C-RiSe

CLIMATE RISK IN THE SEACOAST

Assessing Vulnerability of Municipal Assets and Resources to Sea Level Rise

Rollinsford • Dover • Madbury • Durham • Newmarket • Newfields • Exeter • Stratham • Greenland • Newington

TOWN OF DURHAM, NEW HAMPSHIRE

Vulnerability Assessment

of projected impacts from sea-level rise and coastal storm surge flooding

Prepared by the

Strafford Regional Planning Commission

February, 2017

This project was funded, in part, by NOAA's Office for Coastal Management under the Coastal Zone Management Act in conjunction with the New Hampshire Department of Environmental Services Coastal Program

ACKNOWLEDGEMENTS

The Strafford Regional Planning Commission gratefully acknowledges the participation of Town of Durham staff, as well as board and commission members:

Dave Emanuel	Assistant Fire Chief, Fire Department, Town of Durham
Dave Kurz	Police Chief, Police Department, Town of Durham
Audrey Cline	Code Enforcement Officer, Town of Durham
Gail Jablonski	Business Manager, Town of Durham
Michael Lynch	Director, Public Works Department, Town of Durham
Luke Vincent	Manager of Information Technology, Town of Durham
Jim Rice	Assessor, Town of Durham
Michael Behrendt	Town Planner, Town of Durham
Judy Haskell	Interim Library Director, Town of Durham
Mary Ellen Humphrey	Director of Economic Development, Town of Durham
Todd Selig	Town Administrator, Town of Durham

Cover Photo Credit(s): April Talon, Town Engineer; Kyle Pimental, Principal Regional Planner (SRPC)

Notes on Use and Applicability of this Report and Results:

The purpose of this vulnerability assessment report is to provide a broad overview of the potential risk and vulnerability of state, municipal and public assets as a result of projected changes in sea-levels and coastal storm surge. This report should be used for preliminary and general planning purposes only, not for parcel level or site specific analyses. The vulnerability assessment performed was limited by several factors including the vertical accuracy of elevation data (derived from LiDAR) and the static analysis applied to map coastal areas subject to future flooding which does not consider wave action and other coastal dynamics. Also, the estimated flood impacts to buildings and infrastructure are based upon the elevations of the land surrounding them, not the elevation of any structure itself.

PLANNING TO REDUCE RISK AND VULNERABILITY

New Hampshire's economy and quality of life have historically been linked to its shores, its vast expanses of productive saltmarshes, and inland coastal rivers and estuaries. Increased flooding has the potential to place coastal populations at risk, threaten infrastructure, intensify coastal hazards and ultimately impact homes, businesses, public infrastructure, recreation areas, and natural resources. Accounting for changes in sea level and coastal storms will help lead to informed decisions for public and private risk and vulnerability.

New Hampshire seacoast municipalities are confronted by land use and hazard management concerns that include extreme weather events, storm surges, flooding and erosion. These issues are intensified by recent increases in the frequency and intensity of extreme storm events and increases in sea level.

What is a Vulnerability Assessment?

A vulnerability assessment identifies and measures impacts of flooding from sea level rise and storm surge on built structures, human populations and natural environments. Factors that influence vulnerability include development patterns, natural features and topography. The assessment evaluates existing and future conditions such as:

- inland extent and depth of flooding
- impacts to natural and human systems
- changes in impacts between different flood levels

How can the vulnerability assessment be used?

Information from a vulnerability assessment can help guide common sense solutions, strategies and recommendations for local governments, businesses, and citizens to enable them to adopt programs, policies, business practices and make informed decisions (see below).

Planning for the long-term effects of sea level rise may also help communities better prepare in the short-term for periodic flooding from severe coastal storms. Results from a vulnerability assessment can be incorporated into various municipal planning, regulatory and management documents.

How will the vulnerability assessment benefit the community?

The Climate Risk in the Seacoast assessment is intended to assist coastal NH communities to take actions to prepare for increase flood risk, including:

- Enhance preparedness and raise community awareness of future flood risks.
- Identify cost-effective measures to protect and adapt to changing conditions.
- Improve resiliency of infrastructure, buildings and investments.
- Protect life, property and local economies
- Protect services that natural systems provide
- Preserve unique community character

Master Plan	Capital Improvement Plan	Land Conservation Plan
Zoning Ordinance	Site Plan Regulations	Subdivision Regulations
Roadway Management	Stormwater Management Plan	Facilities Management Plan

TABLE OF CONTENTS

Project Partners:

MAPPING AND ASSESSMENT METHODS

Vulnerability Assessment: Sea Level Rise and Storm Surge Scenarios

The *Climate Risk in the Seacoast* (C-RiSe) vulnerability assessment project produced maps and statistical data about the potential impacts from sea-level rise and storm surge to infrastructure, critical facilities transportation systems, and natural resources in ten inland coastal communities. Three sea-level scenarios were evaluated accounting for a range from the intermediate-low to the highest projected sea-levels at the year 2100.

TABLE 1: Sea-Level and Storm Surge Scenarios in Durham

Sea Level (SLR) Scenarios	SLR	SLR	SLR	SLR + storm surge	SLR + storm surge	SLR + storm surge
Sea Level Rise	1.7ft	4.0ft	6.3ft	--	--	--
Sea Level Rise + Storm Surge	--	--	--	1.7ft + storm surge	4.0ft + storm surge	6.3ft + storm surge

Note: Storm surge is the area flooded by the 100-year/1% change storm event

Baseline: Flooding from the sea-level rise scenarios and sea-level rise plus storm surge scenarios evaluated in this study were 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. The present NTDE is 1983 through 2001 and is considered for revision every 20-25 years (the next revision would be in the 2020-2025 timeframe).*[1]

Storm Surge: *Storm surge is the rise of water level accompanying intense coastal storm events such as a tropical storm, hurricane or Nor'easter, whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the storm event.*[2] Storm surge is mapped using the 100-year/1% chance flood events from the Preliminary Flood Insurance Rate Maps (FIRMs) released by FEMA in 2014. These maps account for the limit of moderate wave action in coastal areas. This assessment does not take into account additional flooding and impacts related to more severe wave action, wind action, erosion and other dynamic coastal processes.

Sea-Level Rise Scenarios

The sea-level rise projections used in this study are based on an earlier study completed in 2011 by Wake et al and are similar to a more recent report issued by the NH Coastal Risks and Hazards Commission's Science and Technical Advisory Panel in 2014.[3]

[1] NOAA website at http://tidesandcurrents.noaa.gov/datum_options.html
[2] EPA website at http://epa.gov/climatechange/glossary.html
[3] For more information on how sea level rise scenarios were mapped, visit: http://granitweb.sr.unh.edu/MetadataForViewers/NHCoastalViewer/RelatedDocuments/Sea_Level_Rise_Narrative_rev20150106_FinalReport.pdf

As shown in Figures 1 and 2 and in the graphics below, while slightly different than the scenarios cited in the 2014 report, the sea level rise scenarios used in the Climate Risk in the Seacoast assessment yield coverage estimates of flooding that are within the mapping margin of error for the scenarios in both the 2011 and 2014 reports.

Figure 1: 2014 Sea Level Rise Scenarios (based on greenhouse gas emissions)

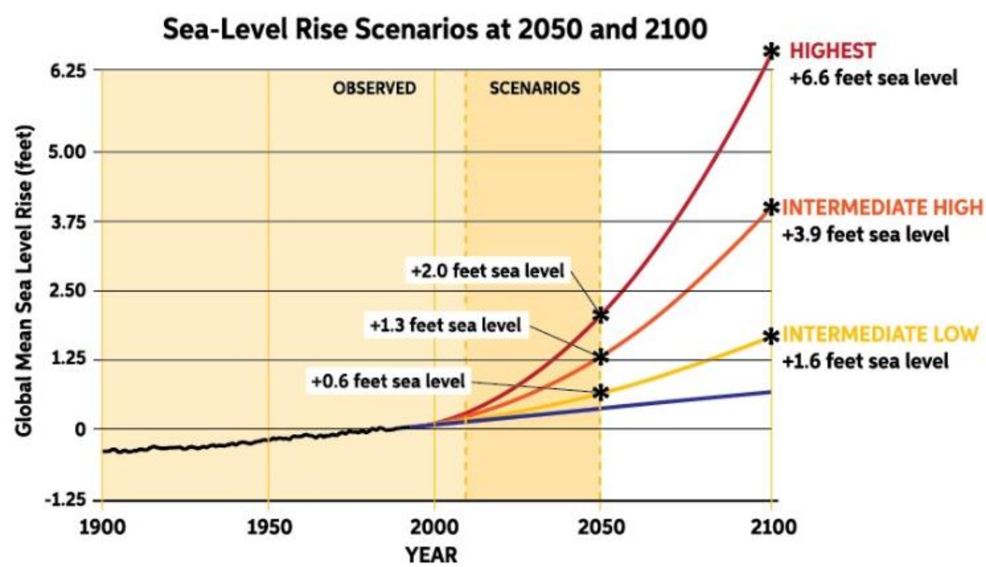
	Lower Emissions (B1)		Higher Emissions (A1fi)	
	2050	2100	2050	2100
Current Elevation of MHHW [a,b]	4.43	4.43	4.43	4.43
100-Year Flood Height	7.78	7.78	7.78	7.78
Subsidence	0.012	0.016	0.012	0.016
Eustatic SLR	1.0	2.5	1.7	6.3
Total Stillwater Elevation [a,c]	**13.2**	**14.7**	**13.9**	**18.5**

a - NAVD: North American Vertical Datum of 1988
b - MHHW: Mean Higher High Water at Fort Point, NH
c - Total Stillwater Elevation may not equal total of components due to rounding

Table 13. Preliminary estimates of future 100-year flood Stillwater elevations at the Fort Point Tide gauge under lower and higher emission scenarios (feet relative to NAVD[a]).

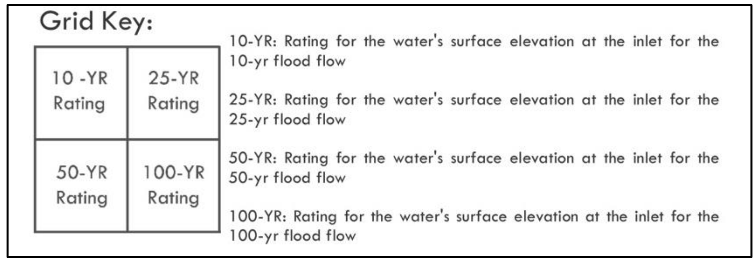
Source: Wake CP, E Burakowski, E Kelsey, K Hayhoe, A Stoner, C Watson, E Douglas (2011) *Climate Change in the Piscataqua/Great Bay Region: Past, Present, and Future*. Carbon Solutions New England Report for the Great Bay (New Hampshire) Stewards.

Figure 2: 2014 Sea Level Rise Scenarios (based on greenhouse gas emissions)

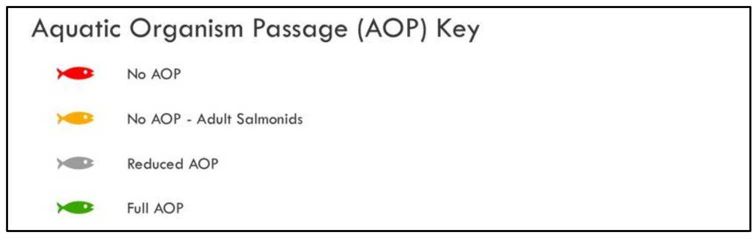


Source: Wake CP, Kirshen P, Huber M, Knuuti K, and Stampone M (2014) *Sea-level Rise, Storm Surges, and Extreme Precipitation in Coastal New Hampshire: Analysis of Past and Projected Future Trends*, prepared by the Science and Technical Advisory Panel for the New Hampshire Coastal Risks and Hazards Commission.

Data, Methods, Calculations, and Results of Hydrologic and Hydraulic Modeling for Road Crossing

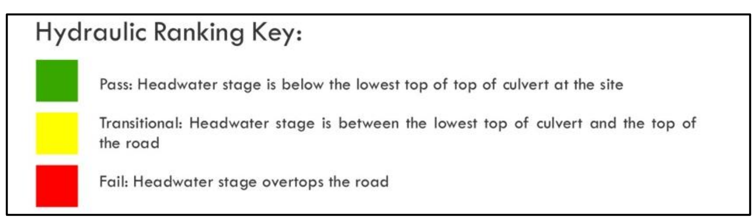


The C-Rise project assessed both aquatic organism passage capacity and hydraulic flow capacity of ten road crossings in each of the ten inland coastal municipalities. The assessment was based on runoff associated with the current 10-, 25-, 50- and 100-year storm events. For each storm, each crossing was assigned a hydraulic rating and an aquatic organism passage (AOP) rating; both ratings are described in greater detail below.



The AOP rating is labeled by color; Red, Orange, Gray, and Green. Ratings of Red and Orange mean that there is estimated to be little to no AOP at that crossing, with Red being no AOP for all species and Orange meaning no AOP for all species except for adult Salmonids. A rating of Gray means that there is reduced AOP at the crossing for all species. A rating of Green means that AOP is expected to be possible for all species.

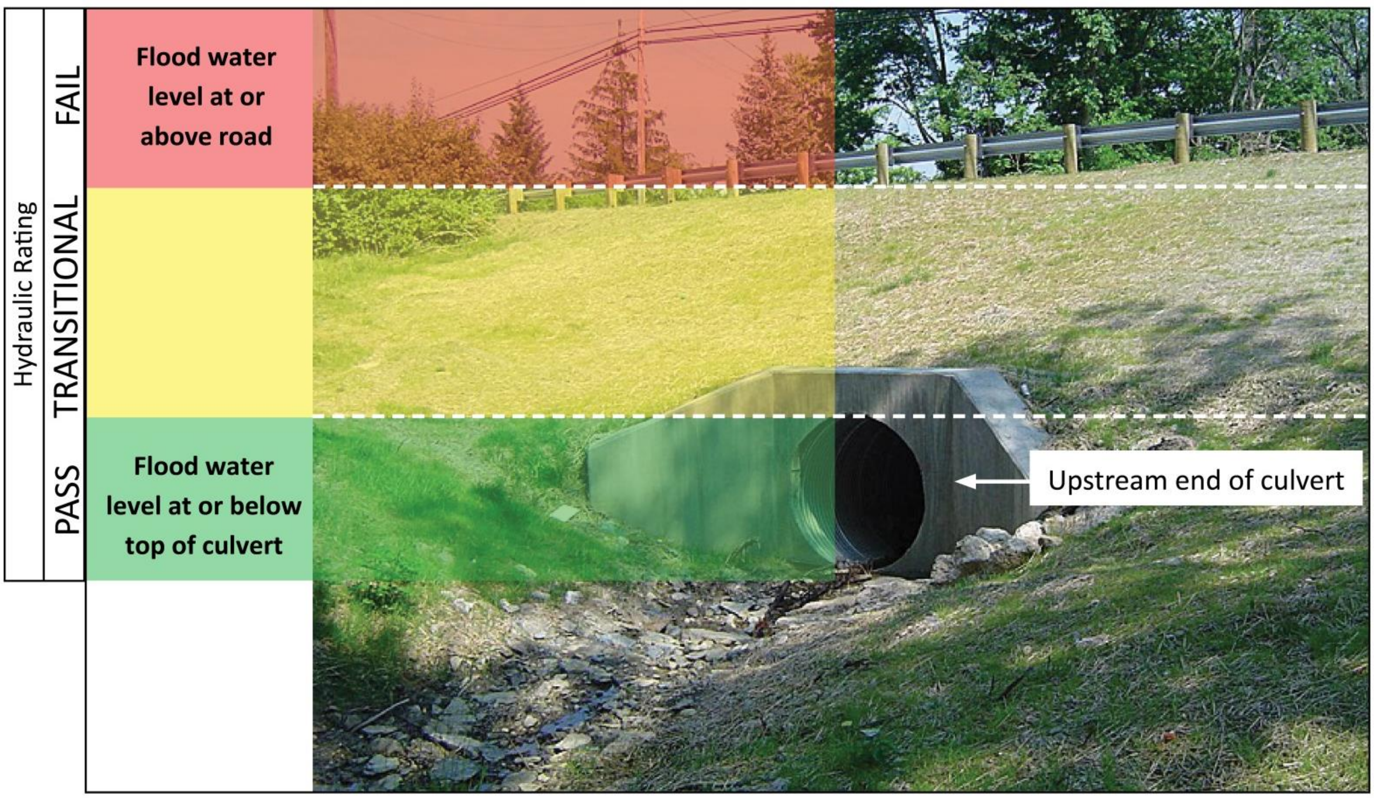
The AOP ratings were developed using the New Hampshire protocol for assessment, which was borrowed directly from the Vermont Culvert Aquatic Organism Passage Screening Tool. This tool uses physical data collected at each crossing and may be used to rate each culvert at a crossing for AOP. At a crossing with multiple culverts, if one culvert is more passable than another, then that culvert is considered to be the path that organisms would utilize. Thus, the best rating for a culvert at a crossing is used as the rating for the crossing as a whole.



The hydraulic rating is color-coded similar to the AOP rating. The peak flows of the 10-, 25-, 50-, and 100-year storm events were used to assess the ability of the culvert to pass the flow (measured by the depth of water upstream of the culvert – known as the headwater depth) was determined and compared to culvert and road elevations. The ratings for hydraulics are: Pass (green), Transitional (yellow), and Fail (red). These ratings describe the depth of the water at the inlet (the Headwater) for the flows for each of the selected storm events compared to culvert and road elevations. A rating of Pass means that the headwater depth is below the lowest top-of-pipe elevation of any culvert at the crossing; a rating of Fail means that the headwater depth is above the road surface; and a rating of Transitional means that the headwater depth is somewhere between these two elevations (see Figure 3).

The hydraulic ratings describe the headwater depth (upstream of the culvert) for each storm event flood. The headwater depths are calculated using field-collected culvert and crossing data. The flood flows were calculated by one of two methods: 1) runoff from rainfall, or 2) regression equation. For all watershed areas smaller than one square mile, the Curve Number[4] method was used; and for watersheds larger than one square mile, flows were calculated using the Regression Equations[5] published by the USGS for New Hampshire. Once the flows at each crossing were calculated, they were input into the Federal Highway Administration's free culvert analysis software, HY-8, along with the necessary culvert and crossing data collected at each location. The program then calculated the headwater depth for each of the flows at each of the sites. This headwater depth is what is shown in the results, and are compared to the pipe crown and roadway elevations to determine the Hydraulic Ratings.

Figure 3: Hydraulic rating diagram



[4] A number from zero to 100 that describes how much rainfall runs off versus is lost to infiltration: a high curve number implies most of the rainfall runs off.

[5] An equation that describes a mathematical relationship between two variables in which one variable is used to predict the other.

Assets and Resources Evaluated

Table 2 lists the three major categories and a detailed list of the assets and resources evaluated as part of the Climate Risk in the Seacoast vulnerability assessment. The assets and resources evaluated are listed in subsequent tables in this report only if they are affected by one or more of the sea-level rise and/or coastal storm surge scenarios.

TABLE 2: Assets and Resources Evaluated for the Vulnerability Assessment

Category	Assets and Resources
State and Municipal Infrastructure	Climate Ready Culverts Federal and State Historic Register Properties Other Assets: graveyards, water access, transmission lines
Municipal Critical Facilities	Municipal Critical Facilities (as identified in Hazard Mitigation Plans)
Transportation Assets & Roadways	State and Local Roadways Bridges Regional and Municipal Evacuation Routes Urban Compact Areas NHDOT Transportation Infrastructure NHDOT Ten-year and Long Range Plan Projects
Natural Resources	Freshwater and Tidal Wetlands Aquifers and Wellhead Protection Areas Uplands Floodplains Wildlife Action Plan – Tier 1 and Tier 2 habitats Land Conservation Plan – Conservation focus areas (not mapped)
Land Use	Residential structures

Map Design and Organization

The Climate Risk in the Seacoast map set is comprised of two components: a map depicting the extent of projected flooding from the three sea-level rise scenarios in shades of green, and a map depicting the three sea-level rise plus storm surge scenarios in shades of pink. Each of the asset categorized evaluated are displayed on these two maps. Two scenario maps are shown on the following page.

Extent of Flooding from Sea Level Rise and Storm Surge

The green and pink color schemes are arranged from lightest to darkest with increasing flood levels and extents.

Figure 4: Sea Level Rise Scenarios 1.7ft, 4.0ft, and 6.3ft

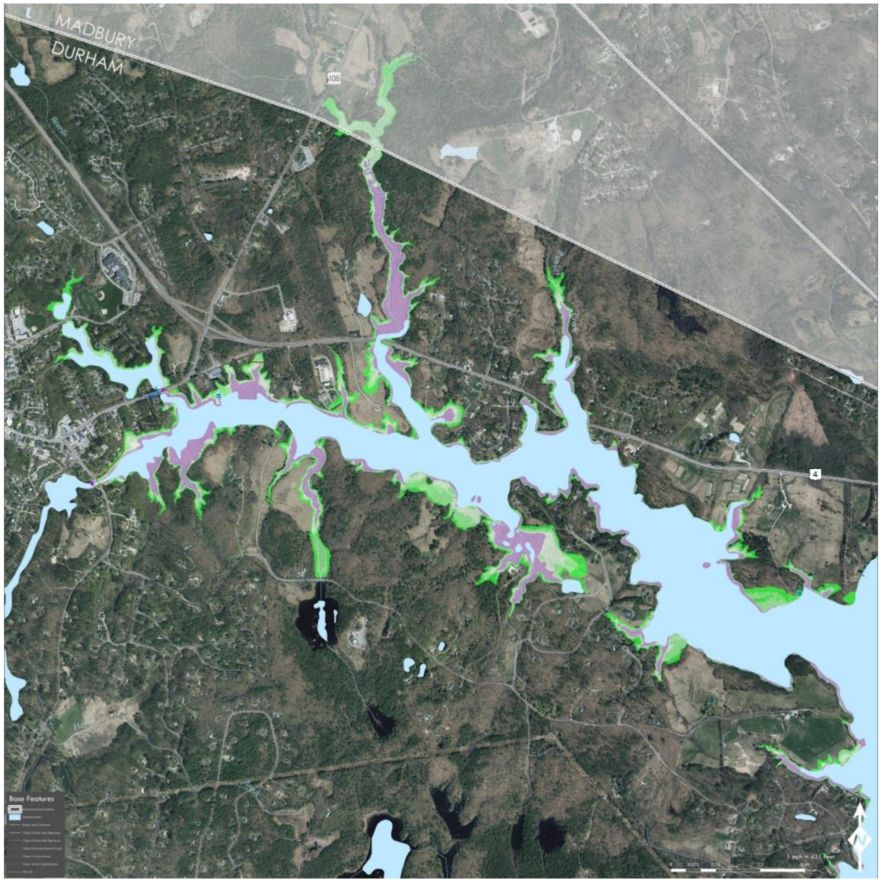
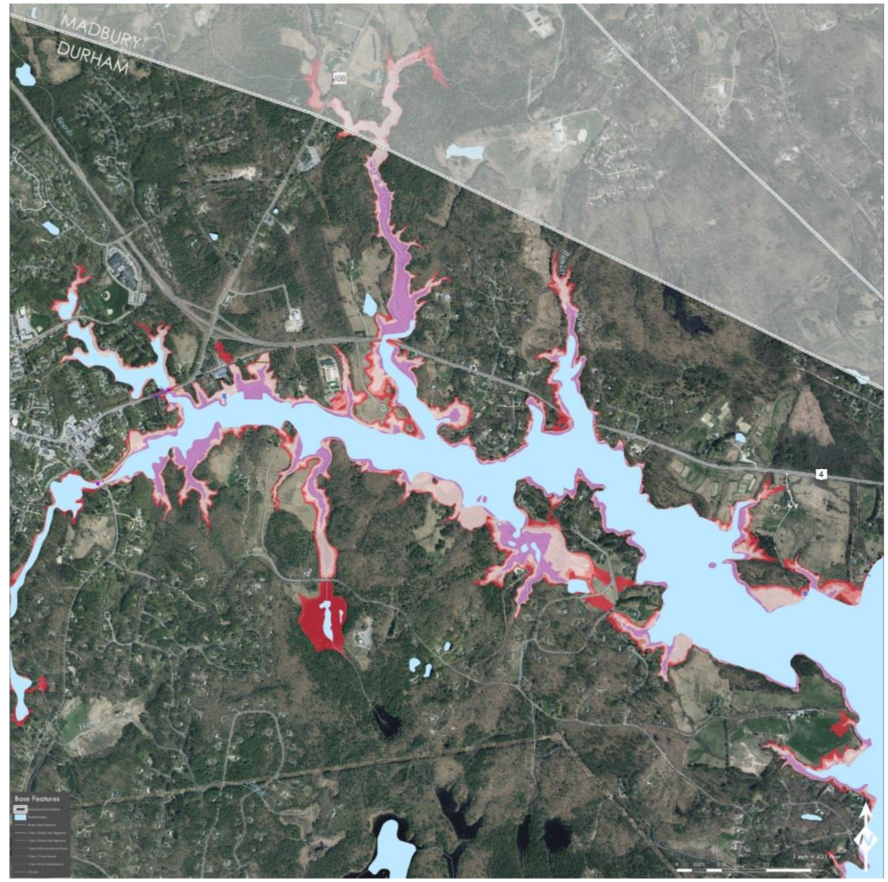


Figure 5: Sea Level Rise Scenarios 1.7ft, 4.0ft, and 6.3ft + storm surge



Note: Storm surge = 100-year/1% chance flood.

OVERVIEW

The Town of Durham is located in southeastern NH within Strafford County. It is bounded by the City of Dover to the northeast, Madbury and Lee to the northwest, Newmarket to the south, and Newington to the southeast. Durham's land area covers roughly 22.4 square miles and a water area of 2.4 square miles. With an estimated population of 15,182 (2013), Durham is the second most populated municipality in SRPC's coastal region, behind only Dover. However, it should be noted that population figures include both full-time and part-time residents, including students. According to Durham's Housing and Demographic chapter to their Master Plan, it is estimated that Durham's full-time resident population is between 5,500 and 6,200 individuals. The inland coastal portion of Durham that is most susceptible to coastal flooding is located in low areas along the Oyster River and its tributaries; at the confluence of the Oyster River and Little Bay; and along the shores of both Little and Great Bay. These areas are all within the coastal floodplain area, making them particularly vulnerable to flooding from seasonal high tides, coastal storms, and sea-level rise.

Ongoing and Completed Projects

In 2013, Durham developed a Climate Adaption Chapter as an appendix to their Hazard Mitigation Plan, entitled "Developing Strategies to Protect Areas at Risk from Flooding due to Climate Change and Sea Level Rise." This plan presented climate change and sea level rise estimates; developed strategies that protect areas at risk from flooding; and identified various regulatory and non-regulatory options for the town's consideration.

In 2016, Durham participated in a training workshop conducted by the New Hampshire Office of Energy and Planning, NH GRANIT, and the Strafford Regional Planning Commission. The purpose of this workshop was to provide an introduction to the FEMA's Flood Risk Products, present community-specific flood risk data and information, and show how the flood risk data and information can be used in planning initiatives to increase flood resiliency.

VULNERABILITY ASSESSMENT RESULTS

Key findings for the Town of Durham are reported in the tables below based on evaluation of the 1.7 feet (intermediate-low), 4.0 feet (intermediate), and 6.3 feet (highest) sea-level rise projections at the year 2100, and these same sea-level rise projections with an additional 100-year storm surge. Table 3 provides data on the total acreage of each sea level rise scenario. Table 4 provides a summary of assessment data that was analyzed as part of this project.

TABLE 3: Total Acreage of Sea Level Rise Scenarios in Durham

	Sea-Level Scenarios					
Community	1.7ft SLR (acres)	4.0ft SLR (acres)	6.3ft SLR (acres)	1.7ft SLR + storm surge (acres)	4.0ft SLR + storm surge (acres)	6.3ft SLR + storm surge (acres)
Durham	43.85	116.82	216.27	162.00	264.09	385.81

TABLE 4: Summary of Assessment Data

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Infrastructure (# of sites)	2			4		
Critical Facilities (# of sites)	3			5		
Transportation Assets (# of sites)	8			8		
Residential Structures (# of homes)	0	0	6	4	7	14
Uplands (acres)	22.98	79.93	168.64	120.37	197.95	304.39
Roadways (miles)	0.00	0.25	0.68	0.41	0.85	1.57
Freshwater Wetlands (acres)	11.71	24.48	36.81	31.91	55.52	80.50
Tidal Wetlands (acres)	18.98	28.44	31.90	30.47	32.31	33.13
Aquifers (acres)	2.10	8.96	28.72	20.71	31.38	40.56
Wellhead Protection Areas (acres)	2.87	8.89	17.29	12.52	19.95	29.06
Conserved and Public Lands (acres)	15.19	39.47	77.39	57.12	90.07	127.56
Wildlife Action Plan (acres)	27.60	69.90	136.12	100.54	163.74	244.14
Conservation Focus Areas (acres)	15.44	41.50	80.70	60.61	90.58	136.92
100-year Floodplain (acres)	43.85	104.54	120.11	114.20	140.70	168.33

Notes: Upland refers to land above mean higher high water (highest tidal extent). Storm surge is the area flooded by the 100-year/1% chance storm event.

The data indicates that Durham's uplands, floodplains, conserved lands, and lands identified as important habitat (Wildlife Action Plan) are the most vulnerable to flooding from sea level rise and coastal storm surge. In Durham, floodplains are moderately sensitive to flooding from sea-level rise. Roughly 55 percent of the highest sea-level rise scenario (6.3ft) falls within the existing FEMA 100-year floodplain. The town can expect to see further flooding impacts from sea level rise when there is a storm surge on top of the 4.0ft and 6.3ft scenarios. Even so, the 4.0ft scenario with a storm surge falls within 53 percent of the floodplain and the 6.3ft scenario with a storm surge falls with 44 percent of the floodplain. Compared to other municipalities in the region, most of Durham's key infrastructure, community assets, and natural resources are protected.

As shown in *Maps 1 and 2 Extent of Projected Tidal Flooding*, Durham can expect to see impacts along the Oyster River and its tributaries; at the confluence of the Oyster River and Little Bay; and along the shores of both Little and Great Bay. There are a handful of critical facilities impacted, including water and sewer pipes, a sewer lift station, and two dams. Several transportation assets are impacted, including evacuation routes on Routes 4 and 108, future NHDOT projects, and local urban compact areas that should also be considered during long-term planning efforts.

The complete detailed vulnerability assessment information and recommendations are provided in the following sections of this report.

SUMMARY OF VULNERABILITY ASSESSMENT RESULTS BY ASSET TYPE

Infrastructure

Maps 3 and 4 Critical Facilities and Infrastructure show state and municipal infrastructure types affected by sea-level rise and coastal storm surge flooding. Table 5 reports when specific infrastructure types are affected by each sea-level rise and coastal storm surge scenario.

TABLE 5: Infrastructure

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
State and Municipal Infrastructure (# of facilities)						
Water Access	2			2		
Graveyards	0			1		
Historic District	0			1		
Total # of Sites	2			4		

There were four municipal infrastructure assets identified as being vulnerable from either projected sea-level rise or coastal storm surge flooding. They included two water access points at Jackson's Landing and Wagon Hill; one graveyard on Durham Point Road; and an area of the Durham Historic District along Main Street/Newmarket Road.

Municipal Critical Facilities

Maps 3 and 4 Critical Facilities and Infrastructure show the municipal critical facilities affected by sea-level rise and coastal storm surge flooding. Table 6 reports when specific municipal critical facilities are affected by each sea-level rise and coastal storm surge scenario.

TABLE 6: Municipal Critical Facilities

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Municipal Critical Facilities (miles & # of facilities)						
Sewer Pipes	0.02	0.05	0.16	0.13	0.19	0.26
Water Pipes	0.00	0.00	0.01	0.01	0.01	0.11
Total miles impacted	0.02	0.05	0.17	0.14	0.20	0.37
Primary Sewer Lift Station	1			1		
Dams	0			2		
Total # of Sites	3			5		

NOTE: Municipal Critical Facilities as identified in the Town's Hazard Mitigation Plan.

There were five municipal critical facilities identified as being vulnerable from either projected sea-level rise or coastal storm surge flooding. They included minor impacts to sewer and water pipes; one primary sewer lift station near Beards Creek Dam; and two dams (Mill Pond Dam and Beards Creek Dam).

Transportation

Maps 5 and 6 Road and Transportation Assets show the state and municipal roadways affected by sea-level rise and coastal storm surge flooding. Table 7 reports the miles of state and local roadways affected by each flood scenario. Table 8 provides greater detail as to which roads are impacted. Table 9 details other transportation assets, including information on urban compact areas, evacuation routes, and future NHDOT projects.

TABLE 7: State and Municipal Roadways and Infrastructure (miles)

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Roadway Type						
State	0.00	0.03	0.08	0.05	0.10	0.48
Local	0.00	0.11	0.45	0.24	0.58	0.77
Private	0.00	0.10	0.14	0.11	0.16	0.30
Not Maintained	0.00	0.01	0.01	0.01	0.01	0.02
Total Road Miles	0.00	0.25	0.68	0.41	0.85	1.57

There are some areas of Durham's existing municipal roadway network that are sensitive to sea-level rise and coastal storm flooding, with a total of just over a mile and half of roadway being impacted under the 6.3ft of sea-level rise + a storm surge scenario.

TABLE 8: Durham's Road Asset Impacts

Sea Level Rise (SLR) Scenarios		SLR 6.3ft	SLR 6.3ft + storm surge
Road Name	Road Class	Miles Impacted	Miles Impacted
Adams Point Road	Private	0.11	0.12
Back River Road	Local	0.13	0.30
Bay Road	Local	0.01	0.03
Bunker Lane	Not Maintained	0.01	0.02
Cedar Point Road	Local	0.17	0.24
Colony Cover Road	Private	0.00	0.01
Dover Road	State	0.00	0.08
Jacksons Landing	Local	0.01	0.01
Newmarket Road	State	0.01	0.01
No Name	Private	0.03	0.17
Old Landing Road	Local	0.12	0.14

Piscataqua Road	State	0.07	0.39
Riverview Road	Local	0.00	0.03
Watson Road	Local	0.00	0.01
Total Road Miles	-	0.68	1.57

This analysis determined that, in Durham, there are a handful of state, local, or private roads vulnerable to sea-level rise and coastal storm flooding. Roadways that experience the largest stretches of inundation include sections of Back River Road, Cedar Point Road, and Piscataqua Road. Maps 5 and 6 provide a visual representation of these impacts.

TABLE 9: Durham's Other Transportation Asset Impacts

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Roadway Type						
Urban Comact Areas (acres)	17.9			24.4		
Evacuation Routes (# of sites)	3			3		
NHDOT Projects (# of sites)	5			5		

Items in Table 9 are other transportation related assets that are vulnerable to sea-level rise and coastal storm flooding, including: parts of the town's urban compact zone located in the neighborhoods near Route 108 along the Oyster River and Beards Creek; three evacuation routes along Route 4, Route 108, and Back River Road; and five NHDOT future planning projects on Bay Road over Great Bay inlet, Route 4 over Johnson Creek, Route 4 over Bunker Creek, Route 108 bridge replacement over Oyster River, and Route 108 bike shoulder construction.

Natural Resources

Maps 7 and 8 Land Resources and *Map 9 and 10 Water Resources* show natural resources affected by sea-level rise and coastal storm surge flooding. Table 10 reports the number of acres for each natural land resource affected by each sea-level rise and coastal storm surge scenario. Table 11 reports the number of acres for each natural water resource.

TABLE 10: Natural Land Resources (acres)

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Natural Land Resources (acres)						
Conservation Lands	15.19	39.47	77.39	57.12	90.07	127.56
Wildlife Action Plan	27.60	69.90	136.12	100.54	163.74	244.14
Conservation Focus Areas (acres)	15.44	41.50	80.70	60.61	90.58	136.92
Total land resources	58.23	150.87	294.21	218.27	344.39	508.62
* As part of this analysis, conservation focus areas were calculated; however due to their overlap with data from the Wildlife Action Plan, they were not mapped.						

Durham's natural land resources are quite sensitive to sea-level rise and coastal storm flooding. Impacted natural resources include: thirty conservation easements and/or town owned lands (the Rollins tract, Smith Trust, and Wagon Hill Farm represent approximately 40% of all the protected lands that are impacted by the highest scenario with a storm surge) as well as important lands identified in the Wildlife Action Plan along the Oyster River and its tributaries, and along the shoreline of Little and Great Bay.

TABLE 11: Natural Water Resources (acres)

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Natural Water Resources (acres)						
Wellhead Protection Areas	2.87	8.89	17.29	12.52	19.95	29.06
Estuarine and Marine Wetlands	18.98	28.44	31.90	30.47	32.31	33.13
Freshwater Wetlands	11.71	24.48	36.81	31.91	55.52	80.50
Stratified Drift Aquifers	2.10	8.96	28.72	20.71	31.38	40.56
Total water resources	35.66	70.77	114.72	95.61	139.16	183.25

In terms of spatial extent and total acreage, Durham's water resources are not quite as sensitive as that of its land resources. The town's freshwater wetlands along with its stratified drift aquifers are the most impacted water resources. The total acreage (using the highest scenarios) of the town's freshwater wetlands more than doubles in size with a storm surge. Another consideration is the town's groundwater resources – the Johnson Creek Wellhead Protection Area has been identified as an area that may experience future issues. While this study did not analyze the potential impacts from salt water intrusion, this may be a future challenge the town should investigate.

Land Use

Maps 1 and 2 Extent of Projected Tidal Flooding show upland affected by sea-level rise and coastal storm surge flooding above mean higher high water. Upland refers to land above mean higher high water (highest tidal extent). Table 12 reports the number of acres of upland affected by each flood scenario.

TABLE 12: Uplands (acres)

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Uplands (acres)						
Acres	22.98	79.93	168.64	120.37	197.95	304.39
% Upland	0.17	0.58	1.23	0.87	1.44	2.21

Total Upland in Durham = 13,766 acres.

Roughly 2% of Durham's uplands are impacted. Durham's inland coastal area has some low lying areas, mainly in the eastern part of town along Little and Great Bay, and along Oyster River and its tributaries, which has experienced significant riverine flooding in the past.

Parcels and Assessed Value

Table 13 reports the number of parcels affected by each of the six scenarios evaluated and the aggregated assessed value of these parcels. The degree to which the parcel and any development on the parcel are affected by sea-level rise or storm related flooding was not analyzed. Affected parcels were identified based on their location either partially or fully within the extent of the scenarios evaluated. Table 14 reports the number of residential structures affected by each of the six scenarios evaluated and the aggregated assessed value of these homes.

TABLE 13: Parcels and Assessed Value by Scenario

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Parcels and Assessed Value						
Parcels Affected (# of parcels)	207	227	241	235	263	298
Aggregate Value of Parcels ($ value)	$101,760,806	$134,883,867	$138,707,949	$136,601,357	$144,892,381	$152,865,099

For Durham, the number of impacted parcels ranges from roughly 207 to 298 and values of $101,760,806 to $152,865,099 respectively. This analysis shows that there is a significant jump in impacted parcel values between the 1.7ft and 6.3ft scenarios. This includes 34 more parcels at an estimated increase in value of $36,947,140, and represents a 36% increase.

TABLE 14: Residential Structures and Assessed Value

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
Residential Structures and Assessed Value						
Structures Affected (# of homes)	0	0	6	4	7	14
Assessed Value of homes ($ value)	$0	$0	$1,981,758	$1,581,048	$2,381,571	$5,597,384

Durham does not experience any residential impacts under the first two sea-level rise scenarios. However, the town does have a total of six residential structures that are impacted under the 6.3ft sea-level rise scenario and fourteen structures under the 6.3ft of sea-level plus coastal storm flooding. Assessed values range from roughly $2 million to $5.6 million.

Climate Ready Culverts

Maps 11 and 12 Climate Ready Culverts Maps show areas within the 100-year floodplain affected by sea-level rise and coastal storm surge flooding. Table 15 reports the hydraulic and aquatic organism passage ratings for the ten culverts chosen for this analysis.

TABLE 15: Climate Ready Culvert Analysis

Culvert Crossing ID & Location	*Precipitation Flood Flow				***Aquatic Organism Passage (AOP) Rating
	10-yr	25-yr	50-yr	100-yr	
	**Hydraulic Rating				
Culvert Crossing ID & Location					
#28: Madbury Rd over Littlehole Creek	Fail	Fail	Fail	Fail	No AOP
#29: Edgewood Rd over Littlehole Creek	Transitional	Fail	Fail	Fail	Reduced AOP
#30: Bagdad Rd over Littlehole Creek	Fail	Fail	Fail	Fail	Reduced AOP
#31: Madbury Rd over Reservoir Brook	Transitional	Transitional	Transitional	Transitional	Full AOP
#32: Griffith Dr over Unnamed Stream	Fail	Fail	Fail	Fail	Reduced AOP
#33: Bennett Rd over Woodman Brook	Fail	Fail	Fail	Fail	No AOP
#34: Bennett Rd over LaRoche Brook	Fail	Fail	Fail	Fail	Reduced AOP
#35: Bennett Rd over Beaudette Brook	Fail	Fail	Fail	Fail	Reduced AOP
#36: Longmarsh Rd over Longmarsh Brook	Fail	Fail	Fail	Fail	Reduced AOP
#37: Route 108 over Hamel Brook	Fail	Fail	Fail	Fail	Full AOP

**10-YR: Rating for the water's surface elevation at the inlet for the 10-yr flood flow; 25-YR: Rating for the water's surface elevation at the inlet for the 25-yr flood flow; 50-YR: Rating for the water's surface elevation at the inlet for the 50-yr flood flow; 100-YR: Rating for the water's surface elevation at the inlet for the 100-yr flood flow*

***Pass: Headwater stage is below the lowest top of the culvert at the site; Transitional: Headwater stage is between the lowest top of culvert and the top of the road; Fail: Headwater stage overtops the road;*

**** No AOP: For all aquatic organisms including adult salmonids; No AOP – Adult Salmonids: For all aquatic organisms except adult salmonids; Reduced AOP: For all aquatic organisms; Full AOP: for all aquatic organisms*

According to the hydraulic component of the analysis, of the ten culverts chosen, none were able to pass the 10-yr storm event; eight failed; and two ranked transitional. For the 25-yr storm event, nine culverts failed; and one was ranked transitional. For the 50-yr storm event, nine culverts failed; and one was ranked transitional. For the 100-yr storm event, nine culverts failed, and one was ranked transitional. It should be noted that staff from the Public Works Department were aware that these culverts had experienced significant flooding issues in the past and wanted more data.

According to the aquatic organism passage component of the analysis, of the nine culverts chosen, two were able to fully accommodate species to navigate through the culvert; six were reduced; and two failed to provide the opportunity for species to successfully navigate the culvert.

FEMA Flood Hazard Areas

Maps 11 and 12 Climate Ready Culverts Maps show areas within the 100-year affected by sea-level rise and coastal storm surge flooding. The three sea-level rise scenarios generally fall within the current 100-year floodplain, extending beyond into the 500-year floodplain in certain areas.

From a floodplain management perspective, limiting development and/or strengthening existing regulations within the current 100-year floodplain will provide protection against flood impacts from long term sea level rise. Table 16 reports the acreage within the current 100-year floodplain affected by each flood scenario.

TABLE 16: FEMA Flood Hazard Areas (acres) Impacted

Sea Level Rise (SLR) Scenarios	SLR 1.7ft	SLR 4.0ft	SLR 6.3ft	SLR 1.7ft + storm surge	SLR 4.0ft + storm surge	SLR 6.3ft + storm surge
FEMA Flood Hazard Areas						
100-yr floodplain impacted (acres)	43.85	104.54	120.11	114.2	140.7	168.33
Percentage of SLR within the floodplain	100%	89.49	55.54%	70.49%	53.28%	43.63%

Floodplain assessment based on Flood Insurance Rate Maps (FIRMs) released by FEMA in September, 2015.

In Durham, the 100-year floodplain is highly sensitive to flooding from sea-level rise mostly along the Oyster River and its tributaries, and along both the shoreline of Little and Great Bay. According to this analysis, roughly 55 percent of the highest sea-level rise scenario (6.3ft) falls within the existing FEMA 100-year floodplain. The town can expect to see further flooding impacts from sea level rise when there is a storm surge on top of the 4.0ft and 6.3ft scenarios. Even so, the 4.0ft scenario with a storm surge falls within 53 percent of the floodplain and the 6.3ft scenario with a storm surge falls with 44 percent of the floodplain.

ISSUES AND CONSIDERATIONS

The following issues and considerations of local and regional importance were identified during project meetings with municipal staff and land use board and commission members.

- The results of the climate ready culvert analysis will assist the town during long-term planning decisions in regard to the placement, design and size of new culverts or when upgrades and repairs are being made to existing culverts.

- According to the hydraulic component of the analysis, of the ten culverts chosen, none were able to pass the 10-yr storm event, eight failed, and two ranked transitional. The vulnerability and risk of future failure at these locations will become greater with an expected increase in the frequency of extreme precipitation events.

- Improving the town's floodplain management by regulating development within the current 100-year floodplain will mitigate impacts from future long term sea-level rise. The town can incorporate higher freeboard standards into existing regulatory and management frameworks within the Town's Special Floodplain Hazard Overlay District.

- Four municipal infrastructure assets were identified as vulnerable from either projected sea-level rise or coastal storm surge, which include water access points at Jackson's Landing and Wagon Hill, one graveyard on Durham Point Road, and an area of the Durham Historic District along Main Street/Newmarket Road.

- Municipal critical facilities identified as vulnerable from either projected sea-level rise or coastal storm surge include impacts to sewer and water pipes, one primary sewer lift station near Beards Creek Dam, and two dams (Mill Pond Dam and Beards Creek Dam).

- Roadways that can expect to experience the largest stretches of inundation due to flooding from sea-level rise and coastal storm surge include sections of Back River Road, Cedar Point Road, and Piscataqua Road. Flooding to these areas may disrupt local commuting patterns and cause challenges for emergency responders.

- Other transportation related assets vulnerable to sea-level rise and coastal storm flooding, include parts of the town's urban compact zone located in the neighborhoods near Route 108 along the Oyster River and Beards Creek; three evacuation routes along Route 4, Route 108, and Back River Road; and five NHDOT future planning projects on Bay Road over Great Bay inlet, Route 4 over Johnson Creek, Route 4 over Bunker Creek, Route 108 bridge replacement over Oyster River, and Route 108 bike shoulder construction.

- Protecting both freshwater and tidal wetlands will improve floodplain storage capacity, assist to adequately separate development and infrastructure from these areas, and allow for the inland migration of tidal marsh systems and conversion of freshwater systems to tidal systems to accommodate projected changes in sea-levels.

- Providing information about potential flood hazards to businesses and residents, and early notification of flood risk during a coastal storm event would enhance public safety and preparedness.

- Land conservation efforts along Oyster River and its tributaries, at the confluence of the Oyster River and Little Bay, and along the shores of both Little and Great Bay would mitigate future flooding impacts by guiding development away from those areas and increasing flood storage capacity.

- The Town's Johnson Creek wellhead protection area is vulnerable to sea-level rise projections and drinking water resources may be impacted by salt water intrusion. This issue needs further study to identify how saltwater is likely to change the salinity of existing freshwater sources along the coast. Additionally, as sea levels rise, groundwater table elevations are pushed upward, resulting in higher groundwater elevations at significant distances from the coast.

RECOMMENDATIONS

The following recommendations are short-term climate adaptation actions that can be included in Durham's Hazard Mitigation Plan, Master Plan and other planning and policy documents. These actions are focused on strengthening land use development standards, resource protection, municipal policy and plans, and public support to create more resilient development, infrastructure and natural systems.

REGULATORY

R1 - Elevate Structures 2 feet Above Base Flood Elevation. Adopt standards in the town's existing floodplain hazard overlay district that require all new development and redevelopment to be elevated 2 feet above the base flood elevation. Two feet of additional elevation will ensure that structures are protected from flooding based on the highest sea-level rise projection of 2 feet by 2050 (the Town currently requires new development to be built 1ft above BFE).

R2 - Coastal Flood Hazard Overlay District. In the town's zoning ordinance, adopt a Coastal Flood Hazard Overlay District that includes performance based standards that protect against flood impacts from sea-level rise and coastal storm surge. Establish the overlay district boundaries based on current flood hazard areas on FEMA Flood Insurance Rate Maps and projected future high risk flood areas mapped by the C-RiSe Vulnerability Assessment. (Also see similar recommendation in the Community Outreach and Engagement section below.)

R3 - Coastal Buffers and Tidal Marshes. Adopt buffer requirements for setbacks to wetlands that include consideration of climate change in order to protect land that allows coastal habitats and populations to adapt to changing conditions and also provides ecosystem services that protect people, structures, and facilities.

R4 – Culvert Maintenance and Improvement. Adopt ecosystem-friendly approaches in the placement and design of freshwater and tidal stream crossings in order to restore or maintain natural flow regimes to increase ecosystem resilience to extreme weather events and other coastal hazards.

PLANNING AND POLICY

P1 - Natural Hazards Mitigation Plan. Incorporate the vulnerability assessment information and recommendations from the C-RiSe report into the town's next Natural Hazards Mitigation Plan update. Continue revising and updating the assessment information and climate adaptation recommendations in future updates of the Plan as new data and information becomes available.

P2 - Master Plan Coastal Hazards Chapter. Adopt a Coastal Hazards Chapter in the Town's Master Plan that incorporates information and recommendations from the C-RiSe Vulnerability Assessment Profile.

P3 - Capital Infrastructure and Investments. Incorporate consideration of impacts to municipal infrastructure, including water access at Jackson's Landing and Wagon Hill and areas of the Durham Historic District in current and future capital infrastructure projects. Evaluate the extent of sea-level rise and storm surge flooding on individual facilities, including sewer and water pipes; the lift station near Beards Creek; and both Mill Pond and Beards Creek dams.

P4 - Land Conservation. Land conservation offers the greatest opportunities to provide for adaptation to the effects of sea-level rise and coastal storm flooding and climate change impacts.

- Incorporate new scoring criteria into existing land conservation prioritization efforts that consider climate adaptation benefits when evaluating land for conservation purposes.
- Support funding and resources for conservation, land management programs, and land stewardship activities.

P5 - Evacuation Planning. Prepare evacuation plans and coordinate these plans with towns in the coastal region to implement timely and comprehensive planning and notification for coastal storm events.

- Mark evacuation routes with signage and communicate routes to the public with information on the town's website and printed maps.

P6 – Drinking Water Protection. Conduct an investigation of the vulnerability of public drinking water supplies to salt water intrusion. Ongoing groundwater modeling at the University of New Hampshire is investigating the effects of climate change, including sea-level rise, precipitation and temperature, on groundwater levels and the impacts to roads in coastal New Hampshire. The groundwater modeling study will have broader applications as it can be expanded to investigate the effects of climate change on drinking water supply, base flow to streams, and the hydrology of wetlands.

P7 – Road Maintenance. Evaluate the extent of sea-level rise and storm surge flooding to sections of roadway on Back River Road, Cedar Point Road, and Piscataqua Road. Ensure that all future transportation related projects within identified vulnerable areas take projected sea-level rise scenarios into account.

COMMUNITY OUTREACH AND ENGAGEMENT

O1 - Implement FEMA's High Water Mark Initiative. Communities implement the High Water Mark Initiative by providing information on past floods, such as documenting high water marks in public places, and posting maps and photographs of past floods on their website. High water marks can be displayed on public buildings or on permanently installed markers.

O2 - Coastal Flood Hazard Overlay District. Use the Coastal Flood Hazard Overlay District as a tool to inform property owners of existing and future risks and hazards based on projected sea-level rise and coastal storm surge flooding.

O2 - Living Shorelines and Landscaping. Maintaining natural shorelines is an effective way to preserve the functions of shoreline systems (marshes, dunes, estuaries) in providing valuable services including flood storage, recreational areas, and commercial harvesting of fish and shellfish.

- Provide information to property owners about living shorelines and the importance of retaining the functions of natural shorelines, and implementing landscaping best practices.
- Implement living shorelines projects on town lands to demonstrate best practices, and the benefits and effectiveness of living shorelines approaches.

APPENDIX – MAP SET

Map 1: Extent of Projected Tidal Flooding - SLR 1.7', 4.0' and 6.3'
Map 2: Extent of Projected Tidal Flooding - SLR + Storm Surge
Map 3: Critical Facilities and Infrastructure - SLR 1.7', 4.0' and 6.3'
Map 4: Critical Facilities and Infrastructure - SLR + Storm Surge
Map 5: Roads and Transportation Assets - SLR 1.7', 4.0' and 6.3'
Map 6: Roads and Transportation Assets - SLR + Storm Surge
Map 7: Land Resources - SLR 1.7', 4.0' and 6.3'
Map 8: Land Resources - SLR + Storm Surge
Map 9: Water Resources - SLR 1.7', 4.0' and 6.3'
Map 10: Water Resources - SLR + Storm Surge
Map 11: Climate Ready Culverts - SLR 1.7', 4.0' and 6.3'
Map 12: Climate Ready Culverts - SLR + Storm Surge