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:

- 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 identifies potential mitigation strategies that the Massachusetts Department of Transportation (MassDOT) is considering to increase resilience. **Table 4.21-1** summarizes the affected environments and the primary risks assessed within the refined Project Limits and Study Areas.

4.21.1.1 Regulatory Context

This section was prepared in accordance with the following federal and Massachusetts regulatory directives and guidance:

- 23 Code of Federal Regulations (CFR) Section 515.7(c)(1) – Risk management plan for bridges on the National Highway System
- 33 CFR 207.2 – Navigation Regulations, Cape Cod Canal
- 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)

Refer to **Appendix 4.21, Adaptation and Resiliency**, for additional regulatory information.

4.21.1.2 Study Areas

The Study Areas consist of the refined construction Project Limits and a 500-foot buffer for the 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. Key data sources and studies include:

- 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]
- NOAA Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model (Version 3 – June 2022)[3]
- U.S. Army Corps of Engineers (USACE), Massachusetts Hurricane Evacuation Study Technical Data Report, Chapter 2 Hazards Analyses (2016)[4]
- USACE, New England Hurricane Evacuation Study Technical Data Report (June 2016)[5]
- Massachusetts Emergency Management Agency, Cape Cod Emergency Traffic Plan (2018)[6]

Detailed methodology, including hazard-specific design criteria tables, inundation scenarios, and data sources, is provided in **Appendix 4.21, Adaptation and Resiliency**.

[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://gis.data.mass.gov/maps/a9e9d37e363f434f84b28e791b23398b/about
[4] https://www.nae.usace.army.mil/Portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/MA_Ch%202_Hazards%20Analysis.pdf
[5] https://www.nae.usace.army.mil/portals/74/docs/Topics/HurricaneStudies/2016%20State%20Updates/Massachusetts/New%20England%20Hurricane%20Evacuation%20Study.pdf
[6] https://www.mass.gov/doc/cape-cod-emergency-traffic-plan/download

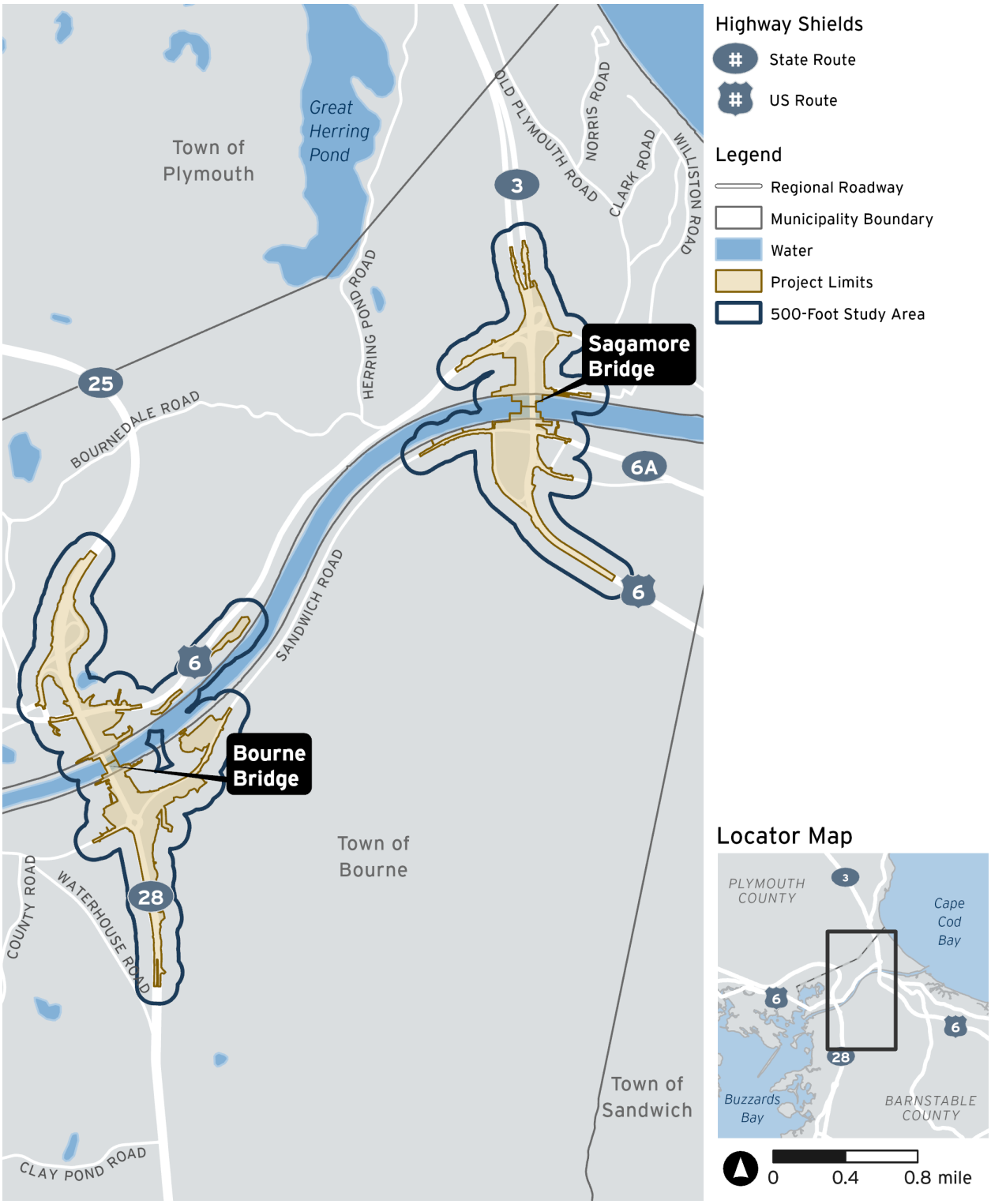
Table 4.21-1. Adaptation and Resiliency Affected Environment

Affected Environment	Related Final 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, 2025

4.21.2 Affected Environment

The affected environment for this section is described in detail in **Appendix 4.21, Adaptation and Resiliency**. A summary by resource area is provided in the following sections.

4.21.2.1 Cape Cod Canal

Section 4.4, Maritime Transportation, Traffic, and Safety, identifies the affected environment for navigation. Cape Cod Canal provides a critical maritime navigation corridor between Buzzards Bay and Cape Cod Bay. The existing Sagamore and Bourne Bridges and the replacement bridges span the canal with approximate low-chord elevations providing approximately 137 feet of clearance under Mean Higher High Water (MHHW), which falls short of the required 138.3-foot vertical navigation clearance.[7]

4.21.2.2 Bridge

Chapter 3, Proposed Action and Alternatives, describes the existing and replacement bridges. The existing Sagamore and Bourne Bridges are steel truss structures designed in the 1930s. Both span over 600 feet across the canal. Due to their age, truss design, and construction-era standards, the existing bridges are susceptible to bridge pier scour, thermal joint expansion, icing of structural members, and aerodynamic instability under extreme wind events. More detailed information is described in **Appendix 4.21, Adaptation and Resiliency**.

4.21.2.3 Stormwater Control Measures

Section 4.10, Water Quality and Stormwater, discusses stormwater control measures. Six existing stormwater outfalls discharge to Cape Cod Canal within the Study Areas. None are equipped with tide gates or backflow preventers. The Bourne North quadrant outfall is particularly vulnerable to tidal influence, with invert elevations as low as 0.36 feet NAVD88 that are approximately 50% submerged at current MHHW. Refer **Appendix 4.21, Adaptation and Resiliency** for outfall inventory data.

4.21.2.4 Land Cover

Land cover is described in 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.

The floodplain within the Study Areas is classified as a previously developed area within the Minimal Wave Action Zone of Land Subject to Coastal Flowage (LSCSF). This resource provides storm damage prevention and flood control functions including dissipating wave energy, receiving and storing coastal

[7]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 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.

floodwaters, allowing lateral flow without channelization, and enabling infiltration. Current impervious surface coverage is 33.0% within the Sagamore Bridge Project Limits and 28.1% within the Bourne Bridge Project Limits.

4.21.2.5 Transportation

Section 4.2, Transportation, Traffic, and Safety, identifies the affected environment for transportation, traffic, and safety. Roadways within the Bourne North quadrant, particularly those through Belmont Circle, are situated within mapped areas of coastal inundation. The Cape Cod Emergency Traffic Plan addresses hurricane evacuation and includes traffic operations to reduce flow to Belmont Circle during emergency events. Existing evacuation routes are vulnerable to coastal inundation, and flooding poses risks to traffic operations and emergency services access.

4.21.2.6 Mobility

Section 4.3, Pedestrian and Bicycle Facilities, identifies the affected environment for pedestrian and bicycles facilities. Shared-use paths and sidewalks within the Bourne North quadrant, particularly those near Belmont Circle, are vulnerable to coastal inundation. Extreme heat also affects users of active transportation infrastructure, and impervious surface coverage contributes to elevated surface temperatures along these corridors..

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 and in more detail in **Appendix 4.21, Adaptation and Resiliency**. **Table 4.21-2** summarizes the No Build Alternative impacts on the affected environment.

Table 4.21-2. 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

Affected Environment	Sea Levels and Storm Surge	Extreme Precipitation	Extreme Heat	Winter Weather	Extreme Wind
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.

Key No Build findings include:

- **Canal:** Fluctuating sea levels would continue to marginally affect the ability of the existing bridges to maintain the 138.3-foot required vertical navigational clearance under MHHW.
- **Bridges:** The existing truss structures would remain vulnerable to icing on structural members and aerodynamic instability due to their age and design. Extreme heat is unlikely to be an impact.
- **Stormwater Control Measures:** Without tide gates or backflow preventers, high tides and storm surge would continue to backflow through the storm drain system; the Bourne North quadrant outfall in particular is at risk. Extreme precipitation impacts are described in **Section 4.10, Water Quality and Stormwater**.
- **Land Cover:** The existing extent and function of LSCSF and mapped floodplains would remain as-is, within no change to flood pathways. Extreme precipitation and impervious surface impacts are addressed in **Section 4.10, Water Quality and Stormwater**.
- **Transportation:** Roadways and evacuation routes through Belmont Circle would remain vulnerable to coastal inundation, with at least a 1% annual likelihood of a coastal flood event. Extreme heat impacts to pavement and winter weather effects on roadway safety would continue.
- **Mobility:** Shared-use paths and sidewalks in the Bourne North quadrant would remain at the same level of flood vulnerability. Extreme heat would continue to affect active transportation users.

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 4.21-3** summarizes the Build Alternative impacts on the affected environment. Detailed analysis is provided in **Appendix 4.21, Adaptation and Resiliency**.

Table 4.21-3. 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
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.

** 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.

Key Build Alternative findings include:

- **Canal:** The replacement bridges would be designed to provide 138.3 feet of vertical clearance under existing MHHW, meeting the required navigational clearance. The Build Alternative is unlikely to impact navigational clearance.
- **Bridges:** The network tied-arch design provides high redundancy and would meet current design standards for scour, thermal expansion, icing, and wind. Scour risk is further addressed through riprap pier protection. Remaining icing risk to cables would be addressed through passive mitigation measures detailed during final design. Extreme heat and extreme wind are not anticipated impacts.

- **Stormwater Control Measures:** Existing outfalls would remain as-is and continue to be susceptible to tidal backflow, consistent with No Build Alternative conditions. The 27 proposed new infiltration basins are generally resilient to coastal inundation; however, seven were identified as potentially vulnerable to storm surge. Backflow preventers are included for these seven basins. Extreme precipitation impacts are addressed in **Section 4.10, Water Quality and Stormwater**.
- **Land Cover:** Proposed grade changes in the Bourne North quadrant would slightly reduce the extent of coastal inundation at the edge of the floodplain but would not affect the flood pathways. Cross-sectional analysis confirms the Build Alternative would not create channelized flow within mapped inundation extents. The Build Alternative would increase total impervious area by approximately 52.3 acres across Project Limits; however, both bridge areas would remain below 50% impervious coverage. Landscaping and vegetation plans would mitigate surface temperature impacts. Extreme precipitation impacts are addressed in **Section 4.10, Water Quality and Stormwater**.
- **Transportation:** The combination of new direct connection ramps from State Route 25 to U.S. Route 6 (Scenic Highway) in the Bourne North quadrant would allow vehicles to bypass Belmont Circle, reducing travel through the mapped coastal inundation area. The replacement of Bourne Rotary with a grade-separated interchange and construction of a new flyover ramp would improve hurricane evacuation capacity. Construction of two separate bridge deck structures would provide service redundancy; however, flooding risk at Belmont Circle would remain. The Cape Cod Emergency Traffic Plan should be updated to reflect new configurations.
- **Mobility**: Cross-canal pedestrian and bicycle lanes would improve evacuation ability for all road users and reduce travel within the extent of inundation. Proposed landscaping along active transportation corridors would mitigate extreme heat impacts.

4.21.5 Mitigation

This section discusses proposed measures beyond standard design best practices. Many impacts under the Build Alternative would be avoided or reduced through the proposed project design, and several are addressed in other sections of this Final Environmental Impact Statement including **Section 4.2, Transportation, Traffic, and Safety**, **Section 4.3, Pedestrian and Bicycle Facilities**, **Section 4.4, Maritime Transportation, Traffic, and Safety**, **Section 4.6, Land Use, Zoning, and Community Cohesion**, **Section 4.9, Wetlands and Floodplains**, and **Section 4.10, Water Quality and Stormwater**. Refer to **Appendix 4.21, Adaptation and Resiliency,** for a full discussion of mitigation.

4.21.5.1 Cape Cod Canal

No mitigation beyond standard design is required. The replacement bridges would be designed to provide 138.3 feet of vertical clearance under existing MHHW, resolving the current navigational clearance shortfall.

4.21.5.2 Bridges

Riprap pier protection along the northern and southern canal banks at Sagamore and Bourne Bridges would address bridge pier scour; no additional scour mitigation is required. No mitigation is required for extreme heat (joint expansion) or extreme wind (aerodynamic stability), as the network tied-arch design meets applicable standards. For winter weather and icing of bridge cables, MassDOT will detail passive mitigation measures during final design, such as modifying cable surface characteristics to reduce ice shedding or incorporating heating cables or exchange pipes in the bridge deck.

4.21.5.3 Stormwater Control Measures

Stormwater mitigation is described in **Section 4.10, Water Quality and Stormwater**. Backflow preventers are not required for the drainage system to function as designed under regular tidal conditions. However, to reduce the risk of backflow into infiltration basins during coastal storm surge events, backflow preventers (in-line check valves at outlet control structures) are included for the seven stormwater control measure infiltration basins identified in **Appendix 4.21, Adaptation and Resiliency,** where surge elevations under a Category 2 Hurricane plus 3-foot freeboard (+19.3 feet NAVD88) would exceed the lowest basin outlet elevation. No additional mitigation is required for extreme precipitation beyond the measures proposed in **Section 4.10, Water Quality and Stormwater**.

4.21.5.4 Land Cover

Land cover mitigation is described in **Section 4.9 Water Quality and Stormwater and Section 4.6, Land Use, Zoning, and Community Cohesion**. No mitigation is required for storm surge and LSCSF function because the Build Alternative would not increase flow velocity or redirect or channelize flow. Since the floodplain is LSCSF, compensatory floodplain storage is not required. Under the Build Alternative, the landscaping and vegetation plan would mitigate the potential intensification of existing extreme heat impacts. No additional mitigation measures are required.

4.21.5.5 Transportation

Transportation mitigation is described in **Section 4.2, Transportation, Traffic, and Safety**. While the Build Alternative would reduce flooding impacts on roadways and evacuation routes, the Cape Cod Emergency Traffic Plan should be updated, as necessary, to reflect new traffic patterns associated with the Build Alternative for both construction phases and program completion, including the remaining flood risk at Belmont Circle. This may include signage and public notices when storms are forecast. No mitigation is required for extreme precipitation or extreme wind.

4.21.5.6 Mobility

Mobility mitigation is described in **Section 4.3, Pedestrian and Bicycle Facilities**. While the Build Alternative would reduce flooding impacts on shared-use paths and sidewalks, MassDOT will communicate remaining flood risk in the Bourne North quadrant at Belmont Circle to the public, which may include National Weather Service safety signage and public notices when storms are forecast. The landscaping and vegetation plan would mitigate extreme heat impacts on active transportation use. No additional mitigation is required.