation Impact
SCM-SS01	13	TBD	21	• FEMA 100-year (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 • CAT 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 • CAT 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 – 15	TBD	18	• FEMA 100-year (El. 16): Exceeds bottom of basin • CAT 2 + 3 feet (El. 19.3): Exceeds top of basin

FEMA = Federal Emergency Management Agency, NAVD88 = North American Vertical Datum of 1988; SCM = stormwater control measures, CAT = Hurricane Category

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

Extreme Precipitation and Stormwater Control Measure Performance

Stormwater control measures would function as intended with 500-year, 24-hour rainfall event under the Build Alternative as described in **Section 4.10, Water Quality and Stormwater**. The infiltration basins' performance may be altered under scenarios where tidal datums would exceed the outfall invert elevation (refer to **Table 4.21-15**). 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 is able to infiltrate or discharge through the outfall. As such, extreme rainfall events with temporarily submerged outfalls would unlikely affect the proposed stormwater control measures.

4.21.4.4 Land Cover

Under the Build Alternative, the land cover, resource areas, and land use would change as described in **Section 4.9, Wetlands and Floodplains,** and **Section 4.6, Land Use, Zoning, and Community Cohesion.**

Storm Surge and Land Subject to Coastal Storm Flowage Function

Figure 4.21-7 and **Figure 4.21-8** show the extent of overland coastal surge for the Build Alternative. These figures also identify areas where changes to site grading and topography are proposed below the associated storm surge elevations. The extent of overland coastal surge for the Build Alternative for Sagamore Bridge would be the same as the No Build Alternative (**Figure 4.21-2**) because there would be no proposed changes to grading within the flood extents. The extent of overland coastal surge for Bourne Bridge for the Build Alternative (**Figure 4.21-7** and **Figure 4.21-8**) would be the same as the No Build Alternative (**Figure 4.21-3**), with the exception of the Bourne North quadrant, where the proposed grade changes near Belmont Circle would accommodate the higher bridge deck elevation spanning the Cape Cod Canal to maintain navigational clearance and connect to existing grades. **Figure 4.21-9** 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 4.21-4**).

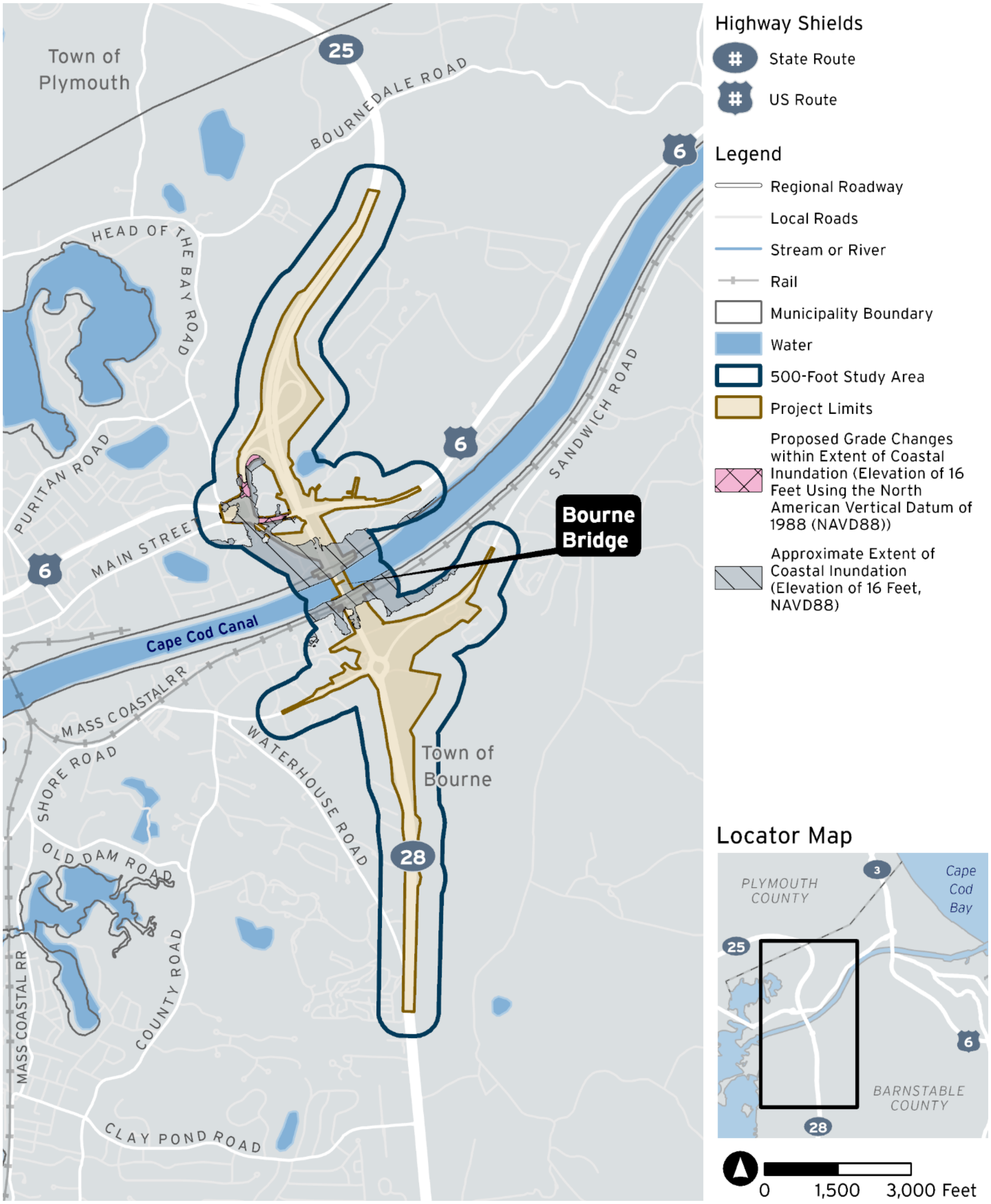
MassDOT took five cross-sections where grade changes are proposed on the ramps and along U.S. Route 6 (**Figure 4.21-10**) to assess potential impacts to flow velocities. **Figure 4.21-11 through Figure 4.21-15** show the cross-sections, which depict the following:

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

The cross-sections on U.S. Route 6 at 701+50 (**Figure 4.21-11**) and 704+50 (**Figure 4.21-12**) 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 4.21-13**) and 104+00 (**Figure 4.21-14**) are subject to parallel flood pathways, and the cross-section on the eastbound ramp at 405+00 (**Figure 4.21-15**) is subject to perpendicular flows where the water travels right to left.

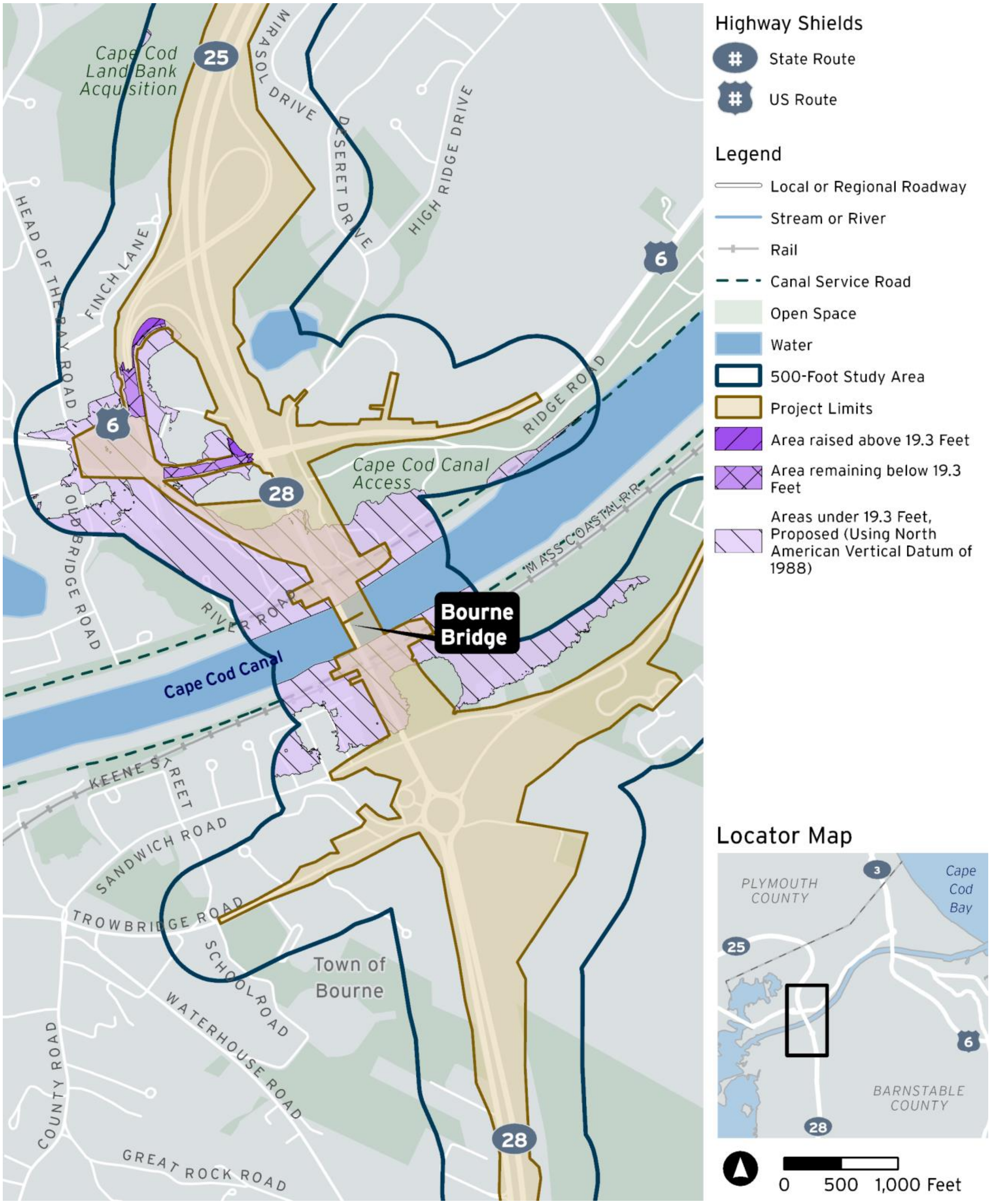
These cross-sections illustrate that the Build Alternative for U.S. Route 6, including changes to landcover and grading, would not likely create channelized flow conditions within the extent of mapped inundation. The proposed changes to the westbound ramps for the Build Alternative would include the 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 would 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 would have already crossed developed areas and the existing wetland; therefore, the changes to land cover from the eastbound ramp are not anticipated to have an impact on the LSCSF functions.

Figure 4.21-7. Build Alternative: Coastal Surge Flood Extents – Existing 100-year Floodplain (Bourne Bridge Study Area)



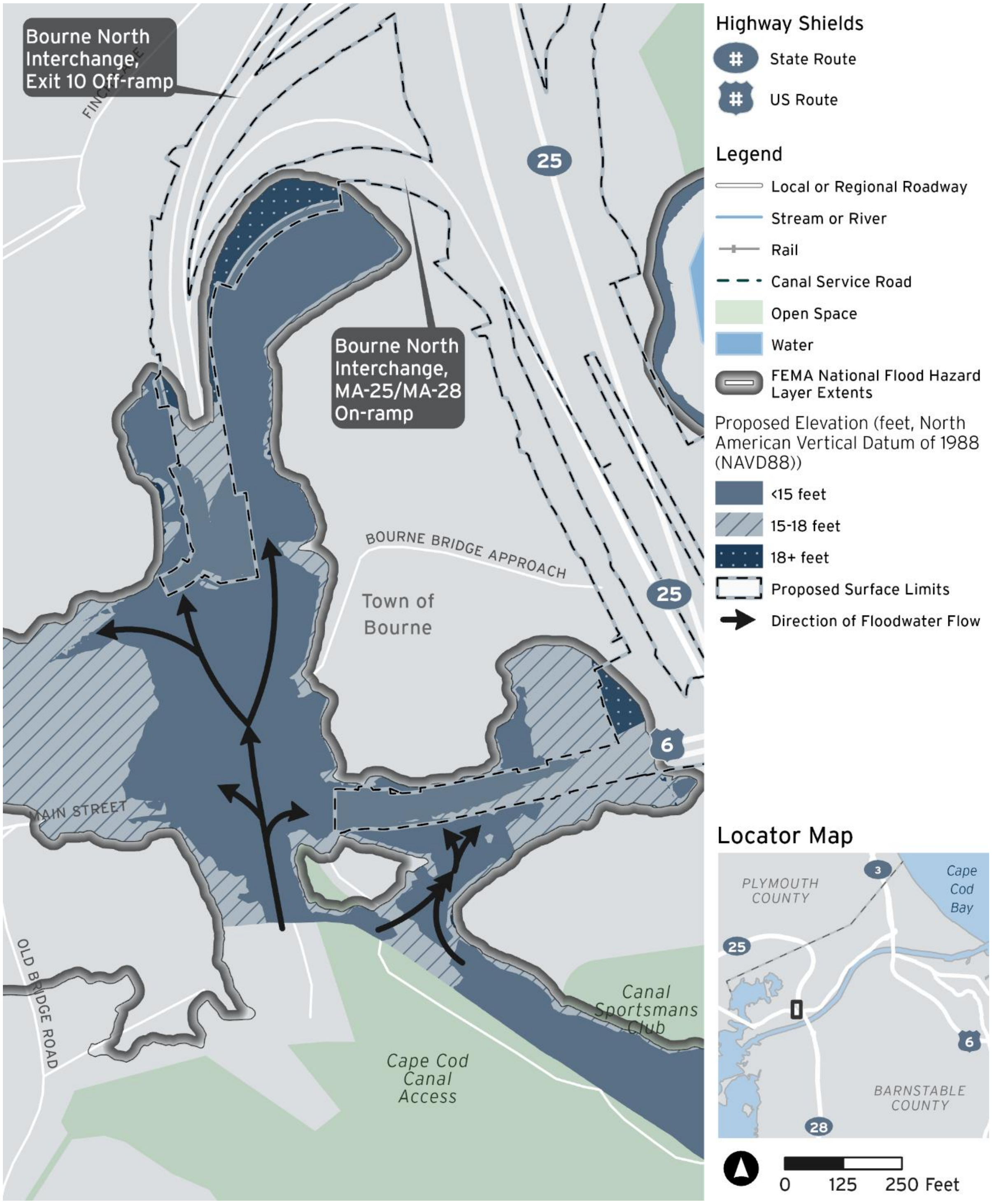
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-8. Build Alternative: Coastal Surge Flood Extents – Category 2 Hurricane + 3 feet Freeboard (Bourne Bridge Study Area)



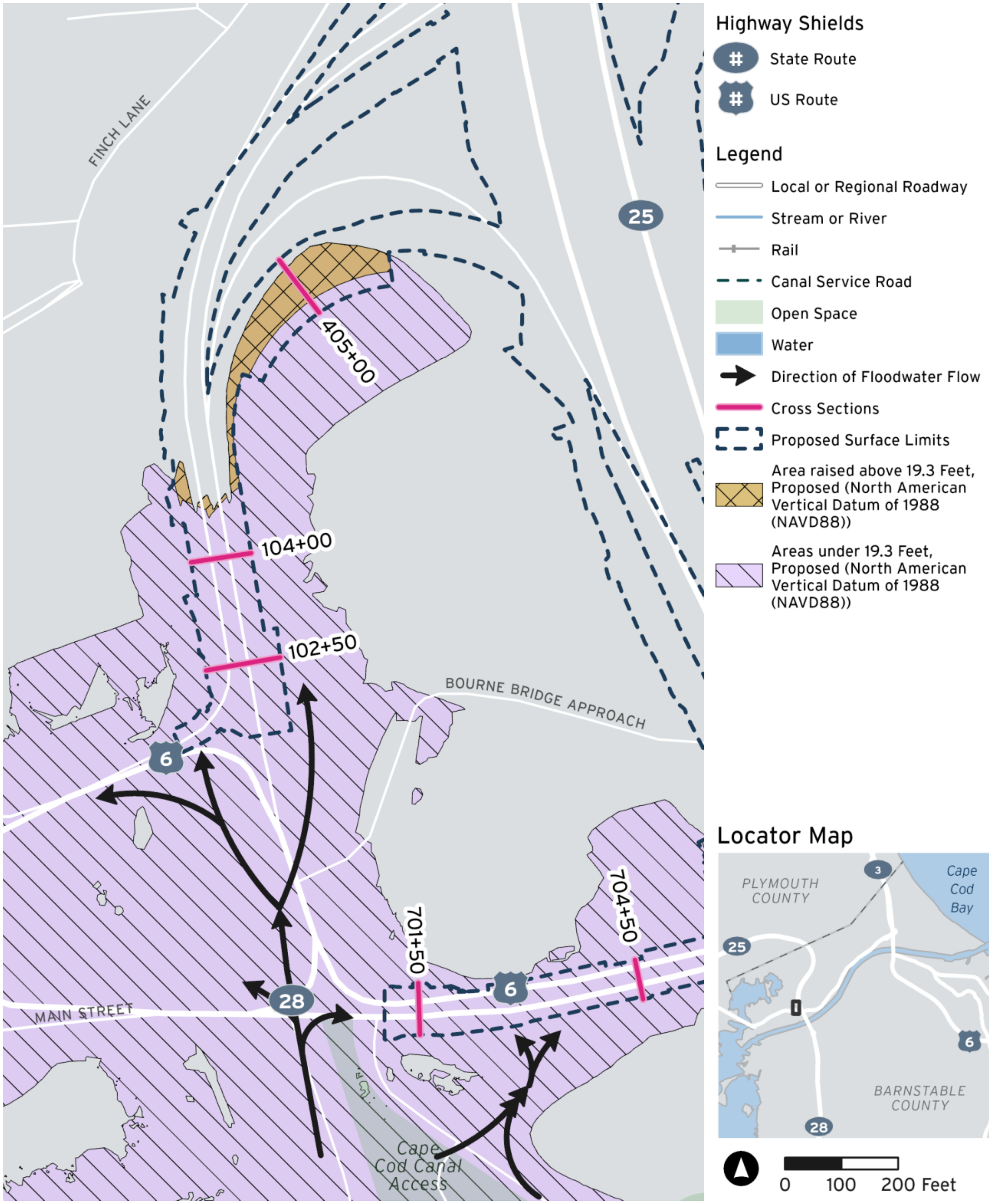
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-9. Build Alternative: Proposed Grading and Flood Pathways (Bourne North Quadrant)



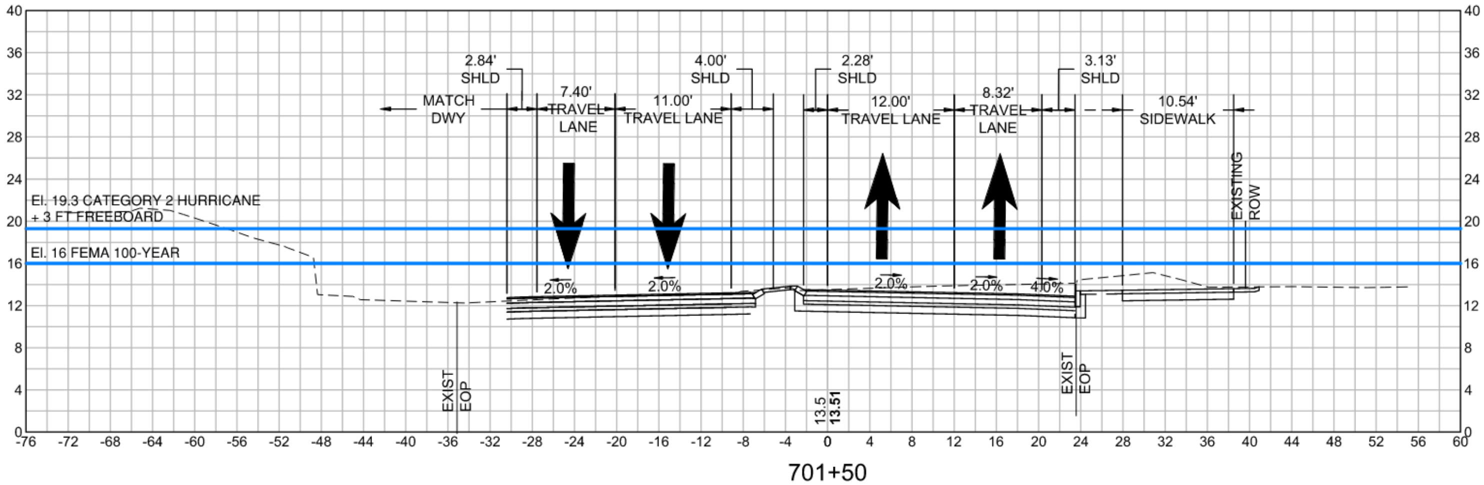
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-10. Build Alternative: Cross-Section Reference for Bourne North Quadrant Grading Plan



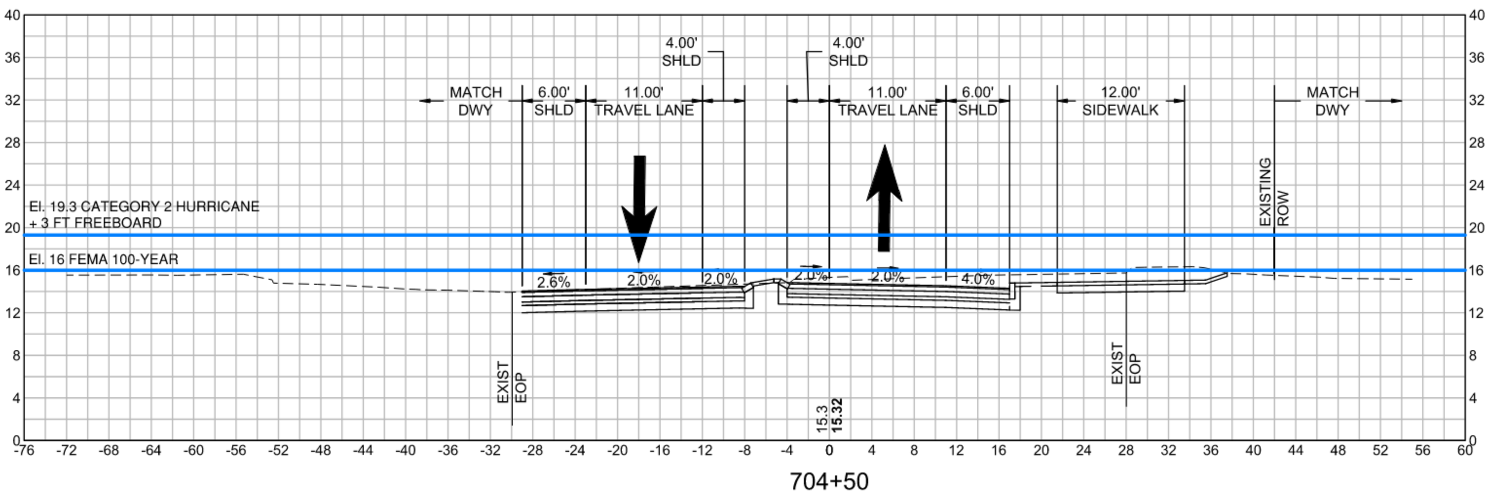
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-11. Build Alternative: Cross-Section U.S. Route 6: 701+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



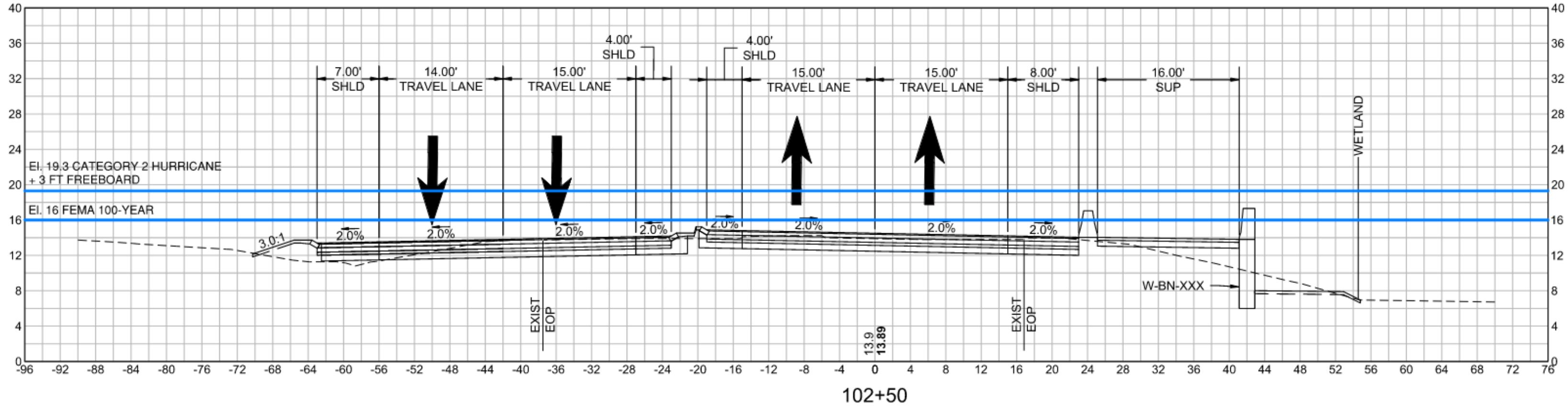
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-12. Build Alternative: Cross-Section U.S. Route 6: 704+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



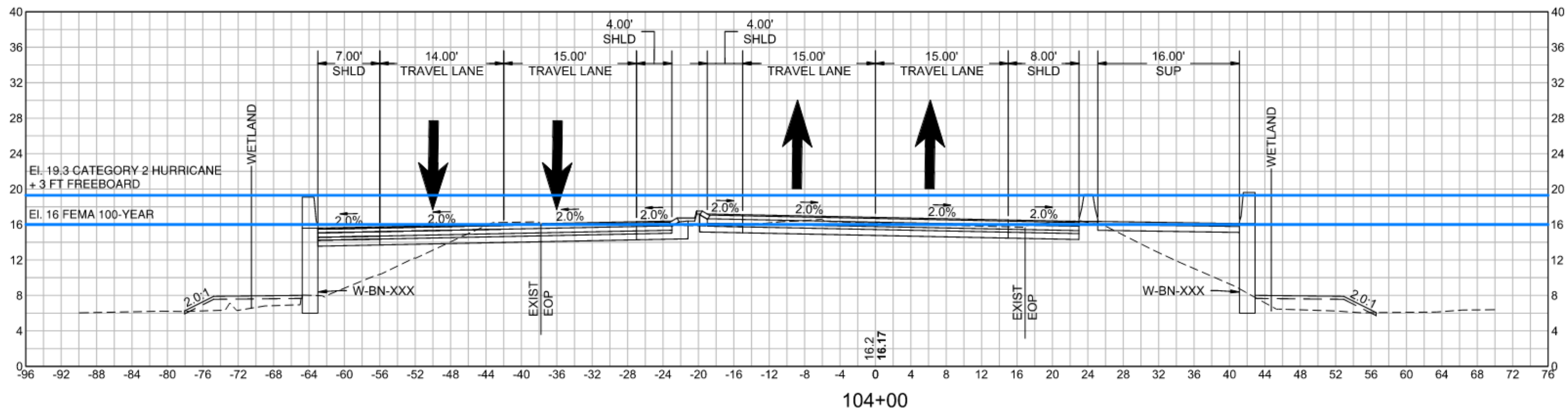
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-13. Build Alternative: Cross-Section Westbound On- and Off-Ramps: 102+50, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



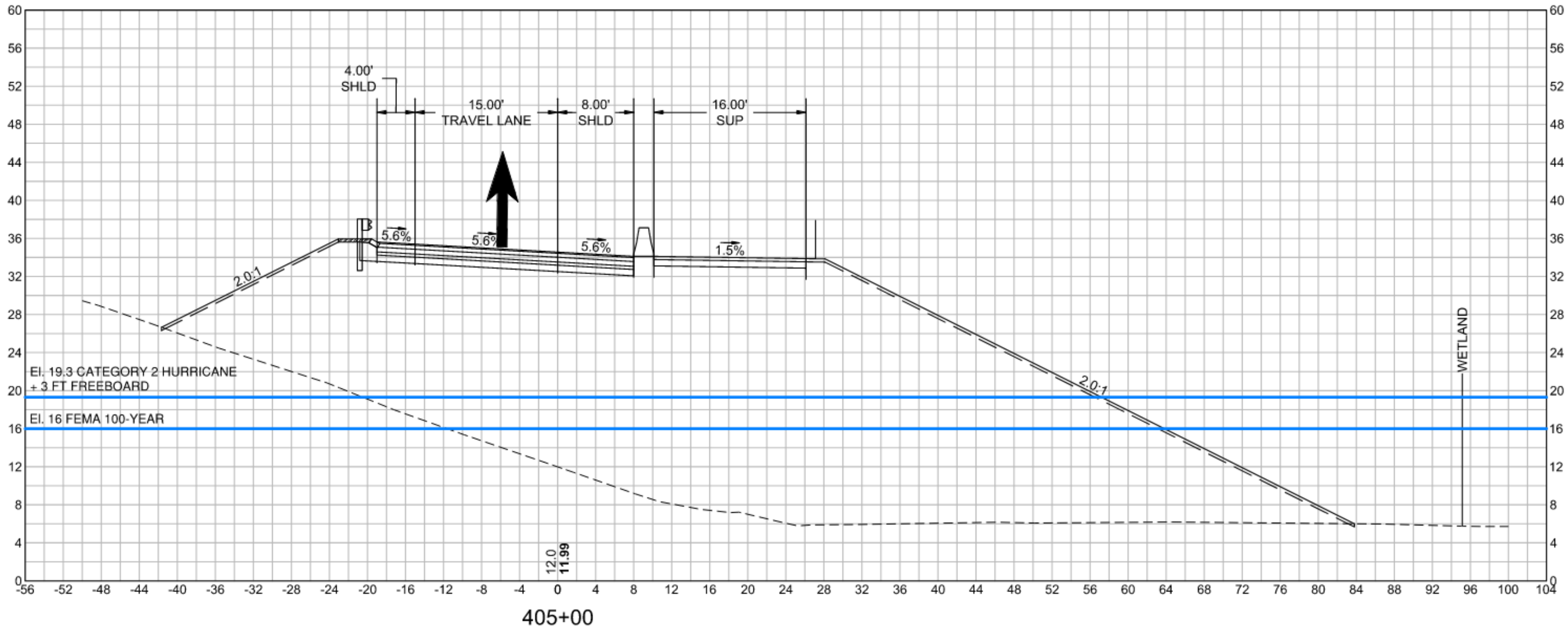
Source: Massachusetts Department of Transportation, 2024

Figure 4.21-14. Build Alternative: Cross-Section Westbound On- and Off-Ramps: 104+00, Proposed Grading, Impervious Surfaces, and Coastal Surge Flood Extents (Bourne North Quadrant)



Source: Massachusetts Department of Transportation, 2024

Figure 4.21-15. 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

Extreme Precipitation and Localized Stormwater Flooding

Stormwater control measures function as intended for the Build Alternative; as such, localized flooding as a result of impervious surfaces and extreme precipitation will be mitigated through the proposed stormwater control measures presented in **Section 4.10, Water Quality and Stormwater**.

Extreme Heat and Surface Temperatures

The Build Alternative would result in an increase in impervious area across the Study Areas of 50.9 acres, and therefore an increase in level of stormwater treatment required, compared to existing conditions as described in **Section 4.10.6.** The proposed increase in impervious areas would increase the total impervious surface (**Table 4.21-16**), however the final impervious area percentage would still be less than 50% for the Build Alternative. As described in **Section 4.21.5**, MassDOT is developing landscaping plans that may offset the increase in impervious surfaces.

Table 4.21-16. Build Alternative: Impervious Surface Area within Study Areas

Study Area	Impervious Surface Area Increase (acres)[1]	Percentage Impervious[2]
Sagamore Bridge	+ 25.3	49%
Bourne Bridge	+ 25.6	39%

[1] Increase in impervious surface area based on **Section 4.10.6**.

[2] Increase from No Build Alternative of 36.4% (Sagamore Bridge) and 29.5% (Bourne Bridge)

4.21.4.5 Transportation

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

Storm Surge and Flooded Roadways and Evacuation Routes

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.[23] The Build Alternative would facilitate emergency egress of high traffic volumes from Cape Cod in the event of a hurricane or other potential hazards by replacing Bourne Rotary with a grade-separated diamond interchange and constructing 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.

While flooding of Belmont Circle has at least a 1% annual likelihood of flooding (or a 1-in-4 chance of flooding over 30 years), the Build Alternative would increase the adaptive capacity of the network to

[23] 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 Build Alternative.

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.

Extreme Precipitation and Localized Stormwater Flooding

Stormwater control measures would function as intended for the Build Alternative; as such, localized flooding as a result of impervious surfaces and extreme precipitation will be mitigated through the proposed stormwater control measures presented in **Section 4.10, Water Quality and Stormwater.**

Extreme Heat and Pavement Performance

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 under the Build Alternative would still affect the performance of the pavement, but to a lesser degree than the No Build Alternative.

Winter Weather and Snow and Ice on Roadways

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

Extreme Wind and Vehicle Rollover Potential

For the Build Alternative, the impact from extreme wind and vehicle rollover potential would be the same as the No Build Alternative.

4.21.4.6 Mobility

Under 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.**

Storm Surge and Flooded Shared-Use Paths

Alternative modes of transportation within the Bourne North quadrant, in particular, 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.

Extreme Precipitation and Localized Stormwater Flooding

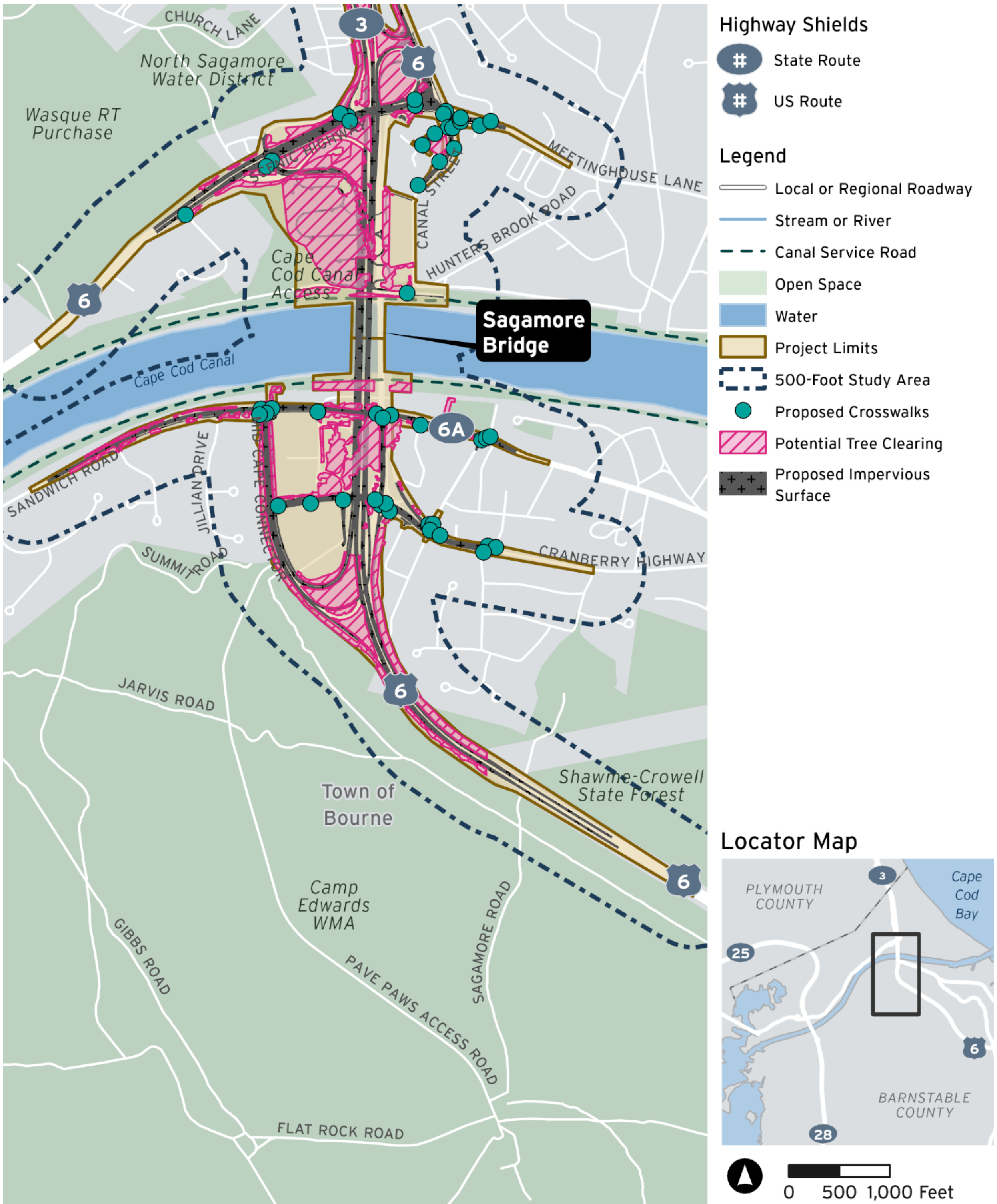
Stormwater control measures would function as intended for the Build Alternative; as such, localized flooding as a result of impervious surfaces and extreme precipitation will be mitigated through the proposed stormwater control measures presented in **Section 4.10, Water Quality and Stormwater.**

Extreme Heat and Active Transportation Use

Extreme heat events and lack of shade are likely to affect people who use alternative modes of travel proposed in the Build Alternative. 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 are exposed while waiting to cross.

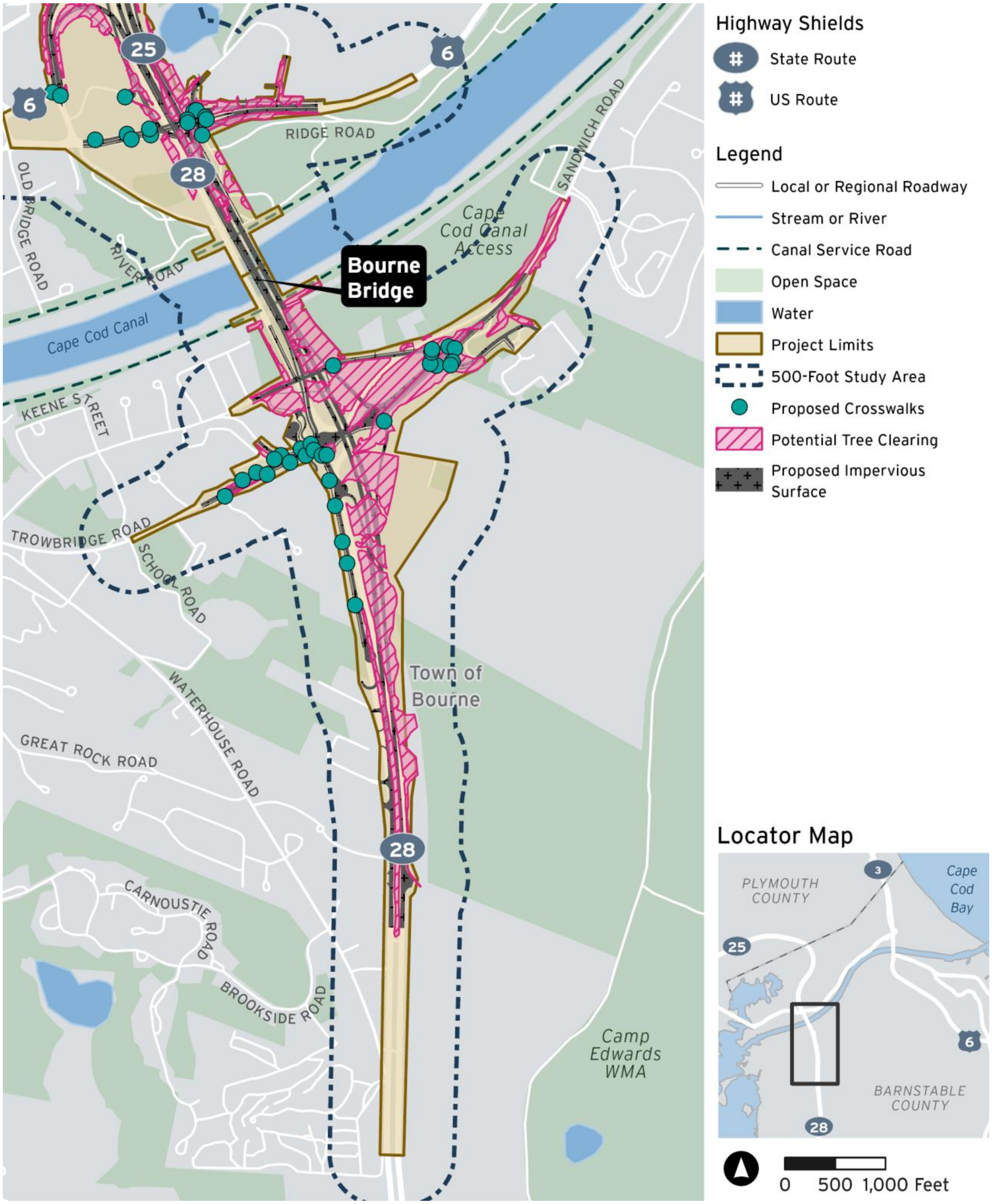
For Sagamore Bridge, these locations would likely include the shared-use path from Scenic Highway to the Canal Service Road, and cross connections from Cranberry Highway, Sandwich Road (State Route 6A) (**Figure 4.21-16**). For Bourne Bridge, these locations would generally be in the area of the replacement 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 4.21-17**).

Figure 4.21-16. Build Alternative: Impervious Surfaces, Tree Clearing, and Crosswalks (Sagamore Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

Figure 4.21-17. Build Alternative: Impervious Surfaces, Tree Clearing, and Crosswalks (Bourne Bridge Study Area)



Source: Massachusetts Department of Transportation, 2024

4.21.5 Mitigation

This section discusses proposed measures beyond standard design best practices to mitigate Build Alternative impacts on affected environments.

4.21.5.1 Cape Cod Canal

Sea Levels and Navigational Clearance

No mitigation will be required.

4.21.5.2 Bridge

Sea Levels and Bridge Pier Scour

No mitigation will be required for Sagamore Bridge. Because MassDOT has not performed the Bourne Bridge scour analyses, the need for mitigation has not been assessed. If mitigation will be required for Bourne Bridge, the mitigation measures will be described in the FEIS.

Extreme Heat and Bridge Joint Expansion

No mitigation will be required.

Winter Weather and Icing

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. MassDOT will detail these measures as designs advance, where appropriate, in accordance with best practices.

Extreme Wind and Aerodynamic Stability

No mitigation will be required.

4.21.5.3 Stormwater Control Measures

Section 4.10.7 describes the stormwater mitigation measures, which would function as intended with the 500-year, 24-hour rainfall event under the Build Alternative. As such, localized flooding will be mitigated.

Sea Levels and Submerged and Partially Submerged Outfalls

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

Storm Surge and Infiltration Basins

The siting and elevations (bottom, overflow, and top) of stormwater infiltration basins proposed for water quality and stormwater mitigation in **Section 4.10.7** will seek to reduce risk of inundation through piped infrastructure and from overland flows.

Extreme Precipitation and Stormwater Control Measure Performance

No mitigation will be required beyond what is proposed in **Section 4.10.7**.

4.21.5.4 Land Cover

Section 4.9, Wetlands and Floodplains, and **Section 4.6, Land Use, Zoning, and Community Cohesion**, describe the land cover mitigation measures.

Storm Surge and Land Subject to Coastal Storm Flowage Function

No mitigation will be required because the Build Alternative would not increase the velocity of moving water, redirect, or channelize flow, but would allow water to spread laterally and landward. Compensatory storage for floodplain volume lost will not be needed because the floodplain is LSCSF. **Section 4.10.7, Water Quality and Stormwater**, and **Section 4.9, Wetlands and Floodplains**, describe strategies that will mitigate the effects of impervious surface on infiltration.

Extreme Precipitation and Localized Stormwater Flooding

No mitigation will be required.

Extreme Heat and Surface Temperatures

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

4.21.5.5 Transportation

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

Storm Surge and Flooded Roadways and Evacuation Routes

While the Build Alternative would reduce the impact of flooded roadways and evacuation routes, the new traffic patterns should be reviewed and the 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.

Extreme Precipitation and Localized Stormwater Flooding

No mitigation will be required.

Extreme Heat and Pavement Performance

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 FEIS.

Winter Weather and Snow and Ice on Roadways

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

Extreme Wind and Vehicle Rollover Potential

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

4.21.5.6 Mobility

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

Storm Surge and Flooded Shared-Use Paths

While the Build Alternative would reduce the impact of flooded shared-use paths and sidewalks, MassDOT will communicate the remaining flood risk in the Bourne North quadrant at Belmont Circle 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.

Extreme Precipitation and Localized Stormwater Flooding

No mitigation will be required.

Extreme Heat and Active Transportation Use

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 would about 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 would not affect road user safety. MassDOT is considering these strategies in conjunction with land use mitigation strategies (e.g., landscaping plans) and will provide more information in the FEIS.