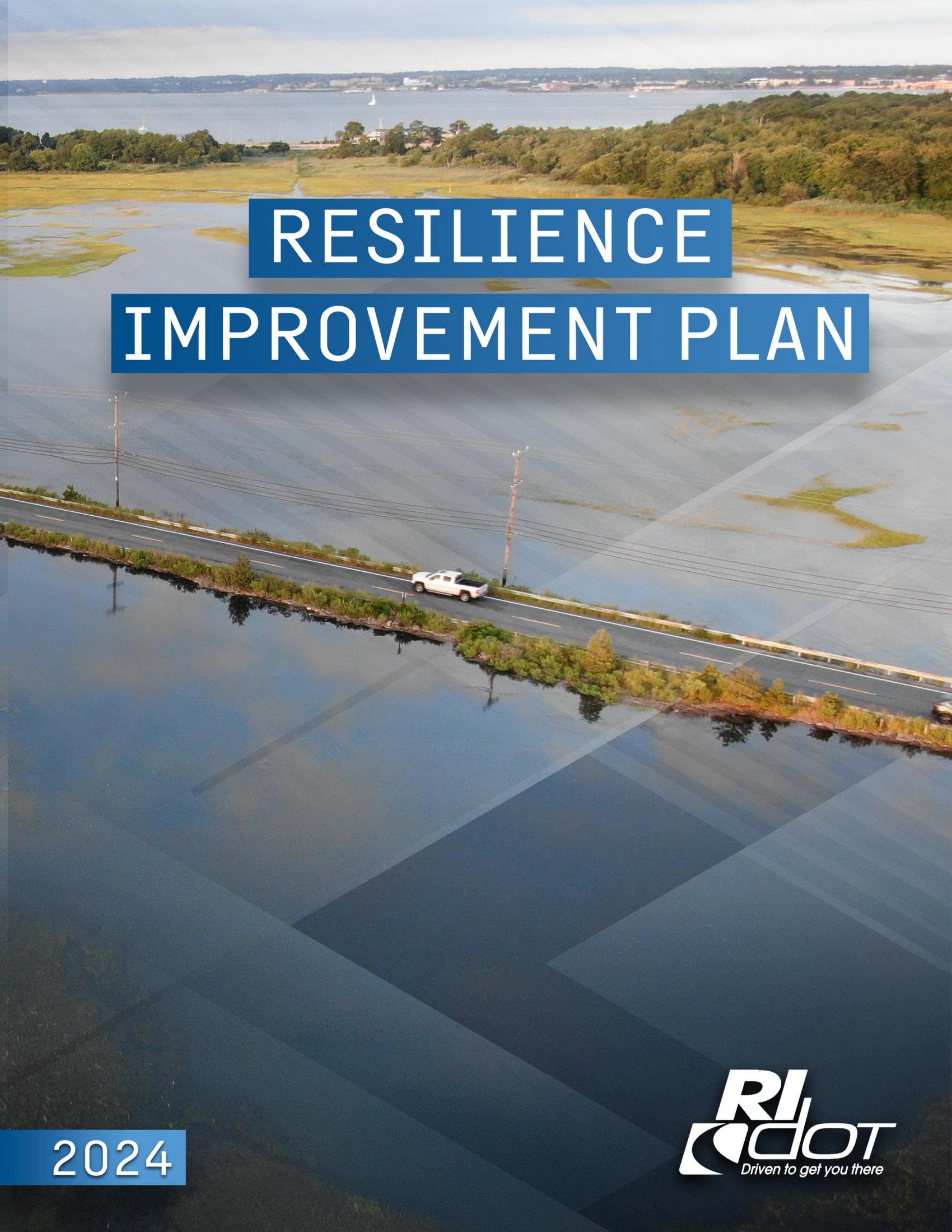

RESILIENCE IMPROVEMENT PLAN

2024

RIDOT
Driven to get you there

Rhode Island Department of Transportation Resilience Improvement Plan

Rhode Island Department of Transportation

date

June 2024

Approved by FHWA: September 16, 2024

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Executive Summary

The transportation infrastructure of Rhode Island is at peril due to climate change and extreme weather events like sea level rise, powerful storms, and flooding both inland and along the shore. They lead to damage to infrastructure, increased maintenance and repair expenses, interruptions of routine transportation system operations, and challenges for transportation project decisions about assets that could potentially be submerged under water or structurally compromised in the next decades. With global temperatures rising and extreme weather occurring more frequently than previously projected, Rhode Island's coastal geography is becoming increasingly prone to related risks. Recognizing the essential role of the state's multimodal transportation system in providing accessibility, mobility, and economic viability for residents of Rhode Island, Rhode Island Department of Transportation (RIDOT) is taking extensive and proactive approaches in planning for the impact of climate change on the state's multimodal transportation system to ensure infrastructure investment decision are made methodically, scientifically, and cost-effectively.

In 2021, Congress passed the Infrastructure Investment and Jobs Act (IIJA) transportation funding bill, which established the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program. The objective of this new program is to help make surface transportation more resilient to natural hazards, including climate change, sea level rise, flooding, extreme weather events, and other natural disasters through support of planning activities, resilience improvements, community resilience and evacuation routes, and at-risk coastal infrastructure. For RIDOT, this provides the opportunity to leverage additional resources to develop a comprehensive policy for managing and integrating resilience into operations .

Building upon the previous effort made by the state and partner agencies in Rhode Island, the Rhode Island Transportation Resilience Improvement Plan (RIP) is designed to fulfill the requirements of the PROTECT program (Table ES.1.1) and it is developed to evaluate transportation infrastructure vulnerabilities and risks to natural and climate stressors, establish resilience strategies, and guide the implementation of resilience projects. The RIP formally establishes a definition for resilience and introduces a framework to guide resilience planning efforts. RIDOT's definition of resiliency is as follows:

Leveraging the latest climate science and data and guided by the risk matrix in the Transportation Asset Management Plan (TAMP), the RIP includes an in-depth criticality assessment and a risk-base vulnerability assessment of the transportation infrastructure owned and/or maintained by RIDOT. The RIP assessed six major asset categories' importance to the unimpeded operation of the transportation system in Rhode Island and evaluates their current and future vulnerabilities to three types of natural hazards determined to pose the greatest risk in Rhode Island by the State Hazard Mitigation Plan (SHMP) and TAMP. The purpose of this process is to identify the most critical and vulnerable components of Rhode Island's transportation infra structure, setting the stage to identify targeted adaptation strategies and implementation needs. As shown in Figure ES.2, the criticality and risk information are combined to help determine where resilience investments are most needed across the RIDOT's multimodal transportation network.

To support decision making, the RIP provides a planning-level estimation of monetized risk of no-action values for each study asset across three different time horizons: 2035, 2050, and 2100.

Study Assets	
Roads	Shared-Use Paths
Bridges	Drainage Pipes
Sidewalks	Stormwater Treatment Units

Study Hazards		
Storm Surge	Sea Level Rise	Flooding

	Requirements	How they are addressed in the RIP	1	2	3	4	5	6	7	8	9
	The plan shall…										
1	Encompass immediate and long-range planning activities and resilience investments	The RIP evaluates current (2024) and future (2035, 2050 and 2100) resilience needs and provides suggestions and guidance on incorporating resilience into the State LRTP and STIP, as well as coordinating with other state plans and planning activities.		x	x	x	x	x	x		x
2	Demonstrate a system-wide approach to transportation system resilience	The RIP analyzes six types of multimodal transportation assets owned and/or maintained by RIDOT transportation system, including roads, bridges, sidewalks, bike paths and drainage infrastructure.		x	x	x	x	x	x		
3	Consistent with and complement State and local hazard mitigation plans	The RIP reviewed the SHMP and uses its hazard priority rankings to guide study hazard selection.				x					

	Requirements	How they are addressed in the RIP	1	2	3	4	5	6	7	8	9
4	Include a risk-based assessment of vulnerability to current and future weather events and natural disasters	The RIP includes a risk-based assessment of transportation assets to storm surge, sea level, rise, and flooding under current (2024) and future (2035, 2050 and 2100) conditions. It considers vulnerability, likelihood, and consequence of potential impact and provides a planning-level estimation of monetized risk of no-action values.				x					
	Shall, as appropriate…										
5	Describe ways to improve response to impacts and changes	The RIP identifies adaptation strategies to help prepare RIDOT's response to the impacts of weather events, natural disasters and is prepared for changing conditions					x	x	x		
6	Describe the codes, standards, and regulatory framework to ensure improvements	Upon acceptance of FHWA, the RIP will be submitted to the State LRTP as an Appendix. The RIP discusses approaches to incorporate resilience into STIP, TAMP, and other state plans.		x					x		
7	Consider benefit of natural Infrastructure	Nature-based/natural solutions are highlighted and discussed as part of the list of strategies.						x			
8	Assess community infrastructure resilience	Community resilience is assessed by including drainage pipelines, and storm water treatments units as part of the study assets, and considering access to health facilities, schools, amongst others in the criticality assessment.			x	x					
9	Use a long-term planning period	The Plan assesses the vulnerability and risk of assets to hazards for a long-term planning period of 2050 and 2100.				x	x		x		
	May also…										
10	Designate evacuation routes and strategies	Evacuation routes are included in Usage and Operational Importance Criticality Factor.									
11	Plan for response to anticipated emergencies	Adaptation strategies are identified to improve operations and emergency Management						x	x		
12	Describe the resilience improvement policies	The RIP describes RIDOT's resilience policy and its importance for resilience implementation.						x	x		
13	Include investment plan & priority projects	The plan includes a project priority list and identifies resilience needs in current STIP projects.						x	x		
14	Use science and data	The assessment in RIP is based on the latest climate science and data.			x	x	x	x			

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illustrates the combined risk on roads and bridges from three study hazards by 2100 if no action is taken to improve resilience.

The RIP also identifies potential adaptation strategies, including nature-based solutions, as well as a framework for evaluating potential projects, and a project list with potential adaptation strategies. These resilience strategies will be integrated into the State Transportation Improvement Program (STIP), State Long Range Transportation Plan (LRTP), and functional thematic areas of RIDOT.

RIDOT recognizes the on-going efforts by municipalities and partner agencies and seeks to collaborate with the appropriate agencies and organizations for information sharing and alignment of resilience strategies. The development of the Rhode Island RIP was supported and guided by targeted and informative stakeholder engagement and communication, including inputs from RIDOT cross-functional team, peer agencies, Federal Highway Administration(FHWA) Division Office, partner agencies such as Rhode Island Emergency Management Agency (RIEMA), Rhode Island Division of Statewide Planning (RIDSP), Rhode Island Public Transit Authority (RIPTA), and Rhode Island Department of Environmental Management (RIDEM), as well as the general public.

As the initial RIP developed by RIDOT, this plan aims to provide a broad yet comprehensive foundation for future resilience planning efforts. For future resilience efforts, RIDOT plans to update the RIP as appropriate on a periodic basis, potentially to coincide with future State LRTP, TAMP, and other relevant plan development processes, and in accordance with FHWA guidelines and recommendations. Ultimately, and through collaboration with other agencies, including the Rhode Island State Planning Council, the RIP can be used to guide additional resilience efforts at the local, regional, and statewide scale.

Upon acceptance of FHWA, the RIP will be submitted to the Statewide Planning for incorporation into the State LRTP as an Appendix along with other statewide plans adopted under the umbrella of Moving Forward Rhode Island 2040.

Table ES.1.1 PROTECT Requirements Addressed in RIP

	Requirements	How they are addressed in the RIP	1	2	3	4	5	6	7	8	9
	The plan shall…										
1	Encompass immediate and long-range planning activities and resilience investments	The RIP evaluates current (2024) and future (2035, 2050 and 2100) resilience needs and provides suggestions and guidance on incorporating resilience into the State LRTP and STIP, as well as coordinating with other state plans and planning activities.		x	x	x	x	x	x		x
2	Demonstrate a system-wide approach to transportation system resilience	The RIP analyzes six types of multimodal transportation assets owned and/or maintained by RIDOT transportation system, including roads, bridges, sidewalks, bike paths and drainage infrastructure.		x	x	x	x	x	x		
3	Consistent with and complement State and local hazard mitigation plans	The RIP reviewed the SHMP and uses its hazard priority rankings to guide study hazard selection.				x					
4	Include a risk-based assessment of vulnerability to current and future weather events and natural disasters	The RIP includes a risk-based assessment of transportation assets to storm surge, sea level, rise, and flooding under current (2024) and future (2035, 2050 and 2100) conditions. It considers vulnerability, likelihood, and consequence of potential impact and provides a planning-level estimation of monetized risk of no-action values.				x					
	Shall, as appropriate…										
5	Describe ways to improve response to impacts and changes	The RIP identifies adaptation strategies to help prepare RIDOT's response to the impacts of weather events, natural disasters and is prepared for changing conditions					x	x	x		
6	Describe the codes, standards, and regulatory framework to ensure improvements	Upon acceptance of FHWA, the RIP will be submitted to the State LRTP as an Appendix. The RIP discusses approaches to incorporate resilience into STIP, TAMP, and other state plans.		x					x		
7	Consider benefit of natural Infrastructure	Nature-based/natural solutions are highlighted and discussed as part of the list of strategies.						x			
8	Assess community infrastructure resilience	Community resilience is assessed by including drainage pipelines, and storm water treatments units as part of the study assets, and considering access to health facilities, schools, amongst others in the criticality assessment.			x	x					
9	Use a long-term planning period	The Plan assesses the vulnerability and risk of assets to hazards for a long-term planning period of 2050 and 2100.				x	x		x		
	May also…										
10	Designate evacuation routes and strategies	Evacuation routes are included in Usage and Operational Importance Criticality Factor.									
11	Plan for response to anticipated emergencies	Adaptation strategies are identified to improve operations and emergency Management						x	x		
12	Describe the resilience improvement policies	The RIP describes RIDOT's resilience policy and its importance for resilience implementation.						x	x		
13	Include investment plan & priority projects	The plan includes a project priority list and identifies resilience needs in current STIP projects.						x	x		
14	Use science and data	The assessment in RIP is based on the latest climate science and data.			x	x	x	x			

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Figure ES.1 Cumulative Composite Risk ($) by 2100

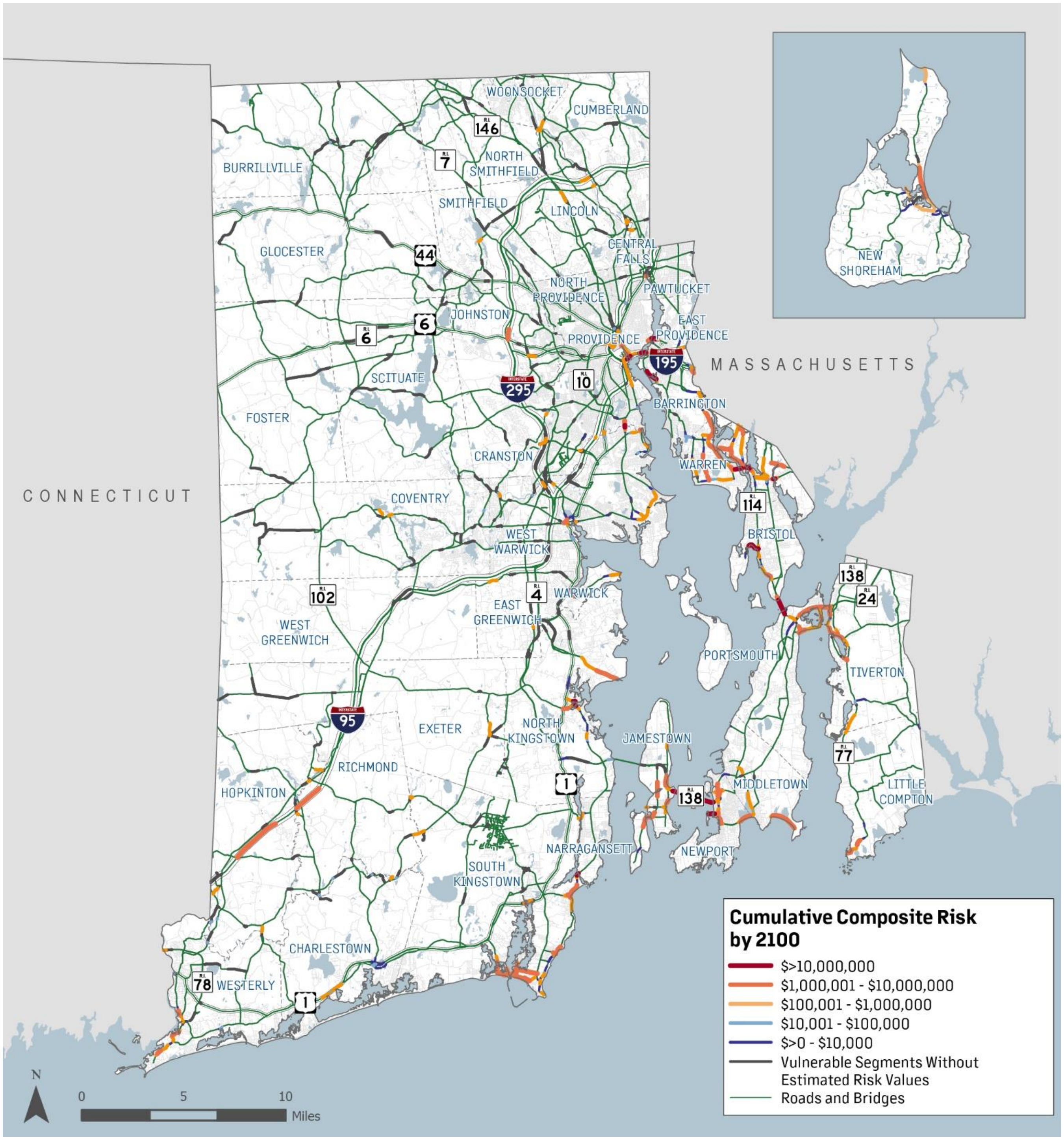
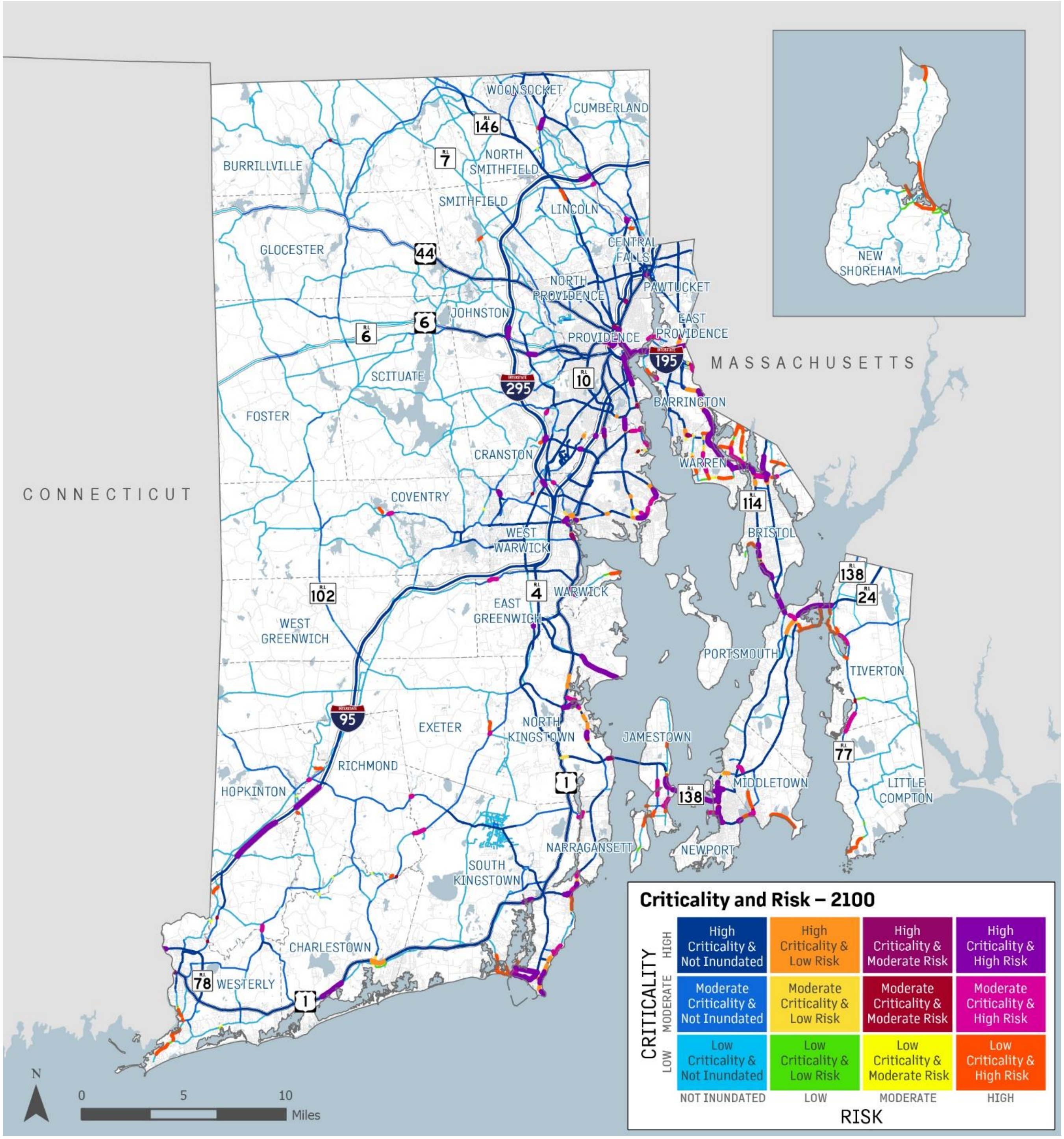


Figure ES.2 Criticality & Risk Through 2100



1.0 INTRODUCTION

1.1 Background and Purpose

Transportation assets in Rhode Island face many current and future climate stressors such as sea level rise, storm surge, flooding, coastal erosion, and other extreme weather events. According to the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information, Rhode Island is projected to experience continued increases in frequency and intensity of extreme precipitation events, sea level rise, and coastal flooding.[1] Sea levels are projected to rise in the state from one to four feet by 2100[2] and more extreme and intense precipitation events are expected to increase between 5 to 10%[3] by the middle of the 21rst century compared to the late 20th century under a high emission pathway. These hazards could damage infrastructure, increase repair and maintenance costs, and disrupt normal operations of transportation systems across the state.

Resilience needs for Rhode Island's multimodal transportation system have already been identified through previous studies. The State LRTP, Moving Rhode Island 2040, identifies coastal resiliency as a concern for the state's coastal counties, and highlights the need to prepare for more frequent flooding and thawing cycles. Improving asset resilience to climate change, storm surge, and sea level rise is also a key component of asset management and a priority focus of the STIP. In addition, RIDOT has conducted several studies and assessments to understand transportation assets' vulnerability to sea level rise and storm surge, and to develop strategies to incorporate resilience into project planning.

To further its effort to improve resilience of transportation assets and processes within the agency, RIDOT has developed a RIP to evaluate transportation infrastructure vulnerabilities and risks to natural and climate stressors, establish resilience strategies, and guide the implementation of resilient projects. The recent passing of the IIJA transportation funding bill in 2021 provides RIDOT an opportunity to leverage additional funding when integrating resilience. As part of the IIJA, by developing RIPs, DOTs and metropolitan planning organizations (MPOs) can reduce local funding match requirements by up to 10% for PROTECT Formula and Discretionary Program applications.[4]

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[1] https://climatechange.ri.gov/sites/g/files/xkgbur481/files/documents/noaa-climate-rhode-island-state-summary.pdf

[2] https://riema.ecms.ri.gov/sites/g/files/xkgbur671/files/2024-02/2024%20RI%20Hazard%20Mitigation%20Plan%20FINAL%20_Reduced%20size.pdf

[3] https://statesummaries.ncics.org/chapter/ri/#:~:text=In%20Providence%2C%20average%20temperatures%20in,inches%20of%20precipitation)%20was%201972.

[4] Applicants are typically required to account for a 20% non-federal match for capital projects. Through the development of a RIP however, for state DOTs and MPOs this non-federal match can drop to 13%. Furthermore, if the RIP is integrated into the agency's LRTP, the non-federal match drops to 10%.

At a minimum, RIPs must accomplish the following objectives[5]:

- Define the objectives and scope of the RIP by taking a long-term planning and a system wide approach to achieving system resilience.
- Include a risk-based assessment of vulnerabilities of transportation assets and systems to current and future weather events and natural disasters, such as severe storms, flooding, drought, levee and dam failure, wildfire, rockslides, mudslides, sea-level rise, extreme weather, extreme temperatures, and earthquakes.
- Develop strategies that include both immediate and long-range planning activities and resilience investments. These strategies could include the benefits of natural infrastructure.
- Ensure that the RIP is ready for integration and implementation, consistent with and complements state and local hazard mitigation plans and incorporates codes, standards, and regulatory framework to ensure improvements.

Tasked with maintaining the transportation infrastructure network of coastal and dense state, the development of a RIP will allow RIDOT to best position itself to address resilience needs.

Table 1.1 Resilience Improvement Plan Components

	PROTECT – Resilience Improvement Plan
	The Plan Shall...
•	Encompass immediate and long-range planning activities and resilience investments
•	Demonstrate a system-wide approach to transportation system resilience
•	Consistent with and complement State and local hazard mitigation plans
•	Include a risk-based assessment of vulnerability to current and future weather events and natural disasters
	Shall, as appropriate...
•	Describe ways to improve response to impacts and changes
•	Describe the codes, standards, and regulatory framework to ensure improvements
•	Consider benefit of natural Infrastructure
•	Assess community infrastructure resilience
•	Use a long-term planning period
	May also...
•	Designate evacuation routes and strategies
•	Plan for response to anticipated emergencies
•	Describe the resilience improvement policies
•	Include investment plan & priority projects
•	Use science and data

5 https://uscode.house.gov/view.xhtml?req=(title:23%20section:176%20edition:prelim)

1.2 Framework and Compliance with PROTECT Requirements

Following the review of general approaches, including through internal and peer agency documentation, the project team proceeded with the development of the RIP framework. The purpose of this process is to provide an initial architecture for the RIP document, based on best available practices, including from national sources.

In consideration of the requirements for the RIP in the PROTECT Funding Implementation Guidance, existing RIDOT documentation, and based on peer agency and national best practices in RIP development, resilience management, and framework design, a framework for RIDOT's RIP has been developed, as shown in Figure 1.1. The RIP Framework is designed to enable RIDOT to address the RIP requirements to be eligible for in the PROTECT Formula and Discretionary Funds. The orange circles on the framework are the connections of each step of the framework with the required and optional elements of a RIP. This is detailed in Figure 1.2. Additionally, the RIP identifies where and how each required and optional element of the RIP is satisfied.

Framework development was guided based on insight from the following sources:

- **NCHRP Project 23-09 – Developing a Highway Framework to Conduct an All-Hazards Risk and Resilience Analysis (2023)**
- **FHWA Vulnerability Assessment and Adaptation Framework, 3rd Edition**
- **Forest Research Resilience Implementation Framework**
- **Cybersecurity & Infrastructure Security Agency Infrastructure Resilience Planning Framework**

Figure 1.1 Resilience Improvement Plan Framework

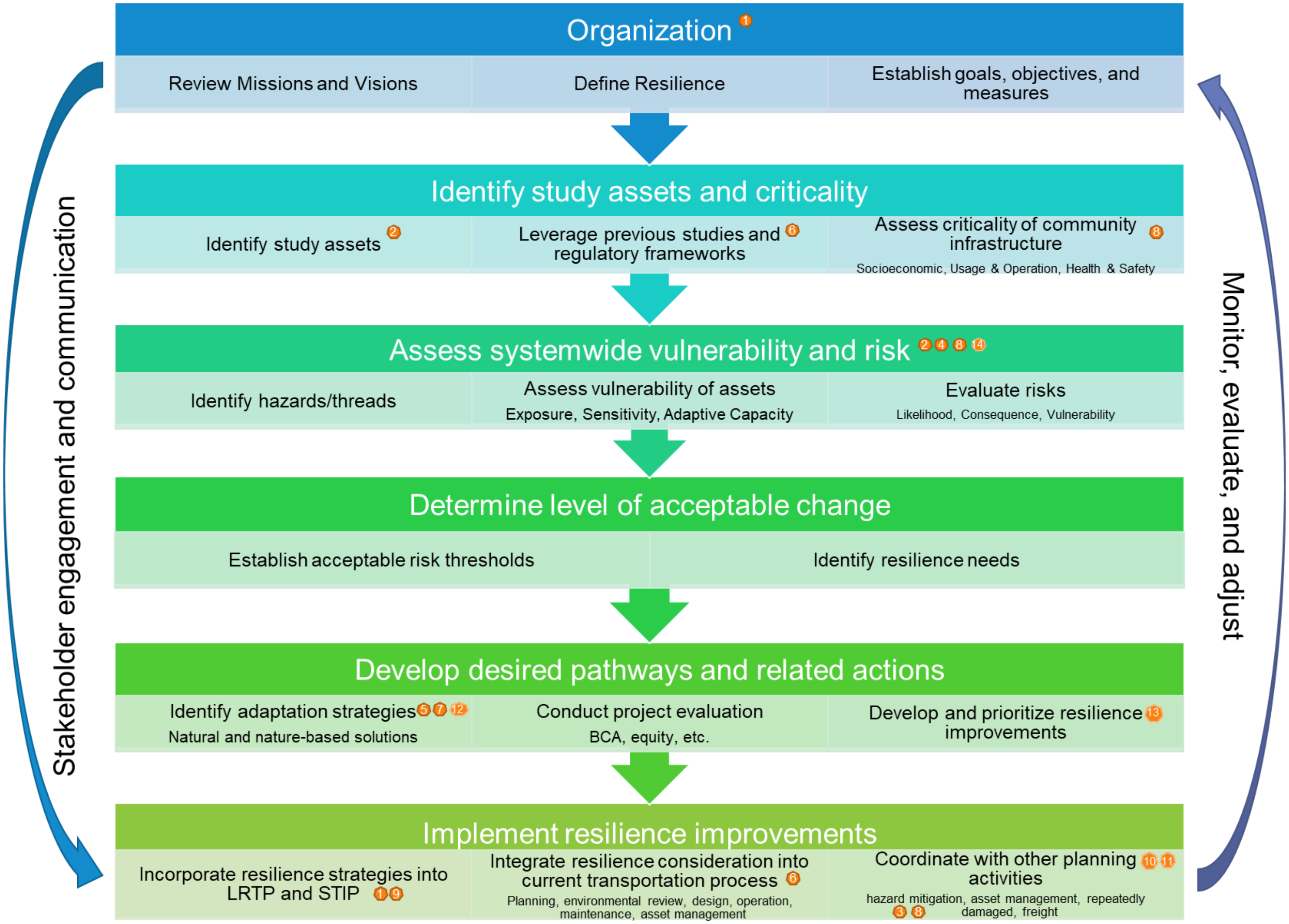


Figure 1.2 Required and Optional Elements of RIP

PROTECT Formular Program Implementation Guide - Resilience Improvement Plan Content		
The Plan Shall..		
1	Encompass immediate and long-range planning activities and resilience investments	(A) shall be for the immediate and long-range planning activities and investments of the State or metropolitan planning organization with respect to resilience of the surface transportation system within the boundaries of the State or metropolitan planning organization, as applicable
2	Demonstrate a system-wide approach to transportation system resilience	(B) shall demonstrate a systemic approach to surface transportation system resilience, and
3	Consistent with and complement State and local hazard mitigation plans	(B) ...be consistent with and complementary of the State and local mitigation plans required under section 322 of the Robert T. Stafford Disaster Relief and Emergency Assistance Act (42 U.S.C. 5165)
4	Include a risk-based assessment of vulnerability to current and future weather events and natural disasters	(C) shall include a risk-based assessment of vulnerabilities of transportation assets and systems to current and future weather events and natural disasters, such as severe storms, flooding, drought, levee and dam failures, wildfire, rockslides, mudslides, sea level rise, extreme weather, including extreme temperatures, and earthquakes (23 U.S.C.176(e)(2)(A-C)).
Shall, as appropriate..		
5	Describe ways to improve response to impacts and changes	...Include a description of how the agency is prepared to respond to the impacts of weather events, natural disasters and is prepared for changing conditions;
6	Describe the codes, standards, and regulatory framework to ensure improvements	...Describe the codes, standards, and regulatory framework, adopted and enforced by the agencies, to ensure that resilience improvements within the impacted area of proposed projects that are included in the plan;
7	Consider benefit of natural Infrastructure	...Consider the benefits of combining hard surface transportation assets, and natural infrastructure, through coordinated efforts by the Federal Government and the States;
8	Assess community infrastructure resilience	...Assess the resilience of other community assets, including buildings and housing, emergency management assets, and energy, water, and communication infrastructure;
9	Use a long-term planning period	...use a long-term planning period...A Resilience Improvement Plan should cover a period at least as long as the relevant SLRTP, MTP, or asset management plan. A longer period that considers the service lives of relevant assets is recommended.
	Other	...Include such other information as the State or metropolitan planning organization considers appropriate
May also..		
10	Designate evacuation routes and strategies	...Designate evacuation routes and strategies, including multimodal facilities, designated with consideration for individuals without access to personal vehicles;
11	Plan for response to anticipated emergencies	...Plan for response to anticipated emergencies, including plans for the mobility of emergency response personnel and equipment and access to emergency services, including for vulnerable or disadvantaged populations;
12	Describe the resilience improvement policies	...Describe the resilience improvement policies, including strategies, land-use and zoning changes, investments in natural infrastructure, or performance measures that will inform the transportation investment decisions of the State or metropolitan planning organization with the goal of increasing resilience;
13	Include investment plan & priority projects	...Include an investment plan that includes a list of priority projects and describes how funds apportioned to the State under section 104(b)(8), or provided by a grant under the PROTECT program would be invested and matched, which shall not be subject to fiscal constraint requirements;
14	Use science and data	... Use science and data and indicate the source of data and methodologies

Sources: PROTECT Formula Funding Implementation Guidance, AASHTO Informal Worksheet with RIP Checklist

The rest of the RIP is laid out following the structure of the RIP framework as follows:

Chapter 2 - Organization

Chapter 2, reviews RIDOT's mission and vision and develops a resilience definition, objectives policy. This definition and policy are meant to support RIDOT's overall mission and align with how RIDOT envisions its system and provision of service will be. This step also establishes the goals, objectives, and performance measures for the RIP, which each encompass immediate and long-rang planning activities and investments with respect to the resilience of RIDOT's transportation system (*PROTECT Requirement #1*).

Chapter 3 - Identify Study Assets and Criticality

Guided by the resilience goal, policy, and objectives established in the previous chapter, Chapter 3 begins the vulnerability and risk assessment process by identifying the six categories of assets to be evaluated. The study assets were identified using a systemic approach and include six categories of multimodal infrastructure (*PROTECT Requirement #2)*: Roads, Bridges, Sidewalks, Shared-Use Paths, Stormwater Pipes, and Stormwater Treatment Units. Levels of criticality are assigned for each asset, leveraging previous studies and regulatory frameworks (*PROTECT Requirement #6*), and through the consideration of importance with respect to usage and operation, socioeconomic characteristics, as well as health and safety (*PROTECT Requirement #8 / #10, #11*).

Chapter 4 - Assess systemwide vulnerability and risk

Chapter 4 includes assesses the vulnerabilities and risks of the six categories of Rhode Island's transportation assets to current and future weather events and natural disasters (*PROTECT Requirement #4*). This includes identifying potential impacts from three categories of high priority natural hazards (sea level rise, storm surge, and flooding). Based on the review of Rhode Island's SHMP *(PROTECT Requirement #3)*, history records, and field observation from RIDOT internal staff and external stakeholders, these hazards are expected to impact Rhode Island's transportation infrastructure through inundation.

The vulnerability assessment evaluates the exposure, sensitivity, and adaptive capacity of each asset in relation to the three types of hazards identified. The risk assessment considers the vulnerability of different assets to the impacts of a hazard, the likelihood of that hazard event occurring, and the consequences that may result from that hazard should it occur, with a time horizon of through 2100 *(PROTECT Requirement #9)*. The assessment also uses the best available science and data (*PROTECT Requirement #14*) and leverages state and local hazard mitigation plans to obtain information about the likelihood and consequence of hazards impacting the study area, and their impacts to transportation system resilience and other community assets, including buildings and housing, emergency management assets, and energy, water, and communication infrastructure.

Chapter 5 - Determine Level of Acceptable Change

With the potential impact from hazards identified previously, Chapter 5 considers at what point do the key assets or functional areas of RIDOT become threatened and require actions. The level of acceptable change, or risk thresholds, are often different for different assets. RIDOT considers the criticality of each of the study assets for supporting its missions and for achieving its visions when determining their risk thresholds. The level of acceptable change, or risk thresholds, is also used to inform the pathways to improve assets and system resilience in the next chapter, including the selection of adaptation strategies and the minimum resilience design standard to which a asset must be protected against.

Chapter 6 - Develop Desired Pathways and Related Actions

Based on the resilience needs identified, Chapter 6 identifies adaptation strategies to help prepare RIDOT's response to the impacts of weather events, natural disasters and is prepared for changing conditions *(PROTECT Requirement #5)*. This includes assessing, wherever possible, the benefits of combining hard surface transportation assets, and natural infrastructure, through coordinated efforts by the Federal Government and the States *(PROTECT Requirement #7)*.

This chapter also develops a framework to evaluate the benefits of resilience improvements, including through the weighing of costs and benefits, as well as the cost of no-action. The cost of no action assists in project prioritization, project benefit and cost evaluation, and selection of strategies. RIDOT worked with its stakeholders to develop criteria to prioritize resilience improvements, taking into account both the quantitative results from the risk-based vulnerability assessment, and other measures that reflects the agencies priorities, such as equity, safety, and mobility (*PROTECT Requirement #13*). Optionally, an investment plan was developed to *describes how funds apportioned to the State under section 104(b)(8) or provided by a grant under the PROTECT program would be invested and matched, which shall not be subject to fiscal constraint requirements*.

Chapter 7- Implement Resilience Improvements

Chapter 7 discusses RIDOT's approach to implement resilience improvements by incorporating insight from the RIP into the State LRTP and STIP. Chapter 7 also includes strategies for integrating resilience into various core thematic areas of RIDOT, including agency-wide operations, planning, project development & environmental permitting, design, as well as operations & emergency management. Lastly, strategies are discussed for integrating resilience into RIDOT's other major planning processes, including its TAMP, Freight Plan, Carbon Reduction Plan(CRP), and Congestion Management Plan(CMP), while setting a foundation for future resilience efforts. This integration into major functional plans and core thematic areas of the agency will help RIDOT comprehensively consider and implement resilience, including in accordance with its resilience policy.

This steps also describes the potential resilience improvement policies, including strategies, land-use and zoning changes, investments in natural infrastructure, or performance measures that will inform the transportation investment decisions of Rhode Island with the goal of increasing resilience (PROTECT Requirement #12).

Chapter 8 - Stakeholder Engagement and Communication

Chapter 8 summarizes the methods of stakeholder which guided the development of the RIP. RIDOT used six methods of stakeholder engagement to verify results, garner further insight, and tailor the plan to best meet the agency's resilience needs. These six methods of engagement include peer agency interviews, interactive workshops, internal working group meetings, community engagement, coordination with ongoing resilience-oriented planning processes, and additional stakeholder meetings that include participation in national level communities of practice such as the American Association of State Highway and Transportation Officials (AASHTO) and the Transportation Research Board (TRB).

Chapter 9 - Monitor, Evaluate, and Adjust the Plan

The final chapter provides RIDOT with a roadmap for furthering resilience efforts by establishing a monitoring and evaluation process by recommending performance measures for implementation. Chapter 9 also establishes guidelines for updating the resilience planning process, for identifying when the RIP will need to be updated, and for identifying when a review by FHWA Division Office is warranted.

Table 1.2 PROTECT Requirements Addressed in RIP

	Requirements	How they are addressed in the RIP	1	2	3	4	5	6	7	8	9
	The plan shall…										
1	Encompass immediate and long-range planning activities and resilience investments	The RIP evaluates current (2024) and future (2035, 2050 and 2100) resilience needs and provides suggestions and guidance on incorporating resilience into the State LRTP and STIP, as well as coordinating with other state plans and planning activities.		x	x	x	x	x	x		x
2	Demonstrate a system-wide approach to transportation system resilience	The RIP analyzes six types of multimodal transportation assets owned and/or maintained by RIDOT transportation system, including roads, bridges, sidewalks, bike paths and drainage infrastructure.		x	x	x	x	x	x		
3	Consistent with and complement State and local hazard mitigation plans	The RIP reviewed the SHMP and uses its hazard priority rankings to guide study hazard selection.				x					
4	Include a risk-based assessment of vulnerability to current and future weather events and natural disasters	The RIP includes a risk-based assessment of transportation assets to storm surge, sea level, rise, and flooding under current (2024) and future (2035, 2050 and 2100) conditions. It considers vulnerability, likelihood, and consequence of potential impact and provides a planning-level estimation of monetized risk of no-action values.				x					
	Shall, as appropriate…										
5	Describe ways to improve response to impacts and changes	The RIP identifies adaptation strategies to help prepare RIDOT's response to the impacts of weather events, natural disasters and is prepared for changing conditions					x	x	x		
6	Describe the codes, standards, and regulatory framework to ensure improvements	Upon acceptance of FHWA, the RIP will be submitted to the State LRTP as an Appendix. The RIP discusses approaches to incorporate resilience into STIP, TAMP, and other state plans.		x					x		
7	Consider benefit of natural Infrastructure	Nature-based/natural solutions are highlighted and discussed as part of the list of strategies.						x			
8	Assess community infrastructure resilience	Community resilience is assessed by including drainage pipelines, and storm water treatments units as part of the study assets, and considering access to health facilities, schools, amongst others in the criticality assessment.			x	x					
9	Use a long-term planning period	The Plan assesses the vulnerability and risk of assets to hazards for a long-term planning period of 2050 and 2100.				x	x		x		
	May also…										
10	Designate evacuation routes and strategies	Evacuation routes are included in Usage and Operational Importance Criticality Factor.									
11	Plan for response to anticipated emergencies	Adaptation strategies are identified to improve operations and emergency Management						x	x		
12	Describe the resilience improvement policies	The RIP describes RIDOT's resilience policy and its importance for resilience implementation.						x	x		
13	Include investment plan & priority projects	The plan includes a project priority list and identifies resilience needs in current STIP projects.						x	x		
14	Use science and data	The assessment in RIP is based on the latest climate science and data.			x	x	x	x			

2.0 ORGANIZATION

2.1 Review of RIDOT's Mission and Vision

RIDOT has set its mission to design, construct, and maintain the state's surface transportation system for a vision of creating a multimodal transportation network that connects people, places and goods in a safe and resilient manner by providing effective and affordable transportation choices that are supportive of healthy communities, provide access to jobs and services, and promote a sustainable and competitive Rhode Island economy.

This is further described by the goals in the State LRTP, Moving Rhode Island 2040:

Support Economic Growth *through transportation connectivity and choices to attract employers and employees.*

Promote Environmental Sustainability *by prioritizing non-single occupancy vehicle focused strategies and investments.*

Strengthen Communities *through the local transportation network to enhance travel, place, and quality of life.*

Maintain Transportation Infrastructure *to create a reliable network providing adequate travel choices Connect People & Places across all modes and options for more efficient and effective travel.*

Connect People & Places *across all modes and options for more efficient and effective travel.*

Resilience as a concept spans from planning and design through construction to operations and maintenance of the transportation system, and therefore cuts across all these goals that are critical to achieving RIDOT's mission and vision.

Transportation assets in Rhode Island face many current and future climate stressors such as sea level rise, storm surge, flooding, coastal erosion, and other extreme weather events. These hazards could damage infrastructure, increase repair and maintenance costs, and disrupt normal operations of transportation systems across the state. Developing a RIP will enable a cohesive approach to incorporating resilience throughout the agency and provide the framework for RIDOT to collaborate with local, regional, and statewide partners to reduce or minimize potential impacts from extreme weather and climate events on transportation system and the community.

2.2 Defining Resilience

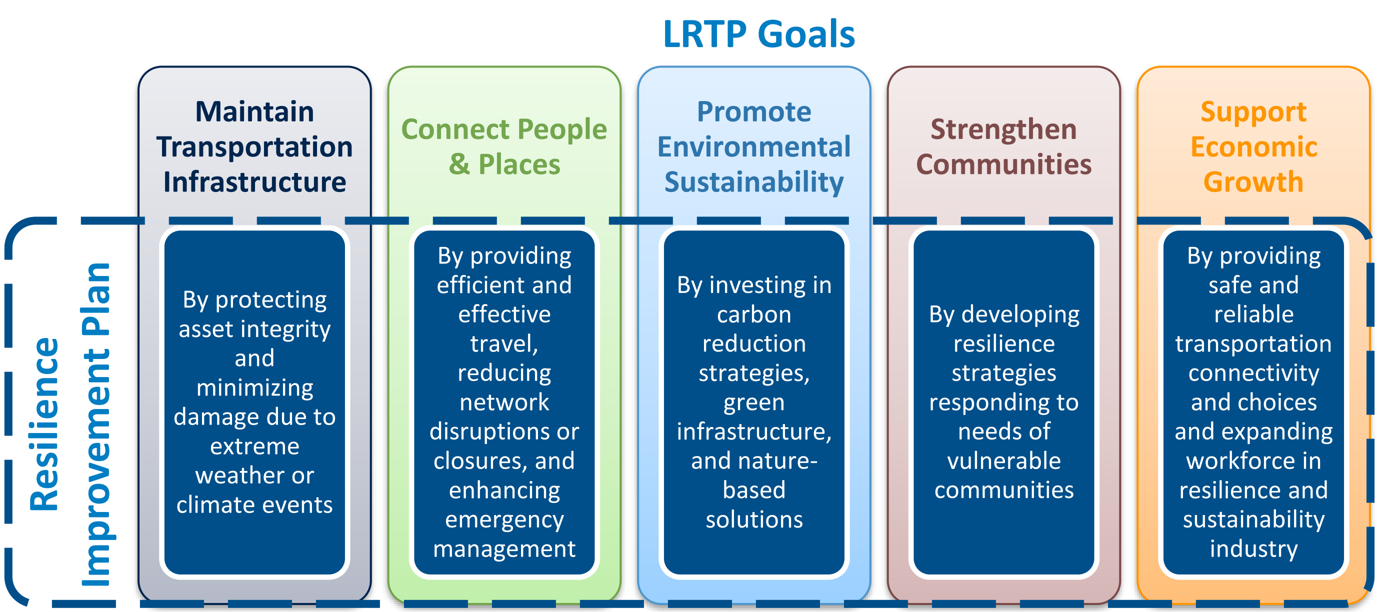
RIDOT has established the importance of resiliency across the statewide transportation network, based on reference to the topic/term across multiple planning efforts. This reference is further strengthened by recent Executive Orders aiming to advance resiliency and sustainability. Given its demonstrated importance, the RIP established a formal definition for resilience by reviewing guidelines from national and state resources and considering stakeholder inputs. A review of the definition of resilience as defined by national resources as well a review of existing mentions of resilience across RIDOT publications can be found in Appendix C: Review of Resilience definitions and Existing RIDOT Literature Where Resilience is Mentioned

Building upon the national and state resources, the RIP defines Resilience for RIDOT as follows:

Resilience is defined by RIDOT as the ability of the Rhode Island transportation system to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to, and recover rapidly from any disruptions.

This definition of resilience is also intended to connect and further RIDOT's goals established in the State LRTP. Figure 2.1 below shows how the RIP is in alignment with the LRTP goals.

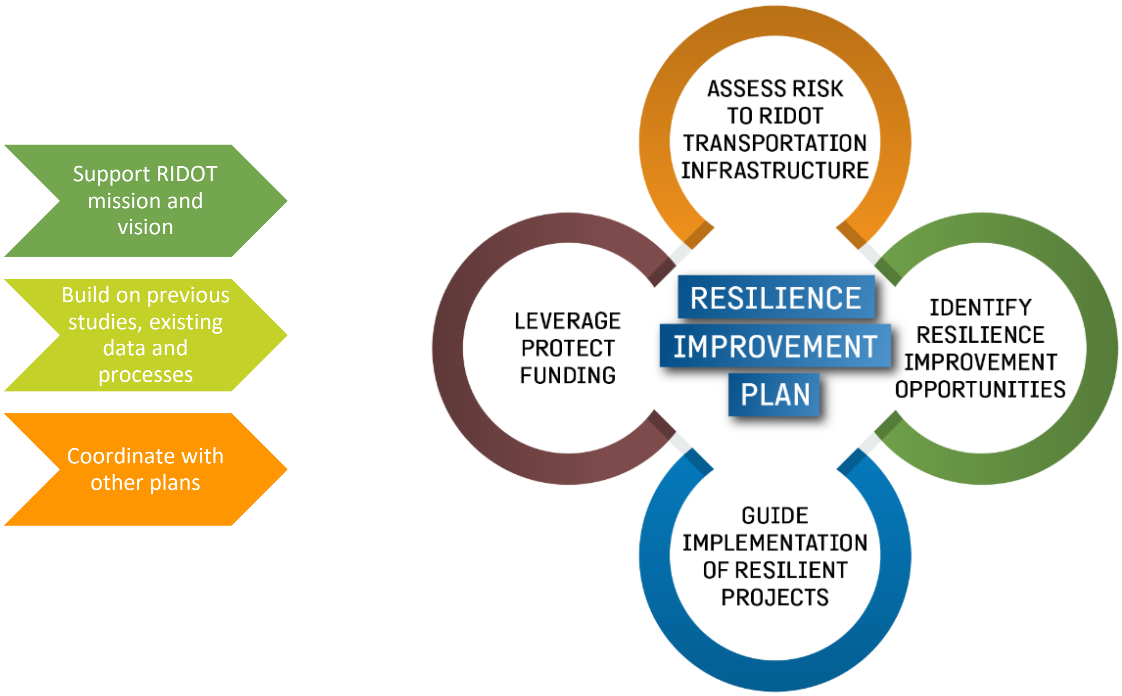
Figure 2.1 Resilience Supports the State LRTP Goals



2.3 Establish Goals, Objectives, and Measures

The goal of the RIP is to support RIDOT in improving the resiliency and reliability of its transportation system through assessing risk to RIDOT transportation infrastructure, identifying resilience improvement opportunities, providing a framework to guide the implementation of resilience projects, and setting them up for PROTECT funding eligibility.

Figure 2.2 RIP Goals



The RIP has the following objectives:

- Identify high priority hazards to the state transportation assets.
- Conduct a risk-based vulnerability assessment of the state transportation assets in Rhode Island to understand the current and future risk.
- Identify resilience needs by considering the acceptable risk tolerances for vulnerable assets.
- Develop resilience strategies for RIDOT to prepare for, respond to, and recovery from the impacts of high priority hazards and changing conditions.
- Create a prioritized implementation check list with actionable resilience opportunities.
- Establish methodology to evaluate resilience investments by their benefits and costs.

- Provide recommendations to integrate resilience into RIDOT's project planning and management process across departments.
- Engage stakeholders and the public in the process of improving resilience in RIDOT.

The RIP also supports the integration of resilience into other key statewide plans, such as the SHMP, TAMP, STIP, and CRP, by providing cross-cutting resilience strategies and measures to key topic areas of challenges and opportunities, including safety, congestion management, aging infrastructure, freight movement, stormwater management, smart growth, shared mobility, active transportation, and economic development.

Performance measures play an important role in tracking progress, and further assessing resilience needs. The following performance measures are proposed to help guide the development and implementation of the RIP:

- Number of resilience-themed projects proposed or implemented
- Percentage of road and transportation network in locations of high exposure, sensitivity

3.0 IDENTIFY STUDY ASSETS AND DETERMINE CRITICALITY

Having previously identified RIDOT's goals, objectives, and an overall definition for resilience, Chapter 3 provides the next step in the resilience planning process which consists of identifying transportation assets and determining criticality considerations for each asset. This provides a foundation for assessing immediate and long-term risk from future weather events and natural disasters, and identifying necessary strategies, planning activities, and investments in the next sections.

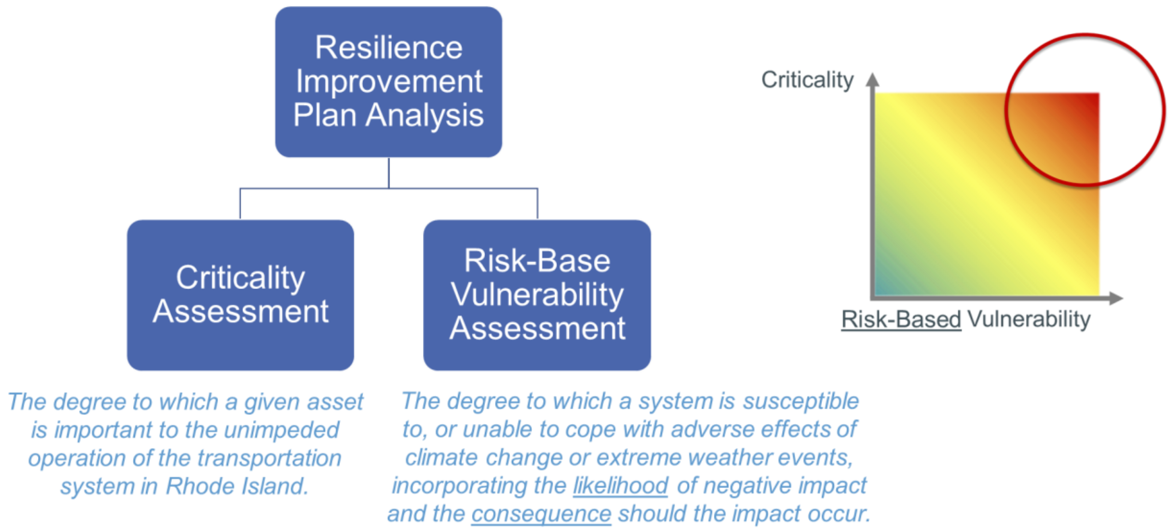
3.1 Study Overview

Building upon the previous resilience work undertaken by RIDOT and its agency partners in Rhode Island, the RIP conducted a systemwide criticality assessment and a risk-based vulnerability assessment to identify and prioritize, and select appropriate strategies for at-risk RIDOT transportation assets for potential resilience improvement. The assessments analyzed risk for a range of multimodal transportation assets in three time-horizons, 2035, 2050, and 2100, and focused on the impact from high priority hazards, sea level rise, storm surge, and sea level rise, as they were identified as having among the highest risk by the SHMP and RIDOT's TAMP. The assessment framework established through this plan can apply to assessing risk from other hazardous events and other types of assets in future updates of RIP.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Elements (1) and (9) by encompassing immediate and ongoing planning activities, as well as long-range planning activities including the LRTP and assessment of risk through 2035, 2050, and 2100.

Figure 3.1 Methodology Overview



3.2 Identify Study Assets

> **Addressing PROTECT Guidance Elements**
>
> This section satisfies PROTECT Guidance Element (2) by encompassing six key asset categories that comprise Rhode Island's multimodal transportation system.

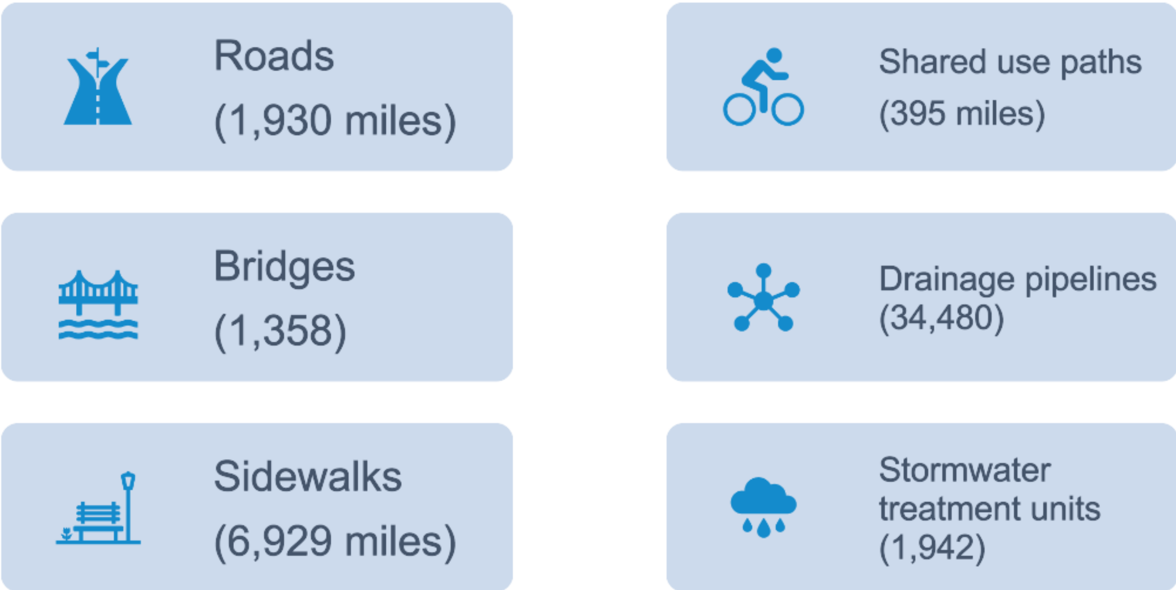
RIDOT leveraged previous studies and regulatory frameworks to guide the identification of asset classes and effectively assess the criticality of each asset and asset class. This included best practices on how to consider the importance of key asset classes in relation to key functional and societal needs.

The initial step in the RIP is to identify which assets will be included in the analysis. Rhode Island's multimodal transportation system is comprised of the network of roads, bridges, pedestrian infrastructure, railroads, pipelines, freight and passenger facilities, and other supporting facilities and systems including stormwater treatment units. This plan's assessment primarily focuses on transportation assets owned or operated by RIDOT. As a result, the RIP directly considers the following assets: roads, bridges, sidewalks, shared-use paths, drainage pipelines, and stormwater treatment units.

These assets are shown in Figure 3.2.[6]

[6] The information for each of these assets was generated from the asset shapefiles downloaded from https://www.rigis.org/. Data downloaded in April 2023

Figure 3.2 Vulnerability & Risk Assessment Assets



The inclusion of these primary six asset classes in this risk-informed vulnerability assessment satisfies the requirements of the PROTECT program which calls for a systemic approach to improving the resilience of surface transportation assets. Together, these six asset classes comprise a large majority of the state's multimodal transportation system and its supporting infrastructure components which are important for evaluating system interdependencies. This includes infrastructure related to drainage where asset failure could impact the entire multimodal transportation system.

Key transportation and civic asset classes not directly owned or operated by RIDOT are primarily considered in the criticality assessments undertaken for the six asset classes by measure of proximity. The proximity of a primary asset to one or more additional civic and transportation asset classes outside the ownership or operation of RIDOT, including the rail network, transit network, and other major freight and civic facilities, increases the criticality of that particular primary asset. The access provided by the transportation assets to the civic infrastructure and other critical non transportation assets indicates the system interdependency of the transportation assets and other infrastructure. The process to assign criticality, resulting in part from this system interdependency, for each primary asset class, is described in the following section.

3.3 Assess Criticality of Community Infrastructure

The RIP formally defines criticality as *the degree to which a given asset is important to the unimpeded operation of the transportation system in Rhode Island*.[7] Broadly, criticality can be thought of as an initial prioritization construct for RIDOT. It serves as the foundation for prioritization and allocation of resources by helping to determine the overall importance of each asset. This level of importance, customizable across each agency or operation, is typically developed based on key priorities and agency objectives. RIDOT's proposed criticality approach is informed by experience leveraged from transportation criticality assessments successfully completed across the U.S., through the development of FHWA's resilience pilots, and through additional related studies. Based on these considerations, criticality, identified for each asset, is comprised of three indicator categories that signify the importance of each transportation asset:

- **Usage & Operational Importance:** A measure of how important the asset is to the overall function of the transportation system.
- **Socioeconomic Importance:** A measure of the extent to which an asset serves people and businesses in Rhode Island, including underserved or disadvantaged communities.
- **Health & Safety Importance:** A measure of the access provided by an asset to essential locations and services related to health and safety, including emergency response and healthcare facilities.

Criticality Definition:

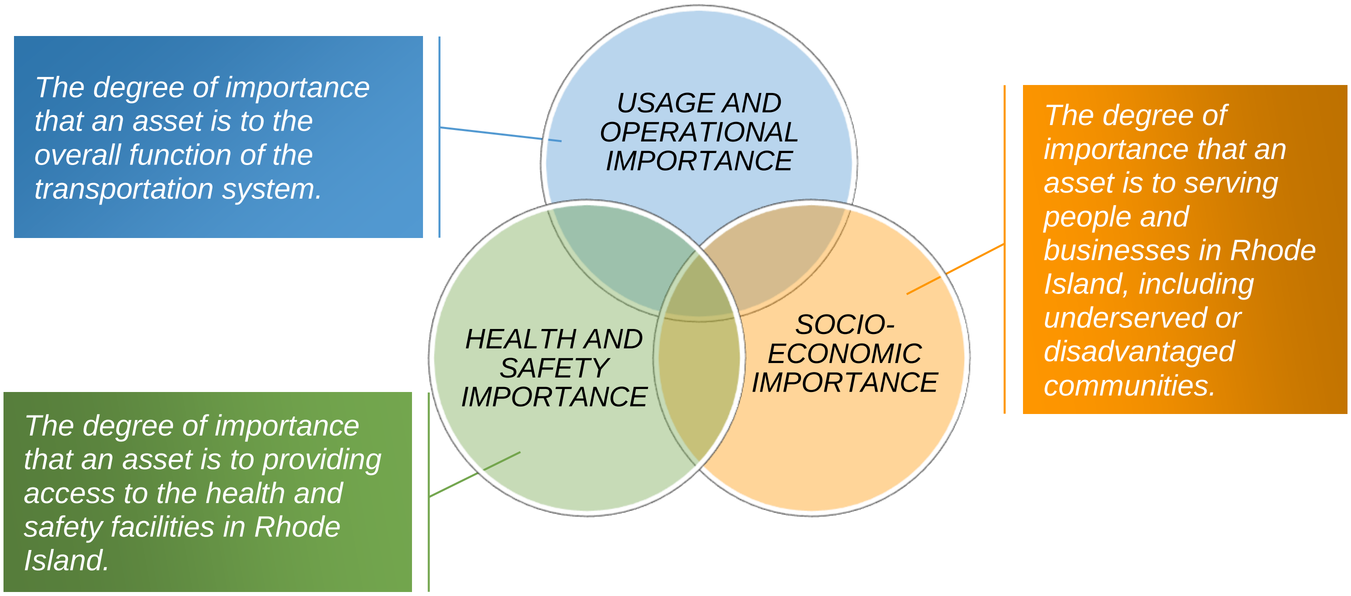
The degree to which a given asset is important to the unimpeded operation of the transportation system in Rhode Island.

-- RIDOT.

The relationships amongst these indicator categories are visualized in Figure 3.3.

[7] The definition of criticality stems from a review of FHWA's criticality definition, and other relevant state and national best practice sources. It was then tailored to fit the needs of RIDOT and the state's multimodal transportation system.

Figure 3.3 Criticality Components



3.3.1 Description of Criticality Indicators

The three categories of criticality indicators are further described below. Each category includes a set of individual indicators identified, and proposed weighting and scoring for each. The criticality scores of each asset are the sum of its scores for all individual indicators, which feed into a defined ranking of each asset by overall criticality. For each category, criticality identified for each individual indicator can be found in Appendix D: Criticality Components.

Usage & Operational Importance

Usage and operational importance incorporates the importance of the asset, primarily roads, to the overall use, designation and operation of the asset as part of the transportation system. The category contains six individual factors, including the following:

- Functional system of the road,
- Average Annual Daily Traffic (AADT)
- Designation of the road as part of the National Highway Freight Network

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Elements (11) through the incorporation of designated evacuation and community lifeline routes as key components of asset criticality.

- Proximity within half a mile of the Northeast Corridor rail line
- Designation as an evacuation route or a lifeline connection to a community
- Presence of a broadband network along the road right-of-way (ROW)

Functional system, AADT and National Highway Freight Network designation reflect the core usage of the transportation system and the characteristics of the vehicular traffic carried along the road. Evacuation and lifeline connection roadways are included as a factor given their importance in the event of natural disaster or other significant disruption. Similarly, proximity to the Northeast Corridor rail network, operating between Washington, D.C. and Boston, is important in Rhode Island as this link serves the most densely populated heavily used passenger rail network in the U.S. Electric grid and various communication infrastructure were not directly evaluated, rather, the presence of broadband network on RIDOT roadways is included as a criticality factor to reflect their importance for communication and emergency management, especially during hazardous events. Table 3.1 provides the scoring of the usage and operation factors.

Table 3.1 Scoring Scheme for Usage and Operational Factors

Factor	Status	Score	Max Score
Evacuation Routes or Lifelines	Not evacuation routes or lifelines	0	2
	Evacuation routes or lifelines	2	
Functional System	Local, Major and Minor Collector	0	2
	Principal Arterial, Minor Arterial	1	
	Interstate, Expressway	2	
AADT	< = 26,300	0	2
	26,300 - 84,000	1	
	>84,000	2	
Freight Network	Not on the freight network	0	2
	On the freight network	2	
Northeast Corridor	Not within a ½ -mile buffer of the Northeast Corridor	0	1
	Within a ½ -mile buffer of the Northeast Corridor	1	
Broadband Network	Without broadband network in the right of way	0	1
	With broadband network in the right of way	1	
Usage and Operational Score			**10**

Socioeconomic Importance

Socioeconomic importance reflects the importance of an asset to the population within the study area, including underserved and disadvantaged communities. This includes three individual indicators:

- Equity areas
- Population density
- Employment density

The presence of an asset in an equity area, measured by location within eligible census tract, considers socially vulnerable communities identified by USDOT's transportation disadvantaged tool, Climate and Economic Justice Screening Tool (CEJST), or RIDOT EJ areas . The population and employment density were calculated by taking the population and employment at the census tract level and dividing it by the area and then assigning it to the roads that were intersected by it. Scoring breaks for population and employment density are based off quantile classification of each asset. Table 3.2 provides the scoring of the socioeconomic indicators.

Table 3.2 Factors and Scoring Scheme for Socioeconomic Indicators

Factor	Status	Score	Max Score
Equity Areas	Not in a equity area.	0	4
	Within equity areas identified by USDOT's transportation disadvantaged tool, Climate and Economic Justice Screening Tool (CEJST), or RIDOT EJ areas.	4	
Population Density	<= 1,100 person/sq. mi.	0	3
	1,100 - 5,000 person/sq. mi.	1	
	5,000 – 17,000 person/sq. mi.	2	
	> 17,000 person/sq. mi.	3	
Employment Density	<= 300 jobs/sq. mi.	0	3
	300 - 2,000 jobs/sq. mi.	1	
	2,000 – 7,000 jobs/sq. mi.	2	
	> 7,000 jobs/sq. mi.	3	
Socio Economic Score			**10**

Health & Safety Importance

Health and Safety Importance factors assess the degree of importance of an asset, measured by distance, to providing access to facilities indispensable for the health and safety of Rhode Island, including in relation to emergency response. This includes the following eleven broad categories of facilities:

- Transit Centers
- Airports
- Seaports
- Maintenance Facilities
- Power Plants
- Schools
- Emergency Shelters
- Fire or Police Stations
- Hospitals
- Dams
- Military Bases

The distance of an asset to these facilities was calculated using the Network Analyst tool in ArcMap, which calculates the approximate distance along a network that it takes to reach a facility. It uses the centroid of each roadway asset as the origin and each facility as the destination. Table 3.3 provides the scoring of the health & safety indicators.

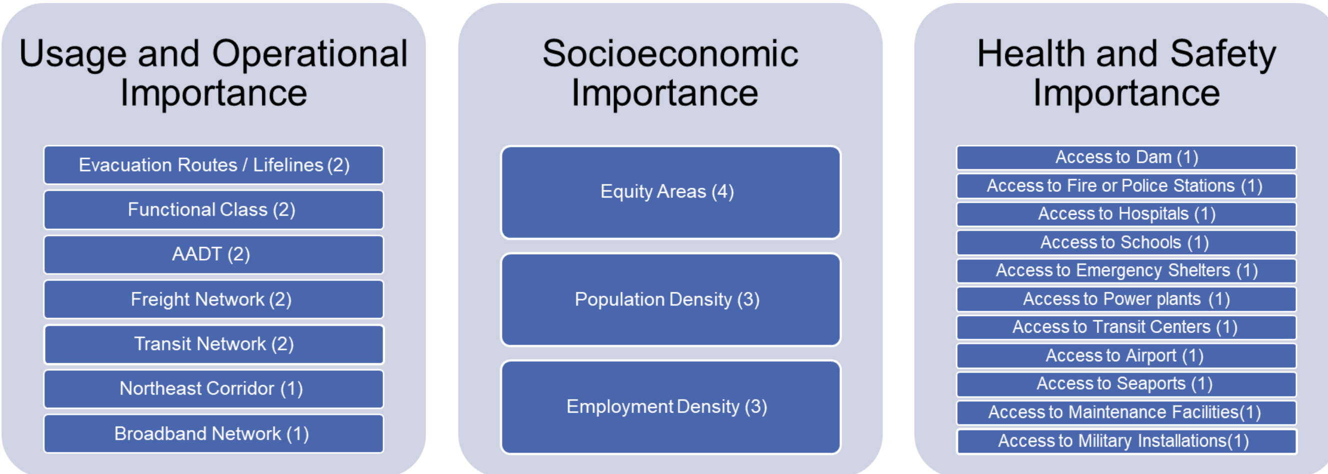
Table 3.3 Factors and Scoring Scheme for Health and Safety Indicators

Factor	Scoring Method	Max Score
Access to Transit centers	Not within a one-mile buffer – score of 0 Within a one-mile buffer - score of 1	1
Access to Airport		1
Access to Seaports		1
Access to Maintenance Facilities		1
Access to Power Plants		1
Access to Schools		1
Access to Emergency Shelters		1
Access to Fire or Police Stations		1
Access to Hospitals		1
Access to Dams		1
Access to Military Bases		1
Health and Safety Score		**11**

3.3.2 Computing Asset Criticality

To compute criticality scores for each asset, the individual indicators comprising each category of importance were summed to generate a value for that particular criticality factor. These factors are shown in Figure 3.4.

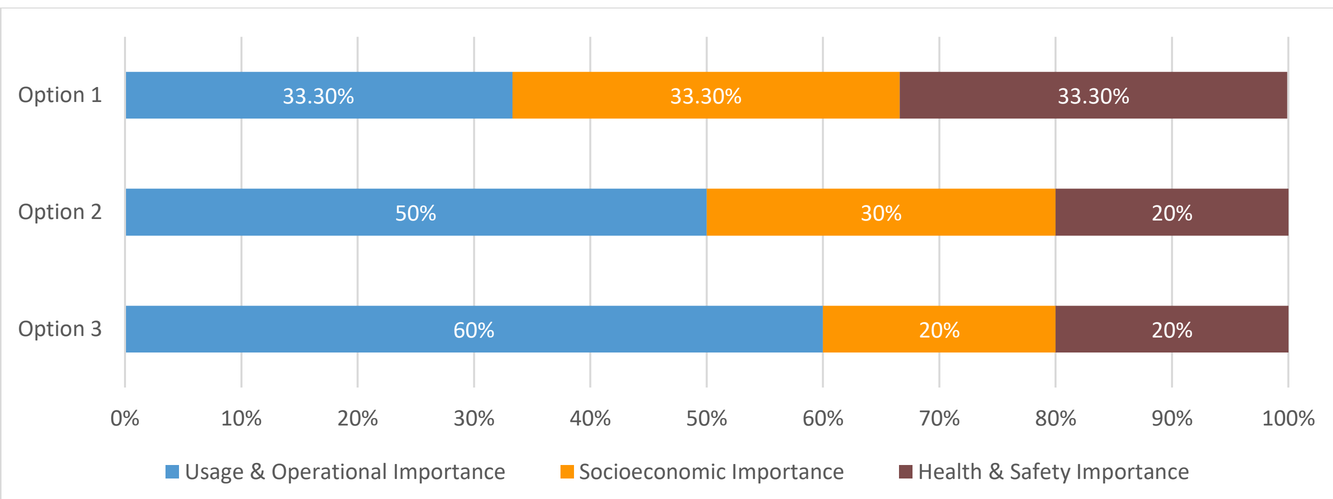
Figure 3.4 Criticality Factors



Next, each of the three criticality factors were assigned a different weighting to directly influence overall criticality levels. As visualized in Figure 3.5, three combinations of weighting were considered:

- **Option 1 – Equal Weighting:** Usage and Operational Importance – 33.3%, Socioeconomic Importance – 33.3%, Health and Safety Importance – 33.3%
- **Option 2 – 'High-to-Low' Weighting:** Usage and Operational Importance – 50%, Socioeconomic Importance – 30%, Health and Safety Importance – 20%
- **Option 3 – Functionality Priority Weighting:** Usage and Operational Importance – 60%, Socioeconomic Importance – 20%, Health and Safety Importance – 20%

Figure 3.5 Criticality Scoring Options



The three options for weighing criticality factors were identified based on discussions with RIDOT staff, and subsequent feedback provided at workshops hosted by RIDOT as part of the RIP development process. This included feedback from the RIDOT's Asset Management Division, the Rhode Island Department of Environmental Management, the University of Rhode Island, and Rhode Island's Transportation Advisory Committee (TAC). Ultimately, based on feedback received, RIDOT selected the third option for determining criticality:

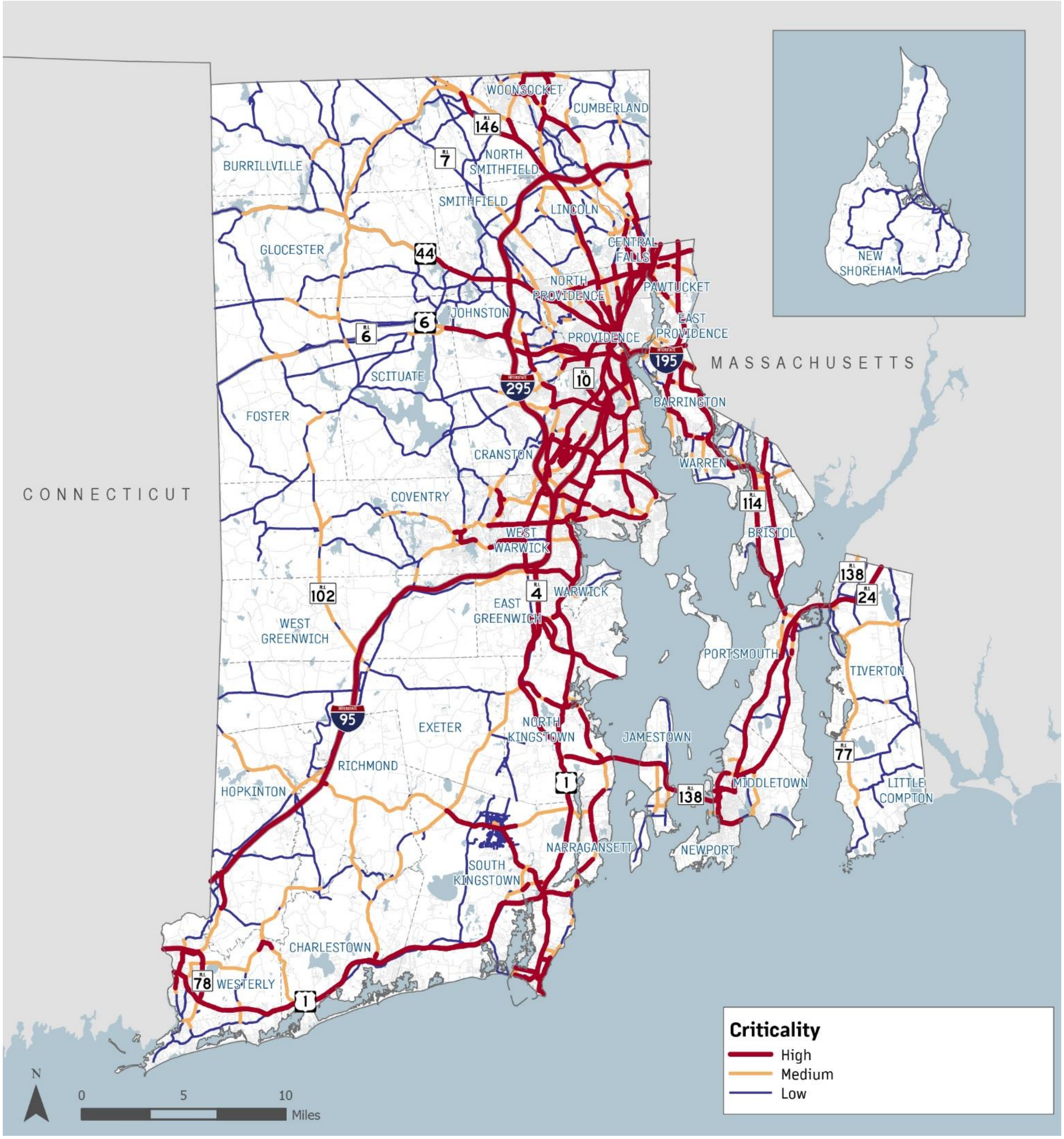
Criticality Score = Usage and Operational Importance * 60% + Socioeconomic Importance * 20%

+ Health and Safety Importance * 20%

After reviewing the range of scores, the results were assigned to three broad categories: High Criticality, Medium Criticality and Low criticality, based on percentile. Overall criticality across the entire Rhode Island road network is shown in Figure 3.6. Based on the third option of criticality weighting, the highest degree of criticality is assigned to many of Rhode Island's major thoroughfares. This includes the entirety of I-95, I-295, US-1, RI-114, RI-138, and RI-146. This also includes the major thoroughfares connecting Rhode Island's coastal communities. Additional portions of the road network designated as high criticality include arterials in and around Point Judith, Warwick, Cranston, and Pawtucket.

With usage & operational importance comprising over half of the total criticality score, overall criticality assigns strong weighting to many of the state's major thoroughfares. Socioeconomic importance as well as health & safety indicators each assign additional localized high criticality scores to additional locations, particularly in urbanized portions of the state and select other communities discussed above. Ultimately, the criticality of each road asset, as identified in this chapter, will feed into the full vulnerability and risk assessment to follow in Chapters 4 and 5.

Figure 3.6 Transportation Network Criticality



4.0 ASSESS SYSTEMWIDE VULNERABILITY AND RISK

With criticality assigned for each asset, and in accordance with PROTECT Formula Funding Implementation Guidance, Chapter 4 provides an assessment of vulnerabilities and risk to current and future weather events and natural disasters. This process is important to determine the magnitude of threats for Rhode Island's most critical transportation assets. It also sets the stage for identifying physical strategies and implementation mechanisms.

4.1 Identify Hazards and Scenarios

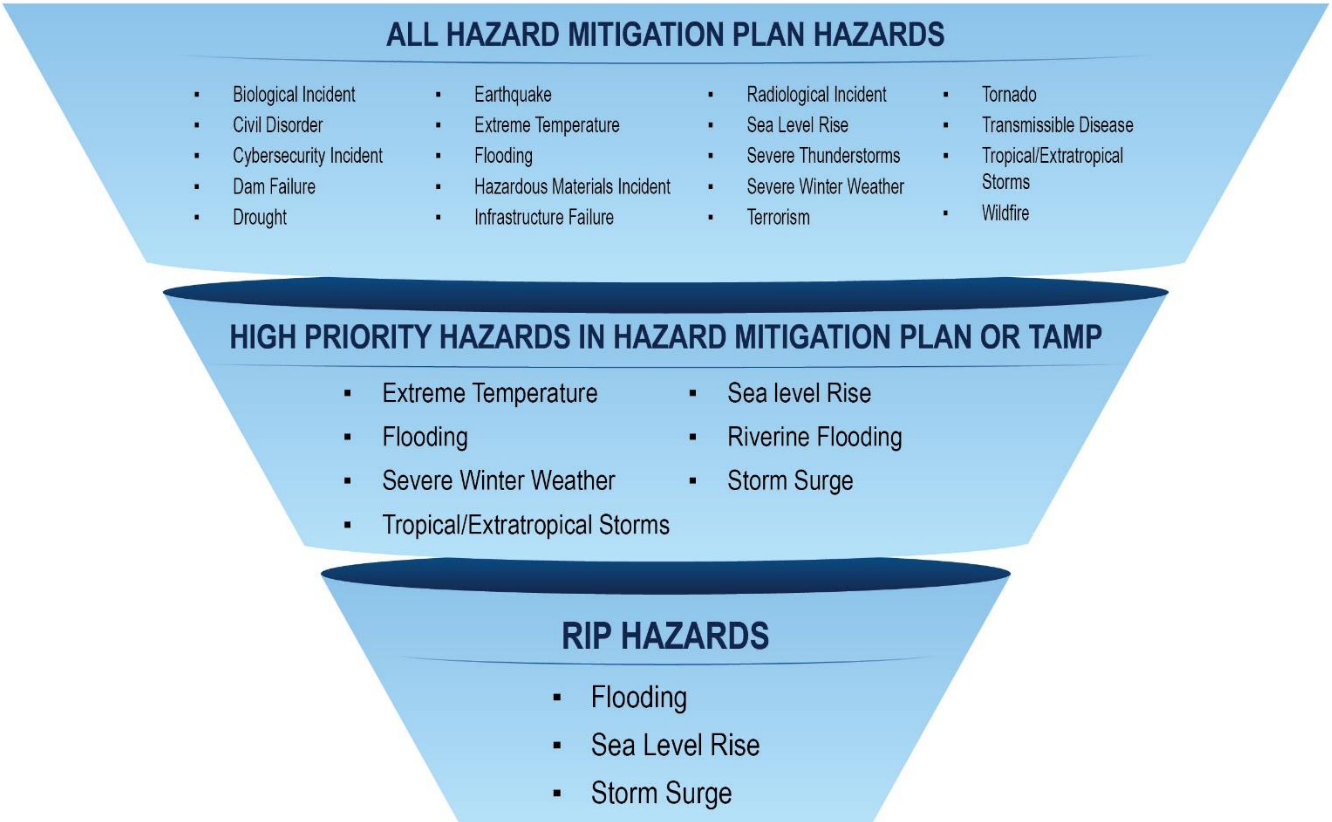
Driven in large part by climate change, the U.S. and its extensive network of transportation assets are becoming increasingly vulnerable to various forms of extreme weather, ranging from floods and hurricanes, to wildfires and droughts. Nicknamed the 'Ocean State', Rhode Island's coastal geography makes it especially vulnerable to the hazardous effects of climate change, with the risks expected to grow in the upcoming decades. The next step in the vulnerability and risk assessment, following the assignment of criticality, is to identify the most significant and relevant hazards and threats to the Rhode Island multimodal transportation system.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (3) by addressing consistency with, and building from existing SHMP efforts which identify and analyze key hazards impacting Rhode Island.

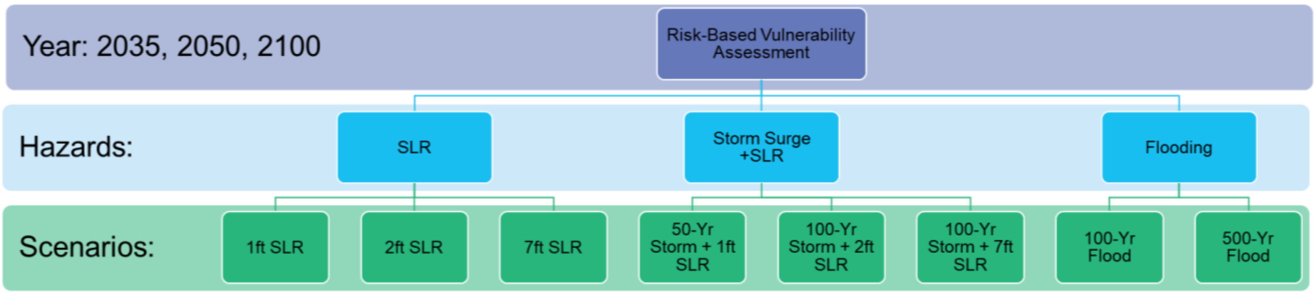
As the initial RIP to be developed addressing the needs of Rhode Island's multimodal transportation system, this vulnerability and risk analysis examined the impacts from sea level rise, storm surge, and flooding. These three hazards were identified given that they pose the greatest physical threat to RIDOT's transportation assets and are identified as high-priority and impactful events. RIDOT's TAMP ranked climate change as the highest risk to RIDOT assets with the highest likelihood and impact among other analyzed risks as it contributes to more significant coastal sea-level rise, riverine flooding, drainage issues, and accelerated asset deterioration. In turn, these threats are expected to produce potentially significant impacts to houses, businesses, and multiple infrastructure components including emergency management assets, energy, and water, as highlighted in the SHMP. Although only three threats (sea level rise (SLR), storm surge, and flooding) are analyzed in the RIP, this analysis will set the foundation and framework for future RIP iterations to assess additional hazards, such as extreme temperatures, severe winter weather amongst others, as identified in Rhode Island's SHMP. Figure 4.1 shows the hazards that were selected for the RIP based on critical SHMP and TAMP hazards.

Figure 4.1 Hierarchy of Hazards for the RIP



For each hazard, multiple scenarios were analyzed to determine the risk across a range of possibilities. The risk of all the analyzed hazard scenarios were combined to estimate a composite risk for 2035, 2050, and 2100, taking into account each hazard scenario' probability of occurring and impact to the transportation system in each of these years. Figure 4.2 shows the study hazards and associated scenarios for the risk-based vulnerability assessment.

Figure 4.2 Hazards and Scenarios



4.2 Assess Vulnerability of Assets

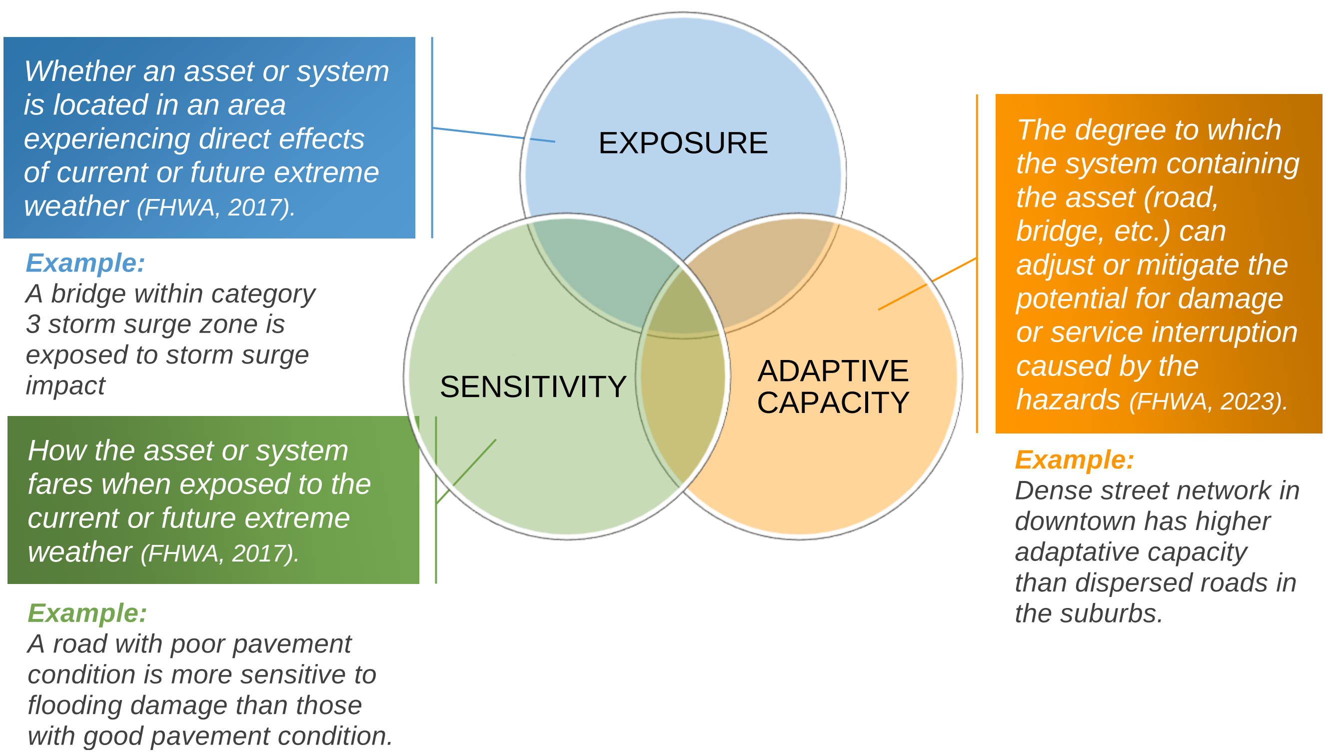
With the three hazards of sea level rise, storm surge, and flooding identified, the next step is to evaluate the vulnerability of each asset. RIDOT adopted FHWA's definition for vulnerability as *the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events*.[8] The vulnerability of an asset is directly is a factor of three components:

- **Exposure:** Identified whether an asset or system is located in an area experiencing direct effects of current or future extreme weather.
- **Sensitivity:** Refers to how the asset or system fares when exposed to the current or future extreme weather.
- **Adaptive Capacity:** The degree to which the asset can adjust or mitigate damage or disruption caused by a hazard or threat.

> **VULNERABILITY Definition:**
>
> The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events.
>
> -- FHWA.

These components are explained in further detail below in Figure 4.3.

Figure 4.3 Vulnerability Components

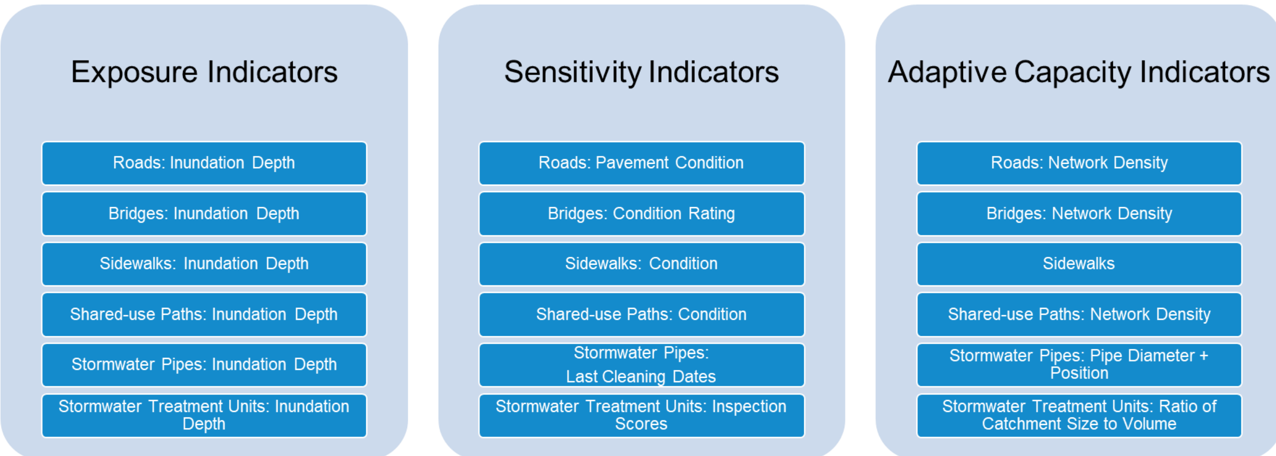


[8] Vulnerability Assessment and Adaptation Framework, 3rd Edition

The RIP employed an indicator-based desktop approach to evaluate vulnerabilities of transportation assets across the state using the Vulnerability Assessment Scoring Tool (VAST) developed by U.S. Department of Transportation. The tool measures vulnerability as a function of exposure, sensitivity, and adaptive capacity and uses certain characteristics of transportation assets as indicators to reflect different assets' exposure, sensitivity, or adaptive capacity, and operationalizes this information into relative vulnerability scores. This was done for the combination of study hazards and asset types within this Microsoft Excel®-based tool (with macros).

Figure 4.4 identifies how exposure, sensitivity, and adaptive capacity are measured across the six asset classes. The three components of vulnerability are each explained in further detail to follow.

Figure 4.4 Indicators of Exposure, Sensitivity & Adaptive Capacity by Asset Type



4.2.1 Exposure

Exposure refers to the geographic location of an asset in relation to a hazard or threat. As defined by FHWA, exposure is determined by whether an asset or system is located in an area experiencing direct effects of current or future extreme weather. As part of this vulnerability and risk assessment, exposure for each of the six asset classes is derived from impacts from each hazard, across three scenarios of inundation:

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (14) by integrating science and data to inform the risk-based analysis.

- **Sea Level Rise Exposure:** Measured by the inundation depth of the mean higher high water (MMHW)[9] level plus 1 foot, 2 feet, or 7 feet of sea level rise. Data for sea level rise exposure is derived from NOAA's sea level rise dataset for Rhode Island.[10]
- **Storm Surge Exposure:** Measured by the inundation depth of the 100-year storm plus 1 foot, 2 feet, or 7 feet of sea level rise. Data for storm surge exposure is derived from the University of Rhode Island's STORMTOOLS website, with location data transferred for each asset. [11]
- **Flooding Exposure:** Measured by whether the asset is located in a current floodway, 100-year floodplain, or 500-year floodplain. Data for flooding exposure is derived from the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer geospatial database, with location data transferred for each asset.[12] For some locations where base flood elevation (BFE) data was also available, the elevation of the asset was subtracted from the flooding depth to better identify which assets would be inundated. BFE and asset height data where available was derived from digital elevation model (DEM) datasets in NOAA North American Vertical Datum of 1988 (NAVD8).

The results of the process to assign exposure scores for each asset class is provided below:

Exposure for Roads

As described above, exposure for each asset class is identified for the three hazards of sea level rise, storm surge, and flooding. To determine exposure scores for sea level rise and storm surge, inundation depths across all three scenarios were applied for each asset, with data classification breaks developed based on Jenks natural breaks optimization. Each road asset is assigned a corresponding value between (1) and (4) based on sea level rise and storm surge in Table 4.1 and Table 4.2. Given that inundation depth was not available for approximately 95% of roads, scoring for flooding exposure is based on the presence of each road in a floodplain, ranging from (0) for those roads not in a floodplain to (4) for those roads located in a current floodplain. Flooding exposure scoring for roads is shown in Table 4.3.

[9] MMHW is defined by NOAA as the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch.

[10] https://coast.noaa.gov/slrdata/

[11] https://stormtools-mainpage-crc-uri.hub.arcgis.com/

[12] https://www.fema.gov/flood-maps/national-flood-hazard-layer

Table 4.1 Sea Level Rise Exposure Scoring for Roads

Inundation Depth	Score
0 – 0.5 ft	1
0.5 – 1 ft	2
1 – 2 ft	3
2 – 11 ft	4

Table 4.2 Storm Surge Exposure Scoring for Roads

Inundation Depth	Score
0 – 2 ft	1
2 – 5 ft	2
5 – 10 ft	3
10 – 30 ft	4

Table 4.3 Flooding Exposure Scoring for Roads

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3
Within Floodway or inundated by Base Flood Elevation	4

Exposure for Bridges

For bridges, a similar desktop exercise was conducted to determine how the approaches of the bridges are exposed to sea level rise, storm surge, or flooding. The overall scoring approach as explained for the roads above was replicated for the bridges.

Table 4.4 Sea Level Rise Exposure Scoring for Bridges

Inundation Depth of Bridge Approaches	Score
0 – 0.5 ft	1
0.5 – 1 ft	2
1 – 2 ft	3
2 – 11 ft	4

Table 4.5 Storm Surge Exposure Scoring for Bridges

Inundation Depth of Bridge Approaches	Score
0 – 2 ft	1
2 – 5 ft	2
5 – 10 ft	3
10 – 30 ft	4

Table 4.6 Flooding Exposure Scoring for Bridges

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3
Within Floodway or inundated by Base Flood Elevation	4

Exposure for Sidewalks

Similarly, to determine exposure scores for sea level rise and storm surge, inundation depths across all three scenarios were applied for sidewalks, with data classification breaks developed based on Jenks natural breaks optimization, as shown in Table 4.7 and Table 4.8. For sea level rise the inundation depth of water above just under 5 inches (0.4 ft) is assigned the highest exposure score. At this approximate level of inundation the ability of a pedestrian of average strength and build to walk becomes cumbersome. Flooding exposure scoring breaks are shown in Table 4.9.

Table 4.7 Sea Level Rise Exposure Scoring for Sidewalks

Inundation Depth (in feet)	Score
0.001 – 2	1
2 .01– 5	2
5.01 – 10	3
10.01 – 30	4

Table 4.8 Storm Surge Exposure Scoring for Sidewalks

Inundation Depth (in feet)	Score
0 – 0.1	1
0.1 – 0.13	2
0.13 – 0.4	3
0.4 – 2.5	4

Table 4.9 Flooding Exposure Scoring for Sidewalks

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3
Within Floodway	4

Exposure for Shared- Use Paths

For shared-use paths/bikeways, a similar desktop exercise was conducted to determine exposure to sea level rise, storm surge, or flooding based on inundation depths. The scoring approach as explained for the roads above was replicated for the shared-use paths/bikeways. See Table 4.10 to Table 4.12 for exposure scoring for shared-use paths/bikeways for sea level rise, storm surge, and flooding.

Table 4.10 Sea Level Rise Exposure Scoring for Shared-Use Paths

Inundation Depth	Score
0 – 0.5 ft	1
0.5 – 1 ft	2
1 – 2 ft	3
2 – 11 ft	4

Table 4.11 Storm Surge Exposure Scoring for Shared-Use Paths

Inundation Depth	Score
0 – 2 ft	1
2 – 5 ft	2
5 – 10 ft	3
10 – 30 ft	4

Table 4.12 Flooding Exposure Scoring for Shared-Use Paths

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3
Within Floodway or inundated by Base Flood Elevation	4

Exposure for Stormwater Pipes

The exposure of stormwater pipes was measured by the inundation depths of stormwater to the three hazards. The analysis used the elevation of the ground from the Digital Elevation Model (DEM) as a proximity to the elevations of stormwater pipes. The inundation depths and their associated scores for sea level rise and storm surge, are shown in Table 4.13 and Table 4.14. For flooding, the same values and scores as those for roads were used, as shown in Table 4.15.

Table 4.13 Sea Level Rise Exposure Scoring for Stormwater Pipes

Inundation Depth (in feet)	Score
0 – 0.1	1
0 .1 – 0.5	2
0.5 – 1	3
1 – 12	4

Table 4.14 Storm Surge Exposure Scoring for Stormwater Pipes

Inundation Depth (in feet)	Score
0.0001 – 2	1
2– 4	2
4– 10	3
10– 30	4

Table 4.15 Flooding Exposure Scoring for Stormwater Pipes

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3

Within Floodway or inundated by Base Flood Elevation	4

Exposure for Stormwater Treatment Units

The exposure of stormwater treatment units was measured by the inundation depths of stormwater treatment units to the three hazards. The analysis used the elevation of the ground from the DEM as a proximity to the elevation of the stormwater treatment unites. The inundation depths and their associated scores for sea level rise and storm surge, are shown in Table 4.16 and Table 4.17. For flooding, the same values and scores as those for roads were used, as shown in Table 4.18.

Table 4.16 Sea Level Rise Exposure Scoring for Stormwater Treatment Units

Inundation Depth (in feet)	Score
0 – 0.05	1
0 .05– 0.3	2
0.3 – 0.5	3
0.5 – 6.5	4

Table 4.17 Storm Surge Exposure Scoring for Stormwater Treatment Units

Inundation Depth (in feet)	Score
0.0001 – 2	1
2– 4	2
4– 10	3
10– 26	4

Table 4.18 Flooding Exposure Scoring for Stormwater Treatment Units

Location Relative to Floodplains	Score
Not in Floodplain	0
Within 500-year Floodplain	2
Within 100-year Floodplain	3
Within Floodway or inundated by Base Flood Elevation	4

4.2.2 Sensitivity

As defined by FHWA, sensitivity refers to how the asset or system fares when exposed to the current or future extreme weather. A highly sensitive asset will experience a large degree of impact even from a relatively minor hazard or climate variation, whereas a less sensitive asset could withstand relatively higher levels of hazard or climate variation before exhibiting any degree of deterioration. As an example, a road with poor pavement

condition is considered more sensitive to flooding damage than a road whose pavement condition is rated well. The process to assign sensitivity scores for each asset class is provided below.

Sensitivity of Roads

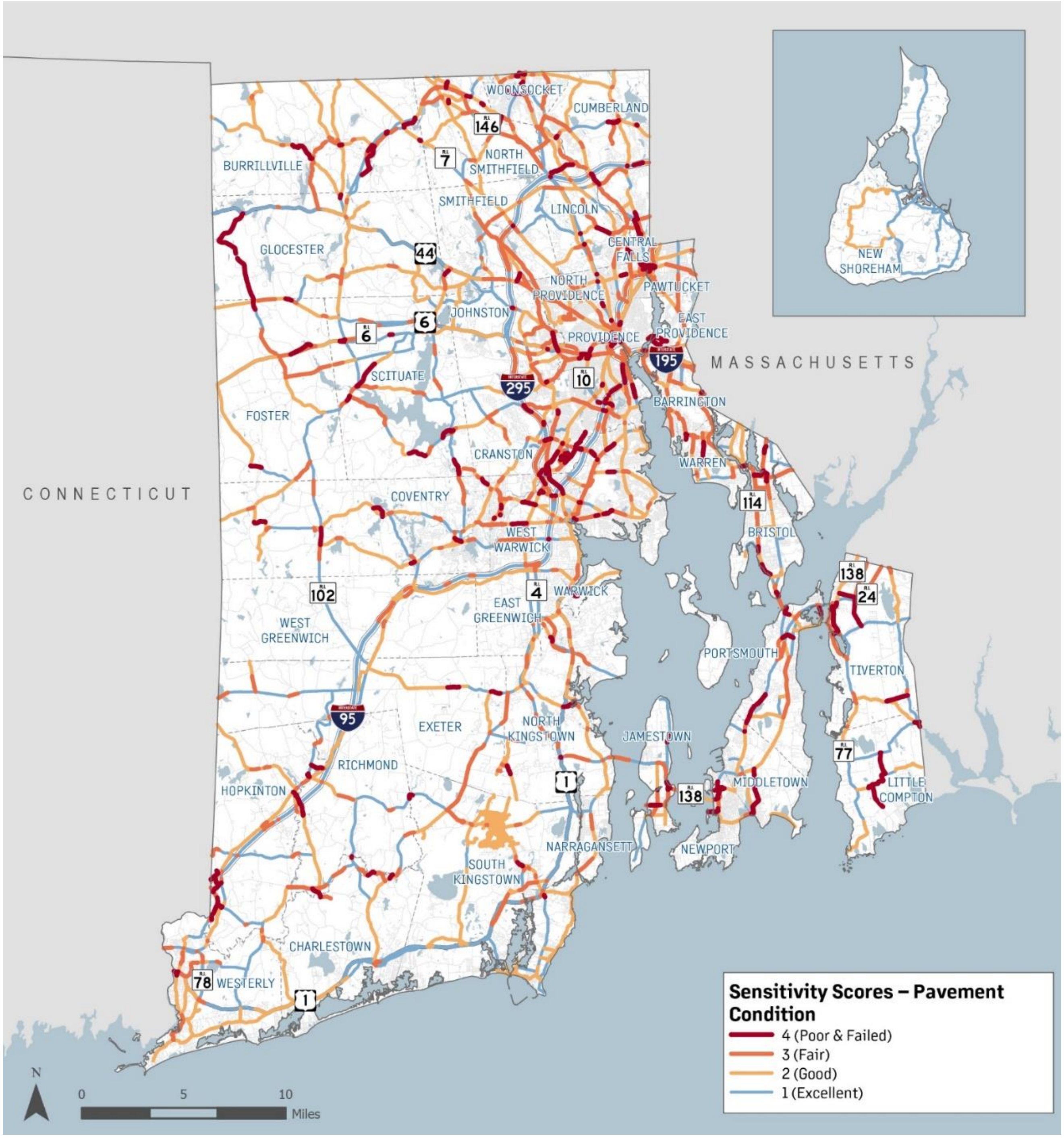
The sensitivity of roads is measured by its pavement condition. To visualize this information geographically, pavement condition data was spatially joined to the roadway network using ArcMap. As identified in RIDOT's TAMP, pavement condition is measured through the Pavement Structural Health Index which assigns values to each road asset based on factors of cracking, patching, rutting, and roughness. To develop data classification breaks and the scoring methodology for road asset sensitivity, each asset is assigned a value between 1 and 4 according to the Pavement Structural Health Index value, as shown in Table 4.19.

Table 4.19 Sensitivity Scoring for Road (Pavement) Condition

Pavement Structural Health Index	Condition	Score
90 - 100	Excellent	1
80 – 89	Good	2
70 – 79	Fair	3
0 – 69	Poor or Failed	4

These Pavement Structural Health Index and the corresponding scoring system are visualized across the Rhode Island network in Figure 4.5 for arterials, interstates, and expressways. The majority of the road network generates a sensitivity score of 2 or 3, based on pavement conditions of 'Good' or 'Fair'. Locations with a sensitivity score of 4, based on a pavement condition of 'Poor' are found in scattered areas of the state in segments. These segments are most concentrated in the northern half of the state, in addition to coastal Rhode Island. Especially the case with coastal Rhode Island, these areas to tend to generate the highest exposure and criticality scores as well.

Figure 4.5 Sensitivity Scores for Roads: Pavement Condition



Sensitivity of Bridges

The sensitivity of bridges is measured by the bridge condition ratings. Table 4.20 shows how bridge condition data was classified into four breaks and the scores that were assigned to these dates in the VAST.

Table 4.20 Sensitivity Scoring for Road (Pavement) Condition

Bridge Condition	Score
Good	1
Fair	3
Poor	4

Sensitivity of Sidewalks

The sidewalks dataset does not contain infrastructure condition information. As a result, pavement condition for roads is assumed to be apply for sidewalks, and was spatially applied to the sidewalks layer in ArcMap.

Table 4.21 Sensitivity Scoring for Sidewalks

Pavement Structural Health Index	Condition	Score
90 - 100	Excellent	1
80 – 89	Good	2
70 – 79	Fair	3
0 – 69	Poor and Failed	4

Sensitivity of Shared-Use Paths

The shared-use path dataset does not contain infrastructure condition information. As a result, pavement condition for roads is assumed to apply for shared-use paths, and was spatially applied to the shared-use paths layer in ArcMap. Only shared-use paths along the road network were selected for the analysis.

Table 4.22 Sensitivity Scoring for Shared-Use Paths

Pavement Structural Health Index	Condition	Score
90 - 100	Excellent	1
80 – 89	Good	2
70 – 79	Fair	3
0 – 69	Poor and Failed	4

Sensitivity of Stormwater Pipelines

The sensitivity of stormwater pipes is measured by their last cleaning dates. Pipes that have not been cleaned and flushed in a long time are more susceptible to the impacts of the three hazards of sea level rise, storm surge or flooding. For records that didn't have a last cleaning date, a score of "0" was assumed. Table 4.23 shows how the cleaning dates were classified into four breaks and the scores that were assigned to these dates in the VAST.

Table 4.23 Sensitivity Scoring for Stormwater Pipelines

Last Cleaned Dates	Score
2017 and earlier	4
2018 - 2019	3
2020 - 2021	2
2022 and later	1

Sensitivity of Stormwater Treatment Units

The sensitivity of stormwater treatment units is measured by the stormwater treatment condition. Table 4.24 shows how stormwater treatment unit condition data from RIDOT was classified into four breaks and the scores that were assigned to these dates in the VAST.

Table 4.24 Sensitivity Scoring for Stormwater Treatment Units

Stormwater Treatment Condition	Score
>0 and <= 30	4
30 - 60	3
60- 90 & No Data	2
90-100	1

4.2.3 Adaptive Capacity

As defined by FHWA, adaptive capacity refers to the ability of a transportation asset or system to adjust, repair, or flexibly respond to damage caused by climate variability or extreme weather. As an example, if an asset is closed or restricted due to a hazard, adaptive capacity would measure how detrimental this closure would be to the functionality of the entire transportation network. The process to assign adaptive capacity scores for each asset class is provided below:

Adaptive Capacity for Roads

The adaptive capacity of road assets is measured by network density, identified by the number of roadway links per square mile, calculated around each asset. A higher degree of network density would indicate a higher level of adaptive capacity for a particular road, given the likelihood that more detour options would likely be possible in the event of disruption to one or more parts of the network. Inversely, a road with a lower degree of network density, such as rural or exurban link, would have less detour options in the event of disruption.

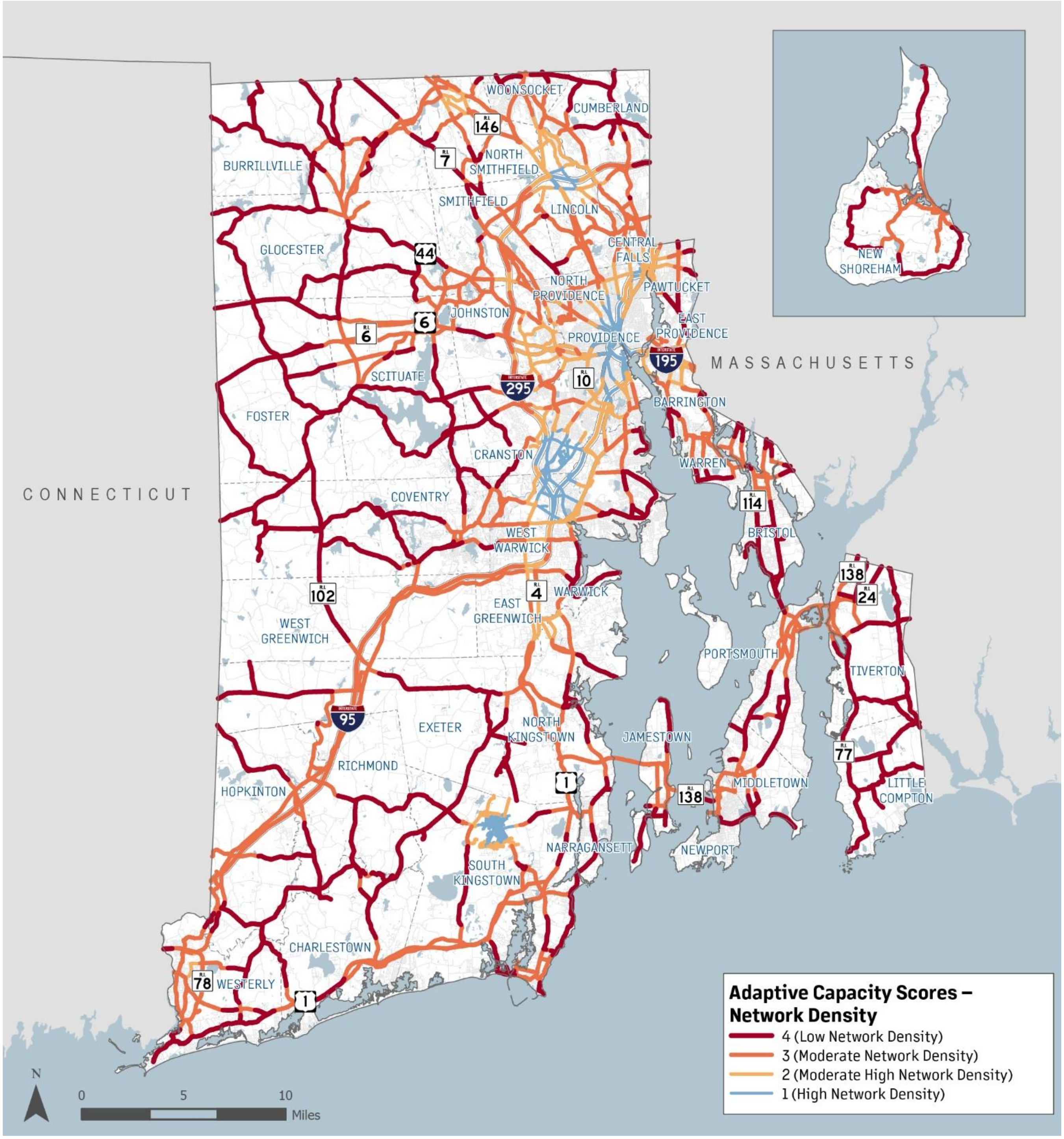
To visualize this information geographically, the Kernel Density Spatial Analyst Tool of ArcMap is utilized. Subsequently, the Zonal Statistics tool is used to transfer the resulting raster data into the primary feature class data layer. Lastly, summary statistics are calculated to help identify meaningful data classification breaks, measured by the number of roads per square mile. Each road asset is assigned a corresponding value between (1) and (4) based on network density as shown in Table 4.25.

Table 4.25 Adaptive Capacity Scoring for Roads

Network Density (Number of Roads per Square Miles)	Score
0.1 – 1	4
1.01 – 2	3
2.01 – 3	2
3.01 – 5	1

Network density is visualized on the road network in Figure 4.6. Network density is highest in and around Providence and Cranston. This is expected given that these are the most urbanized portions of the state. Although most of coastal Rhode Island has a relatively dense population density, the comparatively smaller number of thoroughfares into and out of these area limits total network density.

Figure 4.6 Network Density of Roads



Adaptive Capacity for Bridges

The adaptive capacity for bridges is also measured by network density, identified by the number of bridge links per square mile. The methodology and resulting dataset generated for roads was subsequently applied to the bridge dataset. As a result, the adaptive capacity scoring for roads, shown in Table 4.26 is applied for bridges as well.

Table 4.26 Adaptive Capacity Scoring for Bridges

Network Density (Number of Roads per Square Miles)	Score
0.1 – 1	4
1.01 – 2	3
2.01 – 3	2
3.01 – 5	1

Adaptive Capacity for Sidewalks

The adaptive capacity for sidewalks is also measured by network density, identified by the number of sidewalk links per square mile. The methodology and resulting dataset generated for roads was subsequently applied to the sidewalk dataset. As a result, the adaptive capacity scoring for roads, shown in Table 4.27, is applied for sidewalks as well.

Table 4.27 Adaptive Capacity Scoring for Sidewalks

Network Density (Number of Roads per Square Miles)	Score
0.1 – 1	4
1.01 – 2	3
2.01 – 3	2
3.01 – 5	1

Adaptive Capacity for Shared-Use Paths

The adaptive capacity for shared-use paths is also measured by network density, identified by the number of shared-use path links per square mile. Using the same methodology for roads, a separate network density analysis was conducted for the shared-use path network. Each bike lane asset is assigned a corresponding value between (1) and (4) based on network density as shown in Table 4.28.

Driven to get you there

Table 4.28 Adaptive Capacity Scoring for Shared-Use Paths

Network Density (Number of Bike Lanes per Square Miles)	Score
0.1 – 0.3	4
0.301 – 0.5	3
0.501 – 0.8	2
0.801 – 1.3	1

Adaptive Capacity for Drainage Pipelines

The adaptive capacity of stormwater pipes is measured by the location of the stormwater pipes, specifically whether it is upstream or downstream. Pipes that are located upstream will have better adaptive capacity (thus lower adaptive capacity scores) than those that are downstream due to downstream pipes becoming increasingly inundated from upstream flow. The Digital Elevation Model was used to find the locations of these stormwater pipes and the following scoring approach as shown in Table 4.29 was applied for the VAST.

Table 4.29 Adaptive Capacity Scoring for Stormwater Pipes

Value (DEM)		Score
0 – 95	Downstream	4
95.1 - 200		3
200.1 - 335	Upstream	2
335.1 - 611		1

Adaptive Capacity for Stormwater Treatment Units

The adaptive capacity of stormwater treatment units is measured by the treatment depth or the Stormwater Treatment Unit Volume/ Catchment Area. A treatment depth of an STU greater than 7.3 will be able to capture the entirety of a 50 year storm whereas a stormwater treatment unit with a treatment depth less than 2.7 will only be able to capture a <1 year storm event. The adaptive capacity of the former is better (thus with lower scores contributing for vulnerability) because it will be able to withstand stronger storms and will take less time and resources for repair if it gets damaged because of these storm events.

Table 4.30 Adaptive Capacity Scoring for Stormwater Treatment Units

24 hour (Type III) Rainfall Amount (inches)	Score
0 – 2.7 (< 1 yr storm)	4
2.7 – 4.9 (1 – 10 yr storm)	3
4.9 – 7.3 (10 – 50 yr storm)	2
>7.3 (>50 yr storm)	1

4.2.4 Visualization of Vulnerability

Vulnerability, as a factor of exposure, sensitivity, and adaptive capacity combined, is described in the following sub-sections, primarily for the most serious scenarios of 7-foot sea level rise, and 100-year storm overlaid to 7-foot sea level rise, as well as inland flooding. For each asset type, additional vulnerability maps for the lesser 1-foot and 2-foot sea level rise, and 1-foot sea level rise, and 100-year storm plus 2-foot sea level rise can be found in in Appendix F: Vulnerability Outputs.

Roads & Bridges

The overall vulnerability of roads & bridges up to 7-foot sea level rise scenarios is shown in Figure 4.7. Under scenarios of 1-foot and 2-foot sea level rise, total vulnerability is isolated to a few portions of coastal Rhode Island, primarily in Narragansett, Newport, and Portsmouth. Under a 7-foot sea level rise, total vulnerability is expanded to include additional portions of coastal Rhode Island, including scattered portions of the RI-114 corridor. Arterials within these locations are expected to have the highest total vulnerability.

Figure 4.8 assess total vulnerability across the multiple scenarios of storm surge overlaid to sea level rise. Overall, the addition of, and progressive increase in storm surge produces gradual increases in vulnerability across most portions of coastal Rhode Island between Point Judith and Providence. Under a scenario of a 100-year storm overlaid to 7-foot sea level rise, the majority of coastal Rhode Island, including a sizable portion of the area's arterials are expected to fall under the category of high vulnerability.

Lastly, vulnerability to inland flooding is shown in Figure 4.9. Overall, scattered arterials throughout Rhode Island are expected to have a high degree of vulnerability to inland flooding. This includes portions of a number of arterials across inland and western Rhode Island, as well as a higher concentration of arterials and thoroughfares in and around Newport, the RI-114 corridor, and other portions of coastal Rhode Island.

Figure 4.7 Vulnerability of Roads & Bridges to 7-Foot Sea Level Rise Scenario

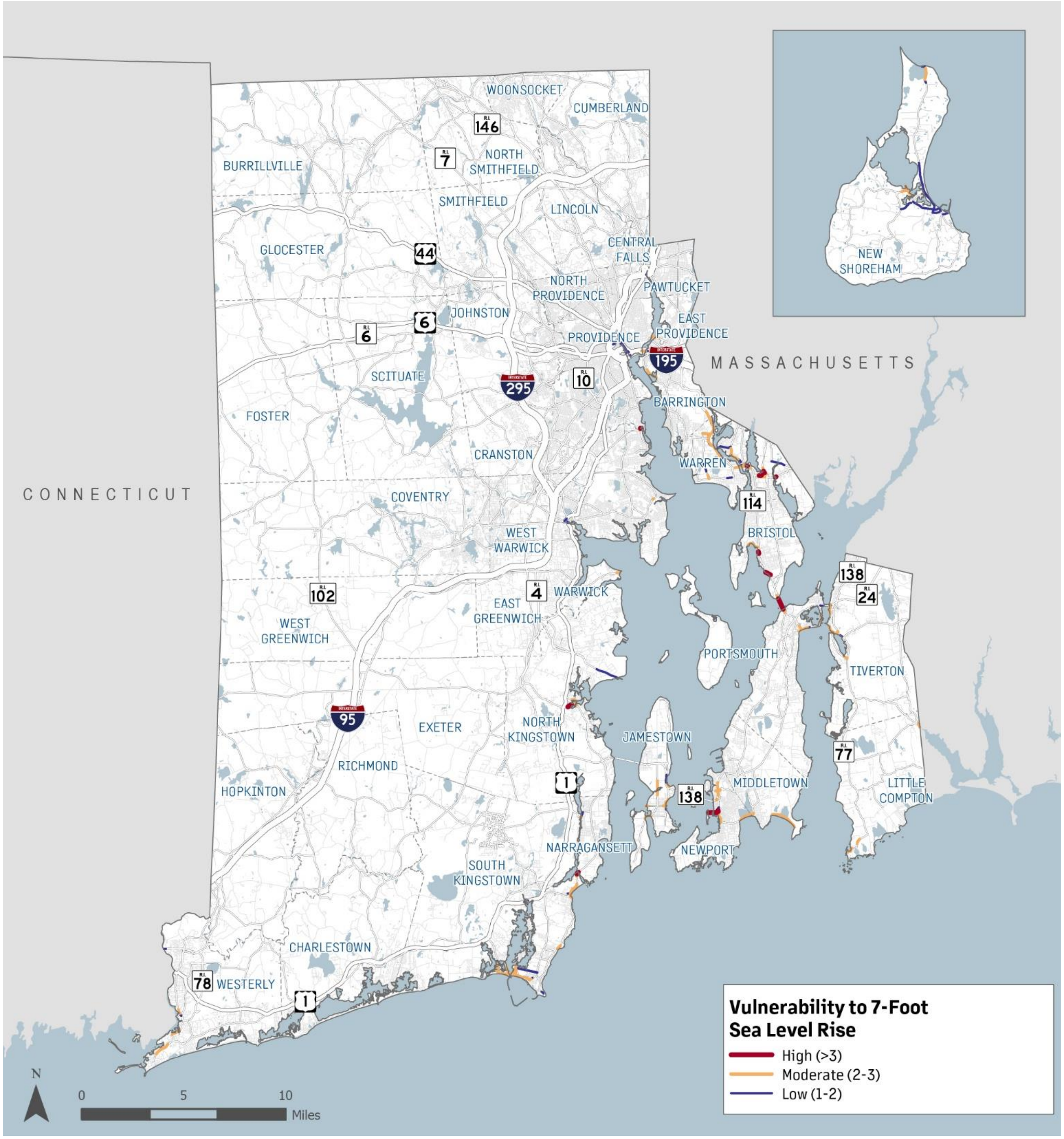
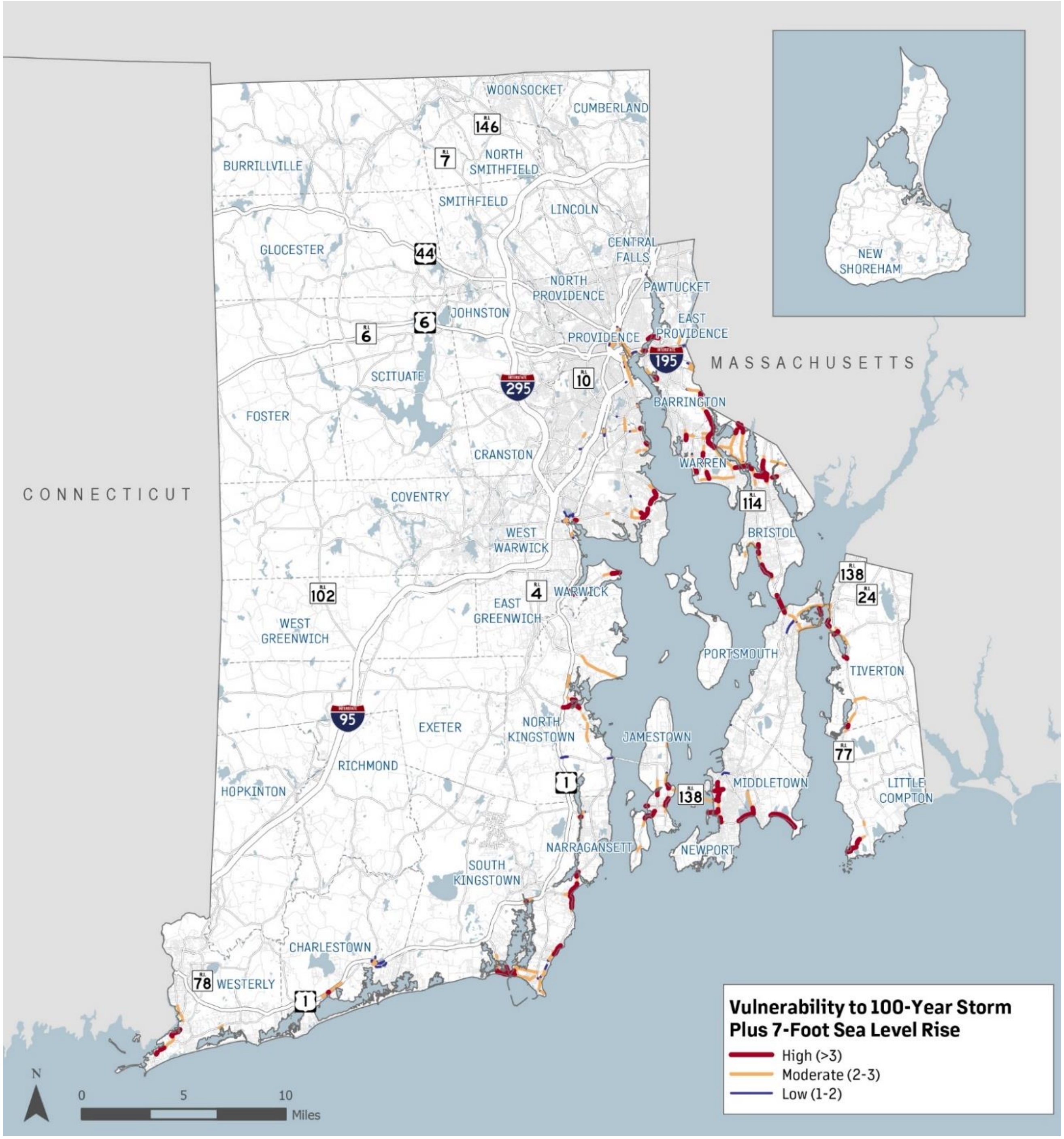
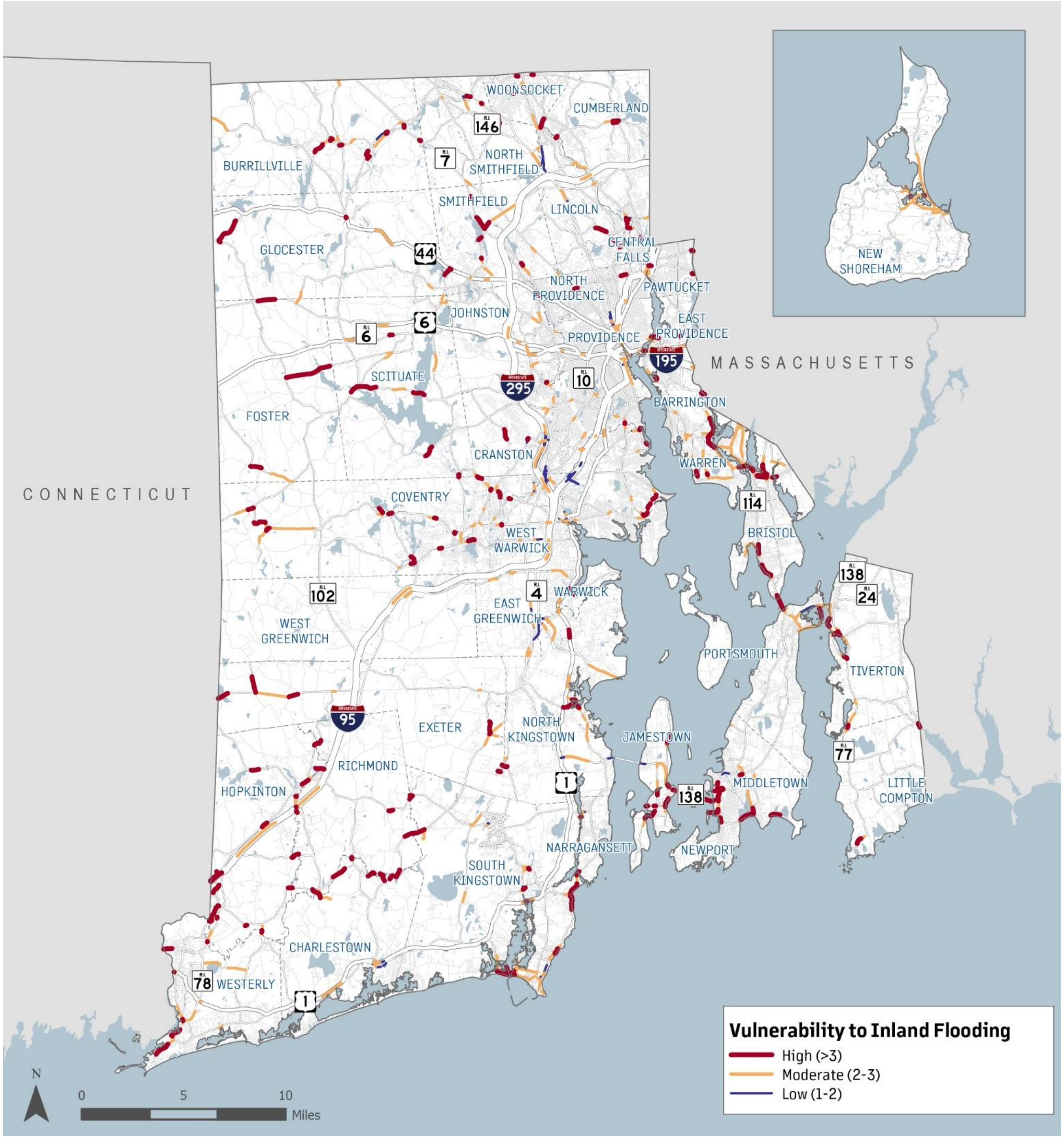


Figure 4.8 Vulnerability of Roads & Bridges: Inundation of 100-Year Storm + 7 Foot Sea Level Rise Scenario



Note: Storm Surge data is not available for New Shoreham.

Figure 4.9 Vulnerability of Roads & Bridges to Inland Flooding



Sidewalks

The overall vulnerability of sidewalks to 7-foot sea level rise scenarios is shown in Figure 4.10. Under scenarios of 1-foot and 2-foot sea level rise, total vulnerability is isolated to a few portions of coastal Rhode Island, primarily in Central Falls, Providence. Under a 7-foot sea level rise, total vulnerability is expanded to include additional portions of coastal Rhode Island, including scattered portions of the RI-114 corridor, sidewalks in Middletown, New Shoreham and south of Narragansett.

Figure 4.11 assesses total vulnerability across the multiple scenarios of storm surge overlaid to sea level rise. As these three figures show, the addition of, and progressive increase in storm surge produces gradual increases in vulnerability across most portions of coastal Rhode Island between Bristol and Providence and in Middletown and Jamestown. Under a scenario of a 100-year storm overlaid to 7-foot sea level rise, the majority of coastal Rhode Island, including a sizable portion of the area's arterials are expected fall under the category of high vulnerability.

Lastly, vulnerability to inland flooding is shown in Figure 4.12. Overall, sidewalks scattered throughout the inland areas and at the coast of Rhode Island are expected to have a high degree of vulnerability to inland flooding. This includes portions of sidewalks across inland and western Rhode Island, as well as a higher concentration of sidewalks along arterials and thoroughfares in and around Newport, the RI-114 corridor, and other portions of coastal Rhode Island.

Figure 4.10 Vulnerability of Sidewalks to 7-Foot Sea Level Rise Scenario

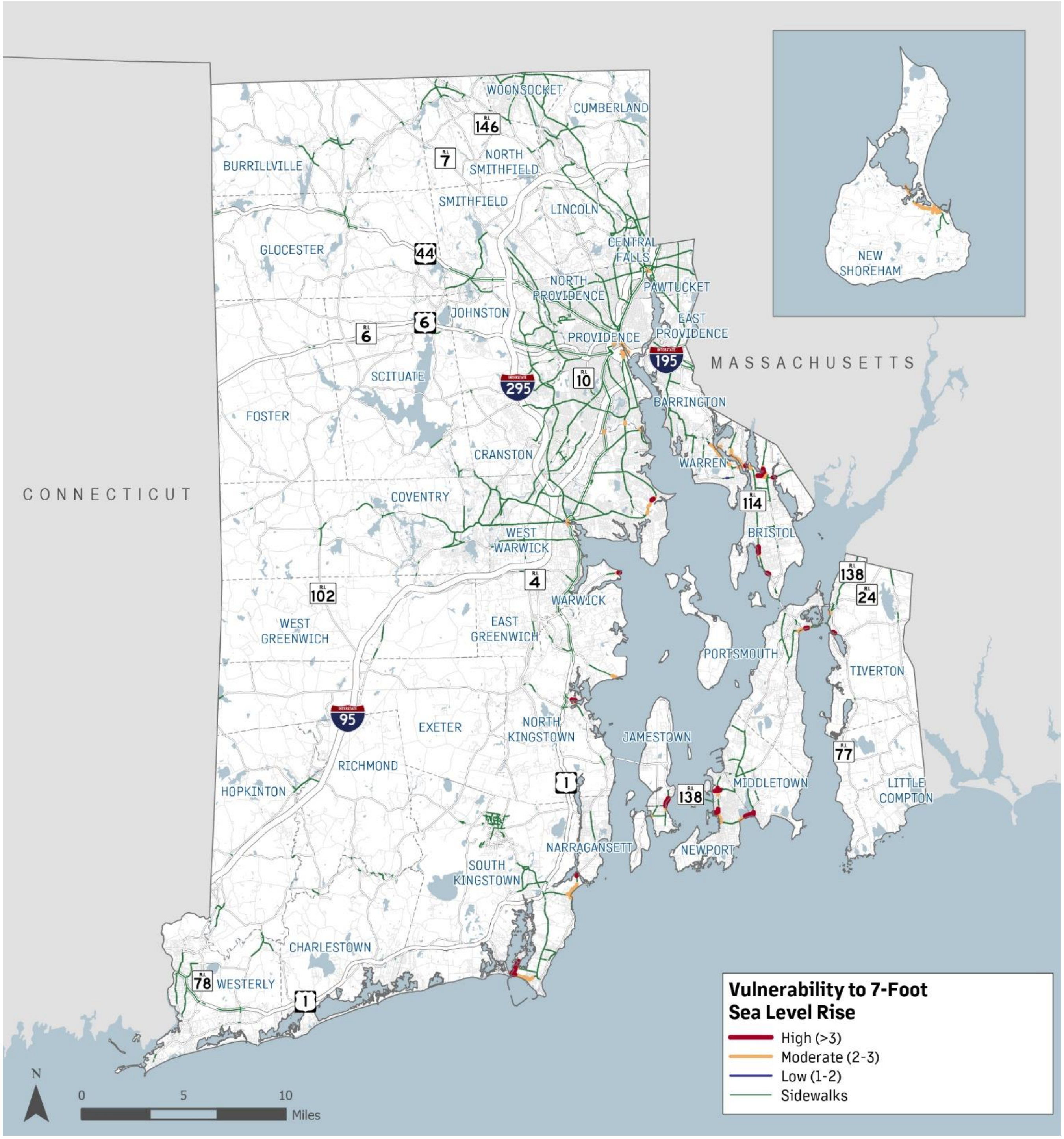
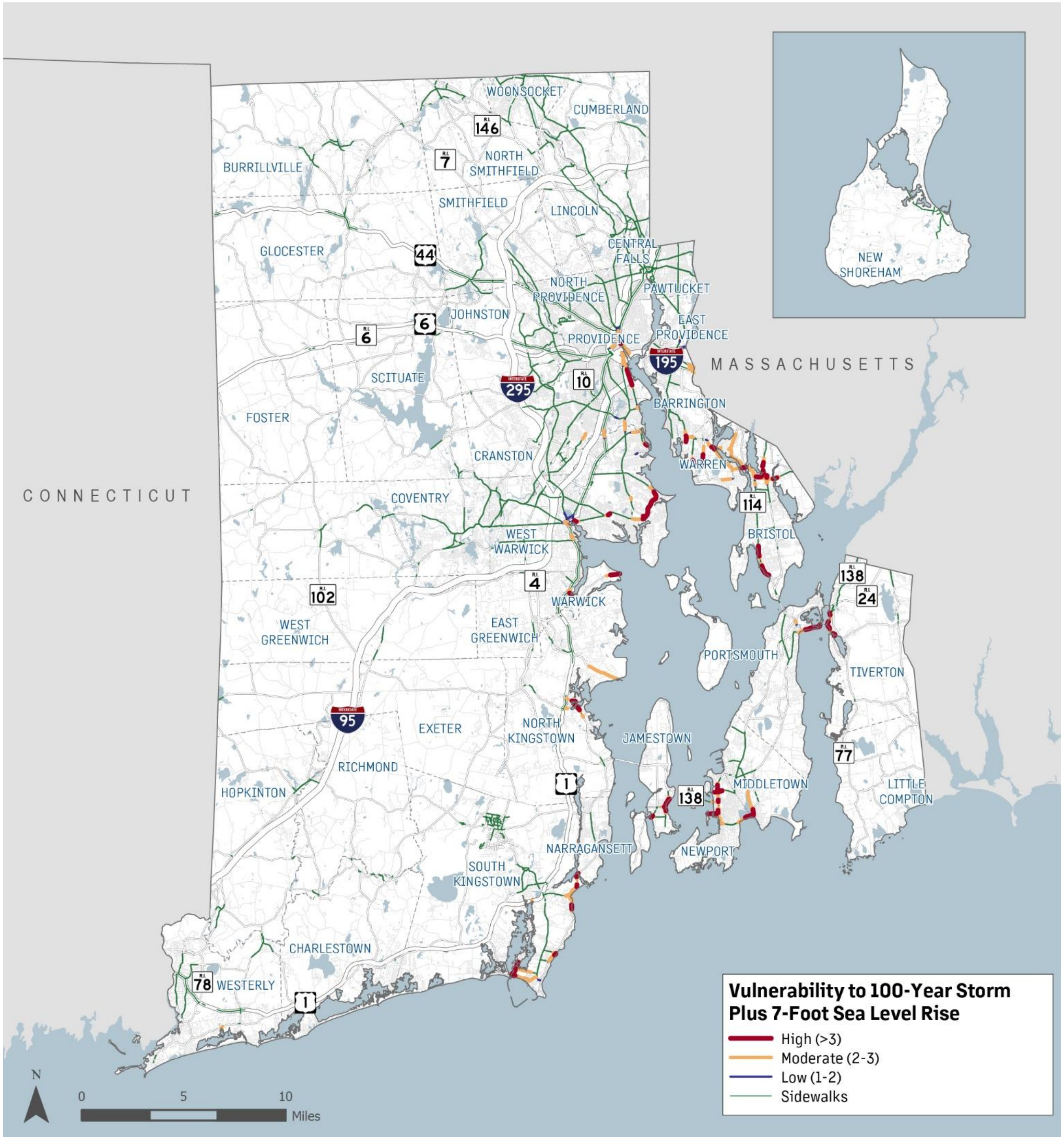
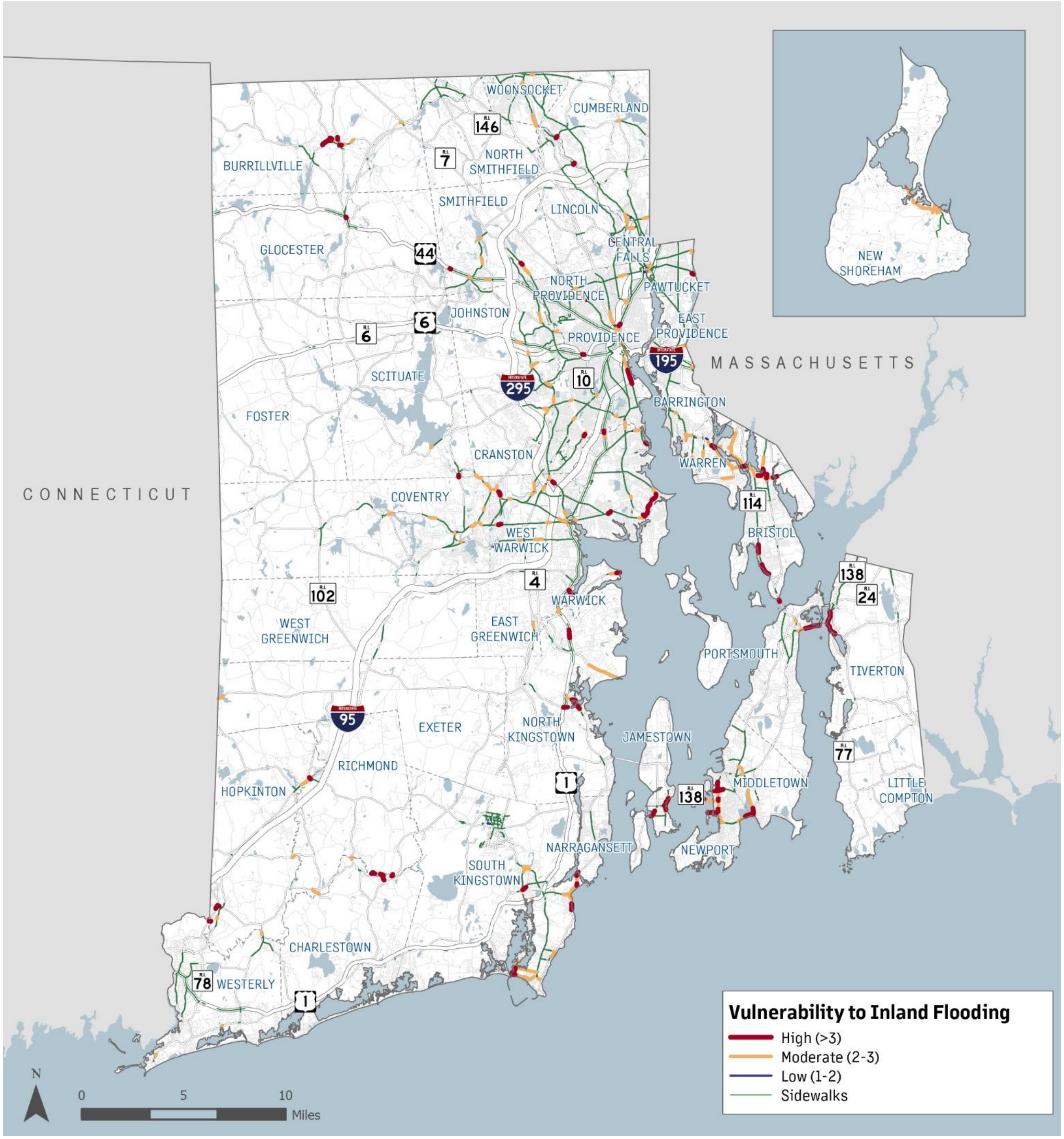


Figure 4.11 Vulnerability of Sidewalks: Inundation of 100-Year Storm + 7 Foot Sea Level Rise Scenario



Note: Storm Surge data is not available for New Shoreham

Figure 4.12 Vulnerability of Sidewalks to Inland Flooding



Shared Use Paths

The overall vulnerability of shared use paths increases progressively over the 7- foot scenario as shown in Figure 4.13. In the 1- foot sea level rise scenario there are no shared use paths that are vulnerable, proceeding to some segments falling under low vulnerability in the 2- foot scenario in Bristol and then a combination of low and moderate vulnerability in the 7- foot scenario in Bristol, Newport and south of Narragansett.

Figure 4.14 assesses total vulnerability across the multiple scenarios of storm surge overlaid to sea level rise. As these three figures show, the addition of, and progressive increase in storm surge produces gradual increases in vulnerability in areas close to Providence, Newport, Warwick, and Narragansett and portions to the south of it.

Lastly, vulnerability to inland flooding is shown in Figure 4.15. Vulnerable shared used paths to flooding are scattered inland and along the coast of Rhode Island, with those showing high vulnerability concentrated in the Newport region.

Figure 4.13 Vulnerability of Shared-Use Paths to 7-Foot Sea Level Rise Scenario

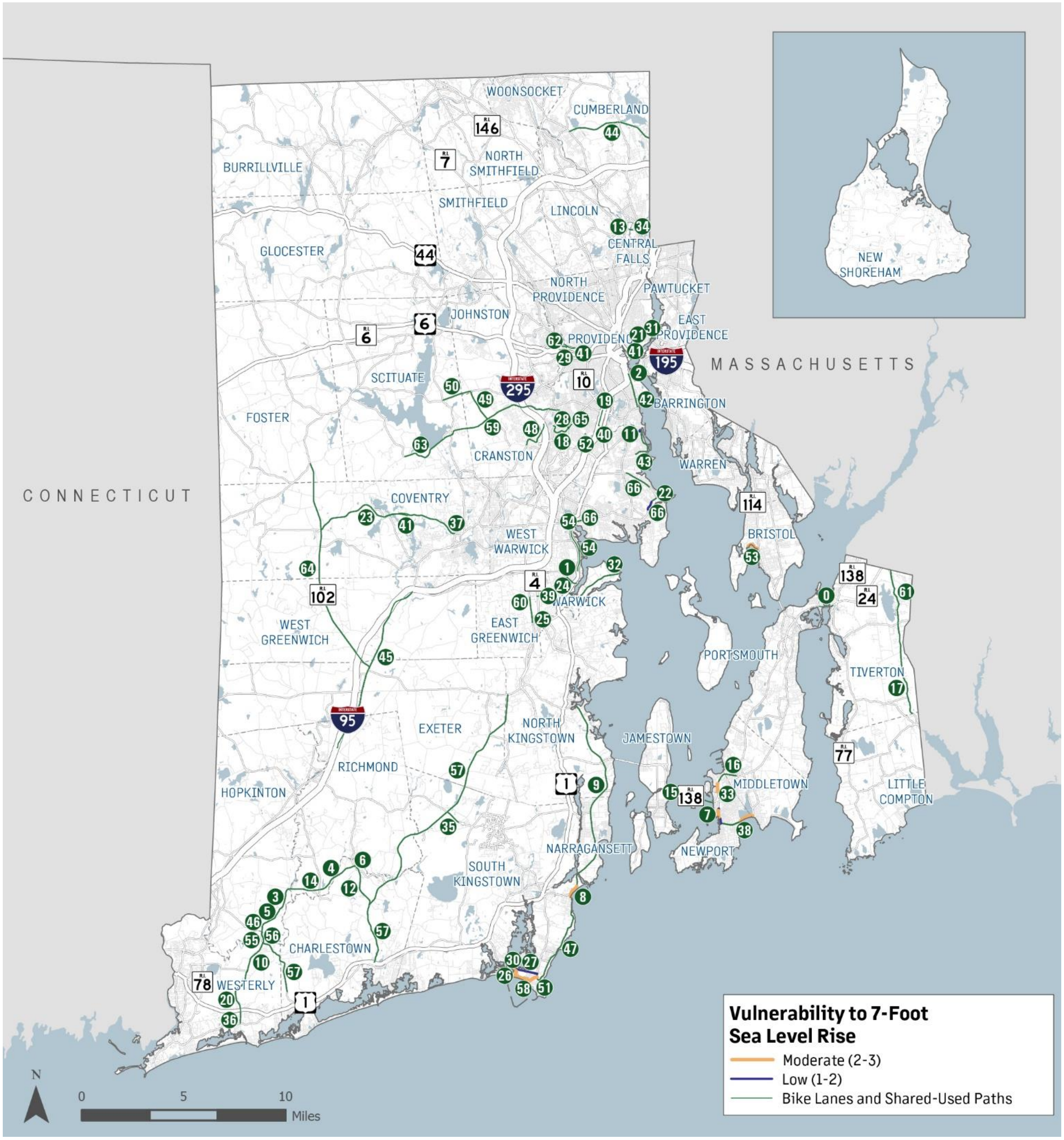
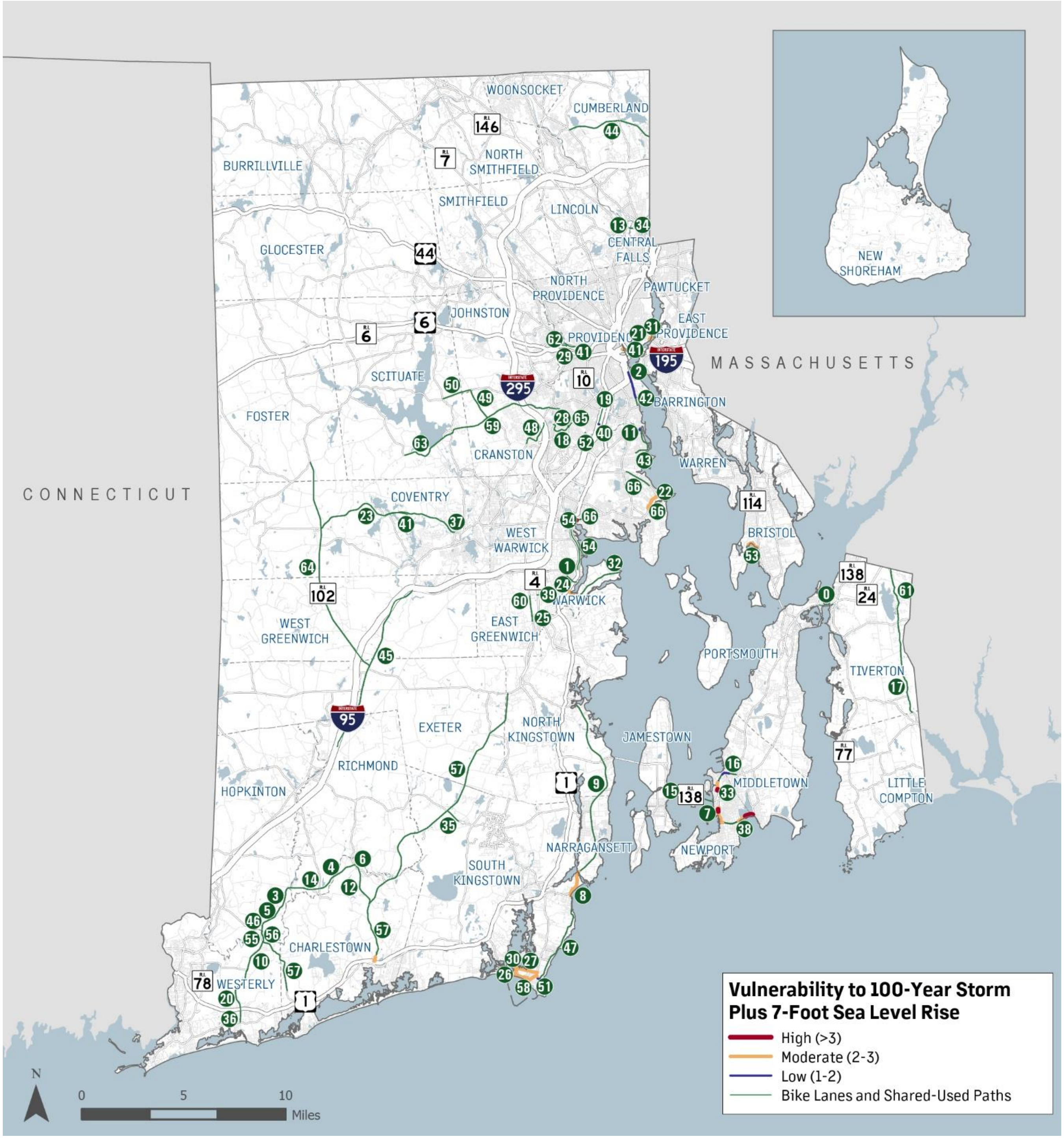
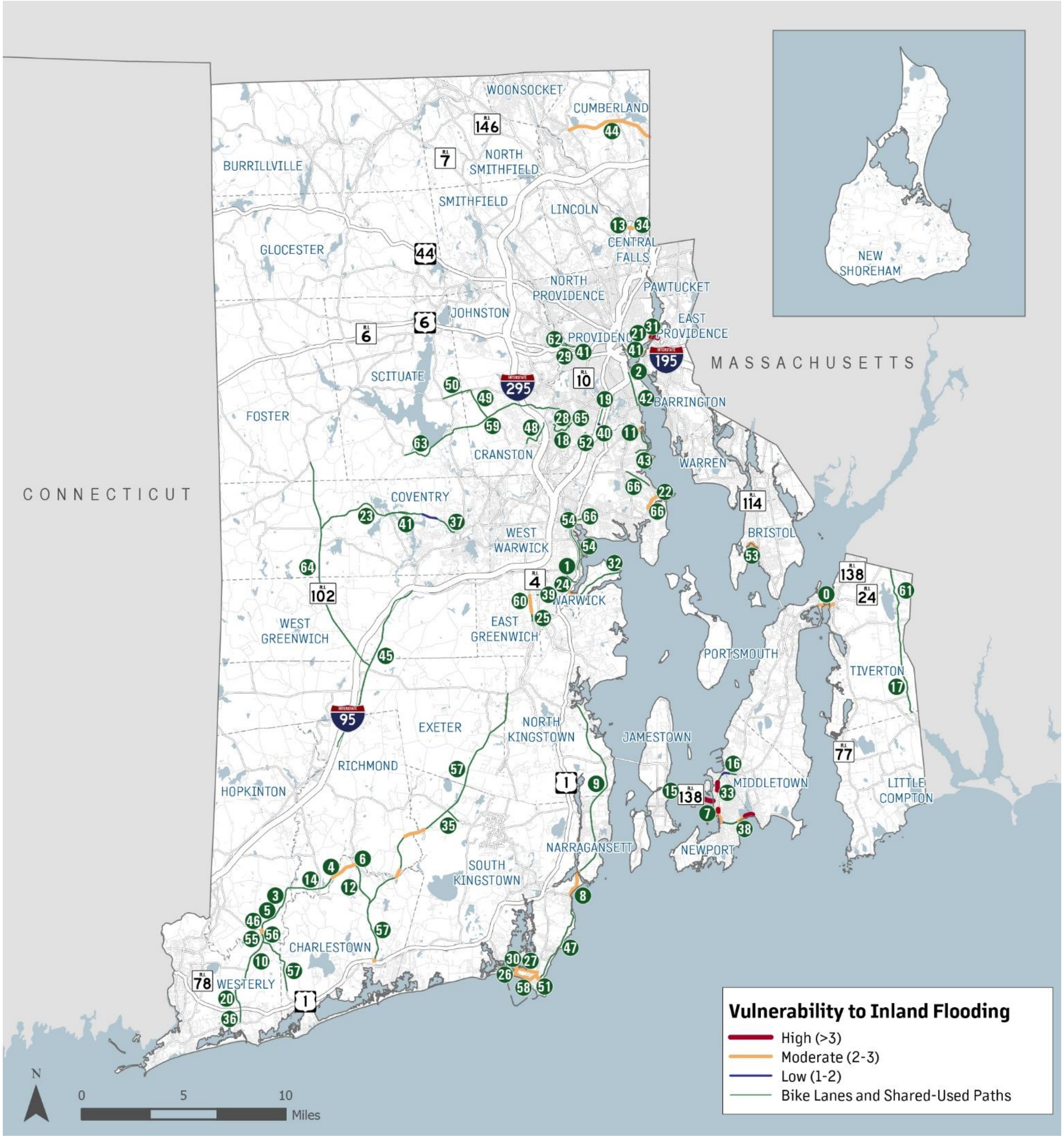


Figure 4.14 Vulnerability of Shared-Use Paths: Inundation of 100-Year Storm + 7 Foot Sea Level Rise Scenario



Note: Storm Surge data is not available for New Shoreham

Figure 4.15 Vulnerability of Shared-Use Paths to Inland Flooding



Stormwater Pipes

The overall vulnerability of stormwater pipes to 7-foot sea level rise scenarios is shown in Figure 4.16. Under the initial 1-foot sea level rise scenario, there are a cluster of stormwater pipes between Middletown and Tiverton that are highly vulnerable, with some medium vulnerability ones clustered around Jamestown. In scenarios of 2-foot and 7 -foot the number of highly vulnerable stormwater pipes increase and form many more clusters. In the 7-foot scenario there are lot of highly vulnerable stormwater pipes all along the coast of Rhode Island.

Figure 4.17 assesses total vulnerability across the multiple scenarios of storm surge overlaid to sea level rise. As these three figures show, the addition of, and progressive increase in storm surge produces gradual increases in vulnerability across most portions of coastal Rhode Island. Under a scenario of a 100-year storm overlaid to 7-foot sea level rise, the majority of stormwater pipes along coastal Rhode Island fall under the category of high vulnerability.

Lastly, vulnerability to inland flooding is shown in Figure 4.18. Stormwater pipes vulnerable to inland flooding are predominantly in the inland areas with a cluster of highly vulnerable stormwater pipes around the Providence region.

Figure 4.16 Vulnerability of Stormwater Pipes to 7-Foot Sea Level Rise Scenario

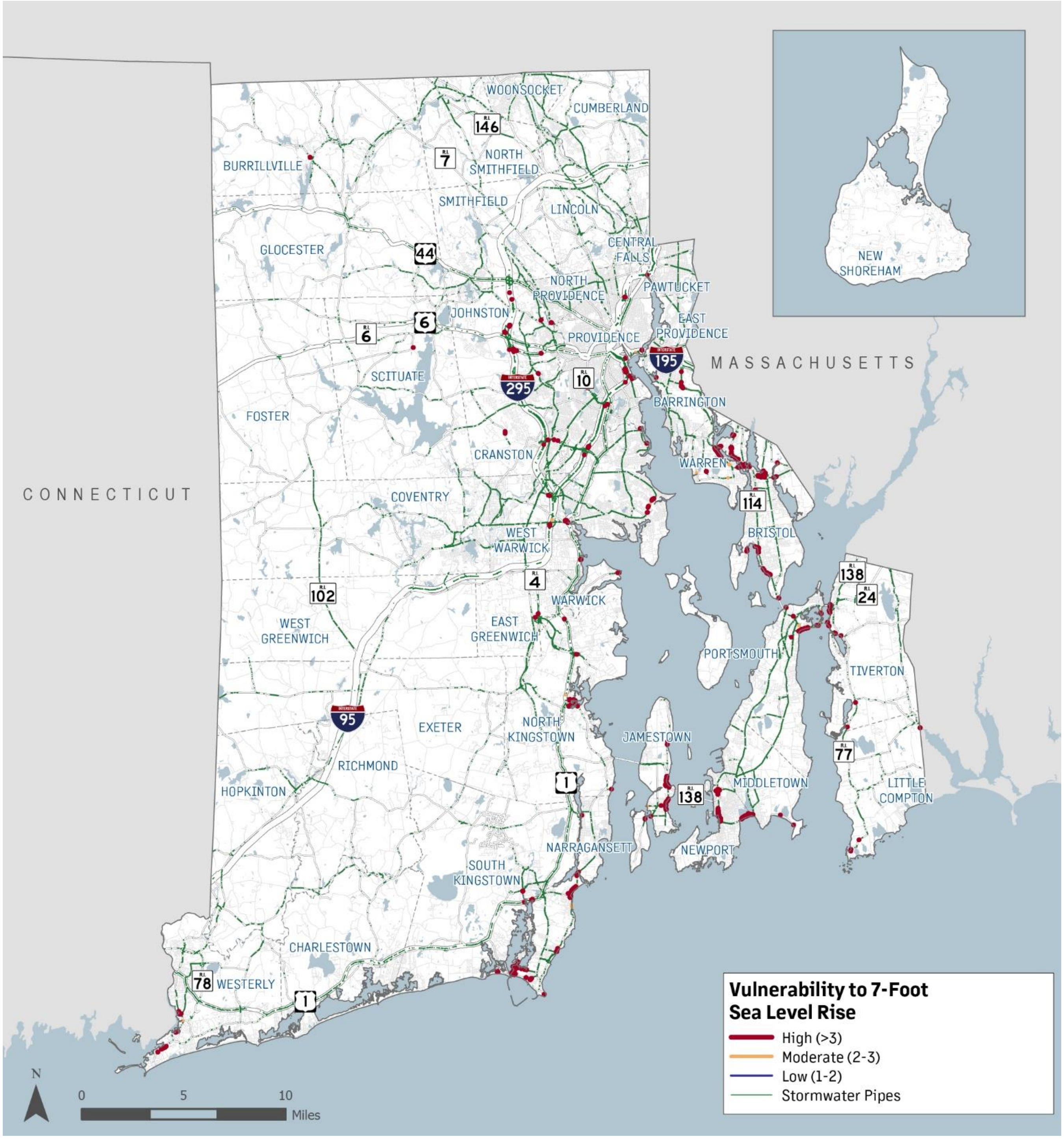
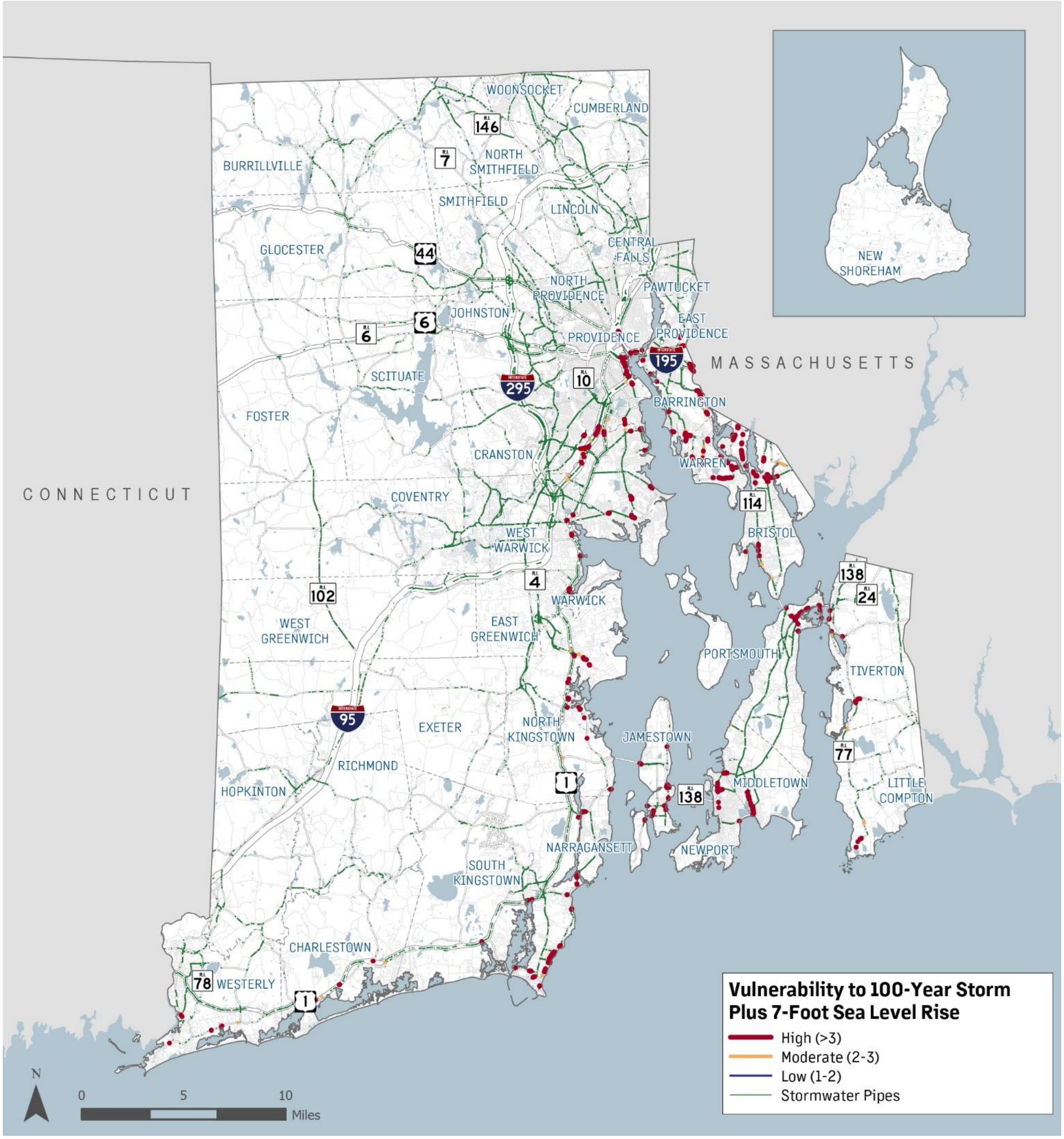
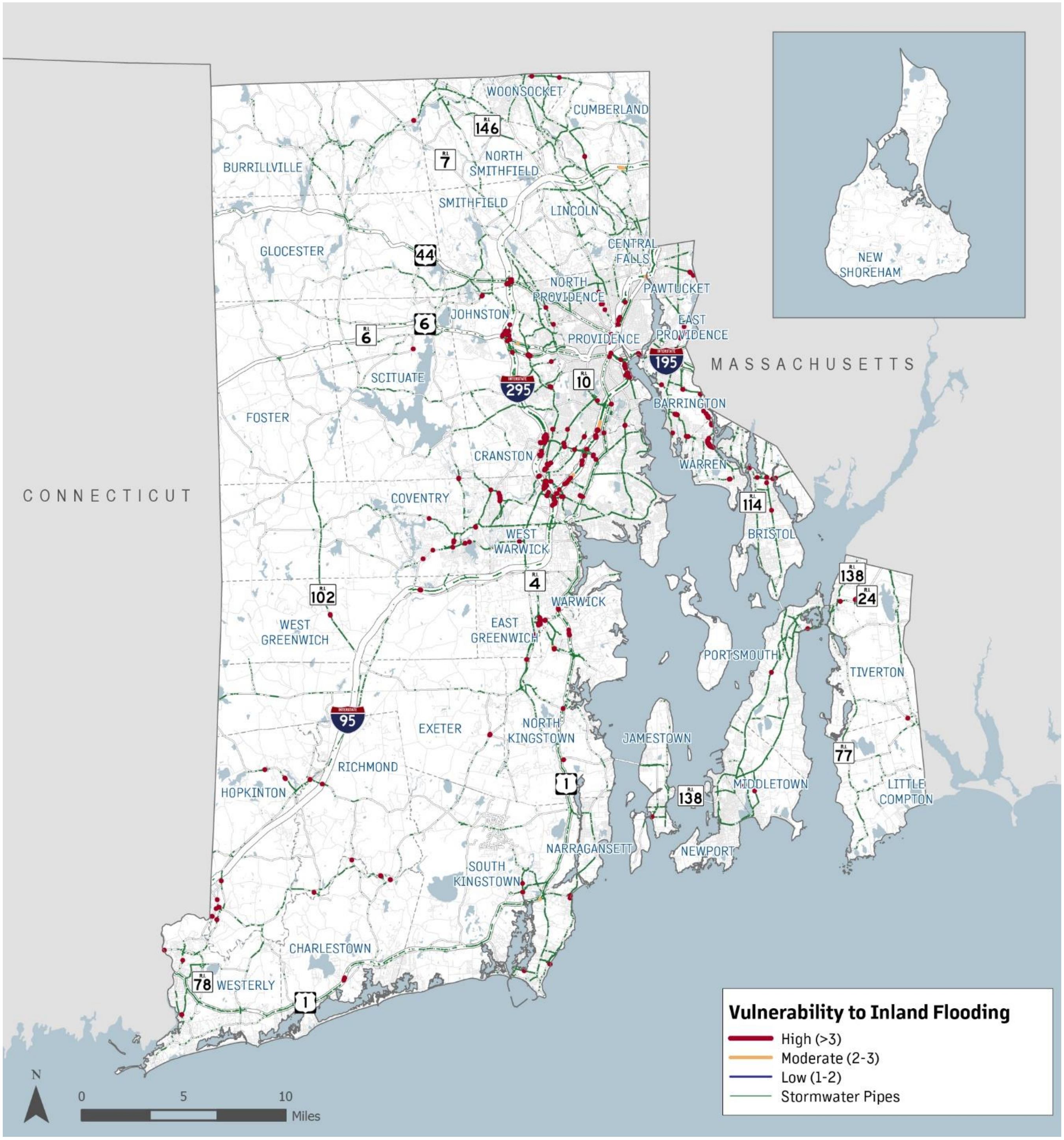


Figure 4.17 Vulnerability of Stormwater Pipes: Inundation of 100-Year Storm + 7 Foot Sea Level Rise Scenario



Note: Storm Surge data is not available for New Shoreham

Figure 4.18 Vulnerability of Stormwater Pipes to Inland Flooding



Stormwater Treatment Units

The overall vulnerability of stormwater treatment units to 7-foot sea level rise scenarios is shown in Figure 4.19. Under the initial 1-foot sea level rise scenario, four (4) stormwater treatment units are expected to have a high level of vulnerability, with a few more expected to have a moderate level of vulnerability. These stormwater treatment units are located primarily in coastal and urbanized portions of Rhode Island, including Newport, Cranston, and Providence. In scenarios of 2-foot and 7-foot sea level rise, additional stormwater treatment units in coastal and urbanized portions of the state are expected to have a moderate or high level of vulnerability. The greatest increase in concentration of highly vulnerable stormwater treatment units is expected in and around Providence, as well as coastal Rhode Island between South Kingstown and Newport. Furthermore, in a scenario of 7-foot sea level rise, the majority of vulnerable stormwater treatment units are expected to have a particularly high degree of vulnerability.

Figure 4.20 assesses total vulnerability across the multiple scenarios of storm surge overlaid to sea level rise. As these three figures show, the addition of, and progressive increase in storm surge produces gradual increases in vulnerability across most portions of coastal Rhode Island between Point Judith and Providence.

Lastly, vulnerability to inland flooding is shown in Figure 4.21. Overall, scattered arterials throughout Rhode Island are expected to have a high degree of vulnerability to inland flooding. This includes storm water treatment units around Providence, Woonsocket, Cranston, South Kingston, Warwick amongst others.

Figure 4.19 Vulnerability of Stormwater Treatment Units to 7-Foot Sea Level Rise Scenario

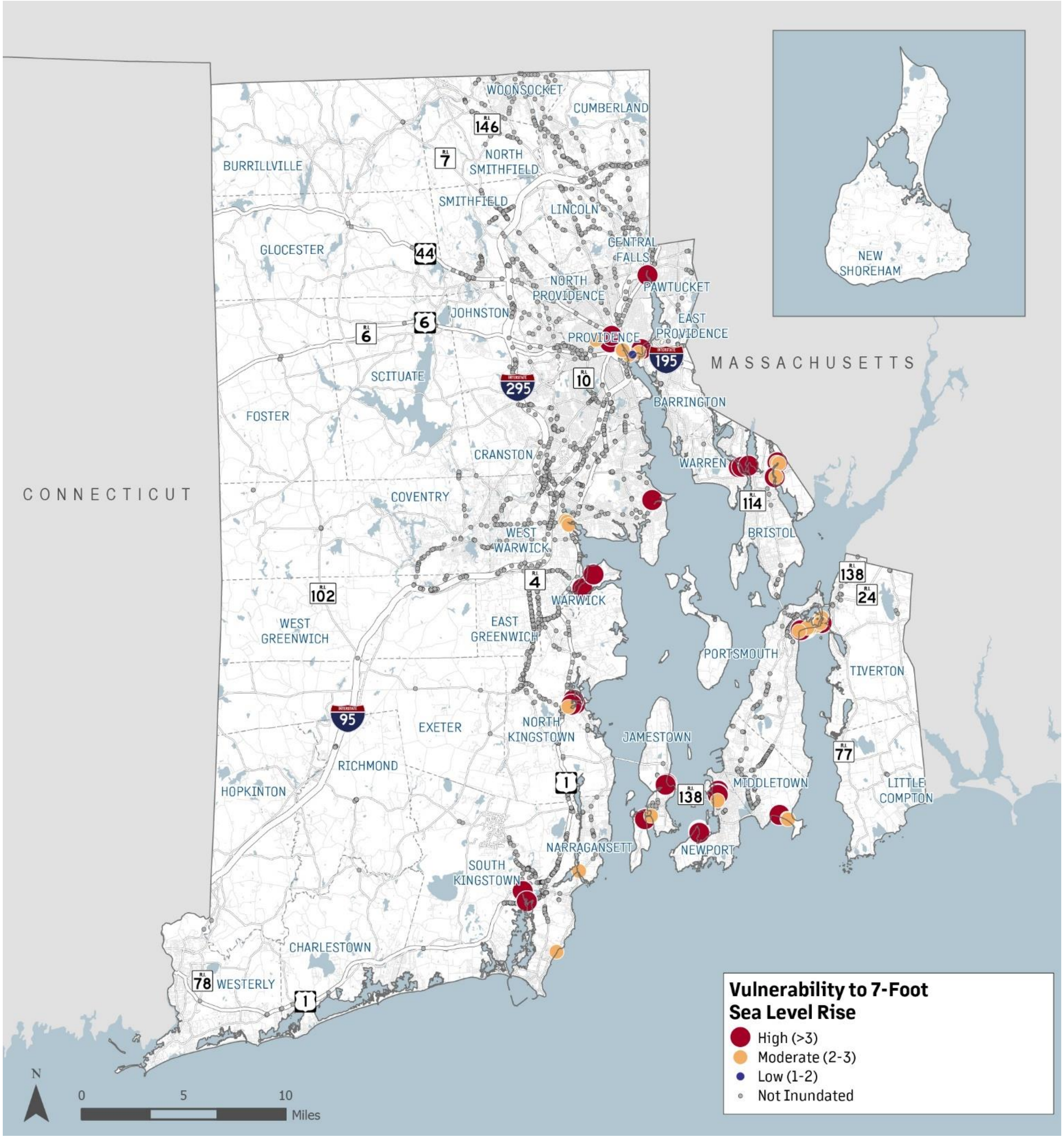
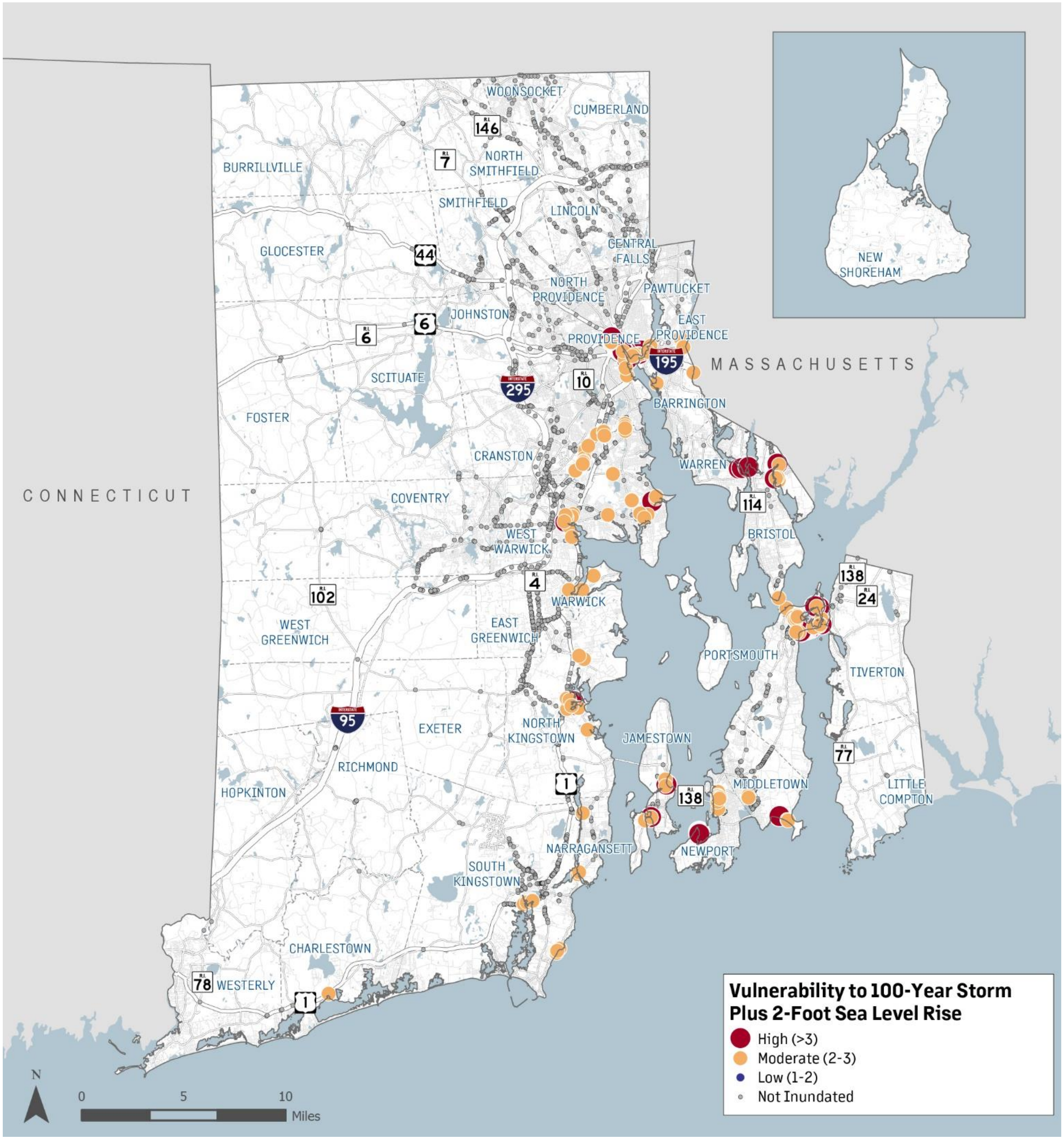
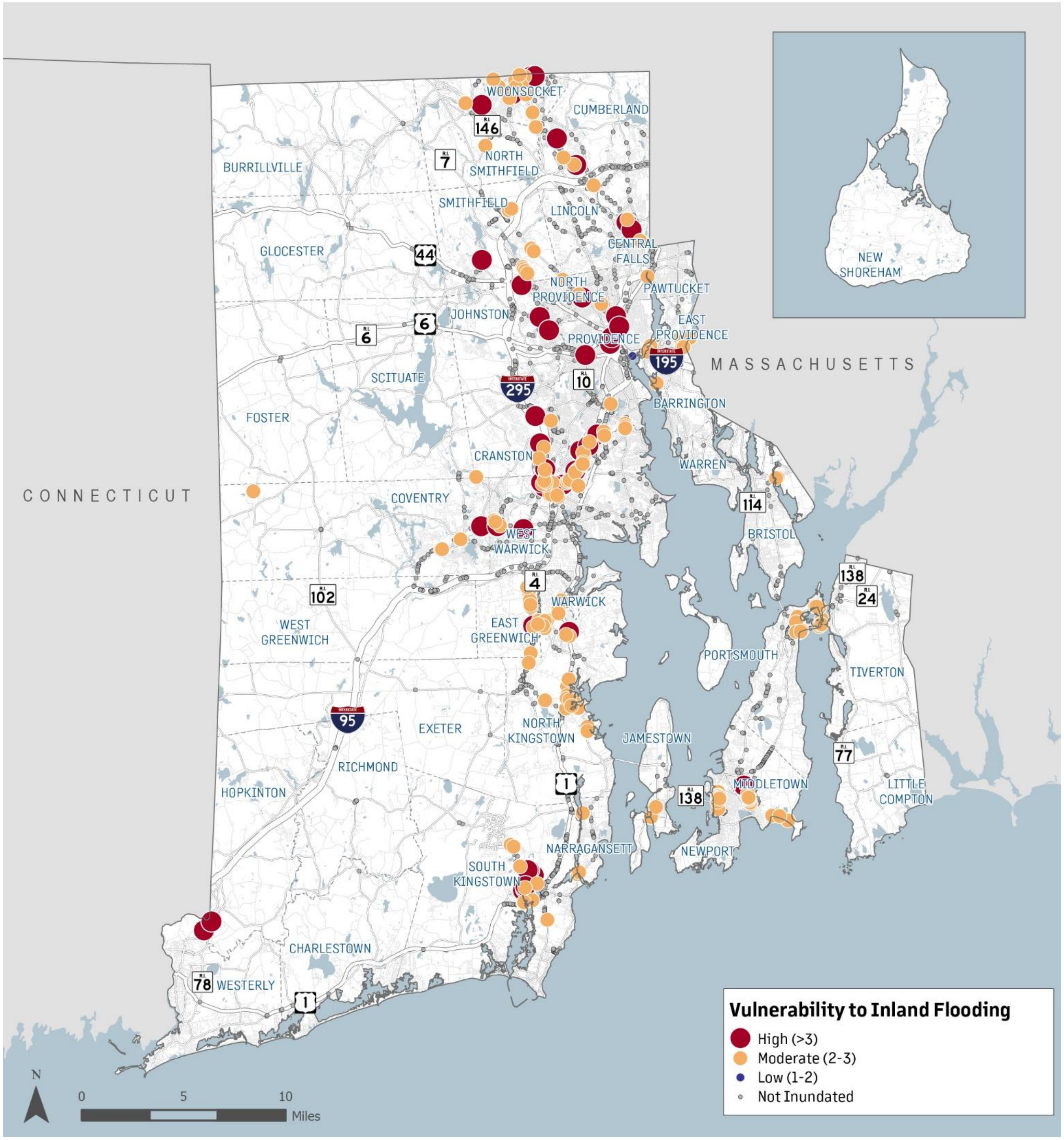


Figure 4.20 Vulnerability of Stormwater Treatment Units: Inundation of 100-Year Storm + 7 Foot Sea Level Rise Scenario



Note: Storm Surge data is not available for New Shoreham

Figure 4.21 Vulnerability of Stormwater Treatment Units to Inland Flooding



4.3 Incorporate Risk

With vulnerability calculated for each asset, the last next step in the planning process involves the full calculation of risk. This fulfills the requirement of PROTECT guidance for a risk-based assessment of vulnerabilities of transportation assets and systems to current and future weather events and natural disasters through the development of a risk-informed vulnerability assessment which considers probabilities and consequences of potential impacts.

FHWA considers resilience risk as the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or likelihood of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (4) by incorporating a risk-based assessment of the impacts from identified hazards to Rhode Island's transportation assets, and through the incorporation of vulnerability. Through the use of science and data to develop this quantitative risk assessment, PROTECT Guidance Element (14) is satisfied. Through the evaluation of each asset's criticality, vulnerability, and risk, overall asset resilience is assessed, which satisfies PROTECT Guidance Element (8).

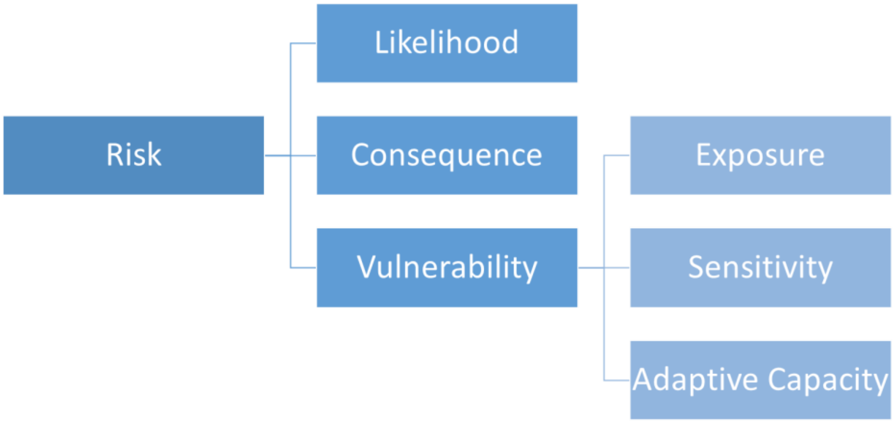
The RIDOT TAMP currently evaluates and prioritizes various types of asset risks already, through the use of a matrix of likelihood compared to impacts of hazardous event occurrences. The TAMP ranks climate change as the risk to RIDOT assets with the highest likelihood and impact to impact the state's transportation assets. This is attributed to corresponding impacts from coastal sea-level rise, storm surge, and riverine flooding which can impact drainage and accelerate asset deterioration.

This risk assessment builds on the risk definition and analysis developed previously and further assess risk of sea level rise, storm surge, and inland flooding at the individual asset level by evaluating the likelihood of these events happening and incorporating each asset's vulnerability in the estimation of the associated consequence/impact of such events happening. By considering each asset's location and characteristics, which are reflected by the exposure, sensitivity, and adaptive capacity scores in the vulnerability assessment, this approach allows the localization of risk to asset level. As shown in Table 4.19, risk, assessed for a singular asset, is a function of the following components:

- **Vulnerability:** As defined in the previous section, the degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events. Vulnerability, a function of exposure, sensitivity, and adaptive capacity, is assessed for each asset class through different measurements.

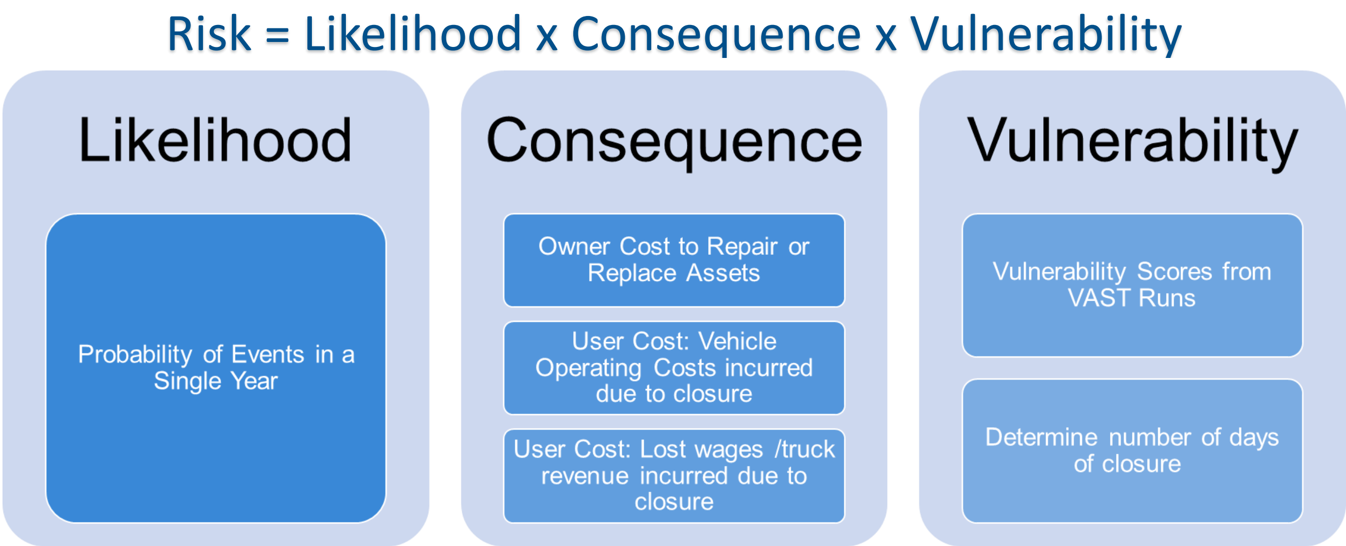
- **Consequence:** Defined as the costs that would be incurred as a result of an event happening. For this risk assessment, consequence is annualized and modeled for sea level rise, storm surge, and flooding events for forecast years of 2035, 2050, and 2100.
- **Likelihood:** Defined as the probability of an event occurring. For this risk assessment, the likelihood of sea level rise, storm surge, and flooding events are modeled through 2035, 2050, and 2100.

Figure 4.22 Calculation of Risk



The versatility of risk stems from the monetizing of each of those factors identified in Figure 4.22. This is achieved through the inclusion of consequence, which is identified in the form of owner costs and user costs. This monetization is made useful for decision making purposes, including at the agency level, through the annualization of costs combined with likelihood. Figure 4.23 further describes these components, which are further described in the following sections:

Figure 4.23 Risk Equation and Variables



4.3.1 Likelihood

Likelihood is the component of the risk equation representing the probability of a hazard occurring. This assessment considers likelihood of various scenarios of sea level rise, storm surge, and flooding in 2035, 2050, and 2100. The likelihood of sea level rise, storm surge, and flooding scenarios in 2035, 2050, and 2100 is shown in Table 4.31. The methodology to assign likelihood across the three hazards is explained below.

Sea Level rise

The likelihood of 1-foot, 2-foot, and 7-foot sea level rise scenario happening in 2035, 2050, and 2100 is derived from the 2022 NOAA Sea Level Rise Technical Report, which provides various projection curves for future sea level from 2020 to 2100. This is done by identifying the best matching projection curve for each of the study scenarios (1-foot, 2-foot, and 7-foot sea level rise) in each of the study timeline (2035, 2050, 2100) and assigning the probability of the projection curve to the corresponding scenario. Intermediate (SSP2-4.5) to high (SSP3-7.0) emission was assumed for the analysis.

Storm Surge plus Sea Level Rise

The likelihood of storm surge plus sea level rise events were calculated as the probability of storm surge event and sea level rise event happening at the same time. For example, the likelihood of a 50-year storm surge happening in any given year is 2% whereas the likelihood of a 1-foot sea level rise happening in 2035 is 1%. The likelihood of 50-year storm plus 1-foot sea level rise event is the product of the two, which is 0.02%.

Flooding

The likelihood of a 100-year flooding happening in any given year is 1% whereas the likelihood of a 500-year flood happening in any given year is 0.2%.

Table 4.31 Likelihood of Hazard Scenarios by Year

	Sea Level Rise		Storm Surge + Sea Level Rise		Flooding	
	Scenario	Probability	Scenario	Probability	Scenario	Probability
2035	1 ft	1%	50-yr Storm + 1-ft Sea Level Rise	0.02%	100-yr flood	1%
	2 ft	0%	100-yr Storm + 2-ft Sea Level Rise	0 %	500-yr flood	0.20%
	7 ft	0%	100-yr Storm + 7-ft Sea Level Rise	0%		
2050	1 ft	99%	50-yr Storm + 1-ft Sea Level Rise	1.98%	100-yr flood	1%
	2 ft	1%	100-yr Storm + 2-ft Sea Level Rise	0.01%	500-yr flood	0.20%
	7 ft	0%	100-yr Storm + 7-ft Sea Level Rise	0 %		
2100	1 ft	99%	50-yr Storm + 1-ft Sea Level Rise	1.98%	100-yr flood	1%
	2 ft	82%	100-yr Storm + 2-ft Sea Level Rise	0.82%	500-yr flood	0.20%
	7 ft	1%	100-yr Storm + 7-ft Sea Level Rise	0.01%		

4.3.2 Consequence

Consequence is defined as the costs that would be incurred as a result of an event happening. For this vulnerability and risk assessment, consequence is comprised of the following costs:

- **Owner Cost:** Defined as the cost for RIDOT to repair a damaged section of an asset as a result of a hazard.
- **User Cost:** Defined as the cost for users of the Rhode Island transportation network given the disruptions, route alterations, and inconvenience associated with a hazard.

These components of consequence, and the process to assign costs, are explained in further detail below. The section is broken down into owner costs that is the cost incurred to the owner to repair a damaged asset and user cost which is the cost incurred to a user of the asset if it is damaged. The owner cost is calculated using the

unit cost of repair, preservation, or replacement of roads and bridges from RIDOT TAMP. Due to the absence of specific unit costs for sidewalks and bike lanes/shared used paths, the roads and bridges unit cost was used for these two assets.

Stormwater pipes and stormwater treatment units are designed to contain water; inundation by sea level rise, storm surge, or flooding would not necessarily cause direct damage to the facilities themselves. However, such impact will likely reduce the capability of the stormwater infrastructure to drain excess water from the surface and cause flooding of the transportation infrastructure or other properties within the catchment areas. Therefore, the estimation of consequence for stormwater pipes and stormwater treatment units being inundated by the study hazards focuses on the potential impact it might have on transportation infrastructure which may be impacted. The method to calculate their risk is discussed in the cumulative composite risk section later in the chapter.

Owner Cost

Owner cost is the cost to RIDOT to repair a damaged section of an asset, in this case stemming from one of the three identified hazards. RIDOT's TAMP was referenced to assign costs of maintenance, preservation and replacement of assets with relation to the vulnerability scores that were generated using VAST.[13] The treatment costs for roads were categorized in the following manner, based on three classifications of vulnerability:

- **Low Vulnerability Roads:** Assumed minimal impacts from the hazard, resulting in Maintenance & Preservation (Level 1) treatment
- **Medium Vulnerability Roads:** Assumed moderate impacts from the hazard, resulting in Preservation (Level 2) & Minor Rehabilitation treatment
- **High Vulnerability Roads:** Assumed serious impacts from the hazard, resulting in Major Rehabilitation & Replacement treatment

A similar approach was applied for bridges, where the treatment costs were also taken from the TAMP. In the case of bridges, it was tied to the vulnerability of the bridges in the following manner:

- **Low Vulnerability Bridges:** Assumes minimal impact from the hazard, resulting in Preservation, Level 1 treatment
- **Medium Vulnerability Bridges:** Assumes somewhat serious impacts from the hazard, resulting in Minor Rehabilitation treatment
- **High Vulnerability Bridges:** Assumes serious impacts from the hazard, resulting in Major Rehabilitation or Replacement treatment

[13] https://www.dot.ri.gov/documents/RhodeWorks/RIDOT_TAMP_2022.pdf

The costs of the various types of treatment from the TAMP do not consider the costs of planning and design. To account for these additional costs, a 30% increase was also applied to base totals. This increase was inferred from RIDOT's Blue and Green Sheet tool which provides planning level estimates of project budgets and schedules. Unit owner costs for roads and bridges are assigned for the three levels of vulnerability in Table 4.32 and Table 4.33.

Table 4.32 Unit Owner Costs by Level of Vulnerability for Roads

Vulnerability	Treatment	Construction Cost (per sq ft)	Total Cost (per sq ft)
Low Vulnerability	Maintenance, Preservation (Level 1)	$72	$94
Medium Vulnerability	Preservation (Level 2), Minor Rehab	$143	$185.9
High Vulnerability	Major rehab, Replacement	$215	$280

Table 4.33 Unit Owner Costs by Level of Vulnerability for Bridges

Vulnerability	Treatment	Average Unit cost (per sq ft)	Total Cost (per sq ft)
Low Vulnerability	Preservation Level 2	$250	$360
Medium Vulnerability	Minor rehab	$500	$720
High Vulnerability	Major Rehab	$1,000	$1,430

In the case of flooding, the owner consequence was only assigned to assets that were inundated by base flood elevation and those that were in the floodway. The inundation breaks and costs for those assets affected by flooding were updated as shown in Table 4.34Table 4.34.

Table 4.34 Unit Owner Costs by Level of Vulnerability for Roads

Flooding Inundation	Treatment	Average Unit cost (per sq ft)
>0 and <= 2 feet	Preservation Level 2	$72
2- 5 feet	Minor rehab	$143
>= 5 feet	Major Rehab	$215

User Cost

User costs are defined as the disruption to a user's travel when an asset is damaged due to a hazard. The estimation of user cost for each asset considers multiple factors, such as the number of users, detour mileage, additional travel time, vehicle operating cost, and value of time. Some of these components are visualized in Figure 4.24.

Figure 4.24 Components of User Cost

User Cost for Roads / Bridges

User cost for roads and bridges comprised of additional vehicle operating cost and lost of wages due to delay. Vehicle operating costs incur when an asset is closed for a period of time due to a hazard. The estimation of vehicle operating costs for roads and bridges considers the additional cost for vehicles and trucks (passenger and freight vehicles). The equation used to calculate vehicle operating costs is shown in Figure 4.25. Vehicle operating costs are a function of AADT, vehicle running costs, the number of closure days where a detour is required, and the size and characteristics of the detour in comparison to the original route. Constant variables, including vehicle and truck running costs were taken from USDOT Transportation Benefit-Cost Analysis Guidance for Discretionary Grant Programs.[14]

[14] The estimated number of days for road closures, between 1 day and 3 days, was estimated based on the vulnerability of the road with more vulnerable roads requiring additional closure time. The period of time required for a road closure based on vulnerability score is shown in Table 4.35.

Figure 4.25 Vehicle Operating Costs Equation

$$VOC = ((C2 \times AADT_{vehicle}) + (C3 \times AADT_{truck})) \times D \times C7$$

$AADT_{vehicle}$ = Average annual daily traffic (non-truck)
$AADT_{truck}$ = Average annual daily truck traffic
C2 = Vehicle running cost ($/vehicle-mile)
C3 = Freight running cost ($/truck-mile)
D = Number of closure days

Table 4.35 Number of Closure Days by Vulnerability Score

Vulnerability	Number of closure days
Low Vulnerability (>=1 – 2)	1
Medium Vulnerability (>=2 – 3)	2
High Vulnerability (>=3)	3

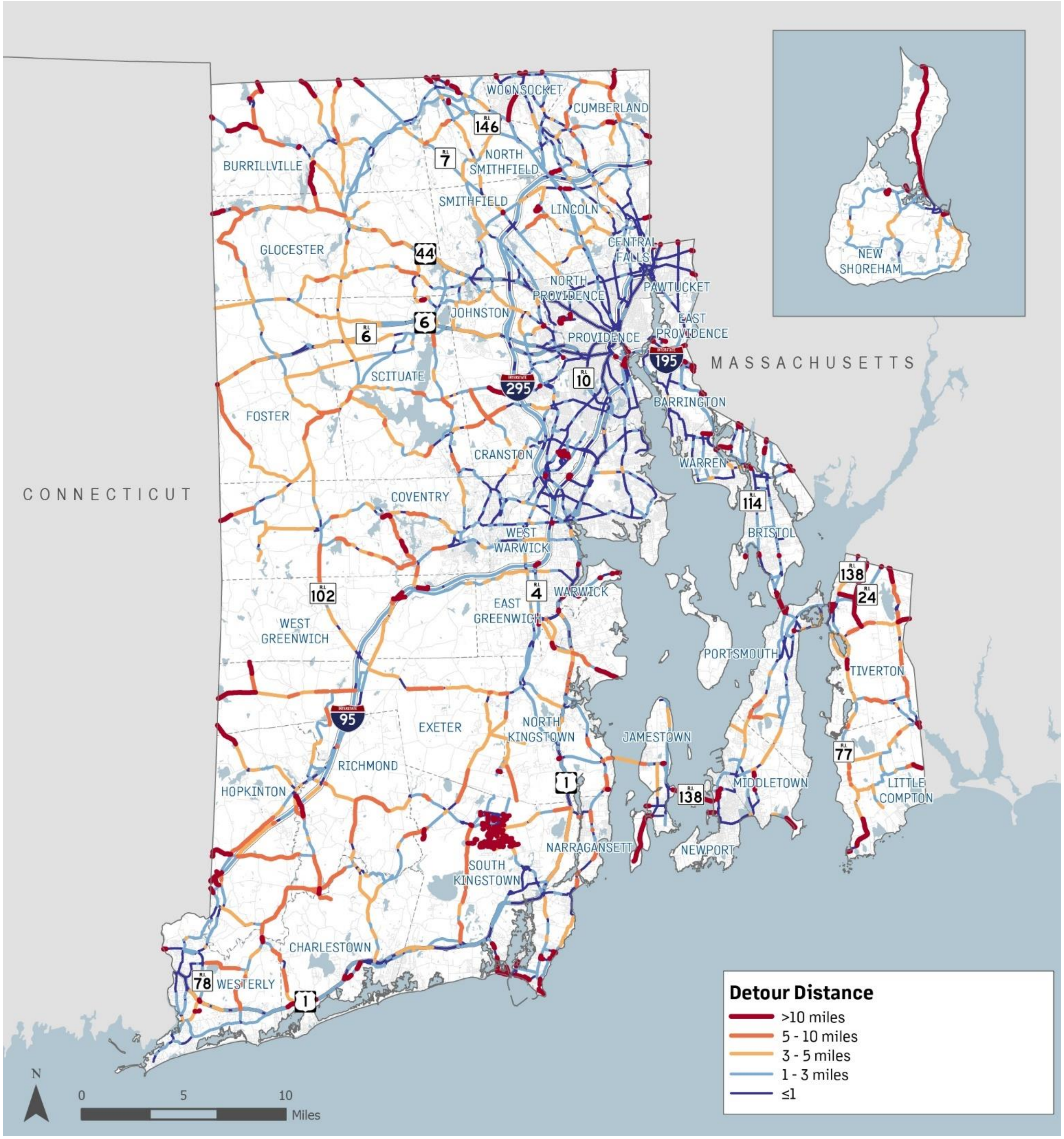
For flooding, since the owner and user consequence is not tied to the vulnerability of the assets, the number of closure days was updated for assets affected by flooding. Similar to how the owner costs were assigned based on the inundation depths of assets to flooding, the number of closure days is also tied to the flooding inundation depths as shown in Table 4.36.

Table 4.36 Number of Closure Days by Flooding Inundation depth

Flooding Inundation Depth	Number of closure days
0.001 - 2	1
2.001 – 5	2
>= 5	3

The resulting estimated detour distance across the Rhode Island road network is shown in Figure 4.26. Detour distance tends to vary across the state, although it tends to be highest in lower density and slightly more rural portions of Rhode Island. Similarly, detour distance tends to be lowest for those arterials and locations closest to Providence, as well as I-95, I-295, US-1, and RI-114.

Figure 4.26 Detour Distance



Addition to vehicle operating costs, lost wages incurred when an asset is closed are calculated using the equation shown in Figure 4.27. The constants in this equation, such as the average value of time, average value of freight time and the average occupancy (one occupant per vehicle was assumed) are taken from the USDOT's Benefit Cost Analysis Guidance for Discretionary Grant Programs.[15] Extra travel was calculated as a function of the distance and speed, assumed at 55 mph on all roads and bridges. The sum of lost wages and vehicle operating costs due to asset closure were calculated to generate the total user cost. Finally, this was added to the owner cost to generate the total consequence of an asset affected by a hazard.

Figure 4.27 Lost Wages Equation

$$\textbf{Lost wages due to closure} = ((C4 \times O \times AADT_{vehicle}) + (C5 \times AADT_{truck})) \times D \times (D_t/60)$$

$AADT_{vehicle}$	=	Average annual daily traffic (non-truck)
$AADT_{truck}$	=	Average annual daily truck traffic
C4	=	Average value of time ($/adult-hour)
O	=	Average occupancy (adult/vehicle)
C5	=	Average value of freight time ($/truck-hour)
D	=	Number of closure days
D_t	=	Extra travel time on detour (minutes)

User Cost for Sidewalks

The user costs calculated for sidewalks applies similar approach as the method for roads and bridges, with modification to replace vehicle and truck traffic amount to pedestrian counts and remove vehicle operating cost. The formula used to calculate the consequence for sidewalk user costs is shown in Figure 4.28.

Figure 4.28 User Cost Equation for Sidewalks

Pedestrian User Consequence = Value of travel time savings x Pedestrian Count x Closure Days x Difference in the distance between detour and original

User Cost for Shared-Use Paths

Similarly, bicyclist counts are used to calculate the user cost for shared-use paths. The formula used to calculate the consequence for shared-use paths user costs is shown in Figure 4.29.

[15] https://www.transportation.gov/sites/dot.gov/files/2022-03/Benefit%20Cost%20Analysis%20Guidance%202022%20%28Revised%29.pdf

Figure 4.29 User Cost Equation for Shared-Use Paths

Biking User Consequence = Value of travel time savings[16] x Bike counts x Closure days x Difference in the distance between detour and original

Consequence for Stormwater Pipes and Treatment Units

As discussed earlier, the estimation of consequence for stormwater pipes and stormwater treatment units being inundated by the study hazards focuses on the potential impact it might have on transportation infrastructure that might be impacted. Each of the stormwater assets were spatially joined with a catchment and in turn the total consequence of all the roads and bridges falling in the catchment was calculated, which was then transferred to the stormwater pipes and stormwater treatment units.

The consequence of each stormwater asset are estimated as a proportion of the total consequence of all the roads and bridges falling in the catchment based on their vulnerability scores.

- For stormwater pipes and stormwater treatment units with high vulnerability, the full amount was assigned,
- For those with medium vulnerability, 2/3 of the total consequence was assigned,
- Similarly for Stormwater pipes and stormwater treatment units with low vulnerability, 1/3 of the total consequence of the roads and bridges in the catchment area was assigned.

4.3.3 Calculation of Risk

Based on the likelihood and consequence values identified above, risk of each of the sea level rise, storm surge, and inland flooding scenarios was calculated by multiplying the likelihood of these events happening in each of the forecast years of 2035, 2050, and 2100 with the consequence values when these events occur. This process also incorporated each asset's vulnerability in the estimation of the associated consequence/impact of such events happening. Risk, assigned as a monetary value, is displayed across the Rhode Island transportation system and explained in the following sections.

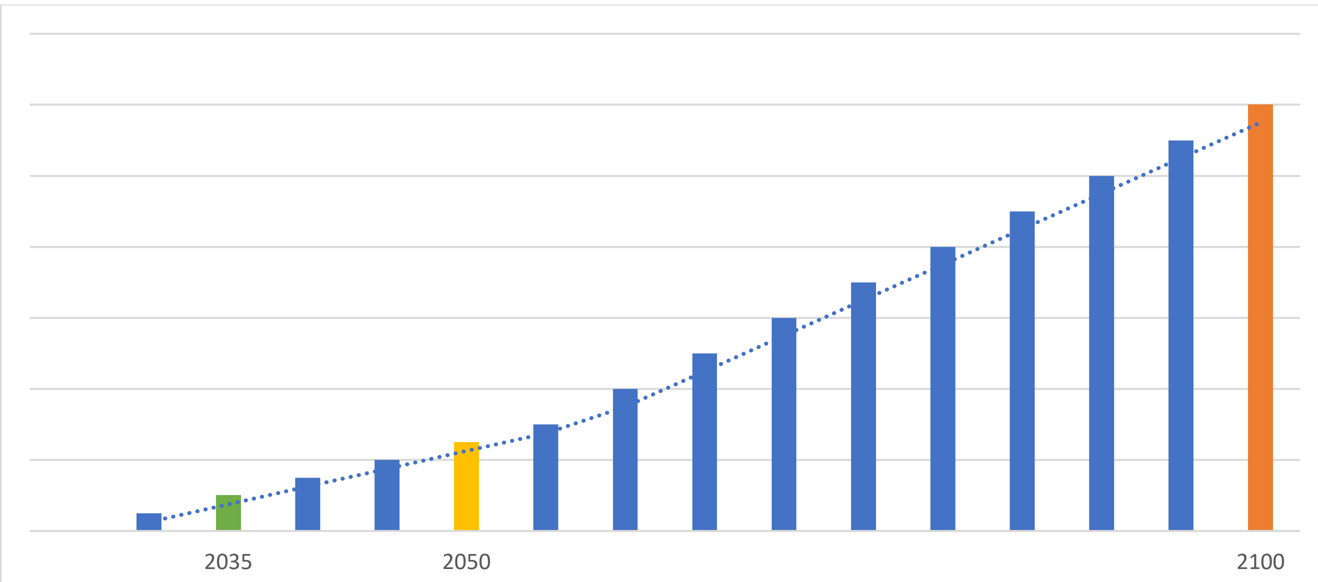
Risk = Likelihood x Consequence x Vulnerability

[16] https://www.transportation.gov/sites/dot.gov/files/2022-03/Benefit%20Cost%20Analysis%20Guidance%202022%20%28Revised%29.pdf

Risk is discussed through the following methods:

- **Individualized Risk:** Risk assessed individually across the Rhode Island transportation system for each of the three hazards of sea level rise, storm surge, and flooding.
- **Composite Risk:** Combined risk assessed for the three hazards of sea level rise, storm surge, and flooding, for each of the forecast years of 2035, 2050, and 2100.
- **Cumulative Composite Risk:** Aggregation of all the annual composite risk for years between now (2024) and each of the forecast years of 2035, 2050, and 2100. This is done through interpolation of composite risk for years between now (2024) and each of the forecast years of 2035, 2050, and 2100 using linear curves calculating the sum of their risk values.

Figure 4.30 Cumulated Composite Risk



Individualized Risk

Overall, risk stemming from sea level rise alone is relatively minor and highly localized. Through 2100, the highest risk from sea level rise can be found in and around the crossings into Bristol. Additional risk through 2100 of up to approximately $360,000 can be found scattered across coastal Rhode Island, including some arterials in and around Point Judith, Newport, Middletown, Bristol, and Warren.

Through 2050, the highest risk from storm surge overlaid to sea level rise is found along the approaches to the Jamestown Bridge where risk exceeds $1.1 million. Additional risk of up to $40,000 can be found along some of the arterials of coastal Rhode Island between Westerly and Providence. As shown in Appendix H**Error!**

Reference source not found., additional pockets of increased risk are expected in Point Judith, Bristol, and Barrington (up to approximately $410,000), as well as in Portsmouth and Bristol (up to approximately $1.2 million).

In addition to the Mt. Hope Bridge between Portsmouth Bristol (annual flooding risk of over approximately $82,000), locations with the highest risk of inland flooding include I-95 in Hopkinton near the Connecticut border, as well as arterials in Point Judith, Newport, Middletown, and Bristol. At these locations, annualized flood risk is expected to exceed approximately $25,000. Maps of individualized risk across Rhode Island can be found in Appendix H: Risk Outputs.

Composite Risk

Composite risk of all hazards is limited to localized portions of Point Judith, Newport, Middletown, Bristol, Barrington, and East Providence. For most of these locations composite risk is expected up to $100,000. Additional composite risk of a similar amount can be found in localized segments along the major thoroughfares of I-95 and I-295. Through 2050, an increased portion of those arterials scattered across coastal Rhode Island are expected to see composite risk of up to $100,000. Additionally, a greater proportion of those coastal arterials already experiencing composite risk in 2035, are expected to see increased composite risk of up to $1 million in 2050. Lastly, portions of Barrington - East Providence corridor are expected to see increased composite risk of over $1 million through this time frame. By 2100, these trends associated with composite risk are expected to accelerate with additional portions of coastal Rhode Island expected to see greater composite of over $1 million. On the other hand, composite risk is expected to remain relatively constant and subdued between 2035 and 2100 along the I-95 and I-295 corridors, in comparison to coastal portions of Rhode Island. Maps of composite risk across Rhode Island can be found in Appendix H: Risk Outputs.

Cumulative Composite Risk

The following figures examine cumulative composite risk as result of all three study hazards through 2035, 2050, and 2100 respectively. High risk areas in the cumulative composite risk through 2035 (Figure 4.31) is limited to localized portions of Point Judith, Newport, Middletown, Bristol, Barrington, and East Providence, as well as localized portions of I-95 and I-295. Through 2050, as shown in Figure 4.32, cumulative composite risk of at least $1 million is expected for multiple arterials across coastal Rhode Island from Point Judith to Providence, as well as a portion of I-95 in Hopkinton near the Connecticut border. By 2100, the majority of at-risk assets are expected to see a cumulative composite risk value of at least $1 million, including a widespread portion of arterials in coastal Rhode Island between Point Judith and Providence.

Figure 4.31 Cumulative Composite Risk by 2035

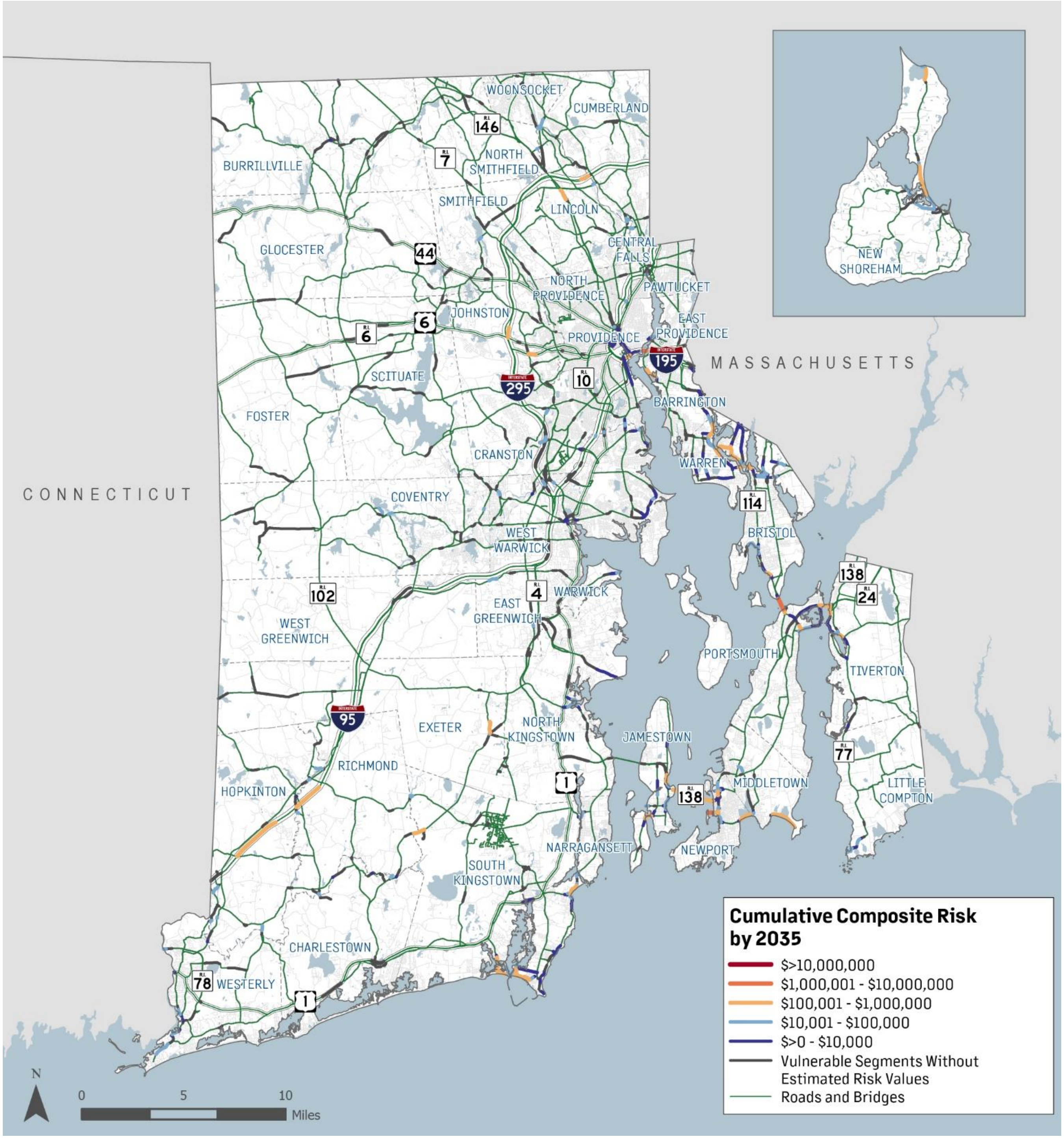


Figure 4.32 Cumulative Composite Risk by 2050

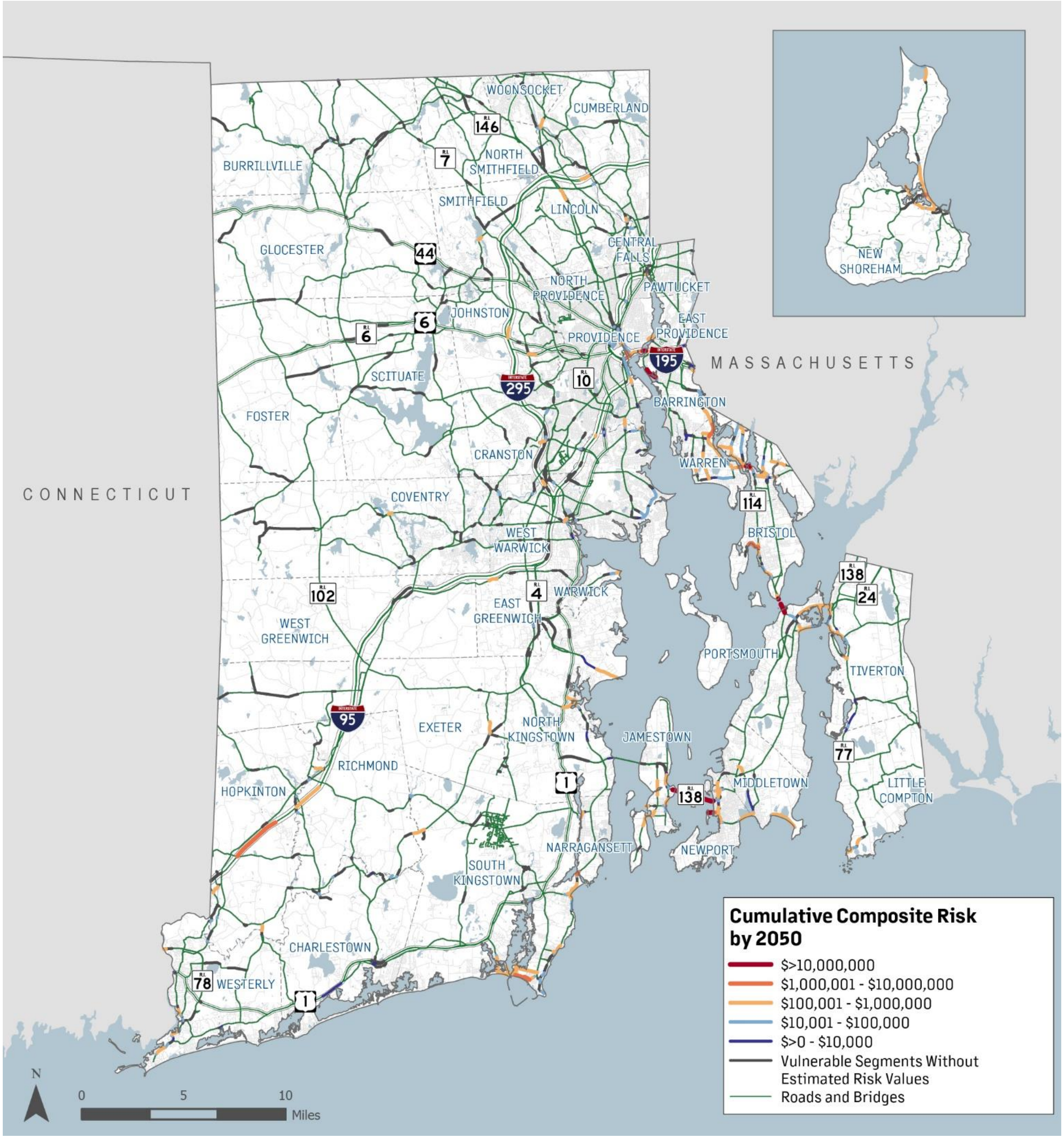


Figure 4.33 Cumulative Composite Risk by 2100

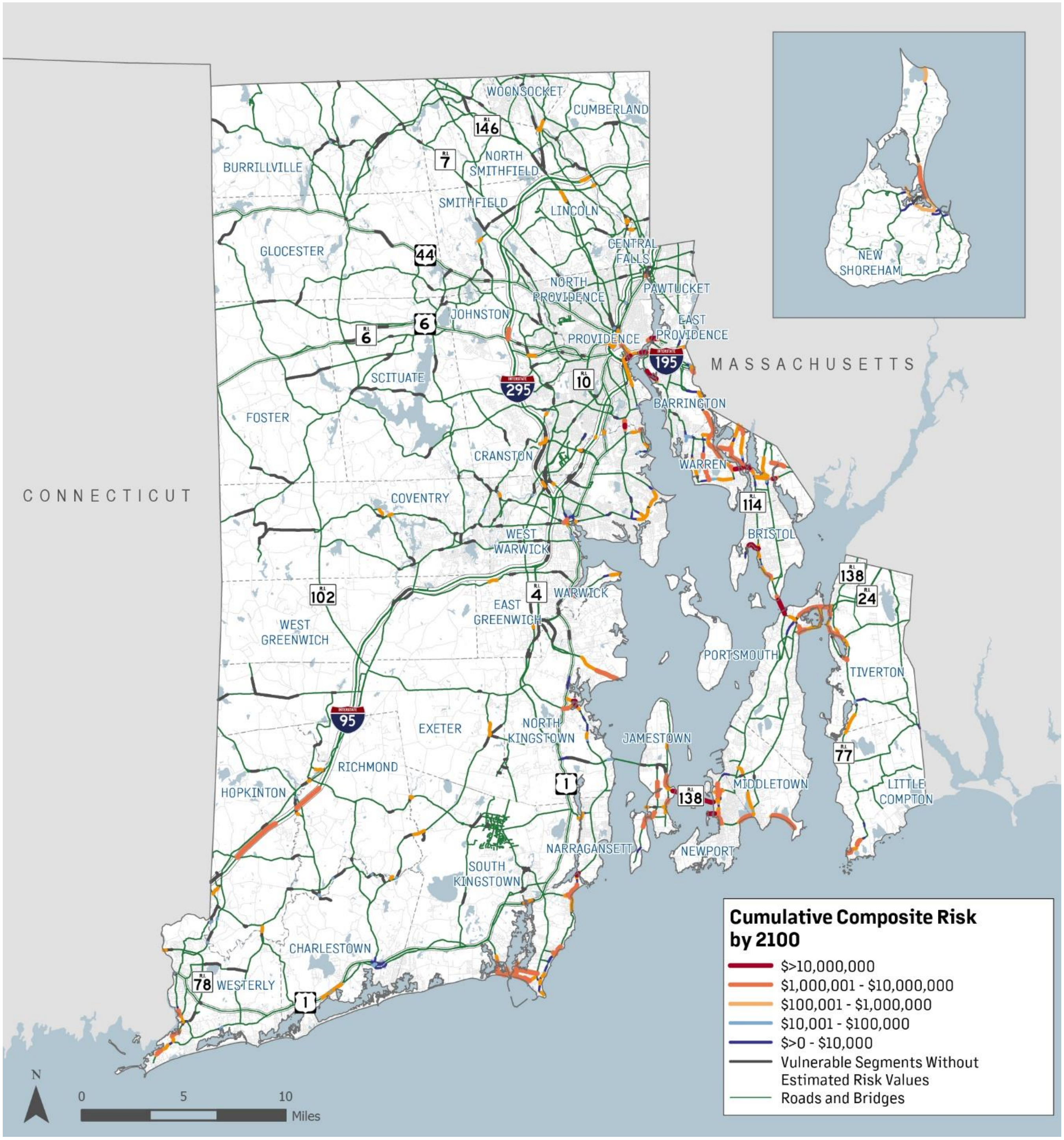


Figure 4.34 Cumulative Composite Risk of Sidewalks by 2035

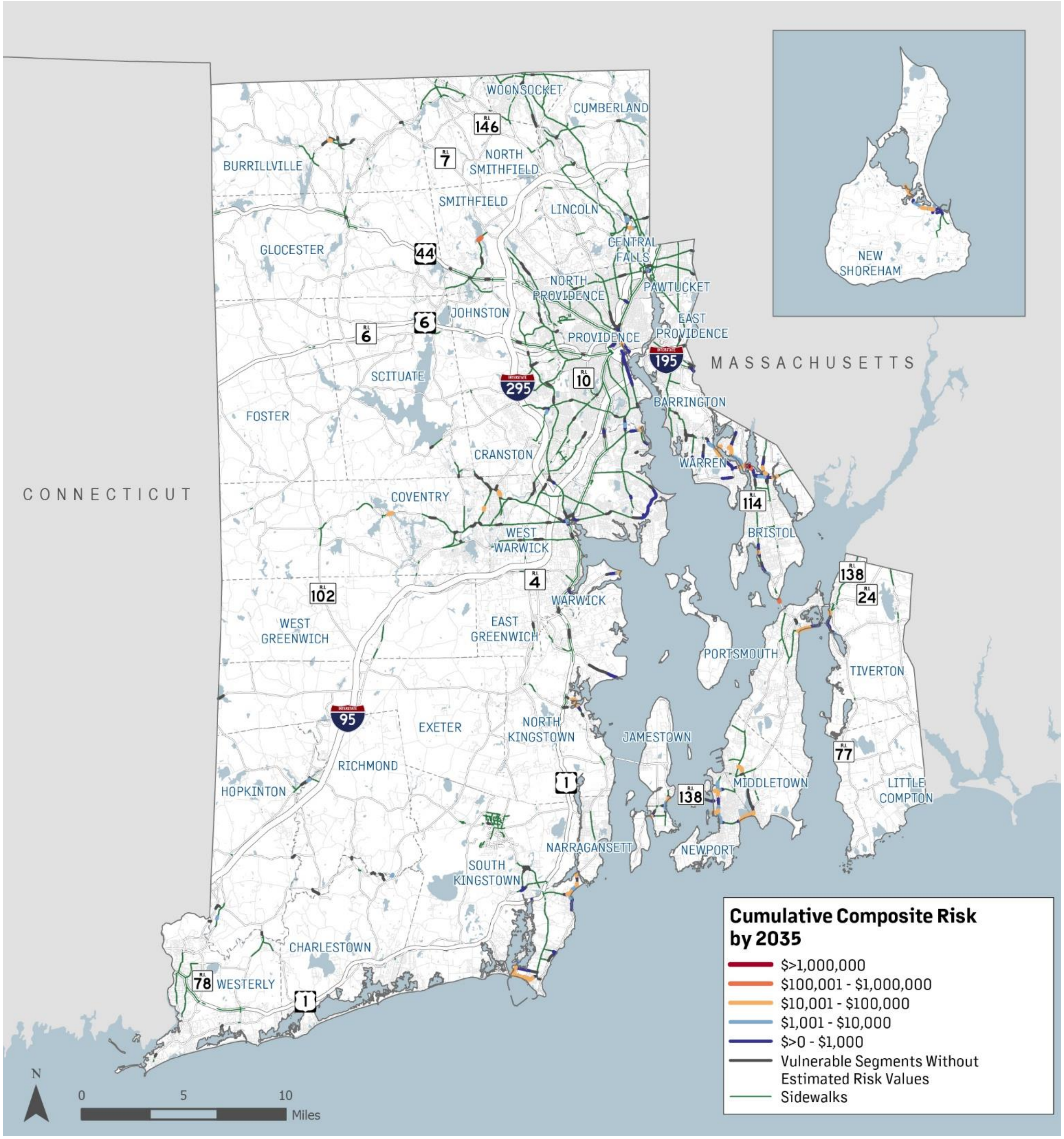


Figure 4.35 Cumulative Composite Risk of Sidewalks by 2050

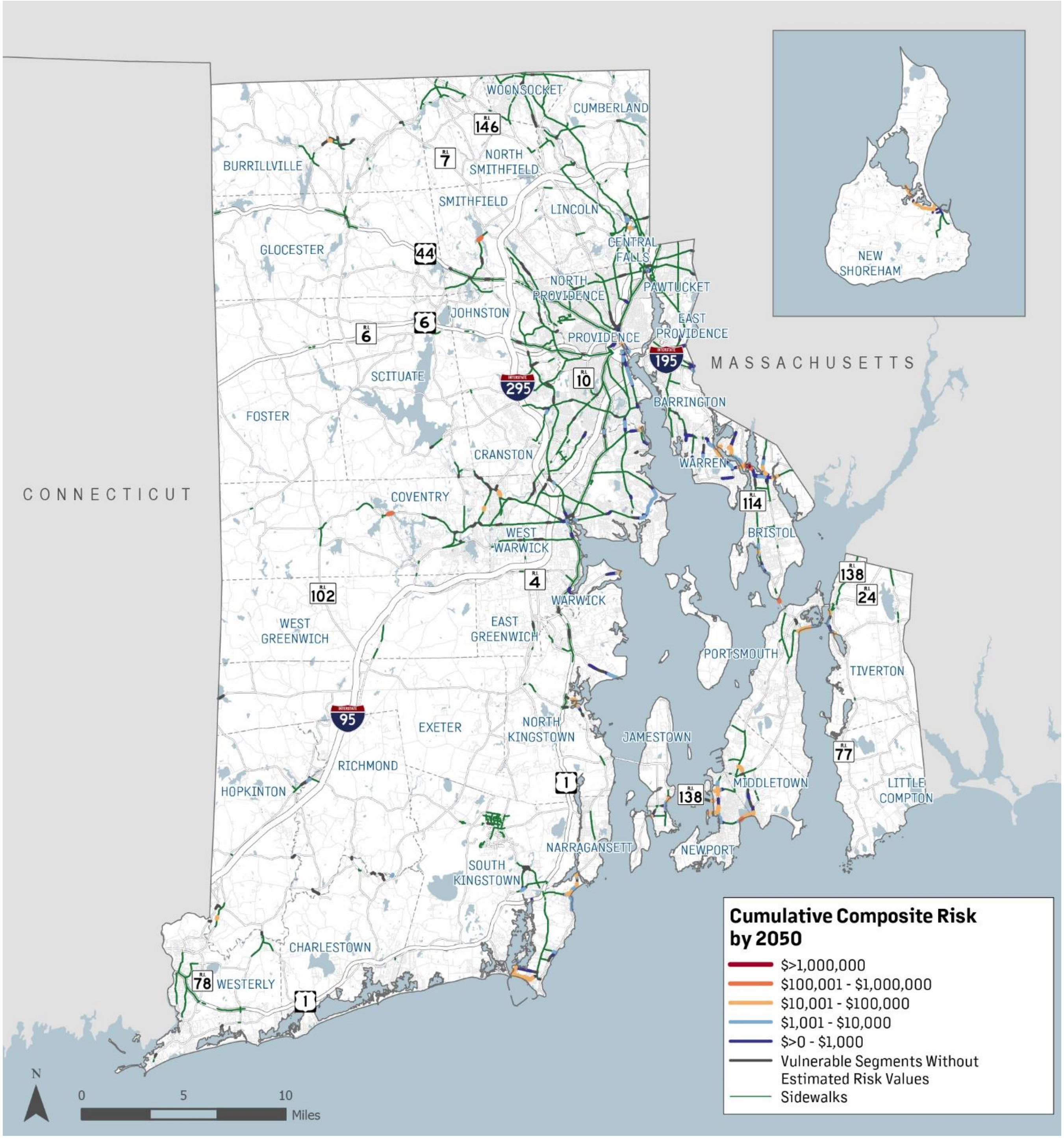


Figure 4.36 Cumulative Composite Risk of Sidewalks by 2100

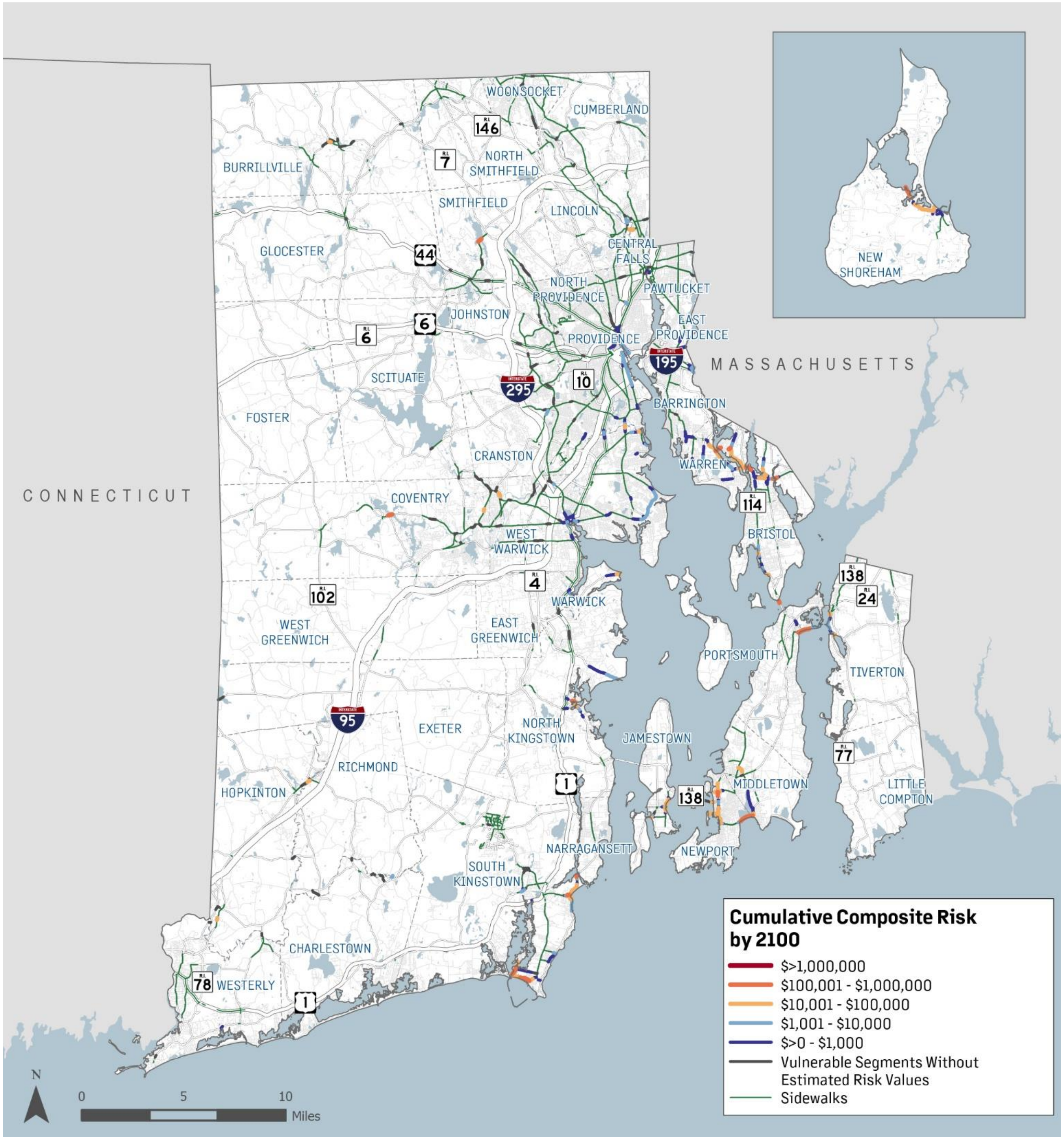


Figure 4.37 Cumulative Composite Risk of Bike/ Shared Use Path by 2035

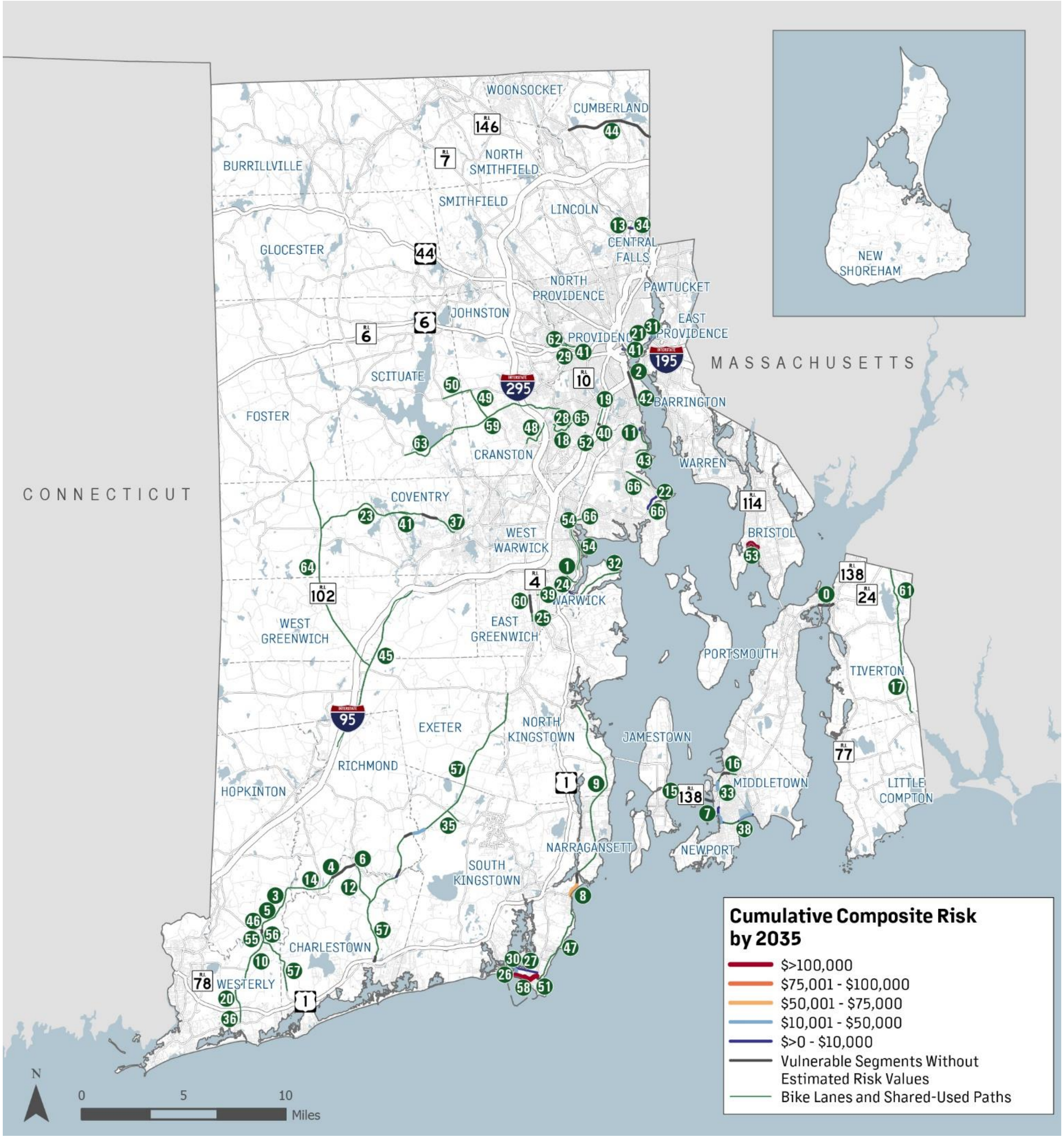


Figure 4.38 Cumulative Composite Risk of Bike/ Shared Use Path by 2050

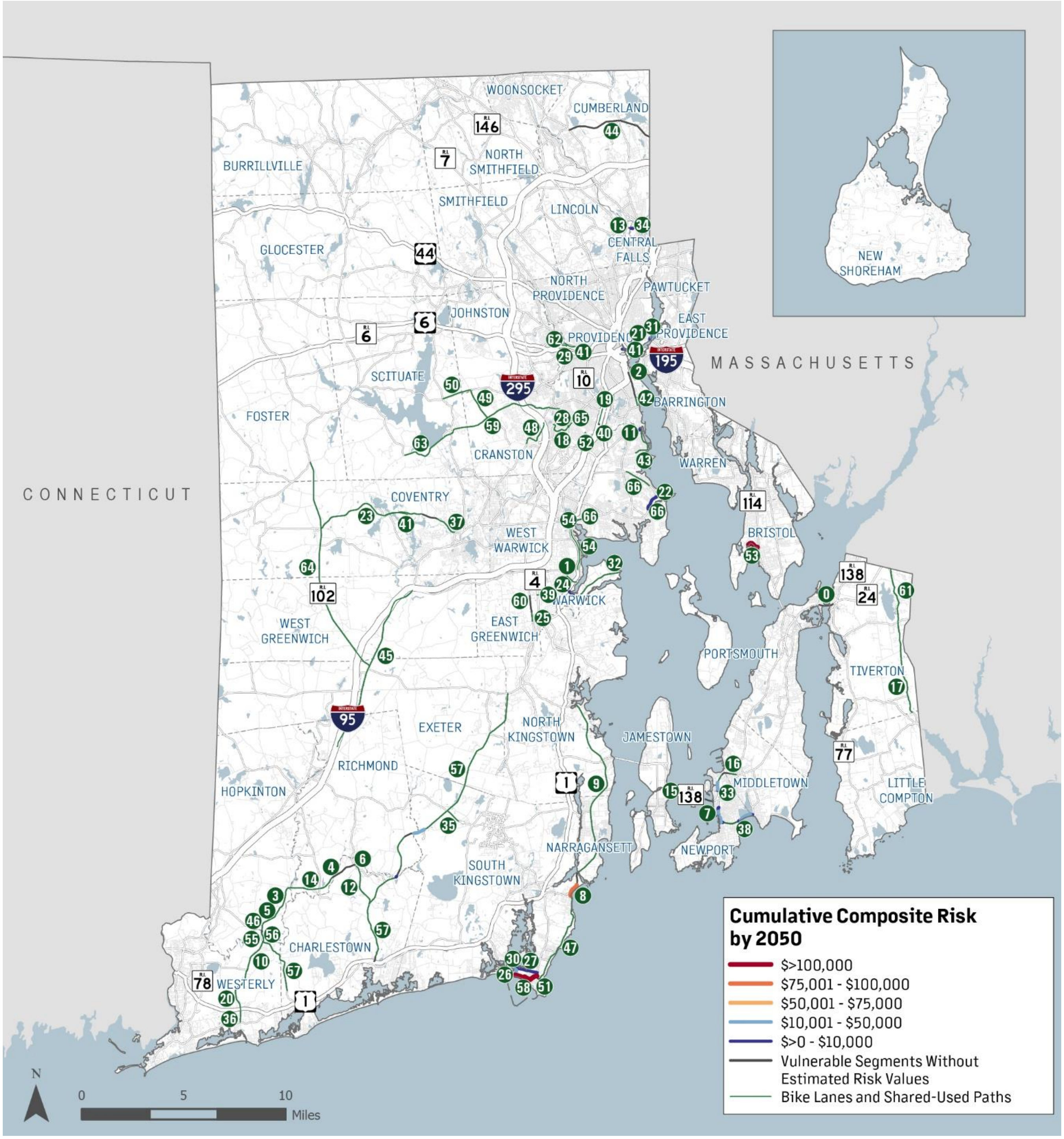


Figure 4.39 Cumulative Composite Risk of Bike/ Shared Use Path by 2100

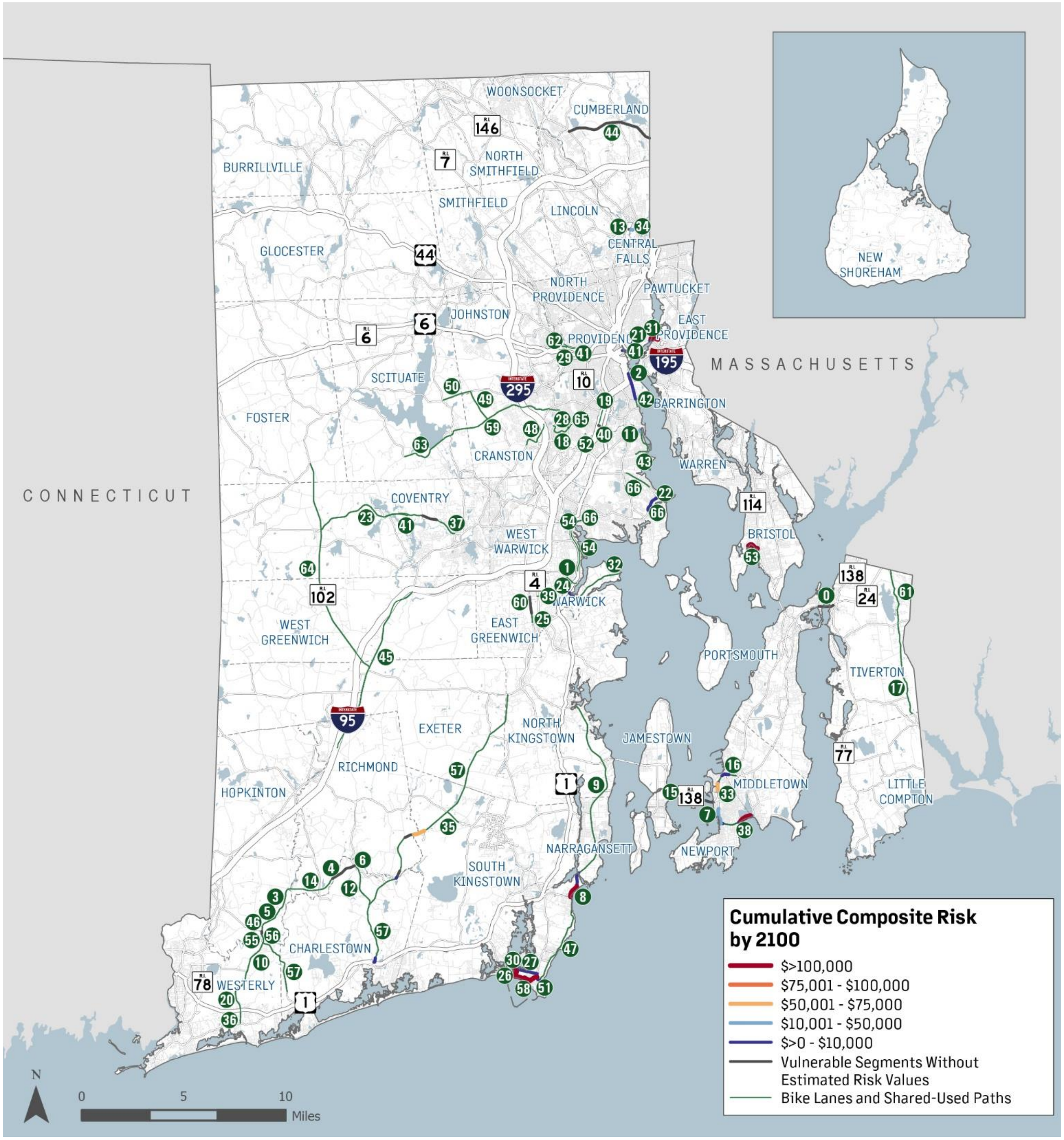


Figure 4.40 Cumulative Composite Risk of Stormwater Pipes by 2035

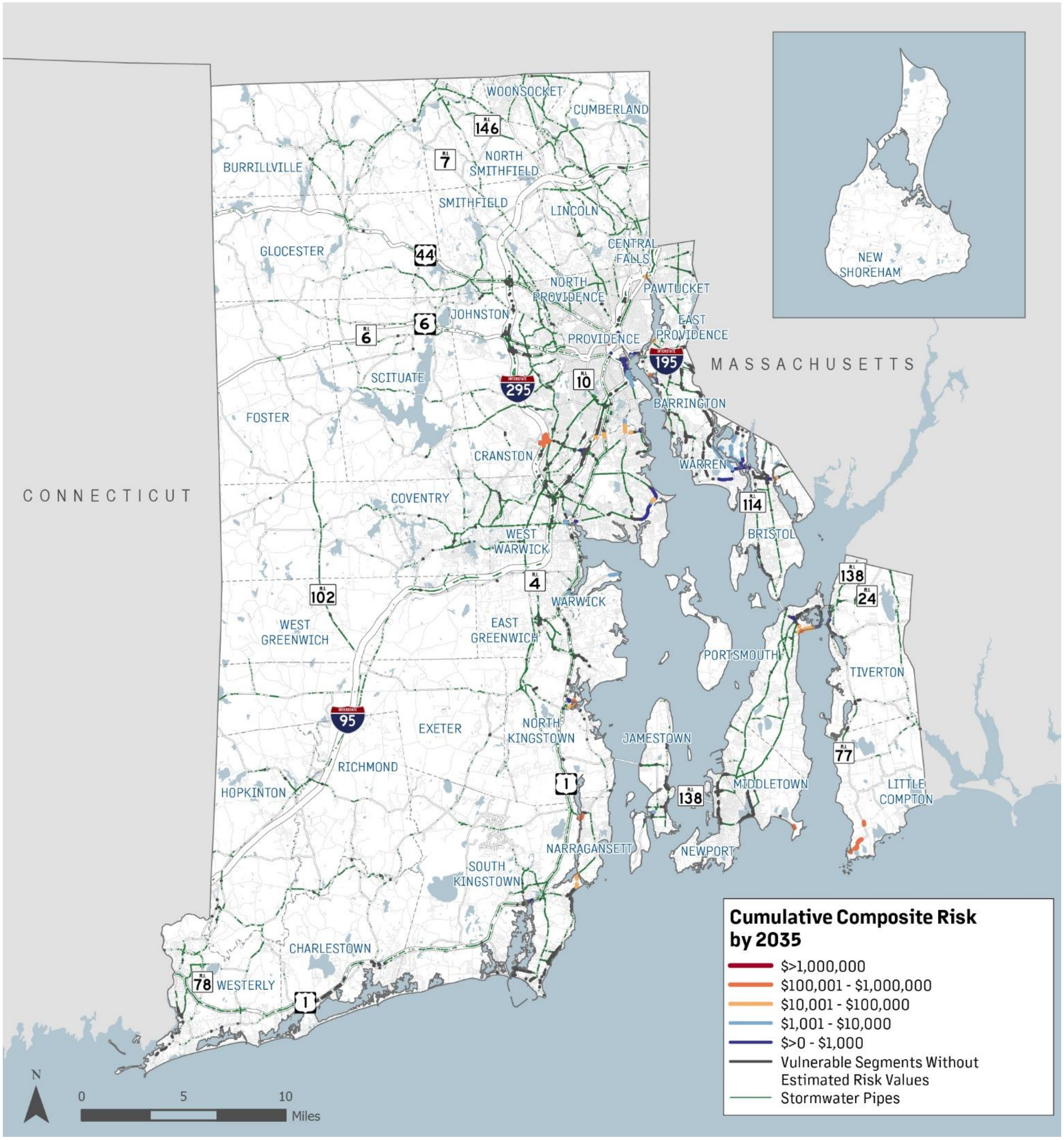


Figure 4.41 Cumulative Composite Risk of Stormwater Pipes by 2050

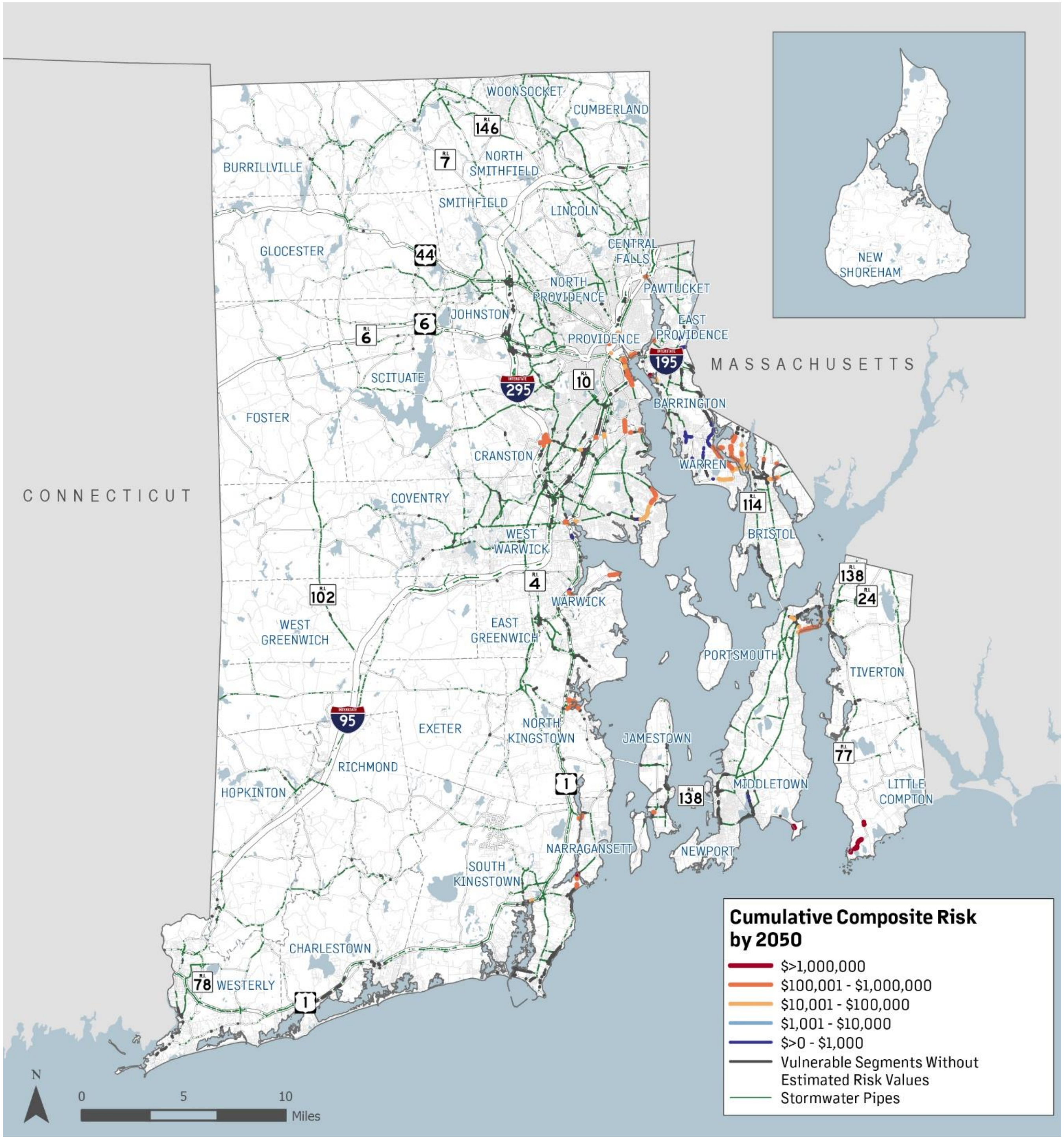


Figure 4.42 Cumulative Composite Risk of Stormwater Pipes by 2100

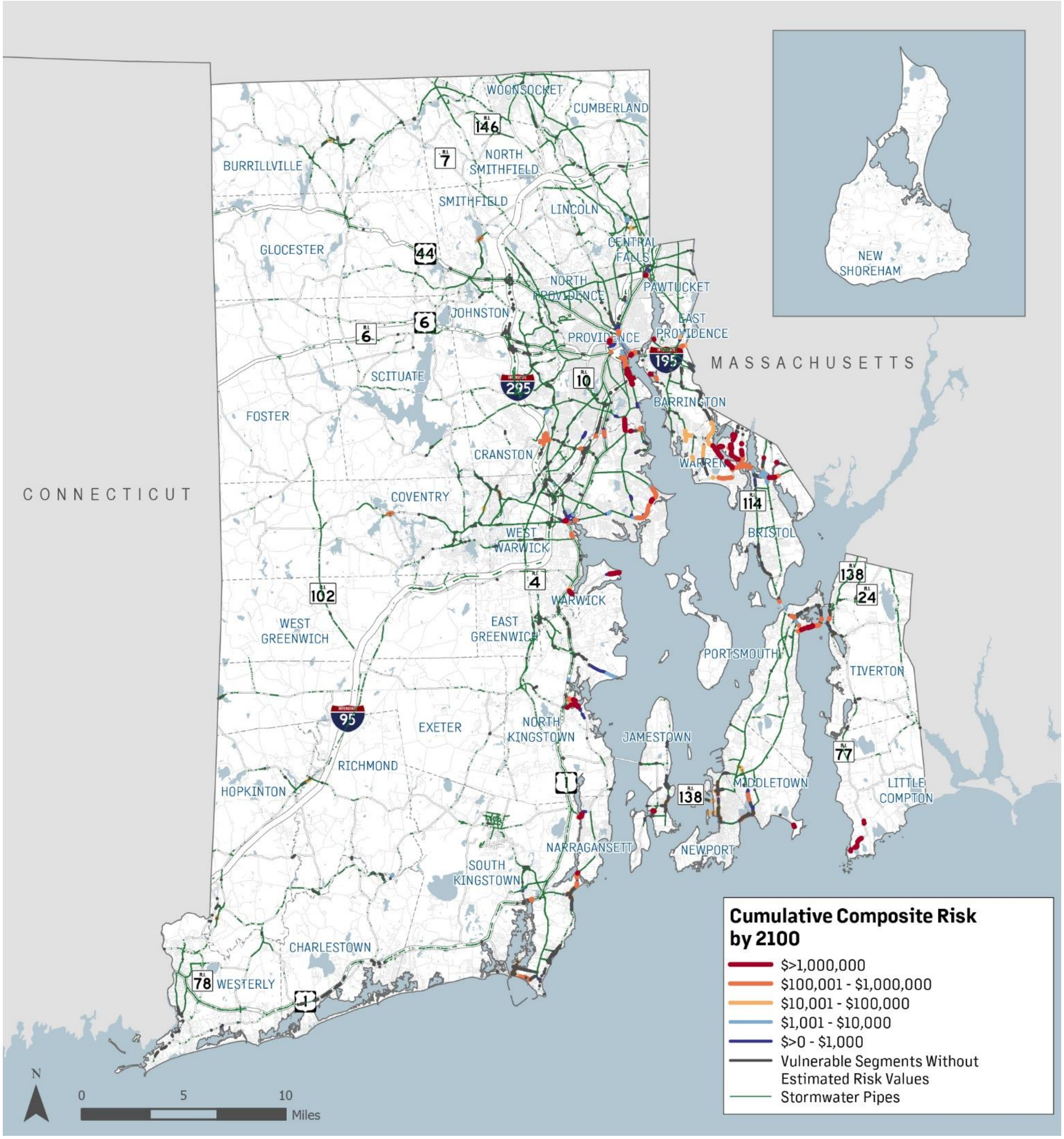


Figure 4.43 Cumulative Composite Risk of Stormwater Treatment Units by 2035

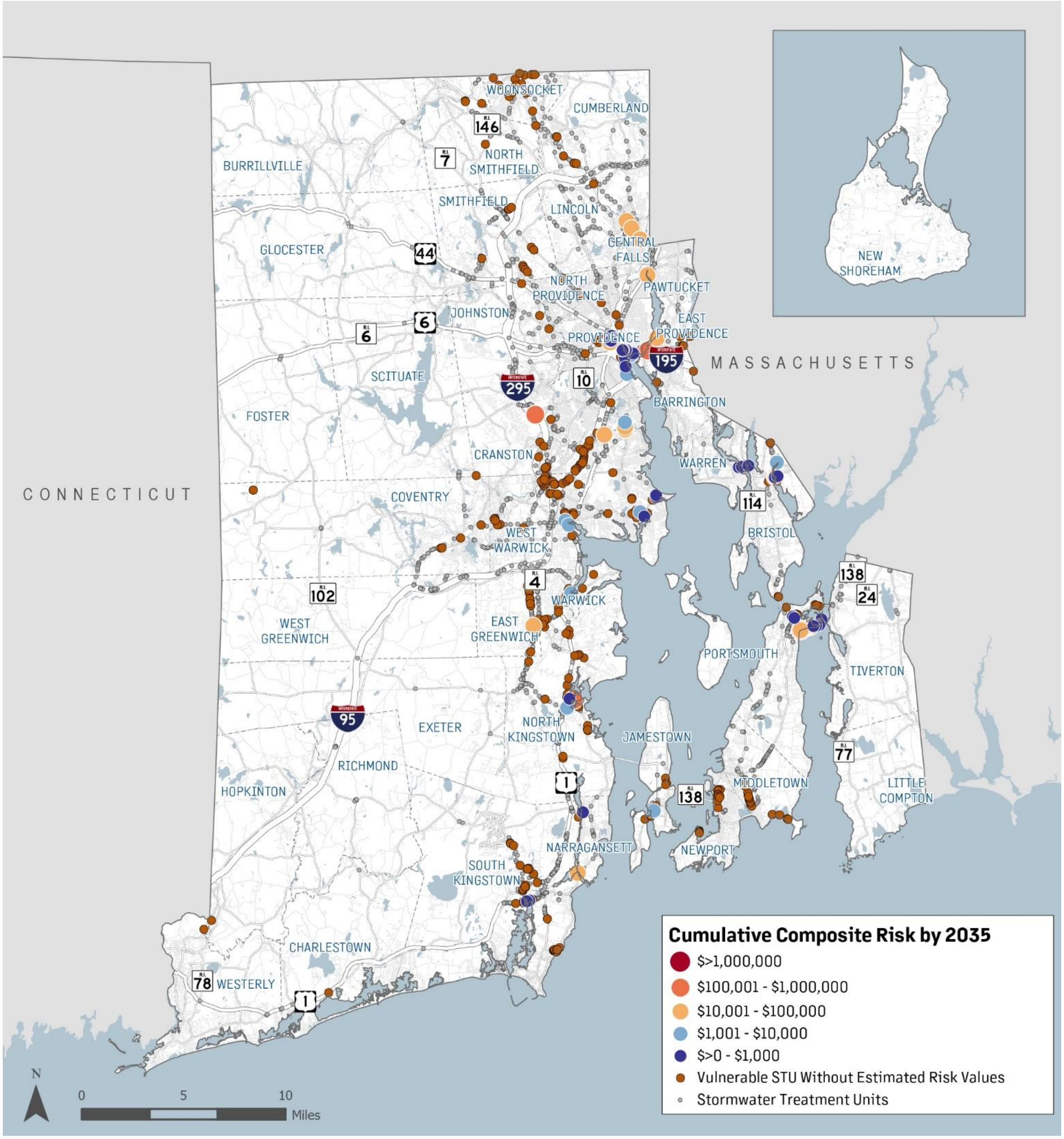


Figure 4.44 Cumulative Composite Risk of Stormwater Treatment Units by 2050

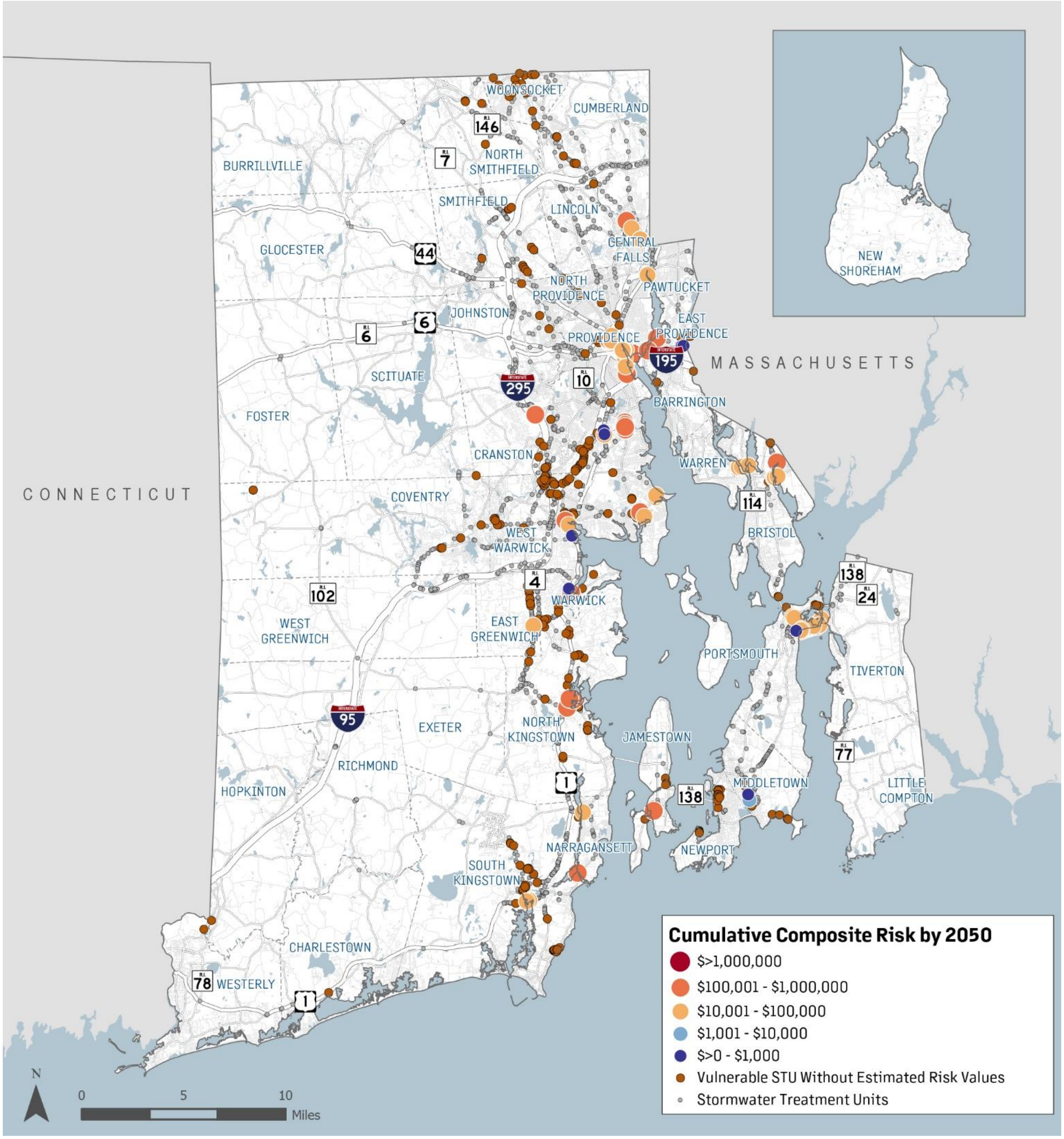
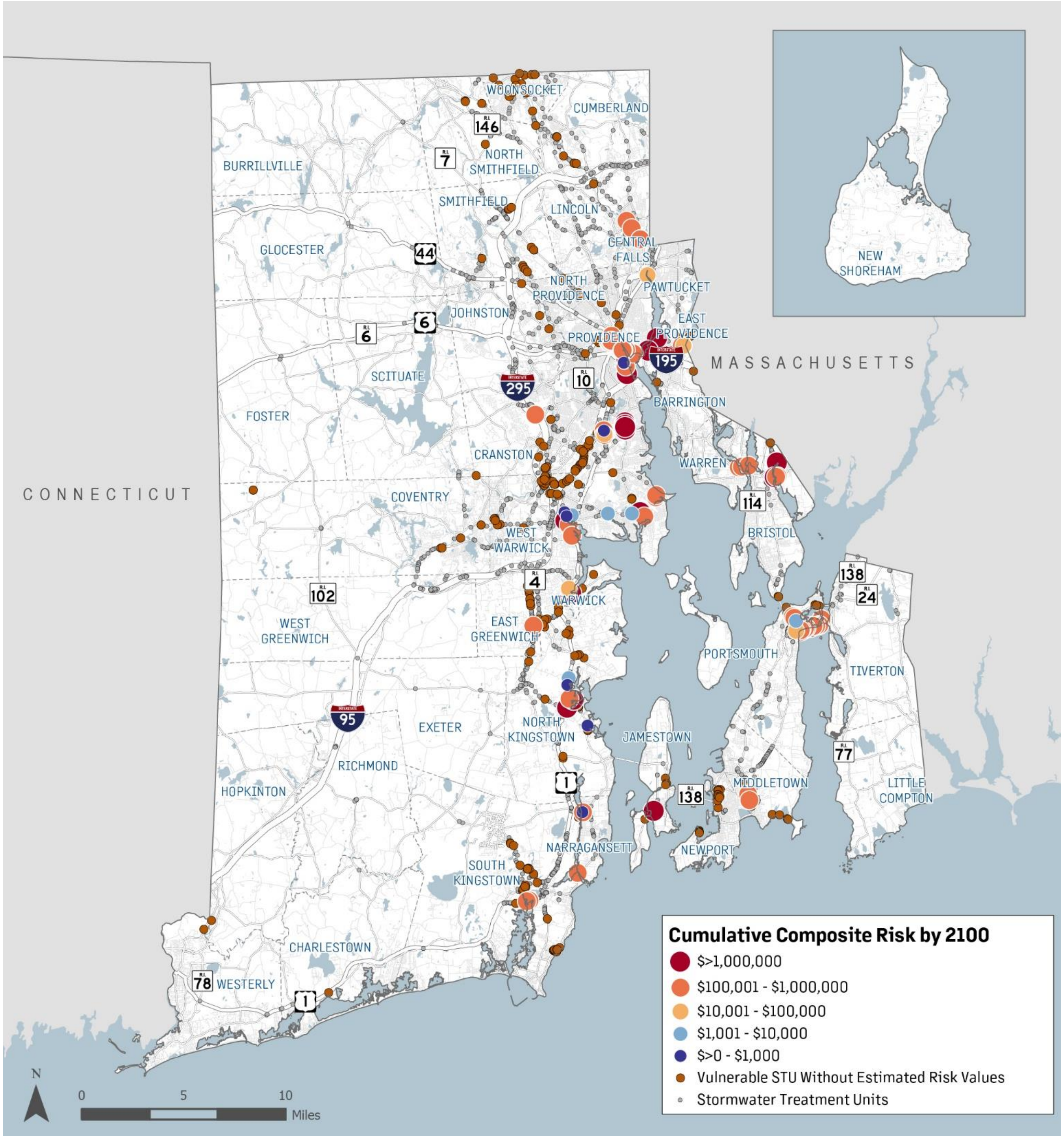


Figure 4.45 Cumulative Composite Risk of Stormwater Treatment Units by 2100



5.0 DETERMINE LEVEL OF ACCEPTABLE CHANGE

Chapter 5 builds on the assessment of vulnerability and risk by establishing risk thresholds for the RIDOT transportation network. This is accomplished through the development of a framework to determine levels of acceptable change, in a manner that relates criticality and risk. The insight gathered through this analysis is also used to establish mitigation targets for each asset class as a result of hazard occurrences.

5.1 Establish Acceptable Risk Thresholds

Acceptable risk thresholds, or risk tolerance, is the acceptable level of variance to the unimpeded operation of RIDOT's transpiration system. Although each transportation asset spanning the RIDOT network has its own unique characteristics and needs, a standardized process is needed to efficiently and accurately assess which portions of the network not only carry the greatest risk, but also carry the greatest risk relative their risk ability to carry risk. To develop this process, a framework to identify risk threshold, defined as risk capacity, is proposed. This framework will help RIDOT consider at what point do key assets become threatened enough to require further action. These actions, consisting of adaptation and mitigation strategies are discussed in Chapter 6.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (5) through the establishment of risk thresholds as a means of planning for risk from changing conditions. These risk thresholds form the basis for targeted investments and decision making.

The proposed Acceptable Level of Change Framework is shown in Figure 5.1. Broadly, the framework is divided into four sections:

- **Assessment of Criticality:** As identified in Chapter 3, each asset is assigned a level of criticality based on its role in the RIDOT transportation network.
- **Assessment of Vulnerability & Risk:** As identified in Chapter 4, each asset is assigned a level of vulnerability and risk.
- **Comparison of Risk & Risk Tolerance:** Determination of whether the risk associated with an asset exceeds its risk tolerance.

- **Identification of Resilience Needs & Adaptation Strategies:** Determination of the necessary strategies to balance risk and risk tolerance of an asset.

Figure 5.1 Acceptable Level of Change Framework

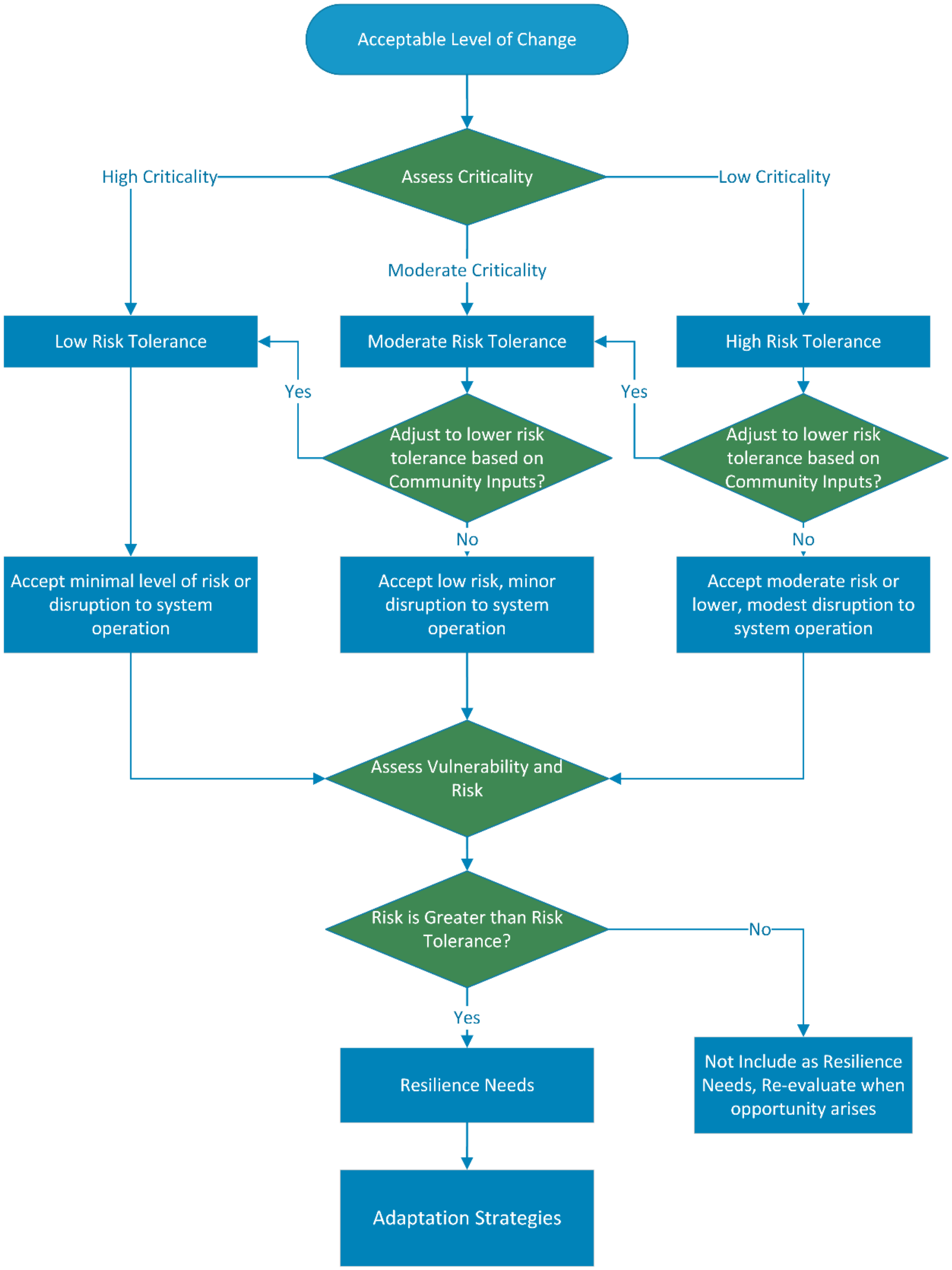


Figure 5.2, the assessment of criticality includes three thresholds of criticality: High, Moderate, and Low. Criticality is assumed inversely related to risk tolerance in that an asset with a high level of criticality, is assumed to have a proportionally low risk tolerance. Similarly, an asset with a low level of criticality is assumed to have a high risk tolerance. For those assets with a moderate or high risk tolerance, RIDOT should assess if there's a need to increase the criticality of any individual components. Correspondingly, assets with a low risk tolerance would need to be protected from all hazard levels.

Figure 5.2 Resilience Tolerance by Asset Criticality

Asset Criticality	High Criticality	Moderate Criticality	Low Criticality
Risk Tolerance	Low Risk Tolerance	Moderate Risk Tolerance	High Risk Tolerance
	Accept minimal level of risk or disruption to system operation	Accept low risk, minor disruption to system operation	Accept moderate risk or lower, modest disruption to system operation
Resilience Needs	Need to mitigate high, moderate, and low risk	Need to high and moderate risk	Need to mitigate high risk

The risk levels by asset categories were developed as shown in Table 5.1 using the cumulative composite risk amount developed in Chapter 4: No Risk (no inundation), Low, Moderate, and High.

Table 5.1 Risk Level by Asset Category

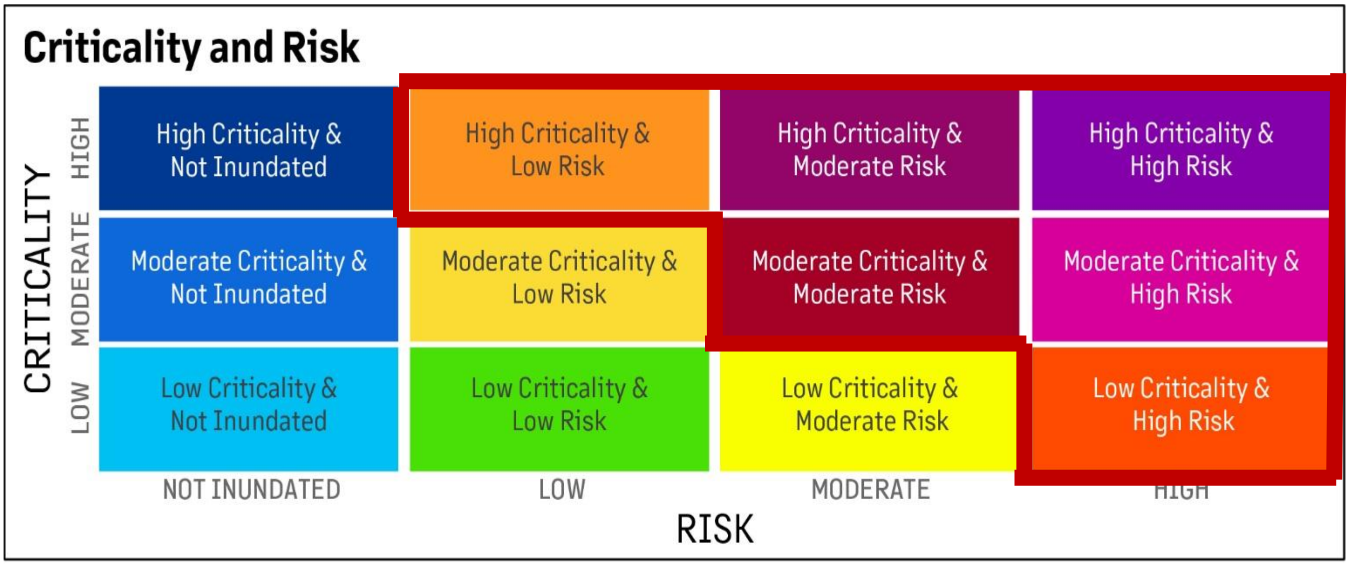
Risk Level	Roads & Bridges	Sidewalks & Shared-Use Paths	Stormwater Treatment Units	Stormwater Pipes
Not Inundated	$0	$0	$0	$0
Low	> $0 - $100,000	> $0 – $50,000	> $0 - $10,000	> $0 - $50,000
Moderate	$100,0001 - $1,000,000	$50,001 - $75,000	$10,001 - $100,000	$50,001 - $75,000
High	>$1,000,001	>$75,001	$100,001	$75,001

5.2 Identify Resilience Needs

As shown in Figure 5.3, the comparison between risk tolerance (determine by criticality) and risk consists of a matrix. Based on the flowcharts illustrated in Figure 5.1 and Figure 5.2, the categories highlighted within the red

box are those where risk matches or exceeds risk tolerance. In other words, an ideal system would not have any aspects which are deemed to have an equal or higher risk level than a criticality level.

Figure 5.3 Criticality and Risk Matrix



In relation to the matrix in Figure 5.3, there is a need to identify those assets that fall into the following categories towards the upper-right hand corner of the matrix. This includes the following categories:

- **High Criticality / High Risk:** Assets deemed to be at high risk, but which only have a low risk tolerance. Risk exceed risk tolerance.
- **High Criticality / Moderate Risk:** Assets deemed to be at moderate risk, but which only have a low risk tolerance. Risk exceed risk tolerance.
- **High Criticality / Low Risk:** Assets deemed to be low risk, but which also have a low risk tolerance. Risk equals to risk tolerance.
- **Moderate Criticality / High Risk:** Assets deemed to be at high risk, but which only have a moderate risk tolerance. Risk exceed risk tolerance.
- **Moderate Criticality / Moderate Risk:** Assets deemed to be at moderate risk, but which also have a moderate risk tolerance. Risk equals to risk tolerance.
- **Low Criticality / High Risk:** Assets deemed to be at high risk, but which also have a high risk tolerance. Risk equals to risk tolerance.

Based on these risk thresholds, the most urgent assets which will require attention would be grouped into the High Criticality / High Risk threshold, where risk most exceeds risk thresholds. Rhode Island's road network is

grouped into each of the categories of the Risk and Criticality matrix through 2035, 2050, and 2100 based on cumulative composite risk, in Figure 5.4, Figure 5.5, and Figure 5.6. Overall through 2100, the majority of Rhode Island's road network falls under the 'No Risk' thresholds at varying degrees of criticality. On the other hand, through 2035, many of the locations frequently discussed in Chapter 4 fall into one of the six categories which should require attention. This includes isolated portions of I-95 and I-295, as well as arterials in Point Judith, Narragansett, Jamestown, Newport, and Middletown, as well as scattered portions of the RI-114 corridor through coastal Rhode Island, which are considered to be High Criticality / High Risk. A number of additional arterials in coastal Rhode Island, including in Block Island, as well as in and around Providence are expected to fall in the High Criticality / Low Risk threshold. Through 2050, as shown in Figure 5.5, an increased portion of at-risk assets are expected to fall under the High Criticality / High Risk threshold, including some arterials in Providence, and additional portions of the RI-114 corridor through coastal Rhode Island. Through 2100 a majority of at-risk assets, as commonly discussed in Chapter 4, are expected to fall into the High Criticality / High Risk threshold. Furthermore, nearly every asset at risk of inundation is expected to fall into one of the six risk thresholds requiring additional attention.

Figure 5.4   Criticality & Risk Through 2035

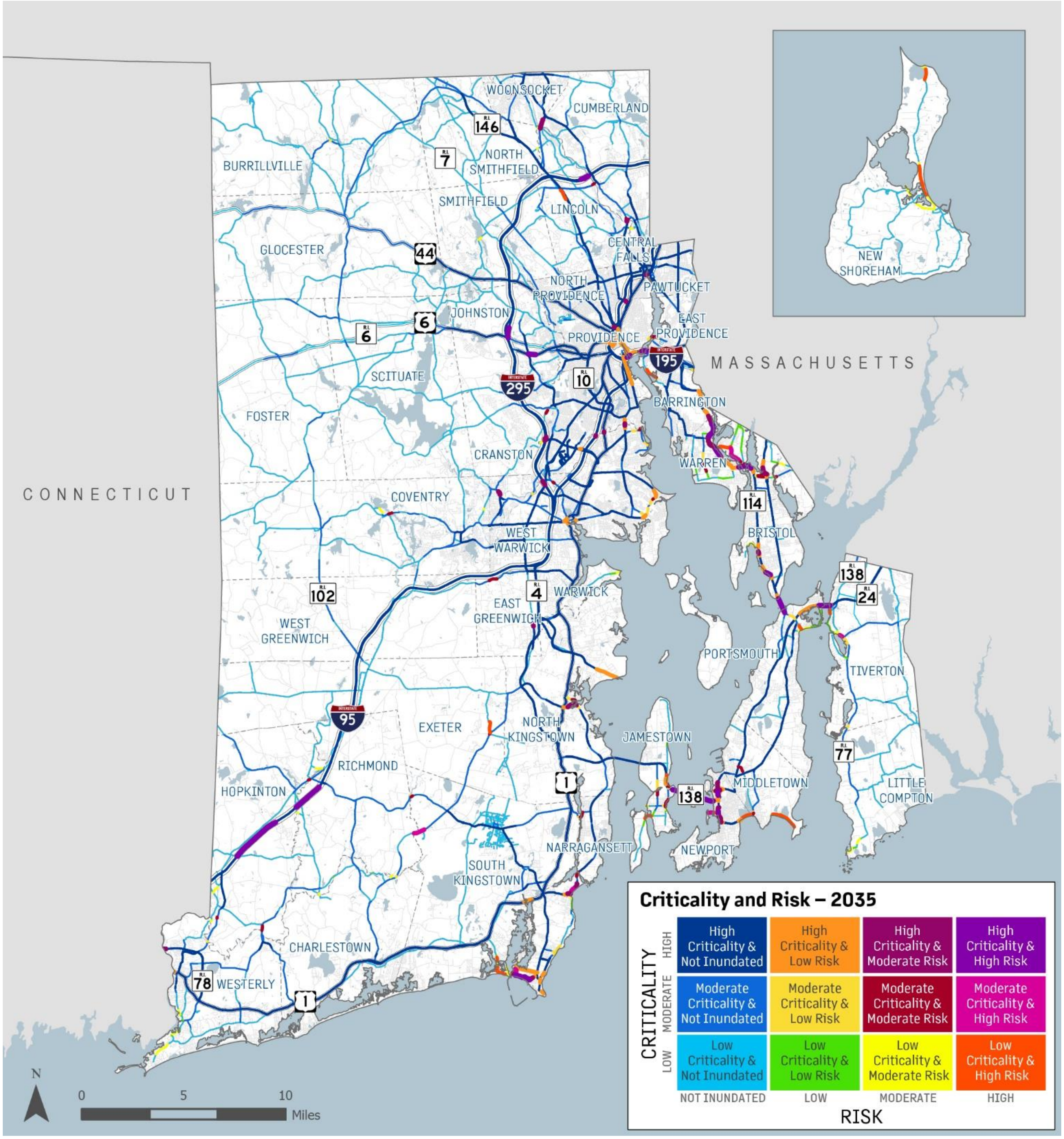


Figure 5.5 Criticality & Risk Through 2050

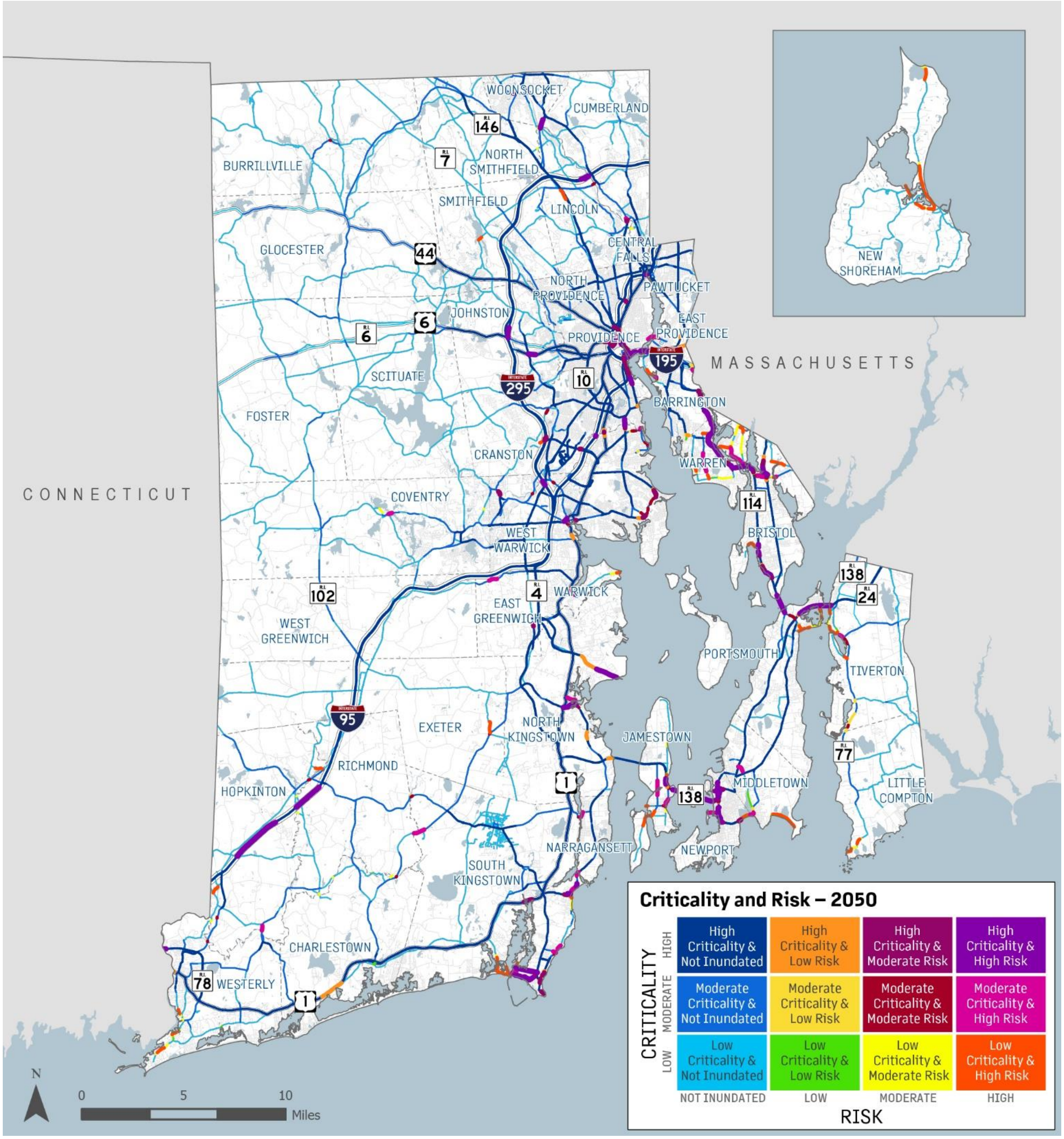
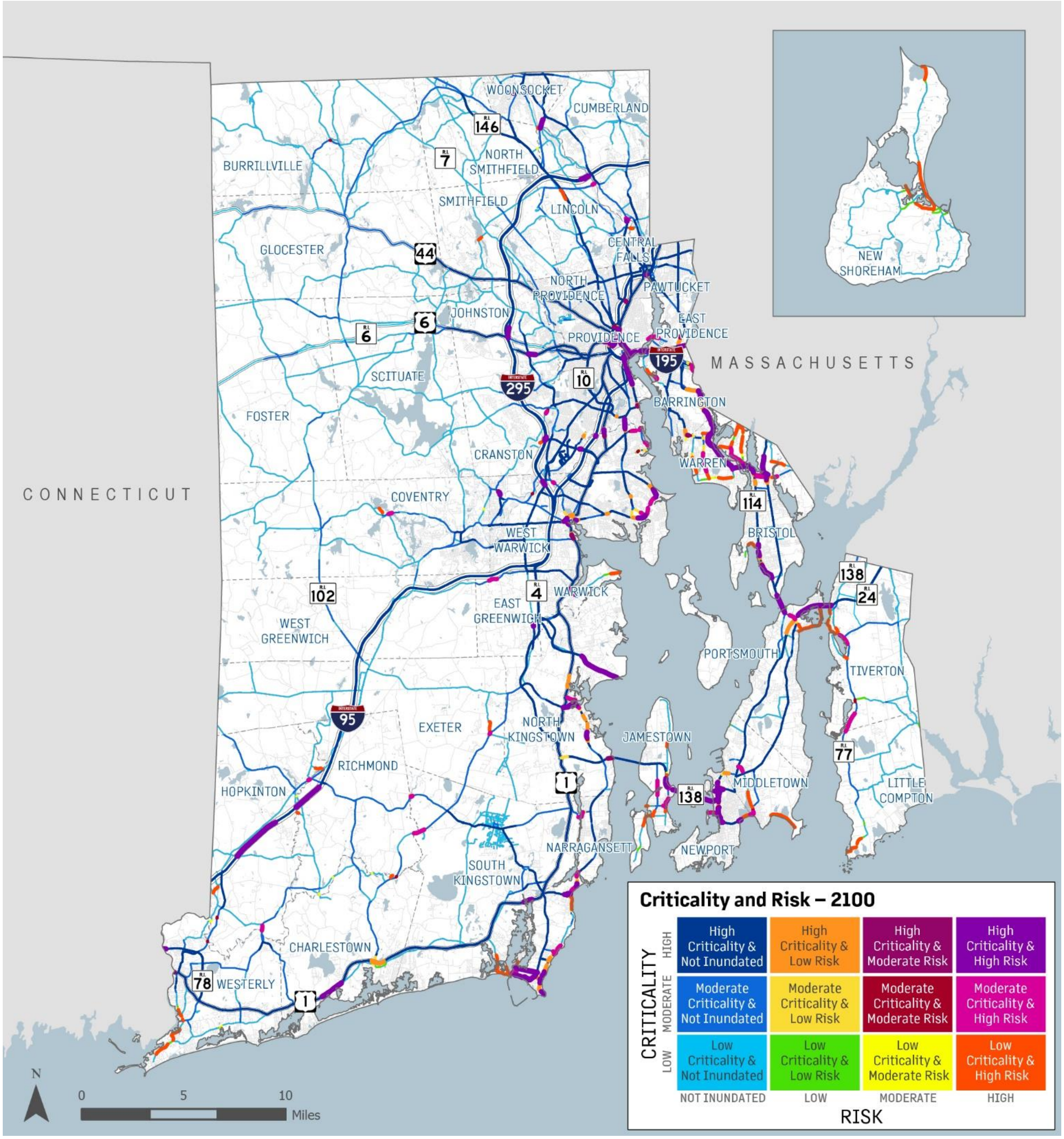


Figure 5.6 Criticality & Risk Through 2100



5.3 Establish Mitigation Objectives

The previous section established acceptable risk thresholds for the purposes of identifying locations where assets risk exceeds risk tolerance. This section builds on this analysis to identify mitigation objectives and resilience needs for low, moderate, and high levels of risk tolerance, as discussed in the previous section. Proposed mitigation targets are identified in Table 5.2, based on the categorization of hazard event likelihood, as discussed in Chapter 4. Hazard events are grouped into four categories as follows:

- **Very High Consequence / Very Low Probability (<0.2% Annual likelihood of Occurring):** These events are classified as less frequent than once in 500 year floods. Although the probability of occurrence is very low, these events would generate the significant consequences as a result of inundation.
- **High Consequence / Low Probability (0.2% Annual likelihood of Occurring):** These events are classified as once in 500 year floods. Although the probability of occurrence is low, these events would generate the large consequence as a result of inundation.
- **Moderate Consequence / Moderate Probability (1% Annual likelihood of Occurring):** These events are classified as once in 100 year floods. The probability of occurrence is moderate, with a moderate level of consequence generated from inundation.
- **Minor Consequence / High Probability (1% Annual likelihood of Occurring):** These events are classified as more frequent than once in 100 year floods. The probability of occurrence is high, with a lower level of consequence generated from inundation.

Table 5.2 Examples of Mitigation Objectives

Event Category	Mitigation Targets		
	High Criticality, Low Risk Tolerance	**Moderate Criticality, Moderate Risk Tolerance**	**Low Criticality, High Risk Tolerance**
Very High Consequence, Very Low Probability (<0.2%)	No structural damage, short service closure (<24 hrs)	Minor structural damage, moderate service closure (<72 hrs)	Moderate structural damage, long service closure (>72 hrs)
High Consequence, Low Probability (0.2%)	No structural damage, no service closure	No structural damage, short service closure (<24 hrs)	Minor structural damage, moderate service closure (<72hrs)
Moderate Consequence, Moderate Probability(1%)	No structural damage, no service closure	No structural damage, no service closure	No structural damage, short service closure (<24 hrs)
Minor Consequence, High Probability(>1%)	No structural damage, no service closure	No structural damage, no service closure	No structural damage, no service closure

Based on this matrix of likelihood and risk tolerance, the following resilience needs are identified for the RIDOT transportation network:

For those assets with a low risk tolerance (high criticality), there is a need to ensure that assets do not require any service closure, and do not suffer any structural damage from hazard events with a severity of up to a once in 500-years flood. For hazard events with an inundation severity greater than a once in 500-year flood, there a need to ensure that there isn't any structural damage, and that service closures last no longer than 24 hours. Applied to the Rhode Island road network as shown in Figure 3.6, there is a need to ensure that most of Rhode Island's major thoroughfares, including I-95, I-295, RI-114, and RI-138 are sufficiently protected from hazards so that closures aren't required, besides from only the strongest hazard events.

For those assets with a moderate risk tolerance (medium criticality), there is a need to ensure that assets do not require any service closure, and don't suffer any structural damage from hazard events with a severity of up to a once in 100-years flood. For hazard events with an inundation severity of once in 500-years flood, there is a need to ensure no structural damage, and that service closures last no longer than 24 hours. For hazard events with an inundation severity greater than a once in 500-year flood, there a need to ensure that there is only minor damage, and that service closures last no longer than 72 hours. In Rhode Island, many of the arterials assigned to medium criticality perform important roles. This includes providing a greater degree of connectivity between the I-95 and US-1 corridors, while providing greater network density in and around Providence.

For those assets with a high risk tolerance (low criticality), there is a need to ensure that assets do not require any service closure, and don't suffer any structural damage from hazard events with a severity of less than a once in 100-years flood. For hazard events with an inundation severity of once in 100-years flood, there is a need to ensure no structural damage, and that service closures last no longer than 24 hours. For hazard events with an inundation severity of once in 500-years flood, there is a need to ensure that there is only minor damage, and that service closures last no longer than 72 hours. For hazard events with an inundation severity greater than a once in 500-year flood, there a need to ensure that there is only moderate damage, and that service closures last no longer than 72 hours. In Rhode Island, the collectors and arterials designated as low criticality have highly important roles. This includes providing connectivity to suburban and exurban communities in Rhode Island, while providing increased network density in the urban and coastal portions of the state. As a result, there is a need to ensure that closures and disruptions are minimized.

6.0 DEVELOP DESIRED PATHWAYS AND RELATED ACTIONS

The development of desired pathways and related actions is the next step in the resilience planning process. This step identifies RIDOT's strategic process to address vulnerabilities, risk, and resilience needs in the statewide transportation system, as identified in Chapters 3 and 4. The desired pathways and related actions are grouped into the following actions:

- Identify Adaptation Strategies: Physical and design strategies recommended for consideration by RIDOT.
- Conduct Project Evaluation: Introduces recommended processes for RIDOT to evaluate potential resilience projects and upgrades.
- Develop and Prioritize Resilience Improvements: Establishes a framework for prioritizing, and subsequently implementing identified adaptation strategies.

6.1 Identify Adaptation Strategies

Chapter 3 identified inundation from sea level rise, storm surge, and flooding as the most pressing hazard and threat to the Rhode Island transportation system. This can be attributed to multiple factors, including the state's coastal and low-lying geography, as well as a dense transportation network that supports a large statewide population. Adaptation strategies are identified as the physical and design strategies used to respond to hazards and threats, and reinforce resiliency. This 'Toolbox' of options is intended to introduce RIDOT to some of the most relevant adaptation strategies that can further reinforce resilience and reduce the risk associated with critical assets. Adaptation strategies are identified for the six asset categories identified in Chapter 3. For each asset, strategies are identified based on the hazard that is addressed through each mitigation. Key geographic context is also provided for each strategy, as well as identification nature-based strategies. When the geographic context and other considerations allow for it, there are multiple benefits of utilizing nature-based strategies, including in tandem with other physical strategies. These strategies tend to be more cost effective, while also increasing sustainability through the introduction of native plant species and the overall addition of efficiently porous and pervious surfaces.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (7) by considering the benefits of natural infrastructure as adaptation strategies.

6.1.1 Road Adaptation Strategies

The 1,930 miles of roads form the vast majority of the Rhode Island transportation network. The road network is comprised of the system of interstates, freeways & expressways, arterials, collectors, and local roads. Functioning as the economic and societal backbone of Rhode Island, there is a need to ensure a high degree of reliability, and manageable level of risk for roads across every level of criticality. Table 6.1 summarizes potential adaptation strategies for roads to help mitigate risk associated with inundation hazards. These strategies are grouped into the following categories: Coastal Asset Protection, Inundation Protection, and Asset Protection. A full description of identified adaptation strategies can be found in Appendix I: Adaptation Strategies.

Table 6.1 Road Adaptation Strategies

Theme	Roads						
	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
Inundation Protection	Raised Profile  Source: *Capping fill with Driving Surface Aggregate* https://dirtandgravel.psu.edu/wp-content/uploads/2022_Annual_Workshop_Field_Sites_Handout.pdf	$$$	• Raising of profile (shape and elevation of road surface) to withstand inundation. • Potential impacts to drainage of surrounding area drainage. • Magnitude of profile raise dependent on factors of costs, risks, and potential inundation levels.		Flood Sea Level Rise Storm Surge	• With potentially significant impacts to area drainage, this strategy should be reserved for roads deemed to have high criticality, especially with high levels of health & safety importance. • This strategy may be more challenging to implement in urbanized areas with high levels of network density.	• Short-term: significant reduction in potential damage to a road by avoiding significant inundation . • Long-term: no subsequent cost in addition to typical maintenance. Cost can then be offset by the protection offered to the road itself as well as the surrounding structures
Asset Protection Strategies	Enhanced Road Surface  Source: *Asphalt Mining* https://www.gspavement.com/asphalt-milling/	$	• Enhancement of initial HMA surface layer through the application of approximately 2” of course material. • Necessary to prevent cracking and other defects resulting from inundation and surge.		Flood Sea Level Rise Storm Surge	• Typical context and geography considerations should be applied, as with any pavement action.	• Short-term benefits are achievable from improved infrastructure conditions. • Long-term benefits will need to take into account the potential for increased infrastructure wear.

Theme	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
	Roads						
Asset Protection Strategies	Enhanced Sub Surface  Source: *Tie bars along a longitudinal joint* https://pdhonline.com/courses/c509/FHWA%20Full-depth%20conc%20repair.pdf	$$	• Thickness enhancements of between 4" and 6" of the sub surface. • Provides increased strength and protection from more severe inundation and surge impacts.		Flood Sea Level Rise Storm Surge	• Typical context and geography considerations should be applied, as with any pavement action.	• Short-term benefits are achievable from improved infrastructure conditions. • Long-term benefits will need to take into account the potential for increased infrastructure wear.
	Complete Rebuild  Source: *A road in Naka, Ibaraki prefecture, Japan: left, how it was on the day of the earthquake; right, six days later* https://www.theguardian.com/world/2011/mar/24/japan-disaster-reconstruction-road-recovery	$$$	• Reconstruction of the roadway surface. • Necessary for recovery if inundation and surge levels are high enough, or when other infrastructure upgrades are also planned.		Flood Sea Level Rise Storm Surge	• Typical context and geography considerations should be applied, as with any pavement action.	• Short-term benefits are achievable from improved infrastructure conditions. • Long-term benefits will need to take into account the potential for increased infrastructure wear.

	Roads						
Theme	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
Asset Protection Strategies	Enhanced Shoulders & Medians  Source: *https://www.geofabricsmining.com.au/sites/default/files/2020-11/GEOFABRICS_Geoweb-General-Brochure-M056-10-14AU.pdf*	$$	• Implementation of sheet pilings, gabions, paving and surface enhancements to reduce effects from inundation and surge. • Strategy selection dependent on geography (coastal or inland), vulnerability, and risk constraints.		Flood Sea Level Rise Storm Surge	• This strategy is primarily applicable for roads with a larger width, or sufficient right-of-way for shoulder or median upgrades.	• Short-term benefits include increased infrastructure protection from related upgrades. • Long-term benefits will need to take into account the potential for increased infrastructure wear and inundation levels.
	Permeable Pavement  Source: *Grey concrete flooring blocks assembled on a substrate of sand with grass - type of flooring permeable to rain water as required by the building laws used for sidewalks and parking areas* *https://stock.adobe.com/images/grey-concrete-flooring-blocks-assembled-on-a-substrate-of-sand-with-grass-type-of-flooring-permeable-to-rain-water-as-required-by-the-building-laws-used-for-sidewalks-and-parking-areas/448750489*	$$	• Modified pavement structure designed to drain excess water and reduce runoff. • Feasible only for highways with low grades, low weight limits, and low speed limits.		Flood Sea Level Rise Storm Surge	• Based on the limitations of permeable pavement, this strategy would be feasible only on a local street with a low AADT and speed limit.	• Short-term benefits include increased infrastructure protection from related upgrades and increases in overall permeability. • Long-term benefits will need to take into account the potential for increased infrastructure wear.

Theme	Roads						
	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
Coastal Protection / Living Shoreline Strategies	Beach Nourishment & Dune Restoration  Source: *Fort Lauderdale, Florida - Sand is added to the Atlantic Ocean seashore as part of a beach restoration project.* *https://www.alamy.com/stock-photo-fort-lauderdale-florida-sand-is-added-to-the-atlantic-ocean-seashore-104156910.html*	$$$	• Restoration of beaches and construction of sand dunes to provide a barrier between seaward ocean forces and infrastructure. • Nourishment does not end erosion; it is usually an ongoing process, which leads to higher costs over time. • May require additional maintenance and restoration practices to avoid sand from washing away, such as installing sand mats.	✓	Storm Surge	• This adaptation strategy is primarily applied to adjacent beaches, as opposed to the road itself. • Ownership of the beach / dune is a key consideration. Require collaboration with the community and other stakeholders to implement. • Relies solely on natural material.	• Short-term: flexible and fast option to provide protecting barriers between wave/tidal actions and roadways compared to hard infrastructure. • Long-term: provide additional space for coastal tourism, recreation activities and coastal habitats preservation.
	Vegetation as Erosion Control  Source*: https://lakeshorecustoms.com/shoreline-erosion-control-5-methods/*	$	• Planting of dune grass and other native fauna along beaches and vulnerable locations to reduce erosion. • Plants require a few years to establish root structures and strengthen, in order to provide maximized benefits.	✓	Storm Surge	• This adaptation strategy is primarily applied to scenarios where there is only minor to moderate wave or overtopping actions • Ownership of the beach / dune is a key consideration. If the beach / dune is located on private property, the process of implementation may include more complexities.	• Short-term: the root systems of plants help to bind together soils and reduces erosion. The vegetation also helps to filter water that is entering the drainage system • Long-term: increased protection will be achieved as plants further grow and establish their root systems.

Theme	Roads						
	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
Coastal Protection / Living Shoreline Strategies	Revetments & Sea Walls  Source: *Brenton Point Sea Wall, Photo by : Stefano Bloch* https://livingnewdeal.org/sites/brenton-point-sea-wall-newport-ri/#lg=1&slide=3	$$$$	• Implementation of a sea wall or revetment to protect and harden the seaward side of the road embankment. • Revetments are layers of protection on the top of a sloped surface to protect the underlying soil. Seawalls are walls designed to protect against large wave forces.		Sea Level Rise Storm Surge	• As a more complex infrastructure project, the installation of a revetment or sea wall may require more logistical considerations, and could be a challenge for a road in a more urbanized or heavily trafficked area. • This strategy is optimal for a non-urbanized location by measure of logistical planning and considerations.	• Short-term: relatively high up-front implementation cost. • Protect coastal assets against many different conditions. • Long-term: long lasting and minimum maintenance needs in comparison to nature-based solutions.
	Wave Attenuation Devices  Source: *Wave Attenuation Devices near Skyway Fishing pier, Tampa Bay* https://www.fox13news.com/news/new-wave-attenuation-devices-to-be-installed-near-skyway-fishing-pier-to-help-prevent-erosion	$$$$	• Construction of floating or anchored structures to reduce the force of waves striking the coastline. • A relatively newer form of asset protection, with costs and potential benefits dependent on the type of WAD installed, and desired level of wave force control.		Storm Surge	• Applied as an offshore adaptation strategy, a key consideration will be where and how to position onshore labor and materials. • Community opposition to these devices may be high if they are proposed in a location that is highly visible from onshore beaches, businesses, and residences.	• Short-term: Protect significant lengths of coastline against major events such as hurricanes and reduce wave force prior to reaching shore. • Long-term: considerations are needed for potential for increased strength of wave through scenarios of increased storms such as hurricanes.

Theme	Roads						
	Strategy	Resource Commitment	Description	Nature-Based Solution	Hazard	Context & Geography Considerations	Benefits
Abandonment & Relocation	Abandonment & Relocation  Source: *Water spills onto Hoopers Island Road in Hoopersville, Md., during high tide.* https://eos.org/articles/photography-focuses-on-sea-level-rise-and-eroding-communities	$$$$	• Likely needed for scenarios with increased exposure to storm surge and flooding. • Primary option when other options are not feasible or cost-effective.		Flood Sea Level Rise Storm Surge	• Opportunities for road relocation are likely limited in Rhode Island, given the presence of development along most of the state's coastal and riverside locations. However, abandonment may be a necessary process in some instances, especially for vulnerable local roads.	• As a long-term strategy, abandonment and relocation is beneficial and likely necessary for locations where increased and prolonged inundation cause unsafe and impassable conditions.

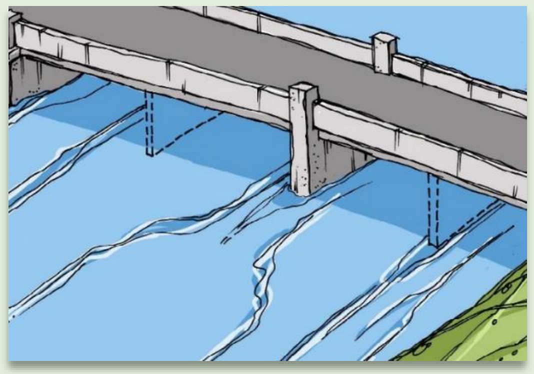
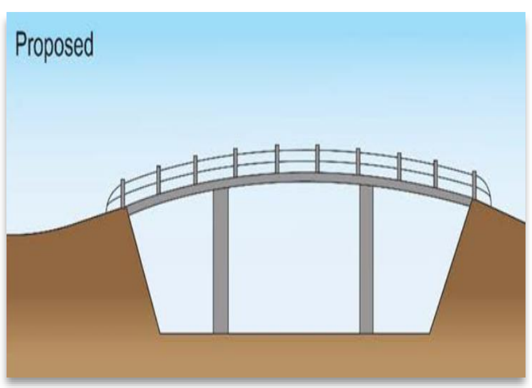
6.1.2 Bridge Adaptation Strategies

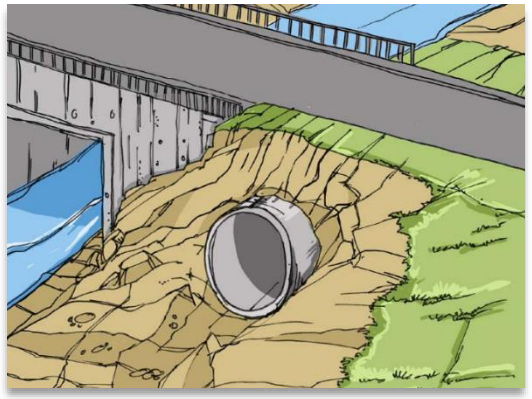
As a coastal state characterized by numerous waterbodies, bridges are a particularly critical component in the state's multimodal transportation infrastructure network. The network 1,358 bridges also includes many overpasses and underpasses, as well as culverts which function as smaller structures channeling water below the road surface. Adaptation strategies to address bridge and culvert needs from sea level rise, storm surge, and flooding are grouped into the following categories:

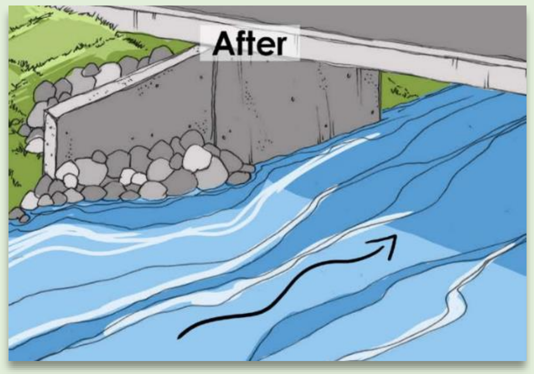
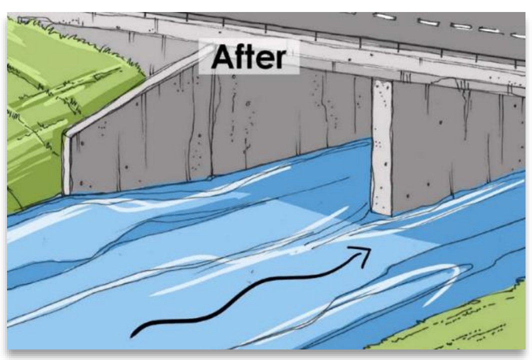
- Improve Flow Under Structure
- Develop Erosion & Scour Countermeasures
- Reduce Debris Damage: These strategies
- Relocation

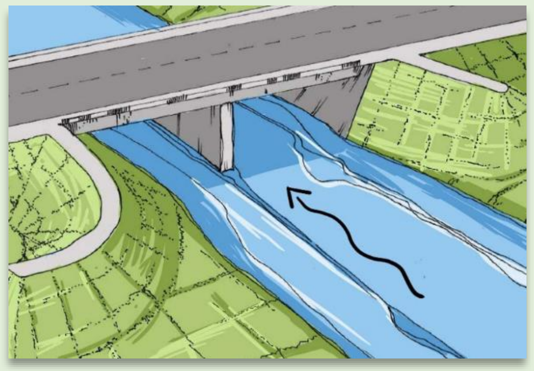
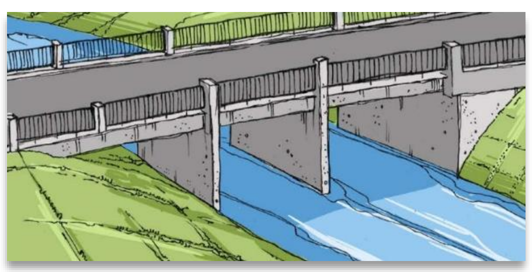
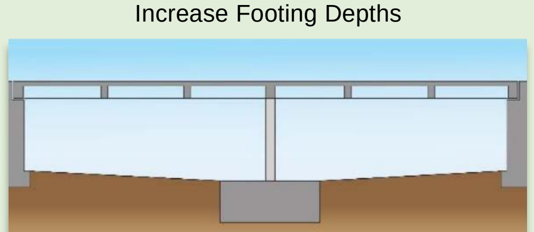
These strategies are summarized in Table 6.2. A full description of identified adaptation strategies can be found in Appendix I: Adaptation Strategies

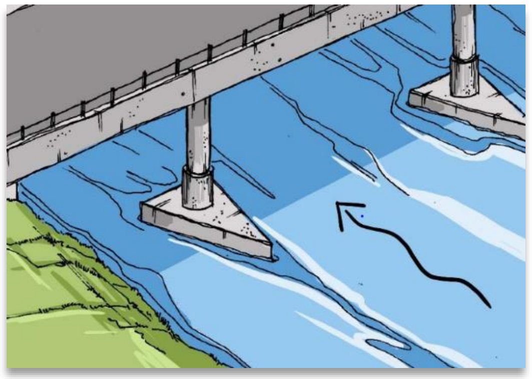
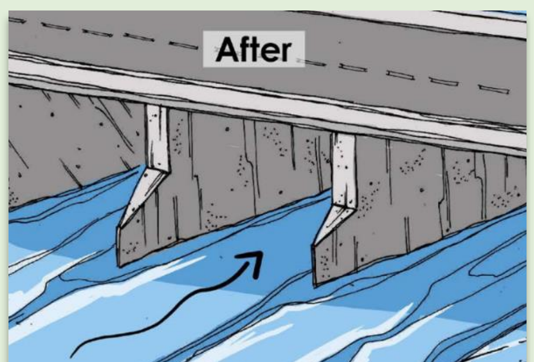
Table 6.2 Bridge Adaptation Strategies

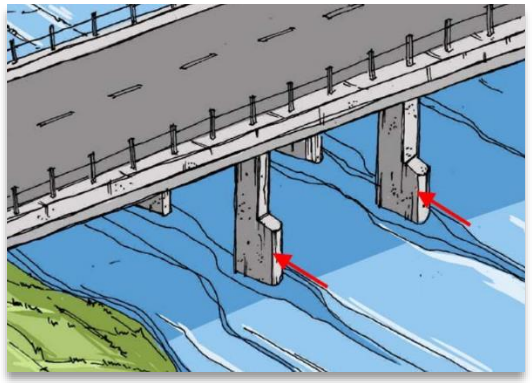
Theme	Bridge / Culverts						
	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
I Improve Flow Under Bridge Crossing	Replace Multi-Spans with a Single-Span Bridge  Source: *Reducing the number of spans can increase the flow amount under the bridge.* *https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$$	• Use of a single-span bridge to eliminate the number of piers and increase waterflow. • May require significant design considerations and resource requirements.		Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• The implementation of a single-span bridge is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.
	Elevate Bridge Deck  *Source: Increasing the size of a bridge opening by raising the bridge deck can increase flow volume under the bridge.* *https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$$	• Elevation of bridge deck and superstructure beyond flood level to increase bridge opening. • May require significant design considerations and resource requirements, making cost-effectiveness a challenging goal.		Flood Sea Level Rise Storm Surge	• May require additional right of way on either side of the bridge, which could add to complexities if the bridge is located in a dense or urban location.	• The elevation of a bridge deck is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.

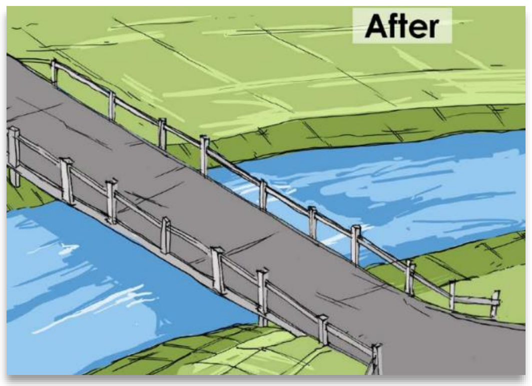
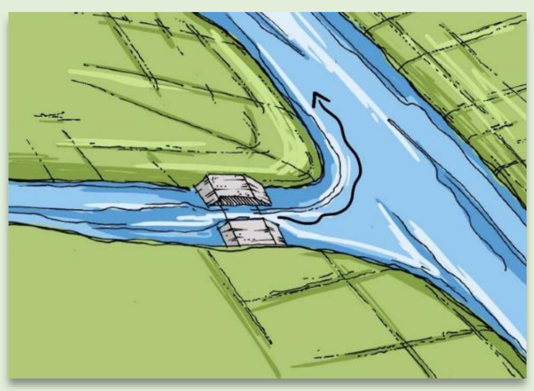
Theme	Bridge / Culverts Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Improve Flow Under Bridge Crossing	Increase Bridge Length  Source: *Lengthening a bridge can provide additional overflow capacity beneath the bridge.* *https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$$	• Increasing of bridge length through the installation of additional spans or openings to increase space for flow volume.		Flood Sea Level Rise Storm Surge	• May require additional right of way on either side of the bridge, which could add to complexities if the bridge is located in a dense or urban location.	• The increasing of bridge length is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.
	Construct a Relief Opening  Source: Building a relief opening can help prevent flooding of bridges. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$$	• Construction of an additional culvert or relief opening to provide additional space for flow volume.		Flood Storm Surge	• May require additional right of way on either side of the bridge, which could add to complexities if the bridge is located in a dense or urban location.	• Short-term benefits will be achievable upon completion in the form of increased flow volume capacity. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Bridge / Culverts						
	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Construct Erosion & Scour Countermeasures	Install Riprap  Source: Riprap can protect bridge piers and abutments against erosion and scour. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$	• Placement of riprap along approaches, abutments, and piers to reduce erosion.	✓	Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced erosion and resulting increased volume capacity. • Long-term benefits will likely require periodic replacement of riprap to ensure full functionality.
	Construct Bridge Wingwalls  Source: Riprap can protect bridge piers and abutments against erosion and scour. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$$	• Extension of approach abutments in an angular direction to protect embankments from erosion.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced erosion and resulting increased volume capacity. • Long-term benefits benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Bridge / Culverts						
	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Construct Erosion & Scour Countermeasures	Construct Spur Dikes  Source: *Spur dikes can direct flood flows, reducing erosion and scour around bridges.* *https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$	• Extension of embankments in a straight or elliptical shape to redirect flow to reduce erosion.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced erosion and resulting increased volume capacity. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.
	Realign Piers & Abutments  Source: *Realigning piers and abutments can decrease the damage from erosion and scour.* *https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$$	• Realignment of bridge piers and abutments to better parallel flow. • May require significant design considerations and resource requirements.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• The realignment of piers and abutments is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.
	Increase Footing Depths  Source: *Increasing footing depth can protect bridge foundations against scour.https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$$	• Extension of pier and abutment footings below pre-determined scour depth based on flood risk and magnitude.		Flood Sea Level Rise Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced erosion and resulting increased volume capacity. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Bridge / Culverts Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Construct Erosion & Scour Countermeasures	Install Flow Detector  Source: *Installing flow deflectors immediately upstream of bridge piers can help protect them against scour.*https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$	• 'V' – shaped structures placed on piers and abutments in the direction of flow to protect against scour and erosion.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced erosion and resulting increased volume capacity. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.
Reduce Debris Damage	Install Debris Deflectors  Source: *Debris deflectors can protect bridge piers and abutments from impact damages and debris accumulation.* https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$	• Upstream-facing fins installed on piers and abutments to orient floating debris away from piers and abutments.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced debris. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Bridge / Culverts						
	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Reduce Debris Damage	Install Semicircular or Triangle Endnoses  Source: *Endnoses installed on the upstream end of piers (shown by red arrows) can protect piers from debris impacts.https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$	• Compact metal sheets oriented to direct floating debris away from piers and abutments.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced debris. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.
	Install Batters  Source: *Steel plate batters protect piers from the impact of floating debris. https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf*	$$	• 'V' – shaped steel plates placed on the ends of concrete piers and abutments to deflect floating debris.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced debris. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
	Bridge / Culverts						
Reduce Debris Damage	Replace Steel Truss Bridges with Open Deck Bridges  Source: *Replacing a solid deck with an open deck can reduce trapped debris.* https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$$$	• Remove below-deck framing to eliminate impediments and components which may trap and accumulate debris. • May require significant design considerations, and a complete replacement may be more feasible.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• The implementation of open deck bridges is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.
	Construct Debris Catchments  Source: *Debris catchments trap debris before it reaches bridge piers and abutments.* https://www.fema.gov/sites/default/files/documents/fema_p-2181-fact-sheet-1-4-bridges.pdf	$$	• Construction of catchments, such as barriers or low-height dams on smaller branch streams upstream to capture debris before it reaches the structure.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced debris. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.

Theme	Bridge / Culverts Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
Reduce Debris Damage	Install Debris Sweepers  Source: *Debris sweepers.* *https://gis.penndot.gov/BPR_pdf_files/Documents/LTAP/TS_152.pdf*	$	• Cylindrical devices that rotate and float up and down with the water surface to sweep debris away from bridge piers and through bridge openings. • May be attached to piers or driven into the streambed.		Flood Storm Surge	• Typical context and geography considerations should be applied, as with any bridge project.	• Short-term benefits will be achievable upon completion in the form of reduced debris. • Long-term benefits will need to take into account infrastructure wear and increased inundation levels.
Relocation	Relocate the Bridge  Source: *Detroit's newest bridge is slowly moved into position. Photo by : David Kidd. https://www.governing.com/now/moving-a-5-million-pound-bridge*	$$$$$	• Likely needed for scenarios with increased exposure to storm surge and flooding, beyond the bridge deck • Primary option when other options are not feasible or cost-effective.		Flood Sea Level Rise Storm Surge	• Opportunities for bridge relocation are likely limited in Rhode Island, given the presence of development along most of the state's coastal and riverside locations.	• Bridge replacement is primarily a long-term strategy for protection given that these involve larger-magnitude projects and construction.

6.1.3 Sidewalks / Shared-Use Paths Adaptation Strategies

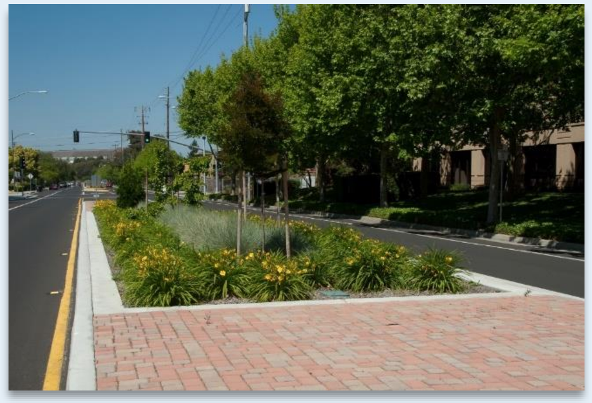
Sidewalks & shared-use paths comprise an additional critical component of the state's multi-modal transportation infrastructure. Sidewalks are particularly important in the state's urban and suburban areas, including for Americans with Disability Act (ADA) accessibility needs. Shared-use paths can be found throughout the state and include the state's urban, suburban, and rural bike paths and rail trails. Adaptation strategies for roads are also assumed to apply for sidewalk and shared-use path assets given the similarities in the infrastructure comprising these asset categories.

6.1.4 Drainage Pipes / Stormwater Treatment Unit Adaptation Strategies

Stormwater infrastructure consists of the sewers, piping, and treatments which collect stormwater. This stormwater is collected through a surface inlet and drained, often inlet to inlet, or through another appropriate outlet, such as a stream or other waterway. Stormwater infrastructure management is important for a number of reasons. First, as a highly urbanized state, Rhode Island has a large degree of impervious surface coverage. Second, the state's geography, consisting of low-lying elevation, coastal plains, inhabited barrier islands, and wetlands, exacerbates inundation risk. Correspondingly, impervious surfaces are much less efficient at draining excess water in comparison to natural surfaces and land cover which filter and better absorb excess runoff. This can lead to excessive ponding and flooding, and the exacerbation of geography-induced risks. Stormwater infrastructure strategies for drainage pipes and stormwater treatment units are focused on integrating pervious surface and more efficient materials into the state's transportation infrastructure. These strategies are summarized in Table 6.3 below.

Table 6.3 Stormwater Infrastructure Adaptation Strategies

Theme	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
	Stormwater Infrastructure						
Stormwater Drainage Improvement Strategies	Swales & Ditches Capacity  Source: *Brick swale located in Balfour street pocket park.* *https://commons.m.wikimedia.org/wiki/File:Planted_brick_swale,_balfour_street_pocket_park.JPG*	$$	• Increased presence, or capacity of swales and ditches adjacent to infrastructure, for the purposes of increasing drainage capacity. • Requires sufficient availability of land adjacent to infrastructure.	✓	Flood Storm Surge	• Likely to be more feasible along arterials and larger roads where land use / zoning provide adequate space for swale / ditch construction. • Ownership of the land proposed for additional capacity is another consideration. If the land is located on private property, the process of implementation may include more complexities.	• Short-term benefits will be achievable upon completion in the form of increased capacity to reduce floods. • Long-term benefits will need to take into account infrastructure inundation levels.
	Retention & Detention Pond Capacity  Source: *Detention pond. https://www.constructionecoservices.com/blog/detention-ponds-do-they-really-need-to-be-maintained/*	$$	• Utilized for scenarios where additional drainage capacity is needed beyond swale & ditch capacity. • Requires more land than swales & ditches, given the increased size and capacity.	✓	Flood Storm Surge	• Likely to only be feasible along arterials and larger roads where land use / zoning provide adequate space for pond construction. • Ownership of the land proposed for additional capacity is another consideration. If the land is located on private property, the process of implementation may include more complexities.	• Short-term benefits will be achievable upon completion in the form of increased capacity to reduce floods. • Long-term benefits will need to take into account infrastructure inundation levels.

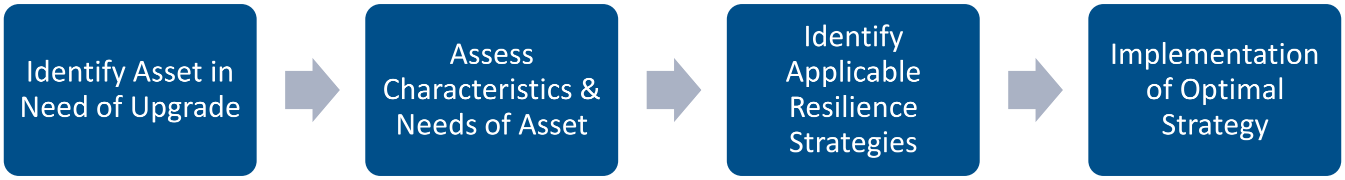
Theme	Stormwater Infrastructure						
	Strategy	**Resource Commitment**	**Description**	**Nature-Based Solution?**	**Hazard**	**Context & Geography Considerations**	**Benefits**
Stormwater Drainage Improvement Strategies	Depressed or Raised Medians  Source: Medians on Whisman Road, Mountain View. https://pgadesign.com/projects/whisman-road-medians/	$	• Planting of swales and ditches along highway medians. • Capacity and costing considerations dependent on median widths.	✓	Flood Storm Surge	• Likely to be feasible only along roads where the width is wide enough to accommodate a median.	• Short-term benefits will be achievable upon completion in the form of increased capacity to reduce floods. • Long-term benefits will need to take into account infrastructure inundation levels.
	Green Stormwater Infrastructure  Source: *Stormwater planter.* https://www.pennfuture.org/what-is-green-stormwater-infrastructure	$ - $$	• Use of bioswales, planter boxes, and the incorporation of green spaces and/or permeable surfaces to reduce impervious surface coverage. • Aesthetically pleasing designs, which could increase the likelihood stakeholder buy-in. • These options may require increased coordination at the local scale to account for needs along local roads and private ROWs.	✓	Flood Storm Surge	• Relatively easy strategy to implement across most geographies and settings, subject to standard safety considerations.	• Short-term benefits will be achievable upon completion in the form of increased capacity to reduce floods. • Long-term benefits will need to take into account infrastructure inundation levels.

Theme	Strategy	Resource Commitment	Description	Nature-Based Solution?	Hazard	Context & Geography Considerations	Benefits
	Stormwater Infrastructure						
Pipe & Treatment System Infrastructure	Materials / Infrastructure Condition  Source: *Permeable Pavement.* *https://mntransportationresearch.org/2013/06/21/permeable-pavements-could-protect-environment-save-taxpayer-dollars/*	$ - $$$	• Use of durable materials in pipe and stormwater treatment construction. • Ensuring that the most critical portions of the infrastructure system are maintained to top condition.		Flood Storm Surge	• Typical context and geography considerations should be applied.	• Short-term benefits will be achievable upon completion in the form of increased capacity to reduce floods. • Long-term benefits will need to take into account infrastructure inundation levels.

6.2 Conduct Project Evaluation

With adaptation strategies identified for each asset category, there is a need to identify which strategy is most appropriate for each location or asset risk scenario. This process of evaluation involves the following steps, as shown in Figure 6.1 and explained below:

Figure 6.1 Project Evaluation Process



- **Identify Asset in Need of Upgrade:** This involves the selection of which assets are in need of upgrade. As identified in Chapter 5, there is a need to address the needs of those assets which are assumed to have a risk threshold matching or exceeding their risk tolerance. For these assets, over the long term, the cost of 'no action' will exceed the cost of implementing an adaptation strategy, based on the calculation of cumulative composite risk.
- **Assess Characteristics & Needs of Asset:** This step involves identifying the key characteristics of the asset, including physical traits, safety, and other related considerations, including the following:
  - Asset Type – Determination of the type of asset. If the asset is a road, this incudes its functional class.
  - Geography – Determination of whether the asset is located in an urban, suburban, or rural setting. This also includes general characteristics of the asset's setting, including size, AADT, and presence of residences or businesses along and around the asset.
  - Safety & Other Special Considerations – This would include any additional defining traits that would need to be taken into consideration for the asset, such as an existing unusual safety or geometry characteristic. For example, an asset to prone to safety incidents, such as collisions, may require additional upgrades beyond resilience strategies.
- **Identify Applicable Resilience Strategies:** Once key characteristics and asset needs have been identified, this step involves identifying which adaptation strategies, identified in the previous section, are applicable for each location. See Table 6.1, Table 6.2, and Table 6.3 for more information on the context and geography considerations for each adaptation strategy. Where possible, nature-based solutions should be prioritized given their cost-effectiveness and emphasis on sustainability.

- **Implementation of Optimal Strategy:** Once applicable resilience strategies have been identified, there is a need to identify the most optimal strategy.

Overall, project evaluation involves the vetting process applied to those potential adaptation projects identified in the previous section. To conduct project prioritization, a multi-criteria analysis (MCA) is recommended. This involves comparing adaptation options across a range of qualitative and quantitative criteria and provides the opportunity to standardize a variety of criteria. Resilience is a particularly complex topic within transportation, which spans several thematic areas including system functionality, equity, economic competitiveness, safety, and environmental sustainability. Each of these thematic areas can be evaluated through a series of criteria, including through quantitative and qualitative approaches. As a result, MCA provides the ability to normalize the evaluation process across these very different, yet interconnected criteria.

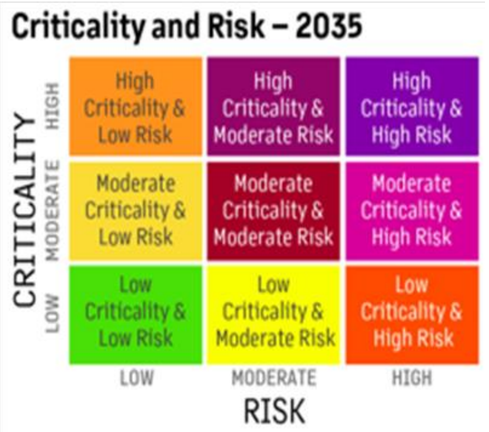
Currently, there is not an established best practice MCA framework for evaluating resilience projects. Rather, agencies can tailor the process to reflect the overarching mission, as well as key goals and objectives. RIDOT's mission, as well as key goals & objectives, derived from the State LRTP, can be found in Chapter 2 and Chapter 7 to follow. For RIDOT, project evaluation, and the ability to rank the competitiveness of a potential adaptation strategies applied to one or more key locations discussed in Chapters 3 and 4, should include the following criteria:

- **Cost & Economic Competitiveness:** The most competitive projects should be cost efficient and yield future cost savings. The long-term expected costs of not undertaking the adaptation strategy should exceed the costs of implementing the resilience improvement.
- **Criticality Competitiveness:** As discussed in Chapter 3, location criticality should be directly reflected in the evaluation of projects.
- **Assessment of Project Benefits:** This should include benefits including overall project lifespan, the ability of the strategy to maintain operational continuity, further equity needs, protect homes, jobs, and businesses, protect bicycle and pedestrian amenities, transit routes, reduce traffic delays, and protect sensitive ecosystems. In weighing project benefits, RIDOT should consider community input, garnered through public participation processes in the LRTP and other major functional plans.

6.3 Develop and Prioritize Resilience Improvements

With a framework in place to evaluate adaptation projects and resilience improvements, resilience projects were prioritized based on their criticality and risk level (Table 5.1). Project were first ranked based on their criticality and risk level in the order below (only these categories were identified as resilience needs in Chapter 5).

1. High Criticality, High Risk
2. Moderate Criticality, Moderate Risk
3. High Criticality, Moderate Risk
4. Moderate Criticality, Moderate Risk
5. Low Criticality, High Risk
6. High Criticality, Low Risk



Projects were then ranked by their cumulated composite risk amounts within the same criticality and risk level. A prioritized list of potential resilience projects and their rankings based on criticality and risk in 2035, 2050, and 2100 is shown in section 6.3.1. A list of STIP projects was also prepared where resilience needs are overlapped with STIP projects which is shown in section 6.3.2.

6.3.1 Potential Resilience Projects

A list of prioritized resilience projects was developed for each study asset with rankings based on criticality and risk in 2035, 2050, and 2100. As illustrated in maps below, there are 131 projects identified for roads and bridges, 39 projects identified for sidewalks, 17 projects identified for shared-use paths, 50 projects identified for stormwater treatment units, 89 projects identified for drainage pipes.

Addressing PROTECT Guidance Elements

This section satisfies PROTECT Guidance Element (13) through the inclusion of an investment plan and priority project list.

Table 6.4 is a subset of the prioritized project list for roads and bridges. The full lists of projects for all six study asset categories can be found in Appendix J, including roads, bridges, sidewalks, shared-use paths, drainage pipes, and stormwater treatment units.

Table 6.4 Potential Resilience Project List – Roads and Bridges

ID	Road Names	Criticality	Risk			Risk of No-Action ($)				Project Length (Mile)			Rank			Hazards	Work type
			2035	2050	2100	By 2024	By 2035	By 2050	By 2100	2035	2050	2100	2035	2050	2100		
68	FERRY RD	High	High	High	High	$1,076,282	$12,915,385	$326,299,584	$2,244,357,399	1.23	1.23	1.67	1	1	1	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
52	I 195 W	High	Low	High	High	$187,947	$2,255,368	$147,694,047	$1,185,650,161	1.82	1.82	2.26	57	2	2	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
71	MAIN ST	High	Medium	High	High	$229,436	$2,753,226	$58,523,934	$547,715,685	1.61	1.61	1.87	9	3	3	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
66	GOAT ISLAND CONN	Medium	Medium	Medium	High	$149,679	$1,796,151	$65,308,579	$456,409,158	0.69	0.69	0.69	25	51	4	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
40	HOPE ST	High	Low	Medium	High	$18,461	$221,528	$3,815,767	$408,518,322	1.49	1.49	2.7	61	30	5	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
6	STATE HWY 138 W	High	Low	Medium	High	$56,009	$672,103	$47,891,318	$342,543,086	4.33	4.33	5.08	59	27	6	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation
49	HENDER-SON BRIDGE	Medium	Medium	High	High	$26,569	$318,822	$3,348,743	$302,576,135	0.67	0.67	1.13	28	18	7	SLR, Storm Surge, Flooding	Coastal Flood Risk Mitigation and Inland Flood Risk Mitigation

Figure 6.2 Potential Resilience Projects – Roads and Bridges

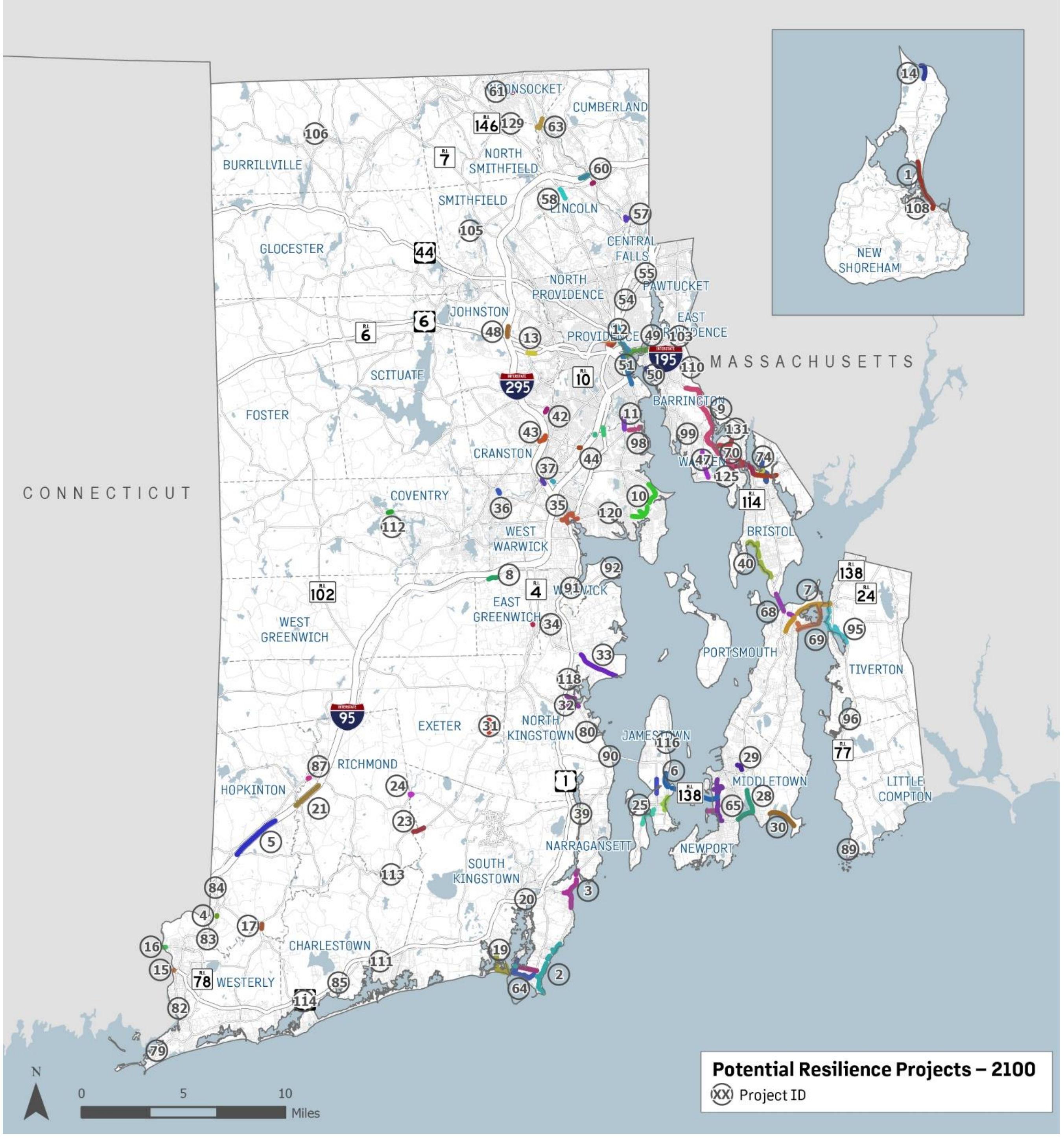


Figure 6.3 Potential Resilience Projects – Sidewalks

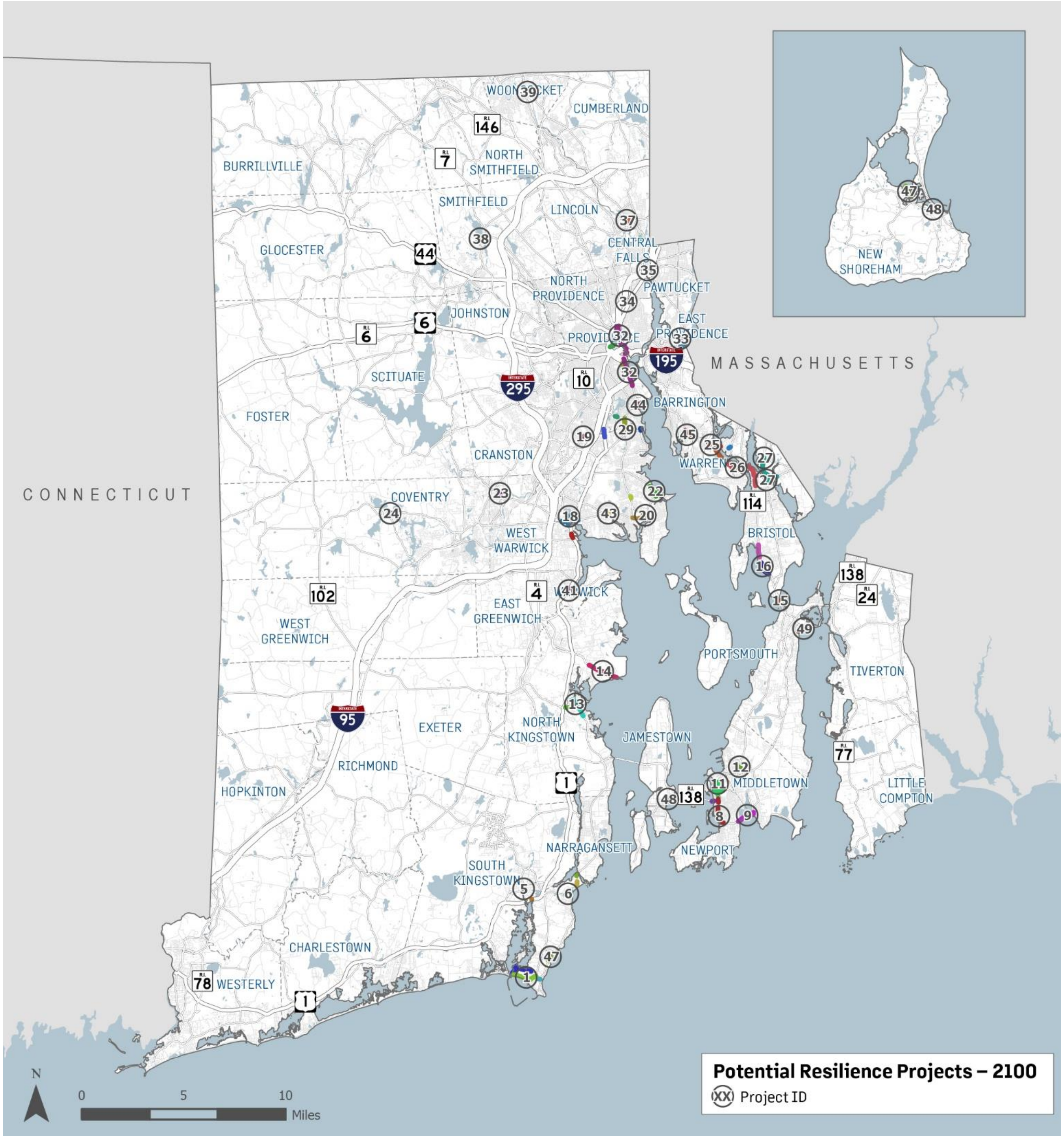


Figure 6.4 Potential Resilience Projects – Shared-Use Paths

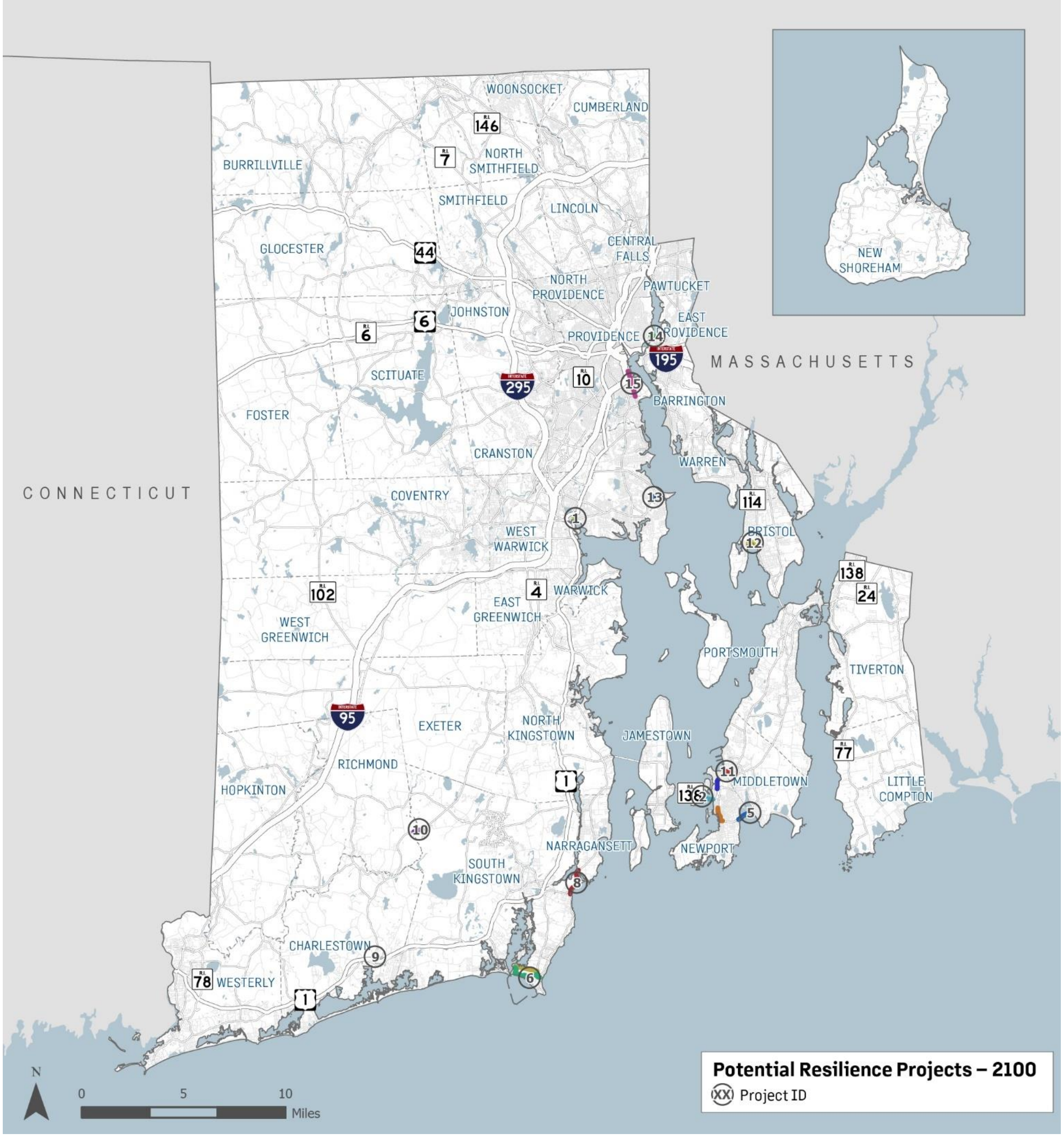


Figure 6.5 Potential Resilience Projects – Stormwater Treatment Units

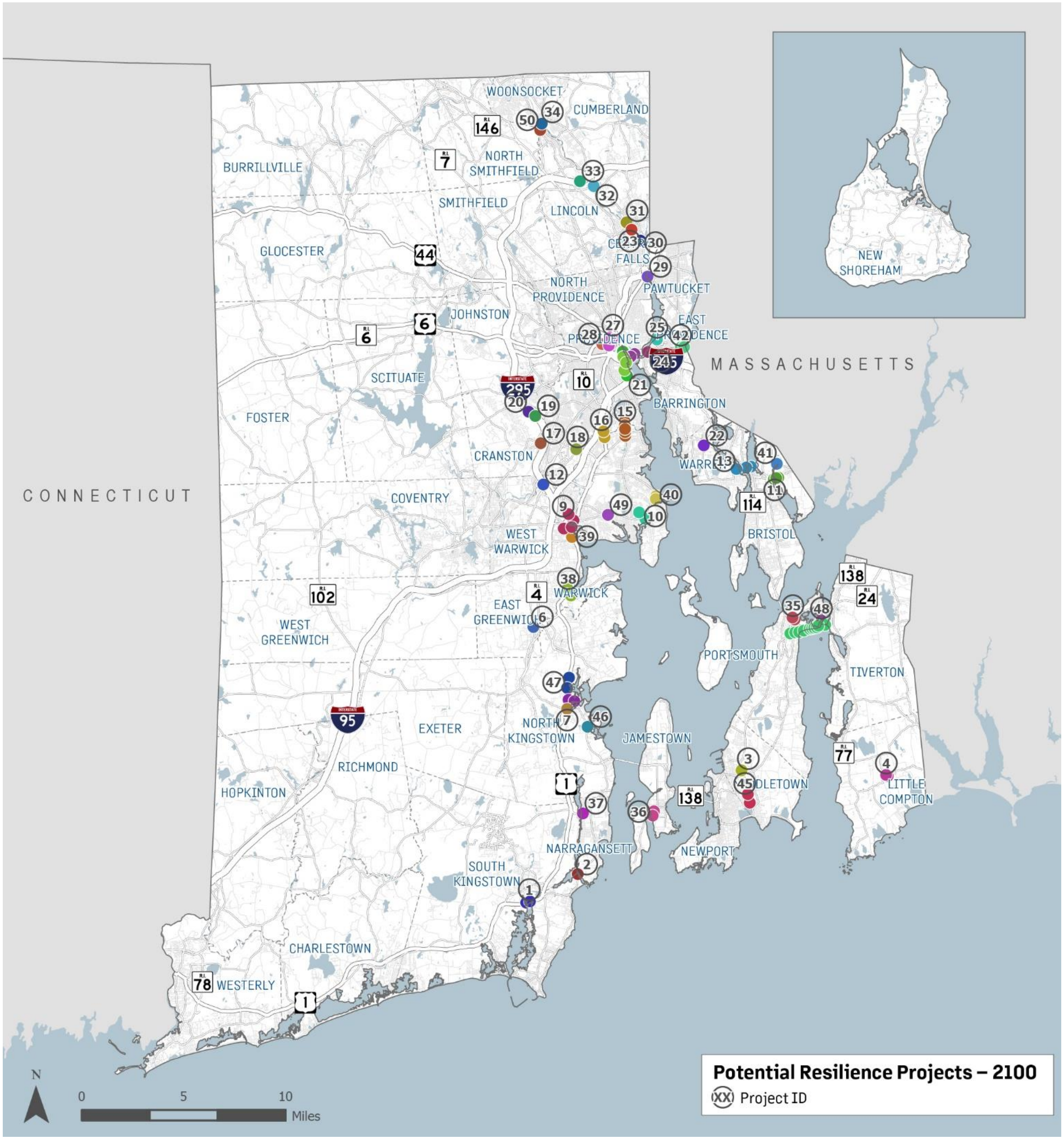
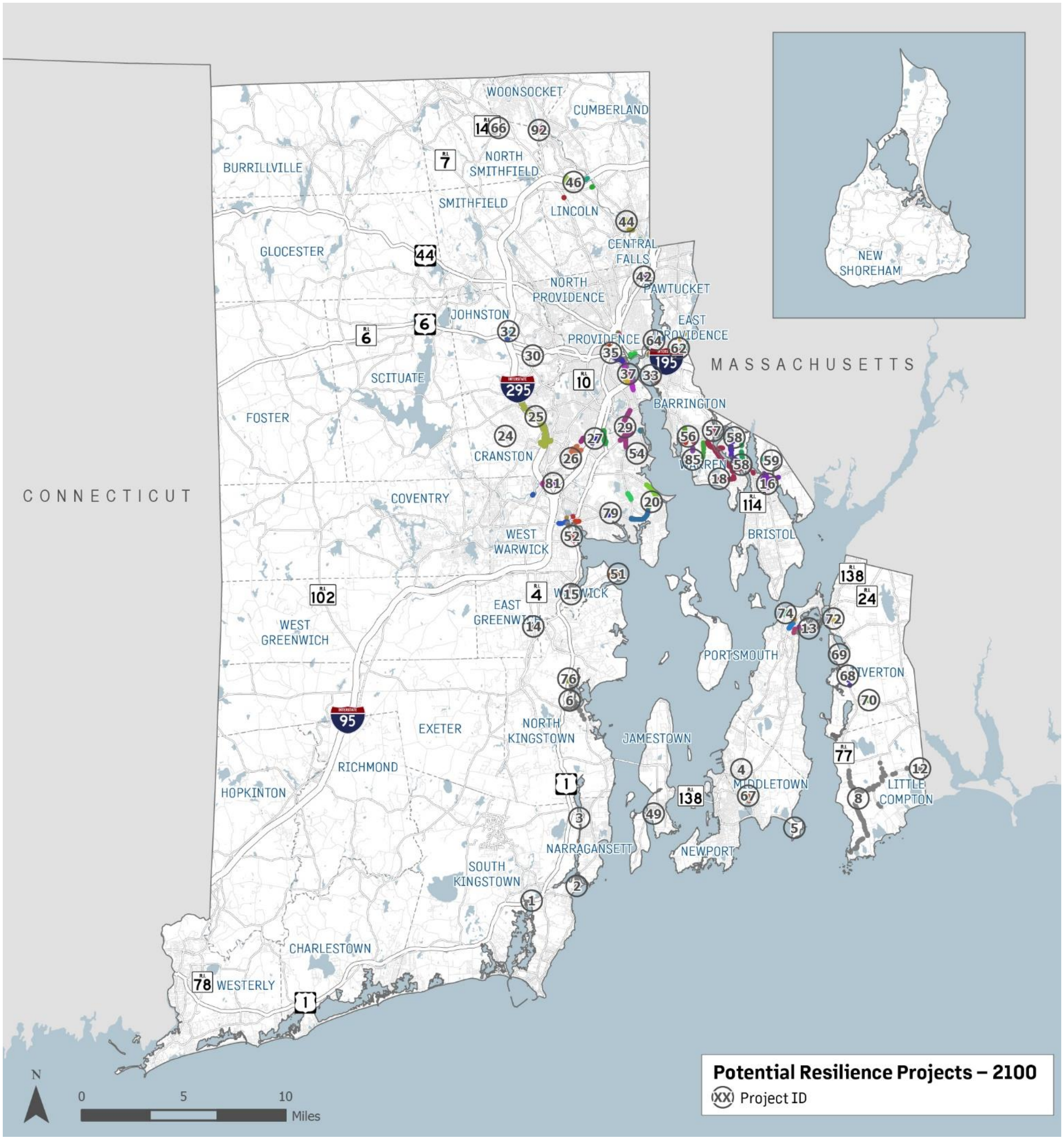


Figure 6.6 Potential Resilience Projects - – Drainage Pipes



6.3.2 Resilience Opportunities in STIP

In addition to the potential resilience projects identified above, an overlay of resilience needs and STIP projects before construction phase was developed to identify opportunities to incorporate resilience considerations in STIP project development process. The results are illustrated in the following maps and in a tabular format in Appendix K.

Figure 6.7 Resilience Opportunities in STIP – with Risk by 2035

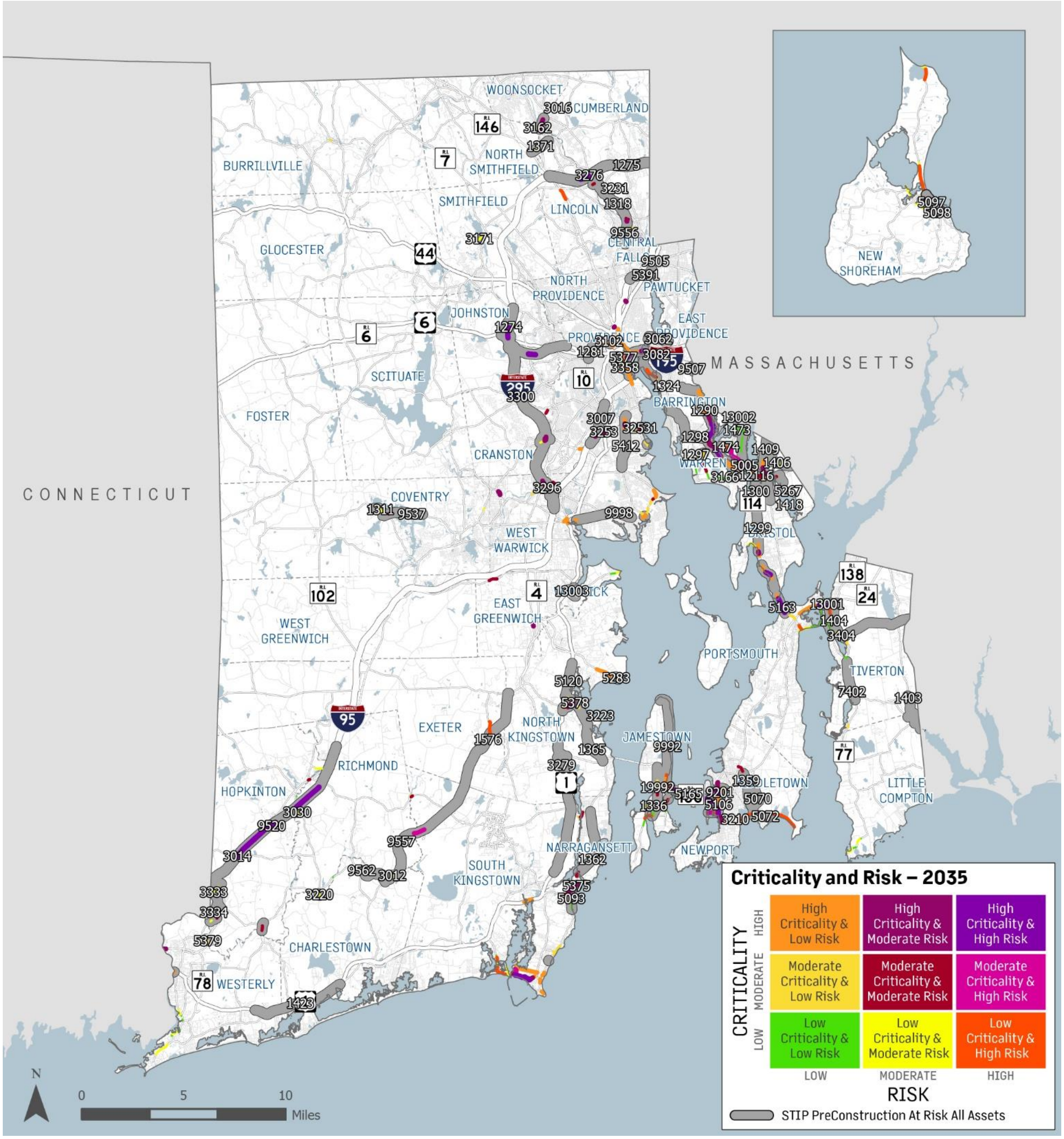


Figure 6.8 Resilience Opportunities in STIP – with Risk by 2050

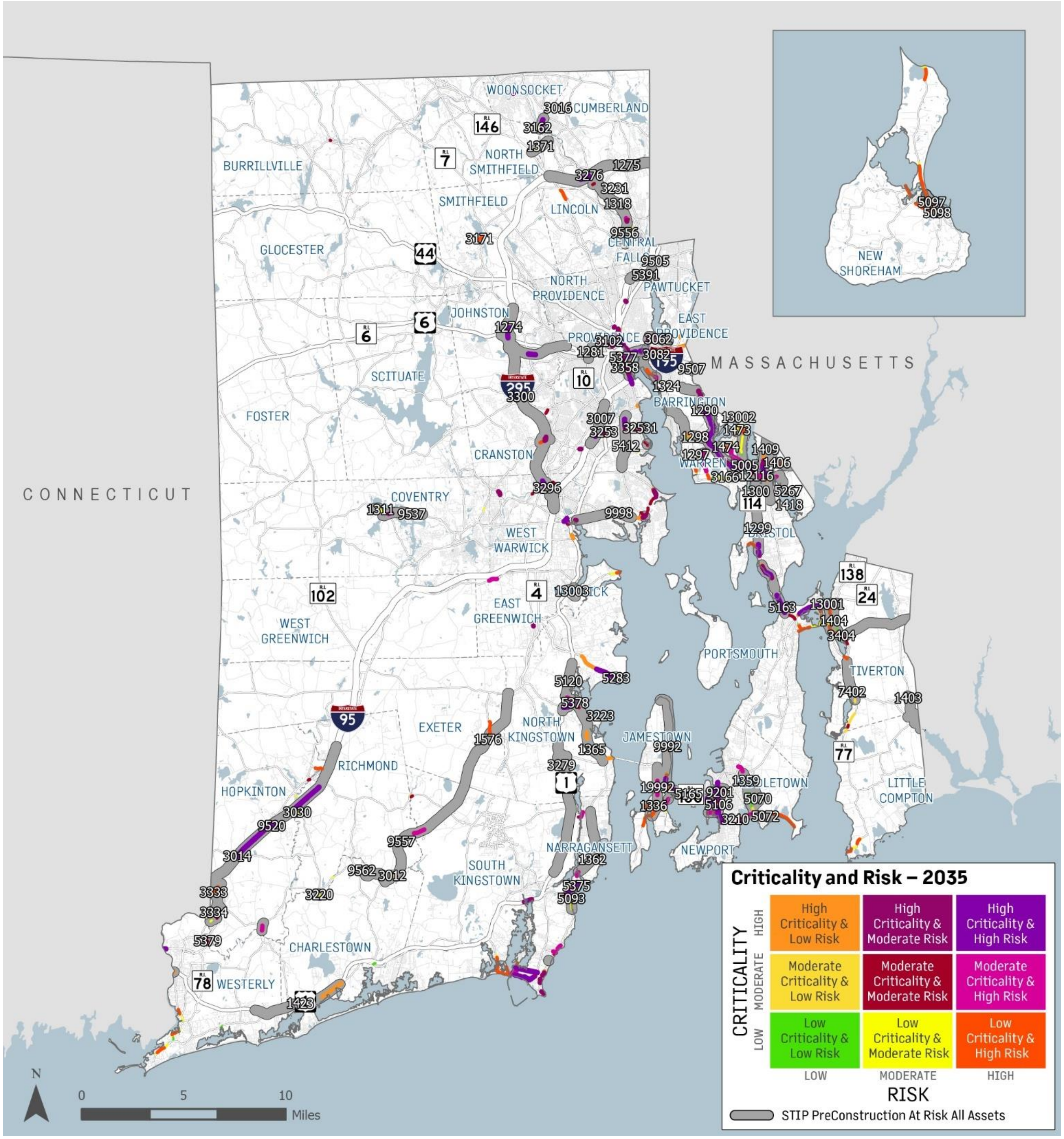
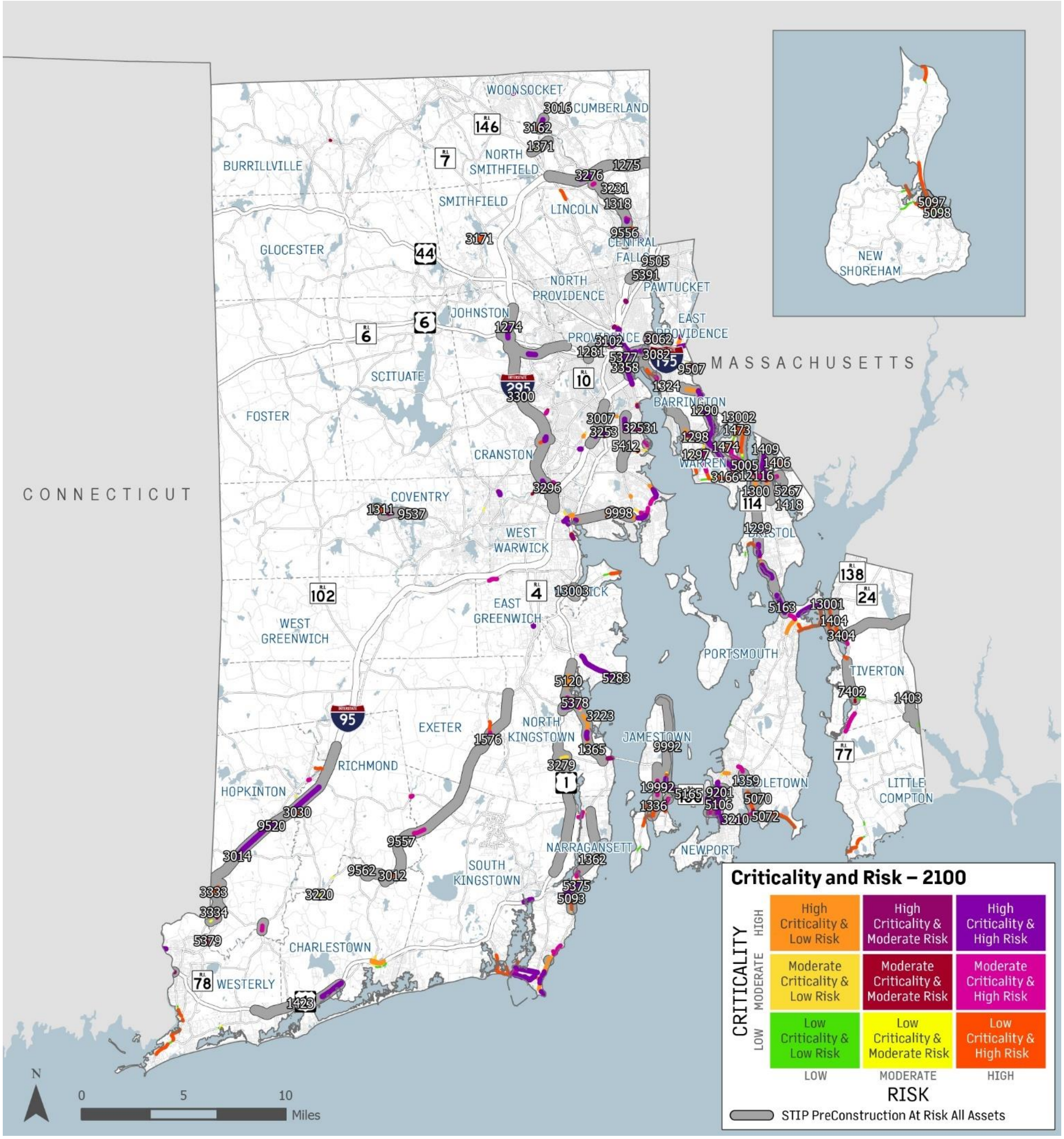


Figure 6.9 Resilience Opportunities in STIP – with Risk by 2100



7.0 IMPLEMENT RESILIENCE IMPROVEMENTS

A successful implementation process is key for integrating resilience into day-to-day operations, as well as long-term capital programs. In the case, of RIDOT, success will consist of a process where resilience is a primary goal and mindset of the agency, and resilience is a key factor in how projects are conceptualized, selected for funding, and implemented. Chapter 7 identifies recommendations on how to incorporate resilience into the State's LRTP, STIP, as well as the agency's overall transportation planning processes, and other planning activities. These recommendations, explained in further detail below, revolve around some key themes including alignment of goals and strategies, agency-wide buy-in, and coordination.

7.1 Incorporate Resilience Strategies into LRTP

> **Addressing PROTECT Guidance Elements**
>
> This section satisfies PROTECT Guidance Element (12) through the description of those policies and mechanisms to implement resilience and adaptation strategies. This section also satisfies PROTECT Guidance Element (6) through a description of the various mechanisms and standards to carry out resilience improvements.

Incorporation into Rhode Island's LRTP is one of the most important steps in the implementation of resilience. The RIP will be incorporated into the State LRTP as an Appendix along with other statewide plans adopted under the umbrella of Moving Forward Rhode Island 2040. Rhode Island's LRTP serves two functions. The first of these functions is to outline and formalize the state's collective vision and goals for the statewide transportation system. The second of these functions is to identify and prioritize related transportation projects for funding and implementation. As the recipient of federal funds, RIDOT is required to undertake and update these documents on a frequency of at least every five years. In 2022, federal funds accounted for approximately 58% of RIDOT's total expenditures[17], further highlighting the importance of successfully incorporating resilience strategies into the process. The LRTP development process includes a focus on multiple goals, performance measures, and strategies to address the needs of Rhode Island's multimodal transportation system. Each of these is critical to the long-range planning process, given the establishing of consistency and cohesion from the identification of system goals to the implementation of key decisions.

[17] https://omb.ri.gov/sites/g/files/xkgbur751/files/2022-04/0_Complete%20Volume%20IV%20%E2%80%93%20Public%20Safety%2C%20Natural%20Resources%20and%20Transportation%20%281%29.pdf

Incorporating the RIP into the state's LRTP aligns the state's long-term transportation investment plans given the significant impacts and threats from the major threats of storm surge, sea level rise, and flooding. Moreover, the current LRTP is a policy-based document, and as such, resilience is integrated throughout to embed existing policies, procedures, and plans that RIDOT has developed around climate resilience. Similar to the LRTP, the RIP looks as the systemwide state transportation assets while focusing on systems under the direct responsibility of RIP and considering interdependencies with other systems such as transit and active transportation. The RIP will also utilize a time horizon consistent with the available climate science information, which is often until the end of the century.

7.1.1 Goals, Objectives, and Priorities

Initially, goals, objectives, and priorities provide a foundation for the content and strategies identified further on in the LRTP. Specific goals, seeking to fully integrate resilience with other key focus areas could include the following:

- Increase resiliency to support economic competitiveness & the tourism industry of coastal communities.
- Foster social equity in vulnerable communities by providing a resilient transportation system.

Overall, resilience can be interweaved into a variety of goals, objectives, and priorities, including themes related to asset management, the economy, freight, operations, technology, safety, equity, and emergency management. A key consideration is that these goals are both achievable and supplemented by corresponding performance measures and strategies. It is noted that Rhode Island's LRTP addresses resilience across the document, including through goals and objectives. Opportunities exist to further strengthen the emphasis on resilience would also include direct connections to the RIP, and related key findings.

7.1.2 Performance Measures

Performance measures are an important component of the LRTP in that they establish accountability and allow agencies to directly track and monitor performance towards key goals. With the realized integration of resilience into DOT operations still largely in the early stages, there aren't formalized or standardized related performance measures. This gives DOTs the leeway to develop their own performance measures best tailored to their own agency needs.

RIDOT has not yet developed resilience-specific performance measures. However, RIDOT maintains an extensive list of performance measures as developed in the agency's LRTP. RIDOT's existing performance measures, developed in 2020, address the following goals:

- **Connect People and Places:** Across all modes and options for more efficient and effective travel.

- **Maintain Transportation Infrastructure:** To create a reliable network providing adequate travel choices.
- **Strengthen Communities:** Through the local transportation network to enhance travel, place, and quality of life.
- **Promote Environmental Sustainability:** By prioritizing non-single occupancy vehicle focused strategies and investments.
- **Support Economic Growth:** Through transportation connectivity and choices to attract employers and employees.

Many of the specific performance measures identified for each of these goals relate to resilience in various ways. They include goals to increase public transit ridership, reduce total VMTs, and state of good repair. The greatest opportunities for further integration of resilience into performance measures are likely found in RIDOT's goal of maintaining transportation infrastructure. These performance measures are shown in Figure 7.1.

Figure 7.1 State LRTP Maintain Transportation Infrastructure Performance Measures

Performance Measures	Baseline	2040 Target
» Percentage of Pavements of the Interstate System in Poor Condition	0%	≤5%
» Percentage of Pavements of the Non-Interstate NHS in Poor Condition	20%	≤20%
» Percentage of NHS Bridges in Poor Condition (Structurally Deficient)	24%	<10%
» Rolling Stock (Fixed Route Bus, Paratransit, Flex): The percentage of revenue vehicles that exceed the useful life benchmark (ULB)	16%, 55%, 35%	16% 35%, 35%
» Equipment: The percentage non-revenue service vehicles (by type) that exceed the ULB	44%	56%
» Facilities (Admin/Maintenance, Passenger): Percentage of facilities within an asset class rated below 3.0 Transit Economic Requirements Model (TERM) scale	0%, 100%	0%, 0%
» No. of annual traffic fatalities (5 year avg)	59	25
» No. of annual traffic serious injuries (5 year avg)	351	163
» No. of ped./bike annual traffic fatalities and serious injuries (5 year avg)	78	47
» No. of transit fatalities	TBD	TBD
» No. of transit injuries	TBD	TBD
» No. of transit safety events	TBD	TBD
» Mean distance between major mechanical failures (fixed route)	TBD	TBD
» Bicycle Dedicated Lane Miles	100	310
» Bus Transit Dedicated Lane Miles	0.8	18.1
Tracked Measures	**Baseline**	**2040 Target**
» No. of bridges vulnerable to sea level rise	77	downward trend
» Miles of roadways vulnerable to sea level rise	84	downward trend
» No. of intermodal hubs vulnerable to sea level rise (freight, passenger)	6, 2	downward trend

These transportation infrastructure performance measures address topics of pavement condition, bridge condition, rolling stocks, safety, and facilities. They also include the number of bridges, miles, and intermodal hubs vulnerable to sea level rise. These performance measures could be expanded on in the following ways:

- Expansion of performance measures related to infrastructure condition to address percentages and totals for vulnerable locations. This includes areas of persistent poverty, historically disadvantaged communities, and the overlay of locations vulnerable to storm surge and sea level rise.
- Expansion of tracked measures to fully account for the vulnerability and risk assessment conducted in the RIP, including all six assets and all three hazards.
- As a tracked measure, the number of projects directly addressing resilience needs should be considered. This could be a broad measure or more specific target, such as identifying the number of projects which specifically address storm surge or sea level rise.

7.1.3 Strategy Development

The development of strategies in future iterations of the LRTP should build off the strategies included in the RIP. This will help provide a firm foundation for resilience integration. In addition, the following actions are also recommended to further integrate resilience into LRTP strategy development:

- Maintain consistency amongst goals, strategies, and performance measures, amongst those components which include resilience.
- Include and highlight resilience projects in the LRTP project lists.
- Further identify opportunities for resilience integration in existing strategies.

7.2 Incorporate Resilience Strategies into STIP

Rhode Island STIP is a list of projects to be implemented through the use of federal funding. Rhode Island's State Planning Council, acting as the single statewide MPO for Rhode Island, is required to update and adopt a new STIP at a minimum of every four years. RIDOT's current STIP covers the FY 2022 through FY 2031 period and was adopted in September 2021. The STIP includes a fiscally-constrained four year time period of FY 2022 through FY 2025, as well as anticipated projects for the FY 2026 through FY 2031 six year time period. With up to approximately 80% of transportation capital and maintenance spending stemming from federal sources, STIP project inclusion is a critical and necessary component of realizing statewide transportation planning goals & initiatives.

Recommendations for the incorporation of resilience strategies into the STIP draw heavily from stakeholder engagement. In particular, RIDOT's second workshop included a peer exchange where other nationwide DOTs were invited and encouraged to provide insight on how they work to integrate resilience into their own statewide operations. See Chapter 8 for more information on how this information was solicited.

Figure 7.2 STIP Development Process

Figure 7.3 STIP Implementation Process

7.2.1 STIP Development Recommendations

The workflow process for the STIP consists of development and implementation processes. The Rhode Island State's STIP development process consists of five steps, as shown in Figure 7.2. This process includes the following components:

- **Solicit Projects:** Solicited by the RIDSP for applicants to submit potential projects for consideration.
- **Estimate Budgets & Schedules:** Including reviews of project readiness through the evaluation of feasibility issues, challenges, and risks. This step also includes preparation of an initial budget.
- **Scope & Evaluate Projects:** Reviewing and scoring of projects, based on potential costs and benefits for Rhode Island.
- **Prioritize Projects:** Grouping of selected projects into four tiers, based on timeframe within the STIP.
- **Program Capital Funds:** Estimation of funding sources, totals, and programming based on phase of project development.

Under existing conditions, Rhode Island State's STIP does not include a streamlined process for considering, prioritizing, and promoting resilience. Rather than a shortcoming of the existing STIP development process, the existing methodology functions as an efficient method for project solicitation at a statewide scale. The following recommendations are identified and grouped by steps within the STIP Development Process:

Step 1: Project Solicitation

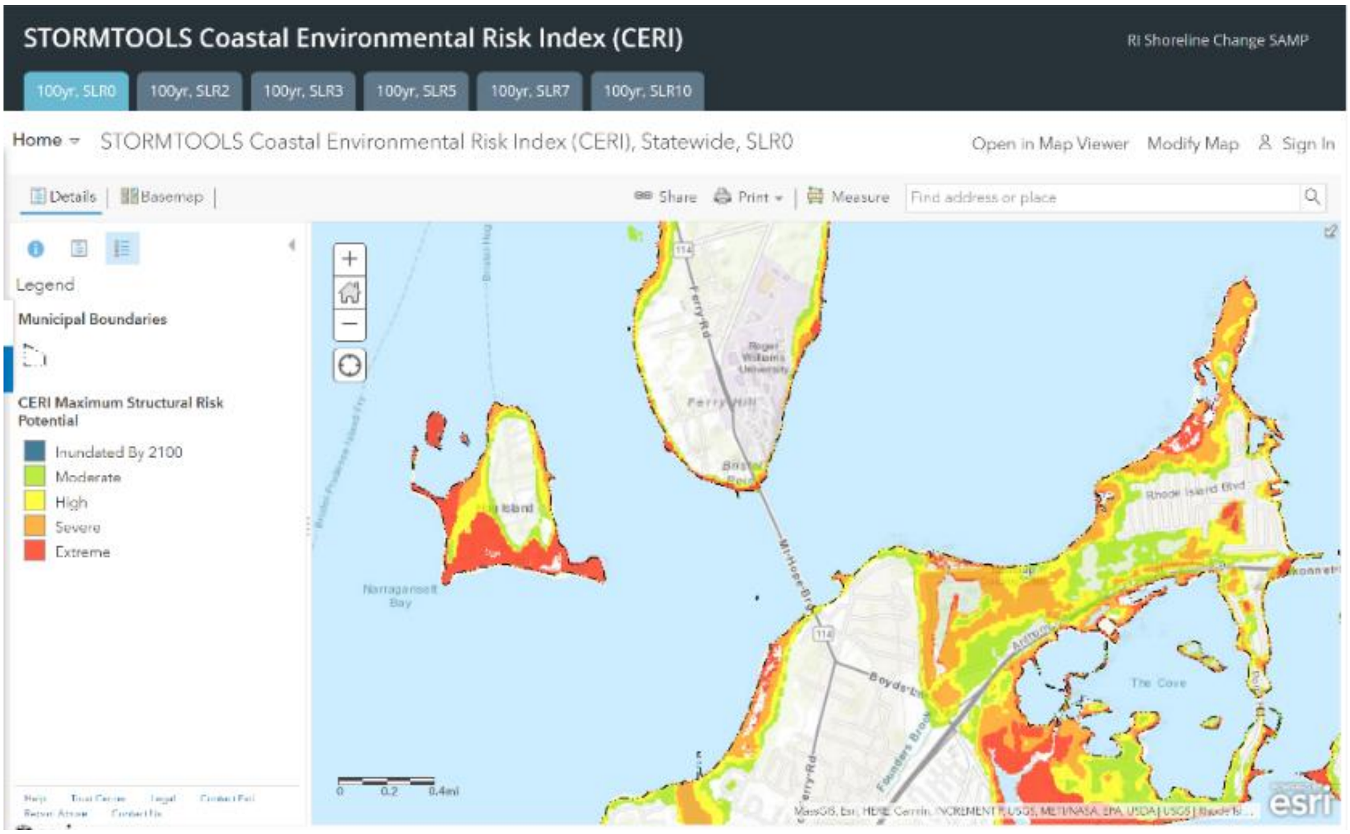
As the initial step in the STIP development process, project solicitation entails outreach to stakeholder applicants located across Rhode Island. The current process includes key project questions and a geospatial component to identify project-specific details and boundaries. Currently, project questions cover topics including project/infrastructure type, permitting, Environmental Justice (EJ), and tie-ins to statewide comprehensive planning. Beyond the subject of EJ, the process does not include any questions on resiliency. As a result, it is recommended that the project solicitation and intake step include a formalized section of questions dedicated to resiliency. This section could also include a direct tie-in to EJ given the overlaps. This resiliency section could be developed through one of the following methods:

- Broader questions asking applicants to describe how the proposed project addresses resiliency needs. This method assumes that applicants have a strong understanding of resilience needs, including those that affect their local communities.
- Specific questions asking applicants how the proposed project would impact or respond to specific trends or components. For example, RIDOT could provide specific information on storm surge and sea level rise

scenario planning, including those results from the Vulnerability Assessment from Section 4.0. RIDOT could then ask applicants to describe how potential projects would address or be impacted by resilience considerations.

The inclusion of resiliency in project solicitation should be supplemented by a standardized data visualization tool. Specifically, applicants should be given access to a standardized set of tools and access to GIS-based datasets to help clearly delineate project boundaries and determine whether and how projects are located in overlays such as EJ zones and flood maps.

Figure 7.4 URI Rhode Island STORMTOOLS Feature



Source: University of Rhode Island

Step 2: Estimation of Budgets & Schedules

The budgeting and scheduling process is an important consideration for the integration of resilience into the STIP. This is especially the case given that the resilience improvements and upgrades can further add to capital budgets and project complexities. Furthermore, applicants may lack the resources to understand, comprehend, and integrate costs of planned or desired resilience improvements. To address these needs, it is recommended that RIDOT establish guidelines for resilience integration. These guidelines, should include the following:

- Estimated capital costs associated with resilience improvements. These should consider key resilience improvements including nature-based solutions, raised profile, and pavement improvements, and overall project readiness.
- Estimated maintenance costs associated with each type of resilience improvement.
- A combined unit cost which factors in capital and maintenance costs over the lifespan of each resilience improvement.

In developing and providing these figures, consistency and predictability will be important to ensure a standardized and reliable set of figures which could be utilized by applicants. In turn, this process of standardization will streamline the review process on the part of RIDOT, including across the next steps in the STIP development process.

Step 3: Project Scoring & Evaluation

Factoring resilience into the project scoring and evaluation process is critical to advance related projects to the final of STIP development. RIDOT is currently in the conceptual phases of including resilience in the scoring and evaluation process. However, a number of strategies may be considered to further this process:

- Include considerations for the societal costs associated with no-build scenarios of resilience projects;
- Provide incentivization in the form of improved scores for projects addressing critical roadways, such as hurricane evacuation routes.
- Consider benefits of resilience improvements on factors such as property values and vulnerable populations.

Through the improvement of the project scoring and evaluation process, it will be important for RIDOT to communicate these updates to applicants. In doing so, RIDOT should also provide updated policy guidance that prioritizes and incentivizes resilience improvements.

Step 4: Prioritization

For those projects identified as candidates for STIP funding, the prioritization process relates to what stage of the STIP's 10-year time horizon, identified by tier, each project is programmed into. Recommendations on prioritization are primarily focus on policy needs. In particular, resilience should be designated as a top priority by the Transportation Commissioner. This should also include a goal such as a certain percentage of annual funding each year applied towards related resilience needs. With this proactive approach and agency direction in mind, RIDOT can begin to designate and prioritize resilience projects. Key methods of prioritization could include:

- Prioritization based on project readiness. This approach prioritizes shovel-ready projects regardless of their size and magnitude.
- Address simple projects such as culvert upgrade in the initial tiers of the STIP, given their simplicity and overall return on investment.
- Prioritization based on projects that directly impact and further performance measures and targets.

The method of prioritization used by RIDOT should be policy-driven, including based on what makes the most sense in terms of both needs and funding opportunities. Regardless of which method is used, project readiness should be considered as well. RIDOT may want to consider outreach to other states where resilience is being directly prioritized and integrated to further discern related best practices.

Step 5: Programing of Capital Funds

Recommendations for the final step of the STIP address the availability of funding. In particular, it is recommended that RIDOT identify and estimate funding opportunities from the PROTECT program and other available grants. This information should be disseminated to applicants, along with BCA tools to help estimate the benefits of resilience improvements in comparison to capital and ongoing costs.

7.2.2 STIP Implementation Recommendations

The Rhode Island State's STIP implementation process consists of five steps, as shown in Figure 7.3 above. This process includes the following components:

- **Operationalize Schedule:** Coordination between RIDOT Planning & Scoping staff to review.
- **Outreach Project Stakeholders:** Collaboration between departmental subject matter experts, local officials, and other stakeholders to provide input on scoping elements.
- **Assign Task Orders:** Selection of engineering consultants to complete project readiness reports, and scoping, budgets, and stakeholder feedback are provided.
- **Submit & Review Reports:** Review of project readiness reports and identification of any deficiencies.
- **Handoff to Scoping:** Finalization of project readiness reports, and advancement of projects up to 30% design.

As with the STIP development phase, Rhode Island State's STIP implementation process is not structured to directly highlight and prioritize resilience projects. Rather than a shortcoming of the existing STIP development process, the existing methodology functions as an efficient method for project solicitation at a statewide scale. The following recommendations are identified and grouped by steps within the STIP Implementation Process:

Step 1: Operationalize Schedule

Also known as the project pre-scoping phase, key recommendations for the initial step of the STIP implementation process are related to the identification and dissemination of clear and concise information. Existing tools, including those geoprocessing tools identified in the STIP development steps should clearly outline project information, including risks, project magnitude, and project purpose. The entire process should be transparent and automatic to ensure a trusting relationship between applicants, stakeholders, and RIDOT. This process should also directly consider and assess that hydraulic and hydrology studies are conducted before potential projects are further scoped.

Step 2: Stakeholder Outreach

Recommendations for stakeholder outreach are generally broad and include the need for subject matter experts with a background in resiliency to be present during implementation. From a broader perspective, there is an overall need for stakeholder outreach and subject matter expertise across both the implementation and development portions of the STIP.

Step 3: Assignment of Task Orders

The assignment of task orders includes the solicitation of project readiness reports from on-call engineering consultants. These project readiness reports should include a section on resilience, as well as corresponding BCA results, costs of no action, and project readiness. Overall, the results of these project readiness reports should directly take into consideration input on resilience matters from local subject matter experts.

Step 4: Submission & Review of Reports

Recommendations for the fourth step of the STIP implementation process are straightforward. The review process on the should clear and concise. Reports that include and consider resilience should be expedited and given prioritized consideration.

Step 5: Handoff to Scoping

As the final step in the STIP process, it is imperative that resilience improvements be factored into previous steps. Nevertheless, the final step is critical in that appropriate subject matter experts need to be included as projects are advanced further through design phases. These subject matter experts should have a strong background that includes the delivery of resilience-focused projects. This expertise should also include local and geographic considerations.

7.3 Integrate Resilience Consideration into Transportation Project Development Process

Tasked with oversight of the state's multimodal transportation system, RIDOT operations encompass multiple core areas which include a multitude of decision-making strategies. Integration of resilience into Rhode Island State's STIP development and implementation processes is a necessary and achievable step. From a practicality standpoint however, this integration is only achievable if resilience is an overarching guiding principle across the entire agency and the statewide transportation planning process. Key recommendations to further integrate resilience across agency core areas are identified below:

7.3.1 Agency-Wide Needs

At the agency scale, there is an overarching need for a resilience policy to guide decision making. This resilience policy, which would need to be formally adopted by RIDOT's executive leadership, would mandate that resilience needs be considered and/or prioritized across DOT operations. As a similar example, FDOT has formally adopted the following resilience policy:

> *It is the policy of the Florida Department of Transportation to consider resiliency of the State's transportation system to support the safety, mobility, quality of life, and economic prosperity of Florida and preserve the quality of our environment and communities. Resiliency includes the ability of the transportation system to adapt to changing conditions and prepare for, withstand, and recover from disruption.*

FDOT's policy goes on to recognize the various factors influencing decision making in transportation planning, including the need for collaboration across multiple agencies. On the basis of implementation, the policy further discusses the inclusion of resilience in long-range and modal plans; the agency's work program; asset management plans; research efforts; and internal manuals, tools, guidelines, procedures, and related documents which guiding planning, programming, project development, design, construction, operations, and maintenance.

In developing and adopting a formalized resilience policy for RIDOT, a number of factors need to be considered. First and foremost, executive leadership buy-in is necessary, given the strong degree of potential influence across the agency. Second, an emphasis on resilience-oriented workforce development is required to ensure successful adoption and implementation of resilience measures across RIDOT. This working knowledge, including corresponding recommendations, is discussed in further detail below across key functional areas of the agency.

7.3.2 Planning

RIDOT's planning functions include conducting analyses to identify current and future multimodal needs. This includes the development of key performance measures to track progress, assessing risks, securing funding,

and updating and adhering to key components such as the LRTP. Correspondingly, communication and implementation of resilience is heavily dependent on a strong foundation with RIDOT's operations. The role of transportation planning also establishes a critical juncture between designers and engineers, as well as the broader community and population. Whereas engineers and designers possess the technical capacity necessary to realize projects, local community members and stakeholders carry forth the strongest understanding of what is needed from the state's transportation system.

Taking into consideration RIDOT's roles in the realm of planning, there are a number of recommendations that can be applied. As identified in the early portions of Chapter 7, RIDOT's planning functions include the development and oversight of the LRTP and STIP, which provide a strong foundation for guiding the agency. To adhere to and implement those resilience recommendations for the LRTP and STIP, it is recommended that RIDOT's planning tasks include the following components:

- Implement key recommendations for integrating resilience into each component of the LRTP and STIP as identified in Chapter 7.1 and 7.2, including goals and objectives, performance measures, project development, evaluation, and prioritization.
- Develop a toolbox of strategies to implement across functional areas to support stand-alone resilience projects, or additional resilience components to existing projects. This should be part of a larger strategy to disseminate resilience considerations related to project development, grant eligibility, key resilience needs, and stakeholder communication.
- Conduct, manage, and continuously update vulnerability assessments, supplemented by a dynamic risk tolerance framework.
- Leverage and incorporate resilience assessment findings into project scopes of work / purpose and needs statement. When possible, conduct hydraulic and hydrology studies before scoping of projects.
- Ensure that resilience is implemented across other key planning activities. See Chapter 7.4 for more information.
- Leverage and incorporate resilience assessment findings into project scopes of work / purpose and needs statement

7.3.3 Project Development & Environment

The project development and environmental phase of the transportation planning process advances initial needs into specific projects through detailed technical studies and extensive community input. This includes an environmental review consistent with the National Environmental Policy Act (NEPA) and Rhode Island state law.

From a resilience standpoint, a strong working knowledge is necessary to ensure smooth resilience integration amongst multiple project components. The following strategies are recommended:

- Develop a comprehensive process for resilience strategy integration, as the next step in carrying out the toolbox of strategies recommendation listed above.
- Analyze the community, socioeconomic, and environmental impacts or co-benefits from transportation resilience investments and strategies, including through the considerations of no-build scenarios.
- Enhance methods and tools for identifying potential land use and economic impacts of resilience investments and strategies, including impacts on adjacent properties.

7.3.4 Design & Construction

RIDOT's design team prepares the detailed engineering design, contract plans, specifications, and estimates for a project. This is one of the most technical aspects of the transportation planning process, focusing on engineering, feasibility, and project delivery. As experts in the actual construction and implementation of transportation projects, a clear understanding of resilience initiatives, including benefits and impediments, is necessary for the design process. To integrate resilience into the design process of RIDOT, the following recommendations are identified:

- Adhere to an evaluation process to maximize overall benefits, decrease vulnerabilities, mitigate risks, and reduce the overall life cycle costs associated with resilience improvements. This would stem from a strong understanding of those physical strategies identified in Section 6.0, and overlaid with site-specific and general project management considerations, as well as updated design procedures and manuals.
- Increase understanding and implementation of Natural and Nature Based Features (NNBF) to reduce coastal storm risk and provide co-benefits.
- Consider the integration of drainage and stormwater runoff system design across all locations to reduce runoff and flooding systemwide as part of a larger, coordinated stormwater solution strategy.
- Advance adaptive strategies that allow for flexible use of infrastructure and right-of-way, with an emphasis on those adaptation strategies identified in Chapter 6. Correspondingly, there is a need to adopt the use of resilient and sustainable materials and techniques across all projects.

7.3.5 Operations, Maintenance, & Emergency Management

RIDOT operations and emergency management roles include the day-to-day functions necessary to ensure a functional multimodal transportation system. These functions also include those actions necessary to mitigate, prepare for, respond to, and recover from extreme weather events and other major disruptions; a core theme

associated with resilience. As such, the role of operations and emergency management divisions in resilience integration include largely carrying out at the theme, as successfully implemented through the realization of planning initiatives and vital transportation projects, as discussed above. Key recommendations include:

- Expand the use of intelligent transportation system (ITS) technology, sensors, and warning devices to respond to disruptions in the transportation system and strengthen systemwide resilience, including traffic monitoring, emergency response, and data collection before, during, and after extreme weather events.
- Maintain a strong working knowledge of existing conditions, trends, and protocols identified in Rhode Island's State Hazard Mitigation Plan.
- Manage and update when necessary Rhode Island's hurricane evacuation routes. Identify detour routes and closure plans for major roadways during emergencies.
- Work with communities to provide assistance for evacuation of people with no access to vehicles.
- Incorporate future hazard projections into the maintenance schedule to allow for more frequent inspections of sensitive equipment and locations that may be exposed to hazards.
- Provide maintenance needs or deterioration information to planning, project/program management.

7.3.6 Steps of Applying RIP Results to Develop Projects

The risk and vulnerability assessment conducted for the assets and the toolbox of adaptation strategies proposed for the assets by the hazard type can be used by project managers to support project development. This section describes the steps project managers could take to apply resilience data, maps, and strategies in the RIP in their project development process, as illustrated in Figure 7.5. The methodology is described in the text below with an example of application on Hope Street in Bristol.

Figure 7.5 Resilience Project Development Process

Needs Identification

Review asset criticality, vulnerability, and risk

Getting an understanding of the study asset's criticality, vulnerability, and risk is the first step to determining the need for improving resilience. The criticality and risk matrix maps for 2035, 2050, and 2100 shown in Figure 5.4, Figure 5.5, and Figure 5.6 allow quick identification of the criticality and risk ratings for a study asset location. The resilience project lists and maps developed in Chapter 6.3 and Appendix J and Appendix K can be reviewed to determine whether the study asset has been identified in the prioritized resilience project list or STIP project resilience opportunities list. If needed, additional context information regarding asset characteristics, hazards, extend of potential impact, and quantified risk could also be obtains by reviewing the criticality, vulnerability, and risk maps and associated GIS data developed in Chapter 3, Chapter 4, and Chapter 5.

Consider whether and when risk meet or exceed acceptable level of change

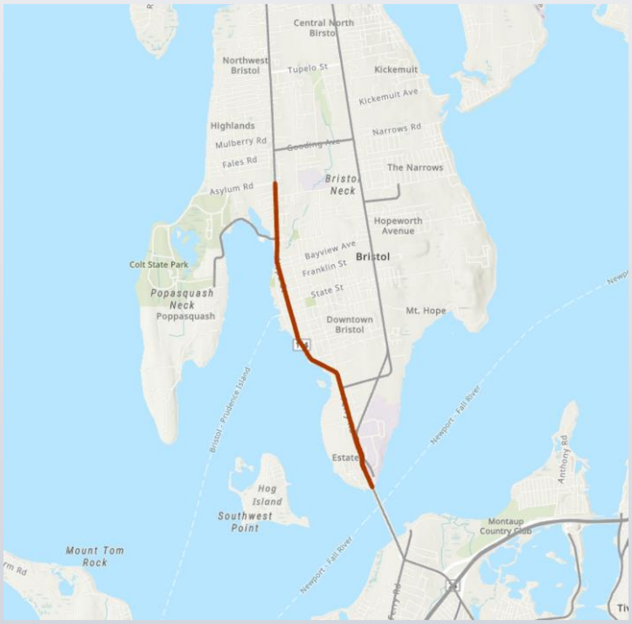
A cross-check of the categories in the red box in Figure 5.3 Criticality and Risk Matrix and the criticality and risk matrix maps for 2035, 2050, and 2100 shown in Figure 5.4, Figure 5.5, and Figure 5.6 can determine whether and when risk meet or exceed acceptable level of change – thus requiring resilience improvement. For those assets with a moderate or high risk tolerance, the project manager should assess if there's a need to adjust based on additional information about the asset or the community it serves.

Identify resilience needs and determine project timeline

Based on the information gathered in the previous steps, the study asset's resilience needs could be drafted to include the describe the hazards and extend of potential negative impact on the transportation system and the community it service that need to be addressed. The year (2024, 2035, 2050, or 2100) when risk meet or exceed acceptable level of change indicates the urgency of the need to make resilience improvements and can help inform project timeline and potentially immediate and long-term strategies.

Example of Application for Needs Assessment

The study asset, Hope Street between Asylum Road and the Mount Hope Bridge, is a state highway that runs along the coast in Bristol.



The Criticality and Risk maps (Figure 5.4, 5.5, and 5.6) show that it has high criticality to the transportation system in Rhode Island. By 2035, the study asset has a mix of high risk and low risk categories. By 2050, the portion with high risk has expanded, and by 2100, the majority of the study asset fall within high-risk category. A further review of the maps in Appendix F identifies the hazard scenarios that the study asset is vulnerable to by 2035, 2050, and 2100. The likelihood of each hazard scenario and the associated inundation depths obtained from GIS data in 2035, 2050, and 2100 are shown in Table 4.31.

Table 7.1 Impacted Hazard Scenarios, Inundation Depths, and Likelihood

		Likelihood		
Hazard Scenario	**Inundation depth**	**2035**	**2050**	**2100**
Flooding	0.5 – 1ft	1%	1%	1%
50-year storm + 1 ft SLR	5 – 10ft	0.02%	1.98%	1.98%
100-year storm + 2 ft SLR	>10ft	0%	0.01%	0.82%
100-year storm + 7 ft SLR	>10ft	0%	0 %	0.01%
Sea Level Rise 7 ft	0.5 – 1ft	0%	0%	1%

Based on Figure 5.2 Resilience Tolerance by Asset Category, the study asset has a low risk tolerance given its high criticality. The study asset meets its risk tolerance in 2035 and exceed its risk tolerance by 2050. It accepts minimal levels of risk or disruption to system operation and the needs to mitigate high, moderate, and low risk identified in the RIP.

Strategy Selection

Review contributing factors of risk

It is important to identify the contributing factors of the risk that the study asset is facing before selecting strategies that can target the root causes. This can be done be checking the indicators that comprise the vulnerability and risk in Chapter 4. For example, raising road profile might be more suitable for assets with high potential inundation (exposure) to sea level rise versus those with lower inundation. Roads with high sensitivity indicates poor pavement condition and should consider asset protection strategies such as enhance road surface or subbase. For assets with limited adaptive capacity, traffic management strategies such as detour planning, dynamic message signs or ITS enhancement could improve emergency response operation.

Establish mitigation objectives

With the contributing factors identified, mitigation objectives for the project should be established based on recommendation in Chapter 5.3 and Table 5.2 Examples of Mitigation Objectives The will also inform the selection of strategies that are most likely to achieve the objectives.

Select appropriate adaptation strategy

Based on information gathered in the previous steps, select potential adaptation strategies identified in Chapter 6.1 by considering the applicable hazards, context and geography Considerations, and short-term and long-term benefit.

Example of Application for Strategy Selection

To better select the appropriate adaptation strategies, it is important to understand the contributing factors of the risk facing the study asset, various vulnerability maps for exposure, sensitivity and adaptive capacity are referenced to identify the scores assigned to Hope Street for each of these factors. The sensitivity map which scores the pavement condition of an asset assigns the sensitivity score of Hope Street to be 4 indicating the pavement condition to be - poor and failed. The adaptive capacity map which measures the network density indicates that the adaptive capacity score for Hope Street is 4 implying that there aren’t too many detour options available around the vicinity of Hope Street.

After reviewing the examples of mitigation objectives in Table 5.2 and the likelihood of each hazard scenario impacting the study asset in Table 7.1, mitigation objectives for the study asset can be draft as follows:

The resilience improvement should be able to make sure that:

- In 2035, there is no structural damage and no more than 24 hours of service closure caused by inland flooding or 50-year storm with 1-ft SLR.
- In 2050, there is no structural damage and no more than 24 hours of service closure caused by inland flooding or 100-year storm with 2-ft SLR.
- In 2100, there is no structural damage and no more than 24 hours of service closure caused by inland flooding, 7-ft SLR, or 100-year storm with 7-ft SLR.

Therefore, asset protection strategies such as enhance road surface and subbase should be considered to harden the infrastructure so that it could withstand the impact from storm surge, with the minimum protection against 50-year storm + 1 ft SLR scenario by 2035 and potential enhancement to withstand stronger impact from 100-year storm with 2-ft SLR scenario in 2050, and 100-year storm with 7-ft SLR. This could be done all at once or two to three phases overtime. The study asset should also be raised by the minimum of one foot plus any freeboard requirement to avoid inundation from flooding and sea level rise. Recognizing that the study asset might still get temporarily inundated during sever storm surge events, drainage improvement strategies such as regular pipe cleaning, retention ponds or rain garden should be implemented to reduce the time of inundation and avoid sever structure damage. Emergency management strategies such as detour planning, dynamic message signs or ITS enhancement should also be considered to reduce the traffic and safety impact from roadway closure as well as expertise clearance.

RI dot
Driven to get you there

Evaluation and Prioritization

Compare improvement cost with cost of no action to evaluate return of investment

Once applicable resilience strategies have been identified, there is a need to identify the most optimal strategy. This evaluation involves the vetting process applied to those potential adaptation projects identified in the previous section. The cumulated composite risk values by 2024, 2035, 2050, and 2100 of each asset (developed in Chapter 4.3 which are also available in the resilience project lists in Appendix J and Appendix K) can be used to compare with the cost of resilience improvements to estimate potential return of investment. The data used for the risk assessment can also be extracted to support additional Benefit and Cost Analysis.

Prioritize by criticality and risk as well as other agency goals

To conduct project prioritization, a multi-criteria analysis (MCA) is recommended. This involves comparing adaptation options across a range of qualitative and quantitative criteria and provides the opportunity to standardize a variety of criteria. In addition to criticality and risk rankings in the prioritized resilience project lists in Appendix J and Appendix K, data regarding the study asset's characteristics could be extracted to assess additional project benefits associated with other agency goals, such as equity, mobility, and safety. These information is available in Chapter 3 and Appendix D.

Example of Application for Evaluation and Prioritization

The study asset is identified in Table 6.4 Potential Resilience Project List as project # 40, with a estimated risk of no-action (based on cumulated composite risk values) of $221,528, $3,815,767, and $408,518,322 for 2035, 2050, and 2100 respectively, which can be used to compare with the cost of resilience improvements to estimate potential return of investment.

Table 7.2 Hope Street in Resilience Project List

ID	Road Names	Criticality	Risk			Risk of No-Action ($)				Rank		
			2035	2050	2100	By 2024	By 2035	By 2050	By 2100	2035	2050	2100
40	HOPE ST	High	Low	Medium	High	$18,461	$221,528	$3,815,767	$408,518,322	61	30	5

It has a priority ranking of 61 in 2035, 30 in 2050, and 5 in 2100, which shows that although resilience improvement might not be an urgent needs in the short term, the risk of no-action is projected escalates with time passes and will become one of the most costly issues in the long term. In addition, the study asset is particularly importance for providing access to health and safety facilities and serving an area with high employment density based on the criticality factors in Appendix D; therefore, improvement might bring other benefit in addition to resilience to the community.

Funding and Programming

Leverage resilience funding

The identification of funding should consider PROTECT program as well as other Federal, State, and local resilience funding opportunities. If the study asset is part of the prioritized project lists (Appendix J and Appendix K) in the RIP, it might be eligible for reduction of non-federal match.

Incorporate into STIP

Resilience needs at the study asset can be incorporated into the STIP if it is overlapping with the current STIP projects.

Coordinate with other planning activities

Resilience project development should also coordinate with other major planning processes, including its SHMP, TAMP, Freight Plan, Carbon Reduction Plan(CRP), and Congestion Management Plan(CMP) to incorporate other transportation needs at the project location and identify opportunities for collaboration.

Example of Application

Because the study asset is identified in the prioritized project list of the RIP, it might be eligible for the benefit of the PROTECT program.

The study asset is also overlapped with STIP project # 1299 (Figure 6.4). Coordination is recommended to determine whether resilience needs can be incorporated.

The project manager should also coordinate with other planning activities to identify opportunity of collaboration.

Implementation

Include resilience needs in scoping

The study asset's resilience needs and other relevant data and information should be included in project scoping.

Consider vulnerability and risk in Environmental Review

The vulnerability and risk identified in the RIP and other relevant data and information about the study asset should be included in environmental review to be further evaluated and quantified.

Assess and refine adaptation strategies in Design

Potential adaptation strategies and other relevant data and information should be included in the next step of the project development process to be further assessed and refined, including comparing the cost of improvement and cost of no-action.

Example of Application

Having looked at Hope street with respect to all the maps and data, it can be summarized that the study asset, Hope Street between Asylum Road and the Mount Hope Bridge, is a highly critical State Highway that is projected to be impacted by Sea level rise, Storm Surge and Inland Flooding, with a estimated risk of no-action (based on cumulated composite risk values) of $221,528, $3,815,767, and $408,518,322 for 2035, 2050, and 2100 respectively.

Resilience improvement is needed to make sure that:

- By 2035, there is no structural damage and no more than 24 hours of service closure caused by inland flooding or 50-year storm with 1-ft SLR.
- By 2050, there is no structural damage and no more than 24 hours of service closure caused by inland flooding or 100-year storm with 2-ft SLR.
- By 2100, there is no structural damage and no more than 24 hours of service closure caused by inland flooding, 7-ft SLR, or 100-year storm with 7-ft SLR.

The study asset's resilience needs, and other relevant data and information should be included in project scoping. The vulnerability and risk identified in the RIP and other relevant data and information about the study asset should be included in environmental review to be further evaluated and quantified. Potential adaptation strategies and other relevant data and information should be included in the next step of the project development process to be further assessed and refined, including:

- Enhance road surface and subbase
- Raising road profile
- Drainage and stormwater improvements
- Traffic and emergency management strategies

7.4 Coordinate with Other Planning Activities

The Rhode Island RIP provides a comprehensive assessment and focus on resilience needs for the state's transportation infrastructure. Implementation is a critical portion of the RIP development process, given the importance of carrying out recommendations. In addition to the LRTP, STIP, and agency-wide operations, there is a need for coordination with other planning activities and functional planning areas, as explained below. Coordination with each of these planning activities assumes an overarching need to consider resilience in planning goals and objectives, and strategies, as discussed in Section 7.1 for LRTP alignment.

7.4.1 State & Local Hazard Mitigation Plans

Rhode Island's SHMP was developed in 2024 and provides a broad assessment of all hazards that pose a potentially significant risk to Rhode Island. The plan, in effect through a five-year cycle through 2029, was developed in accordance with the *Disaster Mitigation Act of 2000*, making Rhode Island eligible for certain FEMA non-emergency pre-disaster and post-disaster assistance. As identified in Chapter 1, Rhode Island's SHMP identifies and analyzes hazards including related to sea level rise and storm surge.

The vulnerability assessment conducted in Section 4.0 directly addresses this component of the SHMP by introducing a data-driven, multi-scenario, and multi-time frame geospatial component. These results also provide a strong foundation for future hazard mitigation planning efforts to consider additional community and equity impacts including through the identification of Historically Disadvantaged Communities and Areas of Persistent Poverty, as well as overlays of critical community assets, flood and storm surge risk, and evacuation routes. Correspondingly, these results will directly strengthen risk assessments conducted in local and municipal hazard mitigation plans across Rhode Island. Opportunities for integration into local and hazard mitigation planning include considerations for land use impacts, cost modeling, emergency services provision, and equity considerations, where appropriate.

7.4.2 Asset Management

At the statewide level, asset management is conducted in accordance with RIDOT's TAMP. The current TAMP was developed in 2022 to cover the 10-year period through 2031, with a purpose of documenting strategic and systemic processes to maximize asset life cycles and minimize capital costs by preserving roads and bridges through sustainable, resilient investments. The planning process includes considerations for life cycle analysis, risk and cost modeling, investment strategies, and implementation.

The content and analyses included in the RIP are directly applicable to asset management through multiple standpoints. First, as a key component of the STIP development recommendations, RIDOT should identify and

provide the costs of resilience improvements, including initial capital investments, ongoing maintenance costs, and costs of no-action. These figures, adjusted to inflation and other considerations in the upcoming years, should be directly integrated into future iterations of the TAMP to accurately identify funding needs and grant opportunities. Identification of key adaptation strategies also provides the opportunity to identify how resilience projects and enhancements impact and prolong the state's multimodal transportation system.

The results of vulnerability assessments identified in Chapter 4 also introduce opportunities to further define risk in relation to asset management. As identified in RIDOT's existing TAMP, the agency's risk register includes an analysis, and corresponding impacts of multiple types of risk, ranging from climate change to faulty materials, political uncertainty, and knowledge drain. A more comprehensive introduction of risks as identified in the RIP can further provide RIDOT with a stronger understanding of infrastructure and agency-wide needs. As a result, there is a strong incentive to maintain alignment between the RIP and TAMP development processes.

7.4.3 Freight Planning

As a recipient of National Highway Freight Program funding, Rhode Island is required to develop an updated state freight plan every four years. Developed in 2022, Rhode Island's *Freight and Goods Movement Plan* identifies the immediate and long-range planning activities and investments associated with the state's freight system. This includes identification of statewide infrastructure used for freight and goods movement, corresponding system needs, statewide investment goals, as well as investment strategies, policies, and data necessary to promote an efficient, reliable, and safe freight transportation network.

As identified in the *Freight and Goods Movement Plan*, multiple key goals of the statewide freight planning process are directly related to resilience and sustainability. This includes the following:

- A need to ensure a resilient post-disaster freight network.
- Reduce the impacts of flooding and runoff associated with the freight transportation system.
- Reduce harmful emissions impacts from freight transportation modes.
- Reduce the impact of future freight transportation network expansion on natural heritage areas and large unfragmented forests.

Moving forward , there are multiple opportunities for integration with ongoing resilience planning efforts. Section 4.0 identifies the results of the resilience vulnerability assessment, including those locations likely to be impacted by storm surge and sea level rise. From the context of freight, these results are significant for multiple reasons. First, a large majority of Rhode Island's population lives in or with proximity to vulnerable locations. Population is a key driver of freight traffic given the corresponding demand for everyday goods and products, construction materials, food, and fuel/energy. From an economic perspective, a number of key industries are located in

similarly vulnerable areas. This includes the tourism, energy, agricultural, and seafood industries, which can be especially vulnerable to unforeseen disruptions.

As a result, those vulnerability assessment results, including key risk considerations, should be integrated into future freight planning efforts to better address resilience needs. This includes overlays with critical freight corridors and infrastructure assets, as well as considerations for future freight growth. In relation to the resilience-oriented goals of the current freight plan, the results and policy considerations of this plan offer multiple opportunities. These include the improved ability to plan for and respond to disruptions to the freight network from adverse conditions, as well as enhanced protections for freight assets, sensitive ecosystems, and vulnerable communities. Physical coastal asset protection strategies identified in Chapter 6 also offer enhanced protection and a blueprint for improved sustainability in the realm of freight planning.

Figure 7.6 Galilee Fisheries

Fishing Fleet in Galilee. Rhode Island's fisheries are a major economic driver for the state and are renowned across the country and world for Port Judith Calamari, oysters, clams, and other seafood products.

Image Source: The Providence Journal

7.4.4 Carbon Reduction Plan (CRP)

As the recipient of Federal Carbon Reduction Program funds, RIDOT's CRP satisfies multiple objectives. This includes supporting the implementation of the 2021 Act on Climate, further assessing and forecasting transportation sector carbon impacts, identifying program funding priorities, and establishing a framework for future carbon reduction planning. As a result, there are multiple opportunities for coordination between the two plans. First, the RIP will act as a supporting plan to help lower emissions and improve efficiencies. This stems from targeted investments in the state's transportation infrastructure network, including to address system vulnerabilities. Additionally, those RIP strategies addressing sidewalks and shared-use paths, as well as green infrastructure should be integrated into the CRP. Additionally, the CRP should consider the application of these strategies to smart growth and public transit investments in efforts to further reduce greenhouse gas emissions.

7.4.5 Congestion Management Plan (CMP)

The purpose of RIDOT's CMP is to identify congestion and causes of congestion, establish a monitoring process for measuring transportation system performance and reliability, and to develop strategies, establish funding, and implement processes for managing congestion. Similar to the case for RIDOT's Cabron Reduction Plan, the RIP will act as a supporting plan to help manage congestion, especially in locations vulnerable to key hazards such as storm surge and sea level rise. Furthermore, the RIP can be used as a foundation for identifying infrastructure assets in need of investment or upgrade to meet the goals and objectives of both planning processes.

7.4.6 Engagement with Local Communities

Engagement with local communities is a key component of transportation efforts spanning RIDOT operations. This includes the preparation of transportation planning documents, solicitation of input on major projects, and for understanding local and community-level needs. The RIP should be used to enhance community engagement, and should serve as a source of knowledge on asset vulnerability, risk, and adaptation needs. Overall, these efforts should serve the goal of ensuring that resilience is a major factor in decision-making.

7.4.7 Future Resilience Planning Efforts

The first statewide RIP for RIDOT provides a strong foundation for future resilience planning efforts through the assessment of critical infrastructure, risks from climate change and extreme weather, identification of potential mitigation strategies, and considerations for integrating resilience into agencywide planning processes. Ultimately, and through collaboration with other agencies, including the Rhode Island State Planning Council, the RIP can be used to guide additional resilience efforts at the local, regional, and statewide scale. Future resilience planning efforts, including updates to the RIP should focus on, and expand the following topic areas:

- Updates to the vulnerability assessments, risk thresholds, and identification of critical infrastructure and vulnerable communities, including those locations repeatedly damaged or impacted by extreme weather and climate change. RIDOT should also determine which changes and updates may warrant review and sign-off from FHWA.
- Analysis of initial and ongoing efforts to integrate resilience across agencywide operations, including overarching policy and decision making.
- Highlights of new and dynamic adaptation strategies, and implementation of related ITS technologies, including case studies, if applicable, within Rhode Island.

8.0 STAKEHOLDER ENGAGEMENT AND COMMUNICATION

RIDOT recognizes the on-going efforts by municipalities and partner agencies and seeks to collaborate with the appropriate agencies and organizations for information sharing and alignment of resilience strategies. Chapter 8 summarizes RIDOT's approach to stakeholder engagement and communication. This includes a summary of key stakeholders and methods used to solicit feedback. Stakeholders in the RIP development process range from RIDOT staff who will ultimately carry out recommendations, to the general public and community members who will benefit from resilience improvements. A wide range of engagement methods were utilized, ranging from internal staff workshops to peer agency interviews and community engagement events.

8.1 Approach to Stakeholder Engagement and Communication

The development of the Rhode Island RIP was guided in large part through targeted and informative stakeholder engagement and participation. This included engagement and communication with the following key stakeholders:

- **RIDOT Staff:** RIDOT is comprised of multiple divisions including planning, policy, design & construction, and maintenance. Together, these divisions are tasked with maintaining a safe and resilient transportation system in accordance with the agency's goals and vision. The development of the RIP is guided by the assumption that RIDOT staff have the strongest understanding of Rhode Island's transportation system, including needs and key nuances, especially in relation to resilience. Given that many resilience strategies are physical enhancements to the transportation system, the RIP development process included extensive outreach to, and collaboration with, staff across every related RIDOT division.
- **Rhode Island Policymakers & Stakeholders:** The RIP development process included engagement with additional Rhode Island public sector agencies, including the RIEMA, RIDSP, RIPTA, and RIDEM. These agencies play a direct role in the identification of hazards and vulnerabilities, and/or responses required to ensure minimal disruptions across the state. As a result, coordination with these agencies was an important component of the RIP development process given the significant overlaps in terms of goals and objectives, including within the scope of the statewide transportation system.
- **General Public:** The ultimate beneficiary of a more resilient transportation system is the general public, including residents, businesses, and visitors to Rhode Island. This stems from increased safety and

reliability, including in response to the hazards and vulnerabilities associated with the transportation system.

- **Peer Agencies:** Overall, the widespread and meaningful integration of resilience into DOT operations is still in the early stages across the country. As evidenced in the literature conducted in the early stages of the RIP development process however, there are various agencies and agency personnel which have been developing and integrating resilience best practices into the operations. Additionally, at the time that the RIP is being developed many DOTs are also undertaking similar plans. As a result, RIDOT sought to engage personnel from peer agencies across the country to facilitate best practices and knowledge transfer.
- **FHWA:** RIDOT maintained close consultation with FHWA for the purposes of guiding key components of the RIP and ensuring that the plan is structured to best address resilience needs.

Figure 8.1 RIP Development Stakeholders

The methods of engagement applied for each of these stakeholders are identified in the following section.

8.2 Methods of Engagement

As part of the RIP development process, RIDOT utilized multiple methods of engagement gather insight from the stakeholders identified above. This included the following methods:

8.2.1 Peer Agency Interviews

In the initial portions of the RIP development process, RIDOT conducted virtual interviews with peer agency personnel from across the United States. This included the identification of those DOTs which have emerged as leaders in resilience integration, and who have already taken steps to undertake a resilience-related plan. The interviews asked participants about their agency’s resilience goals, RIP development status, approaches to vulnerability assessments, strategy identification, implementation, performance monitoring, stakeholder communication, and key lessons learned. In total, RIDOT conducted ten interviews, while reviewing relevant shared content from each interviewee.

8.2.2 Workshops

As part of the RIP development process, RIDOT convened a series of in-person workshops. The purpose of these workshops was to share progress, solicit feedback, facilitate knowledge transfer, and identify best practices. These workshops brought together key RIDOT staff and personnel from key Rhode Island public sector

agencies. One of these workshops also included a peer exchange, bringing together personnel from DOTs across the country. A brief description of each workshop is provided below:

- **Workshop #1 – Fundamental Elements:** RIDOT's first workshop was held in early August 2023, and brought together key policy stakeholders from Rhode Island. The workshop included a presentation of the goals and vision of the RIP, and how the RIP fits into other RIDOT planning initiatives. The workshop also included a description of the criticality framework and vulnerability assessments to be conducted through the RIP. For this component of the workshop, attendees were asked to provide input on important considerations, infrastructure, and other components critical to guiding this incorporation of risk into the criticality framework and vulnerability assessments.

Figure 8.2 Workshop #1 Breakout Session

- **Workshop #2 – Resilience Strategies & Integration Peer Exchange:** The second workshop hosted by RIDOT was held in late August 2023. This multi-day workshop also included invitations to key state DOT personnel from across the country who are focused on resilience planning, and who have emerged as leaders in the topic. With the vulnerability assessments ongoing following the insight from Workshop #1, this second workshop focused on policies and methods to directly integrate resilience into agency operations. The workshop included exercises and discussions on methods for integrating resilience across multiple functional areas, as well as what resources are needed to fulfill these functions. Additionally, RIDOT shared its STIP development and implementation processes with the workshop to identify ideas and best practices for integrating resilience into each five-step process. The second workshop included multiple networking opportunities to further facilitate knowledge transfer amongst the various agencies in attendance.

Figure 8.3 Workshop #2 Presentation

8.2.3 RIDOT Working Group Meetings

To guide the RIP development process, regular working group meetings were held with key RIDOT staff. The purpose of these meetings was to share progress following the completion of key milestones, solicit feedback, and discuss next steps. These working group meetings included presentations by the project team, followed by discussion and collaboration.

8.2.4 Community Engagement

Community engagement meetings were conducted to share analysis findings and support the development of locally preferred adaptation strategies.

8.2.5 Project Coordination

The RIP development process included coordination with the following plans, which were concurrently ongoing:

State Hazard Mitigation Plan

RIMEA is in the latter stages of developing the 2024 SHMP[18]. Building from the 2019 SHMP, the purpose of the 2024 SHMP is to document the corresponding planning process, and to identify applicable hazards (including natural, technological, and human-caused), vulnerabilities, and hazard mitigation strategies. RIDOT staff attended multiple meetings related to the 2024 SHMP development and coordinated with RIEMA personnel to assess important takeaways for the RIP.

Route 114 Resilience Plan

Route 114 is a major thoroughfare in the eastern part of Rhode Island. The route, consisting of 46 miles, connects Newport / Aquidneck Island and Woonsocket, along with population centers in between, including Bristol, East Providence and Pawtucket. The purpose of this plan[19], in its latter stages of development at the time of the RIP development, is to assess the current and future vulnerability of the corridor, and establish stablish conceptual alternatives for reducing coastal flood risks and improving overall resilience in key areas of vulnerability. The plan is being developed in coordination with the Towns of Barrington, Bristol, and Warren, RIDSP, RIPTA, and RIDOT.

Given the overlap between the Route 114 Resilience Plan and the RIP development process, RIDOT hosted a meeting in December 2023 to identify coordination opportunities between the two plans. This meeting included

[18] https://riema.ecms.ri.gov/sites/g/files/xkgbur671/files/2023-11/Draft%20State%20of%20Rhode%20Island%20Hazard%20Mitigation%20Plan%2010.30.2023.pdf

[19] Link for plan to be inserted once its made available.

an overview of both plans, approaches used to develop each vulnerability assessment, and insight on how this regional vulnerability assessment fits into the larger statewide plan.

8.2.6 Additional Stakeholder Meetings

Throughout the RIP development process, RIDOT engaged with additional policymakers and organizations. This included collaboration at the following meetings:

- Following the peer agency interviews and identification of preliminary best practices, key findings were presented at the American Association of State Highway and Transportation Officials (AASHTO) Risk and Resilience Working Group Meeting in May 2023.
- The Resilient Rhode Island Act established the Executive Climate Change Coordinating Council (EC4) in 2014. The council, comprised of 13 members, meets regularly to identify opportunities to increase resilience, set greenhouse gas reduction targets, and ensure that climate change considerations are integrated into policymaking. Multiple members of the EC4 were actively involved in the RIP development process, in at the workshops identified above. Additionally, the project team directly presented to the EC4 in September 2023 to highlight progress and solicit feedback.
- The project team presented the RIP to Rhode Island's State Planning Council in November 2023. The Council oversees the Division of Statewide Planning's work, including the adoption of related goals and policies. Additionally, the project team presented the RIP to the TAC in August 2023. The TAC advises the State Planning Council on transportation planning, and provides input on key documents including the LRTP and STIP.
- The project team conducted multiple meetings with FHWA to provide updates and solicit feedback, including on the criticality framework, and development of strategies.

9.0 MONITOR, EVALUATE, AND ADJUST

The final step in the RIP development process sets the foundation for future resilience planning efforts. This includes RIDOT's steps to monitor, evaluate, and adjust the methodology, strategies, and findings identified in this initial RIP. These efforts are achieved through the development of performance measures and through the establishment of a framework and formalized procedure for future RIP updates.

9.1 Monitoring & Evaluation Process

The framework for future resilience planning efforts is first established through the development of performance measures as discussed in Chapter 7.1. Although RIDOT has not developed performance measures specifically for its RIP, the agency tracks multiple performance measures related to resilience through the State LRTP. These performance measures are grouped according to the plan's goals, with 'Maintain Transportation Infrastructure' performance measures being the most relevant to resilience. The full list of LRTP 'Maintain Transportation Infrastructure' performance measures is shown in Figure 7.1 and includes pavement condition, as well as the number of bridges, miles, and intermodal hubs vulnerable to sea level rise. Chapter 7.1 additionally provides recommendations on how to integrate resilience into performance measures. Correspondingly, these performance measures could be formally adopted for tracking in future resilience planning efforts.

Once resilience-specific performance measures have been formally adopted, RIDOT should have in place a plan to track performance. This will include setting targets for each new performance measure, and assessing how well each target was met over a period of time. This timeline can coincide with future RIP iterations, future LRTP updates, and/or a combination of these two processes. RIDOT should also consider adjustments to the vulnerability and risk assessment methodology as needed, including as new climate and hazard data is made available. These adjustments should directly consider any changes in the vulnerability of Rhode Island's most critical transportation assets.

9.2 Adjustment & Procedure for Future Resilience Planning Efforts

RIDOT plans to update the RIP as appropriate on a periodic basis, potentially to coincide with future LRTP, TAMP, and other relevant plan development processes. In compliance with PROTECT guidance, the following conditions will require updates to the RIDOT RIP, and will warrant an approval from the FHWA Division Office:

- Addition of new hazards, considered as part of current and future weather events and natural disasters, to the risk-informed vulnerability assessment.
- Consideration of any additional asset types to be considered as part of the transportation assets and systems to be considered for resilience improvements.
- An update to the process and methodology for conducting a risk-informed vulnerability assessment of transportation infrastructure.
- Development of a list of resilience projects to support reduction of the non-federal share of the cost under the PROTECT Formula Program.
- Other points of coordination mutually agreed upon by RIDOT and the FHWA Division Office that require an update of the RIP.

In addition to the procedural conditions identified above, future resilience planning efforts may also include the following topics:

- Expansion of the vulnerability and risk assessments to further address the needs of non-RIDOT owned or maintained assets.
- Assessment of physical and adaptive strategies as identified in Section 6.1, as they are applied across Rhode Island.
- Further consideration of additional hazards, including those identified in the SHMP and TAMP.
- Incorporating new data, such as future climate downscale projection data, and probability modeling data for storm surge, sea level rise, and flooding scenarios, with potential collaboration with partner agencies or universities.
- Resilience needs applied to additional core functional areas including freight, hazardous materials, safety, and public transit.
- Coordination of resilience efforts and strategies with neighboring states, including Massachusetts, Connecticut, and New York.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