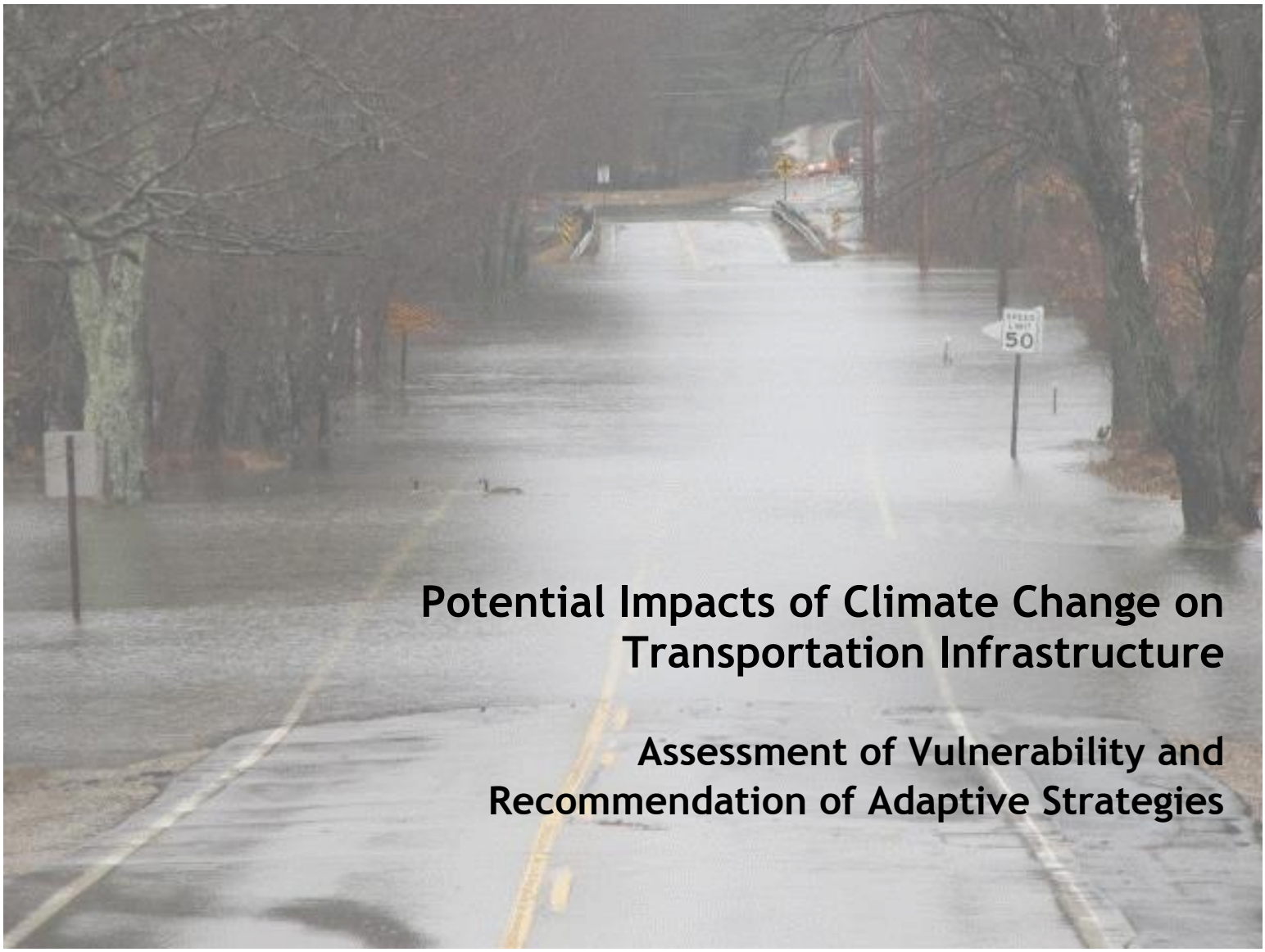
New Hampshire DOT
Department of Transportation



Potential Impacts of Climate Change on Transportation Infrastructure

Assessment of Vulnerability and Recommendation of Adaptive Strategies

April 2014

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Acknowledgements

In December 2012, the Office of Energy and Planning (OEP) began to work with the New Hampshire Department of Environmental Services (NHDES) to put together a project that in light of the devastating effects of Hurricane Sandy on areas of the eastern U.S., would take advantage of a grant opportunity originating from the US Department of Energy. The project, known as the "Resilience and Preparedness in NH State Government Project," builds on work, in which NHDES has been engaged since 2010, to address climate change impacts in New Hampshire through internal program and policy changes within state government. In January 2013, NHDES Commissioner, Tom Burack, invited NHDOT Commissioner Chris Clement to join the project and generate an assessment of vulnerability and adaptation strategies for the Department of Transportation. The project took place from May 1 through September 30, 2013.

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Executive Summary

The earth's climate has shifted naturally and gradually throughout geologic time. It is expected that natural influences will continue to play a role. However, greenhouse gas emissions have amplified the rate and intensity of climate change, adding additional stress to both natural systems and manmade infrastructure. Although much uncertainty about the underlying causes remains, the potential impacts of climate change on the human environment are so significant that many national, state and local organizations have initiated adaptive planning and management in anticipation of the effects of climate change, and to make accommodations to manage those effects.

In New Hampshire, climate change is already producing: warmer temperatures; more frequent and severe weather events; modified stream flow; fluctuations to stormwater runoff patterns and volumes; and rising sea levels. These impacts are expected to increase into the foreseeable future. New Hampshire Department of Transportation (NHDOT) transportation infrastructure is vitally important to the well-being of the state and NHDOT recognizes the necessity of proactively evaluating its physical assets, planning strategies, and operational practices to be prepared for more severe weather events.

The purpose of this report is to help maintain and improve the integrity and function of NHDOT transportation systems (existing infrastructure, operations and maintenance, and design and construction of new facilities) by developing a strategy through which NHDOT could reduce the impact of climate change on their assets and programs. The goals and objectives of this project are to:

1. Identify NHDOT assets, programs, policies and activities (APPA) that are, or may be impacted by climate change, in the future;
2. Explore how changing weather trends may affect NHDOT APPA and assess and rank the vulnerability of Department assets and operations to climate change;
3. Identify and prioritize short, medium and long term opportunities/goals to increase the resilience and preparedness of NHDOT, to protect existing infrastructure and future investments and operations.

This document begins by providing a brief overview of climate change in New Hampshire. It then summarizes NHDOT APPA, and proceeds to address their vulnerability to projected changes in climate through the end of the 21st century based on available information, and evaluates how climate change might impact NHDOT APPA. Four primary climate change variables were identified by NHDOT and are listed below. These variables are interrelated, with one variable perhaps affecting the impact of another.

1. Increases in extreme precipitation events,
2. Sea-level rise and coastal storm surge,
3. Warming winters and associated changes in precipitation freeze/thaw cycles, and
4. General temperature increase.

A prioritized list of NHDOT APPA (see further discussion in Section 3) was evaluated based on these four changing climate variables. A compilation of this information was used to develop an action plan, providing adaptation strategies to help set priorities for the agency and increase resiliency in the future in the face of climate change.

1.0 Introduction

Existing and projected future impacts of climate change are expected to result in significant and serious implications for New Hampshire. Some of these impacts are already being observed and others are being predicted by complex climate models, but all have the potential to dramatically change the lives of the people of NH. In addition to warmer average temperatures, scientists predict that the effects of climate change in New Hampshire will include: increased frequency of short-term droughts (1-3 months) during the summer months, an increase in instances of extreme heat days, earlier ice out on lakes, extended length of growing season, fluctuations in freeze/thaw cycles, a rise in storm frequency and intensity, increases in annual precipitation, less snow and more rain during the winter months, earlier spring runoff, changes in stream flow, evaporation, and evapotranspiration, increased risk of fire, pests, and invasive species, changes in runoff and stormwater volumes, reduced snowpack (density, duration, extent), reduced soil moisture, an increase in the frequency of severe weather events (hurricanes, ice storms, intense rain); and rising sea levels along coastal areas. (Frumhoff et al 2007)

Transportation infrastructure and operations will be affected by many of the climate change impacts noted above. Perhaps the most significant to transportation will be changes associated with the hydrologic cycle, such as increased frequency and intensity of severe storms, especially rainfall, changes in runoff patterns including increased frequency and magnitude of flooding, sea-level rise and increased storm surge along coastal areas and more pronounced freeze/thaw cycles. As a result, it is prudent for NHDOT to evaluate how its APPA may be influenced by climate change and to develop a program of adaptive management to reduce the vulnerability of its APPA to consequences associated with projected trends in weather patterns. This document assists NHDOT toward implementing adaptive management strategies by:

- Providing an overview of the expected climate change factors that will influence NH transportation infrastructure;
- Compiling a list of categories of transportation APPA and providing guidance for assessing the vulnerability of those APPA to climate change;
- Developing an action plan that provides direction to NHDOT for implementing short-, medium-, and long-term actions that strategically improves the resiliency of the Department and it's APPA to climate change.

This comprehensive assessment of climate change vulnerabilities and adaptive management strategies will better position NHDOT to effectively anticipate the impacts of climate change with minimal disruption to the personal well-being of residents and visitors as well as the economic strength of the business community.

2.0 Climate Change Trends

As noted above, NHDOT identified four climate change variables that it considered most significant to transportation issues:

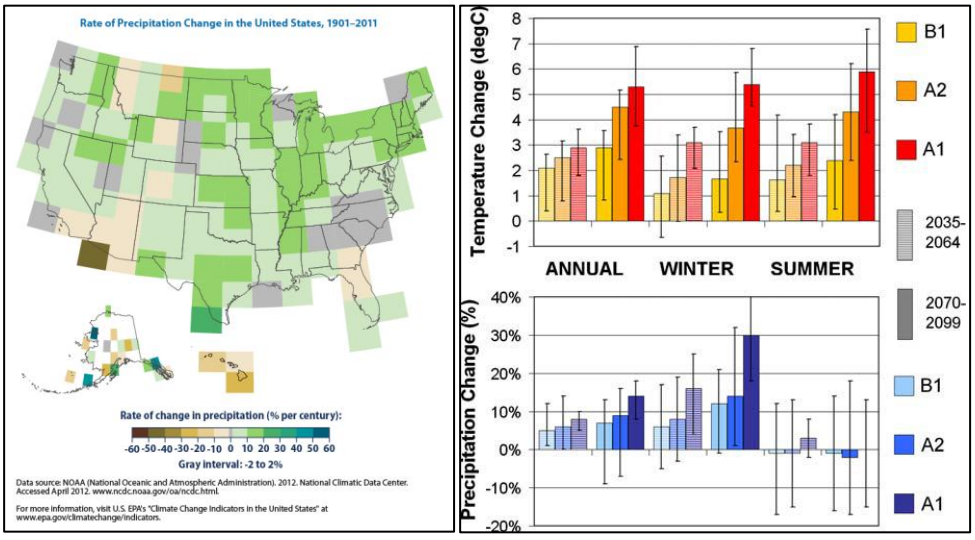
1. Increases in extreme precipitation events,
2. Sea-level rise and coastal storm surge,
3. Warming winters and associated changes in precipitation freeze/thaw cycles; and
4. General temperature increase.

In this section, we examine how these variables have changed or are expected to change by the end of the century.

Extreme Precipitation

Overall, precipitation is expected to increase in both frequency and intensity over the Northeast, with the majority of the expected precipitation increase occurring during the colder months in the form of rain. Some climate models predict that there will be an increase in annual mean precipitation in the northeast by as much as 30% during winter months (Rustad et al., 2012), by the end of this century.

Figure 1 depicts the rate of precipitation change in the United States from 1901- 2011, as identified by the EPA. This figure indicates that in New Hampshire, precipitation has increased between 10%-20% during this time period. The figure also shows projected changes in precipitation and temperature for mid-century and end-of-century for the Northeastern US under low (B1), median (A2) and high (A1) greenhouse gas emission scenarios.

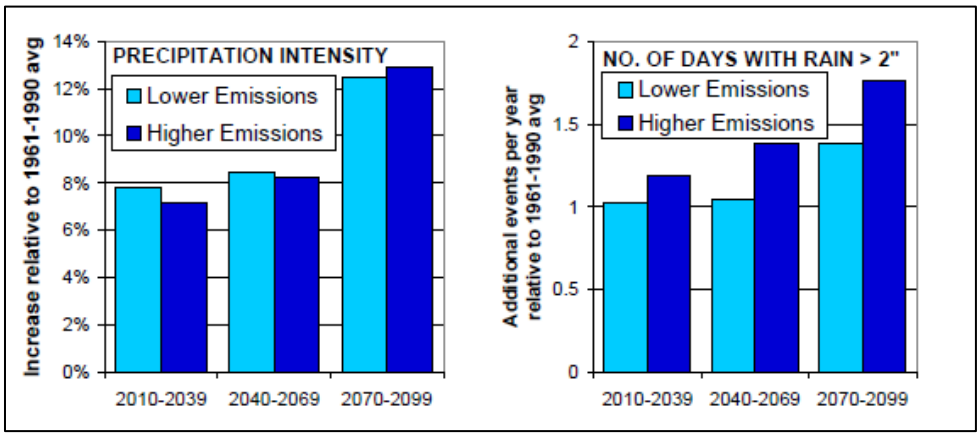


http://www.epa.gov/climatechange/science/indicators/weather-climate/precipitation.html

Figure 1: Existing and predicted precipitation and temperature changes: 1901 - 2099

Figure 2 presents two greenhouse gas emissions scenarios and anticipated changes in precipitation related to **intensity** and **number of days** with rainfall greater than two inches for

different time periods through the end of the 21st century. It is expected that there will be over a 12% increase in intense rainfall events, when compared to the average for 1961-1990 and that that there will be approximately 1.5 to 2 more days per year with rainfall events producing in excess of 2 inches of rain.



Source: NECIA, 2006

Figure 2: Expected increases in precipitation intensity and days with heavy rain: 2010-2099

These changes in precipitation events are expected to result in the following effects:

- **Runoff/Streamflow Increases:** Greater precipitation intensity and duration will result in episodic ("flashy") increases in runoff and resulting streamflow throughout the year. During the winter months, frozen ground inhibits infiltration, resulting in increased runoff and increased risk of winter flooding. Ice and snow, which may obstruct natural and man-made drainage systems, compound the magnitude of winter flooding, in turn resulting in increased needs for immediate and after-the-fact measures to prevent, manage, or repair damage to transportation infrastructure and surrounding property from ice and water.

  In the summer, reduced soil moisture and increased evapotranspiration (Huntington et. al., 2009), coupled with more intense rainfall, will lead to episodic increased runoff and streamflow, increased potential for flooding, and increased erosion and sedimentation within streams and man-made drainage channels and culverts. The greater volumes of runoff associated with episodic events do not replenish groundwater levels as effectively as low-intensity rainfall occurring over a period of several days.

- **Ice:** Reduced snowfall (but increased precipitation in the form of rain) during the colder months can lead to increased icing and winter flooding in small streams and intermittent drainage ways. Snowpack insulates these small drainage ways/stream channels, enabling the flow of water and infiltration to occur even during winter months. Lack of snow cover allows ice buildup during cold periods. This reduces the capacity of culverts and drainage ways, inhibits infiltration, and when combined with expected increased winter rainfall, will lead to increased flooding of roadways and surrounding properties. This is especially problematic in areas that have

undersized or ice-obstructed drainage infrastructure that is unable to accommodate additional overland flow. More frequent rainfall during the colder months could also increase the frequency of ice on roads, resulting in higher levels of salt application over the course of the winter, in spite of projected reductions in snowfall.

Sea Level Rise and Coastal Storm Surge

Sea levels are generally rising around the world, largely in response to climate change associated with global warming. In the Northeast, sea levels have been rising for perhaps a century. Wake et al., 2011 reports that sea level has risen in the city of Portsmouth by approximately six (6) inches since 1926.

Figure 3 presents the recent (1960-2011) sea level rise experienced in the U.S. as reported by NOAA. Furthermore, sea levels are expected to continue to rise for the foreseeable future. By 2100, it is predicted that sea levels will rise an additional two to six feet, depending on the level of greenhouse gas emissions during that timeframe (Wake et. al., 2011).

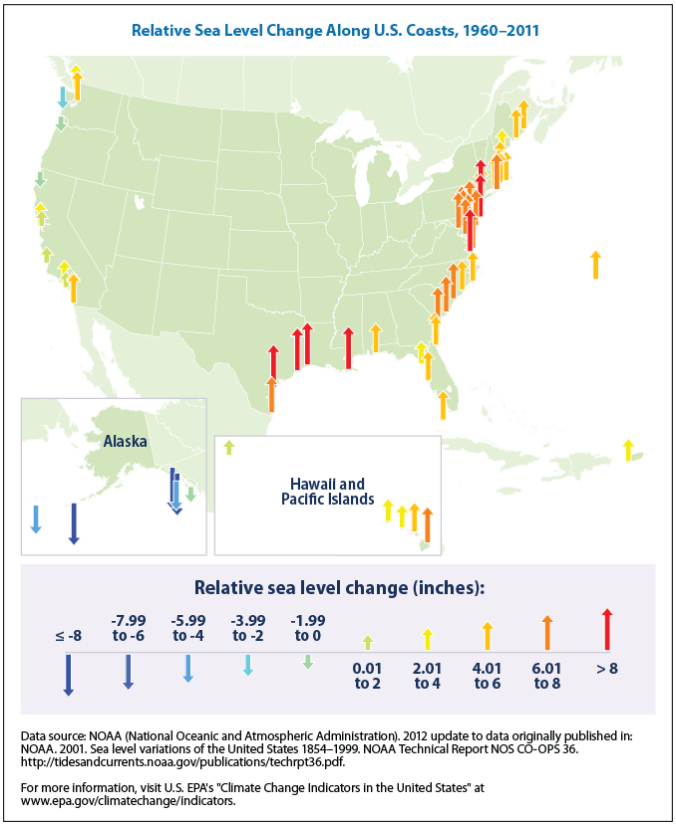


Figure 3: Relative Sea Level Change in the U.S.: 1960-2011

http://www.epa.gov/climatechange/science/indicators/oceans/sea-level.html

Although New Hampshire has only eighteen miles of coastline, sea level rises of the magnitude indicated above (4" to 6") would have significant impacts. Coastal areas support some of the most densely populated communities in the state and some of the state's most heavily used highways – roads that are critical to evacuation in the event of extreme weather events.

NHDOT has already had to undertake repairs to its seawall infrastructure on a more frequent basis in response to storm events, and further sea level rise will exacerbate the problem. Due to the reach of coastal storm surge from intense storm events, particularly those that may coincide with high tide, additional assets geographically located inland of coastal areas are vulnerable to sea-level rise.

Warming Winters

The Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report notes that it is *"very likely"* that the extent of snow cover and the amount of time it remains on the ground will decrease. According to a publication prepared by the Northeast Climate Impact Assessment (NECIA, collaboration between the Union of Concerned Scientists and a team of independent experts) entitled *Climate Change in the Northeast*, the length of the snow season could decline by 25% (lower emissions scenario) to as much as 50% (higher emission scenario) by 2100. (NECIA, 2006)

Changes in snowmelt and snow cover are already occurring. Figure 4 shows that the snow cover area in North America has declined since 1972. Specifically for New England, observed changes in snowfall and snow cover include decreases in snowfall; although from Figure 4 it is evident some New England areas are receiving increased snowfall. A general decrease in snowpack depth and an increase in snowpack density were evaluated at several sites in Maine and results indicated a decrease in the total number of days with snowfall (Huntington et. al, 2009).

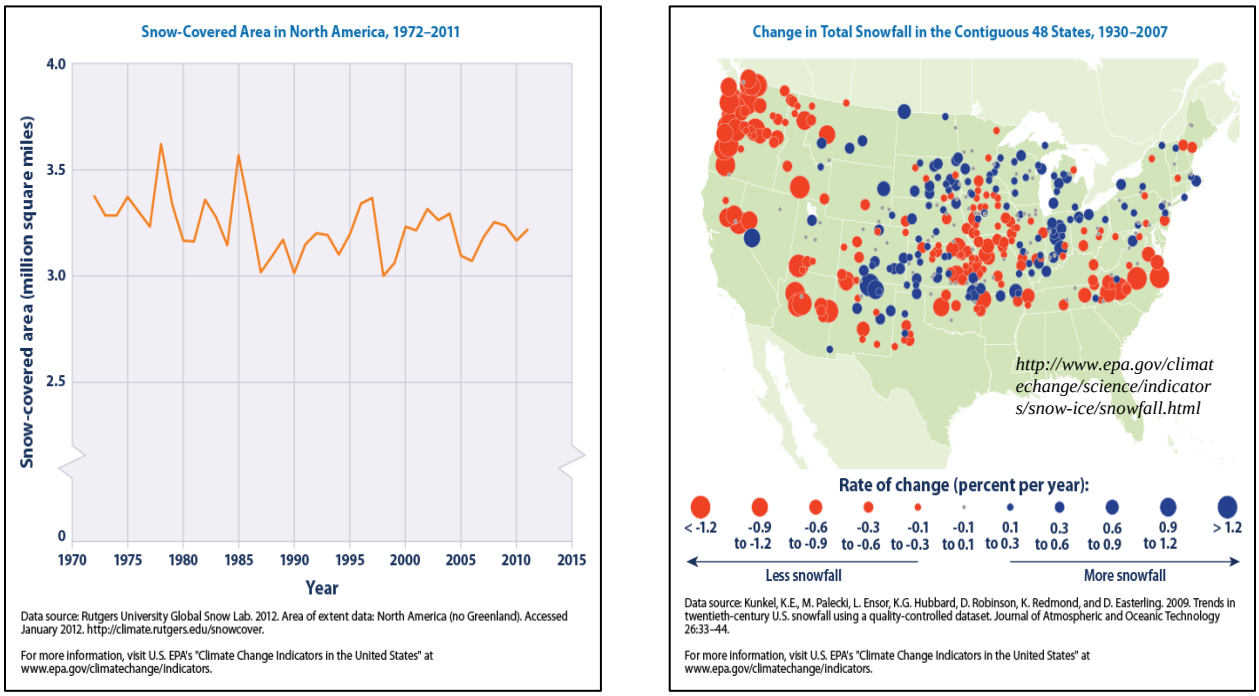


Figure 4: Changes in Snowfall in North American (1972-2011) and the U.S. (1930-2007)

Although warming winters may have many effects on the local climate, such as earlier spring peak flows, reduced ice formation and dynamics in rivers and streams, modified stream flow

patterns; and early last frosts combined with later first frosts of the season, many of these effects don't significantly or only tangentially affect transportation. However, it is anticipated that warmer winters will result in:

Increased Freeze/Thaw Events: Increased winter temperatures are anticipated to result in more frequent freeze/thaw events (as evidenced by the increased density but reduced depth of the snowpack in southwestern Maine). Freezing and thawing are primary factors in pavement failure and pothole formation. Similarly, it has been documented that winters are decreasing in length and that the last day of frost in the spring and the first day of frost in the fall has been coming sooner and later, respectively. Figure 5 presents long-term average spring/fall frost history for the U.S. which demonstrates that the frost free period has increased by about 2 weeks over the last 125 years. Frost free periods and winter freeze thaw events all have implications to transportation operations.

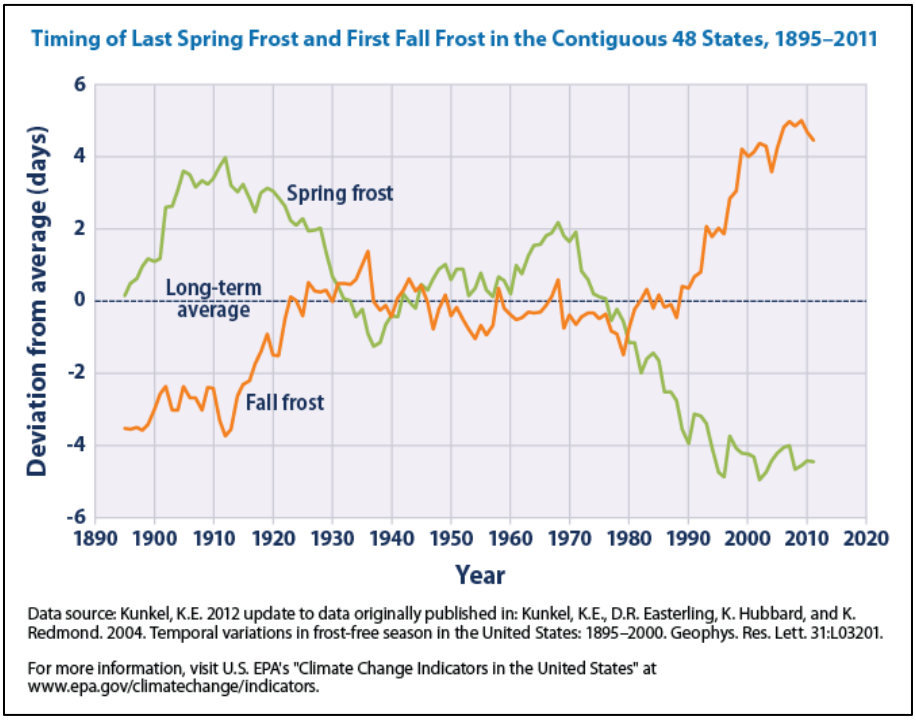
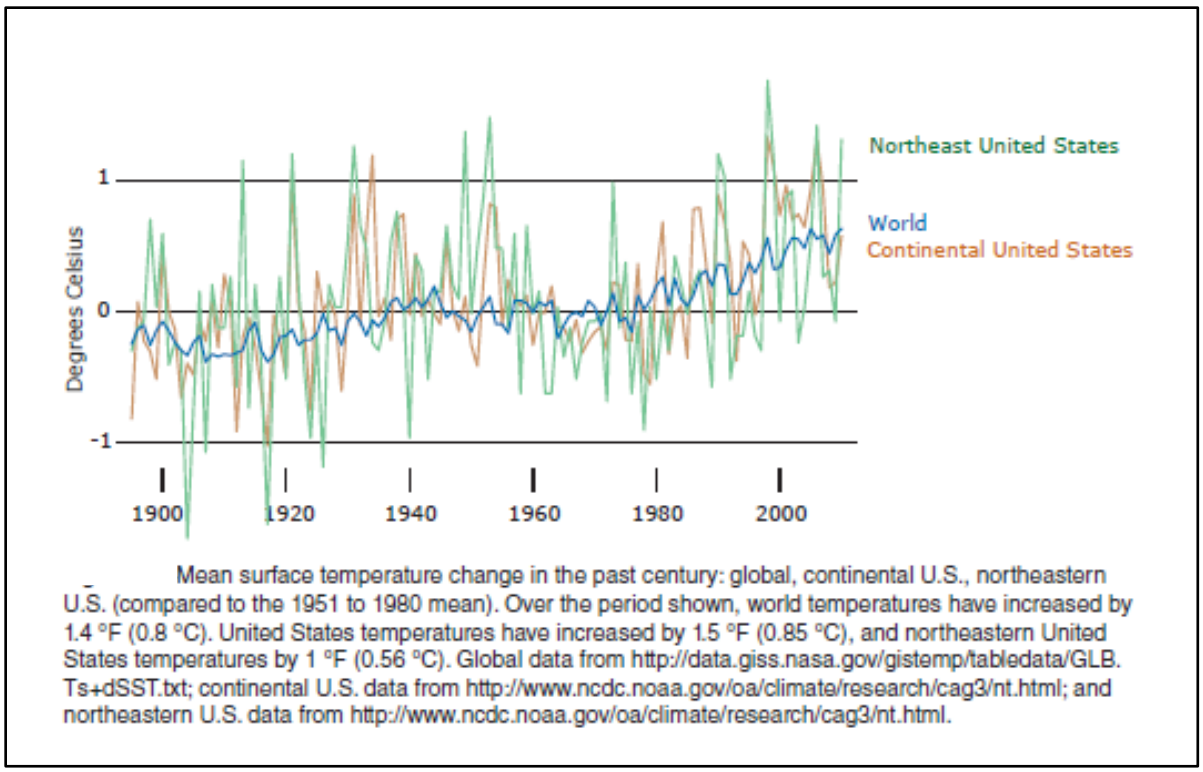


Figure 5: Timing of the Last Spring Frost and First Fall Frost in the U.S. 1985-2011

Temperature

Temperature in the Northeast has increased at a rate of around -17.5 °C (0.5 °F) per decade since 1970 (NCIA, 2007). Winter temperatures have risen faster at a rate of -17.05°C (1.3 °F) per decade during the same period (NCIA, 2007). Projections from the NECIA indicate that over the next several decades, temperatures will rise -16.4°C to -15.5°C (2.5 °F to 4 °F) in winter and -16.9°C to -15.8°C (1.5 °F to 3.5 °F) during the summer, by late century (2070-2099). Under a higher emissions scenario, winters in the Northeast could warm by-13.3°C to -11.1°C (8°F to 12°F) and summers by -14.4°C to -10°C (6°F to 14°F) above historic levels (NECIA, 2006). Figure 6 depicts the mean surface temperature change (°C) over the past century globally, for the United States and the Northeastern United States.



Mean surface temperature change in the past century: global, continental U.S., northeastern U.S. (compared to the 1951 to 1980 mean). Over the period shown, world temperatures have increased by 1.4 °F (0.8 °C). United States temperatures have increased by 1.5 °F (0.85 °C), and northeastern United States temperatures by 1 °F (0.56 °C). Global data from http://data.giss.nasa.gov/gistemp/tabledata/GLB.Ts+dSST.txt; continental U.S. data from http://www.ncdc.noaa.gov/oa/climate/research/cag3/nt.html; and northeastern U.S. data from http://www.ncdc.noaa.gov/oa/climate/research/cag3/nt.html.

Rustad et al. 2012

Figure 6: Global, National and Regional Temperature Changes, late 1800s to present

3.0 NHDOT's Transportation Program

New Hampshire Revised States Annotated (NH RSA) 21-L:2(II)(a) states that the Department of Transportation shall be responsible for "planning, developing, and maintaining a state transportation network which will provide for safe and convenient movement of people and goods throughout the state by means of a system of highways, railroads, air service, mass transit; and other practicable models of transportation, in order to support state growth and economic development and promote the general welfare of the citizens of the state." "Planning, developing, and maintaining" the state's transportation system is by statute part of NHDOT's mission and comports well with this document's discussion of "assets, programs, policies and activities" or APPA, as cited previously. Table 1 lists those definitive APPA that are being considered as potentially vulnerable to impacts of climate change.

Assets

The NHDOT APPA considers its assets (the first letter "A" in the acronym) as the driving force behind its programs, policies, and activities. Table 1 is a list of transportation assets provided by the NHDOT that were identified in the Federal Highway Administration's (FHWA) *Climate Change and Extreme Weather Vulnerability Assessment Framework* (FHWA, 2012).

Table 1: Structural assets provided by NHDOT

Built Environment
• Bridges
• Culverts/Storm Drainage Systems
• Road Segments
• Key Evacuation Routes
• Rail Lines, Rail Yards and Intermodal Transfer Points and Passenger Stations
• Transit System Facilities and Vehicles
• Bicycle and Pedestrian Facilities
• Port and Airport Infrastructure and Access Routes
• Maintenance and Operation Facilities
• Signals and Traffic Control Centers
• Back-up Power, Communication, Fueling and other emergency operations systems
• Sea wall infrastructure
• Intelligent Transportation Systems (ITS)
• Signs and Other Roadside Assets
• Pipelines and Energy Utility Corridors
• Stormwater Management Facilities and man-made systems (constructed wetlands and bio swales)

Source: FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework

While all APPA identified in Table 1 may be influenced by climate change, not all are influenced equally, nor do they have equal priority in terms of importance to the NHDOT transportation program. As part of the vulnerability assessment, these APPA will be further divided and categorized to provide a prioritized listing of APPA based on both vulnerability and significance to NH transportation.

Programs, Policies and Activities

Table 2 provides a list of programs, policies, and activities identified NHDOT as areas it believes warrant further exploration. Details of how each of these groups is impacted by climate change are referenced in the vulnerability assessment portion of this document.

Table 2: NHDOT Programs, Policies, and Activities

Group	Item
PROGRAMS	• Pavement & Paving Program • Bridge Maintenance Program • Bridge Rehab & Replacement Program • Culvert Replacement Program • Municipal Bridge Program (State Aid provides funding to municipalities for bridge rehab/replacement) • Asset Management, Performance and Strategy (AMPS) Section
POLICIES	• Design level for storm frequency (i.e.: 10yr, 50 yr., and 100 yr.) for bridges, culverts, roadside ditches and closed drainage systems. • Culvert inventory, upgrade, and replacement • Drainage Design • Project Development • Maintenance Funding
ACTIVITIES	• Communications with outside entities *(i.e.: Public Utilities, State Police, Emergency Response Groups)* • Maintenance of roadsides versus control of knotweed and invasive plants • Summer Maintenance • Winter Maintenance • Maintenance of seacoast transportation infrastructure
OTHER/ RELATED	• Aging state vehicle fleet • Aging state equipment fleet • Reduced staffing levels • Emergency Transportation Planning • Operations funding and maintenance implementation, routine and emergency • Tree clearing for sun exposure and utility clearance

4.0 Assessing APPA Vulnerability

Definitions of vulnerability vary. In the context of climate change, Moser et al 2008 describes vulnerability as "the extent to which a natural or social system is susceptible to sustained damage from weather extremes, climate variability, and change (and other interactive stressors)." Specifically for the transportation industry, FHWA defines climate change and extreme weather vulnerability as it relates to transportation as a function of a transportation system's sensitivity to climate effects, exposure to climate effects, and adaptive capacity (*Climate Change & Extreme Vulnerability Assessment Framework, December 2012*). According to the *Intergovernmental Panel on Climate Change (IPCC) 2007 Synthesis Report*, "vulnerability to climate change is the degree to which systems are susceptible to, and unable to cope with, adverse impacts." The three components in determining vulnerability of a particular asset are sensitivity (to climate change), exposure, and adaptive capacity.

- ***Sensitivity*** – How an asset fares when exposed to climate change stressors
- ***Exposure*** – Whether the asset is located in an area experiencing direct impacts of climate change, such as temperature or precipitation changes, or indirect impacts, such as sea level rise.
- ***Adaptive Capacity*** – The ability to adjust or cope with existing climate variability or future climate change impacts. Adaptive Capacity is the degree the APPA can change or respond to address climate impacts.

Climate Change: Incorporating Uncertainty

Vulnerability assessment also includes consideration of uncertainty. A climate change variable that is very likely to occur may have considerably greater significance than one that is possible but unlikely. Table 3 presents the likelihood of certain outcomes as developed by the IPCC to assist with assessing climate change vulnerability.

Table 3: Probability of occurrence of climate change variables

Probability	
Virtually Certain	>99%
Very likely	90 to 99%
Likely	66 to 90%
About as likely as not	33 to 66%
Unlikely	10 to 33%
Very unlikely	1 to 10%
Exceptionally unlikely	<1%

Source: IPCC Working Group II, Fourth Assessment
http://www.ipcc.ch/publications_and_data/ar4/wg2/en/tssts-1.html

The IPCC provides the following probabilities of occurrence (Christensen, et. al, 2007) based on projections to the mid to late 21st century:

- **Precipitation** (90-99% probability): Annual mean precipitation is ***"very likely"*** to increase in Canada and the Northeast USA (Christensen, et. al, 2007). Heavy precipitation events and increases in frequency over most areas is ***"very likely"*** to occur (IPCC Fourth Assessment Report, 2007).

- **Sea-level Rise** (66-90% probability): It is ***"likely"*** that there will be an increased incidence of extreme high sea level (IPCC Fourth Assessment Report, 2007).
- **Warming Winters** (90-99% probability): Snow season length and snow depth are ***"very likely"*** to decrease in most of North America, except in the northernmost part of Canada (Christensen, et. al, 2007). This occurrence is reinforced by way of a positive feedback resulting from reduced snow cover.
- **Temperature** (66 to 90% probability): The annual mean warming is ***"likely"*** to exceed the global mean warming in most areas. Seasonally, warming is ***"likely"*** to be largest during winter in northern regions. Minimum winter temperatures are ***"likely"*** to increase more than the average in northern North America. (Christensen, et. al, 2007).

When combining the IPCC probabilities with the climate change variables focused on by NHDOT, we note that all climate change variables of concern to NHDOT are ranked as "very likely" or "likely" (Table 4).

Table 4: Likelihood of climate change variables occurring

Climate Change Variables	
Extreme Precipitation	Very likely
Sea-level Rise and Coastal Storm Surge	Likely
Warming Winters	Very likely
Temperature	Likely

Which Climate Change Variables Impact Specific Transportation Assets

Specific transportation assets that might be vulnerable to climate change were identified by NHDOT. Climate change variables that are perceived to be the most important to transportation assets (and all APPA) have been listed and ranked and the probabilities of their occurrences are presented. Transportation assets may be vulnerable to one or more of the priority climate change variables. The following section discusses how climate change variables impact the natural environment and how these changes impact transportation assets.

Extreme Precipitation

It is very likely that annual precipitation will continue to increase in NH and that some precipitation events will become more extreme in magnitude and intensity. This will result in increased runoff and streamflow throughout the year and during extreme events. Increased runoff and streamflow in all seasons can lead to flooding, erosion and sedimentation, debris and ice damming, and capacity exceedance of stormwater control/water quality enhancement structures. Assets vulnerable to runoff/streamflow impacts include roads, bridges, culverts, and stormwater drainage and management structures along highways and waterways, and structures built in already floodprone areas. Amplified precipitation resulting in higher and faster flows could increase bridge scour potential. Scouring occurs when riverbed sediment is

removed from around bridge abutments and piers, potentially causing instability in the bridge's structure (Wright et al., 2012).

Sea-level Rise and Storm Surge

It is likely the sea level rise and associated higher storm surge will continue into the foreseeable future. As noted previously, New Hampshire has only eighteen miles of coastline, but NHDOT has substantial infrastructure in the coastal area including already stressed sea walls, roads, bridges, and culverts. Many of these assets are vulnerable to sea-level rise and coastal storm surge from intense storm events. An increase in sea-level rise/storm surge would impact low-lying roads, bridges, and culverts as they will be at increased risk to flooding and damage. Both flooding and asset damage will result in more frequent traffic delays and associated impacts to the local and regional economy. Sea wall damage will threaten both public and private assets.

Warming Winters

It is very likely that winters in the northeast will become warmer. Warming winters are expected to result in reduced snowfall which would in turn result in reduced snowpack. In addition, the number of freeze/thaw events will increase (Huntington et. al, 2009). Snow insulates the soil during the colder months; consequently, if the amount of time the snow is on the ground is reduced; the intensity and depth of soil freezing would likewise be affected (Huntington et. al, 2009). Soils with a deep snow pack that develops early in the season may remain unfrozen throughout the winter, even with severely cold air temperatures (Huntington et. al, 2009). Likewise, without snow pack soil freezes earlier and a late developing snow pack can cause soil to remain frozen for a longer duration. Snow pack also moderates fluctuations in soil temperature and therefore reduces the number of freeze-thaw events (Huntington et. al, 2009). Therefore, NHDOT assets that are commonly snow covered during the winter may experience increased damage during warm winter fluctuations.

While snow cover on plowed roadways is not a climate change consideration (except for maintenance), freeze/thaw events do affect roadway stability. An increased number of freeze/thaw events throughout the winter could result in additional frost heaves and potholes on susceptible roadways.

In addition, reduced snowfall during the colder months can lead to increased icing and winter flooding in small streams and intermittent drainage ways. Snow tends to insulate these small drainage ways/stream channels, but lack of snow cover allows ice buildup during cold periods. This reduces the capacity of culverts and drainage ways, due to increased ice in the structures, and when combined with expected increased winter rainfall, would lead to increased flooding of the associated roadway. This is especially problematic in drainage areas that are undersized and unable to handle additional overland flow. Increased precipitation during the colder months could also increase the frequency of ice on roads which could result in increased use of salt for ice control, regardless of the overall reduction in snowfall. Assets and operations that are vulnerable to icing and ice include culverts associated with small streams and drainage ways, runoff and stormwater management structures, and those items that are affected by road salt, including concrete, steel, and waterways subject to TMDLs for road salt concentration.

Temperature

It is likely that annual temperatures will continue to increase, but this increase is not likely to result in significant impacts to transportation infrastructure. Higher maximum temperatures during the summer might increase the risk of pavement buckling and rutting, but it is believed that this risk is comparatively low when considering other climate variables and impacts. Maximum temperatures are not expected to exceed pavement temperature thresholds (NHDOT, 2013, pers. communication). Operationally, hotter summers might impact summer maintenance schedules to have workers avoid the midday hours by adjusting work schedules to the early morning or evening hours when conditions are more ideal.

Other Considerations

Asset vulnerability to climate change is also dependent on factors relating to a specific asset. For example, current condition, age, design considerations, geographic location, existing problems, and land use and land use changes all help determine the asset's vulnerability. Table 5 provides a more complete list of factors to be considered when assessing the vulnerability of transportation infrastructure.

Table 5: Potential Existing Vulnerabilities (Sensitivities) on Assets

Existing Vulnerability	
Age of asset *(variable with asset type)*	Repair/Maintenance Costs
Structural Design	Replacement Costs
Materials Used	Lack of Evacuation Routes
Condition of Asset: *Current/Historical Performance*	Previous Washout Areas *(unresolved)*
Level of use: *traffic counts, forecasted demand*	Problem Areas: *Ice and/or debris jams*
Geographic/Physical Location: *mountainous, coastal, floodplain, adjacent to streams/rivers, urban/suburban, dense tree canopies, risk of rock fall*	Design Lifetime of Asset: *When will it require preservation, maintenance, rehabilitation, or replacement?*

In addition, although outside of NHDOT jurisdiction, existing and future land use patterns may intensify climate change impacts on NHDOT assets. A comprehensive vulnerability assessment must also consider how land use is contributing to asset vulnerability to better plan for climate change impacts.

Table 6 summarizes potential climate change impacts on NHDOT assets. A more detailed table can be found in Appendix A.

Table 6: Climate Change Variables and Expected Impact on NHDOT Assets

Climate Change Inputs	Impact of Climate Variable	Affected NHDOT Asset	Expected Results/Increases From Climate Change	
Extreme Precipitation Events	• Increased intensity & amount of rainfall. • Increased stormwater runoff • Wind damage	• Culverts /drainage systems /stormwater facilities • Roads • Bridges • Road signs • Stream / riverbank stabilizations	- Culvert damage (Capacity exceedances, ice/snow blockages, frequent repair or replacement) - Road/bridge repair - Bridge scouring - Erosion and sedimentation -Increase in maintenance - Flooding - Washouts (roads, culverts, bridges)	- Risk of accidents - Power outages - Traffic delays - Fallen trees (Along/across roadways)
Sea-level Rise & Storm Surge	• Wind damage • Increased sea-levels • Increasing storm surge encroachment	• Culverts/drainage systems/stormwater facilities • Roads • Bridges • Road signs • Sea walls	- Property damage - Delays and traffic re-routing - Transportation infrastructure damage (roads, bridge, sea-walls, culverts, guardrails). - Flooding / washouts	
Warming Winters	• Additional stormwater runoff into drainage areas (winter). • Timing: Earlier peak stream flows. • Reduced extent of snowpack. • Ice treatment for roads/bridges • Increased freeze/thaw events	• Roads • Bridges • Undersized culverts/drainage systems/stormwater facilities	- Culvert damage (ice dams and flooding) - Increase in road maintenance/repair - More treatment for ice on roads/bridges - Increased risk of accidents - Increase in frost heaves & potholes - Longer growing season (increased roadside maintenance - Potential increased road salt use	
Temperature	• Increased average temperatures • Increased maximum summer temperatures • Heat waves	• Roads • Bridges • Light control boxes	- Longer growing season (vegetation management, mowing, construction) - Rescheduling maintenance crews (summer) - Potential for pavement rutting/buckling	

Prioritized Assets and Climate Variables

After first identifying key transportation assets and secondly considering which climate variables were likely to affect which assets, how probable those events were to occur, and evaluating the vulnerability of asset to significant impact, NHDOT developed a prioritized ranking of their assets. This ranking is intended to help guide future adaptive management actions to ensure that mitigation emphasis is placed on those assets that are at greatest immediate risk. Groups were ranked with those assets of the highest importance being in Group A followed by Group B and then Group C.

Table 7: Results of Ranking NHDOT Assets

Group	Asset	Notes
Group A	1. Bridges 2. Culverts/Storm drainage systems 3. Roads 4. Key evacuation routes 5. Maintenance and operations facilities 6. Back-up power, communication, fueling, and other emergency operations systems 7. Sea wall infrastructure	*Tunnels – not applicable in NH* *Any structure having a span length over 10 feet is a bridge.* *Culverts have spans that are less than 10 feet.*
Group B	8. Storm water management facilities (including constructed wetlands & bio-swales) 9. Intelligent Transportation Systems (ITS) 10. Signals and traffic control centers 11. Port and airport infrastructure and access routes 12. Pipelines and energy/utility corridors 13. Rail lines, rail yards and intermodal transfer points & passenger stations 14. Signs and other roadside assets	*Lease out areas for rail and utility corridors DOT ROW*
Group C	15. Roadside vegetation 16. Transit system facilities and vehicles 17. Bicycle and pedestrian facilities	

NHDOT's Programs, Policies and Activities

NHDOT programs, policies and activities (PPAs) provide direction for the design, construction and maintenance of the Department's assets. To deal effectively with asset vulnerability, these PPAs must also assess how asset vulnerability affects their operation and should develop adaptive plans to counter the effects of climate change. The following are expectations for specific PPAs and how climate change is expected to impact each operational component. While PPAs are technically not vulnerable to climate change, they are impacted, so an effective climate change adaptive management program within the Department must necessarily include PPAs.

Programs

The following programs were evaluated for "vulnerability" to a changing climate:

- ***Pavement Resurfacing Program:*** This Program will be affected primarily by increased precipitation frequency and intensity which results in flash flooding and road washouts, thereby requiring more frequent pavement maintenance and repaving. Secondarily, increased freeze and thaw events during the winter period may result in more potholes, frost heaves, and damage on susceptible roadways which would require more frequent road maintenance.

  NHDOT currently uses performance based asphalt which is designed to handle relatively high temperatures. Projected temperature increases by the end of the 21st century may increase the likelihood of pavement buckling and rutting along certain roadways, but for the immediate future, increased temperature is not expected to significantly influence the Pavement Resurfacing Program

  Nevertheless, increased winter icing and freeze/thaw events may require adjustment of paving cycles in the future.
- ***Bridges:*** NHDOT bureaus that have bridge program responsibilities include: Bridge Maintenance, Bridge Design, and Planning & Community Assistance - Municipal Highways. Bridges are vulnerable to climate change in a variety of ways. With warming winters and increased freeze/thaw events, it is expected that bridges will experience increased icing and pothole on bridge decks. In addition, increased precipitation including more winter rain is likely to lead to more frequent ice jams, scouring/erosion and flooding. In coastal areas, bridges may be susceptible to scouring and flooding as a result of rising sea levels and greater storm surges. While temperature increases are not believed to be an immediate threat to bridges, structural design changes for increased expansion due to higher based temperatures may be considered.

  NHDOT already has in place an extensive bridge monitoring program. All bridges (state and municipal) are inspected bi-annually (every two years), in accordance with the National Bridge Inspection Standards (NBIS). Red List, i.e., structurally deficient, bridges are inspected semi-annually. During flood events, all bridges rated as "scour critical" that are experiencing serious flooding may be inspected for scour through notification to the Bridge Inspectors by the Traffic Management Center/Emergency Operations Center. The Municipal Bridge Program provides financial and advisory assistance to municipalities developing projects for the reconstruction or replacement of municipally owned bridges. The impacts of climate change will increase stressors on the bridge infrastructure and will therefore likely increase the need for bridge monitoring, maintenance, and eventual replacement. All Bureaus within the Bridge Program will be affected.
- ***Culverts:*** The Best Management Practices for Routine Roadway Maintenance Activities in New Hampshire provides a culvert replacement and relocation program that includes critical culverts in disrepair needing rehabilitation and/or replacement.
  http://des.nh.gov/organization/divisions/water/wetlands/documents/roadway_bmp.pdf

A culvert inventory and condition/performance rating has been completed for the Operations Division for existing culverts greater than 36 inches in diameter and the Bureau of Turnpike is undertaking an inspection program for culverts greater than 18 inches in diameter. There is no existing comprehensive inventory of smaller culverts. The Department's programmatic approach is to fund needed culvert repair and replacement. Given the probability of increasingly intense storm events and flooding, failure of culverts of all sizes is likely to increase and replacement with larger capacity culverts will generally be warranted.

Asset Management, Performance and Strategy Section: NHDOT has announced the formation of the Asset Management, Performance and Strategy (AMPS) Section. This Section will be responsible for the analysis and evaluation of transportation asset data that will be used to guide the Department's strategic investment decisions. The Administration of the AMPS Section will reside in the Bureau of Planning and Community Assistance for access and coordination with GIS and asset efforts currently underway. The AMPS Section activities will be directed by the Executive Committee of Commissioners and Directors, responsible for the development of the long and short term strategic plans. A "Steering Group" will break down the strategic plans into prioritized objectives and measures and help to drive the activities of the Department through the AMPS Section. A Transportation Asset Management Program is required under the MAP-21, Moving Ahead for Progress in the 21st Century Act, long-term surface transportation program.

Policies

The policies listed below are likely to be impacted by climate change in the following ways:

- ***Design level for storm frequency (i.e.: 10-yr, 50-yr, 100-yr):*** Intensity and magnitude of storm events is changing the standard storm frequencies used for project design. Design storms are now larger than they were historically; design standards used for bridges, culverts, roadside ditches, and closed drainage systems will need to be updated to reflect a changing climate.
- ***Culvert upgrade and replacement:*** Culverts are becoming increasingly vulnerable to climate change because of increased precipitation and resultant runoff. In addition to having a policy of culvert redesign and replacement, NHDOT should implement a policy of increased frequency of culvert monitoring and assessments. Debris washout from roadside areas, caused by increased precipitation and higher peak flows, can block culverts which can cause flooding and road washout. Timely and proper maintenance and replacement as necessary will reduce vulnerability to climate change. Prior to any replacement that would increase the rate and/or volume of streamflow, potential downstream impacts should be evaluated.
- ***Drainage Design:*** Increased precipitation is rendering previous designs for drainage structures obsolete. In recognition of this, NHDOT is currently revising the 1998 Highway Design Drainage Manual to include use of up-to-date precipitation data. However, previously designed and constructed drainage structures are undersized and may require measures, including complete replacement, to increase capacity.

The Department must remain aware of potential downstream impacts when culvert sizes are increased.

- ***Maintenance Funding:*** Although warming winters are expected to reduce snowfall, precipitation frequency and intensity is still expected to result in an increase of periods of heavy rain, snow, and icing events. Wind damage may become more severe in all seasons. When combined with longer growing seasons and increased summer precipitation, it is likely that the need for maintenance funding will increase, regardless of an overall decline in winter snowfall.
- ***Project Development:*** Project Development is responsible for planning and designing transportation projects and supervising their construction. All aspects of project development will be impacted by climate change. Asset vulnerability and priority will affect project planning. Project design will need to account for climate changes and most design manuals (as noted above) will need to be modified, including guidance documents such as the Utility Accommodation Manual. Warming winters will likely extend the construction season, so additional resources may be needed to reflect a changing work schedule. Climate change variables may also result in increased communities needs and funding requests. To provide improved protection of NHDOT assets, additional Right of Way acquisitions might be needed. Increased coordination with permitting agencies is recommended to streamline and shorten the permitting process to ensure timely implementation of projects that will protect critical assets.

Activities

The NHDOT activities presented below are likely to be impacted by climate change in the following manner.

- ***Communications:*** With storms of greater intensity and frequency bringing high winds, ice, heavy rain, snow, flooding, and storm surge in coastal areas, there will be greater demands placed on emergency services. Communication, both internally and with outside entities such as public utilities, emergency services (police, fire, EMS), school systems, and municipalities in response to emergency situations, are likely to increase.
- ***Roadside Maintenance and Invasive Plants:*** It is generally expected that many invasive plant species will benefit from climate change. Increased temperature and precipitation will both likely increase the competitive advantage that invasives have over native species. Roadside invasive species on the NHDOT list include Japanese Knotweed, Oriental Bittersweet, Purple Loosestrife, and Phragmites. Invasive species compromise the function of drainage ditches by clogging and reducing flow capacity, but maintenance efforts are complicated because soils and other materials removed from ditches must be properly handled to avoid spreading invasives to other areas. These problems are likely to worsen with a changing climate.
- ***Summer Maintenance:*** Summer maintenance will likely be impacted by temperature increases as maintenance staff may not be able to work effectively under higher temperatures. More frequent and intense storm events will result in recurrent repairs of damage to highways and local roads. Maintenance crews will likely be

more engaged in resiliency activities including drainage system replacements and upgrades and flood proofing of highways and secondary roads. With a lengthening growing season, summer maintenance undertakings for invasive species might begin earlier and end later in the season.

- ***Winter Maintenance:*** Winter maintenance will likely be impacted by a combination of temperature variations, increased precipitation, stronger and windier storm events and more frequent ice storms. Winter storm damage will likely include increased power outages, more fallen trees/branches from blow-downs and ice, and more icy roads. Maintenance crews will likely have to increase efforts to open closed roadways and increase road and culvert de-icing efforts.
- **Winter Precipitation:** Increased precipitation during the winter months could lead to increased road salt usage to contend with icier conditions, which could exacerbate salt loading to aquatic systems. NHDOT is currently working to reduce salt usage, but reducing salt use without compromising safety is already challenging and may become more so with climate change.
- ***Maintenance of Seacoast Transportation Infrastructure:*** Transportation infrastructure along the coast will become increasingly vulnerable to the effects of sea-level rise and storm surge. These assets include roadways such as I-95, US Route 1, NH 1A, and the Spaulding Turnpike, as well as maintenance facilities, bridges, sea-walls, guardrails, and other stormwater management facilities. Increases in precipitation frequency and intensity will compound the impact of sea-level rise and storm surge on these facilities and assets. These impacts will likely mean increased maintenance, repair and replacement activities.

Other/Related

The remaining topics are those that do not fit neatly within the categories of programs, policies, and activities, but were identified by NHDOT as areas of importance regarding the vulnerability of the agency to climate change.

- ***Aging State Vehicle & Equipment Fleet:*** An aging vehicle and equipment fleet reduces the ability and dependability of the Department to respond in a timely manner to asset damage, emergency situations, and the generally expected increase in maintenance and repair needs that result from climate change. It would also compromise the effort of the Department's responsibility to decrease greenhouse gases.
- ***Reduced Staffing:*** NHDOT has experienced a reduction (involuntary) in staffing in recent years. It is expected that climate change may result in additional staffing needs to contend with the wide variety and frequency of the impacts cited above. Effective adaptation to climate change will require additional personnel, not only during emergency situations, but also in project development and areas of operations.
- ***Emergency Transportation Planning:*** Given the increase of more frequent and more severe storm events, it is expected that there will be an increased need by emergency planning to identify secondary routes, and even tertiary routes, to mitigate for closed primary routes.

- ***Operations Funding and Maintenance Implementation:*** Operations and maintenance activities are expected to increase for both routine and emergency activities. Funding will need to be increased to accommodate these activities.

Table 8 summarizes the potential impact of climate change on transportation programs, policies, and activities.

Table 8: Climate Variables Likely To Impact: Programs, Policies, and Activities

Group	Item	Climate Variable (s)	Impact of Trend
PROGRAMS	Pavement & Paving Program	Warming winters, extreme precipitation, temperature	• Increased maintenance (frost heaves, potholes), maintenance schedule changes (summer temperature extremes)
	Bridge Maintenance Program	Warming winters, extreme precipitation	• Increased frequency of preservation and maintenance (potholes on bridge decks)
	Bridge Rehab & Replacement Program	Extreme precipitation	• Increase scour of susceptible bridge abutments, possibly leading to more frequent repair or bridge closure. • Increase in bridge monitoring • Coastal bridges might be subject to inundation, as well as accelerated corrosion, potentially requiring additional rehabilitation
	Culvert Replacement Program	Extreme precipitation, warming winters	• Culvert replacements for those that are currently undersized to handle future precipitation projections
	Municipal Bridge Program	Extreme precipitation	• Increase in funding to communities for reconstruction or replacement of bridges damaged by increased storm flow and intensity.
	AMPS	All variables	• Managing risks to networks and critical structures
POLICIES	Design Level for Storm Frequency (i.e.: 10yr, 50 yr., and 100 yr.)	Extreme precipitation	• Update design standards for bridges, culverts, roadside ditches, and closed drainage systems to reflect a changing climate. • Incorporate updated precipitation and flood frequency data to reflect future projections.
	Culvert Upgrade and Replacement	Extreme precipitation, warming winters	• More frequent culvert monitoring • Continued culvert assessment & inventory
	Drainage Design	Extreme precipitation, warming winters	• Updated precipitation data needs to be included in revisions to design manuals • The need to include Low Impact Development (LID) techniques where applicable
	Project Development	Extreme precipitation, sea level rise and storm surge, warming winters, temperature	• Climate change impacts to be included in design standards well into the future. • Future projects will need to make design decisions as to recommended project actions on priority assets • Extension of construction season
	Maintenance Funding	Extreme precipitation, sea level rise and storm surge, warming winters, temperature	• The need for winter maintenance funding will continue and may expand. Maintenance crews will be required for removal of snow, ice and clearing roadways from fallen trees.

(continued)

Table 8 (Continued)

Group	Item	Climate Variable (s)	Impact of Trend
ACTIVITIES	Communications With Outside Entities *(i.e.: Public Utilities, State Police, Emergency Response Groups, Municipalities)*	Extreme precipitation, warming winters	• Greater demand on services from more emergency events • Frequency of communication is likely to increase
	Maintenance of Roadsides Versus Knotweed and Invasive Plants	Extreme precipitation, temperature	• Increase in invasive species maintenance • Eliminate opportunities for new introductions & spreading of invasive plants, that could result from maintenance activities
	Summer Maintenance	Temperature	• Crews may have to adjust their work schedule based on safety limits to avoid higher midday temperatures • Expanded tree clearing for sun exposure and utility clearance • Longer summer maintenance season
	Maintenance of Seacoast Transportation Infrastructure	Extreme precipitation, sea level rise and storm surge	• Increased maintenance and repair
	Winter Maintenance	Warming winters, extreme precipitation	• Increase in maintenance: Increase road de-icing efforts and mitigating ice jams in culverts, possible winter flooding events.
OTHER/ RELATED	Aging State Vehicle Fleet	Extreme precipitation, sea level rise and storm surge, warming winters, temperature	• Increased emissions • Increased stress (wear & tear) on vehicles and equipment during all seasons
	Aging State Equipment Fleet	Extreme precipitation, sea level rise and storm surge, warming winters, temperature	• Potential impacts on efficiency of tasks especially in emergency situations • Vehicles and equipment would be less dependable
	Reduced Staffing Levels	Extreme precipitation, sea level rise and storm surge, warming winters, temperature	• Adapting to climate change and responding to related weather events/natural disasters will require additional personnel. There will be a need for staffing increases.
	Emergency Transportation Planning	Extreme precipitation, warming winters	• Need for the agency to establish secondary routes for when primary routes are unavailable.
	Operations Funding and Maintenance Implementation (Routine and emergency)	Extreme precipitation, warming winters	• Additional funds will be needed for increase in operations and maintenance activities

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5.0 Action Plan

The purpose of this Action Plan is to increase the resiliency and preparedness of NHDOT with respect to the impacts of climate change. Based on the vulnerability assessment above and input from DOT representatives, a comprehensive set of recommended actions has been developed, and primary responsibility for actions has been categorized by internal agency divisions (Operations, Project Development, Finance or Aeronautics, Rail & Transit). Because many of the actions overlap within Departments, organizing these actions under agency division was believed to be the preferred method for grouping. Actions are then prioritized and organized into short-term, mid-term, and long-term timeframes to assist the agency in prioritizing their resiliency and preparedness needs. The Action Plan's recommendations account for the agency's current challenges and resources, and are intended to assist NHDOT in developing and managing a resilient and robust transportation system across the state. However, it is recognized that climate change is an evolving issue with a very long time horizon. Accordingly, the overall Plan includes a climate implementation framework that NHDOT can use to build on this initial Plan as experience and expertise evolves. The framework is designed to guide the agency with the implementation of the Action Plan and also toward maintaining the plan in the future.

Resources and Opportunities

A variety of resources and opportunities are available to assist NHDOT in developing effective adaptive management strategies and plans.

Utilizing Documents, Maps, Plans

To better prepare for climate change, resources that are available to assist with decisions include the continued use of GIS for resource (soil, floodplains, wetlands, land use) identification and interactive maps detailing the extent of sea-level rise (e.g., Surging Seas – Climate Central Interactive Sea-Level Rise Map). Updated floodplain maps for the New Hampshire coastline have not become effective yet but are available on the FEMA Map Service Center website. Flood hazard information can be viewed through Google Earth using FEMA's National Flood Hazard Layer. Additionally, viewing the existing municipal hazard maps and zoning maps can assist in the planning effort. Zoning maps can identify existing land use and can help determine the impact of projected future changes, primarily when planning for sufficient stormwater infrastructure. A brief list of representative resources is provided in Table 9. An expanded list of document, map, and plan resources can be found in Appendix A.

Establishing Partnerships

Partnerships with other interstate and intrastate agencies, private companies, municipalities and organizations will be essential to climate change adaption. Coordinating with these entities and interacting with them regularly will help NHDOT overcome challenges and obtain new ideas by learning what other states and organizations have done or are doing, what was effective and what was not, in response to climate change. The Implementation section of this document, described later, includes the establishment of a Climate Change Committee that

would be responsible for reaching out to and maintaining these working relationships regarding issues of climate change.

Table 9: Sample of Local Climate Change Resources

Sea-level Rise Maps	• Surging Seas – Climate Central http://sealevel.climatecentral.org/ • NOAA's Coastal Climate Adaptation http://collaborate.csc.noaa.gov/climateadaptation/default.aspx • Joint ACOE, NOAA, FEMA, USGCRP website http://www.corpsclimate.us/Sandy/
Floodplain Maps	• Floodplain Learning on Demand – NH http://www.nhflooded.org/index.php • FEMA's National Flood Hazard Layer https://hazards.fema.gov/femaportal/wps/portal/NFHLWMSkmzdownload • Coastal NH Floodplain Mapping Project http://www.nh.gov/oep/planning/programs/fmp/coastal-mapping-project/index.htm
Climate and Adaptation Information	• Stormsmart Coast – New Hampshire http://nh.stormsmart.org/ • Northeast Climate US http://neclimateus.org/index.php • NOAA's interactive climate information http://www.climate.gov/
Community Hazard Plans and Adaptation Plans	• New England Climate Adaptation Project http://necap.mit.edu/necap/ • Rye, Nashua, Bedford • Dover http://necap.scripts.mit.edu/necap/wp-content/uploads/2014/03/Dover_Summary-Risk-Assessment_Finalized_March-2014.pdf • Exeter (in progress) • Portsmouth (www.planportsmouth.com/cri/cri-report.pdf)

Taking Advantage of Natural Resources Attributes

Natural resources often provide non-structural opportunities to mitigate for climate change. Termed "ecosystem services", these resources offer low- or no-cost benefits associated with judicious use of natural systems, e.g., taking advantage of flood storage capacity, assuming that adequate stormwater treatment is provided prior to discharge into natural systems. It is recommended that NHDOT take a more holistic look at the whole ecosystem associated with a Department asset, and where practical and feasible, and in concert with their partners, take advantage of the low- or no-cost services that ecosystem can provide to minimize the need for structural solutions. Natural systems can play important roles in reducing vulnerability of the transportation program.

Challenges

One of the biggest challenges the transportation industry faces, aside from funding, is the uncertainty of climate change – how extreme the predicted changes will become and when those changes will occur. Table 10 lists additional challenges facing the transportation industry as it adapts to a changing climate.

Recommendations and Prioritized Actions

The following adaptive actions have been identified based on an evaluation of agency assets, programs, policies, and activities and their vulnerability to climate change. To assist NHDOT in adapting to impacts of climate change, the following short-term (1 year), medium (1 to 3 years) and long-term (1 to 10 years) actions have been suggested in the adaptation process. Both short-term and mid-term actions are categorized as being those actions that can be done now or in the near-term, while long-term actions are those that need to be addressed, but cannot be at present due to a lack of funding. Actions are broken out by NHDOT Division to identify primary responsibility for implementation of recommended actions, as provided in a series of summary tables at the end of this section.

Table 10: Challenges Identified By NHDOT

• Availability of funding: Adequate funding should be provided for proactive measures for climate changes, rather than for disaster response when extreme events occur.
• Update Drainage Design Manuals: The outline of drainage design principals does not "look ahead" and use predictive models under a "rise in sea level" scenario or projected rainfall data.
• Regulatory enforcement: Consistency from and collaboration is needed with state and federal permitting agencies for NHDOT, municipalities, and private developers.
• Risk areas: Identify potential assets and areas that are downstream and at risk from dams and detention basin failures.
• Land use changes: Address the effects of increasing stormwater runoff, exacerbated by climate change. Prepare for upstream activities and land use changes outside of NHDOT jurisdiction, that impact downstream hydraulic/drainage systems, including areas in and around wetlands. The Department does not have a policy to size infrastructure to accommodate potential future land use.
• Wetlands: Permitting/impacts is guided by NHDES. Towns have their own separate ordinances (wetland-watershed protection districts). Wetland setbacks vary by individual towns.
• Availability of staffing resources: Ability to have sufficient staff and resources to address maintenance and project development needs as related to climate change impacts.

Division of Operations

It will be the responsibility of the Division of Operations to execute the following actions:

Short-term:

- ***Improve communication*:** This relates primarily to improving communications with outside groups, including utilities, state police, and other emergency management groups. Improved communication with these entities should be undertaken prior to an emergency event as a proactive measure. The division should develop and maintain a list of statewide emergency services contacts and communicate with these entities, to establish protocols, procedures, jurisdiction, and contact requirements prior to events that could result in emergencies.
- ***Increase knowledge base among staff:*** Specifically, increase the knowledge base among operations, maintenance, and engineering staff as to what 'tools' are available in the maintenance and damage repair 'toolbox' and what procedures have been established for responding to these events. For example, staff could benefit by sharing of experiences, materials, plans, and details, etc., as to what was used successfully (and unsuccessfully) in other similar situations, which would assist NHDOT in responding to future storm events.

- ***Invasive Species Management:*** Best management practices for invasive species management (including actions to reduce spreading) should be a collaborative effort with other state agencies having knowledge of the biology of such species (e.g., NH Department of Environmental Services, NH Natural Heritage Bureau), to allow better control of invasive species and to improve roadside maintenance, thereby improving roadside resiliency to increased precipitation.
- ***Optimizing mowing along the highways:*** During summer maintenance operations, the frequency of mowing along the highways should be optimized. The variety of vegetation is critical to stabilize the roadside and ensure that the shoulder, embankment, and drainage ditch can resist erosion, while also reducing flow velocity from high intensity storm events. Optimized mowing will also ensure that the grasses necessary to prevent erosion will not be choked out and overtaken by invasive species.
- ***Clean out roadside catch basins, ditches, and culverts:*** Cleaning out roadside catch basins, ditches, and culverts to restore drainage capacity can help reduce flooding. Removal of debris and sediment should occur regularly and the frequency should be optimized to ensure the effective use of these actions. NHDOT should meet with NHDES to collaboratively adapt current regulations to facilitate catch basin maintenance while retaining appropriate levels of environmental protection.

  A more aggressive program of monitoring and clearing stormwater-related debris build-up at culverts should be implemented. Flooding and road damage is often caused by debris dams. Increased and more intense precipitation will likely increase the frequency and amount of debris accumulation.
- ***Identify priority sites and assets:*** Each NHDOT District should implement a program to identify specific assets that are vulnerable to the impacts of climate change and to develop a prioritized list of these vulnerable assets. Adaptive plans to protect these assets would be implemented based on the priority listing of the asset.
- ***"On-call" contract for repairs:*** NHDOT should consider having sufficient "on-call" contracts for repairs inplace with local contractors that include repair of slope failures and washouts, cleaning and repair of damaged drainage systems, rebuilding of damaged roadways, and repair of damaged structures all caused by extreme events. Current contracting procedures using Request for Proposals (RFP) are cumbersome and hinder timely repairs being made. Soliciting contracts for emergency repairs after the event also subjects the NHDOT to great risk for incurring high costs for the needed repairs. The on-call contracts should include performance expectations for rapid response, predetermined costs of materials used for emergency repairs, and incentives if necessary for emergency response situations.
- ***Rest areas – Assess stormwater management at these facilities:*** Prioritize rest area upgrades where stormwater management is necessary to adapt to climate change.

Mid-term:

- ***Incorporate changing climate into programs:*** Incorporate climate change into summer and winter operations and maintenance programs. This may include

staffing and schedule adjustments to adapt to increased precipitation, ice, wind damage and warmer summer temperatures. The timing of paving schedules during the warmer months may also require adjustment.

- ***Re-staff maintenance structure:*** Provide sufficient maintenance staff for flexibility to respond to sudden needs. Staff additions/modifications or reassignments may be necessary to effectively address climate change preparedness, and may include temporary and part-time staff or contractors on an episodic basis. Emergency staffing needs might also be met by cross-training within NHDOT and utilizing other state agency personnel.
- ***Develop Emergency Response Plan:*** A refined emergency response plan should be developed detailing emergency communications procedures, NHDOT's response, and identifying secondary and even tertiary evacuation routes for when primary routes are unavailable.
- ***Continue to refine maintenance crew schedule:*** Adapt maintenance staff schedules to reflect a changing climate. Additional maintenance will be needed for more frequent culvert maintenance and debris clearing, ice/snow events, pavement patching, and tree removal both after severe events and proactively as part of routine maintenance.
- ***Vulnerable Assets:*** Determine if the Department's buildings and storage area locations are vulnerable to climate change impacts and develop mitigation plans to protect as needed.
- ***Rest Areas:*** Set up Department displays at rest areas to educate the public about the impacts of climate change and evidence from recent extreme events.
- ***Revisit road salt policy:*** Review timing of road salt application and adjustment for projected climate changes (precipitation, ice); continue research on new alternatives to road salt and new techniques to manage or apply road salt; continue work with NHDES to address road salt issues.

Long-term:

- ***Increase staffing:*** With more frequent and severe weather events, the need for additional staffing of operations crews will be required to respond effectively to increased maintenance needs in normal and emergency situations.
- ***Replacing aging vehicle fleet***: Develop and implement a schedule for replacing and upgrading the vehicle and equipment fleet to account for increased use associated with response to climate change impacts.
- ***Fully integrate climate change:*** The Division of Operations should have fully integrated climate change adaptations into its seasonal activities.
- ***Implement initiatives to protect state facilities from flood impacts:*** Examples include, raising the occupied lowest level above extreme flood elevations, and relocating or finding ways to protect mechanical equipment that could be affected by flood events.
- ***Department facilities:*** Relocate facilities that are in areas susceptible to flooding/damage from extreme weather events.

- ***Education:*** Develop methods to continually educate and inform the public about climate change impacts and the Department's response/preparedness.

- ***Tree removal:*** Identify and remove trees on primary evacuation routes that appear susceptible to damage from high winds and/or ice storms thereby preventing potential blockage of these roadways.
- ***Road repair schedules:*** Re-assess existing road repair schedules and acquire sufficient resources to prepare for and respond to increased repairs of damage from climate change effects on susceptible roadways.

Division of Project Development

It will be the responsibility of the Division of Project Development to take on the following tasks.

Short-term:

- ***Continue Low Impact Development (LID) approaches:*** Continue and expand use of LID techniques as a mitigation tool for increased stormwater management and quality.
- ***Modify ditch-lines parallel to the roadway.*** Modify ditch-lines to increase ditch capacity to transport additional stormwater during precipitation events. If Department owned right-of-way is available, provide a wider ditch bottom by pushing the backslope out the additional 1-2'.
- ***Ensure appropriate stone size along waterways:*** Stone size for bank stabilization should be based on riverine system dynamics and projected peak flows expected as a result of climate change.
- ***Drainage design to account for climate change and increasing human disturbance:*** NHDOT is currently revising the 1998 Highway Design Drainage Manual to include use of up-to-date precipitation data. Designing and building any new infrastructure (e.g. bridges, culverts, roadside ditches, and closed drainage systems) should consider potential sea level changes and increased storm severity and events. With the increases in precipitation and flood frequency, design levels must meet these changing variables by accounting for increased precipitation and peak stream flows. This applies to incorporating updated flood frequency data to reflect future projections. NHDOT should use the best available, recent, regional climate and precipitation data in project designs. For example:
    - Consider sizing to include projected future land use changes.
    - Culverts need to be sized accordingly to stream morphology, a changing climate and adjacent land usage.
    - Review build-out scenarios.
    - Review culvert assessments.
    - Increase waterway area in box culverts.
    - Mitigate existing detention basins to account for increased precipitation.
    - Update drainage design to include modified flood frequency data.

  - Use a larger design year when designing culverts, storm sewer systems, and stormwater facilities

- ***Continue culvert inventory & assessment:*** Continue this inventory through Regional Planning Commissions, NHDOT, NHDES and other agencies. This work can be funded through NHDOT's SPR Part 1 Program as long as it is prioritized for available funding. The Statewide Asset Data Exchange System out of UNH will maintain records.
- ***Provide additional drainage outfalls wherever possible:*** This would eliminate longer drainage systems and their associated concentrated discharge locations and would improve management of stormwater from increased precipitation events.
- ***Raise awareness and improved understanding of climate change issues:*** Improved education to raise awareness of climate change issues should be undertaken at both NHDOT and within municipalities.
- ***Set up specific goals, conduct outreach projects, and engage public involvement:*** Public support is necessary for a successful climate change adaptation program.
- ***Maintain up-to-date information related to climate change science:*** Although primarily a role of the Climate Change Committee, all aspects of project development require involvement by all Bureaus to update climate change data.
- ***Improve Communications:*** Greater integration of transportation and land use planning will require better communication between these groups.
- ***Identify vulnerable assets:*** Review areas impacted by the new but preliminary coastal flood and risk maps.
- ***Review community hazard maps and mitigation plans:*** Refine evacuation routes and alternatives by considering and incorporating community hazards where necessary and mitigation plans where available.
- ***Create a critical slope inventory:*** This inventory will assess and monitor conditions (soil slopes, hydrologic groups) of critical slopes that may be affected by climate change.
- ***Harden flood-prone roads:*** Strengthen and armor roads to prevent damage to downstream side when drainage system is overwhelmed.
- ***Meet with NHDES regularly:*** Regular meetings with NHDES to discuss program needs and permitting obstacles or difficulties will provide opportunity to collaboratively resolve issues prior to emergency events.
- ***Improve entrance hydraulics on existing storm critical culverts and structures:*** Improved entrance hydraulics for culverts and other structures enhances the structure's capacity to handle more extreme precipitation events (e.g. install wing walls or head walls, construct a berm across the low side of a ditch-line pipe or basin to increase head over the inlet).
- ***Bridge Inspections:*** Maintain existing bridge inspection program and Plan of Action for scour susceptible bridges. Incorporate any needed additions to inspection program as necessary to deal with climate change.

Mid-term:

- ***Research innovative solutions:*** Continue to research and implement innovative solutions that provide new technologies and construction approaches that respond to the abnormal pressures of climate change impacts (e.g. rainfall intensity, sea level rise, storm surges, increased mean annual temperature, wind).
- ***Erosion hazards mitigation and monitoring:*** Increased and more intense precipitation will escalated the need for more durable features to effectively control erosion and stormwater runoff.
- ***Partner with municipalities:*** NHDOT should strengthen its partnerships with municipalities to better coordinate climate change and adaptation efforts and response.
- ***Assign central point of contact:*** Each NHDOT Bureau should assign a central point of contact to actively participate in a Department-wide process to integrate climate change mitigation and adaption into Department procedures and policies.
- ***Continue work with Planning Commissions:*** Continue and expand working relationships with regional planning commissions for culvert inventory and assessment and traffic counting.
- ***Research design and maintenance techniques to combat ice buildup:*** Winter freezing without snow cover increases incidences of frozen culverts and ice filled ditch lines that result in additional occurrences of highway flooding and damage during winter rain events. Structures should be sized to not obstruct the winter low flow.

Long-term:

- ***Purchase properties for flood storage:*** Incorporate climate change scenarios into right-of-way acquisitions for the purpose of flood storage for tidal and/or precipitation events. The US Army Corps of Engineers has an established record of purchasing wetlands and flood plains to prevent such areas from being developed and exacerbating flooding through increased impervious surfaces.
- ***Review, revise design manuals as necessary.*** Review, revise design manuals at regular intervals, based on trends from climate change.
- ***Place greater emphasis on climate change as part of Ten Year Plan capital planning process:*** Review the criteria established for the Decision Lens software tool used to rank projects by NHDOT and RPCs. Add resiliency/emergency preparedness in response to climate/severe weather vulnerability and integrate with other criteria so projects that address these needs are recognized and credited in the Decision Lens ranking and selection process.
- ***Assess existing evacuation routes:*** Ensure that designated evacuation routes will remain intact and that they can handle additional traffic volumes and vehicle weight during an emergency. Develop secondary and tertiary evacuation routes to provide redundancy in the event of widespread asset loss.
- ***Research and construct systems that are resistant to weather extremes:*** Explore materials for transportation assets that are minimally impacted by extreme weather/precipitation, freeze-thaw, or high temperature events.

- ***Asset inventory:*** Continue use of GIS mapping of Department assets that have not yet been mapped.
- ***Elevation of bridges and roadways:*** Based on flood/storm surge modeling and as warranted, elevate roadways, develop sea-walls/living shorelines, upgrade, protect, and armor bridges and culverts.
- ***Incorporate climate change in all transportation design:*** Revise policies and standards accordingly to respond to changing climate trends. All new projects and assets to include updated design storm frequencies and precipitation and intensity.
- **Bridge Design:** The range of climate change impacts presented above may require revisions in bridge design tasks and procedures. Modified design may include:
    - Modeling for potential future rainfall rates generating higher design flows
    - Research methods for bridge deck de-icing
    - Bridge design specifications to require risk analysis for increased flood flows
    - Consideration of bridge retrofit for larger storm flows and/or storm surges
    - Research corrosion mitigation techniques
    - Optimal armoring techniques for bridge abutments and piers
    - Design scuppers and closed drainage system on bridges to have the capacity for the projected increase in precipitation
    - Design the roadway profile where bridges are higher than the roadway approaches. Overtopping the roadway first during flood events avoids damage to the bridge.
- ***Bridge Manual to include assessment actions:*** The FHWA Bridge Manual is being updated this year. This manual should include a reference to this Plan and any policies/procedures regarding consideration of climate change impacts to bridges and how these changes are incorporated into the design process.

Division of Finance

It will be the responsibility of the Division of Finance to undertake the following tasks.

Short-term:

- ***Funding:*** Pursue additional funding to prevent decreases in personnel and to potentially increase Department staff. Decreases in personnel limit the Department's ability to properly maintain bridges, pavements, ancillary structures, roadsides, and culverts to guard against extreme event damage due to the effect of climate change. Additional funding will be necessary to allow for the timely execution of necessary maintenance and/or storm-event response.
- ***Shift available funding to highest priority actions:*** Once assets have been prioritized based on climate change vulnerability, available funding should be shifted to fund the highest priority actions. . Through the biannual updates to the 10-Year Plan, this should be balanced with the need for other transportation improvement projects.
- ***Explore pre-disaster mitigation funding for transportation:*** Disaster funding is almost always only available after the fact. Pre-disaster funding would assist

NHDOT in preparing for climate change and preventing or reducing damage from disasters.

Mid-term:

- ***Align maintenance funding:*** Align funding to better implement reasonably simple actions to adapt to projected impacts from climate change.
- ***Secure funding to address locations not funded through routine maintenance programs:*** Funding should be secured for those locations requiring more complex design or construction that cannot be addressed through a routine maintenance program.
- ***Provide sufficient equipment:*** Maintenance equipment, such as road graders, backhoes, etc., should be acquired to enable NHDOT to properly maintain roadsides and culverts more effectively, as well as to respond to emergency situations resulting from climate change impacts.
- ***Pursue adaptation funding to harden roads, ditches, culverts, and bridges:*** Hardening assets where appropriate is a proven method of preventing asset damage during extreme weather events.

Long-term:

- ***Seek funding for ROW:*** Construction of higher capacity stormwater management facilities, restoring floodplains, and accommodating for flood storage will require increased right-of-way purchases. Federal reimbursement or State funds, under current rule, may not be available.
- ***Secure funding for high cost/high value projects***: Asset protection in coastal areas will be expensive, but roadways such as US Route 1, 1A, and I-95 provide high economic value. Planning should be undertaken immediately so that funding can be secured to protect these valuable assets.

Division of Aeronautics, Rail and Transit

It will be the responsibility of the Division of Aeronautics, Rail and Transit to undertake the following tasks.

Short-term:

- ***Non-motorized transportation:*** Identify non-motorized transportation options as mitigation to climate change impacts. Continue expansion of mass transit/buses.
- ***Facilities:*** Further investigate on-highway bicycle and pedestrian facilities.

Long-term:

- ***Rail:*** Continue research on passenger rail and pursue design and construction to expand this transportation option.
- ***Non-motorized transportation:*** Promote increased use and availability of facilities needed for these modes of transportation.
- ***Designated bike lanes:*** Continue to include design of and designate bike lanes in areas within NHDOT jurisdiction. Coordinate with municipalities / planning commissions for bike lanes consistency on other roadways.

- ***Interconnected bike paths:*** Continue working on path networks until bike paths are connected between towns.

The short-, mid- and long-term actions presented above are summarized for each NHDOT division in Table 11.

Table 9: Climate Change Recommendations by Division

Short-term (2015)	Mid-term (2015-2018)	Long-term (2015-2024)
Division of Operations		
• Improve communications	• Incorporate changing climate conditions in summer and winter maintenance program	• Increase staffing
• Increase knowledge base among staff	• Increase and reallocate staff maintenance structure	• Replace aging vehicles and equipment
• Invasive species management & outreach to homeowners	• Develop emergency response plans that address management of invasive species	• Fully integrate climate change into operations and maintenance activities
• Reduce mowing along highways	• Revise maintenance crew schedules to address impacts from climate change	• Implement initiatives to protect state facilities from flood impacts
• Clear out roadside ditches & around culverts	• Assess locations of transportation centers and storage locations and protect vulnerable assets	• Relocate facilities in vulnerable locations
• Identify priority sites and assets that are affected by climate change impacts	• Use of rest areas for climate change education	• Develop a Department climate change education program for the general public
• On-call contract for slope failures and emergency repairs	• Revisit road salt policy: Reassess timing, research alternatives under a changing climate	• Identify critical roadways susceptible to tree fall during heavy wind and/or ice storms
• Assess stormwater management at rest areas		• Re-assess road repair schedules
Division of Project Development		
• Continued use of Low Impact Development approaches	• Research innovative solutions	• Purchase properties for flood storage
• Deepen ditch-lines parallel to the roadway	• Erosion hazards mapping if necessary	• Review, revise design manuals as necessary
• Ensure appropriate stone sizing for bank stabilization along waterways	• Erosion hazards monitoring	• Greater emphasis on climate change as part of 10-Year Plan capital planning process.

(Continued next page)

Short-term (2015)	Mid-term (2015-2018)	Long-term (2015-2024)
• Drainage design standards should account for projected climate change and increasing human disturbance	• Initiate a process to partner with municipal agencies for coordinating adaptation and response efforts to climate change.	• Assess existing evacuation routes
• Rest areas – Assess stormwater management at these facilities	• NHDOT Bureaus should assign central point of contact to integrate climate change mitigation and adaptation	• Research and construct systems that can adapt to weather extremes
• Continue culvert inventory and assessment	• Continue work with Planning Commissions	• Elevate bridges and roadways, develop sea wall/living shorelines
• Provide additional drainage outfalls to decease concentrated peak discharges	• Research new design and maintenance techniques to combat ice buildup	• Incorporate climate change projections in all transportation designs
• Raise awareness and improved understanding of climate change issues		• Modify bridge design tasks and procedures
• Set up specific goals, conduct outreach projects, and engage the public		• Reference Action Plan in Design Manuals
• Maintain up-to-date information related to climate change science		
• Improve communication with municipalities and State/Federal agencies regarding transportation and land use		
• Identify vulnerable assets based on preliminary coastal flood and risk maps		
• Review community hazard maps, and mitigation plans to refine evacuation routes		
• Create a critical slope inventory		
• Harden flood-prone roadways		
• Meet with NHDES on regular basis to resolves emergency response needs		

(Continued next page)

Short-term (2015)	Mid-term (2015-2018)	Long-term (2015-2024)
• Improve entrance hydraulics of culverts and structures		
• Incorporate any needed changes to the bridge inspection program		
Division of Finance		
• Look into funding to decrease personnel cuts.	• Align maintenance funding with needs to address climate change	• Seek funding for right-of-way acquisitions needed for flood storage or stormwater facilities
• Shift available funding to highest priority actions.	• Secure funding to address locations/assets not funded through a routine maintenance program	• Secure funding for high cost/high value projects that address climate change impacts
• Investigate funding for pre-disaster mitigation for transportation assets	• Provide funding for sufficient equipment	
	• Pursue adaptation funding to harden roads and bridges	
Division of Aeronautics, Rail, and Transit		
• Identify non-motorized transportation as a mitigation option to the impacts of climate change		• Continue expansion of mass transit
• Further investigate on-highway bicycle and pedestrian facilities.		• Increase use of non-motorized transportation
		• Construct designated bike lanes
		• Develop interconnected bike paths

(Continued next page)

Implementation

Because adaptation to climate change will ultimately be implemented at the local (e.g., NHDOT District) level, a local and asset specific assessment of vulnerability will need to be conducted to evaluate how best to implement the general recommended actions presented above. The following section presents a process framework intended to assist NHDOT with the development and implementation of an Action Plan to adapt to climate change. The framework contains five main steps with associated sub-headings that provide greater detail on the components of each step. Figure 7 presents the proposed basic framework. A more detailed presentation of this framework is presented in Figure 8, following a discussion of the propose five-step climate change implementation strategy.

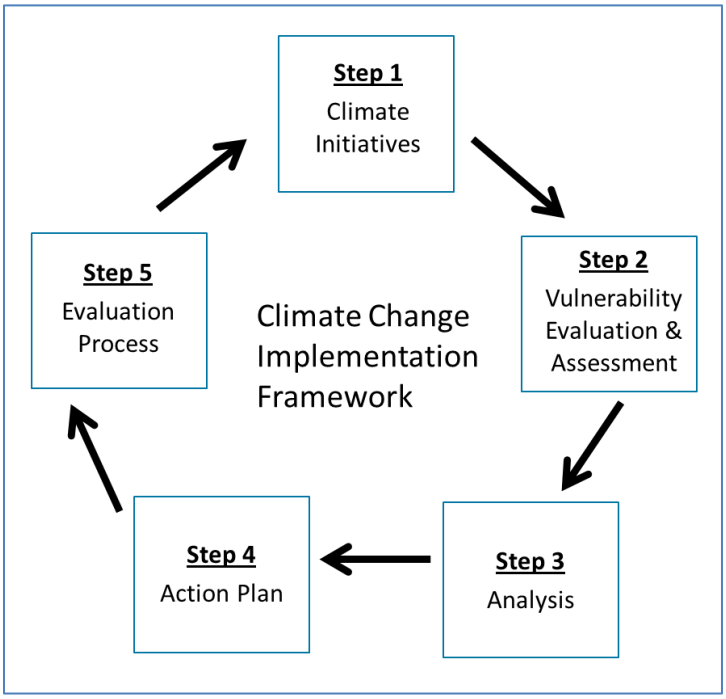

Figure 7: Climate Change Implementation Framework

Step 1. – Climate Initiatives

To oversee the implementation of this Plan, it is recommended that the agency first ensure that three elements are in place to provide a foundation for action:

- Leadership support for the Plan
- A clearly identified central coordinator; and
- A dedicated Climate Change Committee.

The leadership support must come from the Commissioner's Office and will:

- Promote the new initiative as a top-down priority;
- Leverage external resources and high-level support (e.g. legislation); and

- Provide the Plan with credibility and visibility throughout the organization.

The coordinator will:

- Act as a "liaison" between the Commissioner's Office, the Climate Change Committee, other staff, and outside entities;
- Engage a diverse group of the organization's employees in the climate discussion;
- Provide the investment of time that is needed to start and maintain the initiative while allowing others to focus on traditional core areas; and
- Keep up-to-date on climate change knowledge and projections

The Climate Change Committee will:

- Reflect a broad range of expertise and represent key Divisions within the Department;
- Determine a point of contact for each transportation Division;
- Ask each transportation District to appoint a contact;
- Provide guidance on action prioritization and implementation;
- Establish Partnerships: Develop a list of interstate and intrastate agencies, private companies, municipalities, and organizations to interact with on a regular basis as each relates to climate change. Once this has been accomplished, the Climate Change Committee will be the main contact for outside partners on issues of climate change;
- Coordinate with interstate and intrastate agencies, private companies, municipalities, and organizations, and continue climate change discussions;
- Keep up-to-date on climate change information, projections, issues, programs, and national awareness through coordination through other state agencies.
- Revisit the adaptation process on a regular basis; and
- Coordinate with each state transportation District regularly

Step 2: Vulnerability Evaluation & Assessment

The vulnerability assessment is the second step in the process. The Climate Change Committee shall direct each District to conduct a more thorough vulnerability assessment specific to its own region. Each District would be asked to:

1. Identify one main point of contact.
2. Identify assets and programs in their District.
3. Determine vulnerability of assets and programs. As discussed in Section 4, the vulnerability assessment should consider asset sensitivity and exposure to climate change variables and adaptive capacity.
4. Assess which locations and assets are the most vulnerable and likely to be impacted.
5. Determine priority sites which will be a combination of greatest vulnerability and highest value.

Step 3: Analysis

The purpose of this analysis is to determine whether NHDOT has total control of the asset or whether outside parties have some level of jurisdiction. For example, NHDOT could own a road but a down gradient culvert that conveys runoff from the road and needs repair or replacement might be owned by another party, such as a municipal DPW. In this example, the analysis would allow NHDOT to identify the appropriate contacts for that culvert so that the culvert can be replaced and the vulnerability of the road can be reduced.

The analysis step will be carried out by each District. This will include:

1. Identify whether NHDOT has control over the assets, programs, and policies or if outside control affects the assets through permitting or other controls;
2. If an outside entity has some form of control over the asset, identify the entity (or entities) with which coordination efforts must occur; and
3. Identify budgetary opportunities/constraints to implementing corrective actions on vulnerable assets

Step 4: Action Plan

The fourth step in this process is the development of an Action Plan where particular actions are identified and allocated to short-term, mid-term, or long-term action categories.

Step 5: Evaluation

The final step in the climate change framework is an evaluation process that examines the success of the actions taken, and whether that action was one of implementation or for designation of a proposed action to implement at a later date. This evaluation might best be accomplished by a combined effort of the Climate Change Committee and each District, evaluating how the process went and whether new actions or timetables are needed to improve the adaptation process.

Detailed Implementation Framework

Figure 8 provides a detailed overview of the adaptation framework and the steps involved.

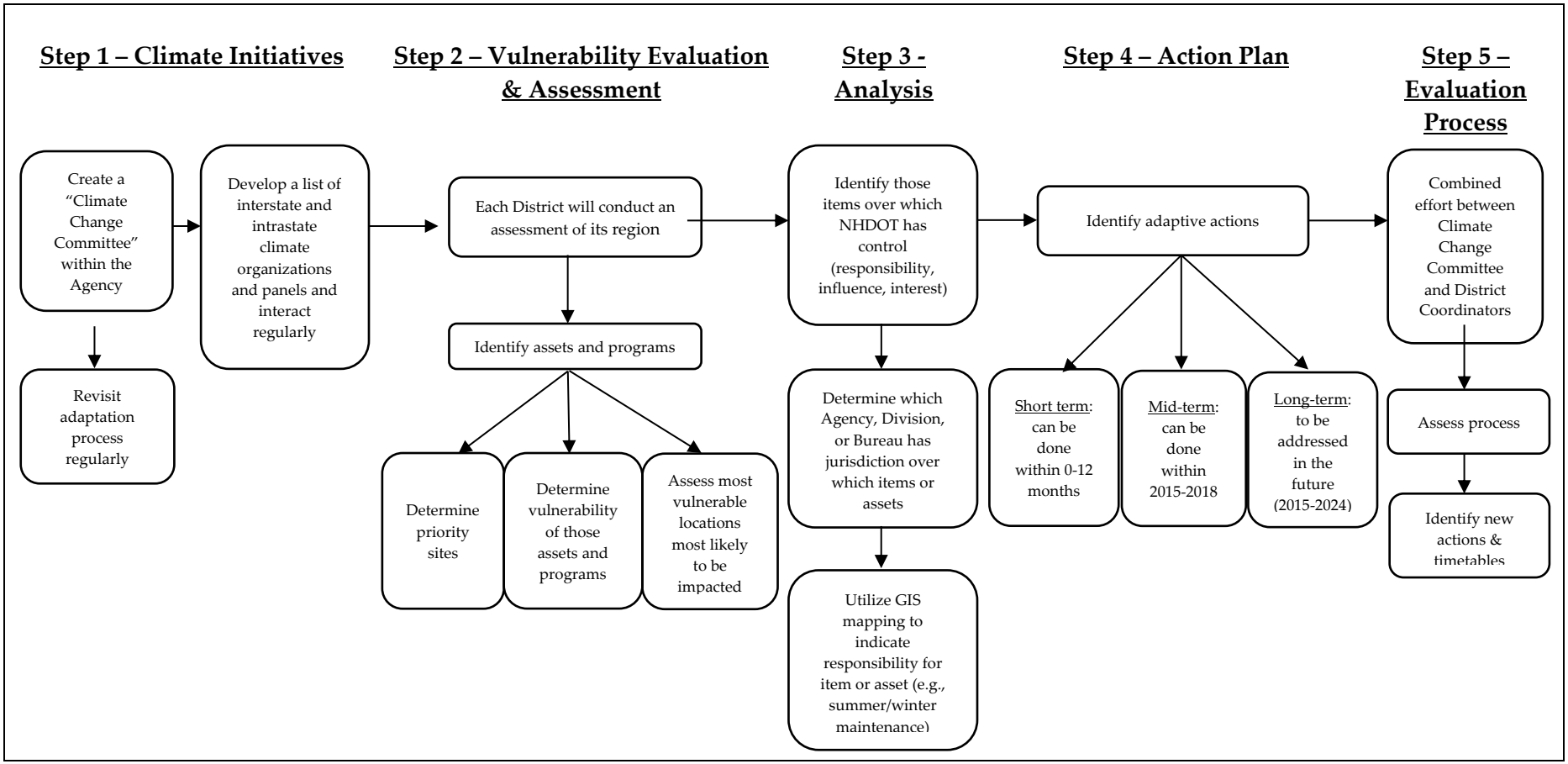

Figure 8: Climate Implementation Framework

6.0 Conclusion

This document presents a process for improving the resiliency and preparedness of NHDOT to deal with the impacts of climate change. Some adaptive measures can be implemented immediately with existing staff and funding. Others require reallocation of staff or budgets or both to achieve sufficient resources to effect meaningful change. And still others, many of which are of equal or even greater importance, require long-term planning to implement effective adaptive measures. Complicating the entire process is the uncertainty associated with the ultimate magnitude of climate change impacts and the fact that impacts to NHDOT assets are also affected by many factors beyond their control. Even so, the framework provided in this document should assist NHDOT in protecting many existing assets, ensure that future assets will be designed to be resilient to anticipated climate change impacts, and will provide for developing collaborative partnerships that will enhance its ability to adapt to climate change.

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Appendix A

Resources

- ***Eligibility of Activities:*** Eligibility of activities to adapt to climate change and extreme weather events under the Federal-aid program can be viewed at: http://www.fhwa.dot.gov/federalaid/120924.cfm.
- ***Education/Outreach/Tech Assistance:*** Information on vulnerability assessments, mitigation and adaptation strategies, etc. can be viewed at: http://www.fhwa.dot.gov/environment/climate_change/.
- ***Proactive Planning Measures:*** An example of land use and transportation scenario planning (Climate Change Cape Cod Pilot Project) can be viewed at: http://www.fhwa.dot.gov/environment/climate_change/adaptation/resources_and_publications/cape_cod/index.cfm .
- FEMA's HAZUS software and methodology for estimating losses could be useful for exploring for risk assessments, mitigation planning, and economic loss scenarios, related to infrastructure loss and damage. Information can be found at: http://www.fema.gov/hazus/.

Appendix B

Impact of Climate Change Variables on Selected NHDOT Assets

Climate Variable: EXTREME PRECIPITATION

Asset	Impact	Result of Impact
Bridges	• Stress on bridge joints • Ice buildup on pavement • Ice on bridge decks • Inland Flooding *(Upstream flooding risk can be increased caused by narrowed channel width)* • Scouring • Erosion • Ice Jams – blocking bridge opening • Bridge degradation • Wind stress • Bridge openings could fill with sediment or become blocked by debris	• Financial loss • Increased vulnerability: Bridges are expensive, take years to design leaving few bridges replaced each year which could leave many potentially vulnerable structures still in service. • Greater bridge replacement costs • Increased maintenance and repair efforts and costs • Traffic delays *(bridge closures, accidents)* • Potential schedule adjustments for road crews *(weather conditions)* • Bridge washouts • Increase in frequency of bridge inspection • Icy roads requiring additional road salt treatment. Increased bridge deterioration from additional chlorides • Potential for increase in number of crashes. • Interruption of transportation related services *(vehicles, trucking for delivery of goods, emergency response, etc.)*
Culverts	• Culvert degradation • Culvert failure / washouts • Ice jams • Perched culverts • Culvert filling with sediment eroded upstream or clogged by debris from flash runoff • Culverts fill with sediment /contribute to downstream erosion • Increased stormwater runoff • Flash flooding *(risk also increases from development and narrowed channel width)*	• More frequent culvert replacements • Increased disaster response • Increase in costs – more money spent over time • Water quality impacts • Insufficient organism passage • Traffic delays

Asset	Impact	Result of Impact
Road Segments	• Icy roads *(Could be less of a problem if temperatures become warm enough)* • Stormwater runoff • Sedimentation / erosion • Debris / tree fall from wind • Flooding *(risk also increases with development)* • Road segment washouts • Slope failure debris extends beyond Right-of-Way into private lands, waterways or floodplains • Greater frequency of cut and embankment slope failures caused by saturated ground conditions or by being undercut at the toe by erosion along water courses	• Increased road maintenance and repair • Increase in costs • Increased emergency response • Increased road salt runoff • Long duration road segment closure • Traffic delays *(accidents, road closures)* • Asphalt degradation • Icy roads requiring additional road salt treatment
Key Evacuation Routes	• Flooding • Road washouts	• Traffic delays *(accidents, road closures)* • Increased road maintenance and repair • Increased costs
Maintenance and Operations Facilities	• Flooding	• Facility damages
Back-up power, communication, fueling, and other emergency operations systems	• Salt water spray	• Maintenance & repair costs
Sea-wall Infrastructure	n/a	n/a

Asset	Impact	Result of Impact
Stormwater Management Facilities: (Includes constructed wetlands and bio-swales, dams, storm sewers)	• Overflow & flooding	• Increased repair time and costs • Property damages • Water quality impacts
Intelligent Transportation Systems (ITS) - Message boards, cameras, weather systems, fiber optics	• Wind • Flooding	• Trees taking out power lines • Increased repair costs
Signals & Traffic Control Centers	• Storm event intensity (ice/wind)	• Potential failures from storms (ice/wind)
Port & Airport Infrastructure & Access Routes	• Airport flooding • Wind damage • Icy runways • Structural damage (airport terminal, navigational aids, etc.)	• Infrastructure damage • Increased repair and replacement costs
Pipelines & Energy Corridors	• Wind • Flooding	• NHDOT does not own pipelines or energy corridors however, pipelines & energy corridors that are in NHDOT right of way can impact procedures / programs
Rail lines, rail yards and intermodal transfer points, and passenger stations	• Flooding	• Delays • Track repair

Asset	Impact	Result of Impact
Signs & Other Roadside Assets	• Damage from storms (wind/ice)	• Increase costs due to more frequent repair & replacement
Roadside Vegetation	• Continued growth of invasive species	• Reduced buffer capacity along streambanks where there are roads as essential species are crowded out • Increased likelihood of erosion • More maintenance time & money on eliminating invasive species instead of re-vegetating areas

Climate Variable: SEA-LEVEL RISE & STORM SURGE

Asset	Impact	Result of Impact
Bridges	• Flooding where bridges do not have the clearance for rising sea-levels. • Corrosion • Wind stress • Scouring • Erosion • Bridge degradation • Bridges could fill with sediment or become blocked by debris	• Financial loss • Increased vulnerability: (Bridges are expensive, take years to design leaving few bridges replaced each year which could leave many potentially vulnerable structures still in service. • Greater bridge replacement costs • Increased maintenance & repair efforts & costs • Traffic delays (bridge closures) • Potential schedule adjustments for road crews (weather conditions) • Bridge washouts • Bridge elevation • Increase in frequency of bridge inspection . • Interruption of transportation related services (vehicles, trucking for delivery of goods, emergency response, etc.)
Culverts	• Coastal flooding/inundation • Culvert degradation • Culvert failure / washouts • Perched culverts • Culvert filling with sediment eroded upstream or clogged by debris from flash runoff • Culverts fill with sediment /contribute to downstream erosion • Flash flooding *(risk also increases from development and narrowed channel width)*	• More frequent culvert replacements • Increased disaster response • Increase in costs – more money spent over time • Water quality impacts • Traffic delays
Road Segments	• Coastal flooding/inundation • Debris on roadways • Road segment washouts	• Increased road maintenance & repair • Increase in costs • Elevation of roads

Asset	Impact	Result of Impact
		• Increased emergency response • Long duration road segment closure • Traffic delays *(accidents, road closures)*
Key Evacuation Routes	• Flooding • Road washouts	• Traffic delays *(road closures)* • Increased road maintenance and repair • Increased costs
Maintenance & Operations Facilities	• Flooding	• Facility damages - relocation
Back-up power, communication, fueling, & other emergency operations systems	• Salt water spray	• Maintenance & repair costs
Sea-wall Infrastructure	• Flooding / inundation	• Infrastructure damage • Increased repair costs
Stormwater Management Facilities: (Includes constructed wetlands & bio-swales, dams, storm sewers)	• Overflow & flooding	• Increased repair time and costs • Property damages • Water quality impacts
Intelligent Transportation Systems (ITS) - Message boards, cameras, weather systems, fiber optics	• Flooding / inundation (depends on location)	• Increased repair costs if not in a secure area
Signals & Traffic Control Centers	n/a	n/a

Asset	Impact	Result of Impact
Port & Airport Infrastructure & Access Routes	• Flooding / inundation	• Infrastructure damage • Depends on proximity to the coast
Pipelines & Energy Corridors	• Flooding / inundation (depends on location)	• NHDOT does not own pipelines or energy corridors however, pipelines & energy corridors that are in NHDOT right of way can impact procedures / programs
Rail lines, rail yards and intermodal transfer points, and passenger stations	• Flooding /inundation (depends on location)	• Delays • Track / station repair • Track elevation
Signs & Other Roadside Assets	• Flooding /inundation (depends on location)	• Increase costs due to more frequent repair & replacement
Roadside Vegetation	n/a	n/a
Transit System Facilities & Vehicles	• Flooding /inundation (depends on location)	• Maintenance / facility repair

Climate Variable: Warming Winters

Asset	Impact	Result of Impact
Bridges	• Increased ice on bridge decks from	• More frequent maintenance & repair
Culverts	• Less snow volume in the ditchlines to insulate winter flows that normally flow year-round under the snow cover.	• Increased ice volumes and depths in the ditchline, which reduces capacity for stormwater flow. • Ice forms onto the roadway causing a hazardous driving surface that requires additional treatment or removal by mechanical means. • Lack of snow cover over culvert inlets and outlets allows the culverts to freeze, causing stormwater flow onto the pavement, which might freeze on the travel surface, cause a ponding hazard, or an erosion hazard on the opposite shoulder. • More frequent maintenance & repair
Road Segments	• Increase in frost heaves & potholes (freeze & thaw disruption)	• More frequent maintenance & repair
Key Evacuation Routes	• Increase in frost heaves & potholes (freeze & thaw disruption)	• More frequent maintenance & repair
Maintenance & Operations Facilities	n/a	n/a
Seawall infrastructure	n/a	n/a
Back-up power, communication, fueling, and other emergency operations systems	n/a	n/a

Asset	Impact	Result of Impact
Stormwater Management Facilities: (Includes constructed wetlands & bio-swales, storm sewers)	n/a	n/a
Intelligent Transportation Systems (ITS)	n/a	n/a
Signals & Traffic Control Centers	n/a	n/a
Port & Airport Infrastructure & Access Routes	n/a	n/a
Pipelines & Energy Corridors	n/a	n/a
Rail lines, rail yards and intermodal transfer points, and passenger stations	n/a	n/a
Signs & Other Roadside Assets	n/a	n/a
Roadside Vegetation	n/a	n/a
Transit System Facilities & Vehicles	n/a	n/a

Climate Variable: TEMPERATURE

Asset	Impact	Result of Impact
Bridges	• Potential stress on bridge joints (Only in extreme heat – not an immediate concern)	• Increased repair and maintenance costs
Culverts	n/a	n/a
Road Segments	• Pavement rutting (Only in extreme heat – not an immediate concern)	• Increased repair and maintenance costs • Traffic delays (Road closures)
Key Evacuation Routes	n/a	n/a
Maintenance & Operations Facilities	n/a	n/a
Back-up power, communication, fueling, and other emergency operations systems	n/a	n/a
Seawall Infrastructure	n/a	n/a
Stormwater Management Facilities: (Includes constructed wetlands & bio-swales)	n/a	n/a
Intelligent Transportation Systems (ITS)	• Potential difficulties from increased temperatures	• Increased repair and maintenance
Signals & Traffic Control Centers	• Increased energy demand	• Power outages • Communication disruption
Port & Airport Infrastructure & Access Routes	n/a	n/a
Pipelines & Energy Corridors	n/a	n/a

Asset	Impact	Result of Impact
Rail lines, rail yards and intermodal transfer points, and passenger stations	• Rail buckling and expansion	• Track repair • Delays
Roadside Vegetation	• Continued grown of invasive plants	• More maintenance time & money on eliminating invasive species instead of re-vegetating areas
Transit System Facilities & Vehicles	• Potential for vehicles overheating	• Vehicle replacement / repairs
Bicycle & Pedestrian Facilities	n/a	n/a