Seacoast Transportation Corridor

VULNERABILITY ASSESSMENT AND RESILIENCY PLAN

Rockingham Planning Commission
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Terms, Acronyms and Definitions

Average Annualized Daily Traffic (AADT): A measure of traffic volume on a roadway where observed count data is factored to an annual average to remove seasonal and other biases. In New Hampshire most AADTs are calculated from 3-7 day observed counts. Factors are then applied to the collected data to account for the type of roadway and the time of year of the count in order to get the annual average.

New Hampshire Coastal Adaptation Workgroup (CAW): A collaboration of more than 30 organizations working to ensure that coastal communities in New Hampshire area ready and resilient to the impacts of extreme weather and long-term climate change.
www.nhcaw.org

Coastal Risks and Hazards Commission (CRHC): The New Hampshire Coastal Risk and Hazards Commission was established in 2013 by bi-partisan legislation. The purpose of the CRHC, as stated in the law, was to "*recommend legislation, rules and other actions to prepare for projected sea-level rise and other coastal watershed hazards such as storms, increased river flooding and storm water runoff, and the risks such hazards pose to municipalities and state assets in New Hampshire.*" The CRHC produced two publications; the 2014 Science and Technical Advisory Panel (STAP) Report, ***Sea-Level Rise, Storm Surges, and Extreme Precipitation in Coastal New Hampshire: Analysis of Past and Projected Future Trends***, the CRHC final report and recommendations, ***Preparing New Hampshire for Projected Storm Surge, Sea-Level Rise, and Extreme Precipitation***. The STAP Report provided scientific guidance to the CRHC in developing its recommendations, while the CRHC Final Report summarizes New Hampshire's coastal vulnerabilities to projected coastal flood hazards and puts forth recommendations and actions for the State and coastal and tidal municipalities to minimize risk and increase resilience. The CRHC final report was unanimously adopted on October 21, 2016 and the commission sunset at that time. www.nhcrhc.org

Functional Classification: The roadway system is grouped into classes of roadways based on capacity for traffic, the type of service that is provided, and the level of access to individual properties. Local roads provide access to individual properties and neighborhoods. These streets feed into collector roads that are higher capacity and provide connections within a community. These collectors feed to arterials, often state highways, which have higher capacity and provide connections between communities and access to principal arterials (Interstates, for instance) that provide connections between regions and states.

Mean Higher High Water (MHHW): The average of the higher of the two daily high tides over time. (NOAA)

Mean Lower Low Water (MLLW): The average elevation of the lower of the two daily low tides over time. (NOAA)

Metropolitan Planning Organization (MPO): An MPO is an agency designated to implement the Federal Transportation Planning process within an urbanized area. The RPC is designated as the MPO for the Portsmouth-Kittery Urbanized area and a portion of the Boston urbanized area.

NHDES Coastal Program (CZP): The New Hampshire Coastal Program protects clean water, restores coastal habitats, and helps make communities more resilient to flooding and other natural hazards through staff assistance and funding to 42 coastal towns and cities as well as other local and regional groups. The NHCP is one of 34 federally approved coastal programs authorized under the Coastal Zone Management Act and is administered by NHDES. https://www.des.nh.gov/water/coastal-waters

New Hampshire Department of Environmental Services (NHDES): The mission of the New Hampshire Department of Environmental Services is to help sustain a high quality of life for all citizens by protecting and restoring the environment and public health in New Hampshire. The protection and wise management of the state's environment are the main goals of the agency. www.des.nh.gov

New Hampshire Department of Transportation (NHDOT): The Department of Transportation (NHDOT) provides safe and secure mobility and travel options for all of the state's residents, visitors, and goods movement, through a transportation system and services that are well maintained, efficient, reliable, and provide seamless interstate and intrastate connectivity. www.dot.nh.gov

Rockingham Planning Commission (RPC): The Rockingham Planning Commission is one of nine regional planning commissions in New Hampshire established by RSA 36:46. The Commission's region consists of twenty-seven communities within Rockingham County. Operating as a regional government organization, the Commission serves in an advisory role to local governments to promote coordinated planning, orderly growth, efficient land use, transportation access and environmental protection. www.therpc.org

Sea-Level Rise (SLR): Sometimes called Relative Sea-Level Rise (RSLR), this is the measurement of changes in elevation of the sea and subsidence of adjacent land.

State Ten Year Plan (TYP): New Hampshire RSA 228:99 and RSA 240 require that the New Hampshire Department of Transportation (NHDOT) propose a plan for improvements to the State's transportation system every two years. The purpose of the Ten Year Plan is to develop and implement a plan allowing New Hampshire to fully participate in federally supported transportation improvement projects as well as to outline projects and programs funded with State transportation dollars. RPC prioritizes regional transportation improvement projects for inclusion into the Ten Year Plan. https://www.nh.gov/dot/org/projectdevelopment/planning/typ/index.htm

Tides to Storms: The Tides to Storms project assessed the vulnerability of coastal municipalities and public infrastructure to flooding from expected increases in storm surge and rates of sea-level rise. The project's purpose was to develop a regional scale understanding of what and where impacts from sea-level rise and storm surge will occur on New Hampshire's coast. The study did not include an assessment of the specific degree of damage nor estimate monetary losses to specific sites or properties. https://therpc.org/tidestostorms

Tolerance for Flood Risk (TFR): Tolerance for Flood Risk refers to the willingness of decision makers to accept a higher or lower probability of flood impacts, based on relevant project characteristics such as project value or replacement costs, capacity to adapt, importance for public safety, and sensitivity to inundation. (NH Coastal Flood Risk Science and Technical Advisory Panel, 2020)

Travel Demand Model (Model): A travel demand model attempts to quantify the amount of travel on the transportation system in a region as well as predict, analyze, and understand travel patterns and how the system responds to change. RPCs Model is a TransCAD based, "Standard 4-Step" system that includes modules for trip generation, trip distribution, mode choice, and assignment. The model simulates the movement of people and vehicles within the region during an average day (2015 base year) and produces daily and hourly traffic assignments for each roadway included.

1. Introduction

The New Hampshire Seacoast is a popular tourist destination due to its attractive beaches and recreation opportunities. The Hampton Beach area, along with the entire Seacoast region, serve as an important revenue source for the State. Ease of access via a robust transportation network enhances the appeal of the region as a place to live, work, and recreate. The transportation network, referred to throughout this study/report as the Seacoast Transportation Corridor (STC), is composed of several North-South and East-West routes. These routes provide for both local and regional circulation as well as connections between the coast and interior New Hampshire and adjoining states.

Storm Damage to NH 1A in Rye from the March 2018 Nor'easter. Photo courtesy of Tim Roache.

Route 1A is immediately adjacent to the Atlantic Coast and connects New Hampshire's most popular beaches, tourist amenities and active working waterfronts. The proximity to the immediate coastline makes this roadway vulnerable to extreme weather events, storm surges, flooding, coastal erosion. In January and March 2018, two Nor'easters hit the New England coastline resulting in top ten highest tides on record from Boston, Massachusetts to Portland, Maine. Both storm events occurred during astronomically high tides which combined with strong onshore wind exacerbated flooding conditions on the New Hampshire coastline. Total water levels reached 13.24 feet Mean Lower Low Water (MLLW) during the January 4, 2018 storm, which exceeded the Town of Hampton's threshold for Major Flooding (13' MLLW). Similarly, on March 2, 2018, total water levels reached 12.79 feet MLLW (equivalent to Moderate Flood Stage). Interestingly, greater damage was incurred during the March storm, despite slightly lower total water levels. This storm was a longer duration event and occurred over multiple high tide cycles. Route 1A sustained significant damage in the March 2, 2018 Nor'easter, resulting in a Presidential Disaster Declaration and FEMA Public Assistance. This type of damage is projected to increase in the future as climate change brings more frequent and intense storms to the region along with rising sea levels and groundwater levels and these storm events serve as a reminder of future "sunny day" high tide flooding as sea levels rise. According to the Summary of High Tide Flooding Recorded by the Hampton, New Hampshire Tide Gauge: 2013-2020, Under a 2-foot sea level rise scenario, the average number of days per year with a major flood (over 13 feet) on the NH Seacoast would increase to 27 days (NH Coastal Program, 2021) Frequent sunny day flooding events over successive high tide cycles will, over time, rendering roadway infrastructure impassible.

Damage to transportation assets from recent storms as well as the threat of increasing sunny day high tide flooding have mobilized the Rockingham Planning Commission (RPC), New Hampshire Department of Transportation (NHDOT), and the New Hampshire Coastal Program (NHCP) to collaborate on a Seacoast Transportation Corridors (STC) Vulnerability Assessment and Plan. The goal of this study is to further regional understanding of the impacts of sea-level rise on the transportation network and identify appropriate responses to mitigate those impacts and ensure full functionality. This is the first step in identifying the effects of sea-level rise (SLR) on the transportation network and cataloguing potential adaptation measures that can be implemented to maintain network connectivity, improve resiliency and maintain access to the New Hampshire seacoast under higher flood risk conditions.

The New Hampshire Coastal Risks and Hazards Commission was established by bipartisan legislation in 2013 to "*recommend legislation, rules and other actions to prepare for projected sea-level rise and other coastal watershed hazards such as storms, increased river flooding and storm water runoff, and the risks such hazards pose to municipalities and state assets in New Hampshire*." The work of this commission was completed in 2016 and the final report identified thirty-five recommendations to address needed science, the regional economy, built landscape, natural resources, and cultural heritage. The concept of the Seacoast Transportation Corridor Vulnerability Assessment (STCVA)Report developed out of the Tides To Storms (2015) study, the work of the CRHC, and discussions of coastal roadway vulnerability at the Coastal Adaptation Workgroup (CAW), Based on those efforts, funding was secured through a NOAA Project of Special Merit to implement CRHC recommendations CCI and CC2:

- CC1: Secure new and allocate existing funding sources for state agencies and municipalities to conduct vulnerability assessments of assets at appropriate scales and to implement

Hampton Police blocking a section of US Route 1 through the Hampton-Seabrook Estuary during high-tide flooding in 2019. Photo courtesy of Scott Bogle.

- CC2: Identify vulnerable state and municipal assets at regional, municipal, and site-specific scales as appropriate.

In 2015 the RPC completed the Tides to Storms vulnerability assessment which provided a preliminary assessment of threats to coastal infrastructure using a simple bathtub model of projected SLR. The Tides to Storms vulnerability assessment identified the coastal corridors as a highly vulnerable network of assets, given the number of north-south and east-west roadways (including NH 1A and 1B, US 1, NH 27, NH 111, NH 101, NH 286, and I-95) that are vulnerable to SLR and induced ground water rise in certain areas. In addition to carrying day to day traffic, many of these roadways function as evacuation routes in the event of a coastal emergency.

According to the Tides to Storms analysis, 43% of the 18 miles that make up Route 1A will be inundated twice daily under a high SLR scenario of 6.3 feet by 2100, significantly impacting the 18,000 vehicles that use the road daily during peak summer season. US Route 1 and I-95, the other primary north-south roadways in the coastal region, are situated further inland, resulting in reduced vulnerability to storms and short-term sea-level rise, however, in the long-term, low-lying segments remain vulnerable, see higher traffic volumes than Route 1A, and would expect to receive additional traffic burden from Route 1A, in the event parts of Route 1A are no longer usable. In addition to the impacts to north-south travel, many of the east-west connections between those three corridors face inundation risk. Should 6.3 feet of SLR occur, 20 of the 22 east-west travel options will be unusable due to flooding.

This assessment builds on the Tides to Storms assessment by focusing on the daily operation of the roadway network under higher sea-level conditions. Areas that are inundated today only under flood conditions will become inundated daily overtime based on projected SLR. The intent is to understand how the flooding of portions of roadways in the current roadway network impacts the overall function of the transportation system and how traffic patterns adapt to changes in

Photo of NHDOT plowing water off NH 1A. Courtesy of Tim Roache (March, 2018).

King tide flooding a parking lot adjacent to NH 286 in Seabrook. Courtesy of Dave Walker (November 2021).

route availability. The STCVA is based on the extent of inundation that would result under four scenarios of static sea-level rise: 1.0 feet (baseline-low), 1.7 feet ("intermediate-low"), 4.0 feet ("intermediate high"), and 6.3 feet ("highest") as was utilized in the Tides-to-Storms study. The assessment assumes that the impacted segments of the road network are impassible due to repeated inundation, freeze thaw cycles and tidal action, resulting in failure of the substructure and pavement resulting in sinkholes and scour zones. Using this approach, the STCVA, shows a snapshot of a potential future should the SLR scenarios occur without mitigation or adaption strategies.

While storm conditions are not explicitly considered in this assessment, each of the scenarios could double as a storm condition that have closed roadways due to temporary flooding.

1.1 Purpose and Objectives

Seacoast Transportation Corridor Vulnerability Assessment has the goal of completing a vulnerability assessment of transportation assets in the Coastal Zone and developing recommendations to better prepare for climate change impacts. It will also advance implementation of two NHCRHC recommendations:

- CC1: Secure new and allocate existing funding sources for state agencies and municipalities to conduct vulnerability assessments of assets.
- CC2: Identify vulnerable state and municipal assets at regional, municipal, and site-specific scales.

With these goals in mind, primary objectives are to:

- To identify sites in the coastal transportation network that are subject to greatest flood risk, vulnerability, and impacts from sea-level rise, and when regularly inundated, render portions of the transportation network impaired or nonfunctional.
- Examine and assess the direct and network impacts of roadway closures at impacted sites including rough timeframes for expecting inundation. This will utilize the 1 foot, 1.7 feet, 4 feet, and 6.3 feet scenarios identified as part of the 2015 Tides to Storms study.
- Prioritize inundation sites and identify and assess adaptation options at up to ten priority locations.
- Identify timeframes in which project development should begin to allow for implementation prior to inundation from SLR.
- Establish a long-term adaptation framework to incorporate coastal hazards and prioritize resilience in local, regional, and state transportation planning.

1.2 Project Partners

The STCVA is funded via a 2019 NOAA Project of Special Merit and the Rockingham Planning Commission (RPC) Transportation Planning Work Program. The effort is a partnership between the RPC, NH Department of Environmental Services Coastal Program (NH Coastal Program), New Hampshire Department of Transportation (NHDOT), Dr. Jo Sias Ph.D., P.E. and Dr. Jennifer Jacobs Ph.D., P.E., professors at the University of New Hampshire Department of Civil and Environmental Engineering, and the ten RPC coastal communities of Portsmouth, New Castle, Rye, North Hampton, Hampton Falls, Hampton, Seabrook, Exeter, Stratham, and Greenland.

The involvement of the partners in the project occurred through multiple forms. Coordination and consultation between the RPC team and the NH Coastal Program occurred monthly and included discussions of process and progress in addition to addressing content. NH Coastal Program staff provided important guidance and assistance throughout the project.

Drs. Sias and Jacobs provided their expertise in hydrologic processes and pavement structures throughout the project. They led the site assessments, the two case studies, and the development of adaptation options for the two priority locations.

Coordination with the NHDOT was frequent beginning with a kick-off meeting at the start of the project in which RPC and NH Coastal Program staff shared the proposed approach and expected final products and obtained contacts and feedback from NHDOT. NHDOT staff were involved in the site prioritization process and participated in the establishment of criteria and provided critical feedback on the draft priority sites. NHDOT District VI staff participation in the June 2021 site visits and subsequent workshop provided an understanding of local conditions that was particularly important to the establishment of priorities and ultimately to the development of adaptation options.

The involvement of communities occurred through participation in the Corridor Advisory Committee which met multiple times as well as through discussions with individual communities at one-on-one meetings where RPC and Coastal Zone staff presented on progress, the transportation network analysis results, and possible adaptation options.

The project was also discussed in wider forums. RPC presented the project at the 2021 Hampton Beach Area Commission Coastal Resilience Symposium, the 2021 New Hampshire Climate Summit, and the 2021 ACEC NH Technical Transfer Conference, and the Coastal Adaptation Workgroup in March of 2022. In addition, staff updated the Metropolitan Planning Organization Transportation Advisory and Policy committees on project progress and potential outcomes on multiple occasions.

2. Study Area

The New Hampshire Seacoast region of New Hampshire is home to approximately 153,000 people (US Census Bureau, 2020), over 84,000 jobs (US Census Bureau, 2022) and is annually visited by 2.2 million (overnight) tourists (Dean Runyan Associates, 2022) and additional millions of day-trip visitors that utilize the beaches and other recreational opportunities available in the area. In addition to the Atlantic Coast, the Seacoast region includes the Great Bay Estuary where fresh water from the Bellamy, Cocheco, Lamprey, Oyster, Salmon Falls, Squamscott, and Winnicut Rivers meet the tidal water from the Gulf of Maine.

Twelve communities (approximately 100,000 population and 65,000 jobs) on the Atlantic Coast and Great Bay are within the boundaries of the Rockingham Planning Commission[1], and of those, eight are expected to see direct impacts to the primary transportation network from SLR at 6.3 feet or below. This includes six of the seven Atlantic Coast communities as well as two of the five that border on the Great Bay Estuary. Those communities not directly impacted by SLR, may experience repercussions indirectly as traffic patterns adjust to changes in route availability for accessing coastal and near-coastal areas.

2.1 Corridor Description

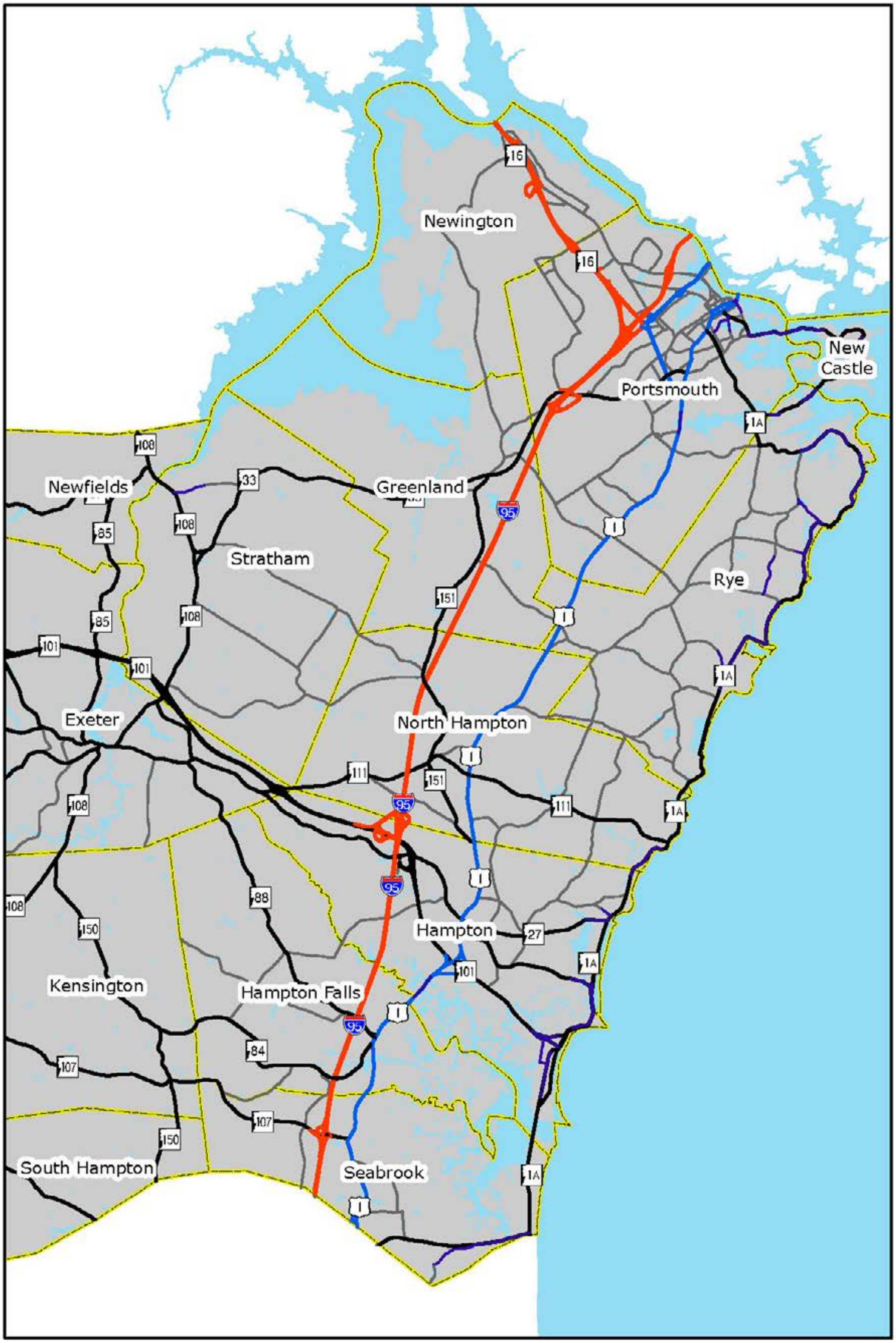
The New Hampshire Seacoast Transportation Corridor (STC) is a network of interconnected roads, transit routes and bike lanes that work as a system to facilitate mobility and accessibility in the region (See Map 2.1). North-south travel in the region occurs via three primary arterial roadways; Interstate 95, US Route 1, and NH Route 1A. There are over 20 possible east-west travel routes that connect the interior to the coastal region. The primary paths are via the major state routes in the region; NH 286, NH 101, Winnacunnet Road (NH 101E), NH 27, NH 111, and NH 1B, however, several other lower-volume local roadways provide alternatives as well.

Interstate 95

Interstate 95 is the main north-south in the East Coast of the United States. It is about 1,908 miles in length, I-95 runs from U.S. Route 1 in Miami, Florida to the Canadian border in Maine. In New Hampshire, I-95 is part of the State Turnpike System connecting Massachusetts and Maine and includes interchanges with I-495 and Route 286 (in Massachusetts), NH 107/US 1, NH 101, and NH 16/ US Route 1 Bypass that provide connections to interior regions and the surface roadways in the coast. I-95 is four lanes in each direction except for the portion from the NH 16 (Spaulding Turnpike) interchange in Portsmouth to the Maine border where the road is three lanes in each direction. I-95 carries between 80,000 and 100,000 Annualized Average Daily Traffic (AADT) with peak summer travel up to 50% higher and approaching 150,000 vehicles per day.

[1] RPC communities on the coast are Hampton, Hampton Falls, New Castle, North Hampton, Portsmouth, Rye, and Seabrook. Great Bay communities are Exeter, Greenland, New Fields, Newington, and Stratham. Other Great Bay communities outside of RPC are Barrington, Dover, Durham, Madbury, Newmarket, and Rollinsford.

Map 2.1: Study Area



US Route 1

US Route 1 is a principal arterial roadway running from the Massachusetts Border to the Maine Border and, depending on location, carries between 16,000 and 25,000 AADT. US Route 1 is generally a 3-5 lane roadway to accommodate high volumes of traffic accessing adjacent businesses and shopping areas as well as traveling to the coast. The facility plays a critical role in providing regional mobility that contributes to the economic health of the region. The roadway connects all the east-west routes as well as Interstate 95 and NH 1A and because of this, even minor impacts to Route 1 may have a significant effect on the functionality of the transportation network in the region. Situated well inland from the immediate coastline, vulnerability to the impacts of rising sea-levels is limited to segments of the road that cross through tidal estuaries.

NH Route 1A

NH Route 1A is a secondary roadway that provides a vital north-south transportation link on the immediate coast and is essential to coastal communities for access, safety, livability, recreation and for the continued viability of coastal tourist economy. The roadway serves as the primary access to Hampton Beach, and all the State Beach Parks, Odiorne Point, Seacoast Science Center, as well as tourist lodging, local businesses, and residential neighborhoods. While the roadway averages between about 2,000-9,000 vehicles per day over the course of the year, peak summer season volumes are generally double those values and can approach 20,000 vehicles per day in some areas. The southern portion of the facility is four-lanes (two in each direction) from the intersection of NH 286 in Seabrook through the "North Beach" area and the connection with NH 27 (High Street) in Hampton. The roadway does narrow to one lane in each direction on the Seabrook-Hampton Bridge (Neil Underwood Bridge), and near the northern end North Beach. Just north of the bridge, NH 1A splits into northbound (Ocean Boulevard) that runs close to the beach and southbound (Ashworth Avenue) which runs further inland with mixed-use development in between. Near Highland Avenue the two directions rejoin as Ocean Boulevard but are separated still by parking areas for beach visitors. North of the intersection with NH 27 (High Street), NH 1A tapers to a two-lane secondary arterial and follows the immediate coastline

Seabrook-Hampton Bridge (Neil Underwood Bridge). Courtesy of Laura Harper Lake.

through much of North Hampton and Rye into Portsmouth. Volumes are generally lower in this section of the corridor and east-west connections are distributed between lower-volume state and local roadways. Much of NH 1A is sandwiched on relatively high ground between the shoreline and inland tidal wetlands and estuaries. This exposure creates conditions that leave this transportation asset extremely vulnerable to coastal flooding and disruption from sea-level rise.

NH 286

NH 286 provides the southern-most east-west connection in New Hampshire. The roadway connects US Route 1 in Salisbury, Massachusetts to NH 1A in Seabrook, providing access to Seabrook Beach and the adjacent residential and commercial land uses. The roadway is a two-lane facility and development along it is generally focused at the eastern and western ends separated by the Blackwater River and surrounding wetlands (Part of the Hampton-Seabrook Estuary). The roadway currently carries an 14,300 (2019) AADT with summer season volumes approaching 18,600 vehicles.

NH 101

NH 101 is a four-lane, high-speed, grade separated east-west arterial that connects between the north-south routes of Interstate 93, NH 125, and Interstate 95 and carries as much as 50,000 vehicles per day. East of Interstate 95, the roadway transitions from grade-separated to a two-lane limited access facility connecting to US 1 and then terminating at NH 1A in Hampton Beach. The average volume in this section is substantially lower (around 8,100 AADT), however the direct access to Hampton Beach sees peak summer volumes significantly higher than the annual average and that approach as much as 18,000 vehicles per day. The approach to Hampton Beach utilizes a causeway across the Hampton-Seabrook Estuary and then splits into eastbound (Highland Avenue) and westbound (Church Street) segments. Eastbound volumes decrease significantly on Highland Avenue as about 50% of the traffic turns onto Brown Avenue and Island Path to access NH 1A further south rather than directly via Highland. Traffic westbound on Church Street averages 5,100 annually but can reach 8,400 during peak summer travel.

Winnacunnet Road (NH 101E)

Winnacunnet Road connects US Route 1 in the center of Hampton to NH 1A at the southern end of North Beach and sits between NH 101 and NH 27. The road is generally a low-speed facility with many driveways and cross streets serving the mix of residential, government, and commercial land uses adjacent to the roadway. The roadway carries 4,000-5,000 AADT with summer volumes that can exceed 7,000 vehicles per day. The portion of the roadway just west of NH 1A passes between the northern edge of the Hampton-Seabrook Estuary and the southern edge of the Meadow Pond wetland area.

NH 27 (High Street)

NH 27 is situated roughly parallel to NH 101 and provides a surface connection between the Manchester area and the seacoast. In Hampton, NH 27 connects between NH 101 just east of Interstate 95, US Route 1, and NH 1A at the northern end of North Beach. Between Route 1 and NH 1A, the roadway is known as High Street and serves the residential and commercial land use along the corridor. The roadway carries around 5,600 AADT however summer tourist traffic can push volumes to nearly 9,000 vehicles per day. Near the approach to NH 1A, the roadway crosses the Meadow Pond wetlands through a low-lying area highly susceptible to flooding.

NH 111 (Atlantic Avenue)

NH 111is an east-west corridor that connects between interior southern New Hampshire and the seacoast. The roadway connects to NH 101 in Exeter and US 1 in North Hampton. The section between Route 1 and NH 1A is known as Atlantic Avenue and serves a largely community-focused and residential land use. The location and lack of direct access to Interstate 95 keeps tourist volumes relatively low and the roadway carries only about 4,200 AADT with summer volumes around 5,600 vehicles.

NH 1B

NH 1B loops from NH 1A in the northern part of Rye out across New Castle Island and then back to NH 1A in Portsmouth along New Castle Avenue and Marcy Street. The road provides access to the community of New Castle as well as attractions such as the Wentworth Country Club, the Wentworth Hotel, and New Castle Common. The Roadway is generally low volume with between 3,000 and 5,000 AADT depending upon location. Summer volumes are somewhat higher approaching 6,000 vehicles per day. The slow speeds, low traffic volumes, and scenic vistas makes this roadway a popular bicycle and pedestrian route as well. In Portsmouth, development adjacent to the roadway is largely residential with some interspersed commercial and recreational uses including Prescott Park and Strawberry Banke.

Other Roadways

The transportation network in the Seacoast is mature and interspersed with a variety of local roadways that provide connections between the communities and the coastal area. In Hampton, Cusack Road and North Shore Road provide alternative connection points between NH 1A and points west. In North Hampton, Willow Avenue connects interior roadways to NH 1A. Rye in particular has a large number of local road connections with Causeway Road (on the border with North Hampton), Central Road, South Road, Sea Road, Cable Road, Locke Road, Harbor Road, Washington Road, Wallis Road, Marsh Road, Parsons Road, and Brackett Road all providing capacity to connect between the interior and the coast. Further, Mill Road in Hampton and North Hampton, Woodland Road in Hampton, North Hampton, and Rye, and Brackett Road in Rye all provide low-volume interior north-south connections that generally parallel US 1 and

NH 1A. In addition to the coastal roadways, the presence of the Great Bay Estuary and associate tidal river systems means that SLR will have impacts on the floodplains and adjacent land for those communities. While this impacts each of the RPC communities adjacent to the Great Bay, transportation system impacts are limited to sites in Stratham and Exeter.

NH 108

NH 108 provides travel connecting between Massachusetts in the south and Rochester, NH in the north. In the STC region, the roadway provides a surface connection alternative to the Spaulding Turnpike along the west side of the Great Bay between Exeter, Stratham, Newfields, Newmarket, Durham, and Dover. Land use is varied along the corridor but is generally residential in the areas susceptible to SLR in Stratham. That section of roadway carries close to 14,000 AADT in the vicinity of Squamscott Road.

Squamscott Road (Stratham)

Squamscott Road is a local street that provides access to residential properties in Stratham. The roadway is also situated to make a convenient connection between NH 108 to the north and NH 33 to the east that allows drivers save time, as well as bypass the Stratham Circle. No direct traffic count data is available for the roadway however counts on NH 108 to the north and south show approximately a 4,000 vehicle per day difference in volume. Near NH 108 the roadway crosses over Jewell Hill Brook and wetlands adjacent to the Squamscott river.

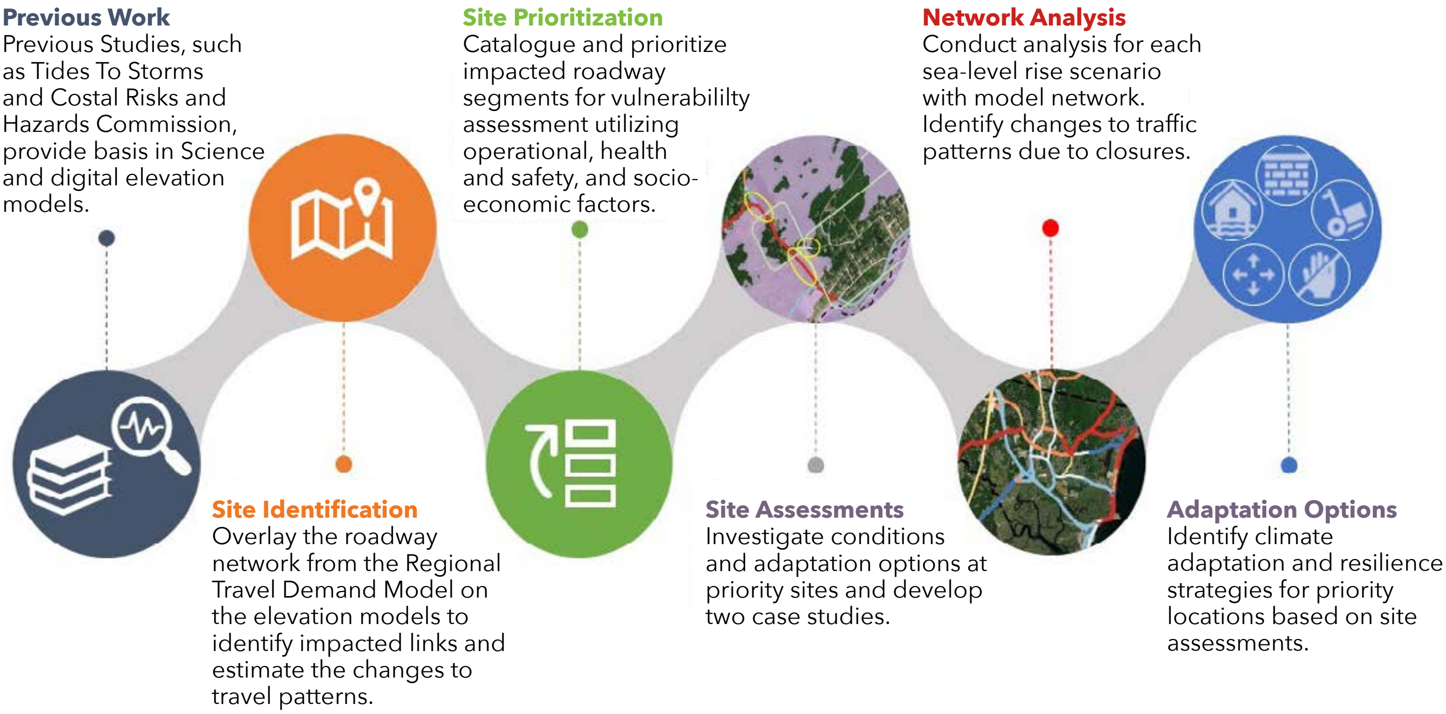
Water Street (Exeter)

Water Street in Exeter is the southern terminus of NH 85 which connects between that community and NH 108 in Newfields. The roadway includes an interchange with NH 101 and serves largely residential, municipal, and recreational use. A low railroad trestle limits commercial traffic on the roadway to some degree. The roadway is susceptible to flooding where it crosses Norris Brook and runs immediately adjacent to the Squamscott River.

3. Methodology

This assessment builds on the Tides to Storms and C-RISE studies and the work of the Coastal Risk and Hazards Commission. Using that work and science as a background and basis, sites were identified and prioritized, the New Hampshire Coastal Flood Risk Guidance was applied, and a transportation network analysis was conducted using the regional travel demand model. Work concluded with the development of adaptation options for priority locations, two case studies, and the development of findings and recommendations (Figure 3.1).

Figure 3.1: Methodology Overview



Previous Work
Previous Studies, such as Tides To Storms and Costal Risks and Hazards Commission, provide basis in Science and digital elevation models.

Site Identification
Overlay the roadway network from the Regional Travel Demand Model on the elevation models to identify impacted links and estimate the changes to travel patterns.

Site Prioritization
Catalogue and prioritize impacted roadway segments for vulnerabililty assessment utilizing operational, health and safety, and socio-economic factors.

Site Assessments
Investigate conditions and adaptation options at priority sites and develop two case studies.

Network Analysis
Conduct analysis for each sea-level rise scenario with model network. Identify changes to traffic patterns due to closures.

Adaptation Options
Identify climate adaptation and resilience strategies for priority locations based on site assessments.

3.1 Sea Level Rise Assumptions and Data

The Tides to Storms study (RPC, 2015) selected sea-level rise assumptions based on current science, conditions specific to the Piscataqua River, The Great Bay, and the Atlantic Coast as well as other localized and regional planning studies. The C-RISE study followed (RPC, 2017) utilizing those same assumptions, but focused on the impacts to Great Bay Communities. Subsequent to that analysis, the Coastal Risks and Hazards Commission (CRHC) recommended that analyses utilize the National Climate Assessment scenarios in formulating findings and recommendations. While the Tides to Storms study scenarios are slightly different than those used in the National Climate Assessment, the estimates of flood coverage are within the margin of error and so are still applicable to the region.

Given the interest in remaining consistent with previous work in the region, this assessment utilizes the three sea-level rise scenarios (1.7 feet, 4.0 feet, and 6.3 feet of SLR) developed for the Tides to Storms study. The flooding from these scenarios was mapped from Mean Higher High Water (MHHW) which is 4.4 feet in the coastal region of NH. Mean Higher High Water is the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. The National Tidal Datum Epoch (NTDE) refers to the specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken (NOAA, 2022). As a note, the DEMs were developed from Light Detection and Ranging (LiDAR) and other remote sensing data. This method produces precise data however it is not perfectly accurate. The LiDAR data used in this case has a vertical error of ±6 inches and a horizontal error of approximately ±13 feet. While amount of error is reasonable for planning level analysis, care should be taken on how the information is applied to specific locations, and particularly around the edges of inundation.

Figure 3.2: Site 13

Site 13 is composed of 6 model links and multiple locations where water intersects the roadway

To identify the locations impacted by SLR, Rockingham Planning Commission (RPC) utilized the scenario digital elevation models (DEMs) created through the Tides to Storms project. The DEMs estimate the impacts of rising sea levels on the landscape and RPC used the 1.0', 1.7', 4.0', and 6.3' SLR scenarios for the STCVA.

Locations identified as susceptible to SLR utilizing the Tides to Storms Data were overlayed on the highway network from the Regional Travel Demand Model (Model). Any Model roadway segment (link) that was in an area that was inundated was considered impacted and incorporated into the analysis. The individual model links were then grouped based on adjacency, and abutting inundated links were considered part of the same site. This allowed the consolidation of many impacted links in higher SLR scenarios into a more manageable number of sites for the purposes of prioritization and analysis. Figure 3.2 shows an example of this, while Table 3.1 shows a summary of how inundated roadway links were connected to the travel demand model and then converted into sites for the purposes of this study.

Table 3.1: Converting Impacted Roads to Model Links and Sites

Scenario	Approx Miles of Roadway Impacted	Impacted Locations	Sites
1 Foot	0.5	4 model links	3
1.7 Feet	1.0	13 model links	5
4 Feet	16.8	126 model links	25
6.3 Feet	28.0	259 model links	52

3.2 Site Prioritization

Determining priority locations for analysis employed a multi-step approach to evaluation. The process was designed to consider multiple factors and expert input to determine which of the identified inundation sites would be priorities for conducting the vulnerability assessments. A set of evaluation criteria was developed establish "criticality" of each location and to identify an initial set of priorities. This was followed by gathering expertise and site knowledge from NH Department of Transportation and NH Coastal Program staff as well as the study team. Based on the initial assessment and the input from experts, a final set of priorities was set for the vulnerability assessment and the locations of the two case studies identified. A summary of this process is below with the more complete methodology included as Appendix A to this document

Table 3.2: Site Prioritization Factors

Area/Factor	Share of Score
Operations	
Functional Classification	20%
Current Traffic Volume	20%
Health and Safety	
Access to Emergency Services	15%
Availability of Alternate Routes	15%
Socio-Economic	
Social Vulnerability Index	10%
Access to Community Facilities	10%
Land Value	10%

STEP 1: Establish Network Criticality: Early work with the Regional Travel Demand Model (Model) indicated that completing a network analysis for the 6.3 feet of SLR scenario was unlikely and to remain consistent, the preliminary list of priority locations was limited to those locations impacted at up to 4.0 feet of SLR. This included 25 sites that were evaluated against a set of prioritization criteria (see Table 3.2) that include operational, health and safety, and socioeconomic considerations utilizing existing data. Included in this was an understanding that those locations impacted in the lowest SLR scenarios would be included as priorities as they represent the most vulnerable areas of the transportation network. A composite score was developed for each of the 25 sites from this assessment and a draft priority listing was established.

STEP 2: Select Preliminary Priority Sites: Utilizing the outputs from Step 1, this phase engaged NH Department of Transportation and NH Coastal Program staff in a review and utilized their expertise and familiarity with site conditions and ongoing efforts to confirm data and understand other factors for consideration beyond the those used in the initial scoring. A list of preliminary priorities was provided to provide a starting point, and feedback included consideration of:

- The results and recommendations of the Hampton Harbor and Meadow Pond Flood studies in Hampton
- The ongoing study of adaptation options for NH 1B bridges and causeways
- Concerns about the applicability of transportation focused adaptation measures in densely developed areas.

That discussion prompted adjustments to priorities and the recognition that the focus should be primarily on locations where other studies are not occurring to minimize overlap.

STEP 3: Finalize Priority Sites: The input received under step 2 was utilized to adjust the initial set of priorities into a final prioritized list. In the end, factors such as local site conditions, ongoing analysis and engineering in some locations, and the potential applicability of results to more than one location played an important role in determining the sites selected. Once priority sites were selected, visits to each location occurred with NH Department of Transportation and NH Coastal Program staff to verify understanding of site-specific conditions and obtain additional information and insight for possible adaptation options.

3.3 Application of NH Coastal Flood Risk Guidance

In 2018 a Science and Technical Panel was convened in New Hampshire for the purpose of providing a synthesis of the coastal flood risk science, provide updated projections for the state regarding coastal storms, sea-level rise, groundwater rise, precipitation, and freshwater flooding. The result of that effort was the 2019-2020 New Hampshire Coastal Flood Risk Summary which was composed of *Part 1: Science* (Wake et al., 2019), and *Part 2: Guidance for Using Scientific Projections* (NH Coastal Flood Risk Science and Technical Advisory Panel, 2020). The guidance provides a seven-step process for incorporating coastal flood risk projections into project planning:

Step 1: Define Project Goal, Type, Location, and Timeframe
Step 2: Determine Tolerance for Flood Risk
Step 3: Select and Assess Relative Sea-Level Rise (RSLR)
Step 4: Identify and Assess RSLR-Adjusted Coastal Storms
Step 5: Identify and Assess RSLR-Induced Groundwater Rise
Step 6: Identify and Assess Projected Extreme Precipitation
Step 7: Assess Cumulative Risk and Evaluate Adaptation Options

For the purposes of this study, application of the guidance focused on the first three steps as well as Step 7. While coastal storms and extreme precipitation are important considerations that should be planned for, this study is concerned with the day-to-day operation of the transportation network as opposed to storm-specific or evacuation focused operations. At the same time, each of the scenarios could stand in as a representation of the function of the transportation network under various storm conditions and be used to identify problematic locations during evacuations or where populations are likely to be isolated without roadway access in the event of extensive flooding.

Defining Project Goal, Type, Location, and Timeframe

This assessment is a planning project with the goal of developing strategies that will aid in maintaining the function of the transportation network and coastal accessibility through 2100.

Determining Tolerance for Flood Risk

The guidance describes projects with a low tolerance for flood risk as "those that have high value or high replacement costs, lack capacity to adapt or be adapted, are critical to public function or safety, and/or are highly sensitive to inundation." Utilizing the framework included in Table 3.3 below, the

Table 3.3: Framework for Determining Project Tolerance for Flood Risk

Adapted from NH Coastal Flood Risk Guidance for Using Scientific Projections

Tolerance for flood Risk	High	Medium	Low	Very Low
Description	Decision makers have a high tolerance for flood risk to the project	Decision makers have a medium tolerance for flood risk to the project	Decision makers have a low tolerance for flood risk to the project	Decision makers have a very low tolerance for flood risk to the project
Possible Project Characteristics: Tolerance for flood risk will depend on the mix and importance of these project characteristics	Low value or cost	Medium value or cost	High value or cost	Very high value or cost
	Easy or likely to adapt	Moderately easy or somewhat likely to adapt	Difficult or unlikely to adapt	Very difficult or unlikely to adapt
	Little to no implications for public function and/or safety	Moderate Implications for Public Function and/or Safety	Substantial implications for public function and/or safety	Critical implications for public function and/or safety
	Low sensitivity to inundation	Moderate sensitivity to inundation	High sensitivity to inundation	Very high sensitivity to inundation
Corresponding ASCE 24-14 Flood Design Class	1	2	3	4
Recommended Coastal Flood Risk Projections	Lower magnitude, Higher probability	↔		Higher magnitude, Lower probability

roadway network in the coast, with some variation, would qualify for low-to-very-low tolerance for flood risk. The infrastructure is costly and replacement costs are high. The roads also have critical implications for public function and/or safety (again with some variation) and are challenging to adapt given that they are already in place. Finally, decision makers and the public generally want the roadways to be accessible as much as possible which indicates a high sensitivity to, and low tolerance for, inundation.

Select and Assess Relative Sea-Level Rise (RSLR)

Because this study was based on the work previously completed as part of the Tides to Storms study, the selection of SLR scenarios was established at 1.0 feet, 1.7 feet, 4.0 feet, and 6.3 feet to be consistent with that previous work. The Coastal Flood Risk Guidance enhances this by providing timeframes for these scenarios that are dependent upon the tolerance for flood risk at the sites. These are probability-based recommendations in that the lower magnitude estimates of SLR have a higher probability of occurring. Table 3.4 below is directly from the guidance and shows the potential timeframes that should be planned for each SLR magnitude dependent upon the tolerance for flood risk at the site.

Table 3.4: Recommended Decadal SLR Estimates

Adapted from Step 3, Table A of the NH Coastal Flood Risk Summary

TIMEFRAME	**HIGH** Tolerance For Flood Risk	**MEDIUM** Tolerance For Flood Risk	**LOW** Tolerance For Flood Risk	**VERY LOW** Tolerance For Flood Risk
	Plan for the following RSLR estimate (ft)* compared to sea level in the year 2000			
	Lower magnitude, Higher probability	↔		Higher magnitude, Lower probability
2030	0.7	0.9	1.0	1.1
2040	1.0	1.2	1.5	1.6
2050	1.3	1.6	2.0	2.3
2060	1.6	2.1	2.6	3.0
2070	2.0	2.5	3.3	3.7
2080	2.3	3.0	3.9	4.5
2090	2.6	3.4	4.6	5.3
2100	2.9	3.8	5.3	6.2
2110	3.3	4.4	6.1	7.3
2120	3.6	4.9	7.0	8.3
2130	3.9	5.4	7.9	9.3
2140	4.3	5.9	8.9	10.5

* Feet above 2000 levels based upon RCP 4.5, project timeframe, and tolerance for flood risk.

Evaluate Adaptation Options

When combined with the risk of flooding of the facilities, the selection of tolerance for flood risk has implications regarding the types of adaptation measures that are considered in each location. Those areas where inundation is infrequent can afford to take minimal action to prepare, such as doing nothing and prioritizing investment outside of flood zones. On the other hand, those areas where the risk of flooding is high must take more active approaches to addressing the problem. With much of the coastal area subject to a high risk of flooding and much of the infrastructure having a low to very low tolerance for flood risk, the assessment matrix suggests that the adaptation measures should be focused on accommodating the water during flooding, implementing measures to resist the flooding, or making the ultimate decision to remove the infrastructure or relocate it to another location. The five categories of adaptation options are shown in Figure 3.3.

Figure 3.3: Categories of Adaptation Options

No Action
Do nothing.

Avoid
Prioritize investment out of the water's way.

Accommodate
Options that allow you to better live with the water.

Resist
Options that keep the water away.

Relocate
Move assets of facilitate retreat away from the water.

3.4 Vulnerability Assessment

This analysis of the impacts to the transportation system looks at the site-specific impacts and the influence of those impacts on the functionality transportation network.

Site Specific Impacts

The STCVA used the DEM for each SLR Scenario in concert with the Travel Demand Model to evaluate the locations where roadways are anticipated to be inundated by water due to SLR. It was assumed that the repeated flooding from successive high tides resulted in the impacted road segments being impassible to vehicular traffic. Note that each progressively higher SLR scenario is inclusive of the impacts of at the lower SLR scenarios.

Network Impacts Assessment

In addition to examining the direct effects of SLR on the roadways, this analysis considers the wider effects of road closures on the region's transportation network. The Regional Travel Demand Model (model) was utilized to estimate network impacts when roadways are inaccessible. This allowed

RPC to identify how travel patterns shifted under each scenario and compare that to the baseline condition and better understand how traffic re-routes around closed segments. Scenario traffic volumes were compared to the baseline volumes to estimate the amount of change (percent) under each. These percentages were then applied to current traffic volume count data to bring the scenario outputs into a context that is consistent with existing conditions.

Travel Demand Model

The Regional Travel Demand Model (Model) is a TransCAD based tool for predicting, analyzing, and understanding how the transportation system responds to changes in the network or land use at a regional level. The model is what is known as a "Standard 4-Step" system that includes modules for trip generation, trip distribution, mode choice, and assignment. The model simulates the movement of people and vehicles within the region during an average day (2015 base year) and produces daily and hourly traffic assignments for each roadway included. The model includes 600 internal Transportation Analysis Zones (TAZs) organized around Census Block Groups and which incorporate data such as housing units, employment, vehicle ownership, and other socio-economic factors. The 4-step process is an iterative process that seeks to assign all origin-destination trip pairs and to the most efficient routes available:

1. A model analysis starts by calculating the total number of trips (trip generation) between each TAZ based on land use and socio-economic data.
2. These trips are then paired into origins and destinations in the distribution model.
3. The trips are then split into travel modes (auto, bus, walking, biking) in the mode split module.
4. Vehicle-based trips are assigned to the highway network in the assignment module.

Four SLR scenarios were developed to compare to the baseline (current 2015) condition. Scenario analysis requires several assumptions. Some of these are particular to the Model and some are specific to this assessment. The most critical of these are listed here and the full set are listed in Appendix B.

Model Specific Assumptions

- The model includes all state highways and many, but not all, local roadways. This can result in some obvious and direct alternate routes not being utilized. Island Path in Hampton Beach is an example of this.
- The travel demand model is calibrated and validated at the regional level and individual links and intersections can sometimes show significant deviation from observed traffic volumes.

Scenario Specific Assumptions

- Each scenario utilizes identical trip generation, distribution, and mode split while the assignment module is unique to each scenario. This means that all assumptions and settings are the same except for the routes available for travel which vary by SLR scenario.

- Roadway links inundated from SLR are restricted with a very low (or zero) capacity for traffic and are, in essence, "shut off" to simulate road closures. This forces the model to assign the traffic to the next most efficient route available.
- Where roadways are not included in the model or we do not have recent observed traffic counts, volumes are estimates.
- The links in the model are, in many cases, longer than the segments of roadway expected to be flooded due to SLR. For this analysis, if part of a link is inundated, the entire link is considered non-operational.
- Model volume outputs are utilized to estimate the scale of expected changes under each SLR condition. The volumes on coastal roadways are compared to the baseline volumes and a percent change is calculated. This percent change is applied to Annualized Average Daily Traffic (AADT) information from current traffic count data to produce outputs consistent with current traffic volume. If information is available to indicate that peak summer traffic is significantly higher than the annual average, that information is included as well.
- All traffic volumes discussed are estimates and are rounded to the nearest 100.

3.5 Adaptation Options

A technical analysis to identify specific climate adaptation and resilience strategies was undertaken to consider the feasibility of site improvements and adaptative capacity at the identified priority sites. Visits to priority sites were conducted on June 2, 2021, to assess localized conditions and obtain additional information for identifying possible adaptation alternatives at each. A workshop including representatives from the project team, NHDES, and NHDOT was held on June 17, 2021, to develop a list of adaptation alternatives for each priority site and to select two sites for detailed analysis. Adaptation alternatives were considered for each of the five action categories identified in the New Hampshire Coastal Flood Risk Summary, Part II: Guidance for Using Scientific Projections (2020), including: No Action, Avoid, Accommodate, Resist, and Relocate.

Water Levels due to SLR

For the two case studies, SLR impact levels from the assessment of adaptation options were further classified based on visual inspection from the STCVA flood mapping tool using the 1.0 foot, 1.7 foot, and 4.0 foot SLR scenarios, and from the NH Coastal Viewer for 2 ft of SLR under MHHW. For each mapped SLR scenario, the Map Site was classified as "Open", "Water on the Road", or "Inundated".

- "Open" indicates that water has not reached the surface of the roadway and it is fully available for carrying traffic.
- "Water on the Road" indicates that a portion of the roadway edge is inundated, but that the entire cross-section is not under water.
- "Inundated" indicates that the entire cross-section of the roadway is submerged.

The granular base layer saturation depends on the location of the groundwater table relative to the roadway. While mapped groundwater levels were available from previous studies, they are relatively coarse compared to the scale of this analysis. Instead, the current (2020) depth to groundwater was estimated based on SLR scenario that resulted in "Water on the Road" and would saturate the pavement. Below these levels, the pavement was determined to be partially saturated or dry based on the hot mix asphalt (HMA) or total structure thickness, respectively.

The above analysis produced road surface and base layer status for the four SLR thresholds. The analysis of adaptation options used each site's Tolerance for Flood Risk (TFR) to estimate when these thresholds will likely occur. Wake et al. (2019) was used to determine the projected SLR values by decade from 2030 to 2150 for the site's TFR. The projected SLR values were compared to the site's SLR thresholds (1.0, 1.7, 2.0, or 4.0 foot) that cause partial and complete inundation to determine the status of the road surface and granular base layer for each site and decade from 2030 to 2100. All roads were classified as "Open" for 2020 (present day) and future year values based on the level of inundation as follows:

- A road was classified as "Open" if the projected SLR value was less than the SLR thresholds that cause partial or complete inundation.
- A road was classified as "Water on the Road" if the projected SLR was greater than that the SLR threshold (1, 1.7, 2, or 4 ft) corresponding to "Water on the Road," but less than the SLR threshold (1, 1.7, 2, or 4 ft) corresponding to "Inundated."
- A road was classified as "Inundated" if the projected SLR was greater than the SLR threshold for

Road base layer status was classified in a similar manner between "Dry", "Partially Saturated", and "Saturated":

- A road base was classified as "Saturated" when the SLR depth exceeded the "Water on the Road" depth indicating the groundwater table was at the road surface.
- A road base was classified as "Dry" if the depth to groundwater was greater than the pavement depth, and;
- "Partially Saturated" for all other values which correspond to a groundwater table elevation within the pavement structure.

In this analysis, the current NHDOT pavement design procedure was used, which uses the general approach outlined in the American Association of State Highway Transportation Officials (AASHTO) 1972 design guide. NHDOT standard values for the pavement design input values (structural layer coefficients, regional and soil support factors, and terminal serviceability level) were used in the analysis. An initial assumption was made that the existing pavement structures are adequate for the current traffic levels at each site. For each site, the allowable traffic loading for the existing structure was calculated assuming that the drainage of the pavement is good to fair, and that the pavement structure is not typically exposed to moisture levels that approach saturation (so-called 'dry' condition). Next, the pavement structure was analyzed under constantly saturated conditions and the additional thickness of asphalt concrete required to achieve the same capacity (traffic loading) as under 'dry' conditions was determined.

4. Roadway Network Vulnerability Assessment

Utilizing the methodology established in Section 3, sites anticipated to be inundated due to SLR were identified and prioritized based on the set of sea-level rise assumptions established for the analysis. This assessment examines the site-specific vulnerabilities as well as the transportation network impacts of flooding. Adaptation options have been assessed for the priority locations and two case studies are included that provide more depth of analysis.

Note that not all roadways in the region are included in the Regional Travel Demand Model (Model) and this analysis is only inclusive of those inundation sites that are also on the Model transportation network. There are other locations that are impacted by SLR that are not included in this analysis. In most, but not all cases, these will typically be very low volume neighborhood streets that do not serve a function as a through street connection between locations.

The travel demand model operated successfully under the 1.0 foot, 1.7 foot, and 4.0 foot SLR scenarios and produced useable results that are detailed in the following pages. The large number of closed roadway segments and inaccessible areas in the 6.3 foot scenario caused trip distribution and assignment errors that crashed the model. No results are available for that scenario however an abbreviated discussion of vulnerabilities and general network impacts is included.

Rather than listing impacts by individual community, the network assessments are grouped into northern corridor communities (Portsmouth, New Castle, and Rye) and southern corridor communities (North Hampton, Hampton, and Seabrook). Community by community volume tables are available for each scenario in Appendix B.

4.1 Site Identification

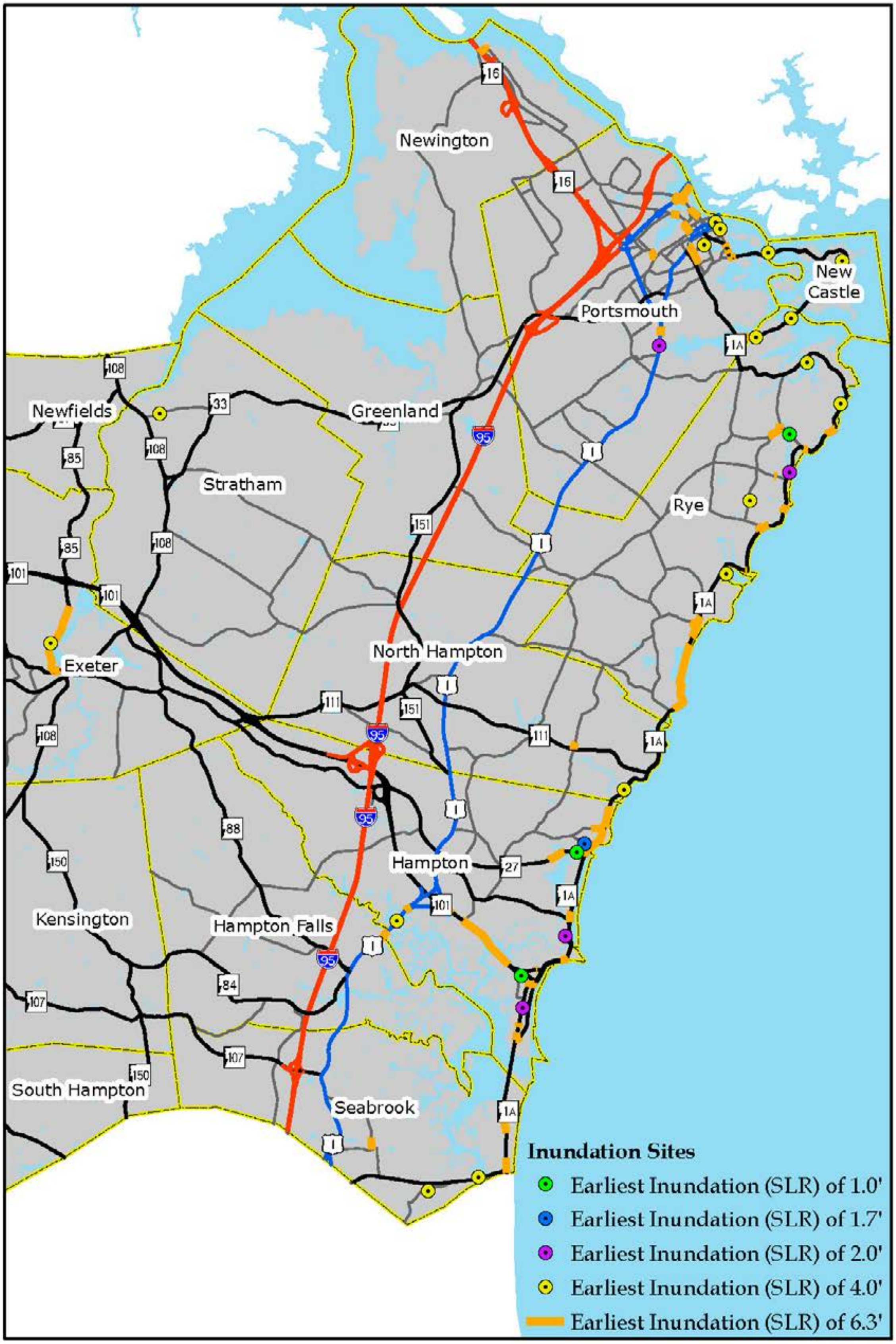
Using the data from the Tides to Storms study and the highway network from the Regional Travel Demand Model, sites impacted under each SLR scenario were identified. There are three locations impacted at 1.0 feet of SLR, five impacted at 1.7 feet, and 25 impacted at 4.0 feet of SLR. At 6.3 feet of SLR, the inundated area expands to include 52 sites. These sites are listed in Table 4.1 (page 24) and shown on Map 4.1 (page 25).

Table 4.1: Roadway Locations Impacted under each SLR scenario

Each scenario is inclusive of the sites listed under the lower scenarios
The number in brackets (#) represents location number included in the vulnerability assessment.

Community	1' SLR	1.7' SLR	4' SLR	6.3' SLR
Portsmouth			• State St/Daniel St (1) • Marcy St (2) • New Castle Ave (4) • Parrott Ave (3) • Junkins Ave (3) • US 1 @ Sagamore Creek (25)	• Market St/Russell St. • Bartlett St • Richards Ave • Bridge St • NH 1B at Rye town line • NH 1A at Sagamore Creek • US 1 North of Sagamore Creek
Newington				• Shattuck Way near NH 16 underpass
New Castle			• NH 1B (Portsmouth Ave) on Causeway (4) • NH 1B @ Neal Pit Ln (5)	
Rye	• Marsh Rd (10)	• Parsons Rd (10)	• NH 1B west of Sanders Poynt (6) • NH 1B east of Portsmouth Marina (7) • NH 1A near Odiorne Point Boat Launch (8) • NH 1A south of Odiorne Point (9) • NH 1A between Wallis Sands State Park and Wallis Rd (11) • Wallis Rd East of Brackett Rd (11) • Brackett Rd south of Wallis Rd (12) • NH 1A adjacent to Rye Harbor (13) • Locke Rd (13)	• NH 1A at Church Rd • NH 1A at Cable Rd • NH 1A at Washington Rd • NH 1A south of Locke Rd • NH 1A from Locke Rd to north of Rye Harbor State Park • NH 1A from south of Concord Point to north of Marsh Rd • NH 1A east of Brackett Rd • Cable Rd • Washington Rd • Brackett Rd north of Clark Rd
North Hampton			• NH 1A @ N. Hampton State Beach Park (14)	• Woodland Rd north of NH 111
Hampton	• High St (16) • Highland Ave (18)	• Cusack Rd (15) • Brown Ave (18)	• NH 1A at N. Hampton Town Line (14) • Winnacunnet Rd (17) • Church St (18) • Ashworth Ave (19) • NH 1A south of Winnacunnet Rd (17) • US 1 through Hampton-Seabrook Estuary (20)	• Ocean Blvd North of Dover Ave • NH 101 at US 1 Interchange • NH 1A between High St & Cusack Rd • NH 1A at Acorn Rd • North Shore Rd
Hampton Falls				• US 1 at Hampton/ Hampton Falls Town Line • NH 84 at Hampton Falls River
Seabrook			• South Main Street (21) • NH 286 (22)	• Centennial Rd • NH 1A @ NH 286 • NH 1A between River St and Andover St.
Exeter			• Water Street adjacent to Swazey Pkwy (23)	• Water Street Between Dewey St and Spring St
Stratham			• Squamscott Rd (24)	• NH 108 at Squamscott River

Map 4.1: Identified Sites of Inundation on the Transportation Network



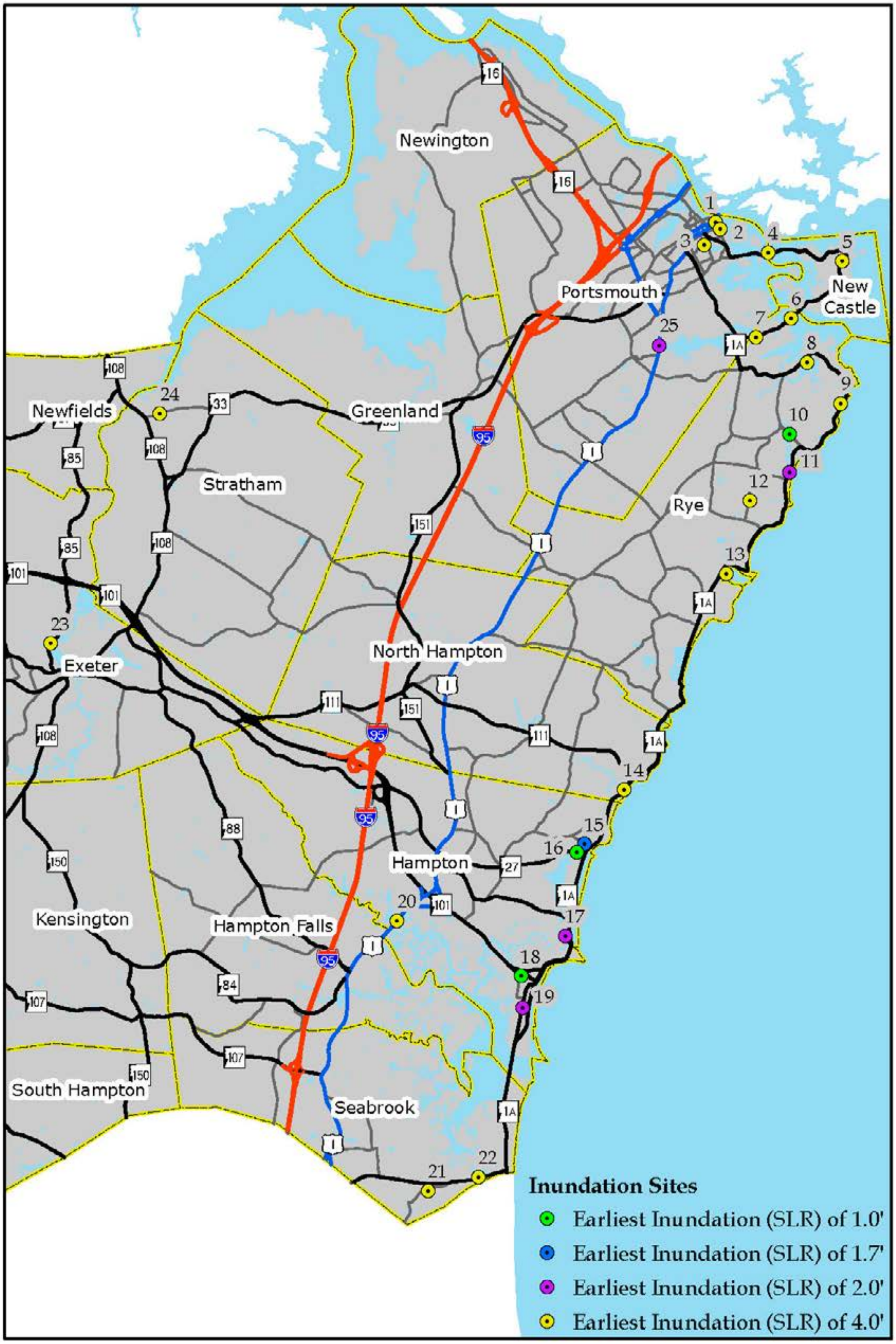
4.2 Site Prioritization

Utilizing the process described in Section 3.3, the RPC scored all sites identified in the 1.0 foot, 1.7 feet, and 4.0 feet of SLR scenarios. Because the Regional Travel Demand Model was unable to complete the analysis for the 6.3 feet of SLR scenario, the decision was made to keep the sites prioritized for the development of adaptation options consistent with those where travel demand model and network impact analysis results are available. For that reason, the prioritization results included in Table 4.2 are inclusive of the SLR scenarios up to 4.0 feet. The 25 sites are shown in Map 4.2 (page 27). The full scoring details are included in Appendix A.

Table 4.2: Initial Scoring Results against Criteria

Site #	Community	Roadways	Overall score (0-50)	Draft Priority
20	Hampton	US 1 through the Hampton-Seabrook Estuary	40.0	1
22	Seabrook	NH 286 over the Blackwater River in the Hampton-Seabrook Estuary	39.5	2
19	Hampton	Ashworth Ave in Hampton Beach	38.0	3
18	Hampton	NH 101 in Hampton Beach including Highland Ave, Church St, and Brown Ave	37.6	4
16	Hampton	High St near the intersection with NH 1A	37.5	5
1	Portsmouth	State St near the Memorial Bridge	36.5	6
5	New Castle	NH 1B near Neals Pit Lane	34.5	7
7	Rye	NH 1B near Portsmouth Marina	34.5	8
2	Portsmouth	Marcy St near Prescott Park	34.0	9
6	Rye	NH 1B near Sanders Poynt	34.0	10
24	Stratham	Squamscott Rd near NH 108	34.0	11
4	Portsmouth/ New Castle	NH 1B (New Castle Ave/Portsmouth Ave)	33.0	12
17	Hampton	Winnacunnet Rd and NH 1A	32.9	13
3	Portsmouth	Junkins Ave and Parrott Ave	32.2	14
14	North Hampton/ Hampton	NH 1A Near North Hampton State Beach Park and south	31.0	15
25	Portsmouth	US 1 over Sagamore Creek	31.0	16
13	Rye	NH 1A Near Rye Harbor including Locke Rd	27.8	17
23	Exeter	NH 85 (Water St) near Swazey Parkway	27.0	18
8	Rye	NH 1A north of Odiorne Point	26.5	19
21	Seabrook	South Main St	26.5	20
11	Rye	NH 1A and Wallis Rd	25.3	21
12	Rye	Brackett Rd south of Wallis Rd	24.5	22
10	Rye	Marsh Rd and Parsons Rd	24.0	23
9	Rye	NH 1A south of Odiorne Point	22.0	24
15	Hampton	Cusack Rd	20.0	25

Map 4.2: 25 Sites Included in Prioritization Process



Based on the initial scoring, RPC coordinated comments and discussions regarding the sites between NH Department of Transportation, the NH Coastal Program, and the project team. These discussions included consideration of site-specific factors, the understanding of other ongoing analysis, and specific priorities identified by project partners. Specifically included were consideration of:

- The recently completed Hampton Harbor and Meadow Pond Flood Studies
- Ongoing NHDOT study of NH 1B bridges and causeways
- Ongoing analysis of coastal revetments
- Concerns about the viability of transportation solutions due to substantial adjacent development
- The viability of detours around inundated locations

After the discussions regarding the considerations above, a revised list of sites prioritized for vulnerability assessments was assembled. In the end, 13 sites (Table 4.3) were selected for inclusion in the vulnerability assessment although three locations, Sites 5, 6, and 7 on NH 1B in New Castle and Rye, were considered a single site due to similarity in circumstances as well as that all three would need to be addressed to maintain access to New Castle Island. From those sites, two (highlighted in blue in Table 4.3) were chosen for more detailed case studies. The sites were chosen to broadly represent the different types of situations encountered in the region as well as a broad set of adaptation alternatives.

Table 4.3: Priority Sites for Vulnerability Assessment

Town	Site	Site number	SLR Impact level*
New Castle/ Rye	Wentworth Rd	5,6,7	4'
Rye	Marsh Rd, Parsons Rd (Case Study)	10	1'
Rye	Ocean Blvd, Wallis Rd	11	4'
Rye	Locke Rd, Ocean Blvd	13	4'
Hampton	Cusack Rd	15	1.7'
Hampton	High St	16	1'
Hampton	Ocean Blvd, Winnacunnet Rd	17	4'
Hampton	Brown Ave, Church St, Highland Ave, NH 101	18	1'
Hampton	Lafayette Rd (Case Study)	20	4'
Seabrook	South Main St	21	4'
Seabrook	Route 286	22	4'

The two sites selected for the case studies; Marsh Road/Parsons Road in Rye, and Lafayette Road in Hampton, are representative of different approaches to mitigating the impacts of SLR on the roadway network. The Rye site is an example where the impacts to other network assets may play a role in the decisions made about addressing SLR at that site, while the Hampton site is a critical component of the regional network and will need to be addressed directly to maintain function.

4.3 Scenario 1: SLR at 1.0 Feet

The data indicates that water will likely inundate the transportation network in three locations (Sites 10, 16, and 18) at 1.0 foot sea-level rise creating relatively localized traffic disruptions. Flooding is anticipated on Marsh Road in Rye and on High Street and Highland Avenue in Hampton. Marsh Road is a low-volume roadway with multiple alternative routes available, resulting in minimal disruption to traffic. High Street and Highland Avenue in Hampton are more heavily travelled, and any closures will produce a more pronounced shift in traffic patterns. In total, the Model estimates approximately 10,000 vehicle trips per day that must be re-routed around road closures under these conditions.

Vulnerable Areas

Marsh Road, Rye (Site 10): Marsh Road is inundated in the southern-most section where the roadway passes through Parsons Creek Marsh. There is one side street (Alan Court) located at the southern end of the road, and two driveways located at the northern end close to the intersection with Parsons Road. No direct traffic counts are currently available for Marsh Road but an estimate of 1,000 vehicles per day is used as a baseline volume for analysis purposes.

NH 27 (High Street), Hampton (Site 16): High Street is inundated between Mill Pond Lane and Kings Highway where the roadway passes through the Meadow Pond marsh/wetland area. The data indicates that flooding along this section of High Street would be widespread and impact all of the residential units on that segment as well as some of those that border Kings Highway such as along Gentian Road, Greene Street, and Meadow Pond Road.

NH 101 (Highland Avenue), Hampton (Site 18): The eastbound leg of NH 101 is inundated just east of Brown Avenue. The density of development is high in this vicinity and there would be twenty or more buildings with varying levels of access limitations. Given that Highland Avenue is one-way eastbound, all driveways east of the area of impact would lose access under the current roadway configuration.

Network Analysis

At 1.0 foot of SLR the network impacts are generally localized in the vicinity of the three inundated sites. Traffic is diverted around those closed roadways, however the volumes of traffic shifted are relatively small and the alternate routes do not add substantial time or distance to travel. Map 4.3 (page 32) shows the percent change in volume on each roadway under this scenario and these values should be taken to indicate the magnitude of change on the particular roadway as opposed to a precise value.

Portsmouth, New Castle, and Rye

- The closure of Marsh Road in Rye (1,000 AADT estimated) eliminates a low-volume connection from interior Rye to NH 1A near Wallis Sands State Park. The closure shifts traffic currently using Marsh Road to Wallis Road and Parsons Road as alternative routes. The Model does not include the easterly portion of Parsons Road and so those redirects traffic to Wallis Road to access Bracket and Sagamore Roads. Clark Road would also be expected to see a modest increase in volume as well.
- Current volumes on NH 1A between Foye's Corner and Bracket Road in Rye are over 3,600 AADT with historic count data showing peak summer volumes of near 10,200 vehicles per day. Flooding on Marsh Road will re-route much of the traffic away from the northern segment of Bracket Road and towards Sagamore Road. This results in an approximate 27% decrease in volume on this section of NH 1A to approximately 2,600 vehicles per day.
- South of Marsh Road, NH 1A traffic volumes in Rye are estimated to increase as traffic that would have used Marsh and Parsons Roads now use Wallis and Bracket Roads to move to/from the coast. Current volumes are about 2,100 AADT with summer peaks of around 6,300 vehicles per day. Under this scenario, daily averages would increase approximately 50% to 3,200 with summer peaks approaching 9,500 vehicles.

North Hampton, Hampton, and Seabrook

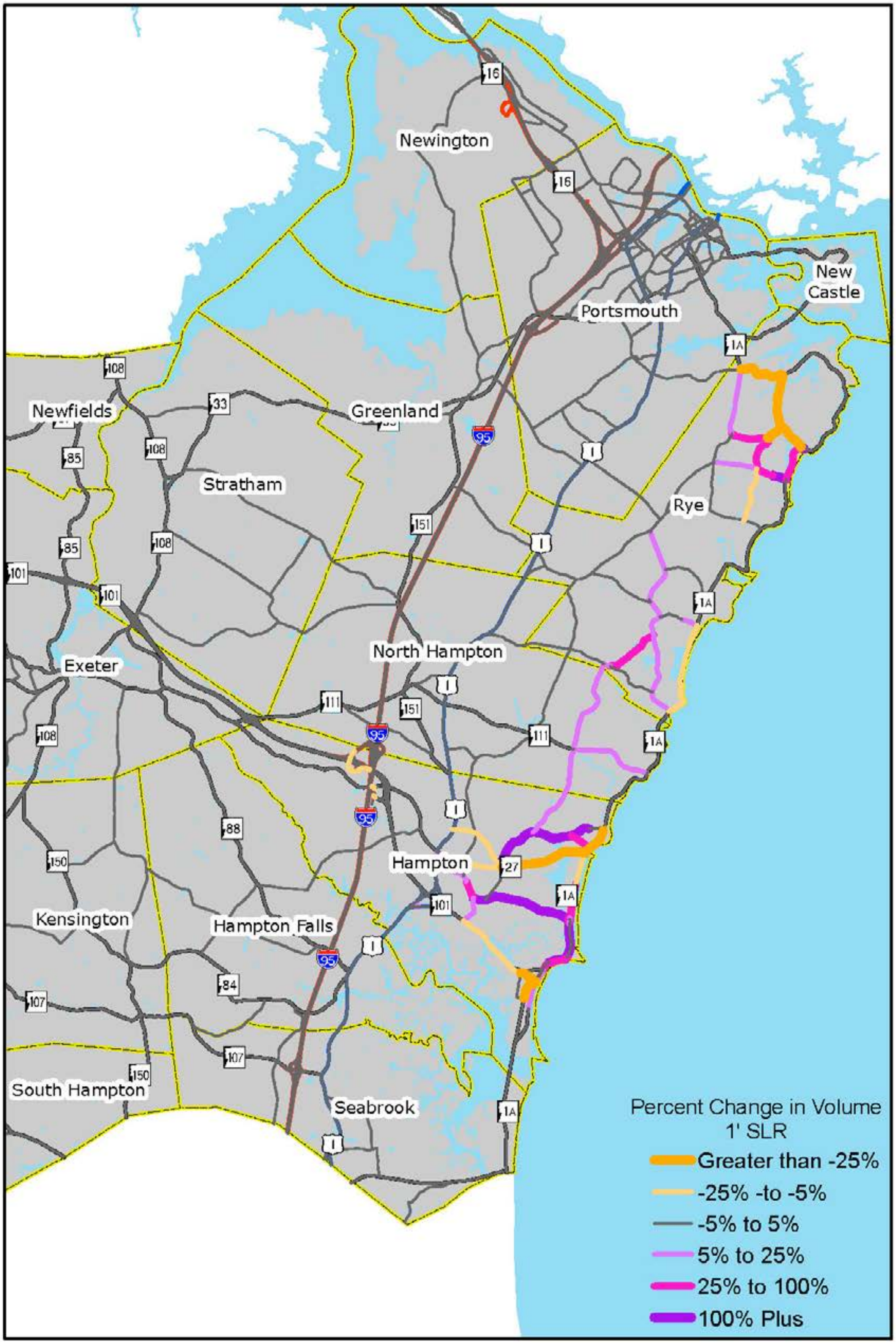
The closure of High Street (5,600 AADT) and Highland Avenue (3,300 AADT) in Hampton will impact access to Hampton Beach and creates a more widespread disruption in traffic than seen in Rye around Marsh Road. Under this scenario, traffic on the inundated segments of High Street and Highland Avenue drop to near zero and are re-routed to Winnacunnet Road and Brown Avenue. This also impacts traffic volumes along NH 1A as it is redistributed based on the remaining access points to Hampton Beach.

- The Model indicates a 22% reduction in traffic on the eastbound portion of NH 101 just west of Brown Avenue in Hampton. This shifts traffic US 1 and Landing Road to connect to Winnacunnet Road to access the coast.
- The traffic that continues to use NH 101 eastbound would likely use a combination of Brown Avenue and Island Path to access the coast. The analysis estimates that this change

would add approximately 2,000 vehicles per day to Brown Avenue, bringing the AADT up to approximately 6,000 vehicles. Island Path is not included in the Model but serves as a connection between Brown Avenue and Ashworth Avenue in Hampton Beach and would likely also see an increase in traffic. The roadway currently carries around 2,600 vehicles per day and would be expected to increase to almost 4,000 vehicles per day in this scenario.

- The combination of impacts to High Street to the north and Highland Avenue to the south increases Winnacunnet Road's importance for coastal access in Hampton. The road currently averages just over 4,000 AADT (2019) just west of NH 1A, however, summer traffic can be closer to 6,000 vehicles per day. The segment west of Landing Road shows an increase of 23-27% while the segment east of Landing Road shows 113-166% increase in volume. This would increase the AADT to approximately 6,600 vehicles per day and peak daily volumes to around 10,000 vehicles.
- Traffic counts on North Shore Road (1,200 AADT in 2017), Woodland Road (1,437 AADT in 2019) and Cusack Road (900 AADT in 2018) in the northern part of Hampton indicate that those are low-volume roads primarily utilized for local circulation. Summer volumes are only slightly higher than the annual average, approaching 2,000 vehicles per day at times. Model outputs indicate a roughly 200% increase in traffic on these roadways which would translate to approximately 4,000 vehicles per day on North Shore and Woodland Roads. On Cusack Road, the Model indicates an approximately 30% increase in volume as most trips use North Shore Road to connect to NH 1A. That estimate could be on the low end as Cusack Road would provide more direct access to NH 1A in this area.
- Woodland Road, which connects Hampton and North Hampton, currently carries approximately 1,000 AADT (2017) south of NH 111, and about 840 AADT north of NH 111. This scenario would increase traffic by approximately 12% south of NH 111 and 8% north of NH 111 adding another 120 vehicles and 60 vehicles respectively.
- NH 111 (Atlantic Avenue) currently carries approximately 4,200 AADT on the segment east of Woodland Road in North Hampton. The Model indicates a small increase in volume (9%) under this scenario which would add roughly 400 vehicles per day increasing the AADT to about 4,600.

Map 4.3: Percent Change in Traffic Volume on Network Roads at 1.0 feet Sea-Level Rise



4.4 Scenario 2: SLR at 1.7 Feet

The 1.7 feet of SLR scenario indicates seven inundated roadways grouped into four sites (10, 15, 16, 18) for this analysis. The area of inundation at Marsh Road in Rye expands to include portions of Parsons Road. In Hampton, Cusack Road is added, and the Highland Avenue (eastbound NH 101) site expands to include Brown Avenue and Church Street (westbound NH 101). Closure of Cusack Road produces minimal disruption while the combination of inundation on Highland Avenue, Church Street and Brown Avenue creates a significant disruption in traffic patterns and access to Hampton. This scenario is the first where larger regional effects on traffic patterns begin to occur and disrupts approximately 20,000 vehicle trips on the coastal network.

Vulnerable Areas

Marsh Road/Parsons Road, Rye (Site 10): The inundated area expands beyond the 1.0 foot impacted area and extends to include the portion of Parsons Road just south/east of the Brackett Road intersection adjacent to Marsh Road Pond. This will likely impact a few houses on that segment and potentially isolate them or force them to use the eastern segment of Parsons Road to access their properties.

Cusack Road, Hampton (Site 15): Cusack Road is a low volume street connecting North Shore Road NH 1A just north of High Street and travelling through the same tidal marsh area. Development is largely residential and clustered on each end of the street with open space through the wetland area. The flooding of this roadway would have limited direct impacts on accessibility to adjacent land uses.

NH 27 (High Street), Hampton (Site 16): No functional changes at this site between the 1.0 foot scenario and this one. The area of flooding increases somewhat inundating additional houses and properties.

NH 101 (Highland Avenue/Church Street/Brown Avenue), Hampton (Site 18): The inundated area expands to include a longer segment of Highland Avenue and portions of Church Street. This precludes any direct access or egress to/from the coast via NH 101 as well as saturating nearby residences and businesses. On Brown Avenue, inundation occurs in the vicinity of Diane and Susan Lanes, impacting multiple homes and precluding through traffic using this roadway to connect between NH 101 and Ashworth Avenue. Inundation in this area would also limit access to the Hampton Police Beach Precinct and Beach Fire Station and potentially impact emergency response times.

Network Analysis

The expansion of the Marsh Road site in Rye to include Parsons Road at 1.7 feet of SLR has similar traffic impacts to the 1.0 foot scenario. In Hampton however, flooding on NH 101 constrains access to Hampton Beach. In all, approximately 20,000 trips per day are disrupted in this scenario, or double what is observed in the 1.0 foot scenario. The increased volume of disrupted traffic creates expansive and widespread impacts on the network and volumes on some roads could require capacity and safety improvements to remain functioning at current conditions. Map 4.4 shows the percent change in volume on each roadway under this scenario and these values should be taken to indicate the magnitude of change on the particular roadway as opposed to a precise value.

Portsmouth, New Castle, and Rye

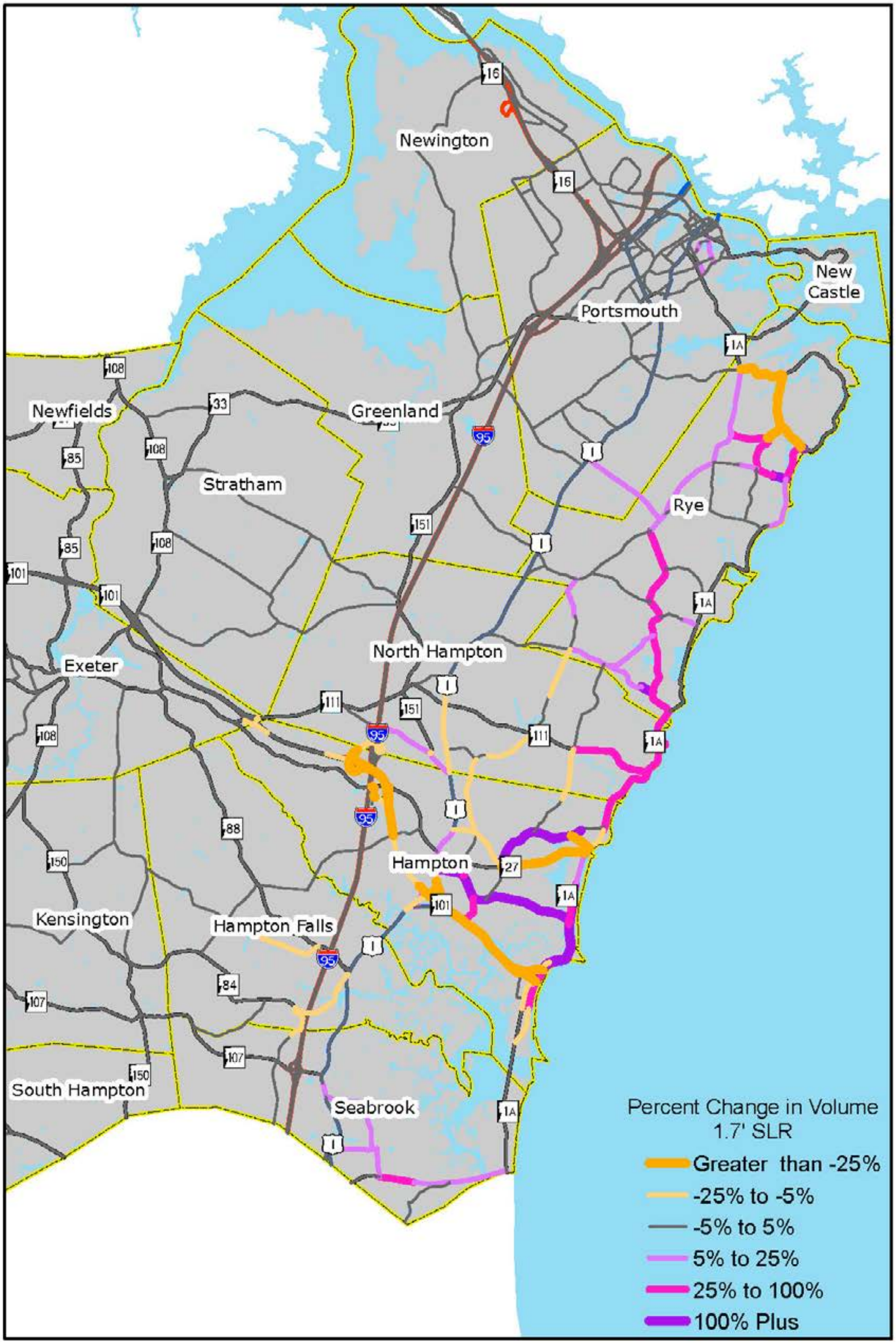
- The expansion of inundation to incorporate Parsons Road in addition to Marsh Road does not substantially change the traffic pattern in that area of Rye from what is expected at 1.0 feet SLR. The surrounding roadways show volumes and percent volume changes similar to the 1.0 foot scenario.
- There are some observed changes in central Rye. Lang Road (+18%) and Central Road (+15-80%) see higher volumes. This may reflect changing traffic patterns from closures which result in these other routes becoming the more efficient pathways remaining to the coast for access from the north.
- South of Central Road, there is a sharp increase in traffic volume (68%) on NH 1A. The only recent traffic count available on NH 1A in Rye is south of Central Road at the North Hampton Town Line and shows a 2019 AADT of just over 3,900. Increasing those volumes by 68% would create an average of around 6,600 vehicles per day and would see summer peak volumes that could exceed 10,600 vehicles per day.

North Hampton, Hampton, and Seabrook

- The Travel Demand Model does not include Island Path and this results in some counter-intuitive traffic patterns in Hampton under this scenario. The model focuses traffic on Winnacunnet Road and NH 286 in Seabrook. However, inundation would not prevent traffic on NH 101 from using the northern portion of Brown Ave and then switching to Island Path to access Ashworth Avenue. This would place approximately 9,000 vehicles per day on Island Path which is about a 250% increase over current volumes.
- Inundation on NH 101 (Highland Ave, Church Street), and NH 27 (High Street) leaves Winnacunnet Road as the most direct route to and from Hampton Beach. The portion of Winnacunnet Road west of Landing Road shows an increase of up to 133%, while east of Landing Road a much greater increase in volumes is expected. Model outputs indicate a 682% growth in traffic which would increase the AADT to over 32,000 vehicles per day with peak summer volumes pushing over 45,000 vehicles per day. This seems unrealistically high compared to current volumes but should be considered indicative of the change in role for that roadway if both NH 101 and NH 27 are unavailable for travel to the coast. Any change to traffic on Winnacunnet Road that increases volume to over 20,000 vehicles per day would likely require a set of improvements to address driveway and side street access, safety and intersection capacity.
- Removing NH 101 access to Hampton Beach shifts a significant portion of that traffic to NH 286 in Seabrook. NH 286 currently carries 14,300 (2019) AADT with volumes close to 18,600 vehicles observed during summer peak traffic. That volume would expect to increase by approximately 28%, growing to 18,300-23,800 vehicles per day. This could create some capacity issues at the NH 1A/NH 286 intersection and potentially at the US 1/ Route 286 intersection in Massachusetts. Driveway and side street access could also become challenge at these higher traffic volumes.
- Rerouting some of the NH 101 south traffic to utilize NH 286 would also increase volumes on US 1 in Seabrook by 15% in the area south of NH 107. The roadway currently carries 18,300 (2018) AADT with peak volumes topping 29,000. These volumes would expand to 21,000 AADT and 33,600 peak days which may require some improvements to mitigate congestion and delay along the corridor.
- Higher traffic volumes are expected along the North Hampton portion of NH 1A reflecting the additional importance of NH 111 as a route to the coast. Volumes on this segment of NH 1A averaged just under 5,300 AADT (2017) and this SLR scenario estimates a 68% increase in volume. This translates to 8,900 vehicles per day and peak volumes of approximately 14,000 vehicles per day.

- NH 1A in Hampton shows traffic concentrating in some areas and declining in others reflect how the closure of multiple east-west routes changes the distribution of traffic:
    - A 60% increase (to approximately 9,200 AADT) between North Shore Road and the North Hampton town line.
    - A 15-25% decrease between High Street and North Shore Road reflecting the shift from High Street and Cusack Road to North Shore Road and NH 111 in North Hampton. This brings the volumes down to about 4,300 AADT.
    - An 80% increase north of Winnacunnet Road and a much greater increase (275%) south of Winnacunnet as that roadway becomes the primary access point to Hampton Beach. Volumes south of Winnacunnet could approach 30,000 AADT under this scenario.
- NH 111 (Atlantic Avenue) begins to see higher traffic volumes as other coastal access points are closed. AADT on Atlantic Avenue east of Sea Road is just under 1,900 (2017) but summertime volumes can approach 5,000 vehicles per day. Under this scenario, traffic east of Woodland Avenue is expected to increase by approximately 70%, increasing AADT to approximately 3,200 and summer peaks to around 8,300 vehicles per day. This volume of traffic should be well within the capacity of the roadway but may increase delays for left turns and side street access. Consideration may also need to be given to introducing turn lanes at intersections.
- Little River Road, Woodland Road, and North Shore Road together provide an alternate route to NH 27 (High Street) for localized traffic in Hampton. With NH 27 closed under this scenario, those roadways experience a large increase in traffic volume as they form the only way to the coast in Hampton other than Winnacunnet Road. Traffic on the Little River Road/ Woodland portion shows the same increase as under the 1.0 foot SLR scenario (200%) to approximately 4,200 vehicles per. North Shore Road, however, receives the traffic that would have previously used Cusack Road and the Model indicates it will raise volumes from 1,200 to 3,600 vehicles per day.

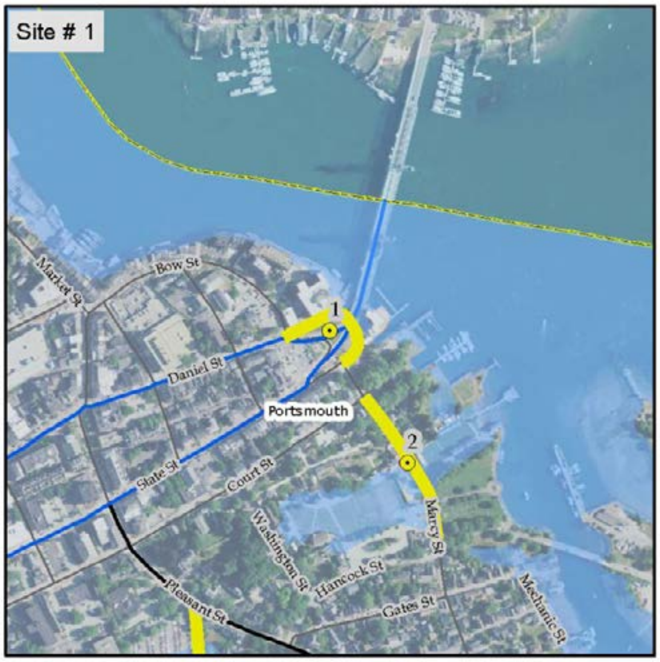
Map 4.4: Percent Change in Traffic Volume on Network Roads at 1.7 feet Sea-Level Rise



4.5 Scenario 3: SLR at 4.0 Feet

The impacts of 4.0 feet of SLR on the transportation network are widespread and inundation sites are seen beyond Hampton, Rye, and the immediate coast for the first time. Twenty-five sites of inundation have been identified on the Model network and, importantly, this impacts 15 of the 22 east-west pathways to the coast of New Hampshire, as well as multiple locations along on US 1 and NH 1A making north-south travel challenging. The restricted access to the coast and number of closed roadways disrupts about 108,000 trips per day as all but a few connections in the Travel Demand Model are severed.

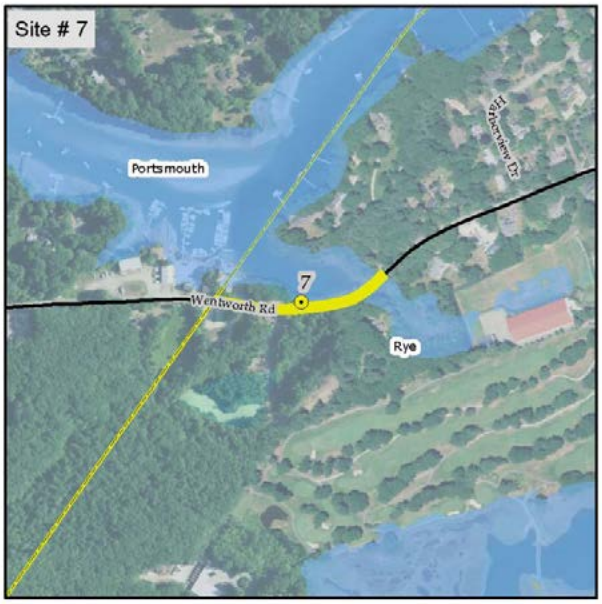
Vulnerable Areas



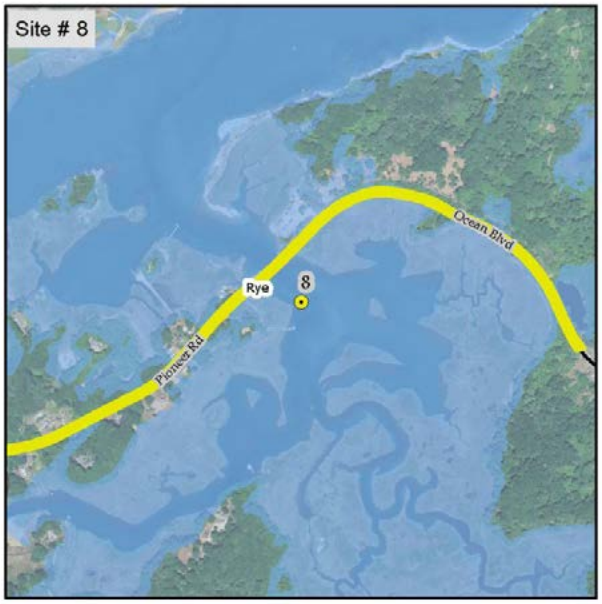
Portsmouth City Streets (Sites 1, 2, and 3): 4.0 feet of SLR brings inundation to Junkins Avenue, Parrott Ave, Marcy Street, and State Street/ Daniel Street. The segment of roadway underneath the Memorial Bridge ramp (Site 1 – State Street/Daniel Street) is inundated and traffic will need to be re-routed. Flooding along Marcy Street (Site 2) limits access to Prescott Park, Strawberry Banke, Pierce Island, as well as all of the many homes and businesses along the waterfront between Pierce Island Road and New Castle Avenue. Impacts around the South Mill Pond affect Junkins and Parrott Avenues (Site 3) and limit accessibility to City Hall, the Public Library, and the Middle School.

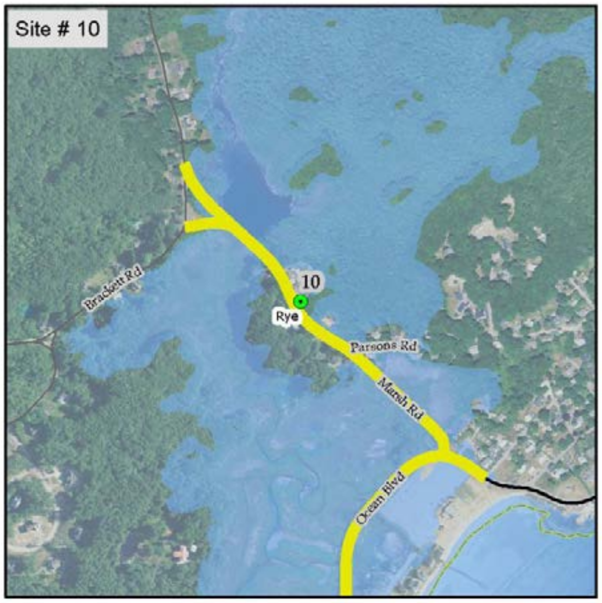
US 1 at Sagamore Creek, Portsmouth (Site 25): The area where US 1 crosses Sagamore Creek in Portsmouth currently sees frequent inundation of the adjacent businesses. At 4.0 feet of SLR this begins to impact US 1 as well and closes this segment requiring up to 25,000 vehicles per day to use alternate routes. Most development at this location is currently outside the flood zone and the area impacted is relatively small and primarily limited to the shopping center southwest of the existing bridge over Sagamore Creek.

NH 1B in Portsmouth, New Castle, and Rye (Sites 4, 5, 6, and 7): NH 1B is inundated in several locations along its length. New Castle Avenue between Marcy Street and the bridge to Shapleigh Island (Site 4) is inundated from the north and from the south potentially isolating approximately 50 residences in Portsmouth as well as those on Shapleigh and Goat Islands. In New Castle, the causeway between Goat and New Castle Islands is overtopped and a culvert that crosses under NH 1B and Neals Pit Lane (Site 5) will be fully under water causing NH 1B to be flooded as well. Further south in Rye, water will encroach on the roadway at a low point near Sanders Poynt (Site 6) and the Wentworth Golf Course. Finally, the low section of roadway just west of the Portsmouth Marina (Site 7) will be inundated as well. These sites eliminate ccess to New Castle Island and given the inundation at Neals Pit Lane, effectively segment the island into two. This isolates the approximately 1000 New Castle residents as well as 30-40 homes in Rye, the Wentworth Country Club, the Wentworth Hotel, Great Island Common and the Fort Start Historic Site.



NH 1A , Rye (Sites 8, 9, 11, and 13):
There are multiple locations inundated along NH 1A in Rye. The section between the Odiorne Point Boat Launch and Odiorne State Park (Site 8) , between Odiorne State Park and the Davis Road/The Breakers neighborhood (Site 9), between Marsh Road Concord Point (Site 11), between Washington Road, Rye Harbor, Locke Road and Cable Road (Site 13). These closures will impact a substantial number of homes and businesses as well as limit access to Odiorne Point State Park, the Seacoast Science Center, Rye Harbor, and Wallis Sands Beach Park among others.

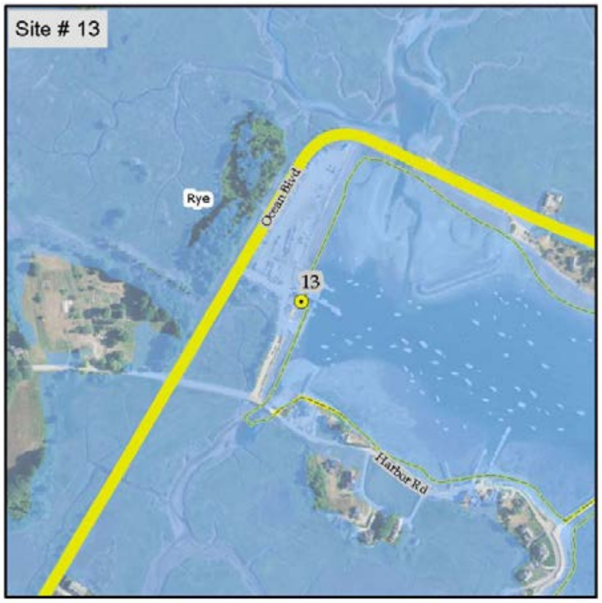




Marsh Road and Parsons Road, Rye (Site 10): The inundated area expands further to affect Parsons Road just east of the intersection with Brackett Road and combined with impacts to NH 1A, isolates many of the residences on Marsh and Parsons Roads.

Wallis Road and NH 1A, Rye (Site 11):
The eastern-most portion of Wallis Road floods where it passes through Wallis Marsh and this severs the connection to NH 1A. NH 1A travels alongside the marsh for much of this section and is expected to be inundated at multiple points. The flooding at Wallis Road occurs in a largely undeveloped section however there are likely impacts to houses and businesses adjacent the wetlands along Appledore Ave to the west and along NH 1A to the east.

Brackett Road, Rye (Site 12): The southernmost section of Brackett Road between Wallis Road and Washington Road is inundated under this scenario. There are a few houses that are impacted at this site and this eliminates a local north-south route that runs parallel to NH 1A between Washington Road and Wallis Road.



NH 1A, North Hampton and Hampton (Site 14): In North Hampton, the land NH 1A sits on tends to be somewhat higher and impacts are limited to the area between Sea Road and the town line with Hampton. This does isolate North Hampton Beach Park and a number of houses along NH 1A as well as in some adjacent cul-de-sacs in that area. The area of inundation continues south to approximately Noreast Lane in Hampton and potentially isolates the houses in that neighborhood as well.

Cusack Road, Hampton (Site 15): Flooding of this roadway is somewhat more extensive than seen at 1.7 feet SLR and nearly extends to NH 1A. Additional nearby houses and businesses are impacted however this does not change anything from the perspective of roadway functionality.

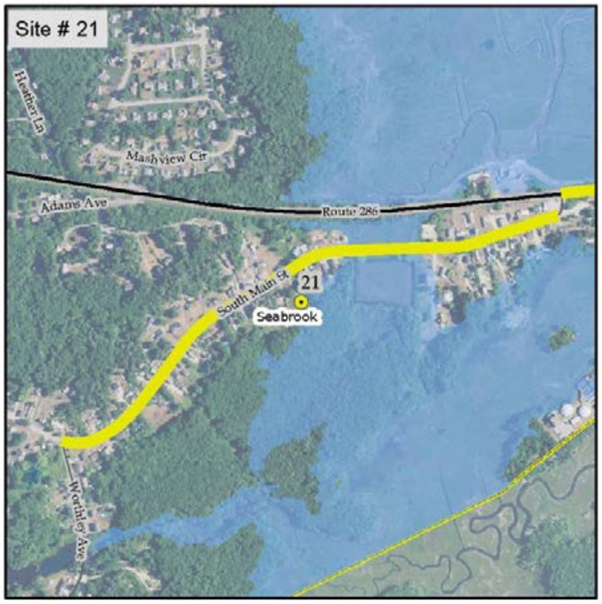
High Street, Hampton (Site 16): 4.0 feet of SLR sees flooding extending into the neighborhoods adjacent to Meadow Pond and impacts Kings Highway and all the neighborhood to the west and some of the area to the east. More of High Street is flooded but functionally little changes from the 1.0 foot or 1.7 feet SLR scenarios.

Winnacunnet Road, Hampton (Site 17): Winnacunnet Road is inundated between Viking Street and the intersection with NH 1A making much of the development in that area inaccessible. At this level of flooding, everything along Winnacunnet Road from NH 1A to Viking Street is inaccessible. Flooding touches on NH 1A at the intersection with Winnacunnet Road and potentially eliminates southbound travel between there and Great Boars Head. At Great Boars Head, water is expected to be entirely over NH 1A restricting travel in both directions and restricting access to that neighborhood.

NH 101 Corridor (Site 18): The area of NH 101 impacted begins in Hampton near Glade Path on the approach to Hampton Beach, continues through the intersection with Brown Avenue, and extends approximately 50% of the distance between Brown Avenue and NH 1A along both Highland Avenue and Church Street. The flooding also includes a large portion of Brown Avenue and Island Path and limits access to almost everything west of Ashworth Avenue.

Ashworth Avenue (NH 1A southbound), Hampton (Site 19): Ashworth Avenue is inundated in several locations between Island Path and Q Street. This eliminates southbound travel (current configuration) and isolates the extensive development to the west of the roadway as well as some of the houses and businesses to the east.

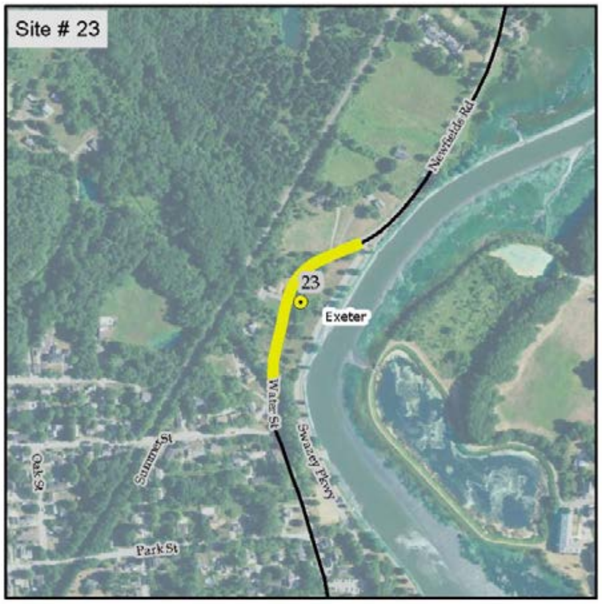
US 1, Hampton (Site 20):
Located just south of the interchange of US 1 and NH 101, this section of US 1 is low-lying and currently experiences occasional storm and extreme high tide flooding where the roadway passes over the Taylor River and through the Hampton-Seabrook Estuary. Development along this section of US 1 is sparse due to the surrounding wetlands and limited upland however several businesses will be impacted by any flooding in that area. Carrying 25,000 AADT, the closure of this roadway has significant impacts on the transportation network.



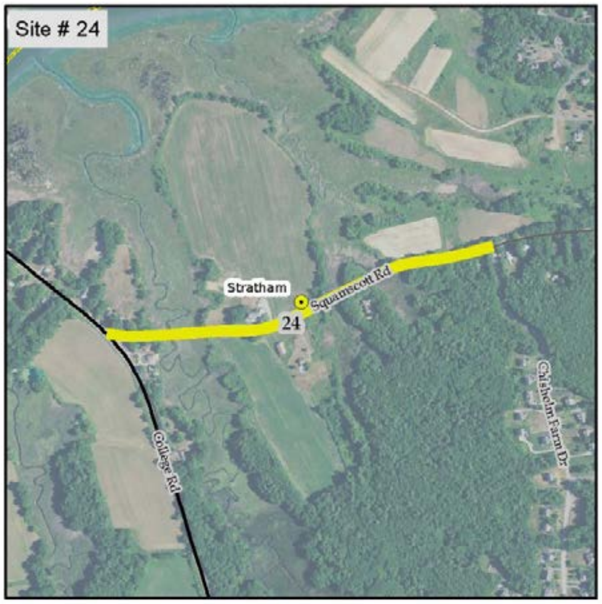
South Main Street, Seabrook (Site 21): The flooded location on South Main Street, approximately 0.2 miles west of the eastern intersection with NH 286, cuts that street into two segments. Much of South Main Street is accessible via the western connection to NH 286 while a small segment with a few homes and other properties is only accessible via the eastern connection to NH 286. The location of the inundation should not impact any homes directly but eliminates this roadway as a through road and a connection to Salisbury, MA**.**

NH 286, Seabrook (Site 22): The southern-most east-west connection to NH 1A is inundated where it passes over the Blackwater River and the Hampton-Seabrook Estuary. This closure, combined with those in Hampton, isolates the hundreds of houses and businesses along Seabrook beach in Hampton and Seabrook.

Water Street, Exeter (Site 23):
Water Street is inundated between Summer Street and the Swazey Parkway where the roadway crosses over Norris Brook. This divides the northern portion of this street from the southern and somewhat isolate a few houses, the public works facility, and the sewer treatment plant from the remainder of the downtown area and require vehicles to reroute using NH 101.



Squamscott Road, Stratham (Site 24): Squamscott Road is flooded where the roadway crosses Jewell Hill Brook just east of NH 108. This roadway is a popular bypass of the Stratham Circle for traffic moving between NH 108 to the north and NH 33 to the east. Closing the roadway at that location would have minimal direct impacts on residences or businesses but forces more traffic through Stratham Circle.



Network Analysis

4.0 feet of SLR limits the functionality of the transportation network in the coastal region due to the widespread number of impacted road segments and many locations that are potentially inaccessible. Twenty-five (modeled) sites are directly impacted including many of the primary access ways to the coast. In total, of the 22 primary east-west pathways to the coast, 15 are expected to be inundated by 4.0 feet SLR, including access to New Castle Island, much of the coastline in Rye, as well as Hampton and Seabrook Beaches. Further, north-south travel is also limited due to inundation at more than 10 locations along NH 1A and two on US 1. Map 4.5 shows the percent change in volume on each roadway under this scenario and these values should be taken to indicate the magnitude of change on the particular roadway as opposed to a precise value.

Portsmouth, New Castle, and Rye

- The impacts to US 1 at Sagamore Creek (Site 25) in Portsmouth create a shift in the traffic pattern as the 20,000-25,000 vehicles that currently use that roadway must be rerouted:
    - The model indicates a 21% increase in volume over current conditions on Sagamore Road (northern terminus of NH 1A in Portsmouth). That road currently carries 7,100 AADT and the closure on US 1 would increase that to roughly 8,500 vehicles per day.
    - Much of the US 1 traffic is redirected to Greenleaf Avenue, relatively low-volume connector street between the US 1 Bypass and Peverly Hill Road. The estimated current volumes on Greenleaf Avenue are 4,800-6,500 AADT and the closure on US 1 would increase volumes by almost 150% to 11,900-16,100 vehicles per day. This volume is large enough to create congestion and safety issues along that roadway.
    - The model indicates that as part of the detour around the closure on US 1, Peverly Hill Road would see a 166% increase in volume. Current traffic counts show an AADT of 9,500 (2019) with peaks approaching 12,800 vehicles. The increase indicated by the model would raise the volume to 25,300-34,000 vehicles per day. This well exceeds the capacity of that roadway and improvements would be required to maintain functionality.
    - Banfield Road, with connections to US 1 and Ocean Road in Portsmouth, shows a 42% increase in volume. The model shows the roadway increasing from 2,200 to 3,100 vehicles per day however there are no recent traffic counts available to compare making the true impact difficult to gauge.
- The impacts to Portions of Daniel/State Street (Site 1), Marcy Street (Site 2), and Junkins and Parrott Avenues (Site 3) causes traffic pattern shifts within the City of Portsmouth. The complexity of the network makes teasing out realistic changes challenging however, a few can be identified.
    - South Street would be expected to see a substantial increase in traffic volume. Current volumes on the roadway range from 3,200 (near Junkins Avenue) to 7,400 (near Middle Road) AADT. The area around Junkins Ave shows a 47% increase in volume to roughly 4,700 vehicles per day while the segment near Middle Road shows a small decrease to under 7,000 vehicles per day as more vehicles utilize Sagamore Avenue instead.
    - Penhollow Street shows a 57% increase in traffic and Richards and Miller Avenues see large increases as well (22-52% and 17-22% respectively). There are no counts on these roadways to compare against however model volumes indicate numbers in the hundreds with the exception of Miller Avenue which shows a baseline volume of approximately 3,800 which increases to about 4,700 vehicles per day in this scenario.
- Both approaches to New Castle (Sites 4, 6, and 7) are inundated making NH 1B, New Castle Island, and the adjacent portion of Rye potentially inaccessible by motor vehicles from either direction. The Model indicates a 96% reduction in volume on NH 1B on New Castle Island as it is limited to local circulation on the island only. In addition, flooding at the eastern intersection

of Neal Pit Lane and NH 1B (Site 5) splits the transportation network on the island.

- 4.0 feet of SLR fragments NH 1A in Rye due to inundation in multiple locations. Traffic is essentially eliminated from NH 1A around Odiorne Point, and from the area between Washington Road and Cable Road, including Rye Harbor. Inundation decreases volumes between Wallis Beach State Park and Concord Point by about 50% as well. In general, that traffic is shifted away from NH 1A to parallel inland roads in Rye and North Hampton:
    - o Sagamore Road shows a 9-14% increase in Rye which would raise AADTs to the 4,100 vehicles per day range.
    - o Long John Road shows a 29% increase to approximately 1,000 vehicles per day (model volume not AADT)
    - o West Road indicates a 10-35% increase to about 2,000 vehicles per day (model volume not AADT)
    - o Love Lane increases by 220% To just over 1,000 vehicles per day (model volume not AADT).
    - o Woodland Road shows an estimated 86% increase in volume in North Hampton and Rye which would bring this roadway to 1,500-1,900 AADT
- NH 1A between Cable Road in Rye and Atlantic Avenue (NH111) in North Hampton remains accessible. This stretch is densely populated and includes Jenness Beach making it likely that traffic would increase in this area as one of the few remaining accessible beaches in New Hampshire. This impact cannot be estimated within the current analysis however due to model limitations.
- Brackett Road (Site 12) in Rye shows a 100% decrease in volume from 250 vehicles per day to zero due to the inundation in that segment. Given that most of the houses on that roadway are still accessible, the actual volume drop would not be 100% but would still remove most of the traffic. There are no current counts available on this section making gauging the impacts of this closure difficult to place into context with observed volumes.

North Hampton, Hampton, and Seabrook

- The closure of NH 1A in North Hampton near North Hampton State Beach Park pushes traffic to Woodland Road which shows a 125% increase in volume on the portion south of Atlantic Avenue (to about 2,400 AADT) and an 86% increase on the portion north of Atlantic Avenue to about 1,500 AADT.
- Closures on US 1 South of NH 101 (Site 20), NH 101 as it approaches the coast (Site 18), Brown Avenue, Ashworth Avenue (Site 19), and Ocean Boulevard severely disrupt traffic patterns in Hampton compared to current conditions. Combined with the closure of NH 286 in Seabrook (Site 22), it becomes impossible to access most of the coast in Hampton. Closures on NH 1A limit the accessible areas of the coast to between Winnacunnet Road and the Hampton/North Hampton town line.

- North Shore Road becomes the only way to access NH 1A in Hampton and all the regional traffic to the coast is focused onto that roadway. The model indicates a nearly eight thousand percent increase in volume, and while this is partially due to the very low baseline volume (50 vehicles per day), the roadway would be expected to carry much of the traffic that is currently using NH 101, High Street, Winnacunnet Road, and Cusack Road and potentially NH 286. Current volume totals for those facilities are approximately 34,000 AADT with summer peak volumes approaching 53,000 vehicles per day. The roadway is not designed for this volume of traffic.
- Little River Road becomes the main conduit of traffic to North Shore Road and the coast and shows volume increases accordingly. The model indicates a nearly 700% increase in volume which, applied to observed AADT data, would increase traffic on that street to nearly 11,000 vehicles per day and just over 19,000 during peak summer traffic. Like North Shore Road, the street is not designed for that volume of traffic and substantial upgrades would be required to support the increase.
- The US 1 closure south of the NH 101 interchange (Site 20) shifts traffic to I-95 and a combination of NH 88 and local roads to maintain north-south travel
  - NH 88 traffic increases 96% to nearly 8,000 AADT, while Brown Road and Towle Farm Road increase by about 87 percent to 4,500 AADT. In Hampton, the section of NH 27 between Towle Farm Road and US 1 increases 30% to 14,700 AADT.
  - I-95 shows a 6% volume increase between Exits 1 and 2 which translates to an additional 5,000 vehicles per day added to the current 72,000 AADT (more during the summer) and increases on the NB Exit 2 off ramp traffic by 43% and the SB Exit 2 on Ramp by 46% adding approximately 8,000 vehicles per day to those facilities.
- NH 286, Seabrook's only east-west access to the coast, is inundated at 4.0 feet of SLR (Site 22) and removing the connection to Seabrook Beach and the coast. Traffic remains on the western portion of the roadway but is reduced 70%, to approximately 4,300 AADT, with the elimination of the beach traffic.

Exeter and Stratham (Great Bay Estuary communities)

At 4.0 feet SLR the first impacts to the communities along the Great Bay are observed with locations in Stratham and Exeter expected to experience inundation.

- Squamscott Road in Stratham (Site 24) is inundated and inaccessible. This roadway is the most direct route between NH 108 north and NH 33 east and eliminates the need to travel through the Stratham Circle for vehicles moving those directions. The Model indicates the following impacts on Stratham Circle:
  - Closing Squamscott Road results in an approximately 2,500 additional vehicles per day utilizing the Stratham Circle increasing the traffic on the Northern approach to the circle (From NH 108 north) by 25-30%.

    - Assuming that 50% of these vehicles will enter the traffic circle and want to turn onto NH 33 to travel towards Greenland and Portsmouth, the section of the circle that facilitates this movement will see a nearly three-fold increase in volume from around 700 vehicles per day to nearly 2,000. This could result in some additional congestion and delay at the circle during peak periods.
    - The westbound approach/eastbound egress along NH 33 would each see a 48% increase in volume. This could potentially create additional driveway and side street access problems on NH 33 between the circle and the Squamscott Road intersection.
- In Exeter, the inundation on Water Street near Swazey Parkway (Site 23) will disconnect NH 85 from downtown Exeter.
    - A 2018 traffic volume count indicates an approximately 6,500 AADT on this roadway. Recent construction on NH 85 provides a good indicator of how this traffic would be redirected and would utilize either NH 27 (Epping Road) or NH 108 (Portsmouth Avenue) to make this connection.
    - The model indicates very little change in traffic volume (-6%) because the location of the closure does not eliminate access to adjacent residential areas and so only through traffic is eliminated from the roadway. This is likely underestimating the impact to some degree.

4.6 Scenario 4: SLR at 6.3 Feet

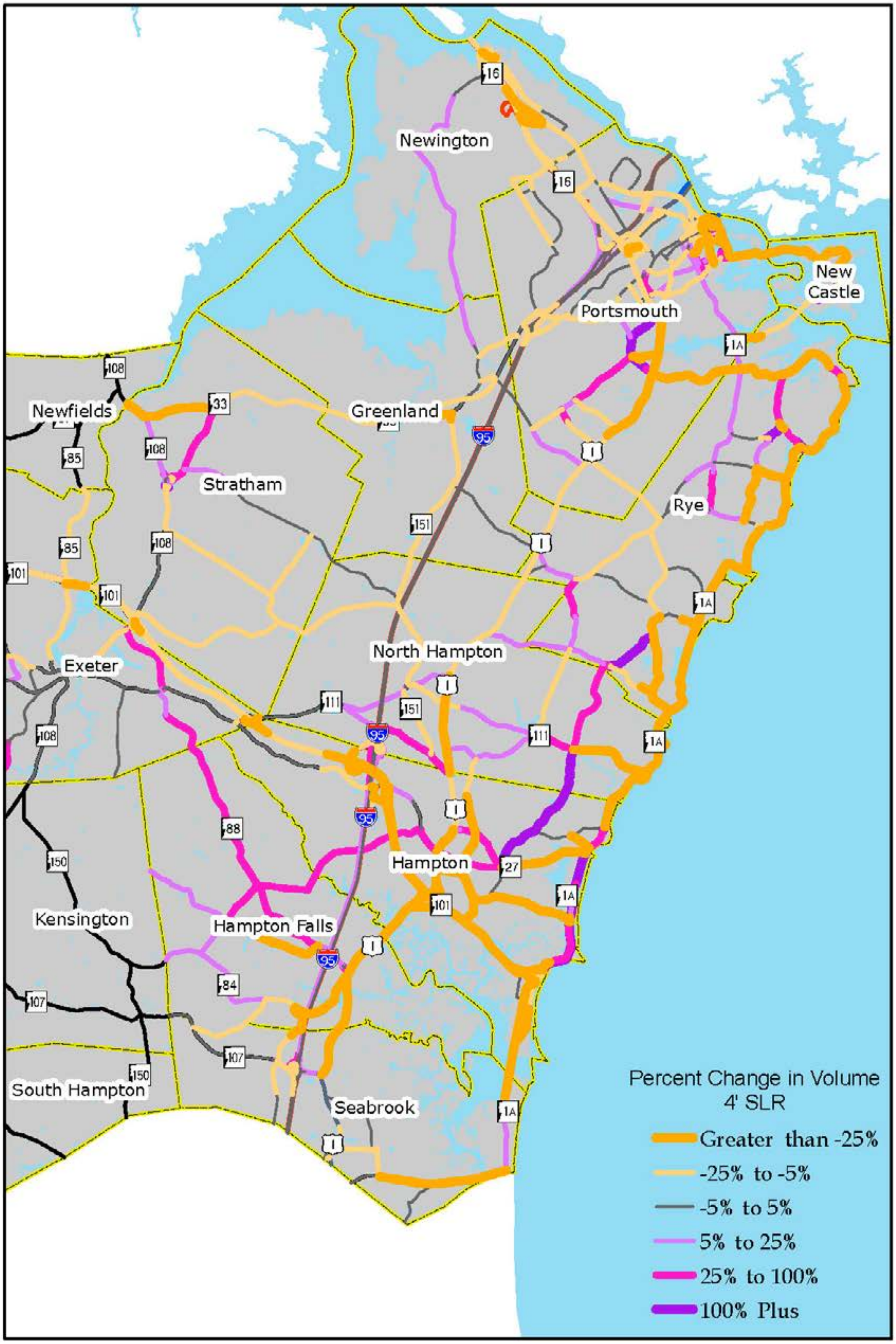
The impacts of 6.3 feet of SLR on the transportation network are substantially more widespread than observed at 4.0 feet. Over fifty sites of inundation have been identified on the model network and, importantly, this impacts 20 of the 22 east-west pathways to the coast of New Hampshire, multiple locations along on US 1 and NH 1A, and potentially even on I-95 make travel in the coastal region challenging.

Vulnerable Areas

The impacts of 6.3 feet of SLR on the transportation network expand the area of inundation at the 25 locations identified under the 4.0 foot SLR scenario, and add another 27 sites (52 total). The areas impacted are too extensive to list out individually as in the other scenarios however can be summarized as follows:

- Of the 22 east-west pathways between the interior and the coast of New Hampshire, only two remain viable options, and even then, travel north and south along NH 1A will be all but impossible. The extensive number of state and local roadways inundated limits the functioning of the transportation network along the coast and significant portions of the region are potentially inaccessible by road. At 6.3 feet of sea-level rise, only South Road in Rye and NH 111 (Atlantic Avenue) in North Hampton are available for travel.
- NH 1A is inundated at 22 locations along its length between Sagamore Road in Portsmouth and the Massachusetts border.

Map 4.5: Percent Change in Traffic Volume on Network Roads at 4.0 feet Sea-Level Rise



- There is extensive flooding within the City of Portsmouth further reducing the availability of roadways and impacting many properties. This includes parts of Market Street, the Port of New Hampshire, Maplewood Avenue, a large area around both the North and South Mill Ponds, as well as other sites.
- Much of Hampton Beach is submerged with only a narrow strip along Ocean Boulevard (NH 1A northbound) not impacted by flood waters.
- The NH 101/US 1 interchange is inundated impacting access to both facilities and extending into the adjacent neighborhood and Winnacunnet High School.
- The upper reaches of the Hampton-Seabrook Estuary extend into adjacent neighborhoods impacting Towle Farm Road, Drakeside Road, and potentially I-95 where it crosses the Taylor River.
- Around the Great Bay, Water Street in Exeter has extensive areas of flooding and NH 108 is potentially inundated where it crosses the Squamscott River near the Stratham/Newfields town line.

Network Analysis

The RPC travel demand model will not run the 6.3 feet of SLR scenario due to the large number of links with capacity reduced to zero. This causes the model to error out, as many trips cannot leave the zone of origin or reach those for which they are destined by any means. Under this scenario almost every roadway that connects to NH 1A is inundated with only NH 111 in North Hampton and South Road in Rye not directly impacted by rising water. Multiple locations along the length of NH 1A, US 1, NH 101, and numerous other roadways in the region that substantially limit travel into coastal New Hampshire to a few locations. While this is not the ideal result, it is likely indicative of the ability of people to reach the coast via the existing roadway network given that much change in sea-level.

5. Adaptation Options

The site prioritization component of this analysis was conducted for the purpose of narrowing the number of identified sites to those most critical for the development of adaptation options. The intent is that the analyses at these sites can provide a planning level assessment that can be utilized to begin discussion of options and potentially narrow alternatives. In addition, many of the options can be applied to the other inundated locations in coastal New Hampshire.

Adaptation alternatives were considered for each of the five action categories identified in the New Hampshire Coastal Flood Risk Summary, Part II: Guidance for Using Scientific Projections (2020), including: No Action, Avoid, Accommodate, Resist, and Relocate. Various alternative actions were developed for Accommodating and Resisting SLR while the options for No Action and Avoid categories were collectively determined for all of the priority sites. Assessments for the viability of Relocation were conducted on a case-by-case basis dependent upon site-specific conditions. Further, the implications of the No Action alternative need to be considered for each site, including the potential for increased maintenance requirements and costs as well as impacts from road closures on both the immediate area and the larger transportation network. The Avoid option includes a moratorium on further development (residential, commercial, etc.) at each site and no significant road upgrades or reconstruction.

5.1 Adaptation Options for Priority Locations

The Accommodate, Resist, and Relocate options for each site are summarized in Table 5.1 (page 54) and described further in the individual tables for each site included in the Site Profiles in Appendix C.   The same options for No Action and Avoid categories were determined for all the priority sites. The implications of the No Action alternative need to be considered for each site, including potential increased maintenance required and associated costs as well as impacts from road closures. The Avoid option includes a moratorium on further development (residential, commercial, etc.) at each site and no significant road upgrades or reconstruction. Generally, the adaptation options for the Accommodate and Resist categories are of the following types:

- Different Materials: Utilizing materials in the construction of roadways that are more tolerant of saturation from groundwater and can maintain structural integrity. This can also include the addition of materials, such as pavement, to maintain structure under higher groundwater saturation conditions.
- Evaluation of Culverts: Determining whether the existing drainage systems are adequate for current and future needs and that culverts are not overloaded or obstructed.

- Detours: Are there viable alternative routes available to redirect traffic around flooded areas temporarily or permanently.
- Raise Road: Increase the elevation of the roadway.
- Bridge: Replacement of a culvert in an area of inundation with a bridge to span the expected flooded area around a body of water.
- Causeway: A causeway is a raised roadway that provides passage over wetland areas and can be on raised ground or a structure.
- Berms or floodwalls: Structures installed adjacent to the roadway to keep floodwaters off the facility. Because they are vertical, they can be installed in areas with limited space for flood risk management.

There are some site-specific considerations that account for some of the adaptation options selected in this analysis.

Aspects of several sites in Hampton were included in two recently completed flood studies and the results of those efforts form the basis for the adaptation options presented in this analysis. Winnacunnet Road between Viking Street and NH 1A (Site 17) including NH 1A south to vicinity of Dumas Avenue was included in the Meadow Pond Flood study and the NH 101 connection to Hampton Beach including Highland Avenue, Church Street, and Brown Avenue (Site 18) were part of the Hampton Harbor Flood Study. The options presented from those studies are discussed in this section and included in the Site Profiles, however the associated reports should be consulted for detailed discussions of those options.

Sites 5, 6, and 7 are located at different points along NH 1B in New Castle and Rye but all are low elevation sections with tidal stream crossings. A decision was made to consider these three sites together due to the need to address all three locations to maintain access to New Castle Island at 4.0 feet of SLR and because the likely adaptation options are similar for all three.

The adaptation options listed represent a planning level examination of options at each location and need additional analysis and vetting prior to selecting an appropriate option to implement. The case studies in Section 5.2 provide an example of some additional analysis that can be conducted in this regard.

Table 5.1: Considerations for Various Adaptation Options

Town	Site	Map number	SLR Impact level*	Accommodate	Resist	Relocate
New Castle/ Rye	NH 1B at Neal Pitt Ln, near Sanders Poynt, and near Portsmouth Marina	5,6,7	4.0 feet	• Different materials • Evaluate culverts • Drain pond to west (5)	• Raise road	Limited alternate options, likely not recommended
Rye	Marsh Rd, Parsons Rd	10	1.0 foot	• Different materials • Causeway • Detour signage	• Raise road • Berms	Consider in conjunction with sites 8 & 9 with respect to timing
Rye	Wallis Road and NH 1A	11	4.0 feet	• Different materials • Evaluate culverts • Detour signage	• Raise road	Possible for Wallis Road, needs to be considered in conjunction with sites 8, 9, & 10
Rye	NH 1A near Rye Harbor & Locke Rd	13	4.0 feet	• Different materials • Evaluate culvert on Locke • Detour signage	• Raise road – possible dam categorization • Wave action impacts	Locke Rd possible, need to consider Rye Harbor status
Hampton	Cusack Rd	15	1.7 feet	• Raise road • Berms	Different materials	Viable option with multiple alternative routes nearby
Hampton	High St	16	1.0 foot	• Raise road	Different materials	May be necessary at some point
Hampton	Winnacunnet Rd & NH 1A	17	4.0 feet	• Raise road • Armor banks	Different materials	May be necessary at some point
Hampton	Brown Ave, Church St, Highland Ave, NH 101	18	1.0 foot	No viable options	Causeway	May be necessary at some point
Hampton	US 1 through the Hampton-Seabrook Estuary	20	4.0 feet	• Raise road	Different materials	Not desired option – high traffic volumes and important transportation facility
Seabrook	South Main St	21	4.0 feet	• Raise road	Different materials	Possible option with minimal impacts to nearby residents
Seabrook	Route 286 near Blackwater River in the Hampton-Seabrook Estuary	22	4.0 feet	• Raise road	Different materials	Not desired – evacuation route

*SLR level at which site is first impacted based on 1.0 foot, 1.7 feet, 4.0 feet, and 6.3 feet analyses.

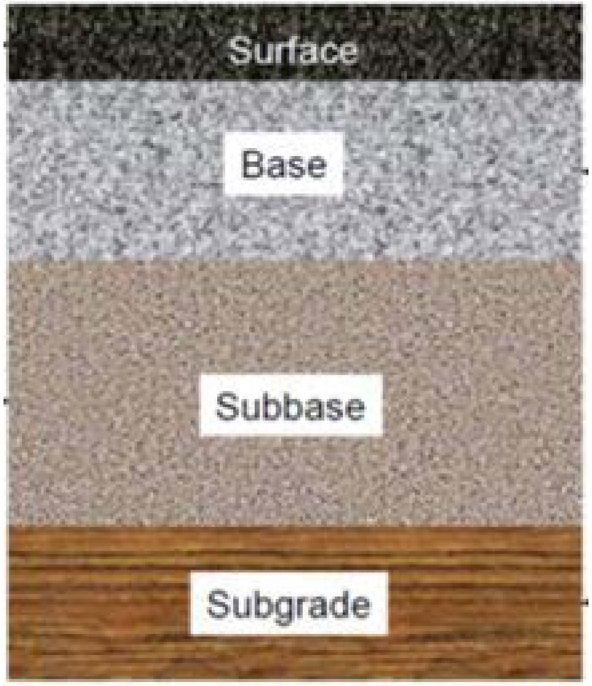
5.2 Case Studies

Two sites were selected for a more in-depth evaluation: Marsh Road and Parsons Road in Rye (Map Site 10) and Lafayette Road in Hampton (Map Site 20). The Marsh Road and Parsons Road site provides an opportunity to evaluate the timing of different adaptation options by considering the site in the context of the nearby road network, specifically NH 1A in Rye (Map Sites 8 and 9). In contrast, the Lafayette Road analysis will exemplify adaptation options at the asset level (bridge, culvert, roadway). These two sites were also selected because the analysis process and the options evaluated at both sites are anticipated to be transferable to other sites in coastal New Hampshire.

Pavement Design

Flexible pavements consist of layers of asphalt concrete on top of granular materials that are placed on the natural soils (subgrade). These layers of materials (Figure 5.1) work together as a system to carry the traffic loads under existing environmental conditions over the design life of the pavement (typically 10 to 20 years). The pavement layers are designed assuming that the granular base and subbase layers are at a relatively low moisture content and are not partially or fully saturated. When the moisture condition of the subgrade or unbound granular materials increases due to rising groundwater levels, the stiffness of these materials decreases. The decrease in stiffness reduces the overall load carrying capacity of the whole pavement structure, meaning that the pavement will deteriorate faster under normal traffic loading, requiring increased maintenance and/or rehabilitation sooner than originally designed. The structural capacity of the pavement can be increased by adding thickness to the pavement layers to compensate for the reduced stiffness of the granular layers and/or subgrade. This is most efficiently done by adding additional asphalt concrete (an overlay) unless a rehabilitation or reconstruction of the pavement structure is taking place, in which case alternative materials and/or thicker layers of underlying layers could be practically considered.

Figure 5.1: Typical Layered Flexible Pavement Structure



In this analysis, the current NHDOT pavement design procedure was used, which uses the general approach outlined in the American Association of State Highway Transportation Officials (AASHTO) 1972 design guide. NHDOT standard values for the pavement design input values (structural layer coefficients, regional and soil support factors, and terminal serviceability level) were used in the analysis. An initial assumption was made that the existing pavement structures are adequate for the current traffic levels at each site. For each site, the allowable traffic loading for the existing structure was calculated assuming that the drainage of the pavement is good to fair and that the pavement structure is not typically exposed to moisture levels that approach saturation (so-called 'dry' condition). Next, the pavement structure was analyzed under constantly saturated conditions and the additional thickness of asphalt concrete required to achieve the same capacity (traffic loading) as under 'dry' conditions was determined.

Marsh Road and Parsons Road in Rye (Map Site 10)

Marsh Road and Parsons Road in Rye are state owned major collector/local connector roads with an average annual daily traffic (AADT) level of 1,240 vehicles per day (Brackett Road volume count just north of Parsons Road, https://nhdotprojects.sr.unh.edu/). Construction records for these roads were not available so the pavement structure for both roadways was assumed to consist of 4 inches of asphalt concrete over 6 inches of gravel, which is typical for this type of roadway. Forensic analysis of the pavements would need to be conducted to adjust the analysis for actual pavement conditions.

There is a low Tolerance for Flood Risk (TFR) at Map Site 10 at Marsh Road, Parsons Road just east of the intersection with Marsh Road, and Parsons Road near the intersection with Brackett Road. Marsh Road is already routinely experiencing overtopping and road closures due to coastal flooding. However, Parsons Rd. remains passable during these same events. Figure 5.2 (page 58) shows that Marsh Road will be inundated during most high tide cycles when SLR equals or exceeds 1.0 feet. Parsons Road near the intersection with Brackett Road will be inundated during most high tide cycles when SLR equals or exceeds 1.7 feet. This will likely occur in 2030 and 2050 for Marsh Road and Parsons Road, respectively (Table 5.2 on page 54). Because Marsh and Parsons Roads are relatively low volume roads and NH 1A provides a readily accessible alternative for traffic, adaptation options for Marsh Rd. and Parsons Rd. should be considered in light of the vulnerability of the alternative route (or routes). Figure 5.2 (page 58) shows that the east site of Parson Road will not be inundated at 2.0 feet of SLR, but will be inundated

Photo of Marsh Road in Rye. Courtesy of Dave Walker (June, 2021).

when SLR reaches 4.0 feet. There is approximately a 40-year difference between the anticipated onset of 2.0 feet and 4.0 feet of SLR based on current assumptions. Unfortunately, there are no maps for SLR values between the 2.0 feet and 4.0 feet elevation models to provide a more specific point of inundation and so an average SLR threshold of 3.0 feet was used to estimate the timing on the east segment of Parsons Road. Based on this, Parson Road just east of the intersection with Marsh Road will experience inundation later than the other two locations at this site.


Drainage structures on Parsons Road. Courtesy of Jo Sias (June, 2021).


Drainage structures on Parsons Road. Courtesy of Jo Sias (June, 2021).


Drainage structures on on Marsh Road. Courtesy of Jo Sias (June, 2021).

Figure 5.2: Surface water inundation during MHHW at Marsh Road and Parsons Road (Site #10)

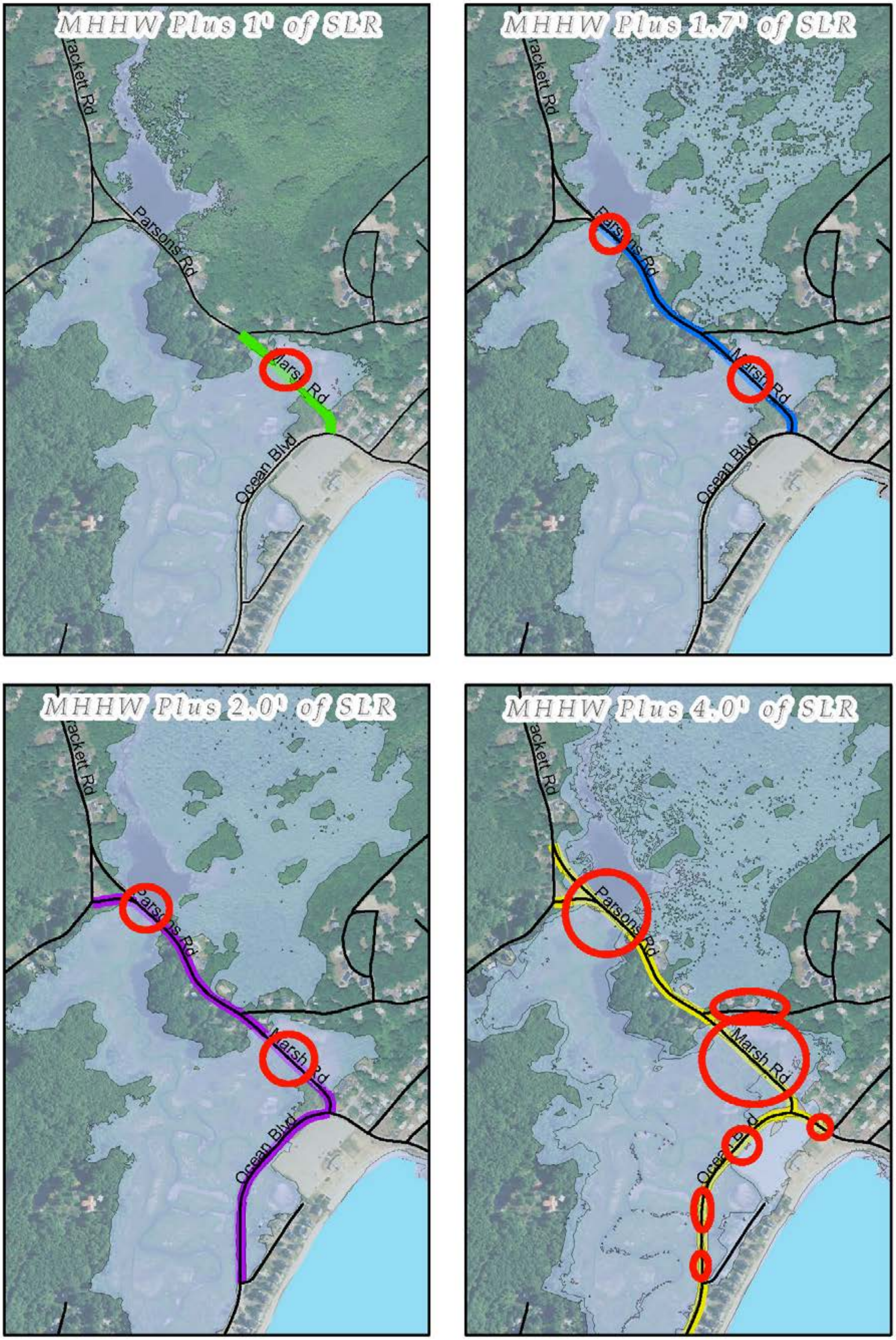


Table 5.2: Considerations for Various Adaptation Options

Road surface and base layer status by year based on the low tolerance for flood risk at Map Site 10 at Marsh Road, Parsons Road just east of the intersection with Marsh Road, and Parsons Road near the intersection with Brackett Road and at Map Sites 8 and 9 (NH 1A) which have a very low tolerance for flood risk. For road surface, Open (light blue) indicates at MHHW the road is not inundated, Water on the Rd. (darker blue) indicates the road is partially inundated as currently designed but accommodation or resist actions are anticipated to maintain functionality and Inundated (darkest blue) indicates the road is inundated and retreat is planned. For road base, Partially Saturated (darker blue) indicates that the groundwater level is within the pavement base layer and Saturated (darkest blue) indicates that the groundwater level is at or above the pavement base layer.

	ROAD SURFACE STATUS				ROAD BASE LAYER STATUS			
Year	**Marsh**	**Parsons & Brackett**	**Parsons East**	**Rt 1A**	**Marsh**	**Parsons & Brackett**	**Parsons East**	**Rt 1A**
2020	Open	Open	Open	Open				
2030	Inundated	Open	Open	Open	Saturated	Partial Sat	Partial Sat	Partial Sat
2040	Inundated	Water on Rd	Open	Open	Saturated	Saturated	Saturated	Saturated
2050	Inundated	Inundated	Open	Water on Rd	Saturated	Saturated	Saturated	Saturated
2060	Inundated	Inundated	Water on Rd	Inundated	Saturated	Saturated	Saturated	Saturated
2070	Inundated	Inundated	Water on Rd	Inundated	Saturated	Saturated	Saturated	Saturated
2080	Inundated	Inundated	Inundated	Inundated	Saturated	Saturated	Saturated	Saturated
2090	Inundated	Inundated	Inundated	Inundated	Saturated	Saturated	Saturated	Saturated
2100	Inundated	Inundated	Inundated	Inundated	Saturated	Saturated	Saturated	Saturated

NH 1A north of Marsh Road and around Odiorne Point includes Map Sites 8 and 9. This section of NH 1A is state-owned and classified as a major collector/regional corridor with an AADT level of approximately 1,400 vehicles per day (2017). Further north, just west of Brackett Road, volume increases to nearly 3,700 AADT. Construction records were not available for this section of NH 1A, so the pavement structure was assumed to consist of 6 inches of asphalt concrete over 12 inches of gravel, which is typical for this type of roadway. Forensic analysis of the pavements would need to be conducted to adjust the analysis for actual pavement conditions.

There is a *very low* TFR for NH1A around Odiorne Point. Figure 5.3 (page 61) shows that this section of NH 1A will not be inundated at 2.0 feet of SLR, but numerous stretches will be inundated when SLR reaches 4.0 feet. Similar to the approach used for the eastern portion of Parsons Road, an average SLR threshold of 3.0 feet was used to estimate the timing of inundation. Inundation of NH 1A is anticipated by 2060 (Table 5.2 on page 59) and based on the determination that NH 1A has a very low TFR, alternatives to mitigate 3.0 feet of SLR should be in place by 2060. This also means that we can assume NH 1A can provide a viable alternative route to Marsh Road and Parsons Road for approximately 30 years.

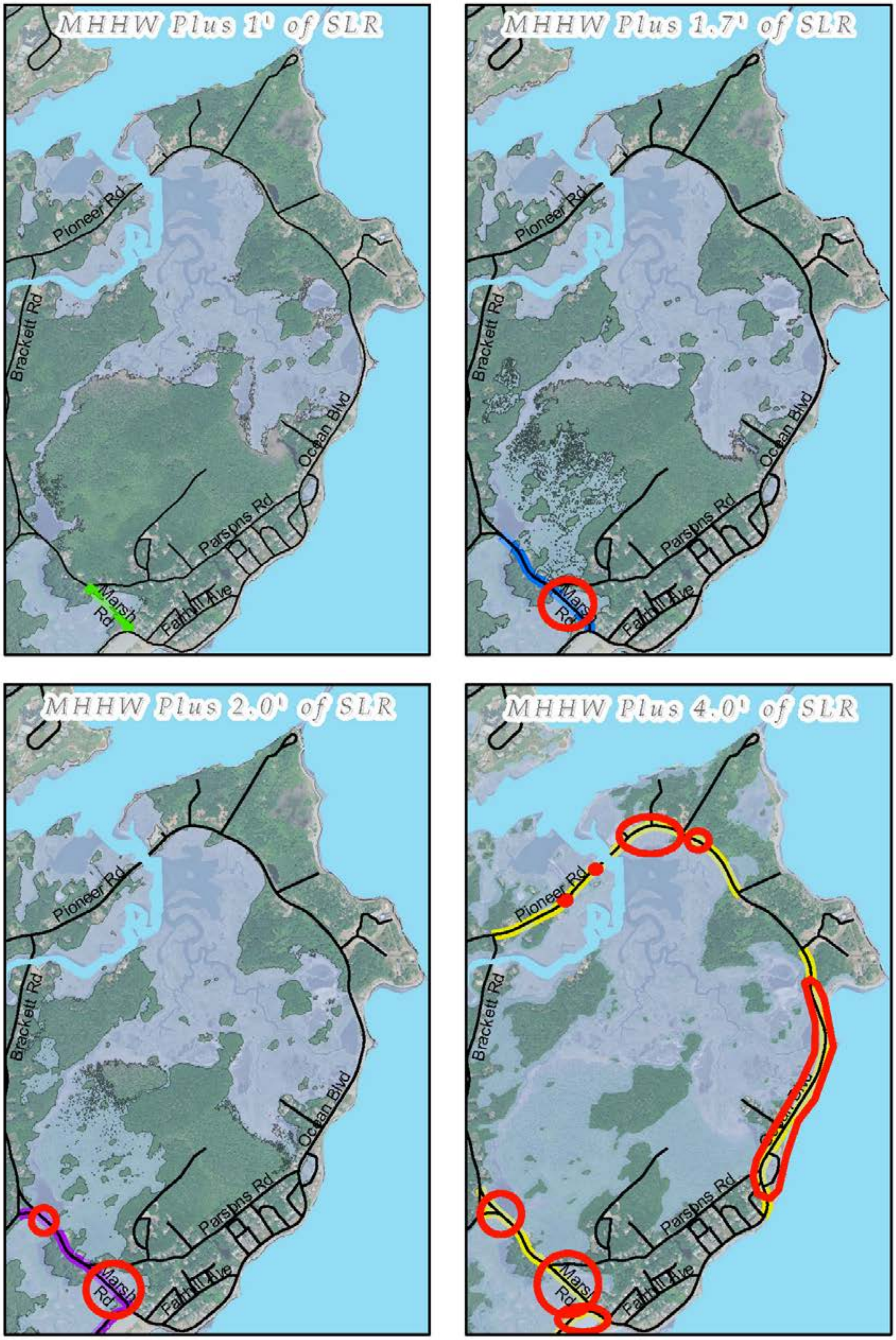
Before the pavements are overtopped, the base layers will become partially or fully saturated due to SLR induced Ground Water (GW) rise. Table 5.2 (page 59) summarizes the status of base layer saturation by site and year. Based on their respective TFR values, all roads are at least partially saturated by 2030 with complete saturation by 2050. Accelerated damage to the pavement at Sites 8, 9, and 10 is anticipated to occur due to the high moisture conditions in the underlying soil materials. Thus, adaptation and detours should consider both SLR impacts that overtop roads, and those that diminish the bearing capacity of the base layers.

Adaptation options and associated time horizons for Map Sites 8, 9, and 10 are summarized in Table 5.3 and described further below.

Table 5.3: Adaptation alternatives and time horizons for Marsh Road and Parsons Road in Rye (Map Site 10) and NH 1A (Site 8 or 9). Note in 2060, NH 1A (Site 8 or 9) is inundated.

Time Horizon	Accommodate	Resist	Reroute
Present until 2030	Detour and Signage at Marsh Road And Parson Road Modify O&M and materials at all sites		
2030 to 2060	Modify O&M and materials at Sites 8 and 9		Reroute Marsh Road and Parson Road via NH 1A Long-Term Detour
2060 forward	Create a causeway at existing Marsh Road And Parson Road	Raise Marsh Road And Parson Road	Reroute NH 1A via Marsh Road and Parsons Road permanent detour

Figure 5.3: Surface water inundation during MHHW at NH 1A (Sites 8 & 9) and Marsh Road/Parsons Road (Site 10).



Present until 2030: Marsh Road is currently experiencing inundation and road closures during periodic high tides and storm events due to backwater flooding. The periodic inundations will occur with increasing frequency over time. Current accommodation is a temporary detour using manual placement of barricades during the event. Access to Parsons Road just west of the intersection with Marsh Road is available via the eastern segment of Parsons Road at its intersection with NH 1A. The primary detour route is along NH 1A (through Map Sites 8 and 9), which will not be inundated until SLR equals or exceeds 3.0 feet. SLR is anticipated to equal or exceed 3.0 feet at this site by 2060 based on the site's very low TFR.

Even with the temporary detours, accelerated damage to the pavement on Parsons Road and Marsh Road is anticipated to occur due to the high moisture conditions in the underlying soil materials. The base layer of Marsh Road is likely at least partially saturated continuously and the base layer along Parsons Road will be at least partially saturated from present to 2030. Using the NHDOT pavement design methodology, an additional 1.0 inch of asphalt pavement will provide the same structural capacity as currently exists, minimizing additional Operations and Maintenance (O&M) costs due to accelerated damage.

2030 until NH 1A (Sites 8 and/or 9) is closed in 2060: Once Marsh Road and Parsons Road are continuously inundated, rerouting via NH 1A is recommended until 2060. As the underlying materials along Sites 8 and 9 become partially or fully saturated, additional structural capacity will be required to prevent accelerated deterioration of the pavement along NH 1A. Partial saturation is likely during high water levels for this period and will increase to full saturation by 2040. Using the NHDOT pavement design methodology, an additional 2 inches of asphalt pavement will provide the same structural capacity as currently exists, minimizing additional O&M costs due to accelerated damage along Sites 8 and 9.

Rt 1A (Sites 8 or 9) closed in 2060: Once NH 1A is closed due to inundation, Marsh Road and Parsons Road can be adapted to serve as the northern extent for NH 1A. These roadway sections must either be raised to the appropriate elevation so that they are not inundated, or a causeway built to keep them out of the water. If the roadway is raised, additional granular material could be added on top of the existing pavement structure and topped with a new layer of asphalt concrete to achieve the required final pavement surface elevation. This would likely require that the roadway footprint be extended into the marsh areas to accommodate embankments or construction of vertical retaining structures to support the new roadbed. Environmental impacts would need to be considered for both options. An additional feature of this adaptation approach is that while traffic is rerouted from Marsh Road and Parson Road to NH 1A, there is a 30-year window in which to implement the long-term adaptation strategies at Marsh/Parsons Rd.

US 1 (Lafayette Road) in Hampton (Map Site 20)

US 1, also known as Lafayette Road (Map Site 20), is a minor arterial/statewide corridor in this part of Hampton with an AADT of 20,600 vehicles per day (2019). Using information from available records from the initial construction in 1918 as well as additional construction activities that occurred in the 1930s, 1978, 2002, and 2016, the pavement structure at this site has been estimated to consist of 2 inches of asphalt concrete surface over 3 inches of asphalt concrete base, 7 inches of Portland cement concrete (PCC) pavement, and 6 inches of gravel base. The condition of the PCC layer is unknown, and therefore the pavement analysis was conducted using a range of values (incorporating reasonable high and low values used for similar materials) for the structural contribution of this layer. Forensic analysis of the pavement would need to be conducted to adjust the analysis for actual pavement conditions.

US 1. Courtesy of Jo Sias (June 2021)

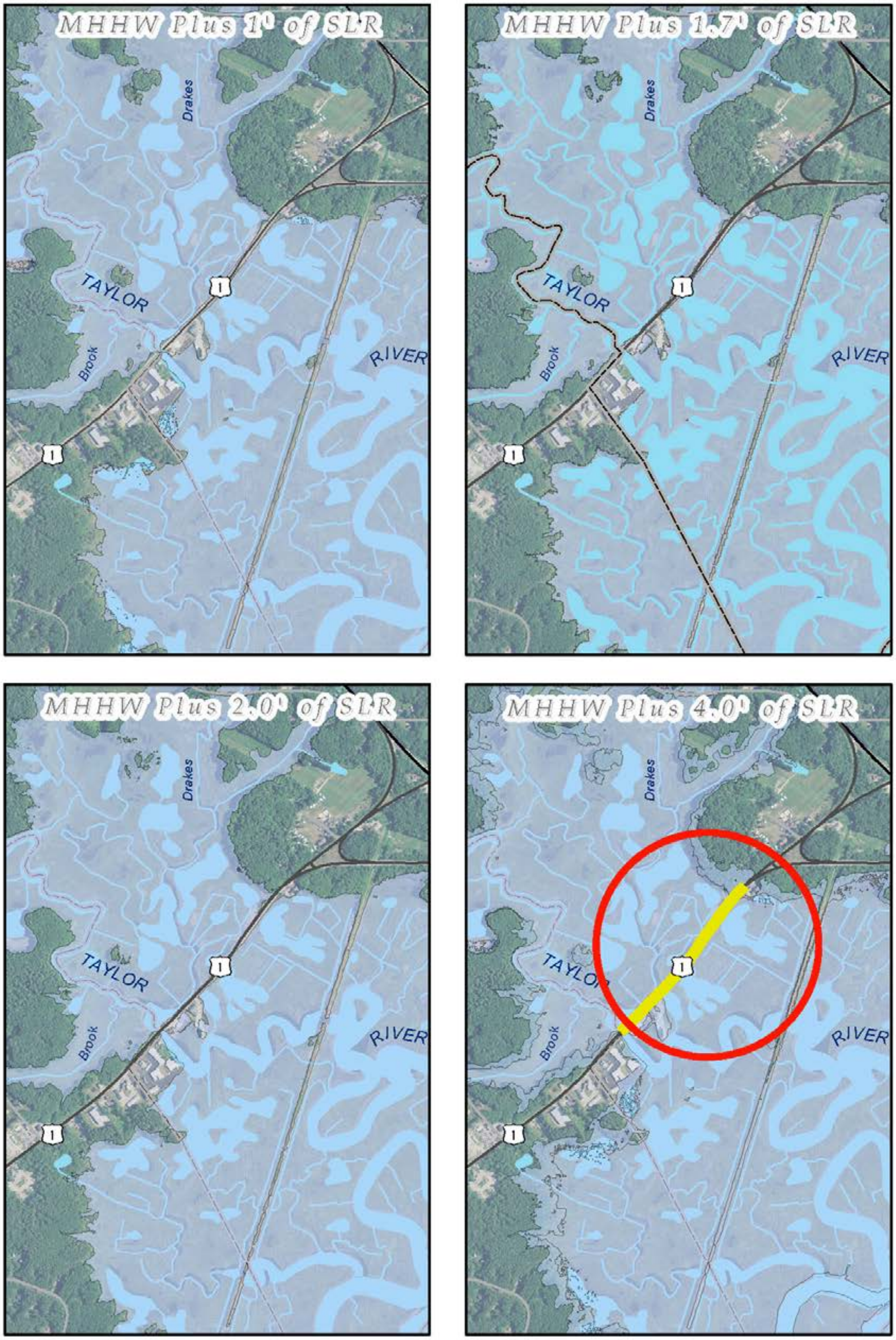
Hampton Police blocking the northbound lane on US 1 through the Hampton-Seabrook Estuary during King Tide flooding. Courtesy of Scott Bogle (October 2019)

Lafayette Road will start to experience water on the roadway at 2.0 feet of SLR and will be inundated when the SLR is greater than 4.0 feet (Figure 5.4 on page 65). Figure 5.4 shows that the entire section of US 1 will be inundated at 4.0 feet of SLR suggesting that the inundation will occur well before SLR reaches the average value of 3.0 feet. Thus, the lower quartile of the difference, 2.5 feet SLR was used to estimate the timing of inundation. Water on the roadway status will occur in 2050 (Table 5.4). The water levels on the roadway will exceed 6.0 inches, making it unsafe for passenger vehicle crossing, by 2060. Because US 1 has a very low TFR, adaptation strategies should be implemented by 2050 to mitigate SLR flood risk. The groundwater levels at this site will begin to intersect the gravel base layer in 2030 (Table 5.4), accelerating the damage to the pavement structure from traffic loading. Completely saturated pavements are anticipated by 2050.

Table 5.4: Road surface and granular base layer status by year based on the very low tolerance for flood risk and flood risk scenario for US 1 (Map Site 20), Hampton, NH. For road surface, Open (lightest blue) indicates the road is not inundated, Water on the Rd. (darker blue) indicates the road is partially inundated as currently designed but accommodation or resist actions are anticipated to maintain functionality and Inundated (darkest blue) indicates the road is inundated and retreat is planned. For road base, Partially Saturated (darker blue) indicates that the groundwater level is within the pavement base layer and Saturated (darkest blue) indicates that the groundwater level is above the pavement base layer.

Year	ROAD SURFACE STATUS	ROAD BASE LAYER STATUS
2020	Open	
2030	Open	Partially Saturated
2040	Open	Saturated
2050	Water on Rd	Saturated
2060	Inundated	Saturated
2070	Inundated	Saturated
2080	Inundated	Saturated
2090	Inundated	Saturated
2100	Inundated	Saturated

Figure 5.4: Surface water inundation during MHHW at US 1 through the Hampton-Seabrook Estuary (Map Site 20)



Using the NHDOT pavement design methodology, an additional 1.0 inch of asphalt pavement will provide the same structural capacity as currently exists, minimizing additional O&M costs due to accelerated damage along US 1 (Site 20). Once the roadway is completely inundated and impassable, the roadway must be raised, or a causeway built to maintain connectivity. If the roadway is raised, additional granular material could be added on top of the existing pavement structure and topped with a new layer of asphalt concrete to achieve the required final pavement surface elevation. This would likely require that the roadway footprint be extended into the adjacent marsh areas to accommodate embankments or construction of vertical retaining structures to support the new roadbed. Environmental impacts would need to be considered for both options.

Adaptation options and associated time horizons for US 1 (Map Site 20) are summarized in Table 5.5 below.

Table 5.5: Adaptation alternatives and time horizons for US 1 through the Hampton-Seabrook Estuary (Map Site 20)

Time Horizon	Accommodate	Resist
2030 to 2050	Add additional 1” of HMA	
2060 forward	Create a causeway	Raise Road

5.3 Costs of Improvements

Developing a full set of planning level cost estimates was not able to be accomplished as part of this assessment however understanding this aspect is a critical component of the decision-making process and implementation. Some insight can be gained from the *Hampton Harbor Flood Mitigation Analysis* (HTA, 2021), and the US Army Corp of Engineers *North Atlantic Coast Comprehensive Study* (NACC) (USACE, 2015) as those two documents provide some general unit cost estimates (Table 5.6) that could be applied to some of the adaptation options discussed in this document.

Table 5.6: Unit Cost Examples

Type of Improvement	Hampton Harbor Flood Mitigation Analysis (HTA, 2021)	NACCS Report (USACE, 2015)
Elevating a Roadway	$123-$316/ft3 (minor rd) $348-$697/ft3 (major rd)	
Concrete Wall/Berm	$2,334/linear foot (Sheet reinforced I-Wall)	$5335/linear foot (T-Wall 10’ high.

Applying those unit costs to the sites included in the two case studies in section 5.2 provides an initial look at what mitigation of SLR impacts may cost. The cost ranges produced are shown in Table 5.6 (page 66) and are current year values that do not include inflation, engineering, or environmental mitigation costs. They are not intended for use in project development or an endorsement of these particular adaptation approaches at these locations, but are simply to provide perspective. There are a lot of other aspects that must be considered in implementation that may change the costs substantially or even determine what is feasible from an engineering perspective.

Table 5.7: Initial Cost Estimates for Some Adaptation Options Based on Unit Costs

		Elevating Roadway 4 feet		**Concrete Berm**	
Location	**Length**	**Low**	**High**	**Low**	**High**
Marsh Road/Parsons Road (Site 10)	2550 ft.	$1,300,000	$3,200,000	$11,900,000	$27,200,000
NH 1A Odiorne Point (Sites 8 & 9)	6,100 ft	$8,500,000	$17,000,000	$14,200,000	$32,500,000
US Route 1 in Hampton (Site 20)	2700 ft.	$3,800,000	$7,500,000	$12,600,000	$28,800,000

For this exercise, the length of impacted roadway was estimated, and the unit cost ranges applied to provide a lower and upper bound. Each location was assumed to be raised four feet for the purposes of elevating the roadway, and for installing berms it was assumed that they would be on both sides of the roadway except for on NH 1A around Odiorne Point (Sites 8 & 9) where they could be placed on the west (marsh) side only.

In the context of Marsh/Parsons Road and NH 1A around Odiorne Point, it can be seen from the values that keeping Marsh and Parsons Roads a viable roadway is substantially less costly (given the assumptions) than keeping NH 1A open if the choice needs to be made between one or the other. At the US 1 inundation site in Hampton (Site 20), it can be seen that the cost of raising the roadway is substantially cheaper than building a concrete berm through the Hampton-Seabrook Estuary.

NHDOT is working on a conceptual design and analysis for the NH 1A coastal revetments (North Hampton-Rye 42312) as well as on several tidal culvert replacements with NH Coastal Program that will provide additional data points for estimating adaptation costs in New Hampshire.

6. Findings and Recommendations

The STCVA assesses the vulnerability of the roadway network to future daily inundation from sea-level rise due to climate change. The assessment examines impacts and inundation sites, evaluates the connectivity and general functionality of the transportation network under these future conditions, and provides potential adaptation options and opportunities to address the inundation on regional roadways. This section summarizes the findings of the vulnerability assessment and establishes a set of recommendations to make progress in improving the resiliency of the roadway network in coastal New Hampshire.

6.1 General Findings

Based on the assumptions and parameters listed above, the vulnerability assessment and scenario analysis indicate that the roadway network in coastal New Hampshire can continue to function reasonably well with up to two feet of SLR but, by four feet of sea-level rise, connectivity and access are severely disrupted and system functionality declines.

> **"… the roadway network in coastal New Hampshire can continue to function reasonably well with up to two feet of SLR but, by four feet of sea-level rise, connectivity and access are severely disrupted and functionality declines."**

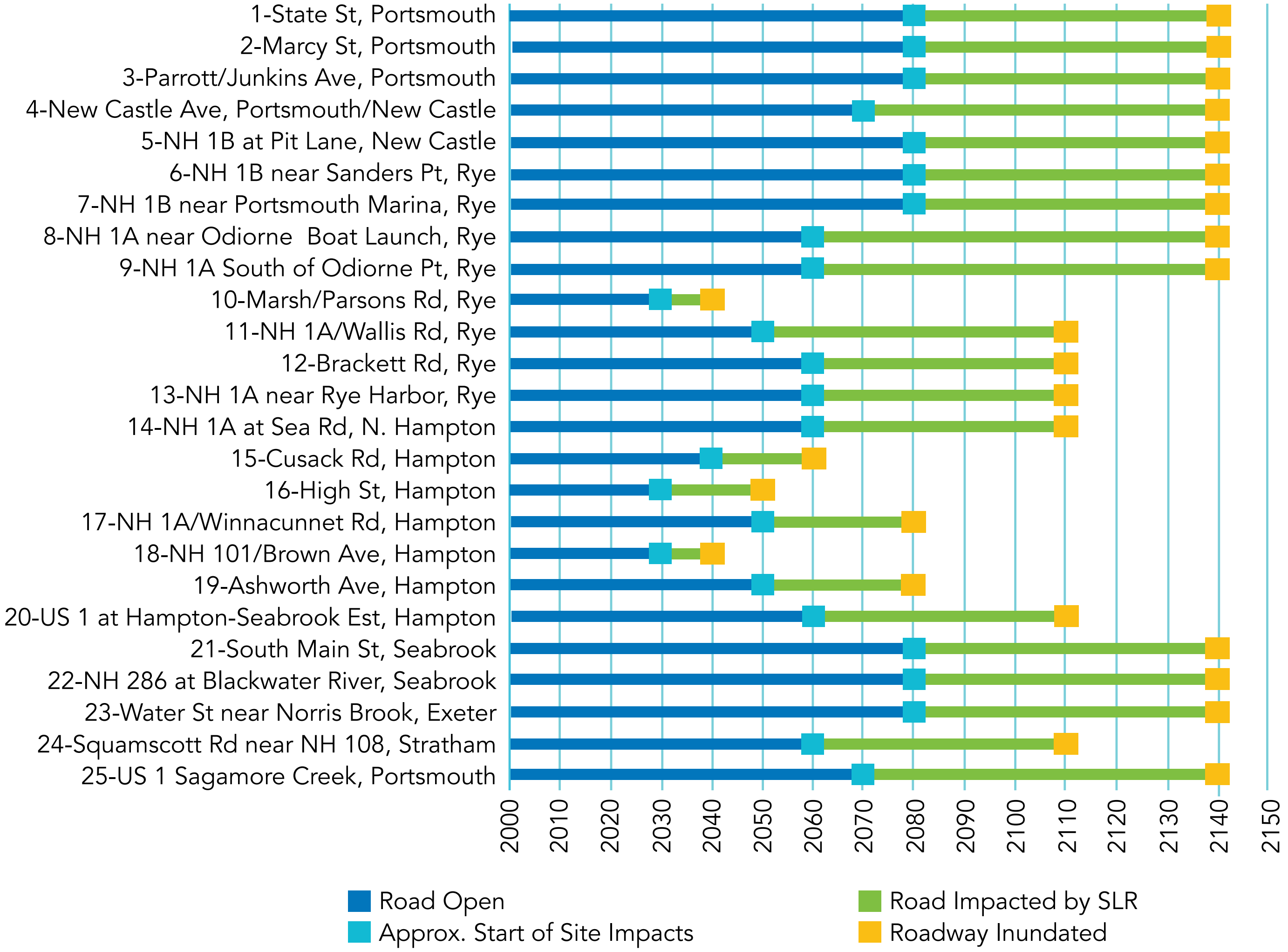
Specifically, the level of disruption and amount of re-routing required for SLR scenarios at 1.0 and 1.7 feet are within the capacity of the roadway system that exists in coastal New Hampshire. This system is mature and the variety of roadway options to access the coast provide the inherent flexibility and redundancy that is needed under lower SLR scenarios. Under these scenarios, re-routing of traffic due to closures of roadway segments shifts vehicles, in most cases, to nearby roadways that have available capacity or could do so with minor operational improvements.
In contrast, the scale of disruption at 4.0 feet of SLR is significantly greater in terms of both the number of impacted locations and the volume of traffic that needs to detour to access the coast. Coupled with the drastic reduction in the number of routes available, this creates a logistical challenge of consolidating traffic from many route options onto just a few as shown in the Table 6.1. The table shows the scale of impacts under each scenario and how the route options decline with each progressive scenario and the volume of disrupted traffic grows exponentially. Figure 6.1 (page 69) shows the range of anticipated timeframes for impacts to the 25 sites identified as impacted by 4.0 feet of SLR. The timeframes in which a site is likely to become regularly inundated vary depending upon the assumptions about Tolerance for Flood Risk (TFR). The conservative planning assumption is that the road network has a Very Low TFR and that SLR will follow the high magnitude, low probability curve defined in Step 3 of the NH Coastal Flood Risk Guidance

Table 6.1: Scale of transportation network impacts under each SLR Scenario

Scenario	Inundated (Closed) Roadway Segments	Uninterrupted North-South routes available (3 to start)	Uninterrupted East-west routes available (22 to start)	Estimated disrupted daily volume
1 foot	3	3	20	10,000
1.7 feet	5	3	18	20,000
4 feet	25	1	7	108,000
6.3 feet	52	1	2	Unknown

(University of New Hampshire, 2020). This produces higher sea-levels at earlier periods and defines the earlier bound of the "Road Impacted by SLR" timeframe for each location designated by the square with diagonal blue stripes. The least conservative planning assumption is that the roadway network has a High TFR, and that SLR follows the high probability, low magnitude curve in Step 3 of the guidance. This forms the later bound of the "Road Impacted by SLR" timeframe and is represented by the solid filled red square.

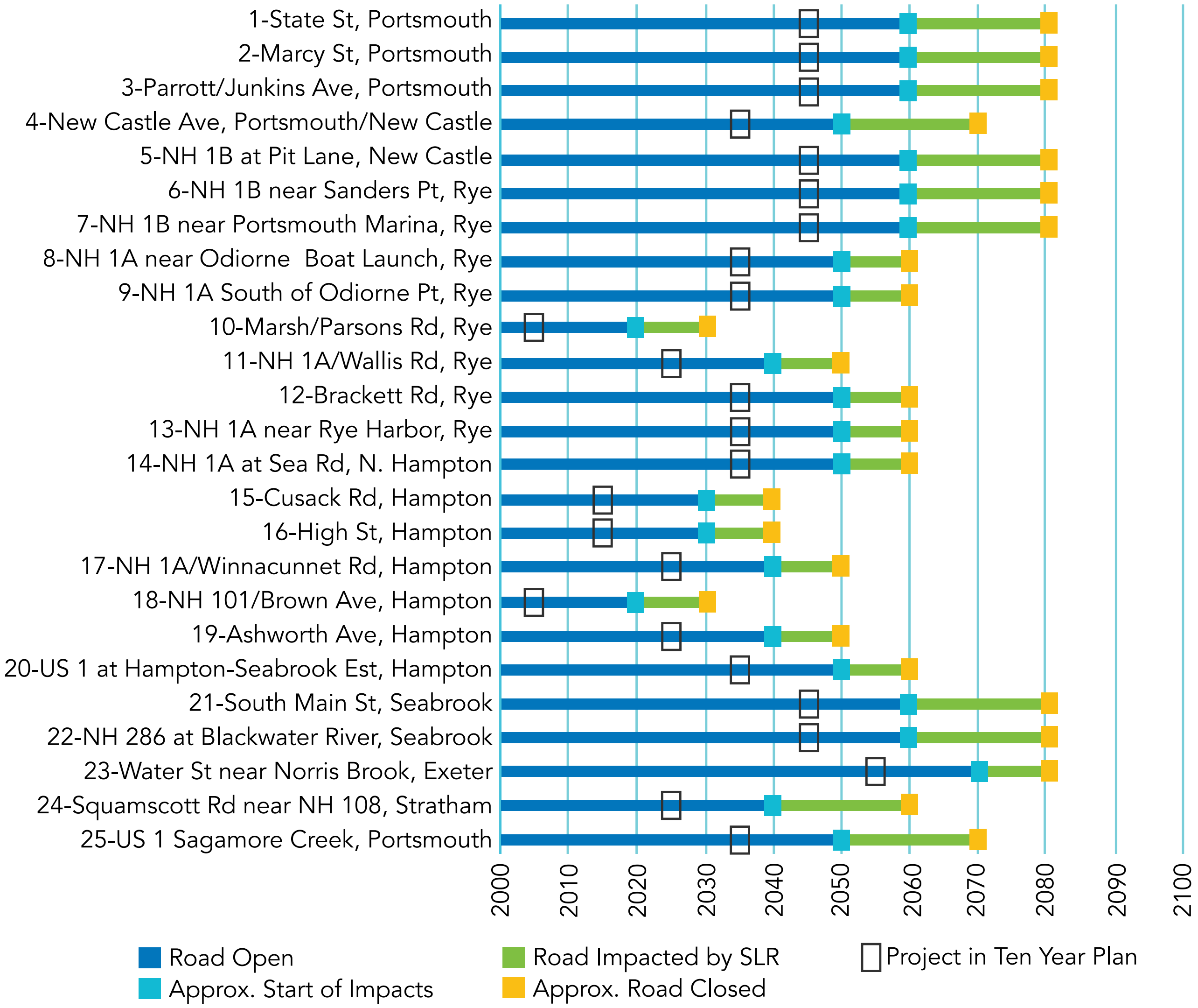
Figure 6.1: SLR Impact Timeframes Sites Varies by Location



The space between the two, represented by the blue with white dots, signifies that the transition from a road being open and useable, to inundated and closed and could occur at any point within this timeframe with a higher probability that higher SLR will occur later in time.

Specifying an assumption regarding the Tolerance for Flood Risk to the data in Figure 6.1 provides a more defined timeframe for planning purposes. Figure 6.2 shows the 25 sites from Figure 6.1 with assuming Very Low TFR (from Table 3.3). That assumption results in a high magnitude of SLR between 2030 and 2150. Under that scenario, the coast of New Hampshire would experience 1.1 feet of SLR by 2030, over 2.0 feet by 2050, and over 4.0 feet between 2070 and 2080 (see Table 3.4 for exact values). The solid blue bar represents an open road and the dotted blue bar represents a road facing inundation pressure. The rectangular shape with blue diagonal stripes represents the approximate timeframe in which SLR impacts may be observed on the roadway while the one that is solid red represents the anticipated timeframe for road closure based on the assumed TFR. Figure 6.2 also adds an clear rectangle (□) to represents the timeframe in which a project would need to be included in the State Ten Year Plan to be constructed prior to inundation from SLR.

Figure 6.2: Planning Timeframes for Addressing Impacted Roadways

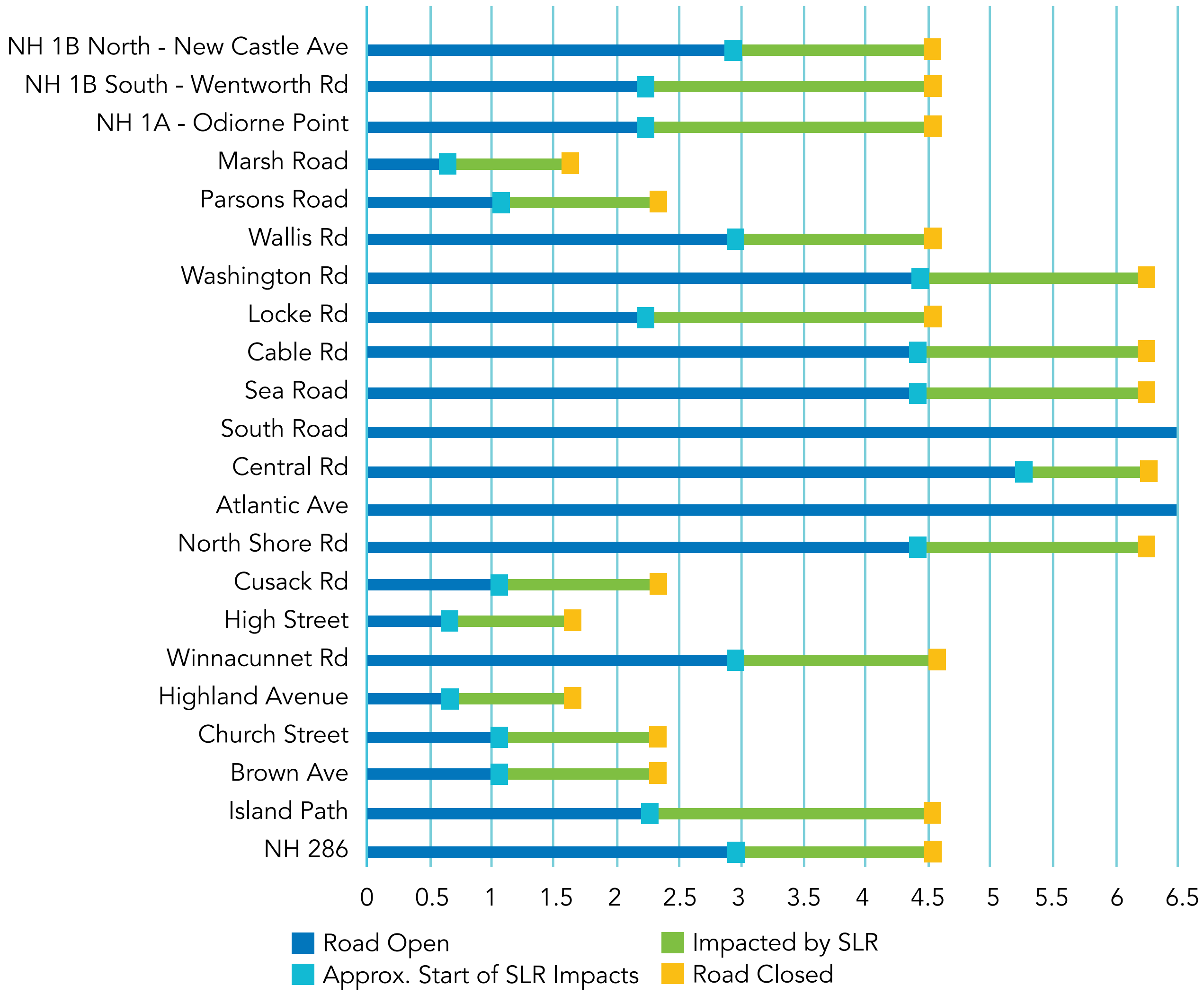


Based on the assumption of a Very Low TFR, work should be initiated immediately to further assess and develop detailed adaptation options for Marsh Road in Rye and High Street and NH 101/Highland Avenue in Hampton as they are facing inundation at low amounts of SLR. The broad transportation network impacts of disruptions in travel to Hampton Beach paired with the impacts estimated from the Hampton Harbor Flood Analysis, indicate that the development of a comprehensive approach to addressing inundation in and around Hampton Beach should be a priority. While this will have transportation components, it will need to address the flooding and drainage issues in the surrounding community to be successful.

Overall, prioritizing and addressing the inundated sites (and sometimes surrounding areas) prior reaching the levels of SLR that flood the roadways on a daily basis is critical to maintain functionality of the network, minimize disruptions and detours, and is preserve access to the coast as it currently exists. The impacts to the east-west routes in the coastal region provide a clear example of this need as shown in Figure 6.3. Currently there are 22 east-west pathways to the

Figure 6.3: East-West Road Inundation Status by Feet of SLR

Assumes Very Low Tolerance for Flood Risk



coast, but those options disappear quickly under higher SLR conditions. At 1.0 feet SLR, three of the 22 roadways are impacted and potentially unavailable and at 1.7 feet this expands to seven if you count NH 101 eastbound (Highland Avenue) separately from NH 101 westbound (Church Street). By 4.0 feet SLR 15 east-west roadways are unavailable or facing some level of inundation. When the region reaches 6.3 feet of SLR, all but two roadways, South Road in Rye and NH 111 in North Hampton, are unlikely to be available for travel.

The study of the impacts of SLR is a rapidly evolving field and new information and techniques continue to help refine our understanding of the consequences. Based on that understanding, there are some general methods that can guide how New Hampshire can successfully address the challenges of mitigating SLR:

- **Use a Systems Approach:** The current roadway network is complex and relies on broad distribution of traffic across many route options to function and to ensure reasonable mobility and access to the coastal region. Improvements to address the impacts of SLR should not be considered in isolation as choices at one location can have ripple effects on other roadways and communities.

- **Be Responsive to Changing Conditions:** Certain adaptation options may mitigate short-term repercussions of sea-level rise and provide time to implement more robust, long-term solutions. For instance, additional pavement thickness may keep a roadway structurally capable of carrying traffic until the water level regularly covers the pavement. This allows additional time for decision-making and implementation of a more complex and costly solution such raising the roadway to mitigate future impacts. Similarly, recommended adaptation options may not work, or may not be cost effective to implement, at some locations due to underlying structural and environmental issues. This may be difficult to determine until detailed engineering and alternatives analysis is underway and may change what viable options exist at that location. Building flexibility into the response to SLR can keep projects moving forward in the face of changing circumstances.

- **Use All Available Tools:** Transportation projects are not the appropriate solutions to address SLR impacts at all the identified locations in coastal New Hampshire as they may be too limited in scope. Many of the sites in Hampton Beach and the city of Portsmouth for instance, will need larger scale public works to address the inundation of properties, houses, and businesses that are sometimes impacted before flooding reaches the roadways. Transportation improvements may be part of the solutions however they cannot be the only options pursued.

- **Follow the Science:** Continue to improve scientific foundation and technical analysis. The current "bathtub" SLR model cannot describe the impacts of waves and wind on the roadway network and the ongoing effort to develop a hydrodynamic model will address man of those deficiencies. Likewise, the regional travel demand model provides a reasonable, but incomplete, assessment of overall transportation network impacts due to an incomplete network and an assessment methodology that exposed some limitations of the tool. The model roadway network is being enhanced via the *Pavement Resilience to Sea Level Rise and Potential Mitigation Options Using Natural and Nature-Based Features* study currently underway and the analysis approach is being refined for future efforts.

6.2 Recommendations

This assessment is the most recent step towards identifying and understanding the consequences of SLR in coastal New Hampshire. It is also an initial effort to understand the systemic impacts to travel in the region under higher sea-level conditions. It is the result of a solid foundation in science, robust engagement from the communities, and a cooperative effort between NH Coastal Program, the New Hampshire Department of Transportation and the Rockingham Planning Commission. Some of these recommendations are agency or community specific, however it will take active commitment at all levels (local, regional, state) to consider the system needs, adapt to changing circumstances, and use the available measures to mitigate the impacts of SLR and build a resilient transportation network. With that understanding, the following recommendations are provided:

- Based on the current planning assumptions, work should begin immediately to identify workable adaptation options and implement improvements at those locations that will be inundated at lower levels of sea-level rise:
    - Address High Street, and NH 101/Brown Avenue locations in immediate future to avoid significant disruptions in access to Hampton Beach. These will require significant investment, planning, and engineering and should enter the State Ten Year Plan as soon as possible.
    - The Marsh Road/Parsons Road sites should also be considered for immediate action with focus on long-term function of the system in the Odiorne Point area. While in the short-term, closure of Marsh Road results in minimal disruption to the network and loss of access, long-term impacts to NH 1A in that area may require Marsh Road to be available as a route option

- Support community efforts to fund projects that enhance coastal resiliency and mitigate the impacts of SLR on the transportation network. While many local roadways where not directly included in this assessment, improvements to those facilities are encouraged to ensure continued access under higher sea-level conditions, reduce flooding impacts of storms, and enhance the safety and security of the overall system.

- Take advantage of opportunities to address SLR inundation issues with current projects where possible. There is an overlap of the findings of this assessment with some projects currently in the State Ten Year Plan and the MPO Long Range Transportation Plan, notably the Hampton 40797 Ocean Boulevard Reconstruction. These projects should be modified as necessary to incorporate addressing SLR inundation as part of the purpose and need statements and as a goal of the project. Project scopes should be modified to address SLR as best as possible.

- A recommended timeframe for beginning planning work on the twenty-five locations identified as impacted at four feet of SLR is in Table 6.2. The dates are included for planning purposes and are recommended to ensure that a project in the State Ten Year Plan has enough time to progress through the queue and be implemented prior to regular inundation of the roadways at a site.

- The results of the Hampton Harbor Flood Analysis (HTA, 2021) indicate that more substantial public works will be needed to maintain Hampton Beach at its current level of development and activity under rising sea-level conditions. The findings of this assessment concur as transportation centric solutions only address part of the inundation issues in and around Hampton Beach. Finding this solution is a pressing priority as SLR will have significant impacts on the community and the economy of the region and it will take considerable effort to organize and fund a response.

Table 6.2: Planning Timeframes for Addressing Impacted Roadways

Immediate	**By 2030**	**By 2040**	**By 2050**	**By 2060**
• High St • NH 101/ Brown Ave • Marsh Rd/ Parsons Rd • Cusack Rd	• NH 1A in Wallis Rd Area • NH 1A/ Winnacunnet Rd • Ashworth Avenue • Squamscott Rd	• New Castle Avenue • NH 1A at Odiorne Point Boat Launch • NH 1A south of Odiorne Point • NH 1A at Rye Harbor •NH 1A at Sea Road/ North Hampton State Beach Park • US 1 at Hampton Salt Marsh • US 1 at Sagamore Creek • Brackett Road	• State St/Daniel St • Marcy St • Parrott Ave/ Junkins Ave • NH 1B at Neals Pit Lane • NH 1B near Sanders Poynt • NH 1B near Portsmouth Marina • NH 286 in Seabrook South Main St in Seabrook	• Water St in Exeter

- Transportation improvements may ultimately be an important component of the solution and may provide some interim benefits that can alleviate current and near-future conditions and provide time to fully investigate and implement a more comprehensive approach.

- Incorporate this analysis and the identified transportation project needs into the Metropolitan Planning Organization (MPO) Long Range Transportation Plan out to a horizon year of 2050. Post-2050 project needs should be included as "illustrative" to remain in view and ensure that sites are added as the horizon year of the plan moves further toward the future. In addition, the network analysis scenarios developed for this assessment can be informative in planning for future system needs.

- Further incorporate resiliency into MPO Project selection process. The current project selection process considers system resiliency and portions of the methodology developed for the STCVA project. The criteria utilized in this analysis to prioritize locations for the vulnerability assessment were a composite score of operational, health and safety, and socio-economic factors. Several of these overlap with existing criteria utilized to prioritize projects for the MPO Long Range Plan and State Ten Year Plan and so integration should focus on those specific criteria which are not already included. These are the Access to Emergency Services, Access to Community Services, and the Social Vulnerability Index (SVI). Efforts should continue to refine this assessment process to improve outcomes.

- Approximately one-half of the locations impacted at 4.0 feet of SLR were not selected for assessing adaptation options. Additional information to support assessments at these sites that should be gathered and organized for future opportunities. This includes projected SLR estimates for multiple future time periods, details on pavement structure and materials for potential redesign and conducting preliminary analyses such as a hydrologic and hydraulic analysis for culverts and berm locations and preliminary bridge or causeway design steps. This includes costs, required permitting, and environmental impacts at each site.

- Conduct additional traffic volume counts to on local roadways to fill in gaps in the data and provide more detailed traffic information and detour options for sites where regular detours with permanent signage are an option.

- There are several studies and other efforts that are in progress that will provide assessment tools, have bearing on adaptation options, or identify the need for future projects. The results of these efforts should be incorporated into any future analysis:

    - **NH 1A Coastal Revetment Resilience Conceptual Design Analysis (North Hampton-Rye 42312):** NHDOT is evaluating alternatives for improvements to the revetment wall along NH Route 1A that aim to protect the highway infrastructure, preserve the coastline, and prevent costly repairs to the revetment following storm events.

- **Pavement Resilience to Sea Level Rise and Potential Mitigation Options Using Natural and Nature-Based Features:** This study is investigating the coastal processes and hazards that damage roadway pavement. This work combines hydrodynamic, groundwater, and pavement models, along with an adaptation impact assessment, to understand overtopping and pavement moisture. A toolkit will be developed for decision-makers to assess the vulnerability of roadways to sea level rise and flooding. The study will also evaluate the effectiveness of natural and nature-based features to protect and increase the longevity of roadway infrastructure. Project is sponsored by NOAA and will be completed in August 2025.

- The development of a **New Hampshire Coastal Flood Risk Model (NH-CFRM)** will provide a dynamic sea-level rise and storm surge model for coastal NH to replace existing bathtub inundation maps. This model will test the effectiveness of community-driven conceptual adaptation alternatives for eight transportation and local development pilot projects; and publish best practices for considering a suite of adaptation options and prioritizing options that consider future flooding, social vulnerability, and nature-based approaches.

- **Neal Pit Lane culvert analysis in New Castle:** Rockingham County Conservation District is working with the Town of New Castle to conduct a site survey, watershed analysis, and hydrologic and hydrology analysis of the wetlands and associated drainage systems adjacent to Neal Pit Lane. The results of this study will inform improvement options at the site and may be applicable to the adjacent sites on NH 1B in Rye, as well as others covered in this assessment.

- **Resilient Tidal Crossings Project:** This partnership between the NH Coastal Program, The Nature Conservancy, and the University of New Hampshire has been evaluating the condition and function of Tidal stream crossings since 2015 and has resulted a tidal crossing assessment protocol, a Resilient Tidal Crossings Report, and has begun to fund preliminary engineering at three sites with support from the National Fish and Wildlife Foundation and the National Oceanic and Atmospheric Administration (NOAA). Three sites selected for engineering are identified as inundated at 4.0 feet of SLR in this analysis; NH 1A in Rye near Rye Harbor (Site 13), South Main Street in Seabrook (Site 21), and Squamscott Road in Stratham (Site 24).

- Pursue funding and technical resources to further assess the impacts of SLR on emergency response in the seacoast. This assessment examined the location of emergency services facilities in comparison to the sites of inundation but an evaluation of changes to response times due to road closures was not able to be completed with available resources. A more complete understanding of how emergency response is impacted could be an important factor to consider in addressing isolated neighborhoods, road closures and detours.

- Pursue funding and technical resources to improve the Regional Travel Demand Model. Work funded as part of the *Pavement Resilience to Sea Level Rise and Potential Mitigation Options Using Natural and Nature-Based Features* study will add local roadways to the model network, however additional enhancements and improvements are needed beyond what can be accomplished within that effort. This includes the acquisition of up-to-date household travel and origin-destination data for the region, more complete traffic volume count information, as well as improved model processes and methodologies.

- Build on the work of the *Hampton Harbor Flood Mitigation Analysis* (HTA, 2021) to develop unit cost data for all adaptation options discussed and calculate planning-level project costs based on that information. These costs can provide some guidance for selecting options and for pursuing more in depth analysis in preparation for implementation.

- Develop a coastal risk tolerance framework for highway assets that provides guiding assumptions regarding sea-level rise and coastal flood risk for planning, design, construction, maintenance, and operation of the roadway network. This will build off the New Hampshire Coastal Flood Risk Summary, Part II: Guidance for Using Scientific Projections (University of New Hampshire, 2020) and provide a step-by-step implementation guide.

- Ensure that projects in the State Ten Year Plan, or entering the Ten Year Plan, have scopes of work of significant detail, budgets, and schedules that are aligned, and include/address climate change and resiliency.

- Continue to develop a framework for a regional sustainability program as a long-term strategy to improve coordination among the many organizations working towards climate resiliency.

6.3 Next Steps

With the completion of this assessment there are several tasks that can be undertaken to implement the findings and prepare for future climate adaptation efforts in coastal New Hampshire. In addition, the role of RPC as the Metropolitan Planning Organization (MPO) for the region requires that the results of this effort be integrated into the regional transportation planning process.

- Integrate findings and potential transportation projects into Long Range Transportation Plan. The MPO Long Range Transportation Plan is a 20+ year planning document that identifies regional conditions, trends, and transportation project needs. The projects included in this document are candidates for the regional projects to be incorporated into the State Ten Year Plan.

- Refine the application of resiliency criteria in project selection process for the MPO Long Range Transportation Plan and the State Ten Year Plan.

- This Assessment should be revisited upon completion of the New Hampshire Coastal Flood Risk Model to address the impacts of wave action and storm surge. In addition, results from the NH-CFRM should identify and incorporate any additional areas impacted and changes to the scale or timeframe of impacts at the existing areas, resulting from newly developed hydrodynamic data.

- Monitor the latest climate science and guidance for SLR to better understand risk and probability of inundation to aid in refining a timeframe for adaption measures.

Next steps in network analysis

In addition to the next steps related to the planning next steps, there are some travel demand model and network analysis specific next steps that can be implemented to enhance the next assessment of SLR impacts on the region.

- A current limitation of the travel demand model is that it does not include all through roadways in the coast and therefore does not provide a thorough assessment of the impacts of closing each road Refine travel demand model networks. Work funded as part of the *Pavement Resilience to Sea Level Rise and Potential Mitigation Options Using Natural and Nature-Based Features* study will add local roadways to the model network and that will allow for a more complete assessment of closures and detours. Additional modifications to the model are needed however that are beyond that study.

- Improve the model through calibration with volume data on local roadways. With more roads being added to the model it will be important to utilize current traffic volume on the local roadways in the seacoast to ensure reasonable outcomes for network analysis.

- Conduct the network impact analysis utilizing the TransCAD Origin-Destination Matrix Estimation (ODME). ODME improves upon the methodology utilized in the current analysis by allowing volumes to limited on specific roadways without entirely removing the link from the network. This creates alternate trip tables with the assigned traffic volumes on certain roadways and adjusts volumes on other roads to maintain the same number of trips between each origin and destination. The alternate trip tables are compared to a baseline to understand the impacts of specific capacity limitations in some areas on the function of the network. This should reduce processing errors and allow for more nuanced analysis of partially closed roadways.

- Model impacts of closures at each individual site (25 separate runs). This will provide insight into the scale of impacts that each site of inundation has on the function of the system and will help to identify those locations where closures result in the greatest consequences to the network.

- Conduct further scenario analyses. An intermediate level of SLR between 1.7 feet and 4.0 would help to further refine the timing of network impacts. In addition, an analysis can be run that assumes that SLR impacts have been mitigated at the 1.0 foot and 1.7 foot sites to how the network responds at 4.0 feet of SLR.

7. Conclusion

This assessment builds on previous work to understand the impacts of SLR and is one of many steps to plan for a resilient New Hampshire Seacoast. Indications from tidal data are showing a growing number of “sunny day” flood conditions that the region will need to adapt to and manage that will evolve to daily flooding at some locations and possibly continuous inundation as well. This analysis provides an assessment of how the transportation system may function under those conditions and the building blocks for how to begin to mitigate the problem.

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Appendices

- Appendix A: Prioritization Methodology
- Appendix B: Travel Demand Model Assumptions and Volume Tables
- Appendix C: Site Profiles