CLIMATE ACTION TOOLKIT

ROADWAY ADAPTATIONS

Southern New Hampshire Planning Commission

December 2023

SOUTHERN NEW HAMPSHIRE PLANNING COMMISSION
SNHPC

About the Southern New Hampshire Planning Commission

The **Southern NH Planning Commission (SNHPC**) is one of nine regional planning commissions in the State of New Hampshire. SNHPC was formed under New Hampshire Statutes in 1966 and serves as the coordinating agency for the planning initiatives of fourteen (14) communities in the southern New Hampshire region.

The Commission is also the **Metropolitan Planning Organization (MPO)** for the region, responsible for conducting transportation planning in a cooperative, comprehensive, and continuous manner. Federal regulations stipulate that highway construction funds in urbanized areas can only be utilized by states with an MPO in place.

SNHPC Communities

Town of Auburn
Town of Bedford
Town of Candia
Town of Chester
Town of Deerfield
Town of Derry
Town of Francestown
Town of Goffstown
Town of Hooksett
Town of Londonderry
City of Manchester
Town of New Boston
Town of Weare
Town of Windham

Contact Us!

Southern NH Planning Commission
438 Dubuque Street, Manchester, NH 03102
Phone: 603-669-4664
Website: snhpc.org
Facebook: facebook.com/snhpc/

Translation / Traduction / Traducción

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Linda Moore-O'Brien
SNHPC Office Administrator
lmoore@snhpc.org
603-669-4664

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Key Regional, State, and Federal Technical Experts

Meghan Butts, Executive Director, Upper Valley Lake Sunapee Regional Planning Commission
Dave Walker, Assistant Director, Rockingham Planning Commission
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Eva Birk, Environmental Protection Specialist, Federal Highway Administration

Climate Champions Advisory Group

Victor Chouinard, Chester Conservation Commission
Jillian Harris, Assistant Planning Director, Town of Bedford
Ann Podlipny, resident, Town of Chester
Elizabeth Roubidoux, Town of Hooksett

Regional Workshop Hosts

John O'Connor, Planning Board Chair, Town of Derry
George Sioras, Planning Director, Town of Derry
Owen Provencher, Director, Derry Community Access Media

Case Study Contributors

Aaron Berube, Police Chief, Town of Chester
Phil Gladu, Fire Chief, Town of Chester
Andrew Hadik, Town Planner, Town of Chester
James Piper, Supervisor of Roads, Town of Chester

Other Contributors

Kathleen Ports, Associate Planner, Town of Bedford
Kathie Vieira, Crew Chief, Town of New Boston
Benji Knapp, Road Agent, Town of New Boston
Liz Goldman, Vice Chair, Dover Traffic Advisory Commission
Dena Hoffman, Environmental Regulation Compliance Specialist, Town of Pelham, NH
David McPherson, Executive Director, Alexander Eastman Foundation
Madeleine DiIonno, Regional Planner, Rockingham Planning Commission
Colin Lentz, Senior Transportation Planner, Strafford Regional Planning Commission
William Rose, Policy & Planning Manager, NH Department of Transportation
Dillan Schmidt, Environmental Manager, NH Department of Transportation

Rhona Thomson, Environmental Analyst, NH Department of Transportation
Katie Kemen, Director of Climate Resilience Services, BSC Group
Bill Lyons, Principal Technical Advisor, USDOT Volpe Center

Key Staff – Southern New Hampshire Planning Commission

Sylvia von Aulock, Executive Director
Suzanne Nienaber, Principal Planner
Cameron Prolman, Regional Planner
Zachary Swick, Senior GIS Analyst
David Tilton, Regional Transportation Planner
Tammy Zamoyski, Regional Planner

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INTRODUCTION

According to the National Oceanic and Atmospheric Administration (NOAA), average global temperature has risen by 2°F since 1880, and rates of warming are increasing. In fact, the 10 hottest years in the historical record have all occurred since 2010.[1] Communities around the world are recognizing that **climate change** is not a faraway future state – its effects are already here. Whether facing sea level rise, hotter temperatures, wildfires and droughts, or catastrophic storms and flooding, the need to address climate change is urgent.

> **Note:** Look for key vocabulary words **underlined in bold** throughout this toolkit. Definitions can be found in the Glossary at the end of the document.

For the Southern NH Planning Commission (SNHPC) region, **inland flooding** is the most significant climate risk. Warming temperatures allow the atmosphere to hold more water, resulting in more intense rainfall and an increased risk of flooding that has the potential to dramatically compromise the region's infrastructure, ecology, and quality of life.

This Climate Action Toolkit provides an important resource to help the SNHPC region become more **resilient**, so that member communities can effectively prepare for, respond to, and recover from climate-related threats. By designing systems that are attuned to an evolving climate, resilient communities not only seek to minimize damage – they also identify new and innovative opportunities for human and ecological systems to thrive together.

The functionality and reliability of the transportation network is a priority issue for every community, and the challenges of road washouts caused by flooding are well-known. For this reason, roadway **adaptation** provides a strategic entry point for bringing stakeholders together to address pressing concerns, while laying the foundation for advancing broader, multi-faceted climate interventions.

Value of a regional lens

Whether a community is grappling with flooding, heat waves, invasive species, or other concerns, it is clear that the wide-ranging impacts of climate change do not adhere to municipal boundaries. Regional, statewide, and even national leadership is needed to truly make an impact. SNHPC is pleased to be coordinating with 14 municipalities in the greater Manchester area to align efforts and foster a more resilient region.

Working together allows for more efficient and effective action across governments and sectors. From adopting a new policy to pursuing a new funding source, a regional lens can help communities coordinate efforts, share resources, and harness technical expertise to address complex climate challenges.

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[1] See Climate.gov: "Climate Change: Global Temperature"

Fortunately, the SNHPC region has excellent models to draw upon, in the form of fellow regional planning commissions that have extensive experience addressing climate issues. For example, Rockingham Planning Commission has been confronting the heightened urgency of sea level rise via collaboration with the Coastal Adaptation Workgroup, while the Upper Valley Lake Sunapee Regional Planning Commission has been playing a leadership role with the Upper Valley Adaptation Workgroup to foster more resilient communities in the wake of Tropical Storm Irene.

The SNHPC region has had its own experience with devasting floods – including the 2006 Mother's Day floods and the 2007 Patriots Day nor'easter, two 100-year flood events that happened less than a year apart, which resulted in millions of dollars in property damage. National climate research indicates that storms of this magnitude will increase in both frequency and intensity, particularly in the Northeastern United States.[2] The collaborative development of this Climate Action Toolkit marks an important opportunity to align efforts in the face of climate change. **The time to act is now**.

Development of this Toolkit

This Climate Action Toolkit details specific strategies to help communities shift from analysis to action in order to more effectively address our region's climate vulnerabilities, with a specific focus on roadway adaptations. It builds upon a range of prior initiatives, including:

- A rigorous Regional Vulnerability Assessment completed in 2020, which systematically documented the **vulnerability** of the region's stream crossings.
- A review of national, state, regional, and local roadway adaptation resources. (See Appendix A for details.)
- A breadth of expertise contributed by 40+ stakeholders who attended an inaugural regional climate workshop in April 2023.

Here is what you will find in each chapter:

Chapter 1. Temperature Check: State of the Region provides a high-level synopsis of climate data and trends, and identifies key opportunities to advance regional climate planning efforts.

Chapter 2. Technical Analysis: Corridor-level Vulnerability outlines metrics for assessing vulnerable stream crossings, and introduces a corridor-scale approach to analyzing roadway vulnerabilities and identifying adaptation priorities.

Chapter 3. Menu of Strategies: Roadway Adaptation distills a list of practical roadway adaptation strategies, along with project examples and practitioner quotes to illustrate potential implementation opportunities.

[2] See Fourth National Climate Assessment. Chapter 18: Northeast.

Chapter 4. Adaptation in Action connects insights from Chapters 1-3 with an understanding of the local planning context. It includes a case study of a specific corridor in the region, followed by a discussion of how asset management and regional transportation planning can be more responsive to climate concerns.

The Appendix provides additional resources, including a list of key publications that informed the development of the Toolkit, and expanded, community-specific tables from the Chapter 2 Technical Analysis.

How to use this Toolkit

The full impact of this Toolkit will rely on the commitment of local and regional stakeholders to pursue collaborative action in the face of climate change. Whether you are a transportation or planning professional, a Town administrator, or a concerned resident, here are a few ideas for how to get started:

1. **Identify high-priority vulnerable corridors and stream crossing sites** to target in your community. (See Chapter 2 and Appendix B.)
2. **Explore the menu of strategies** to generate ideas around specific adaptation opportunities for priority corridors. (See Chapter 3.)
3. **Convene local stakeholders** to talk about climate priorities. Invite SNHPC staff to provide an overview of the Toolkit to help get the conversation started!
4. **Engage in collaborative climate planning activities**. Continue working with SNHPC on regional climate planning efforts.

CHAPTER 1 - Temperature Check: State of the Region

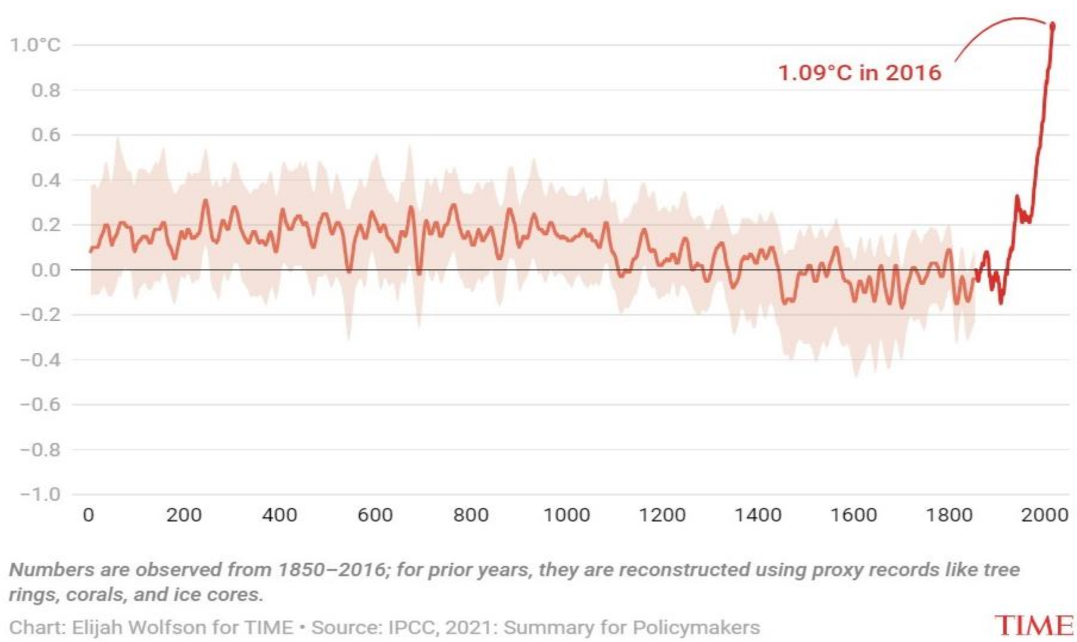
The greatest climate threat currently facing the SNHPC region is **inland flooding** due to extreme precipitation events. Flooding in NH regularly washes out infrastructure, damages the economy and ecology, and can threaten the health and safety of residents. While climate change is increasing **risks** related to a variety of natural hazards – including drought and extreme temperatures – according to the NH Department of Environmental Services, flooding is the state's most common and costly natural disaster.[3]

The good news is the SNHPC region is well-positioned to move forward with the collaboration and innovation needed to respond to climate change. The region can learn from ongoing climate work led by neighboring regional planning commissions, research emerging from the University of New Hampshire, and other statewide initiatives. Collective roadway adaptation efforts can serve as an ideal entry point to take action today, prepare for a changing future, and continue to formulate a vision for a more resilient, climate-ready region.

Understanding climate data and trends

We live on a rapidly warming planet. As the figure below shows, the Earth is in the midst of a "great acceleration" in terms of temperature rise. Mean global surface temperatures have increased by more than 1°Celsius (or almost 2° Fahrenheit) relative to the 1850-1900 average, and are projected to continue increasing rapidly. (See Figure 1.1.)

Figure 1.1: Change in global surface temperature relative to 1850-1900 average



[3] See NH Department of Environmental Services, Flooding.

The extent of future temperature rise will be largely contingent on the effectiveness of efforts to reduce and remove **greenhouse gases (GHG)** from the atmosphere. Since climate scientists cannot fully predict the impact of collective climate efforts, forward-looking projections are often shown according to "lower emissions" or "higher emissions" scenarios. By the end of the century, projected warming will contribute to a mean NH temperature that is several degrees hotter than today. The outcome will depend on how much local and global emissions can be curbed. (See Figure 1.2.)

Figure 1.2: Observed and projected temperature change in New Hampshire

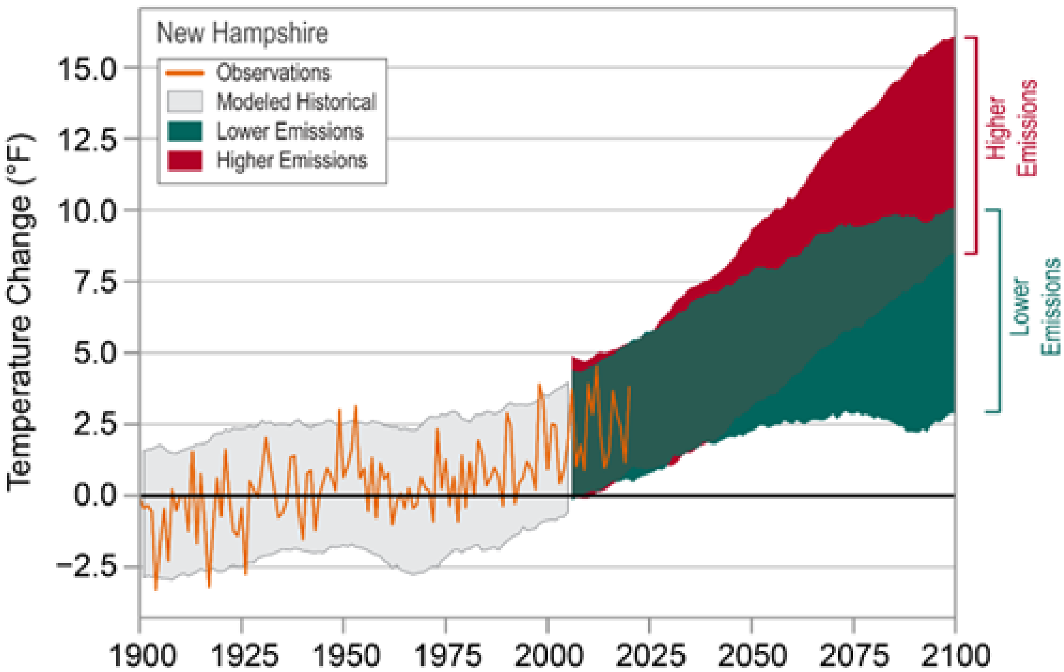


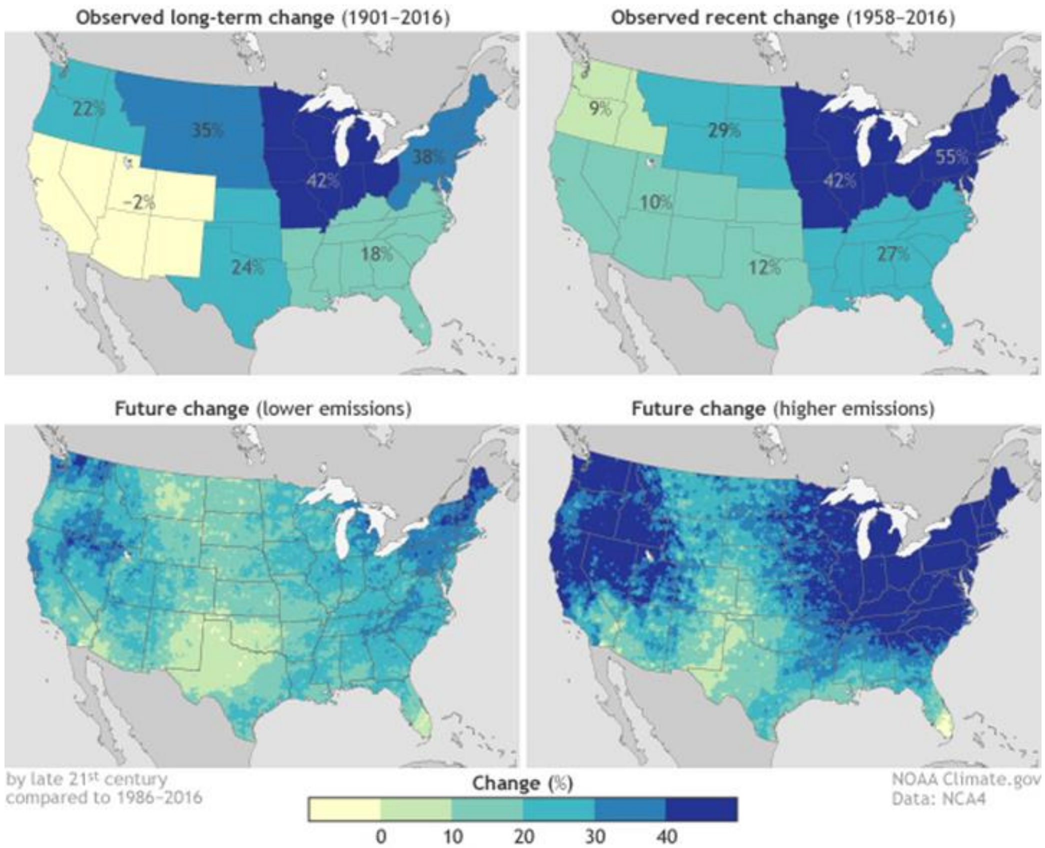
Image courtesy of NOAA National Centers for Environmental Information: State Climate Summaries 2022 – New Hampshire

When it rains, it pours

As temperatures rise, air can hold more moisture, resulting in higher levels of precipitation and greater frequency of **extreme precipitation events** that substantially exceed normal rates. With temperatures warming by 2°C (or about 3.6°F), heavy rain events will become 1.7 times more likely, and 14% more intense.[4] As the following maps indicate, the Northeastern US has already seen a dramatic increase in extreme precipitation in the 20th century, and the pattern is expected to continue throughout the 21st century. (See Figure 1.3.) In fact, in 2023, every state in New England experienced one of their top 10 wettest summers, while New Hampshire and Vermont saw their wettest summers on record.[5]

[4] See UCAR Center for Science Foundation, "Predictions of Future Global Climate."
[5] See NHPR, "When it rained, it poured: 2023 was NH's wettest summer yet."

Figure 1.3: Change in extreme precipitation across the United States



Statewide climate trends

In 2022, climate scientists at the University of New Hampshire Sustainability Institute released the New Hampshire Climate Assessment, a comprehensive report that provides a detailed look at statewide climate data. Their findings indicate that climate shifts in NH are aligned with the trends seen at the national and global scale.

Historic Data

- Temperatures across NH have increased by an average of 3°F since 1901, warming at a faster rate over the past 50 years. The rate of warming was most apparent during the fall and winter seasons and at night.
- Over the same period, annual precipitation has increased by 12%, with inland areas like the SNHPC region seeing an increase in extreme precipitation events exceeding 1” in a day.

Future projections

- Over the next 20 years, NH is likely to see average temperature increases of 2.2-2.4°F. By the end of the century, projected warming ranges from 5.2 degrees (under a lower emissions scenario) to 9.5 degrees (under a higher emissions scenario).
- New Hampshire is expected to see an increase in total annual precipitation, largely in the winter and spring seasons, as well as an increase in the frequency of the most extreme precipitation events (defined as 2+ inches in 24 hours, or 4+ inches in 48 hours).[6]

Climate consequences for roadways

Given rising temperatures and increasing precipitation, inland flooding is the most significant climate concern facing the SNHPC region. Our road networks are particularly vulnerable to this flooding at **stream crossings** where roads cross over waterways via bridges and culverts. Examples from communities across the state show that it doesn't take a hurricane to cause a road washout. Even heavier than average storms can result in serious road failures. (See Figures 1.4 and 1.5.)

Figure 1.4: Lane Road in Chester, July 2023

Image courtesy of WMUR

[6] See Lemcke-Stampone, M. et al. New Hampshire Climate Assessment 2021. University of New Hampshire Sustainability Institute, 2022.

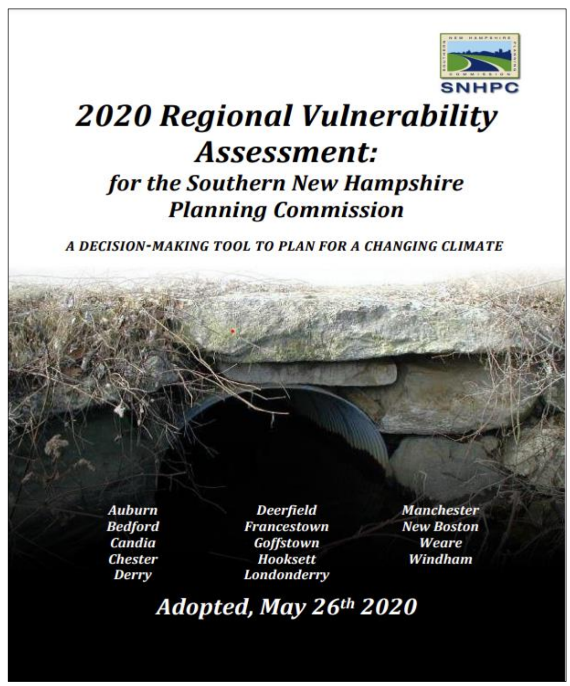
Figure 1.5: Route 123A in Alstead, July 2021

Image courtesy of The Keene Sentinel, © Hannah Schroeder

Assessing roadway vulnerabilities

In 2020, SNHPC released a [Regional Vulnerability Assessment] (RVA) that systematically documented the status of the region's roadway stream crossings in light of available climate data. (See Figure 1.6.) Specifically, the RVA examined more than 1,600 culverts and bridges using a series of criteria developed with input from regional stakeholders including road agents and public works staff. By assessing each crossing and applying the criteria—e.g. traffic volume, hydraulic vulnerability, flood zone proximity—each crossing was given a numeric score that was used to develop a priority list of the most vulnerable stream crossings for each municipality, as well as region-wide. The analysis was also integrated into an [interactive GIS map] that can be used to support regional decision-making around infrastructure improvement needs. Chapter 2 of this toolkit uses the RVA as a starting point to incorporate new insights and expand the scope of analysis.

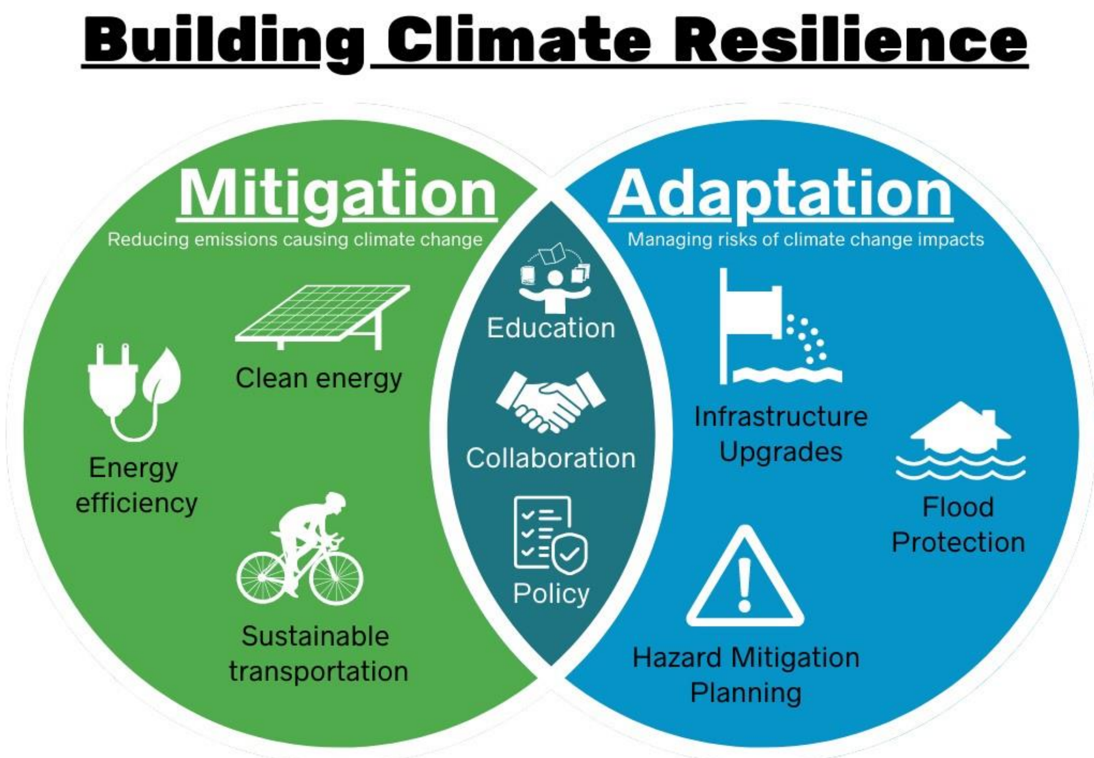
Figure 1.6: Report cover



Roadway adaptation: An entry point for climate planning

While the need to address climate change is urgent, the scale of the problem can be overwhelming. By working together to address shared interests in protecting our roadway networks, the SNHPC region can lay the groundwork for future collaboration on more comprehensive climate planning efforts that address **adaptation**, or actions to manage the risks associated with climate change, as well as **mitigation**, or actions to reduce emissions that contribute to climate change. As Figure 1.7 shows, both adaptation and mitigation strategies across a variety of sectors are necessary to foster **resilience**, which refers to a state in which our communities can survive and thrive in the face of climate change.

Figure 1.7: Building climate resilience



In April 2023, SNHPC hosted an inaugural regional climate planning workshop at the Derry Municipal Center. (See Figure 1.8.) The event brought together municipal officials, regional stakeholders, and state and national experts to discuss key opportunities for adapting our roadways in the face of climate change. A keynote speaker from the Federal Highway Administration shared remarks that reflect the agency's commitment to invest in resilience. Contributions from the workshop have been incorporated throughout this toolkit. SNHPC is committed to continue hosting similar events to further climate leadership and action in our region.

Figure 1.8: 2023 Regional climate workshop

"Extreme weather, sea level change, and changes in environmental conditions threaten the considerable federal investment in transportation infrastructure. FHWA is working with States and metropolitan areas to increase the health and longevity of the Nation's Highways through: assessing vulnerabilities, considering resilience in the transportation planning process, and addressing resilience in project development and design."
– Federal Highway Administration

Since **climate impacts** don't recognize municipal boundaries, SNHPC embraces its role in advancing regional and statewide collaboration to coordinate effective action—supporting opportunities to streamline efforts and pool resources related to funding, data, public outreach and more. Climate change is already here, and SNHPC is working quickly to support the region in responding.

CHAPTER 2 - Technical Analysis: Corridor-Level Vulnerability

SNHPC's 2020 Regional Vulnerability Assessment (RVA) established a strong foundation to strategically assess and prioritize the vulnerability of individual stream crossings in our region. This Climate Action Toolkit expands upon that analysis to incorporate further insights, including:

- **Additional vulnerabilities**. Extending beyond bridges and culverts, the following analysis also assesses vulnerabilities related to **steep slopes** and flood prone areas.
- **A corridor-level approach**. The following analysis explores vulnerability at the corridor level, which allows for an examination of multiple vulnerabilities along a given route. For example, this data can be used to identify a route with a high density of stream crossings, which may also intersect flood prone areas or abut a steep slope. SNHPC has found that a broader frame of analysis allows for a more holistic understanding of a corridor's relative vulnerability, and can support a more integrated, systemwide approach to regional transportation planning.

This chapter applies a step-by-step approach to understand how various types of vulnerabilities impact our transportation network at the corridor level:

Part A describes the frame of analysis, which includes all federal-aid roads in our region

Part B provides an updated approach to assessing and prioritizing individual stream crossings

Part C introduces the corridor-level assessment with subsections for each analyzed vulnerability:

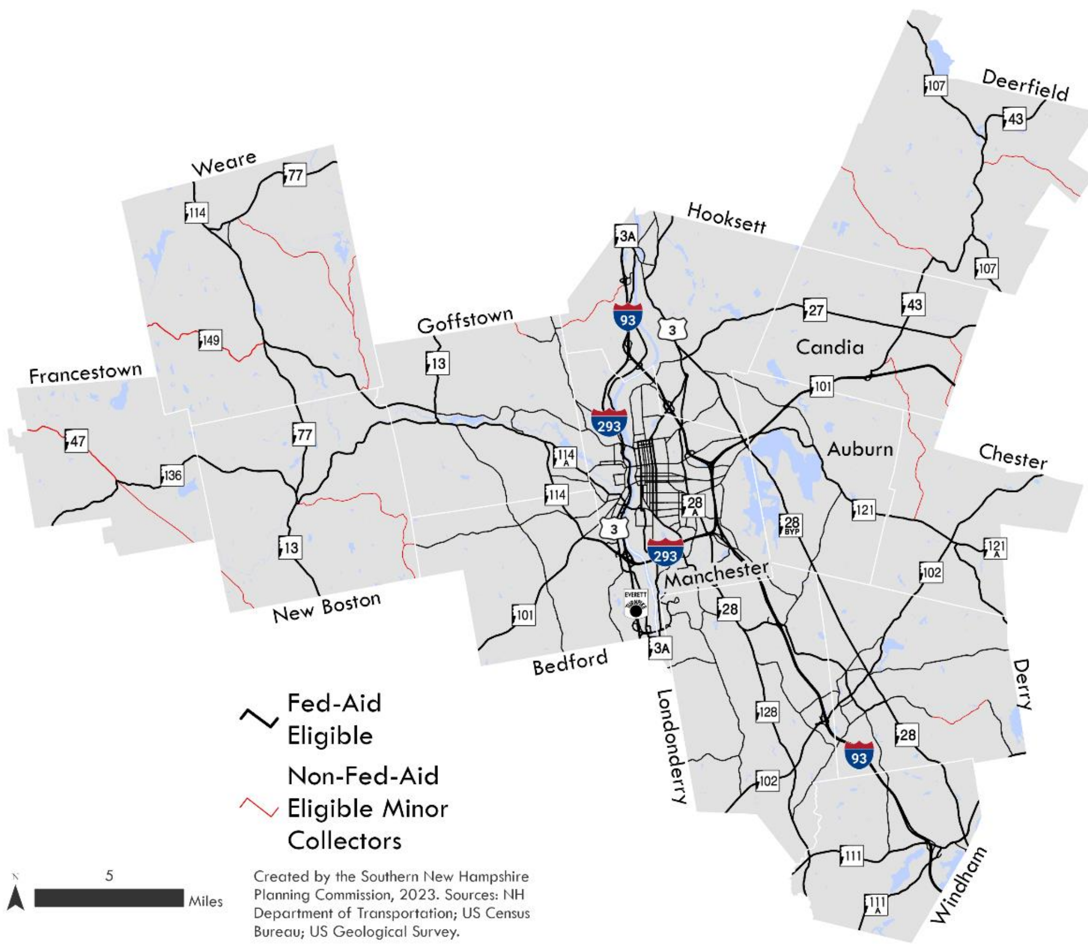
- C.1 prioritizes corridors based on stream crossing density and vulnerability score
- C.2 prioritizes corridors based on proximity to flood zones and identified flood hazards
- C.3 prioritizes corridors based on proximity to steep slopes

Part D synthesizes our current understanding of the region's most vulnerable corridors in terms of stream crossing density, proximity to flooding, and steep slopes.

A. Frame of Analysis: Federal-Aid Roads

This corridor-level vulnerability assessment focuses on **federal-aid roads** (fed-aid) in the region, which are eligible for federal financial assistance to support construction, maintenance, and operations. There are approximately 1,200 federal-aid eligible lane-miles in the SNHPC region, of which 530 are National Highway System (NHS) roadways. (See Figure 2.1.) In terms of Federal functional classification, 280 lane-miles are interstates, 50 are principal arterials (other freeways and expressways), 190 are other principal arterials, 290 are minor arterials, 390 are major collectors, and 2 are local roads that are part of the NHS.[7]

Figure 2.1: Fed-aid roads in the SNHPC region



[7] NH Department of Transportation

B. Prioritizing Stream Crossing Vulnerability: An Updated Approach

SNHPC's 2023 prioritization of stream crossings differs from the one carried out in the 2020 RVA in several ways:

Table 2-1: Stream crossing scoring rubric

AADT	Scored 0 to 5 with 0 representing zero AADT and 5 representing the highest AADT among the scored stream crossings	
Structural Condition	5 =	Poor condition or on bridge redlist
	2.5 =	Fair condition
	0 =	Good condition
10-Year Hydraulic Vulnerability	5 =	Overtop
	4 =	Vulnerable
	2 =	Unknown
	0 =	Pass or not applicable
Geomorphic Compatibility	5 =	Fully incompatible
	4 =	Mostly incompatible
	3 =	Unknown
	2 =	Partially compatible
	1 =	Mostly compatible
	0 =	Fully compatible or not applicable
Flooding	5 =	FEMA floodway
	4 =	FEMA 1% chance annual flood zone or hazard mitigation plan identified flood hazard
	3 =	FEMA 0.2% chance annual flood zone
	0 =	FEMA minimal flood risk flood zone

First, given the frame of analysis, only stream crossings within 200 feet of the centerline of a fed-aid road are considered. The 200-foot buffer accounts for potential inconsistencies in geographic data. All public roads are fed-aid except for rural minor collectors and local roads. Within the SNHPC region, all state-numbered routes are fed-aid with the exceptions of NH-47 and NH-149.

Second, the analysis excludes National Bridge Inventory bridges, or bridges 20 feet or more in length, unless they have been characterized as vulnerable or have failed under a 100-year flooding test. This was done to prevent large, high-volume bridges from skewing the analysis.

Third, the scoring rubric has been redesigned to apply uniform weighting to each scoring variable and avoid the potential for double-counting certain variables. For example, under "Flooding," FEMA flood zone data has been combined with flood hazard data from local hazard mitigation plans to avoid double-counting flood vulnerability features.

The new scoring rubric (see Table 2-1) uses today's best available information to calculate the vulnerability of individual stream crossings in our region according to five key indicators:

1. The **average annual daily traffic (AADT) score** captures the relative importance of a roadway to the overall network based on the number of vehicles it carries. A score of 0 to 5 is assigned proportionally based on the highest

AADT at a stream crossing site. Sites with the highest AADT receive a score of 5 to indicate a higher risk associated with failure. Sites with the least traffic volume receive a score of 0. For example, stream crossing 12701 on I-93 in Windham typically has more than 40,000 vehicles cross it daily and receives an AADT score of 4.9. On the other hand, stream crossing 6702 which spans Watts Brook in Londonderry only sees around 1,900 vehicles a day and receives a score of 0.2.

2. The **structural condition score** may be derived from multiple sources, including data gathered by field survey teams as well as data from bridge inventories completed by professional engineers. When both types of data are available, greater weight is given to the bridge inventory score. Sites with the poorest structural condition receive a 5 to indicate a higher risk of failure. These include state- and municipally-owned **red list bridges** that require more frequent inspections due to their poor condition. Stream crossings in fair condition receive a score of 2.5, while those in good condition receive a score of 0.

3. **10-year hydraulic vulnerability** describes how well a stream crossing transports water flows during storm events and indicates at what point flood water will overwhelm a stream crossing.[8] This metric uses a 10-year (10% annual chance) flood event as its benchmark based on historic precipitation. Stream crossings that fail and overtop received a score of 5. Those that are vulnerable receive a score of 4. Stream crossings where the vulnerability is unknown receive a score of 2. Those that pass a 10-year event or are not applicable receive a score of 0. (See Figure 2.2.)

Figure 2.2: Visualizing hydraulic vulnerability

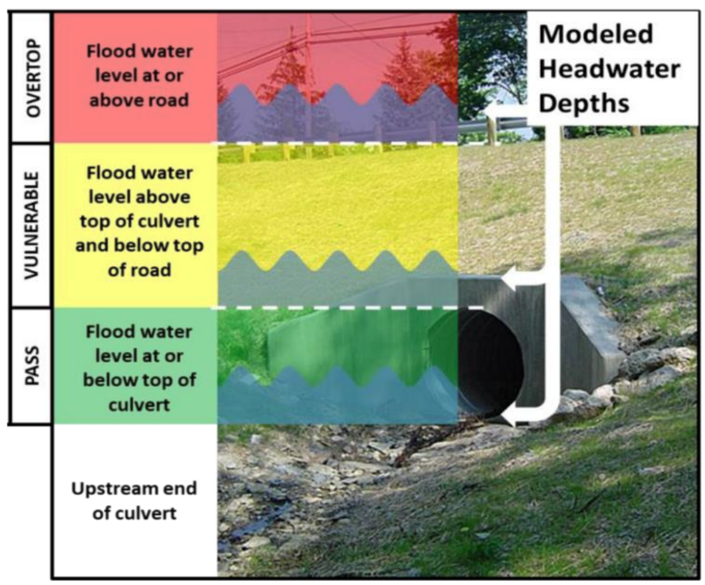


Image courtesy of NHDES

4. **Geomorphic compatibility** refers to "the long-term compatibility of a stream crossing with river channel form and sediment transport."[9] This is determined by the alignment, width, and slope of a stream crossing relative to the channel it is serving, as assessed by

[8] See NH Department of Environmental Services, "Hydraulic Vulnerability and Flood Resiliency."
[9] See NH Department of Environmental Services, "Geomorphic Compatibility."

field survey teams. Geomorphic compatibility of stream crossings is rated on a scale of 0-5, with those that are fully incompatible receiving a 5, as they are most likely to fail over time.

5. **Flooding** is the final measure considered, using data from FEMA as well as areas identified as flood hazards in local hazard mitigation plans. Stream crossings within 200 feet of a FEMA **floodway** receive a score of 5 to indicate the highest level of vulnerability. A floodway refers to the channel of a river or other watercourse as well as adjacent land areas that must be reserved for flood discharge. This special designation comes with additional regulations. Stream crossings within 200 feet of a FEMA 1% chance annual **flood zone** (excluding floodway areas), and/or a locally-identified flood hazard area receive a score of 4. Stream crossings within 200 ft of a FEMA 0.2% annual chance flood zone receive a score of 3. All other stream crossings receive a score of 0.

Regionwide, a total of 364 stream crossings meet the criteria for prioritization. The distribution of vulnerability scores is shown in Figure 2.3, and a map of scored stream crossings is shown in Figure 2.4. Out of a possible score of 25 (indicating the greatest possible risk), the highest scoring is crossing #5926 on Parmenter Rd in Londonderry with a score of 19.9. While Parmenter Rd itself is not a fed-aid eligible roadway, the stream crossing sits very close to the intersection with NH-102 and may potentially be addressed through future improvements to NH-102. The second highest scoring is N High St in Derry with a score of 18.3.

Figure 2.3: Distribution of stream crossing vulnerability scores

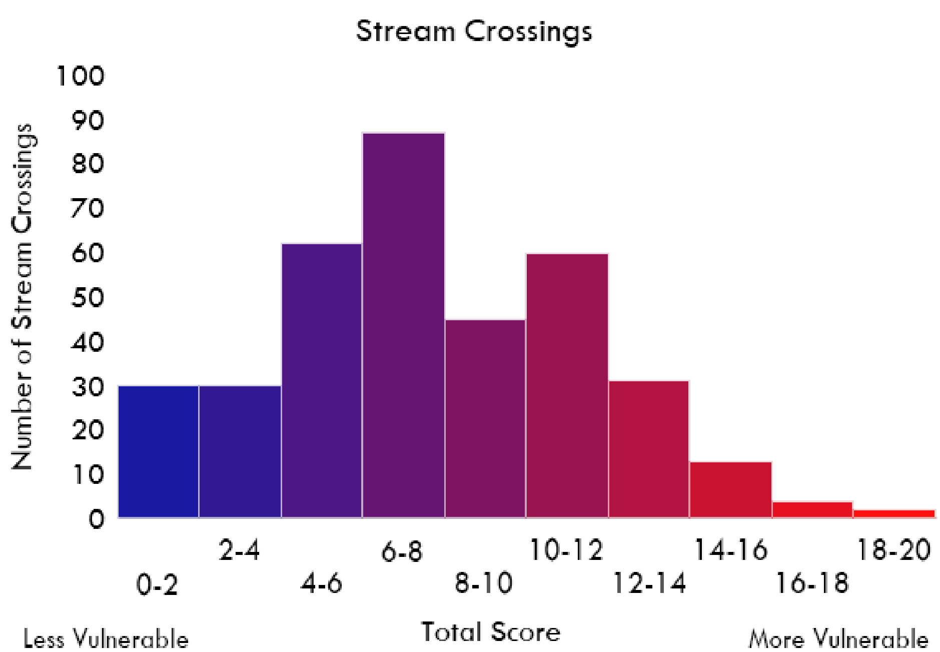
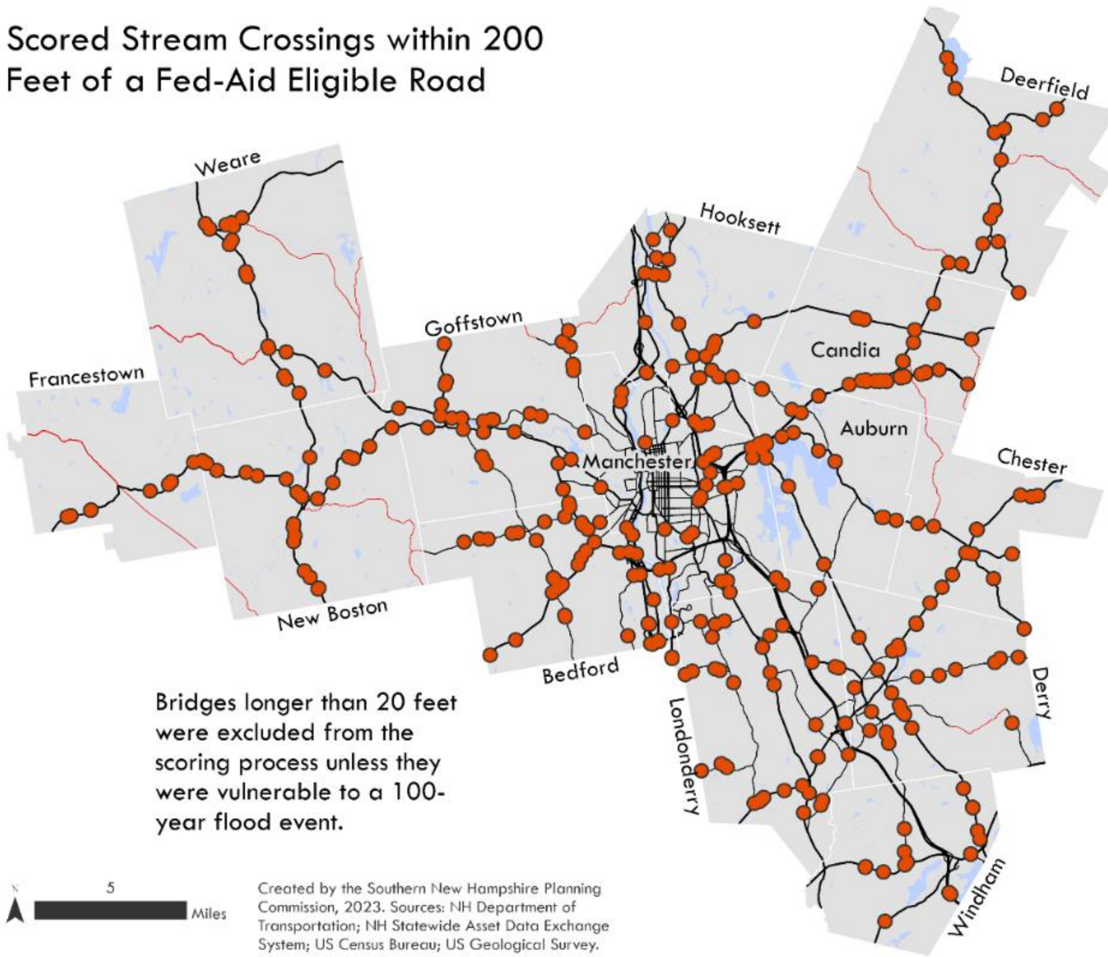


Figure 2.4: Map of prioritized stream crossings



A sample vulnerability calculation is shown below, for a stream crossing on NH-3A in Hooksett. (See Figure 2.5 and Table 2-2.)

Figure 2.5: Site #10248 in Hooksett

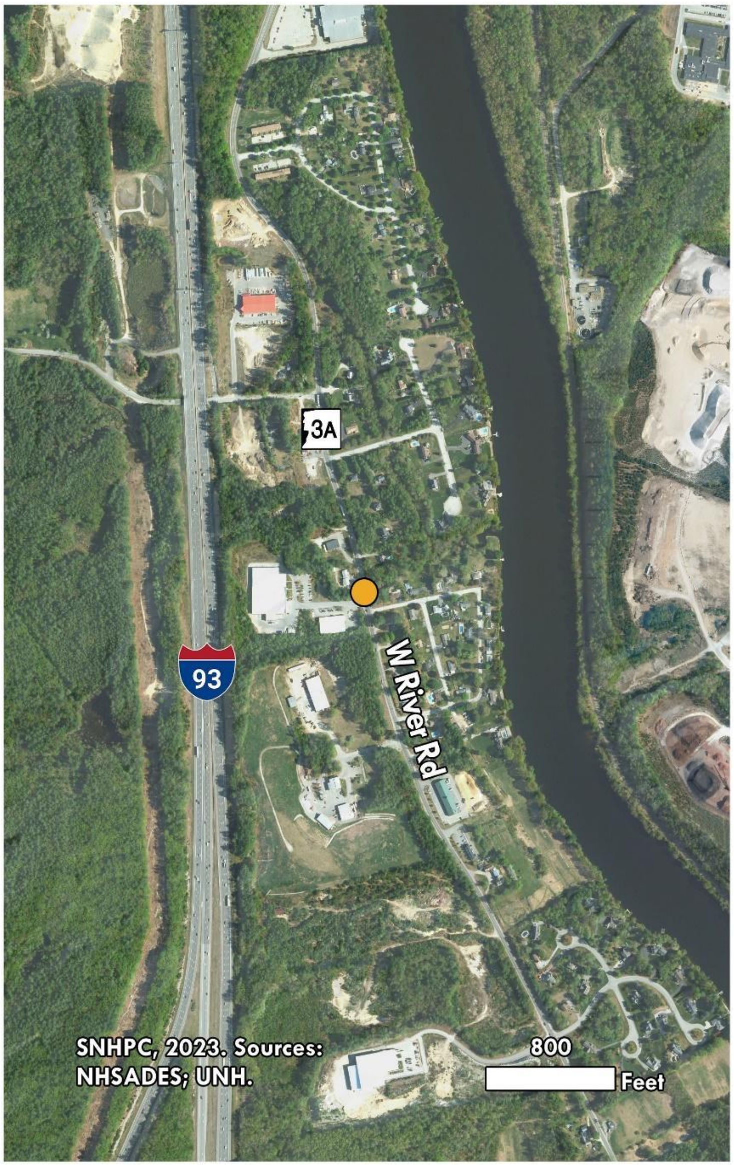


Table 2-2: SADES ID 10248		
Municipality	Hooksett	
Facility	W River Rd	
AADT	20,700	2.3
Structural Condition	Fair	2.5
10-Year Hydraulic Vulnerability	Overtop	5
Geomorphic Compatibility	Partially Compatible	2
Flooding	1% Chance Annual Flood Zone	4
Total Score	**15.8**	

Identifying the region's highest-scoring stream crossings

Table 2-3 shows the top 20 highest-scoring (i.e. most vulnerable) stream crossings regionwide along with their locations and ownership information. While a total of 22 projects are listed, the two shown in blue could arguably be removed for reasons indicated at the bottom of the table. However, they were left in to ensure full transparency.

Table 2-4 provides the same information sorted alphabetically by community. As the data shows, ten communities in the region have at least one site on the list, and seven communities have two or more sites. Four communities don't have any sites in the top 20 list: Auburn, Francestown, New Boston and Weare.

***For further details and additional tables, see Appendix B.** It includes a page for each municipality that shows the top five highest scoring stream crossings, as well as the top five highest scoring locally-managed stream crossings.

Table 2-3: Top 20 highest scoring stream crossings regionwide

SADES ID	Town	Facility	Route	Address	Longitude	Latitude	Crosses Fed-Aid Road	Ownership	Total Score
5926	Londonderry	Parmenter Rd		12 Parmenter Rd	-71.393	42.8361	No	Londonderry	19.9
6232*	Derry	N High St		94 N High St	-71.332	42.8897	Yes	Derry	18.3
2743	Deerfield	Raymond Rd	NH-107	53 Raymond Rd	-71.239	43.1193	Yes	NHDOT	17.8
12603	Manchester	Candia Rd		1163 Candia Rd	-71.408	42.9884	Yes	Manchester	17.6
8911	Goffstown	E Dunbarton Rd		350 E Dunbarton Rd	-71.517	43.0544	Yes	Goffstown	17.2
191	Bedford	NH Route 114	NH-114	Old Bedford Rd	-71.506	42.9665	Yes	NHDOT	16.8
5927	Londonderry	Nashua Rd	NH-102	316 Nashua Rd	-71.394	42.8352	Yes	NHDOT	15.9
10248	Hooksett	W River Rd	NH-3A	226 W River Rd	-71.468	43.0659	Yes	NHDOT	15.8
149	Deerfield	Raymond Rd	NH-107	71 Raymond Rd	-71.242	43.1154	Yes	NHDOT	15.8
5469	Candia	Old Candia Rd	NH-43	51 Old Candia Rd	-71.293	43.0558	Yes	NHDOT	15.5
5994	Derry	Windham Rd		48 Windham Rd	-71.31	42.8631	Yes	Derry	15.5
5930	Londonderry	Nashua Rd	NH-102	302 Nashua Rd	-71.392	42.8371	Yes	NHDOT	15.4
10887	Hooksett	Pleasant St		28 Pleasant St	-71.451	43.1103	Yes	NHDOT	15.2
8916	Goffstown	Wallace Rd		183 Wallace Rd	-71.575	43.0015	Yes	Goffstown	14.9
7199	Windham	Rockingham Rd	NH-28	64 Rockingham Rd	-71.252	42.8206	Yes	NHDOT	14.8
5995	Derry	Sunset Ave		1 Sunset Ave	-71.311	42.8684	No	Derry	14.5
19728**	Manchester	CSX Railroad		400 Gay St	-71.459	42.947	No	NHDOT	14.4
200	Derry	Chester Rd	NH-102	76 Chester Rd	-71.303	42.9082	Yes	NHDOT	14.4
6022	Deerfield	North Rd	NH-107	340 North Rd	-71.264	43.1779	Yes	NHDOT	14.4
6774	Chester	Derry Rd	NH-102	220 Derry Rd	-71.268	42.944	Yes	NHDOT	13.9
12551	Hooksett	Auburn Rd		47 Auburn Rd	-71.411	43.0395	Yes	Hooksett	13.8
9118	Bedford	New Boston Rd		NH Route 114	-71.509	42.9687	Yes	NHDOT	13.8

*Culvert to be replaced as part of the construction of I-93 Exit 4A.

**Railroad bed. Close proximity to I-293 but significant grade separation severely limits interaction.

Table 2-4: Top 20 highest scoring stream crossings regionwide (sorted by municipality)

SADES ID	Town	Facility	Route	Address	Longitude	Latitude	Crosses Fed-Aid Road	Ownership	Total Score
191	Bedford	NH Route 114	NH-114	Old Bedford Rd	-71.5058	42.9665	Yes	NHDOT	16.8
9118	Bedford	New Boston Rd		NH Route 114	-71.5091	42.9687	Yes	NHDOT	13.8
5469	Candia	Old Candia Rd	NH-43	51 Old Candia Rd	-71.2925	43.0558	Yes	NHDOT	15.5
6774	Chester	Derry Rd	NH-102	220 Derry Rd	-71.2679	42.944	Yes	NHDOT	13.9
2743	Deerfield	Raymond Rd	NH-107	53 Raymond Rd	-71.2386	43.1193	Yes	NHDOT	17.8
149	Deerfield	Raymond Rd	NH-107	71 Raymond Rd	-71.2417	43.1154	Yes	NHDOT	15.8
6022	Deerfield	North Rd	NH-107	340 North Rd	-71.2643	43.1779	Yes	NHDOT	14.4
6232*	Derry	N High St		94 N High St	-71.3319	42.8897	Yes	Derry	18.3
5994	Derry	Windham Rd		48 Windham Rd	-71.3097	42.8631	Yes	Derry	15.5
5995	Derry	Sunset Ave		1 Sunset Ave	-71.3112	42.8684	No	Derry	14.5
200	Derry	Chester Rd	NH-102	76 Chester Rd	-71.3027	42.9082	Yes	NHDOT	14.4
8911	Goffstown	E Dunbarton Rd		350 E Dunbarton Rd	-71.517	43.0544	Yes	Goffstown	17.2
8916	Goffstown	Wallace Rd		183 Wallace Rd	-71.575	43.0015	Yes	Goffstown	14.9
10248	Hooksett	W River Rd	NH-3A	226 W River Rd	-71.4678	43.0659	Yes	NHDOT	15.8
10887	Hooksett	Pleasant St		28 Pleasant St	-71.4513	43.1103	Yes	NHDOT	15.2
12551	Hooksett	Auburn Rd		47 Auburn Rd	-71.411	43.0395	Yes	Hooksett	13.8
5926	Londonderry	Parmenter Rd		12 Parmenter Rd	-71.3928	42.8361	No	Londonderry	19.9
5927	Londonderry	Nashua Rd	NH-102	316 Nashua Rd	-71.3942	42.8352	Yes	NHDOT	15.9
5930	Londonderry	Nashua Rd	NH-102	302 Nashua Rd	-71.3915	42.8371	Yes	NHDOT	15.4
12603	Manchester	Candia Rd		1163 Candia Rd	-71.408	42.9884	Yes	Manchester	17.6
19728**	Manchester	CSX Railroad		400 Gay St	-71.4588	42.947	No	NHDOT	14.4
7199	Windham	Rockingham Rd	NH-28	64 Rockingham Rd	-71.2522	42.8206	Yes	NHDOT	14.8

*Culvert to be replaced as part of the construction of I-93 Exit 4A.

**Railroad bed. Close proximity to I-293 but significant grade separation severely limits interaction.

C. Prioritizing Vulnerability at the Corridor Level

While site-level prioritization of stream crossings offers valuable information, it can be very helpful to understand vulnerability at the corridor level in order to better plan and manage our transportation network as a whole. This section details the vulnerability of regional corridors with regard to stream crossings, flood hazards, and steep slopes.

For the purpose of this analysis, a corridor can be thought of as a labeled State or Federal route in our region. Of the 23 labeled routes within the SNHPC region, three are limited-access expressways for their entire extent, and under the control of NHDOT: the F.E. Everett Turnpike (F.E.E.T.), I-93, and I-293. NH-101 is a limited-access expressway from Hampton (outside of the SNHPC region) into Candia, then Chester and Auburn, eventually into Bedford where it transitions to a non-expressway principal arterial; the two sections are considered separately in this analysis. Note, two state routes, NH-47 and NH-149 are currently designated as rural minor collectors and are therefore not federal-aid eligible and do not appear in this analysis.

C.1 Prioritizing corridors: Stream crossing density and vulnerability

One way to prioritize corridors is by considering the relative density and vulnerability of nearby stream crossings. Consider a scenario with two hypothetical corridors, Route A and Route B, which are approximately the same length. Route A has ten stream crossings but none are particularly vulnerable. In contrast, Route B has just three crossings but all of them are highly vulnerable. There is value in knowing that Route A has a higher **stream crossing density**, since crossings could still fail and must be managed. However, it is also valuable to highlight the **aggregate vulnerability** of Route B which, because its stream crossings are more vulnerable, is at higher risk as a corridor when compared to Route A. (See Figure 2.6.)

Figure 2.6: Calculating stream crossing density and aggregate vulnerability

$$\text{Stream Crossing Density} = \frac{\text{Number of Stream Crossings}}{\text{Linear-Miles}}$$

$$\text{Aggregate Stream Crossing Vulnerability} = \frac{\text{Combined Vulnerability Scores}}{\text{Linear-Miles}}$$

Table 2-5 applies these calculations to the SNHPC region. The first portion ranks each corridor based on stream crossing density. It sums the number of stream crossings within 200 feet while dividing by the total length of the corridor in order to determine the density of stream crossings. The results are then reclassified with the highest density redesignated as 100. The second portion looks at aggregate vulnerability, which sums the combined vulnerability scores of the crossings within 200 feet of each corridor, divides by corridor length, and reclassifies each corridor on a 100-point scale.

In terms of stream crossing density, the Everett Turnpike, both the expressway and non-expressway portions of NH-101, and NH-102 all score significantly higher than other corridors. Their priority order changes slightly when aggregate stream crossing vulnerability scores are taken into account. Other corridors that score higher for stream crossing density include NH-136, NH-13, and NH-114. Among these, NH-114 also scores higher for aggregate stream crossing vulnerability.

Table 2-5: Priority corridors by stream crossing density and aggregate vulnerability

Priority Corridors: Stream Crossing Density 0 to 100 With 100 Being the Highest	
F.E.E.T.	100
NH-101 (Expressway)	85
NH-101 (Non-Expressway)	79
NH-102	73
NH-136	66
NH-13	58
NH-114	58
NH-28A	55
NH-43	53
NH-121	48
NH-107	46
NH-77	42
NH-111	41
NH-28	40
NH-3A	37
NH-27	35
US-3	34
NH-128	33
NH-28B	29
NH-121A	20
NH-114A	17
NH-111A	8
I-293	6
I-93	5

Priority Corridors: Aggregate Vulnerability 0 to 100 With 100 Being the Highest	
F.E.E.T.	100
NH-101 (Non-Expressway)	69
NH-101 (Expressway)	67
NH-102	58
NH-114	43
NH-43	39
NH-107	35
NH-28A	35
NH-3A	33
NH-28	32
NH-136	29
US-3	25
NH-77	24
NH-27	24
NH-111	24
NH-121	24
NH-13	23
NH-128	22
NH-114A	18
NH-28B	18
I-293	7
NH-111A	6
I-93	4
NH-121A	2

Breaking down corridor segments by municipality can reveal new priorities as well as variability along a corridor. The graphic below examines aggregate stream crossing vulnerability for non-expressway routes by town. Previous top scorers NH-101 and NH-102 are greatly overshadowed by the segment of NH-114 in Bedford. This acute vulnerability is lost when the corridor is examined as a whole because the other segments of NH-114 are much less vulnerable. Other segments that stand out as more vulnerable in a municipal-level analysis include NH-28 in Windham and NH-28A in Hooksett.

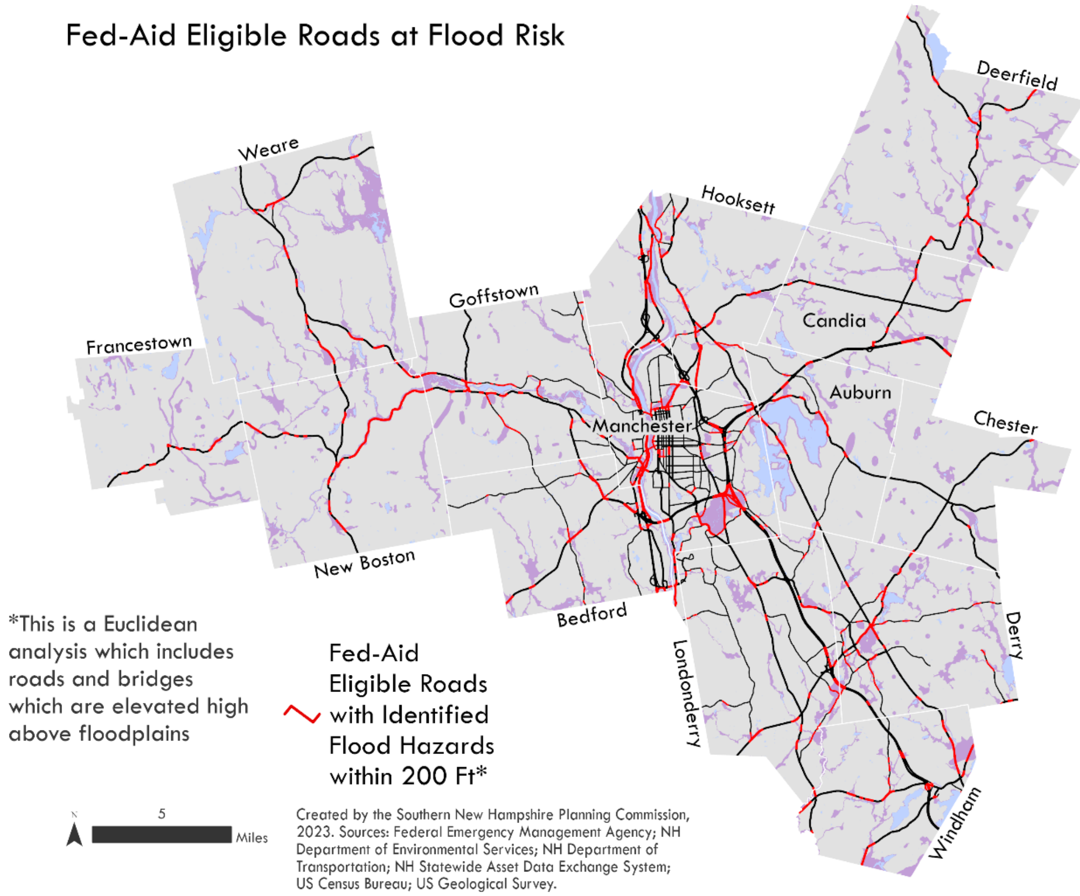
Table 2-6: Non-expressway state route priorities based on aggregate stream crossing vulnerability*

Route	Municipality	Score
NH-101 (Non-Expressway)	Bedford	30
NH-102	Chester	21
NH-102	Derry	16
NH-102	Londonderry	38
NH-107	Deerfield	15
NH-111	Derry	N/A
NH-111	Windham	11
NH-111A	Windham	2
NH-121	Auburn	12
NH-121	Chester	5
NH-121	Derry	N/A
NH-121	Manchester	N/A
NH-121A	Chester	1
NH-128	Londonderry	12
NH-128	Windham	0
NH-13	Goffstown	4
NH-13	New Boston	13
NH-28	Derry	9
NH-28	Londonderry	19
NH-28	Manchester	3
NH-28	Windham	44
NH-28A	Hooksett	40
NH-28A	Londonderry	N/A
NH-28A	Manchester	8
NH-28B	Auburn	7
NH-28B	Derry	13
NH-28B	Hooksett	3
NH-28B	Manchester	N/A
NH-77	New Boston	5
NH-77	Weare	12
US-3	Bedford	19
US-3	Hooksett	10
US-3	Manchester	4
NH-114	Bedford	100
NH-114	Goffstown	14
NH-114	New Boston	0
NH-114	Weare	3
NH-114A	Goffstown	15
NH-114A	Manchester	0
NH-136	Francestown	9
NH-136	New Boston	17
NH-27	Candia	9
NH-27	Hooksett	12
NH-3A	Hooksett	17
NH-3A	Manchester	12
NH-43	Candia	24
NH-43	Deerfield	14

*Corridors less than 1 miles excluded.

C.2 Prioritizing corridors: Flooding vulnerability

Figure 2.7: Fed-aid eligible roads at flood risk



Approximately 130 linear-miles and 270 lane-miles in the SNHPC region are within 200 feet of a FEMA flood zone or a flood hazard identified in a hazard mitigation plan.[10] As shown in Table 2-7, NH-13, NH-3A, and I-293 all have more than 1/5 of their total roadways within 200 feet of a flood prone area. This is not surprising as they parallel rivers for much of their routes. NH-28A also scores high since its entire route was flagged as a flood hazard area in the Hooksett hazard mitigation plan. Other hotspots include NH-111, NH-114A, NH-43, and the non-expressway segment of NH-101.

One significant limitation to this analysis is that it is two-dimensional, and does not account for elevation. Unfortunately, available road data for New Hampshire does not include any information on the height of the road. In other words, certain bridges and roads may technically cross or be adjacent to flood zones, but in reality are elevated to an extent that they

[10] Federal Emergency Management Agency, NH Department of Environmental Services, NH Department of Transportation

are not actually vulnerable to flooding. Therefore, verification by local staff is needed to accurately assess flood risk and vulnerability.

Table 2-7: Priority corridors by flood risk

	% of the Route in the Region Within 200 Feet of a Flood Zone or Flood Hazard
NH-13	30%
NH-3A	22%
I-293	22%
NH-28A	16%
NH-111	14%
NH-114A	12%
NH-43	11%
NH-101 (Non-Expressway)	11%
NH-28	10%
NH-107	10%
US-3	10%
NH-136	10%
NH-121	10%
NH-28B	10%
NH-102	10%
NH-114	9%
I-93	8%
NH-111A	7%
NH-77	7%
NH-27	6%
NH-101 (Expressway)	5%
NH-128	4%
FEET	1%
NH-121A	0%

Sources: Federal Emergency Management Agency; NH Department of Environmental Services; NH Department of Transportation.

Similar to the stream crossing analysis, looking at the corridor segments by municipality produces new insights. (See Table 2-8.) For example, NH-13 has the highest percentage near a flood prone area for the full length of the corridor, but a significant majority of that vulnerability is located within the New Boston segment. Five other segments have at least 20% of their immediate area proximate to a flood zone: NH-114 in Bedford, NH-114A in Manchester, NH-28 in Windham, NH-28A in Hooksett, and NH-3A in Hooksett. In each of these cases, the corridor segments score much higher than the same routes in neighboring towns.

Table 2-8: Percent of non-expressway routes in each municipality within 200 feet of a flood zone or flood hazard*

Route	Municipality	Percent
NH-101 (Non-Expressway)	Bedford	11%
NH-102	Chester	2%
NH-102	Derry	16%
NH-102	Londonderry	12%
NH-107	Deerfield	10%
NH-111	Derry	N/A
NH-111	Windham	15%
NH-111A	Windham	7%
NH-114	Bedford	24%
NH-114	Goffstown	9%
NH-114	New Boston	9%
NH-114	Weare	4%
NH-114A	Goffstown	3%
NH-114A	Manchester	21%
NH-121	Auburn	19%
NH-121	Chester	0%
NH-121	Derry	N/A
NH-121	Manchester	N/A
NH-121A	Chester	0%
NH-128	Londonderry	3%
NH-128	Windham	10%
NH-13	Goffstown	8%
NH-13	New Boston	42%
NH-136	Francestown	11%
NH-136	New Boston	8%
NH-27	Candia	3%
NH-27	Hooksett	10%
NH-28	Derry	4%
NH-28	Londonderry	8%
NH-28	Manchester	11%
NH-28	Windham	25%
NH-28A	Hooksett	27%
NH-28A	Londonderry	N/A
NH-28A	Manchester	13%
NH-28B	Auburn	15%
NH-28B	Derry	8%
NH-28B	Hooksett	5%
NH-28B	Manchester	N/A
NH-3A	Hooksett	33%
NH-3A	Manchester	14%
NH-43	Candia	9%
NH-43	Deerfield	12%
NH-77	New Boston	5%
NH-77	Weare	8%
US-3	Bedford	4%
US-3	Hooksett	11%
US-3	Manchester	12%

*Corridors less than 1 mile excluded. Sources: Federal Emergency Management Agency; NH Department of Environmental Services; NH Department of Transportation.

C.3 Prioritizing corridors: Steep slopes

Steep slopes can be defined as hillsides that have a 25-foot vertical rise or greater for every 100 feet of horizontal run, or in other words, have at least a 25% slope. (See Figure 2.8.) Steep slopes can be particularly dangerous in flood events, when rapid water flows increase the danger of flash floods, washouts, and water pollution.[11]

Figure 2.8: Example of a steep slope on NH-111 in Windham

Image courtesy of Google Maps, 2023.

Steep slopes are relatively rare within the region, generally found along riverbanks or more specifically in Francestown around Crotched Mountain. Steep slopes are also prominent around I-93; however, this is generally to be expected as large earthwork projects are part of building limited-access expressways to ensure they are moderately straight and flat. Other expressways, like the I-293, and NH-101 also have high levels of steep slopes in their immediate proximity. These high numbers should be treated with caution as they likely reflect steep slopes that are planned, carefully engineered, and more closely monitored.

More concerning are those non-limited access expressways with more than 10% of their area abutting steep slopes. Table 2-9 shows the prevalence of steep slopes for each corridor in the region. NH-3A has the highest percentage for all routes, among both expressway and non-expressway routes. It is followed by NH-111, NH-77, NH-13, and NH-114. As previously noted, two of the routes, NH-3A and NH-13, parallel rivers for much of their extent. The higher rates

[11] Southern Tier Central Regional Planning & Development Board, "Water Runs Downhill: Managing Runoff on Steep Slopes," 2021. https://www.stcplanning.org/wp-content/uploads/2021/07/WaterRunsDownhill_Guidance.pdf

for NH-111, NH-77 and NH-114 likely reflect more hilly terrain and substantial earthwork on NH-111 around the new I-93 Exit 3.

Table 2-9: Priority corridors by steep slope prevalence

	% of the Area within 200 Feet of a Route Which Is 25% or Steeper
NH-3A	19%
I-93	18%
I-293	18%
NH-101 (Expressway)	15%
NH-111	14%
NH-77	13%
NH-13	12%
NH-114	11%
NH-101 (Non-Expressway)	9%
FEET	9%
NH-43	7%
NH-28B	7%
NH-136	7%
US-3	6%
NH-111A	6%
NH-107	6%
NH-102	6%
NH-121	5%
NH-28A	5%
NH-114A	5%
NH-28	5%
NH-121A	4%
NH-27	4%
NH-128	3%

Sources: NH Department of Transportation; University of NH.

The proportion of steep slopes can vary significantly along the same route between different towns. Table 2-10 provides a breakdown of routes by municipality. For example, along route NH-3A between Manchester and Hooksett, the percentage of area within 200 ft of roadway that has a 25% slope or steeper increases from 14 % to 24 %. Likewise, NH-13 features steep slopes for just 6% of its length in Goffstown, but that number rises to 15% in New Boston. Other hotspots include NH-111 in Windham, NH-114 in Bedford, New Boston, and Weare, and NH-77 in New Boston and Weare.

Table 2-10: Percent of non-Expressway routes in each municipality within 200 feet of a steep slope*

NH-101 (Non-Expressway)	
Bedford	9%

NH-102	
Chester	4%
Derry	6%
Londonderry	7%

NH-107	
Deerfield	6%

NH-111	
Derry	N/A
Windham	14%

NH-111A	
Windham	6%

NH-114	
Bedford	16%
Goffstown	9%
New Boston	18%
Weare	12%

NH-114A	
Goffstown	2%
Manchester	8%

NH-121	
Auburn	8%
Chester	3%
Derry	N/A
Manchester	N/A

NH-121A	
Chester	4%

NH-128	
Londonderry	3%
Windham	3%

NH-13	
Goffstown	6%
New Boston	15%

NH-136	
Francestown	7%
New Boston	7%

NH-27	
Candia	4%
Hooksett	4%

NH-28	
Derry	4%
Londonderry	7%
Manchester	3%
Windham	7%

NH-28A	
Hooksett	7%
Londonderry	N/A
Manchester	5%

NH-28B	
Auburn	8%
Derry	3%
Hooksett	10%
Manchester	N/A

NH-3A	
Hooksett	24%
Manchester	14%

NH-43	
Candia	8%
Deerfield	6%

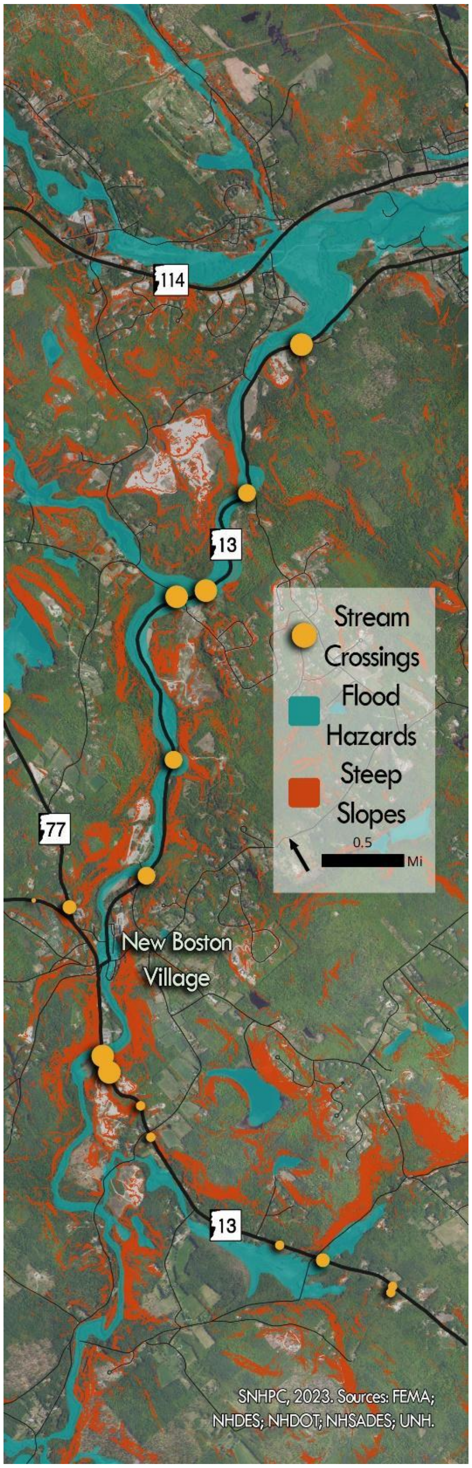
NH-77	
New Boston	12%
Weare	13%

US-3	
Bedford	7%
Hooksett	8%
Manchester	3%

*Corridors less than 1 mile excluded. Sources: NH Department of Transportation; University of NH.

D. Prioritizing Corridor Vulnerability: Putting it All Together

Figure 2.9: Visualizing vulnerabilities on NH-13 in New Boston



Data on stream crossings, flood risk, and steep slopes can be combined to offer a better understanding of the potential vulnerability of a corridor as a whole. As an example, Table 2-11 pulls out key data shown above for NH-13 in New Boston. The map in Figure 2.9 helps visualize where different types of vulnerabilities are overlapping.

Table 2-11: Vulnerability summary for NH-13 in New Boston

Type of vulnerability	Score	Risk assessment (relative to mean score)
Aggregate stream crossing vulnerability	13	Lower risk
Flooding vulnerability	42%	Higher risk
Steep slope vulnerability	15%	Moderate risk

As the data indicates, roadway adaptation efforts along NH-113 in New Boston should likely prioritize flooding vulnerabilities – for example by mitigating flood hazards, preserving wetlands and other natural areas, and integrating stormwater management solutions – while also remaining attentive to individual sites along the corridor that may be at higher risk due to steep slopes and/or stream crossing vulnerability.

Such findings point to the crucial importance of community context and local expertise in addressing the concerns that are most significant to a given corridor. Chapters 3 and 4 provide insights for taking a practical approach to adapting the region's roadways given the unique context of a particular corridor or community.

CHAPTER 3 - Menu of Strategies: Roadway Adaptation

Effective climate adaptation requires taking action to address a community's unique challenges and needs. This chapter outlines a menu of practical strategies that can be applied in our region and beyond to better prepare our road networks for an increasing risk of floods due to extreme precipitation.

Developing these strategies

To develop the strategy list, SNHPC conducted an extensive resource scan to examine a variety of reports, technical guides, plans, and white papers that address roadway adaptation. These resources were developed by a diverse array of organizations—including federal, state, and local government agencies; scientists and academic thought leaders; national non-profits; and professional associations. A full list of publications that informed this chapter can be found in Appendix A. Participants at SNHPC's 2023 regional climate workshop provided feedback on preliminary content, which was used to refine the menu of strategies.

Five key themes

Based on these contributions, this chapter organizes key roadway adaptation concepts according to five major themes:

A. Design & Engineering
B. Nature-based Solutions
C. Operations & Maintenance
D. Outreach & Collaboration
E. Data, Planning, & Policy

Each theme is discussed in further detail and illustrated with potential strategies, project examples, and practitioner insights.

It is important to note that the scale of intervention can vary markedly across the list of strategies—for example, a given strategy may address **site**-level concerns (e.g. upgrading a culvert), **corridor**-wide concerns (e.g. maintenance schedules), or even **systems** change in the way our communities and organizations operate day-to-day (e.g. policy adoption). For this reason, the anticipated scale(s) of intervention are notated for each strategy found in this chapter.

Since every vulnerable corridor and every community faces unique challenges, this menu of adaptation strategies provides an entry point for town staff and community leaders to identify what matters most to their community and take action to adapt their roadways in the face of climate-related threats. The chapter concludes with a "tear sheet" (see page 52-54) that summarizes all the strategies, which can be used as a simple checklist when undertaking a new roadway project or climate-related initiative.

A. Design & Engineering

Design and engineering are crucial tools to tackle roadway adaptation challenges at all scales, whether upgrading a particular bridge or culvert, or recalibrating design standards in response to evolving climate data.

Many communities want to "right-size" their roadway stream crossings to respond to existing flooding concerns and protect against the escalating intensity of future storms. While infrastructure adaptations may be costly in the short-term, they offer numerous benefits that can help save communities money in the long run. For example, upgraded culverts are associated with reduced maintenance needs, lower risks of road failure and flood damage to nearby properties, increased longevity of the **asset**, and preservation of water quality.

Accommodating higher water flow at one site can have downstream impacts for other parts of the community. For this reason, stream crossing upgrades should ideally be accompanied by corridor-wide and systems-scale strategies that establish a cohesive approach to managing roadway improvements.

Table 3-1: Design & engineering strategies

Strategy	Scale	Examples
A.1 Retrofit vulnerable sites to withstand extreme weather events	Site	• Culvert upgrades (e.g. improved hydraulic capacity / geomorphic compatibility) • Enhanced drainage design • Stream bank armoring • Riprap to prevent bridge scour • Rockfall barriers • Elevation of roadways or bridges • Improved stormwater detention
A.2 Model asset lifespan to account for climate hazards	Corridor / Systems	• Performance parameters for asset upgrades • Anticipating climate and land use changes
A.3 Update roadway design standards to reflect latest climate data	Systems	• Developing climate-resilient design guidelines / "climate-ready" standards • Applying updated precipitation models and asset risk assessments based on latest climate data • Updating design calculations and design requirements, including requirements for subdivisions (e.g. hydraulic capacity, flood frequency, stormwater management.)

"We need to start designing for the future now, even when resources are limited. Let's consider where we can start making incremental improvements, and establish a baseline that we can continue to build upon as new resources become available."
- Elizabeth Robidoux, Town of Hooksett

RESOURCE ALERT

- ***Curious about the basic principles of stream crossing design?*** Check out this training slide deck from the NH Department of Environmental Services, "Wetland Rules Training – Stream Crossings: Env-Wt 900." Accessed November 2023.

- ***Ready to dig into specific engineering recommendations?*** The Federal Highway Administration provides a wide array of resources and publications on hydraulic engineering, including *Highways in the River Environment: Roads, Rivers, and Floodplains, Second Edition, 2023.*

Topaz Drive: Restoring Geomorphic Compatibility on the Oyster River, Barrington, NH

The Nature Conservancy, NH Department of Environmental Services and the NH Fish and Game Department teamed up with the Emerald Acres Cooperative, a resident-owned community, to solve for the historic flooding of the only road into and out of the manufactured home cooperative. The project, which also restored passage for Species of Greatest Conservation Need such as the American Brook Lamprey, replaced an undersized, perched and failing corrugated metal culvert with a 50' bridge across the Oyster River. (See figure 3.1.) The new design allows the stream to flow naturally, accommodates higher volumes of water flow, and allows for both fish passage and dry passage on its banks for wildlife.

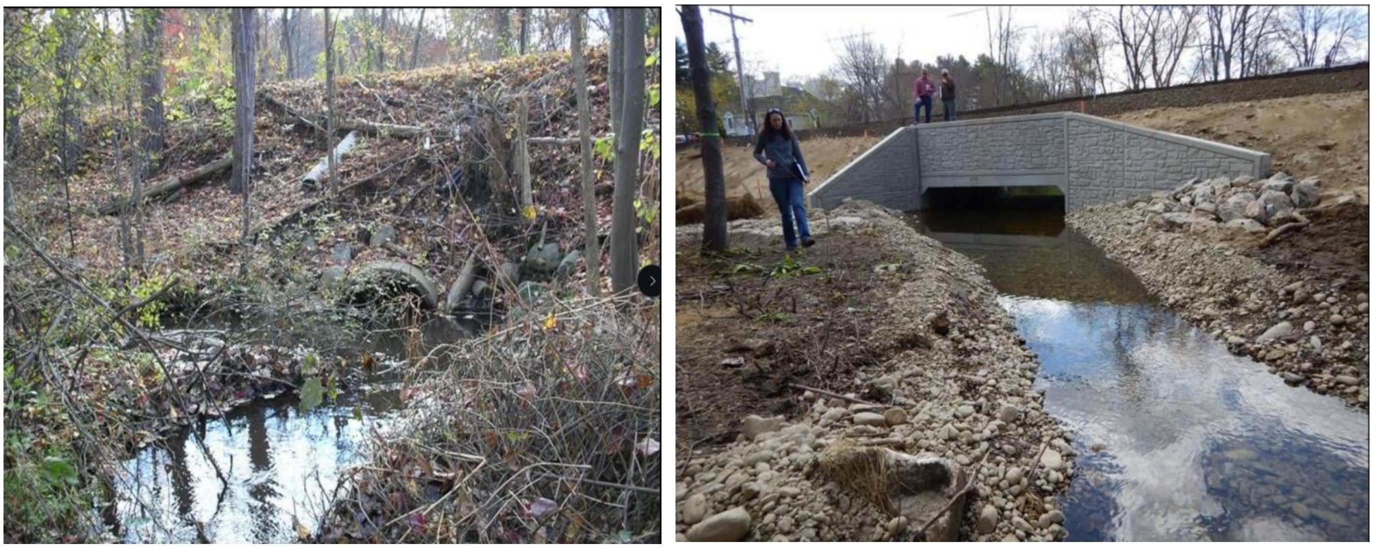
Figure 3.1: (TOP) Image of the original culvert under Topaz Drive
(BOTTOM): A new bridge spans a free-flowing Oyster River

Photos courtesy of The Nature Conservancy; © Jerry and Marcy Monkman/EcoPhotography

Culvert upgrade, Bedford NH

Multiple project partners, including the NH Rivers Council, NH Department of Environmental Services, and the Town of Bedford, worked together to upgrade an undersized culvert on McQuesten Brook that created a flood risk and hindered fish passage for Eastern Brook Trout. The new design reconnects wetland habitat and incorporates stormwater features to improve water quality. (See figure 3.2.) The project was funded in partnership with the NHDES ARM Fund.

Figure 3.2: (LEFT) Original culvert. (RIGHT) Enhanced stream crossing



Photos courtesy of the NH Stream Crossing Initiative, Stream Crossing Restoration: Success Stories across NH.

"We can't just look project by project, we also need to consider networks and systems. For example, when we set up detours due to flood conditions, it impacts the pavement life of detour roads that may not have been designed to handle high levels of traffic."
- Jo Sias, University of New Hampshire Center for Infrastructure Resilience to Climate

B. Nature-Based Solutions

Our natural environment can be a powerful ally in climate adaptation. By managing land use and development in a manner that preserves the functioning of natural ecosystems, communities can be better positioned to decrease stormwater runoff, prevent flooding, and protect infrastructure. The co-benefits of such **nature-based solutions** are plentiful, from protecting habitat resilience to enhancing human health.

Terms such as "nature-based solutions," "green infrastructure," "natural infrastructure," and "low impact development" are frequently used to describe strategies that are inspired by, and supported by, natural systems. When communities protect natural landscapes and effectively weave natural features into design and planning processes, they support a symbiotic relationship between human and ecological systems—which can be instrumental in responding to the pressures of a changing climate. For example, a conservation area that is protected from development can help sustain local ecosystems, while also providing critical flood storage capacity to reduce the impacts of extreme precipitation events.

It is important to remember that natural landscapes are also being shaped by climate change. For example, warmer temperatures can lead to an increase in invasive species, including pests that can put long-standing native habitats at risk. Given these trends, efforts to steward natural landscapes can be a key ingredient to fostering more resilient communities.

Table 3-2: Nature-based solutions strategies

Strategy	Scale	Examples
B.1 Preserve wetlands and floodplains to improve stormwater retention	Site / Corridor	• Right-of-way acquisitions for flood storage • Wetlands management strategy • Open space development requirements • Development setbacks from wetlands and natural resources
B.2 Improve river and stream environments	Site / Corridor	• Vegetated erosion control methods for riverbank protection and armoring • Re-naturalized streambeds • Infrastructure setbacks from river channels
B.3 Enhance stormwater management via green infrastructure / low impact development	Site / Corridor	• Bioretention ponds • Constructed wetlands • Vegetative swales • Infiltration trenches • Rain gardens • Permeable pavement • Stormwater planters and tree box filters • Street trees
B.4 Update vegetation control practices	Site / Corridor	• Management of invasive species • Planting flood-tolerant species

“Environment and infrastructure go hand in hand. Projects should be designed to minimize impacts to wetlands and floodplains, and we can strive to be proactive about drainage improvements. Stormwater management via green infrastructure is a particularly exciting opportunity to explore further. “
- Regional Climate Workshop participant, NHDOT

Aquatic Resource Mitigation (ARM Fund)

The NHDES Aquatic Resource Mitigation Fund uses in-lieu development fees to support wetland preservation and restoration across the state. In Nashua, NH, the ARM Fund helped permanently protect 192 acres of forest, including 49 acres of wetlands, through the Pennichuck Brook Conservation and Restoration project. (See Figure 3.3.)

Figure 3.3: Pennichuck Brook Conservation and Restoration

Photo courtesy of NHDES. Beyond the Beaver Dam: The Success of the NHDES Aquatic Resource Mitigation Fund

Pollinator-friendly bioswales

As a "Pollinator Friendly Community," the City of Greenfield, Wisconsin incorporates native pollinator-friendly plants into its green infrastructure investments. (See Figure 3.4.) This bioswale captures and filters stormwater runoff, supports the bee population, and beautifies the community.

Figure 3.4: Bioswale planted with native pollinators

*Photo courtesy of [Environment America](), © Aaron Volkening CC-BY-*2.0.

Funding opportunities: The intersection of Transportation & Environment

Recognizing the symbiotic relationship between human and natural infrastructure, many funding resources to support roadway adaptation also align with environmental goals. Table 3-3 lists examples of potential funding sources that can be used to advance local roadway adaptation efforts.

Table 3-3: Potential funding sources for roadway adaptation projects

Funding Program	Source	Description
Aquatic Resource Mitigation (ARM) Fund	NHDES	When a project has unavoidable impacts to streams and wetlands developers can make an in-lieu fee payment to the ARM fund administered by NHDES. Funds are distributed via grants for projects that protect, restore, and enhance wetlands and streams.
Bridge Investment Program	DOT Federal Highway Administration	These competitive grants can be used to improve bridge condition and the safety, efficiency, and reliability of the movement of people and freight over bridges.

Funding Program	Source	Description
National Culvert Removal, Replacement & Restoration Grants / Culvert Aquatic Organism Passage (AOP) Program	DOT Federal Highway Administration	This is an annual competitive grant program for the replacement, removal, and repair of culverts or weirs that meaningfully improve or restore fish passage for anadromous fish (i.e. species that are born in freshwater, live in marine environments, and migrate back to freshwater to spawn.)
National Highway Performance Program (NHPP)	DOT Federal Highway Administration	**New eligibilities under IIJA/BIL:** NHPP formula funds can be used for resiliency improvements on the National Highway System, including protective features.
Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT)	DOT Federal Highway Administration	PROTECT includes formula funding as well as discretionary grants to make surface transportation systems more resilient to natural hazards such as climate change, sea level rise, and extreme weather events.
Surface Transportation Block Grant (STBG)	DOT Federal Highway Administration	**New eligibilities under IIJA/BIL:** STBG formula funds can be used for protective features, including natural infrastructure, to enhance the resilience of an eligible transportation facility. Funds can also be used to replace a low water-crossing with a bridge on a non Fed-aid highway.
Watershed Assistance Grants	NHDES	These grants can be used to address nonpoint source pollution through the implementation of watershed-based plans in priority watersheds.
Wildlife Crossing Pilot Program	DOT Federal Highway Administration	This competitive grant program has a goal of reducing Wildlife Vehicle Collisions while improving habitat connectivity for terrestrial and aquatic species.

RESOURCE ALERT

- ***Looking for more examples of nature-based solutions?*** Check out this helpful resource focused on coastal environments, published by the Federal Highway Administration: *Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide*, August 2019.

- ***Looking for more federal funding opportunities?*** Funding for resilience projects is available from a wide array of federal agencies. Here are two key resources to connect to funding streams from FEMA, USDA and more:
  - Department of Defense, Readiness and Environmental Protection Integration Program, *2023 Resilience Project Funding Guide*, April 2023.
  - Green Infrastructure Federal Collaborative, "Navigating Federal Funding for Green Infrastructure and Nature-Based Solutions," June 2023.

C. Operations & Maintenance

When it comes to highway operations and maintenance systems, climate change is already having an impact on seasonal priorities and staffing needs. For many Southern NH communities, less frequent snowfalls can reduce wintertime plowing needs, while heavier rainfall events throughout the year may require an intensive push to keep culverts and drainage infrastructure clear of debris in advance of a pending storm.

Climate change means long-standing trends don't necessarily predict the future, so Public Works and Highway teams need to be well-resourced in order to quickly respond to shifting needs. This can be particularly challenging for smaller communities in the SNHPC region, which may require innovative approaches, community partners, and external resources to address growing flood risks.

Table 3-4 Operations & maintenance strategies

Strategy	Scale	Examples
C.1 Optimize monitoring, maintenance, and replacement of bridges, culverts, and stormwater drainage systems	Corridor / Systems	• Minimizing repair backlogs • Documenting maintenance crew processes and best practices • Reassessing road repair schedules • Budgeting for priority infrastructure upgrades
C.2 Update seasonal maintenance programs in response to climate change	Corridor / Systems	• Developing "climate-ready" standards for operations and maintenance • Monitoring of bridges, culverts, and stormwater drainage systems, including assessment of beaver activity • Removal of debris and sediment • De-icing roadways while reducing salt usage to protect water quality (e.g. via Green SnowPro Certification)
C.3 Establish flexible, responsive maintenance capabilities	Systems	• Interagency coordination and resource sharing • Volunteer programs to assist in monitoring and removing debris • Standby contracts and staffing for extreme event response • Enhanced emergency communications systems • Stockpiling materials and equipment for extreme weather events

"Unpredictable weather patterns can really damage culverts and increase flood risk – especially when we have a big snowstorm followed by warm weather, snowmelt, and more rain. We need to encourage the community to step up and keep their own driveway culverts clear."
– Road Agent, New Boston Highway Department

Falls Brook stream restoration project

In Swanzey, NH, volunteers participated in a "citizen scientist" initiative to survey and improve vulnerable culverts. The project at Falls Brook protects high-quality trout habitat and improves infrastructure resiliency. Once the culvert upgrade was complete, volunteers planted a vegetative buffer with native plants to stabilize widened stream banks and benefit the local ecosystem.

Figure 3.5: Volunteer efforts help stabilize stream bank

Photos courtesy of Nature Groupie, © Emily Lord

"In a rural environment there's not a lot of funding and limited staff, so we need local people involved in grassroots efforts to reduce flood risk."
– Meghan Butts, UVLSRPC and Upper Valley Adaptation Workgroup

D. Outreach & Collaboration

Given the wide-ranging impacts of climate change, outreach and collaboration are essential ingredients to successful adaptation efforts. Communities don't function in a vacuum – and coordinated efforts among local, regional, state, and federal partners can maximize the impact of collective climate actions. In fact, when attendees at the 2023 Southern NH regional climate workshop were asked "What brought you here today?," nearly three-quarters of respondents selected "collaboration" as a driving interest.

In addition to cross-sector collaboration, public-facing outreach is another key priority. Effective communications and candid discussions can help overcome climate skepticism and foster consensus around climate change priorities. Clear, concise messaging is also essential for protecting public health and safety – particularly when communities are confronted with extreme precipitation and flooding events.

Building upon the success of the 2023 regional climate workshop, SNHPC will continue to facilitate ongoing climate-focused collaborations, so that a diverse cross-section of stakeholders can work together to shape a more resilient region.

Table 3-5: Outreach & collaboration strategies

Strategy	Scale	Examples
D.1 Support staff training and knowledge sharing about climate priorities	Systems	• Toolbox of climate resources • Staff training opportunities • Collaborative climate planning activities • Grants, funding, and technical assistance
D.2 Increase public awareness of climate-related risks to infrastructure	Systems	• Information dissemination (e.g. newsletters, user-friendly web resources) • Workshops with community stakeholders and affected property owners, (e.g. downstream effects of clear cutting) • Volunteer programs (e.g. maintaining driveway culverts, capturing stormwater on-site) • Safety signage / safety devices at vulnerable crossings (e.g. flood height indicators)
D.3 Strengthen multi-sector partnerships and collaboration	Systems	• Enhanced communications and knowledge-sharing (e.g. adaptation, conservation, water quality) • Adaptation work groups; annual workshops; tailored working sessions • Pilot projects (e.g. neighborhood rain gardens) • Coordination with State agencies • Cost-sharing (e.g. joint development and maintenance of infrastructure) • Policy alignment

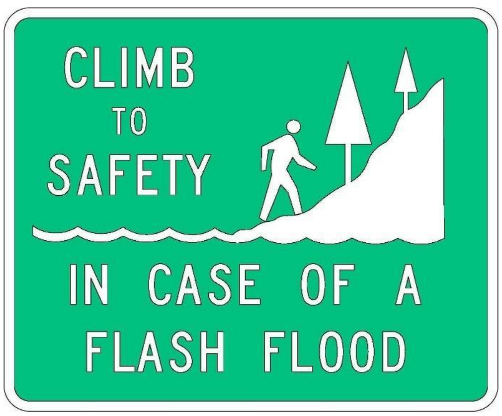
"With a problem as complex as sea level rise, no single agency or entity has all the expertise needed. We have to get on board with learning each other's vocabulary, meeting with community members, and making sure everyone can offer input to tackle this issue."
– Dave Walker, Rockingham Planning Commission

Building public awareness of flood risk

This page shows examples of signage from the US and Australia designed to alert drivers and pedestrians and prevent flood-related deaths. (See Figure 3.6.) According to the National Weather Service:

- A mere 6 inches of fast-moving flood water can knock over an adult.
- It takes just 12 inches of rushing water to carry away most cars.
- Just 2 feet of rushing water can carry away SUVs and trucks.

Figure 3.6: Sample flood safety signage



Moving clockwise from top left, images are courtesy of: National Weather Service; Colorado DOT; IDEAS.org.

NH Coastal Adaptation Workgroup (CAW)

CAW is a collaboration of over 30 organizations working to ensure coastal watershed communities are resourceful, ready and resilient to the impacts of extreme weather and long-term climate change. The collaboration includes public agencies, private businesses, non-profits, and universities. (See Figure 3.7.) Details are available at [nhcaw.org.](nhcaw.org)

Figure 3.7: Coastal Adaptation Workgroup

Images courtesy of NH CAW. Top photo © Rick Cliche / 2023 Rising Tides Photo Contest – Atlantic Coast winner

"Collaboration isn't always easy. Sometimes we have to nudge, push, pull – yet even where there are differences, we can still get work done, and everyone can get some of their priorities met."
– Matthew Thorne, The Nature Conservancy

E. Data, Planning, & Policy

Good data is an essential ingredient to support good decision-making. Climate change impacts are unfolding quickly, and given this rapidly shifting context, Southern NH communities need to stay up-to-date on the latest climate models and projections, ensure that inventories of infrastructure assets are kept current, and continuously evaluate roadway vulnerabilities based on new learnings.

The urgency of climate change also means that climate considerations need to be baked into all plans and policies to foster resilient communities that are prepared to successfully respond to the challenges—and even thrive—in the face of climate shifts.

Administrative practices can also provide communities with essential data they need to support decision-making in the face of climate change. By systematically tracking climate-driven needs related to day-to-day operations, staffing needs, procurement costs, and infrastructure lifecycle management, communities can have essential data at their fingertips to inform better plans and policies.

Table 3-6: Data, planning, & policy strategies

Strategy	Scale	Examples
E.1 Regularly inventory vulnerable assets using up-to-date climate data	Systems	• Documenting asset updates; monitoring changes to vulnerability status • Database maintenance • Updating mapping resources
E.2 Develop climate priorities and incorporate into plans and policies	Systems	• Long-Range Transportation Plans • Hazard Mitigation Plans • Capital Improvement Plans • Land development studies; land use plans • Zoning and site/subdivision regulations • Emergency response plans
E.3 Integrate climate data to guide ongoing decision-making	Systems	• Updated performance measures • Updated procurement criteria, RFPs • Budgeting considerations and cost-tracking (e.g. work order codes to capture climate adaptation & climate-related emergency response) • Increasing transportation system redundancies

"It's essential to connect these strategies together so that resilience becomes a part of how we operate. We need to inventory vulnerable assets, develop resilient design and maintenance standards, and link these with our project and asset management systems so that resilience is baked into transportation planning, maintenance, and operations activities."
– Katie Kemen, BSC Group

NH Stream Crossing Initiative

Four NH State agencies and the University of New Hampshire have established an interagency partnership to systematically survey stream crossings throughout the state. Offering resources including field protocol trainings, database management, and educational materials, the NH Stream Crossing Initiative supports data-driven decision-making to guide investments in transportation, stream connectivity, fish and wildlife habitat, and flood resilience. (See Figure 3.8.)

Figure 3.8: NH Stream Crossing Initiative – Interactive Survey Coverage Dashboard

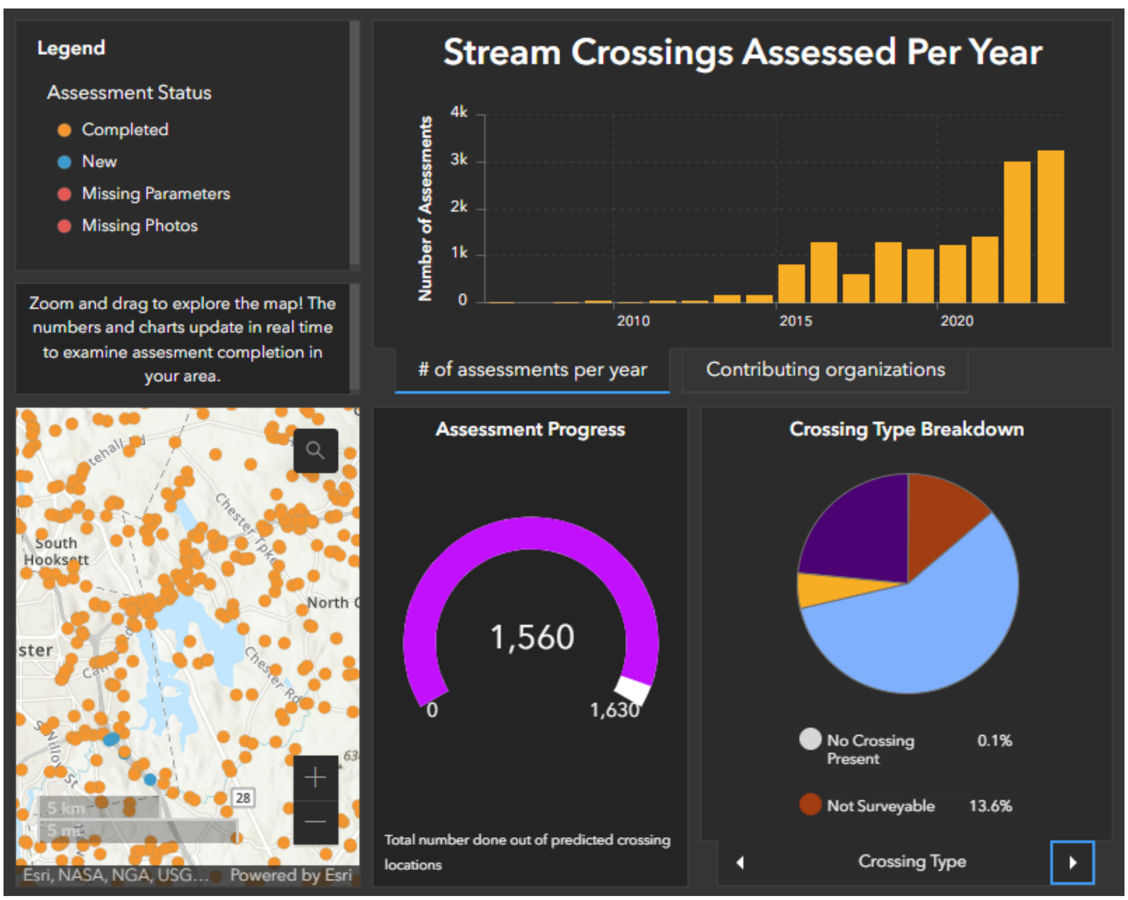


Image courtesy of *[NH Stream Crossing Initiative.]*

MENU OF STRATEGIES: ROADWAY ADAPTATION

A. Design and Engineering

STRATEGY	SCALE	EXAMPLES
A1. Retrofit vulnerable sites to withstand extreme weather events	Site	• Culvert upgrades (e.g. improved hydraulic capacity/geomorphic compatibility) • Enhanced drainage design • Stream bank armoring • Riprap to prevent bridge scour • Rockfall barriers • Elevation of roadways or bridges • Improved stormwater detention
A2. Model asset lifespan to account for climate hazards	Corridor / Systems	• Performance parameters for asset upgrades • Anticipating climate and land use changes
A3. Update roadway design standards to reflect latest climate data	Systems	• Developing climate-resilient design guidelines/"climate-ready" standards • Applying updated precipitation models and asset risk assessments based on latest climate data • Updating design calculations and design requirements, including requirements for subdivisions (e.g. hydraulic capacity, flood frequency, stormwater management)

B. Nature-Based Solutions

STRATEGY	SCALE	EXAMPLES
B1. Preserve wetlands and floodplains to improve stormwater retention	Site / Corridor	• Right-of-way acquisitions for flood storage • Wetlands management strategy • Open space development requirements • Development setbacks from wetlands and natural resources
B2. Improve river and stream environments	Site / Corridor	• Vegetated erosion control methods for riverbank protection and armoring • Re-naturalized streambeds • Infrastructure setbacks from river channels
B3. Enhance stormwater management via green infrastructure/ low impact development	Site / Corridor	• Bioretention ponds • Constructed wetlands • Vegetative swales • Infiltration trenches • Rain gardens • Permeable pavement • Stormwater planters and tree box filters • Street trees
B4. Update vegetation control practices	Site / Corridor	• Management of invasive species • Planting flood-tolerant species

MENU OF STRATEGIES: ROADWAY ADAPTATION

C. Operations and Maintenance

STRATEGY	SCALE	EXAMPLES
C1. Optimize monitoring, maintenance, and replacement of bridges, culverts, and stormwater drainage systems	Corridor/ Systems	• Minimizing repair backlogs • Documenting maintenance crew processes and best practices • Reassessing road repair schedules • Budgeting for priority infrastructure upgrades
C2. Update seasonal maintenance programs in response to climate change	Corridor/ Systems	• Developing more "climate-ready" standards for operations and maintenance • Monitoring of bridges, culverts, and stormwater drainage systems (including any beaver activity) • Removal of debris and sediment • De-icing of roadways while reducing salt usage to protect water quality (e.g. Green SnowPro Certification)
C3. Establish flexible, responsive maintenance capabilities	Systems	• Interagency coordination and resource sharing • Volunteer programs to assist in monitoring and removing debris • Standby contracts and staffing for extreme event response • Enhanced emergency communications systems • Stockpiling materials and equipment for extreme weather events

D. Outreach and Collaboration

STRATEGY	SCALE	EXAMPLES
D1. Support staff training and knowledge sharing	Systems	• Toolbox of climate resources • Staff training opportunities • Collaborative climate planning activities • Grants, funding, and technical assistance
D2. Increase public awareness of climate-related risks to infrastructure	Systems	• Information dissemination (e.g. newsletters, user-friendly web resources) • Workshops with community stakeholders and affected property owners (e.g. downstream effects of clear cutting) • Volunteer programs (e.g. maintaining driveway culverts, capturing stormwater on-site) • Safety signage/safety devices at vulnerable crossings (e.g. flood height indicators)
D3. Strengthen multi-sector partnerships and collaboration	Systems	• Enhanced communications/knowledge sharing (e.g. adaptation, conservation, water quality) • Adaptation workgroups; annual workshops; tailored working sessions • Coordination with State agencies • Cost-sharing (e.g. joint development and maintenance of infrastructure) • Policy alignment

MENU OF STRATEGIES: ROADWAY ADAPTATION

E. Data, Planning, and Policy

STRATEGY	SCALE	EXAMPLES
E1. Regularly inventory vulnerable assets using up-to-date climate data	Systems	• Documenting asset updates; monitoring changes to vulnerability status • Database maintenance • Updating mapping resources
E2. Develop climate priorities and incorporate into plans and policies	Systems	• Long-Range Transportation Plans • Hazard Mitigation Plans • Capital Improvement Plans • Land development studies; land use plans • Zoning and site / subdivision regulations • Emergency response plans
E3. Integrate climate data to guide ongoing decision-making	Systems	• Updated performance measures • Updated procurement criteria, RFPs • Budgeting considerations and cost-tracking (e.g. work order codes to address climate adaptation and climate-related emergency response) • Increasing transportation system redundancies

CHAPTER 4 - Adaptation in Action

This chapter highlights another crucial piece of the adaptation puzzle: a deep understanding of local community context. In some cases, corridor data may be old or incomplete, or implementation strategies may feel abstracted. However, these resources can be used to jumpstart critical conversations about local adaptation needs so that concrete priorities and practical implementation opportunities can be identified. In this way, local expertise is an essential tool for vetting vulnerability data and putting adaptation strategies into action.

Given the value of bringing roadway adaptation actions into a real-world context, this chapter highlights key learnings emerging from a sample case study of a corridor in our region. It concludes with a reflection on how climate change is impacting asset lifecycles and costs, and how our growing understanding of roadway adaptation needs can inform future regional transportation planning efforts.

Corridor Case Study: SNHPC and Chester Staff Examine NH-102 Flooding Concerns

In May 2023, SNHPC staff facilitated an interactive work session with the Town of Chester to focus on one vulnerable corridor and explore adaptation opportunities in further detail. SNHPC prepared detailed maps, presented available data (e.g. stream crossings, steep slopes, and flood hazards), and shared copies of the draft Menu of Strategies in development. Town staff reflected on this material and shared their insights about on-the-ground flooding concerns the community was facing. Collectively, the group was able to successfully narrow down priority sites and issues to be addressed through future adaptation efforts.

Corridor Overview

NH-102 serves an essential east-west transportation corridor in our region. As shown on the following map, it bisects the Town of Chester, providing connections to Derry and I-93 heading toward the southwest (known locally as Derry Road), and Raymond/Route 101 heading toward the northeast (known as Raymond Road). The roadway is owned and maintained by NHDOT, and the pavement is in good condition.

As a major collector road, NH-102 currently has an average daily traffic volume of 7,600 to 9,000 vehicles per day, depending on the location in Town. These volumes are expected to increase, given the construction of I-93 Exit 4A along with associated development pressure in the region.

Flooding is a widely-recognized concern in Chester—particularly since the 2006 Mother’s Day Flood, which left five of the eight routes out of town impassable. Flooding concerns are detailed in the Town’s Hazard Mitigation Plan. Depending on the specific location, an impasse along NH-

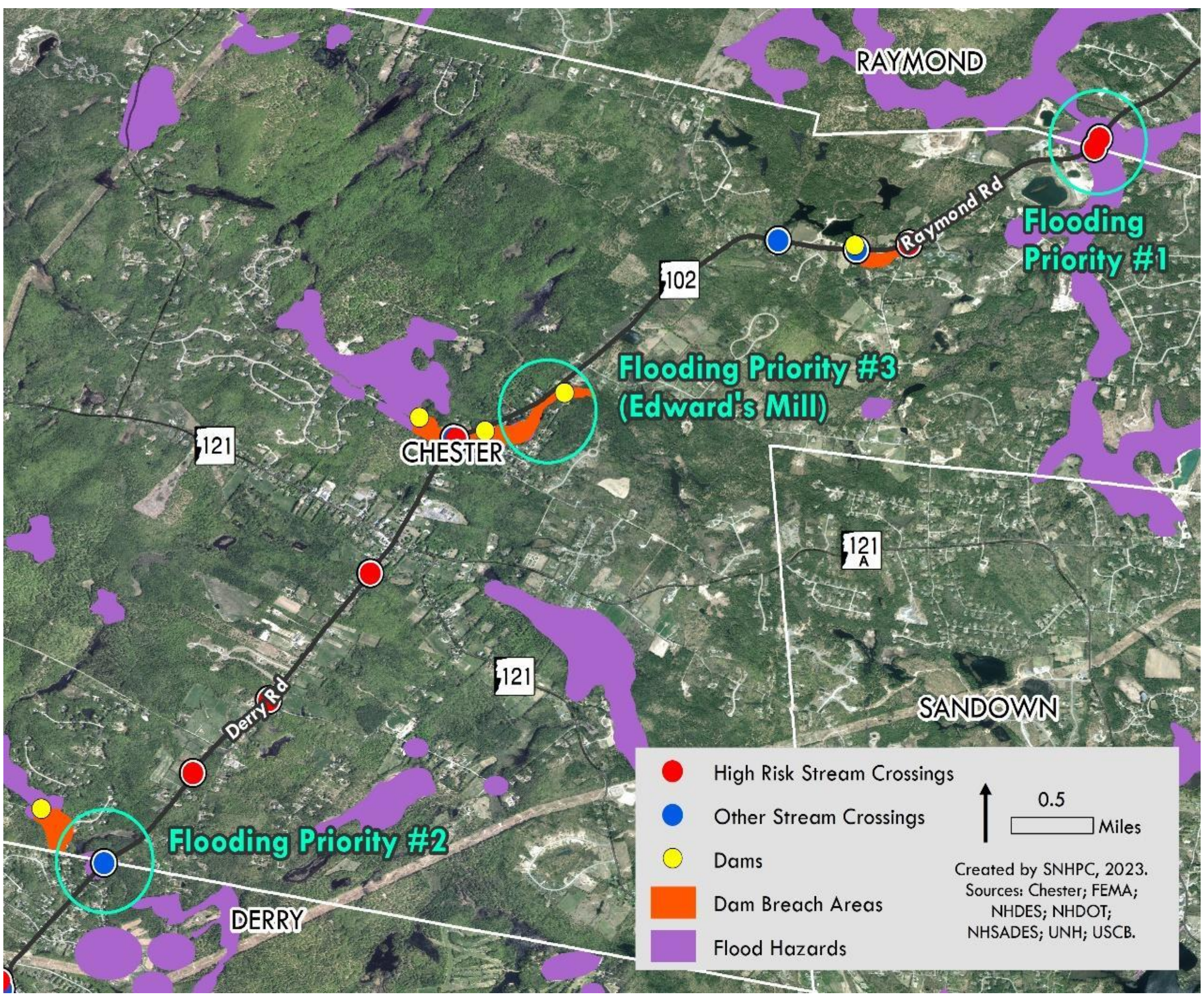
102 could be particularly dire, potentially cutting off access to the nearest hospital in Derry and impeding mutual aid fire and emergency services support from Derry and/or Sandown.

According to the scoring criteria described in Chapter 2, NH-102 in Chester has a total of 10 stream crossings, 6 of which are considered to be high risk for flooding, as shown on the map. Flood hazard and dam breach areas shown come from the Town's most recent Hazard Mitigation Plan.

Sites of concern

At the May 2023 work session, SNHPC staff met with representatives from Chester's Planning, Fire, Police, and Highway departments to discuss roadway adaptation priorities for the NH-102 corridor. The map and associated data analysis provided an entry point for more detailed discussion with town staff, who identified three priority sites of greatest concern. (See Figure 4.1.)

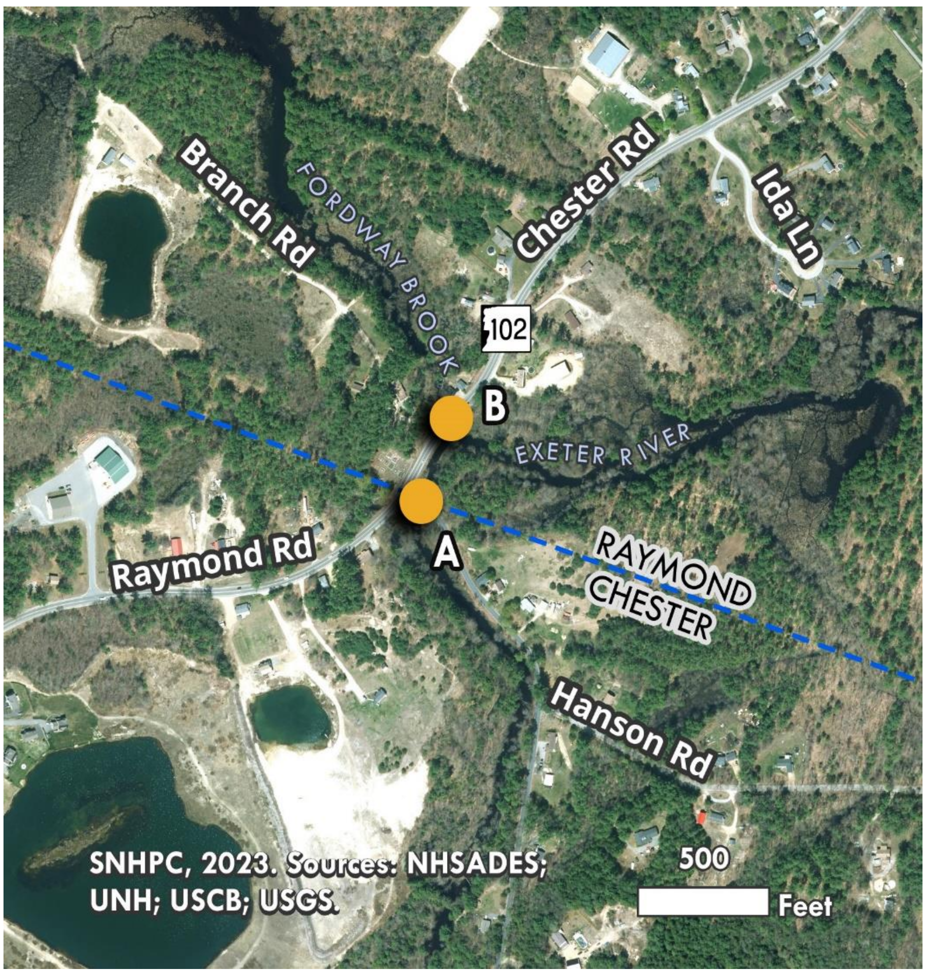
Figure 4.1: Map of NH-102 in Chester, highlighting potential flood risks and priority sites



Priority site #1 – NH-102 at Hanson Road. Here, two red-listed bridges traverse the Exeter River at the Raymond Town line. (See Figure 4.2.) Hanson Road bridge (A) intersects with NH-102. This is a municipal red list bridge for Chester, and the Town is currently undertaking engineering to replace it. The other bridge (B) is a State red list bridge on NH-102 in the Town of Raymond.

Town staff verified that, due to the topography of the area, water floods onto Hanson Road toward 102 during heavy rain events, placing the Hanson Road bridge at further risk for failure. Town representatives mentioned that during one heavy storm in Spring 2023, water levels were just 6-8 inches below the bridges.

Figure 4.2: NH-102 at Hanson Road



Priority site #2 – NH-102 at Derry Town line. In this area, an undersized culvert on Cole Road has contributed to the flooding along NH-102. This section of NH-102 was also flooded and impassable during the 2006 Mother's Day Flood. (See Figure 4.3.)

While an upsized box culvert is in the pipeline, increased water flows will continue to put pressure on the corridor. Meanwhile, a nearby private dam for Harantis Lake is slated for repair or removal, which would turn the surrounding area into a wetland and potentially elevate flood risk along the corridor.

Figure 4.3: NH-102 at Derry Town line

Priority site #3 – NH-102 at Edwards Mill Road. This area represents the most significant wetland complex in Chester. (See Figure 4.4.) Recently, a blocked culvert caused significant damage to Edwards Mill Road near NH-102, highlighting the vulnerability of the corridor in this area.

Figure 4.4: NH-102 at Edwards Mill Road

Key insights:

The work session with Town staff surfaced important insights that are helpful for guiding roadway adaptation planning efforts in Chester as well as the broader SNHPC region.

1. **A corridor analysis helps call attention to cascading flood impacts.** NH-102 is a critical transportation route that's eligible for federal aid, yet it's highly vulnerable to flooding that may result from nearby infrastructure failures – whether that's a red-listed bridge across town lines, a privately owned dam, or blocked culvert on a Class V road. This points to the need to:

a. Continue expanding our scope of analysis in order to more fully capture roadway vulnerabilities;
b. Foster regional and statewide leadership to develop and apply climate-ready roadway design standards and address inter-municipal climate concerns; and
c. Develop innovative, collaborative funding and technical assistance models to advance local adaptation projects that are pivotal to regional resilience needs.

Regional transportation planning processes provide an important avenue for addressing these adaptation priorities. While Chester does not currently have any adaptation-oriented projects in the Metropolitan Transportation Plan (MTP), perhaps certain priority adaptation sites could be integrated via future MTP processes. Forthcoming regional efforts to develop a Resilience Improvement Plan could also position key roadway adaptation projects for Federal funding and implementation.

Strategy highlights:

A.3 - Update roadway design standards to reflect latest climate data

D.3 - Strengthen multi-sector partnerships and collaboration

E.2 - Develop climate priorities and incorporate into plans and policies

2. **Tensions between human development and wildlife contribute to roadway vulnerability and will only be exacerbated as development pressures increase.** Beaver activity is a particular challenge for Chester, and can generate previously unforeseen risks. For example, the collapse of large beaver dams during heavy storms resulted in a very expensive washout on Lane Road in July 2023, and the failure of the causeway across Wason Pond in July 2021. Beaver dams can overwhelm maintenance crews by requiring continuous monitoring and culvert clearing, only to be rebuilt by the beavers as quickly as they are cleared.

   When a community is grappling with challenges related to wildlife – whether it's beavers, an invasive plant species, or insect infestation damaging trees – it points to the need to identify symbiotic adaptation solutions, such as protecting key natural landscapes from development. The Town of Chester is currently working with a professional consultant to develop a Townwide beaver impoundments monitoring and mitigation plan. The plan will include the installation of pond-levelers to reduce the volumes of beaver impoundments that threaten NH-102 and Town-maintained roads.

   Strategy highlights:

   B.1 - Preserve wetlands and floodplains to improve stormwater retention

   C.2 - Update seasonal maintenance programs in response to climate change

3. **Staffing shortages are impacting the region's climate readiness.** New Hampshire is currently experiencing a labor shortage in nearly every sector. In Chester and other Southern NH communities, crucial departments that are essential for preparing and responding to floods like Highway, Police, and Fire are having difficulty filling open positions. While broader socioeconomic trends will take time to resolve (e.g. COVID, inflation, a lack of affordable housing), the next extreme precipitation event could impact our region at any time. To keep our communities safe, it's essential to cultivate greater public awareness about climate risks—and potentially identify opportunities for volunteers to contribute to urgent adaptation needs such as culvert clearing in the face of an impending storm.

   Strategy highlights:
   C.3 - Establish flexible, responsive maintenance capabilities
   D.2 - Increase public awareness of climate-related risks to infrastructure

COST-EFFECTIVE ADAPTATION APPROACHES

The recent Lane Road washout in Chester offers a vivid real-world example of the cost implications related to climate change, and the importance of working proactively to address adaptation priorities. The emergency repair of Lane Road cost the Town approximately $200,000 and did not result in any improved capacity or additional resiliency. However, this was the most viable solution at the time, since installing an upgraded concrete arch culvert sufficiently sized to manage another beaver dam failure would have come with a price tag of more than $750,000.

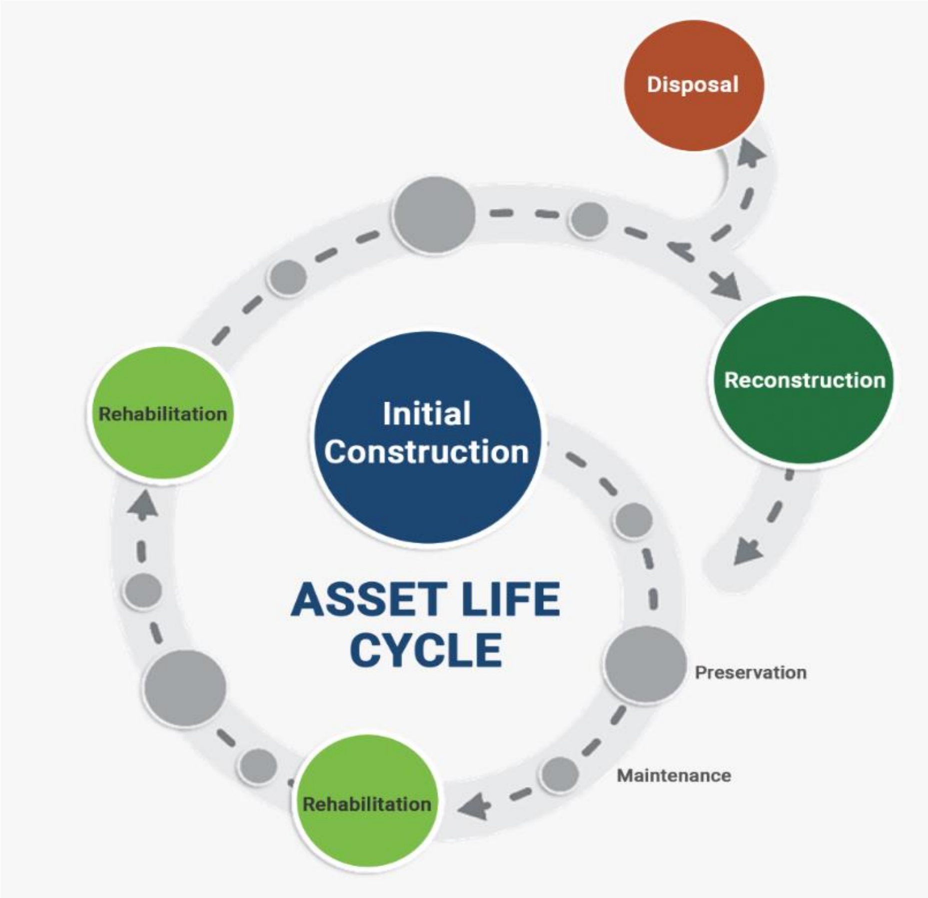
This experience has inspired the Town to take a proactive approach to managing future risks, with a focus on nature-based solutions as well as operations and maintenance. Key strategies include:

- Convening a task force to identify beaver dam impoundments
- Developing a beaver dam monitoring program
- Installing "beaver deceivers" (roughly $2,500 each) in the highest risk locations. These devices use pipes and fencing to ensure water can continue to flow freely as beavers work on their dams.

Climate Implications: Asset Lifecycle Management

All transportation assets have a lifecycle, including planning, construction, maintenance, and rehabilitation, and concluding with removal or replacement. A lifecycle management framework provides an important lens for assessing how climate threats are impacting our roadways, and how adaptation strategies can be used to sustain the life of the roadway while minimizing costs.

Figure 4.5: Visualizing asset lifecycles



Source: Applied Pavement Technology, Inc. 2017

Lifecycle management applies an understanding of past performance to predict an asset's future performance. Yet innovative thinking is needed to address rapidly unfolding climate challenges related to extreme weather, inland flooding, sea level rise, and other environmental conditions. According to AASHTO's Transportation Asset Management Guide, "Even when these changes don't increase the risk of failure, they can require infrastructure owners to change their strategies for managing assets. This is particularly important for long-life infrastructure assets such as bridges, pavement, culverts, and geotechnical assets."[12]

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[12] AASHTO Transportation Asset Management Guide, Chapter 4. Asset Performance, 2020, p.4-19

Climate action across the asset lifecycle

The menu of strategies outlined in Chapter 3 points to key opportunities for systematically integrating adaptation considerations at every phase of the project life cycle. The following table provides a hypothetical model for how a community might select strategies to inform a proactive "climate action" approach to roadway lifecycle management. (See Table 4-1.)

Table 4-1: Hypothetical asset management model: Shifting from a "make-do" mentality to a climate action approach.

Lifecycle Stage	"Make-do" approach	"Climate action" approach
Planning & Design	Meet minimum planning & design standards	Implement climate-ready design standards and performance parameters *(See strategy A.2, A.3)*
Construction	Meet minimum construction standards	Incorporate nature-based solutions that support stormwater management *(B.3)*
Maintenance	Maintenance costs increase due to flooding, wear and tear	Climate-ready plan for shifting costs related to seasonal maintenance & vegetation control *(C.2, B.4)*
Monitoring & Rehabilitation	More frequent rehabilitation required (i.e. "band aid" fixes)	Rehabilitation schedules are predictable and aligned with climate trends *(C.1)*
Reconstruction or Replacement	Infrastructure failures lead to road closures, emergency replacement	Project reaches end of anticipated lifecycle and is re-built to new climate-ready design standards based on latest available data *(E.3, A.3)*

Economic implications

As researchers begin to quantify the full economic implications of climate change, it is becoming clear that adaptation strategies will play a pivotal role in containing escalating costs associated with infrastructure management, repair, and replacement. In 2021, the journal *Climate Change* published a peer-reviewed study titled "Climate effects on US infrastructure: the economics of adaptation for rail, roads, and coastal development." The article applies an economic lens to evaluate future roadway cost scenarios in order to capture direct costs (e.g. capital improvement projects and infrastructure repairs) as well as indirect costs (e.g. costs to individuals related to delays and vehicle wear and tear). The study found that proactive adaptation efforts can result in significant cost savings by the end of the century – particularly if adaptation strategies are accompanied by initiatives to mitigate greenhouse gas emissions.[13]

"THE FUTURE IS NOW": ANTICIPATING THE IMPACTS OF CLIMATE CHANGE

Today's extreme weather events provide insights that can help communities better understand and plan for future climate change. For example, New Hampshire's seacoast communities are already experiencing coastal storm surge and flooding events that illustrate how infrastructure will be impacted by predicted future sea level rise.

Working in conjunction with the National Weather Service, the Rockingham Planning Commission published an ArcGIC StoryMap entitled "The Future is Now," which illustrates the impacts of a storm that took place on December 23, 2022. Due to a confluence of oceanic and atmospheric conditions – including high tide, storm surge, and wave run-up – the storm offered a glimpse into the flooding levels associated with predicted future sea level rise between three and four feet. The images and stories provided point to the urgency of adapting infrastructure today to foster greater resilience in the face of climate change. (See Figure 4.6.)

Figure 4.6: New Castle causeway flooding, December 23, 2022

Photo courtesy of the Rockingham Planning Commission

[13] See Neumann et al, "Climate effects on US infrastructure: the economics of adaptation for rail, roads, and coastal development." *Climate Change* (2021) 167:44.

Climate Implications: Regional Transportation Planning

As the Metropolitan Planning Organization (MPO) for the greater Manchester region, SNHPC is responsible for conducting transportation planning in a cooperative, comprehensive, and continuous manner. A variety of interconnected planning documents address federal and state requirements to ensure our region can effectively program and fund a wide array of transportation improvement projects. Given this role, there are some key opportunities for SNHPC to advance roadway adaptation priorities.

Metropolitan Transportation Plan

The Metropolitan Transportation Plan (MTP) is the region's long-range transportation plan, which captures the region's adopted policies, goals, and project proposals for a 20+ year horizon. The MTP incorporates projects from local master plans and other policy documents, as well as statewide plans and initiatives.

The current MTP lists 119 location-specific projects that are within 200 feet of a federal aid roadway. Among these, only four projects explicitly address adaptation needs (e.g. stream crossing replacements, shoulder and drainage improvements), while another 22 projects may indirectly incorporate adaptation strategies depending on final scope and engineering (e.g. intersection improvements, multi-use paths.) As local, regional, and statewide efforts draw attention to climate-related risks and adaptation priorities, SNHPC anticipates an increase in adaptation-focused projects for future MTP updates.

Project Prioritization

Project prioritization is an important step in identifying projects for the State's Ten-Year Plan (TYP) as well as the region's Transportation Improvement Program (TIP). The TYP is a fiscally-constrained list of statewide transportation projects covering a period of 10 years, while the TIP is a short-range (4-year) implementation program for the region. Both the TYP and the TIP are updated on a regular basis (about every two years) to align with State and Federal requirements.

Ten criteria are used to evaluate projects for inclusion in the TYP and the TIP, as shown in the Table 4-2. The weighting for each criterion is set by the MPO to reflect regional priorities. As the need to address climate concerns becomes more pressing, the region may see an increase in weighting around Natural Hazard Resiliency selection criteria.

Table 4-2: Project evaluation criteria

SNHPC Regional Project Evaluation Criteria			
Category	**Category Weight**	**Criterion**	**Criterion Weight**
Economic Development	12.02%	Local and Regional Economic Dev.	6.29%
		Freight Movement	5.73%
Equity, Environmental Justice, and Accessibility	11.71%	Equity and Environmental Justice	4.26%
		Accessibility	7.44%
Mobility	14.08%	Mobility Need and Performance	7.44%
		Mobility Intervention	6.63%
Natural Hazard Resiliency	11.24%	Hazard Risk	5.41%
		Hazard Mitigation	5.82%
Network Significance	16.85%	Traffic Volume	8.79%
		Facility Importance	8.05%
Safety	17.25%	Safety Performance	7.44%
		Safety Measures	9.81%
State of Repair	12.53%	State of Repair	8.34%
		Maintenance	4.20%
Support	4.33%	Support	4.33%

Resilience Improvement Plan

The federal PROTECT program stands for Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation. It authorizes billions of dollars to help make surface transportation more resilient to natural hazards, including climate change, sea level rise, flooding, extreme weather events, and other natural disasters.

A Resilience Improvement Plan is an important next step to advance roadway adaptation projects and access PROTECT discretionary grants. While construction projects generally require a 20% non-federal match, if a state DOT or MPO develops a Resilience Improvement Plan and incorporates it into the long-range transportation plan, the local match can be reduced by up to 10%. SNHPC is committed to leading the collaborative development of a regional Resilience Improvement Plan that builds upon the insights found in this Toolkit and identifies priority projects for investment.

Coordination with Statewide Initiatives

The State of New Hampshire is slated to receive federal funding to support a variety of initiatives related to climate resilience, and SNHPC looks forward to supporting statewide efforts to bring our region's priorities to the forefront – from leveraging available formula funding to address local adaptation needs, to getting involved with key federal grant opportunities to address climate-related concerns.

For example, NHDES is currently administering a Climate Pollution Reduction Grant from the U.S. Environmental Protection Agency to support the development of a statewide Climate Action Plan, which will include mitigation strategies to reduce greenhouse gas emissions and conserve energy. Simultaneous work is being conducted by the Metropolitan Area Planning Council to develop a Greater Boston Climate Action Plan. Several SNHPC communities lie within that federally-designated area, and SNHPC staff are actively working to coordinate outreach and engagement activities to support both efforts.

Meanwhile, NHDOT is on track to undertake a Statewide Resilience Improvement Plan, which will establish a risk classification methodology for coastal as well as inland transportation infrastructure using the latest climate data. This framework can then be used to target and prioritize resilience improvement projects for the state's most critical roads and bridges – and open up access to further discretionary funding via the PROTECT program.

Through regional workshops as well as ongoing coordination with NHDOT, NHDES, and other key agencies, SNHPC is committed to advancing climate planning efforts that will help our communities survive and thrive in the face of climate change.

GLOSSARY

Adaptation. The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm, or exploit beneficial opportunities.[14]

Asset. In the context of this toolkit, the term asset refers to both physical transportation infrastructure such as roads, rails, and bridges as well as support facilities, vehicles, intelligent transportation systems, and ecosystem related projects.

Climate change. Climate change involves significant changes in average conditions—such as temperature, precipitation, wind patterns, and other aspects of climate—that occur over years, decades, centuries, or longer. Climate change involves longer-term trends, such as shifts toward warmer, wetter, or drier conditions. These trends can be caused by natural variability in climate over time, as well as human activities that add greenhouse gases to the atmosphere like burning fossil fuels for energy.[15]

Climate impacts. Effects on natural and human systems of extreme weather and climate events and of climate change. Impacts refer to effects on people's lives, livelihoods, health, ecosystems, economies, societies, cultures, services, and infrastructure. [16]

Extreme Weather Events. Extreme weather events can include significant anomalies in temperature, precipitation and winds and can manifest as heavy precipitation and flooding, heatwaves, drought, wildfires and windstorms (including tornadoes and tropical storms). Consequences of extreme weather events can include safety concerns, damage, destruction, and/or economic loss. [17] In an **extreme precipitation event,** the amount of rain or snow substantially exceeds what is normal for a given location or season.[18]

Federal Aid Road ("fed-aid"). Under the Federal-Aid Highway Program, these roads are eligible for federal financial assistance for construction, maintenance, and operations. Fed-aid eligible roads encompass the National Highway System and all other public roads not classified as local roads or rural minor collectors, and include the Interstate Highway System, primary highways, and secondary local roads.[19]

Floodway. A FEMA-designated regulatory floodway refers to the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated

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[14] See Intergovernmental Panel on Climate Change (IPCC). Climate Change 2014: Impacts, Adaptation, and Vulnerability – Summary for Policymakers.

[15] See US Environmental Protection Agency, "Frequently Asked Questions About Climate Change."

[16] See IPCC, Climate Change 2014: Impacts, Adaptation, and Vulnerability – Summary for Policymakers.

[17] See SNHPC, 2020 Regional Vulnerability Assessment.

[18] See US Environmental Protection Agency, "Climate Change Indicators: Heavy Precipitation."

[19] See Federal Highway Administration, "Federal-aid Highway Program."

height. Communities must regulate development in these floodways to ensure that there are no increases in upstream flood elevations.[20]

Flood Zone. Locations identified on the FEMA Flood Insurance Rate Map. Zones depicting Special Flood Hazard Areas will be inundated by a 1-percent annual chance flood (also known as the base flood, or 100-year flood). Moderate flood hazard zones will be inundated by a .2-percent annual chance or 500-year flood.[21]

Greenhouse Gases (GHG). These gases trap heat in the atmosphere and contribute to climate change. Carbon dioxide (CO2) is the primary greenhouse gas emitted through human activities, primarily through the combustion of fossil fuels (e.g. coal, oil, natural gas) for energy and transportation.[22]

Inland Flooding. This type of flooding occurs away from the coast, when the volume of water on land exceeds the capacity of natural and built drainage systems to carry it away. Inland flooding may result from extreme precipitation, rapid snowmelt, or dam and levee failures.[23]

Low-Impact Development (LID). An approach to development that works with nature to manage stormwater as close to its source as possible by supporting and/or mimicking natural processes. LID principles include preserving natural features such as riparian buffers and wetlands, and minimizing impervious surfaces. When implemented at a broad scale, LID can help maintain or restore a watershed's hydrologic and ecological functions.[24]

Mitigation. The act of reducing how harmful something is. ***Climate mitigation*** refers to measures to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.[25] ***Hazard mitigation*** refers to any sustained action taken to reduce or eliminate the long-term risk to life and property from hazard events.[26]

Nature-based Solutions. This phrase reflects sustainable planning, design, and management practices that use nature features and processes to promote adaptation and resilience while also addressing social challenges such as climate change, flood risk, and water quality. The phrase is often used inter-changeably with "green infrastructure."[27]

Red list bridge. Per State and Federal requirements, NHDOT inspects bridges on a biannual basis. "Red list" bridges have at least one element rated in poor condition, and must be

[20] See Federal Emergency Management Agency, "Floodway"
[21] See Federal Emergency Management Agency, "Flood Zones"
[22] See US Environmental Protection Agency, "Overview of Greenhouse Gases."
[23] See US Climate Resilience Toolkit, "Inland Flooding."
[24] See Vermont Agency of Natural Resources, "Low Impact Development (LID) Fact Sheet."
[25] See US Department of Transportation, "Definitions."
[26] See New Hampshire Department of Homeland Security and Emergency Management, "Hazard Mitigation."
[27] See Federal Emergency Management Agency, "Nature-Based Solutions."

inspected annually.[28] As of 2023, there were 214 municipally-owned red list bridges and 119 State-owned red list bridges in New Hampshire.[29]

Resilience / resilient. A capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.[30]

Risk. Threats to life, health and safety, the environment, economic well-being, and other things of value when the outcome is uncertain. Risks are often evaluated in terms of how likely an event is to occur (probability) and the damages that would result if it did occur (consequences).[31]

Steep Slopes. Hillsides that have a 25-foot vertical rise or greater for every 100 feet of horizontal run, typically found along riverbanks and in mountainous areas. Steep slopes can be particularly dangerous in flood events, when rapid water flows increase the danger of flash floods, washouts, and water pollution.[32]

Stream Crossing. Any location where a road intersects a waterway requires a stream crossing to convey the water under the road. For the purposes of this report, the term "Stream Crossing" refers mainly to culverts and smaller bridges. In this report, smaller bridges are defined as those less than 20' in span, in keeping with FHWA definitions.[33]

Vulnerability. The degree to which a system is susceptible to, or unable to cope with adverse effects of climate change or extreme weather events. In the transportation context, climate change vulnerability is a function of a transportation system's exposure to climate effects, sensitivity to climate effects, and adaptive capacity.[34]

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[28] See UNH Technology Transfer Center, "New Hampshire Municipal Bridge Checklist of Preservation Activities."

[29] See NH Department of Transportation, GACIT Hearing Presentation, 2025-2034 Draft Ten Year Plan Overview, Fall 2023.

[30] See US Department of Transportation, "Definitions."

[31] See US Global Change Research Program, "The Impacts of Climate Change on Health in the United States," 2016.

[32] See Southern Tier Central Regional Planning & Development Board, "Water Runs Downhill: Managing Runoff on Steep Slopes," 2021.

[33] See SNHPC, 2020 Regional Vulnerability Assessment.

[34] See SNHPC, 2020 Regional Vulnerability Assessment.