AN ANALYSIS OF STATE EFFORTS ON ADAPTATION TO CLIMATE CHANGE IN THE TRANSPORTATION SECTOR WITH APPLICATIONS TO GEORGIA

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AN ANALYSIS OF STATE EFFORTS ON ADAPTATION TO CLIMATE CHANGE IN THE TRANSPORTATION SECTOR WITH APPLICATIONS TO GEORGIA

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God has cared for these trees, saved them from drought, disease, avalanches, and a thousand tempests and floods. But he cannot save them from fools.

John Muir

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ACE	Air Cooled Embankment
ADCIRC	Advanced Circulation
ADOT&PF	Alaska Department of Transportation and Public Infrastructure
Caltrans	California Department of Transportation
DEIS	Draft Environmental Impact Statement
DelDOT	Delaware Department of Transportation
DFMS	Drainage Facility Management System
DOT	Department of Transportation
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
GDOT	Georgia Department of Transportation
GIS	Geographic Information Systems
HISA	High Impact Sub-Advisory
IPCC	Intergovernmental Panel on Climate Change
LID	Low Impact Development
LIDAR	Light Detection and Ranging
MaineDOT	Maine Department of Transportation
MassDOT	Massachusetts Department of Transportation
MDOT	Maryland Department of Transportation
MnDOT	Minnesota Department of Transportation
MPO	Metropolitan Planning Organization

NAS	National Academy of Science
NCDOT	North Carolina Department of Transportation
NCILT	North Carolina Interagency Leadership Team
ODOT	Oregon Department of Transportation
PDT	Project Development Team
PennDOT	Pennsylvania Department of Transportation
PID	Project Initiation Document
PSP	Pennsylvania State Patrol
PSRC	Puget Sound Regional Council
RTPA	Regional Transportation Planning Agency
SEA	Street Edge Alternatives
UKCIP	United Kingdom Climate Impacts Programme
VTrans	Vermont Department of Transportation
WSDOT	Washington Department of Transportation

SUMMARY

With climate change arising as an important issue in the 21th century, many states have been working diligently to develop climate action plans with the hopes of reducing greenhouse gas emissions and stop climate change from occurring. According to scientists' theories, however, many places across the globe are already feeling the effects of a changing climate and must therefore switch their focus from mitigation to adaptation. In the United States, there has been a focus on how climate change will impact one of the most vulnerable parts of the country, the transportation infrastructure. Many countries have already begun adapting their transportation infrastructure to climate change including the United States. This thesis focuses on how states are adapting to climate change by analyzing strategies, frameworks, and reports released by these states in order to document where they stand in regards to adaptation of the transportation network. The states that are adapting their transportation infrastructure are Washington, Oregon, California, Hawaii, Alaska, Florida, North Carolina, Maryland, Delaware, Pennsylvania, Michigan, Connecticut, Massachusetts, Vermont, and Maine. There is also a brief summary of how Canada and the United Kingdom are preparing for climate change with an analysis of frameworks and strategies used to adapt their transportation infrastructure.

The ultimate goal of this thesis is to provide engineers and policymakers with evidence that several states are implementing adaptation into transportation projects and provide a variety of strategies for them to use in their own state. Specifically, this report provides applications of adaptation for Georgia to use, so that they can begin the lengthy process of adapting their transportation infrastructure to climate change.

CHAPTER 1: INTRODUCTION

Climate change has become one of the most discussed global issues in the 21st century and the United States has acknowledged the impacts to be long lasting. One of the major fears that many leaders have about climate change is the crippling effect it could have on the country's transportation infrastructure. These fears have resulted from increased storm intensities and precipitation, extreme changes in temperature, and rising sea levels, all of which have been observed throughout the U.S, affecting the transportation infrastructure in several ways. Most roadways and bridges are designed based on standards developed before climate change really became an issue. Now with the impacts occurring, bridges and roadways have been found more susceptible to thermal expansion and rutting from high temperatures, erosion and flooding from intense storms and inundation by sea level rise. States need to understand that the only way to mitigate these impacts on the transportation infrastructure is to adapt to climate change.

According to the Intergovernmental Panel on Climate Change (IPCC), adaptation is defined as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities [1]. In the United States, adaptation is an emerging idea that is in need of much research. Many states believe they are doing everything that is possible to deal with climate change by mitigating the effects of greenhouse gases. Figure 1 shows that a majority of states are addressing climate change with climate action plans.

Figure 1. States with climate action plans.

Although these climate action plans will lead to a reduction of emissions in each state, it will not change the fact that climatic changes are occurring now and in the next century. For this reason, it should be important that states take up adaptation plans in order to prepare them for the future when the impacts of climate change may create problems for the country's transportation infrastructure.

Based on Figure 2, there are 15 states that have taken up adaptation plans or implementing adaptation strategies into transportation. These states are Washington, Oregon, California, Hawaii, Alaska, Florida, North Carolina, Maryland, Delaware, Pennsylvania, Michigan, Connecticut, Massachusetts, Vermont, and Maine.

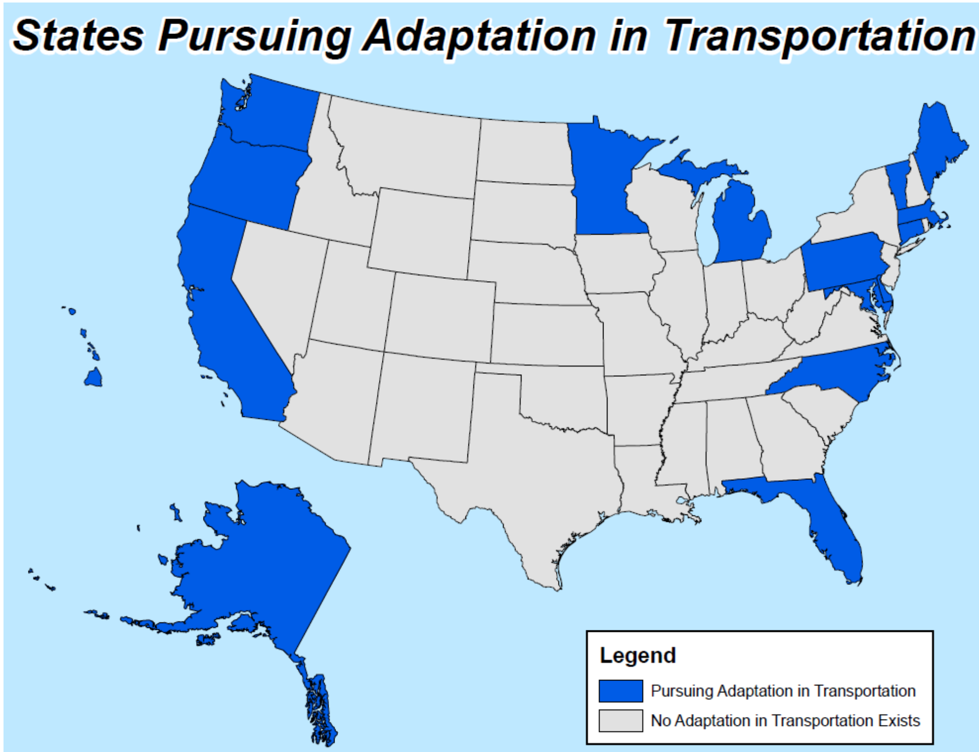

Figure 2. States pursuing adaptation in transportation.

Most of these states are bordered by the ocean, indicating that their most concerning issue is sea level rise. But most states have been able to develop other applications for adaptation that will improve resiliency towards higher temperatures, flooding, and intense storms.

In this thesis, Chapters 2 though 7 give an in-depth analysis of what certain states are doing to adapt their transportation infrastructure to climate change. Chapter 8 then follows up with a brief summary of Canada and the United Kingdom's efforts to adapt. The thesis continues on into Chapter 9 where it discusses applications for implementing adaptation in states that have none. In this case, adaptation applications are geared towards Georgia. Finally, Chapter 10 concludes with a summary of the overall application of adaptation in Georgia and also summaries the states which are adapting to climate change.

CHAPTER 2: WEST COAST STATES CLIMATE ADAPTATION

2.1 California Climate Change Adaptation Efforts

California has been pursuing climate change policy for some time, with many agencies pushing for adaptation to be implemented. Because of its size and location, California experiences several different climate patterns throughout its regions and with one of the longest coast lines in the country, will find adaptation to be a difficult task. According to the 2009 California Climate Adaptation Strategy report, the most significant impacts of climate change the state will see are higher temperatures, more extreme weather, increased precipitation, and sea level rise [2]. Within the transportation sector, the California Department of Transportation (Caltrans) has put continual efforts into adaptation policies and is very close to reaching the stage of implementation. After conducting many vulnerability and risk assessments for its transportation infrastructure, Caltrans has finally been able to introduce a guide for considering sea level rise at the project level [3]. This adaptation guide is recommended for use in all transportation projects along on the coastline where roadways and bridges are most vulnerable to landslides from increased precipitation and sea level rise.

2.1.1 Caltrans Efforts in Adaptation

The sea level rise guidance document is only a small piece of the overall work that Caltrans has completed on adaptation. Caltrans is constantly providing input and funding for projects and studies on adaptation from the national level, all the way to the local level. Currently, Caltrans is developing an “Adaptation Hot Spot Map” and guide for adaptation planning in regional transportation for California MPOs and RTPAs [4]. The Hot Spot Map, which is expected to be completed by mid 2012, is a collection of areas identified with increased infrastructure vulnerabilities due to population, travel, or climate effects. The results of the map, along with a guide for MPOs and RTPAs, will provide planners with tools for developing a climate vulnerability plan and creating strategies for implementing adaptation efforts for transportation infrastructure.

Caltrans has also been providing guidance for a National Academy of Sciences (NAS) Study of Sea-Level Rise and an East San Francisco Bay Sea Level Rise Vulnerability Study [4]. The NAS study involves a team of experts from five California state agencies, including Caltrans, with the goal of developing a "Sea Level Rise Assessment report" for the entire state. Washington and Oregon are also funding this project because of their own interest in sea level rise assessments. After these studies are completed, Caltrans will be able to apply this information along with its own sea level rise guidance to effectively incorporate sea level rise considerations at the project level [4].

2.1.2 Caltrans Sea Level Rise Guidance

In May 2011, Caltrans released its first in a series of guidance reports to assist Caltrans planning and development teams in assessing the risk of sea level rise for projects. Within the "Guidance on Incorporating Sea Level Rise" report, it lists strategies and goals for the planning teams to meet when considering adaptation measures and assessments that will be included in a Project Initiation Document (PID). The first goal of the planning team is to determine whether there is a need to incorporate sea level rise into an individual project by answering three questions: Is it located on the coast or near an area vulnerable to sea level rise? Will the project be impacted by the state sea level rise? Is the design life of the project beyond year 2030? If there is no need to incorporate sea level rise, then the PID must include a short sentence or two explaining why. If considering sea level rise is warranted in a project, then further detailed analysis must be included in the PID along with what adaptation measures to include. The Project Development Team (PDT) also has the option of not including sea level rise if the risk is found to be low or the necessary funding does not exist to include adaptation measures [3].

The PDT can find further guidance for evaluating the risk of sea level rise by consulting the "Coastal-Ocean Climate Action Team Interim Sea-Level Rise Guidance Document." In this report, there are three major assessments for sea level rise: timeframe, adaptive capacity, and risk tolerance. The timeframe of the project can give an assessment of how much sea level rise to expect during the lifetime of the project. Many models have shown similarities in sea level rise projections up to 2050. However, beyond mid-century, it becomes difficult to make predictions because projections vary based on the international community's reaction to greenhouse gas emissions and the speed at which permanent ice fields are melting. As shown in Table 1, there are three basic projections for sea level rise in California: High, Medium, and Low. Projects that appear to have high risks should consider high sea level rise projections, while projects with low risks should consider low sea level rise projections [5].

Table 1. Sea-Level Rise Projections using 2000 as Baseline Year [5]

Baseline Year	**Average of Models**		**Range of Models**
2030	7 in		5-8 in
2050	14 in		10-17 in
2070	**Low**	23 in	17-27 in
	Medium	24 in	18-29 in
	High	27 in	20-32 in
2100	**Low**	40 in	31-50 in
	Medium	47 in	37-60 in
	High	55 in	43-69 in

An assessment of consequences can vary based on the type of impact and the adaptive capacity of the project, as shown in Table 2.

Table 2. Consequences = Impacts x Adaptive Capacity [5]

	Low Adaptive Capacity	Medium Adaptive Capacity	High Adaptive Capacity
High Impact	High Consequences	High Consequences	Medium Consequences
Medium Impact	High Consequences	Medium Consequences	Low Consequences
Low Impact	Medium Consequences	Low Consequences	Low Consequences

Two factors need to be considered when implementing adaptation in projects: adaptive capacity and risk tolerance. Adaptive capacity is the ability of a system to respond to climate change, moderate potential damages, take advantage of opportunities, and cope with the consequences. Risk tolerance is the amount of risk involved in combination with the consequences and likelihood of impacts that may occur from sea level rise [5].

Other factors that are to be considered when applying sea level rise adaptation are project design life, redundancy, anticipated travel delays, goods movement, evacuations, safety, expenditure of public funds, interconnectivity issues, and environmental constraints [3]. For project design life, it is important to look at whether the design life is 20 or more years. With a longer design life, the probability of the asset being affected by sea level rise is much higher. Therefore, it is desirable to implement adaptation strategies if the design life is greater than 20 years. If a transportation corridor lacks redundancy, it is likely that adaptation strategies should be implemented. System redundancy considers whether there are multiple routes that could be used in case a road is inundated or damaged. If it is the only route, especially in emergencies, then it is important to design it to be resilient toward sea level rise. If a transportation asset is a major highway or corridor for travelers and goods movement, then adaptive capacities need to be built into the design. There could be major economic impacts to the area if a major highway becomes inundated and inaccessible. Also, evacuation concerns and safety should be considered, especially if lifeline arteries are threatened [3].

When looking at the scope of a project, it is necessary to consider if the project is a single point or linear. For a linear project, it may be less necessary to incorporate sea level rise concerns over some length of the project. Another important aspect is to consider whether there will be any interconnectivity issues. For example, if the roadway grade was raised, it may require other streets to be reconstructed as well. Also, there could be environmental constraints to the project if this were required [3].

If the PDT determines that sea level rise will affect a project, it must be determined the degree of the impact and the creation of a list alternatives that can be used for adaptation. Once this step is completed, it is recommended that the PDT, 1) evaluates existing vertical elevation data and compares it with current sea level data to determine if the existing data is still current, 2) requests a preliminary assessment of the local land subsidence for the project design life, 3) creates a sea rise projection for the project over the design period, 4) determine the negative impacts on facility function, and make necessary revisions, 5) identifies the cost of sea level rise adaptation to the project, 6) includes all alternatives even if adaptation can create new impacts to the roadway, and 7) applies incremental or staged improvements to address sea level rise [3]. Once these steps are finally completed, the project can move on into the construction phase and implementation of adaptation designs.

2.2 Alaska Climate Change Adaptation Efforts

Over the past several decades, Alaska has been experiencing major impacts due to climate change especially in the form of warmer temperatures. Probably the greatest threats to the transportation infrastructure in the state of Alaska are melting permafrost and sea level rise [6]. When ground permafrost melts, it creates instability in the ground which can cause buildings to shift and roadways to buckle. This can generate substantial costs because this will require continuous maintenance and repairs.

2.2.1 ADOT&PF Efforts in Adaptation

The Alaska Department of Transportation and Public Infrastructure (ADOT&PF) has already experienced the risk to the transportation infrastructure from melting permafrost and is developing designs with higher adaptive capacity. Multiple studies have already been completed identifying locations in Alaska where permafrost is melting, and the Alaska DOT&PF has seen the effects in many locations. At this point, the ADOT&PF is spending approximately $10 million a year on reducing the effects of melting permafrost on the Alaska' highway system. State funds have also been used to relocate airports, roadways, and bridges impacted by severe flooding and coastal erosion [6].

2.2.2 Adaptation Strategies

Although no specific adaptation measures have been implemented, Alaska has been considering adaptation strategies to reduce the impacts that are occurring. According to "Alaska's Climate Change Strategy: Addressing Impacts in Alaska," the three major strategies for achieving this goal are to: 1) create a coordinated and accessible statewide system for key data collection analysis and monitoring, (2) promote improvements that use the current best practice, and (3) build resiliency into the public infrastructure. The first strategy aims to create a system for assessing rates of erosion, permafrost thaw, and flooding by region in order to identify specific locations where the risks and vulnerabilities of the public infrastructure is high. This will allow information to be shared effectively and for funding to be distributed evenly. The goals of the second strategy are to use the information found in the first step to research ways to promote best practices for adaptation. This will also require reviewing engineering practices for effectiveness and identifying project locations. Finally, the third strategy uses the information to implement specific strategies. This will require projects to have updated design standards, codes, and ordinances; higher-than-normal design lives; and produce a resilient design using best engineering standards to withstand climate change impacts [6].

2.2.3 Applying Research Efforts in Adaptation

The University of Alaska has been researching and testing new treatments for roadway foundations that are expected to improve resilience to permafrost melting. Some of the adaptive techniques include using air cooled embankment and shoulder treatments, heat drain embankment and shoulder treatments, and longitudinal convection culverts. Air cool embankments (ACE) as shown in Figure 3, are made of highly porous layers of large rock, 150 to 300 millimeters in diameter that allow for foundation soils to cool. ACE works by forming convection cells that allow cool air to be stored near the bottom of the material and thus creating an insulated layer for the permafrost to stay frozen. Also, due to the angularity and size of the rock pieces, there is the added benefit of giving the structure a much higher shear strength and low density when compared to embankments with conventional dense graded fill. So far it has been proven that ACE is effective in cooling the foundation of soils over several years; however, ACE has not been used in many locations and is still being tested for long term use [7].

Figure 3. Uncovered air cool embankment showing rock material used for construction [8].

Heat drained embankments have been proven to be an effective, yet laborious technique for cooling the ground. This technique involves extending a 25 mm-thick, highly permeable geocomposite sheet 1 meter above natural ground level at a steep angle across the embankment surface. The sheet, as shown in Figure 4, is connected to 100 mm drainage pipes with inlets and outlets, located at the base and the top of the drainage layer.

Figure 4. Geocomposite sheet connected to drainage pipes at top of embankment [9].

Heat drained embankments work by creating conduction and convection air movements in the geocomposite sheets which is induced by the cold air entering through the inlet and forcing warm air out of the outlet located on the top of the embankment [8].

Longitudinal culverts use the same cool down technique as heat drained embankments except they use three, 750 mm-diameter culvert sections interconnected to each other. The assembly involves placing a horizontal section in the embankment shoulder parallel to the road and connecting the ends with a horizontal section placed perpendicular to the road with an air inlet valve and a vertical section exceeding 2 meters above the embankment surface with an outlet valve. During the winter, the valves are opened to allow cold air to flow through the culvert to cool the ground, and in the summer, the valves are closed to avoid warm air entering and creating an inverse effect. Figure 5 shows how the longitudinal pipes appear after construction is completed. Once again both heat drained embankments and longitudinal culverts have been found to be successful at cooling the ground, but still need to be tested for long term use [8].

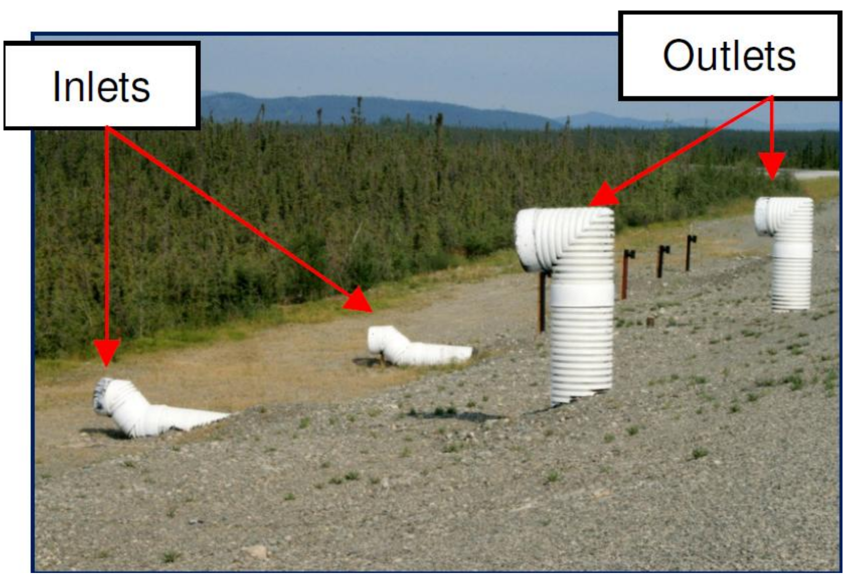

Figure 5. Completed construction of longitudinal culverts [8].

2.3 Washington State Climate Change Adaptation Efforts

The State of Washington is considered one of the states at the forefront of climate change adaptation in transportation. Many cities across the state have begun adopting adaptation strategies and even state departments have begun utilizing these strategies in their planning processes, including the Washington Department of Transportation (WSDOT). So far, several preliminary assessments of climate change have been completed, and several projects are now within the planning stages.

WSDOT has acknowledged that climate change will be a major threat to the transportation infrastructure in the near future and agrees that action must be taken to adapt effectively. The major assets WSDOT believes are the most vulnerable to climate change are roadways from flooding and storm water issues, transportation facilities from storm surge, and railroads from extreme temperatures [10]. However, the biggest threat that WSDOT and other state agencies see to Washington's infrastructure is sea level rise. Much of the transportation planning in climate change adaptation has been focused on understanding how sea level rise will impact the state and what can be done to adapt. Several counties, cities, and councils have been working on sea level rise assessments along with other climate change impacts including the City and Port of Bellingham, the City of Olympia, the City of Seattle, King County, and the Puget Sound Regional Council.

2.3.1 City Efforts in Adaptation

The Port of Bellingham has considered sea level rise adaptation in its draft environmental impact statement (DEIS) submitted for the "New Whatcom Redevelopment Project." This project is an effort by the Port of Bellingham to redevelop a heavy industrial property, used for pulp and chemical operations, into a mixed use, waterfront neighborhood. The DEIS discusses the potential impact of sea level rise on roadway infrastructure within the southern portion of the site and suggests a revised grading plan to elevate streets above an estimated 2.4 foot rise in sea level by 2100. It also suggests designing all new stormwater outfalls with invert elevations significantly higher than the existing Mean High Water in order to mitigate any sea level rise or storm surge problems that may occur in the future [11].

The City of Seattle has been working on a passive way of adapting to climate change by using "green" stormwater infrastructure to mitigate increased rainfall. One of the strategies for its "green" stormwater infrastructure is creating natural drainage systems that utilize plants, trees, and soils to absorb more runoff and effectively manage stormwater flows. The City has been able to implement several natural drainage projects such as the Street Edge Alternatives (SEA) Project. For this project, the goal was to maximize the stormwater time of concentration in order to reduce runoff rates and allow for maximum soil absorption. To do this, impervious areas were reduced to 11 percent less than a traditional street and surface retention or detention in swales was provided along with adding shrubbery and trees. Figure 6 shows a before and after photo of the changes that are made when applying SEA. The project has been a great success in that the total volume of stormwater leaving the street has been reduced by 99 percent [12].

Figure 6. Before and after photo of SEA project [12].

2.3.2 Puget Sound Regional Council Efforts

The Puget Sound Regional Council (PSRC) has released VISION 2040, a long range vision for maintaining prosperity for the region. Adaptation strategies were considered as part of the region's long-range transportation planning process. Some potential strategies described in the report are: changes to design standards for roadway and other facilities to accommodate for more frequent flooding and higher water levels; reconsidering sites of new facilities as to avoid locations where inundation due to sea level rise is a risk; creating a comprehensive operational response plan by analyzing the connectivity and vulnerabilities of the transportation network; incorporating increases in maintenance costs in long-range planning and budgets; and creating an inventory of high valued infrastructure at risk to climate change [13].

2.3.3 King County Efforts

King County has been one of the most active counties in Washington for considering climate change adaptation. The County has been working diligently in making its transportation system more resilient to increased precipitation and sea level rise. For example, the Tolt Bridge spanning the Snoqualmie River was completely rebuilt with longer spans to withstand the possibility of higher flows and reduce river flooding caused by large pieces of debris getting caught under the bridge. King County now has plans to apply this design to many other short span bridges that may experience higher flows in the future [13].

Some passive types of adaptation strategies that many projects in the county have been applying are low impact development (LID). This technique was applied at the intersection of Military Road South and South 272nd Street for the purpose of managing higher stormwater flows. For this project, as shown in Figure 7, porous concrete was used to construct a sidewalk and a rain garden system was built next to it to manage stormwater runoff [13]. By preserving the natural hydrology and reducing the impervious area, it is possible for the ground to absorb more stormwater and prevent flooding from occurring on the streets [14].

Figure 7. Completed LID Project [14].

An example of a transportation project that was chosen as a case study for climate change adaptation in King County was the Dockton Road Preservation Project. Dockton Road was constructed in 1916 and is supported by a seawall that requires frequent repairs. King County considered several options for construction in the corridor, which includes a full rebuild of

Dockton Road or rerouting traffic to other roads and converting the corridor to a multi-use beachfront trail. As part of the initial study for choosing alternatives for the project, consultants for the King County Road Services Division analyzed the risk of the corridor from sea level rise due to climate change. Utilizing GIS software and sea level rise data from the University of Washington Climate Impact Group, the consultants were able to screen for locations where the road and seawall would be impacted. It was discovered that that road was indeed vulnerable to rising sea levels and therefore the County had to consider raising the elevation of the road. It was later found that a major benefit of raising the roadway is that it not only mitigated inundation by sea level, but also reduced the cost of the project. Previously, a full build-out of the project would have required constructing a cantilevered sidewalk, but by raising the road a couple of feet, the foundation would be wide enough to place a sidewalk without cantilevering. This would save the project $2.5 million [15].

2.3.4 WSDOT Efforts in Adaptation

In 2010, the WSDOT received funding from the Federal Highway Administration (FHWA) to pilot a conceptual model to use in conducting vulnerability and risk assessments of infrastructure to the impacts of climate change. WSDOT facilitated a series of workshops that brought together experts to assess the state's transportation infrastructure and the potential impacts of climate change. This information would not only assist Washington State in adaptation, but would also provide invaluable information for developing a conceptual model. The FHWA has created a flowchart that describes the components of the risk assessment model that will be created, shown in Figure 8.

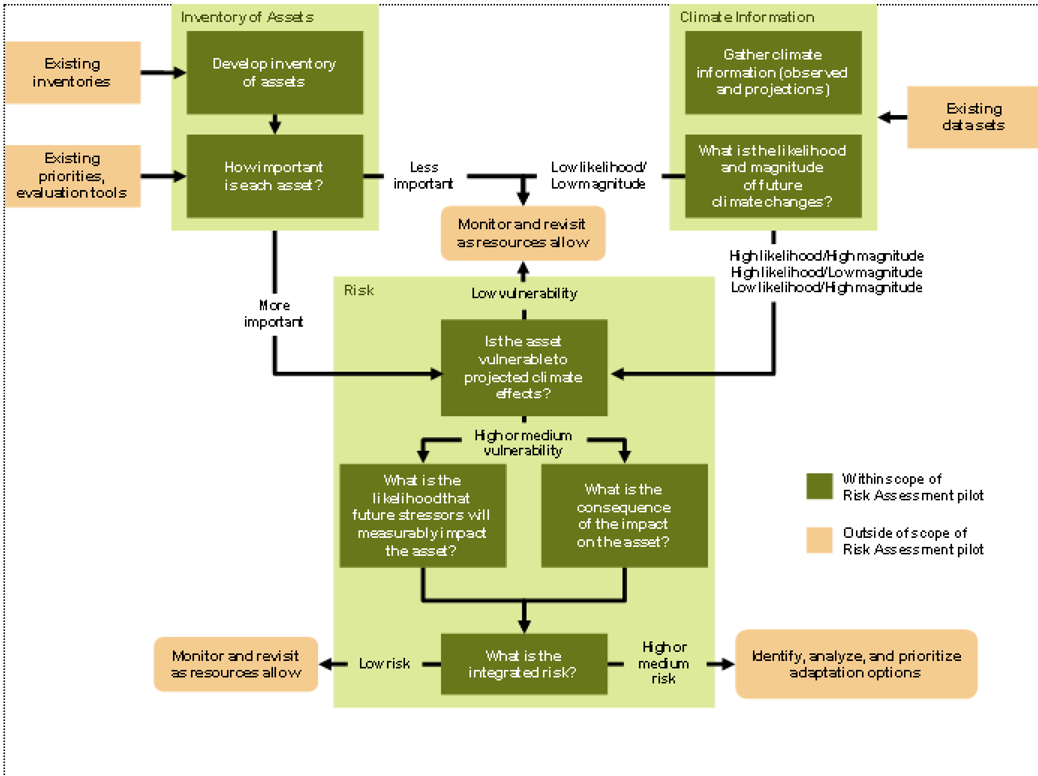

Figure 8. FHWA flowchart for climate change risk assessment [16]

The ultimate goal of the project is to assist the FHWA in perfecting the model and to provide assistance for state DOTs and MPOs to advance adaptation activities. It is expected that the pilot will be completed by the end of 2011 and handed over to the FHWA for further assessment and consideration [16].

2.4 Oregon Climate Change Adaptation Efforts

Oregon is currently working on climate change adaptation planning but is only at the preliminary stages for transportation. At this point, the Oregon Department of Transportation (ODOT) is finalizing its “Interim Climate Change Adaptation Strategy,” which is expected to be completed at the end of 2011 [17]. ODOT agrees that climate change will affect all major infrastructure systems including its roadways, bridges, stormwater, airports, and railroads. Most of their adaptation efforts will focus on coastal roads, bridges, and culverts, infrastructure in floodplains, and roads and bridges at the urban/rural interface. ODOT's current adaptation efforts are being led by a Climate Change Technical group, composing of a team of experts from ODOT that are researching, strategizing, and planning for transportation adaptation. To this date, the group has nearly completed its first stage of adaptation research by sharing research funds with other states to gain understanding of best practices at the local and state levels. Now they have begun working on an assessment of infrastructures risks and vulnerabilities to climate change and a list of strategies for identifying priorities and reducing vulnerabilities. ODOT's end-goal is to complete a long-term adaptation plan in order to guide decision-making and coordination into its own department and other local and state agencies [17].

2.4.1 ODOT Climate Change Efforts

Although Oregon is in the early stages of climate change adaptation, ODOT has been addressing many issues relating to climate change. A list of these projects can be found in the "Oregon Climate Change Adaptation Framework," which was completed in December 2010. For addressing coastal erosion, ODOT is preparing scour analyses of 69 coastal bridges found within its jurisdiction. For addressing flooding, they are installing a couple of automatic flood warning systems while conducting a high-level inventory of vulnerable areas and infrastructures, and are also developing a Drainage Facility Management System (DFMS), to keep an updated detailed inventory of all the culverts within the state. This will allow them to determine which culverts need replacement or expansion for future increases in rainfall. For addressing landsides, ODOT has installed debris flow warning systems on I-84, which can notify motorist and give them time to find an alternative route when a landslide affects the roadway. They have also created an Unstable Slope Management System to track records of landslides and rockslides [18].

2.4.2 ODOT Adaptive Capacity

While the state continues to develop adaptation strategies for its transportation and infrastructure networks, ODOT believes that its current adaptive capacities will allow them to withstand current climate changes. Oregon's adaptive capacities range from larger culvert and bridge span designs to varieties of pavement mixes and materials that can be easily altered from changes in air temperature. ODOT also has several alert systems in place for flooding. One system that is being tested in two of its regions is a bridge alert system that can predict possible bridge instability. This system works by collecting data from existing real time rain and flooding monitoring stations and sending out a notification to maintenance personnel when pre-determined conditions warrant bridge instability. These are just a few examples of the overall adaptive capacity of the state's infrastructure. ODOT is still conducting more research to fully establish all of the adaptive capacities that exist and use the results to support future adaptation projects [19].

CHAPTER 3: MIDWEST STATES ADAPTATION EFFORTS

3.1 Minnesota Climate Change Adaptation Efforts

Much like many other states, Minnesota is in the preliminary stages of climate change adaptation. Although they have not begun applying any adaptation efforts, they have released a report called "Adapting to Climate Change in Minnesota," which was submitted to their Interagency Climate Adaptation Team. This team included representatives from a variety of state departments including the Minnesota Department of Transportation (MnDOT). The report focuses on a preliminary assessment of how climate change will affect Minnesota and includes a small framework for future adaptation. Minnesota agrees that climate change will affect the state in a variety of different ways including more frequent spring flooding events, increased periods of drought, and more extreme drought [20].

3.1.1 MnDOT Efforts

At this point, the MnDOT is participating in a pooled fund study with the Iowa Department of Transportation and the National Weather Service on updating precipitation frequency estimates for the Midwestern region. Since rainfall maps have not been updated for 50 years, many hydrologic structures have been designed using outdated information. The purpose of the project is to update precipitation frequency estimates with the current, previous 50 years of rainfall data. The goal is to develop new data for rainfall durations of 5 minutes to 60 days and storm frequencies from 1 year to 500 years. This new data will allow hydrologic structures to be designed for the current climate expectations and also increase states' adaptive capacity for future increases in intense rainfall [21].

CHAPTER 4: MID-ATLATNIC STATES ADAPTATION EFFORTS

4.1 Pennsylvania Climate Change Adaptation Efforts

One of the ways that the Pennsylvania Department of Transportation has been responding to the onset of climate change is by developing a more robust procedure for responding to more frequent snow and ice storm events. In the last decade, several interstate corridors such as I-80 have encountered numerous vehicular accidents due to quick snow squalls and ice events that have resulted in many injuries and death. Because these storms have become a serious issue, PennDOT has revamped its emergency response by adopting better coordination with the Pennsylvania Emergency Management Agency and the Pennsylvania State Police (PSP), creating a new interstate road closure protocol, and also developing a more accurate weather prediction system [22]. By working with the Pennsylvania National Weather Service, PennDOT and PSP can be warned a day in advance when a High Impact Sub-Advisory snow event (HISA) is about to occur. A HISA is a rapid occurring snow event with heavy snow squalls along with rapid wind and temperature fluctuations that can deteriorate road conditions and increase driver anxiety and confusion. When the National Weather Service predicts a HISA event, it can coordinate with PSP and PennDOT by giving them highway mile-marker information on the timing and path of the snow squall so that accurate warnings can be given out to the drivers [23]. So far all these systems have proven to work effectively, especially after being tested during the storms of 2009-2010 where Pennsylvania was impacted with three 20-inch storms. Now all departments are researching ways of expanding this emergency response system to cover most of the major interstates and highways throughout the state [22].

4.2 Maryland Climate Change Adaptation Efforts

Maryland has been doing a lot of work in climate change adaptation especially with regard to sea level rise. So far the state has developed two documents for addressing adaptation that make up their comprehensive strategy for reducing vulnerability to climate change: "Adaptation Phase I: Sea level rise and coastal storms" and "Adaptation Phase II: Building societal, economic, and ecological resilience" [24,25].

4.2.1 Phase 1 Report

The Phase I document addresses concerns over coastal flooding and sea level rise within the Chesapeake Bay region. According to regional studies, this area is the third most vulnerable to sea level rise behind southern Florida and Louisiana. To explain the severity of climate change, within the past century, thirteen Chesapeake Bay islands have disappeared due to sea-level rise. It was also noted that 31% of Maryland's coastline is experiencing coastal erosion and it is estimated that 580 acres of land is lost per year from erosion. These facts point out that Maryland's coastline infrastructure is highly susceptible to sea level rise and will require state legislatures to enact policy geared towards reducing the impact to the existing-built environment and future growth and development of the area [24].

Although no policies have been enacted yet, the report recommends several policy actions to adapt to climate change. On the local level, the report suggests amending Maryland Planning Article 66B and Chesapeake and Atlantic Coastal Bays Critical Area Act. These amendments will allow for modifying land use areas in an effort to enhance sea-level rise adaptation. For example, some of their options include expanding the distance of vegetated buffers or developing criteria to enable the designation of wetland migration corridors and natural shore erosion areas within Critical Area buffers. On the state level the report suggests allocating state resources to areas that may be impacted by climate change. This includes utilizing GIS technology to analyze areas vulnerable to sea-level rise, aligning state Smart Growth strategies, including priority funding area requirements to reflect areas experiencing population growth and development, and integrating climate change adaptation into the Maryland State Development Plan [24].

The process of implementing some of these polices is in fact occurring. The Maryland Department of Planning has stated that they will begin integrating land use and planning options into the State Development Plan with regards to sea level rise. The Maryland Department of Transportation (MDOT) has also begun assessing the state's critical transportation infrastructure vulnerability to climate change. It is stated that the Department of Natural Resources' Chesapeake and Coastal Program will begin identifying vulnerable sea-level rise inundation areas by acquiring topographic data to assess public and private infrastructure [24].

4.2.2 Phase 2 Report

To follow up to Phase I, the Phase II document of Maryland's assessment for reducing vulnerability to climate change focuses on strategies and recommendations for reducing impact from extreme precipitation and temperatures. It is estimated that 29% of Maryland's bridges are structurally deficient or obsolete and will likely worsen when exposed to increasing variability in temperatures. The state also observes that by 2030, the population is expected to increase by a million which will lead to more impervious pavement and as a result, an increase in urban heating [25].

So far several state agencies have began accepting policy recommendations with regards to climate change. With the help of additional funding, MDOT wants to consider climate change impacts, such as investigating flood impacts for future projects so that they can generate several adaptive alternatives [25].

Maryland is aware that they are far from fully understanding all adaptation measures that can be implemented to reduce the impact of climate change. That is why they will continue to support improving state tools and research methods. Some suggestions for climate change tools include collaboration with federal partners to make use of global, national, and regional climate data for state needs, development of decision-support tools that will identify climate change risks, launching a Climate-Smart Growth and Infrastructure education campaign, and reaching out to local and regional agencies. The last of the two will be most important in that it will engage the public, including engineers and policymakers, to work together to address infrastructure needs from the impact of climate change [25].

4.3 Delaware Climate Change Adaptation Efforts

Delaware has acknowledged that its coast will be highly susceptible to sea level rise and has decided to implement its own statewide adaptation plan to address this issue. The goal of the plan is to formulate recommendations to adapt to sea level rise and incorporate these into policies and programs at local and state levels. In order to guide the project forward, an Advisory Committee was formed, comprised of representatives from state agencies, local governments, business and development advocacy groups, and environmental advocacy groups. Along with this plan, the state has put together a Sea Level Rise Initiative Project Compendium, which is a collection of different projects and studies involving many state agencies with the goal of assessing sea level rise and reducing its vulnerability to the coast. Some of the projects that the Delaware Department of Transportation (DelDOT) is assisting with are the Statewide Sea Level Rise Adaptation Plan, City of New Castle Coastal Resiliency Project, and Bowers Beach Coastal Resiliency Project [26].

The coastal resiliency project for New Castle is an effort to reduce damage experienced throughout city due to flooding by improving existing dikes and flood control structures. The goal of the project is a dike maintenance and improvement plan that exposes deficiencies found in the city's flood control system and implements a plan to address these issues in order to adapt to future sea level rise and increased flooding. The first state of the project has just been completed, which included conducting dike breach analysis, flood gate analysis, and preparing operation and maintenance manuals for the dikes and flood control gates [26].

The coastal resiliency project for Bowers Beach is similar to the project for New Castle in that it is trying to reduce damaged caused by flooding. The goal of the project is to create a priority list of improvement projects designed to adapt to increase flooding. So far, a vulnerability assessment and drainage evaluations have been completed for the project, which include developing conceptual designs to improve the drainage system throughout the city [26].

CHAPTER 5 : NORTHEAST STATES ADAPTATION EFFORTS

5.1 Vermont Climate Change Adaptation Efforts

Vermont is in the early stages of adaptation planning and has produced a set of climate change adaptation papers called "Adaptation White Papers." These papers describe different sectors in Vermont that will be experiencing the impacts of climate change and offers steps that need to be taken to adapt to these impacts. Transportation is one of the sectors included in the Adaptation White Papers and it describes what efforts are being taken by Vermont Department of Transportation (VTrans) to adapt to climate changes [27].

5.1.1 VTrans Efforts

As of now, VTrans has identified several impacts of climate change within the state. These include flooding of transportation infrastructure such as roadways, bridges, culverts, and railroads; increased damage to bridges from scouring and corrosion damage on pavements and other structures; failure of pavement and bridge expansions; pavement damage from increased freeze-thaw cycles; increased potential in pavement rutting and vehicle hydroplaning; increase in extreme wind events causing more debris blockage of roadways and higher wind loading on bridges; higher demand in emergency preparedness and evacuation; and increased maintenance. Because VTrans is in the early stages of adaptation, their current strategy is to create new policies and practices in climate change adaptation for transportation planning and design. These strategies include reanalyzing existing data on historic rainfall, temperature, snowfall data, wind speeds, and growing seasons, identifying data gaps and modeling needs, and partnering with other state and federal agencies to receive useful information and data on climate change adaptation to influence their own agency action. VTrans is also working on mapping storm-related expenditures so they can assess how much funding is going into maintenance and how much the state can save if it applies adaptation to new projects [27].

5.2 Massachusetts Climate Change Adaptation Efforts

Although there has been no implementation of adaptation measures in the state of Massachusetts, many agencies, including the Massachusetts Department of Transportation (MassDOT) understand the importance of adaptation and are participating in multiple workshops and pilot programs, mostly federally funded, so that they can fully understand all that must be done to effectively guide adaptation of future projects and planning. For example, between early 2010 and mid 2011, several transportation agencies in Massachusetts met with other federal, state, and local agencies for an interagency transportation, land use, and climate change pilot project in Cape Cod, Massachusetts. The project consisted of several federally-sponsored workshops that put together multi-agency transportation and land use experts to develop different scenarios for reducing greenhouse gas emissions and dealing with the potential impacts to sea level rise. A report titled "A Framework for Considering Climate Change in Transportation and Land Use Scenario Planning" was released documenting the lessons learned by the pilot project after it was completed [28].

Besides working with other states on adaptation programs, Massachusetts has brought together many of its own local and state agencies to form a Climate Change Adaptation Advisory Committee. In September 2011, the committee released "Massachusetts Climate Change Adaptation Report. This report provides a preliminary framework for addressing the state's climate change adaptation solutions by developing different strategies (no regrets, short- term, and long- term strategies) for many of sectors within the state. In transportation, the no regrets strategies are to maintain existing infrastructure until permanent adaptation plans can be implemented, apply updated floodplain maps and revised peak flood flow calculations to GIS-based asset maps, fund MassDOT and Massachusetts Port Authority to work with regional and local agencies in creating solutions for protecting existing assets in the long and short-term, and upgrading stormwater management structures before much more costly replacements will be necessary due to larger and more frequent storm events. The short-term strategies have transportation agencies adjusting maintenance and inspection procedures and revising new design standards to take into account recent climate change impacts. The long-term strategy is to be prepared for damages that will accrue from climate change by having enhanced water-based transit options for when land infrastructure is damaged, set-aside funding for construction and long-term maintenance and operation costs for damaged infrastructure, and adopting new aircraft technologies, such as improved landing and takeoff performance, that can adapt to more frequent storm events [29].

5.3 Maine Climate Change Adaptation Efforts

Maine has recently been an advocate for climate change adaptation and has been committed to pursuing strategies and options to evaluate its adaptation needs. One agency in particular that is helping the state with adaptation is Maine's Department of Transportation (MaineDOT). MaineDOT has responded to climate change by assessing its own needs for adaptation in "Climate Change and Transportation in Maine." Within the report MaineDOT notes that it is conforming to adaptation policy by creating adaptation strategies, assessing current adaptive capacity, and pursuing adaptation activities [30].

5.3.1 *Adaptation Strategies*

MaineDOT has two lists of strategies: short and long term. Its short-term strategies are to monitor environmental changes and their effects on the infrastructure, determine the capability of the current infrastructure and determine where its weaknesses are, conduct cost-benefit analysis to identify at risk structures such as bridges, and consider adaptation in future decision making and planning. Its long-term strategies are to improve the design lives of transportation infrastructures by building bridges with larger capacities to withstand flooding and sea level rise, designing highways to reduce amount of water on travel surface during heavy rain events, and relocating roads further inland that may experience inundation by sea level rise [30].

5.3.2 *Current Adaptive Capacity*

MaineDOT has always taken steps to maintain the natural environmental and has implemented many environmental policies that will maintain its existing adaptive capacities. A list of MaineDOT adaptive capacities include: measuring and documenting annual peak flows and rainfalls; maintaining existing hydrologic connectivity and not disrupting flows; continual updating of GIS maps; maintaining and restoring natural buffers such as wetlands and coastal salt water marshes that may prevent inundation of land by sea level rise or storm surge; and assessing all bridges every 24 months for structural damage and completing underwater scour assessments every 60 months [30].

5.3.3 *Current Adaptation Activities*

In order to further build upon its existing adaptive capacity MaineDOT has started focusing on several areas that may be vulnerable to climate change. MaineDOT Bridge Maintenance Division is developing a bridge scour plan to identify and manage bridges that have been damaged or have become structurally deficient. The Maintenance and Operation Division just completed a pipe and culvert vulnerability assessment to identify those structures susceptible to more intense storm events. Also, MaineDOT has considered upgrading its design standards from 50 year storms to 100 year storms to build its resiliency to more intense storm events [30].

CHAPTER 6: SOUTHEAST STATES ADAPTATION EFFORTS

6.1 North Carolina Climate Change Adaptation Efforts

North Carolina has recently become an active proponent of applying climate change adaptation efforts in transportation. The state agrees that much of its infrastructure is vulnerable to rising sea levels, increased tropical storm intensity, more droughts, and severe heat waves and believes that these concerns must be addressed soon in order to retain resilient infrastructure. To begin the process of adaptation, the state created a climate change taskforce called the North Carolina Interagency Leadership Team (NCILT). As of now, the NCILT is developing a state wide climate action plan that will discuss the vulnerabilities of climate change to different sectors, including transportation, and formulate adaptation recommendations for addressing its needs. In the meantime, other agencies, such as the North Carolina Department of Transportation (NCDOT), have already begun considering adaptation efforts at the project level. One project to date is the US 64 widening project near the coast in Tyrell and Dare Counties. Two other projects that have also seriously considered adaptation are the Mid-Currituck Bridge and Bonner Bridge located on the Outer Banks. These projects were assessed for climate change adaptation due to their vicinity near the coast and their risk to sea level rise and storm surge [31].

6.1.1 Current Research for Adaptation

In order to understand the future impacts of sea level rise and storm surge, North Carolina has been working on developing advanced models using elevation data collected using Light Detection and Ranging or LIDAR. One type of model being used to assess the North Carolina coastline is an Advanced Circulation (ADCIRC) model. This model simulates water flow based on the shape of the coastline and higher sea levels in order to assess what areas of the coast could be threatened. In particular, the model can simulate different sea level rise scenarios or storm tracks and pin point locations where coastal communities, roadways, and bridges could be inundated. So far this model has been a very popular design model for FEMA to use in updating its floodplain mapping for the coastal areas of the state [31].

CHAPTER 7: OTHER STATES ADAPTATION EFFORTS

There are several other states pursuing climate change adaptation although not as extensive as the previous states. Many of these states have either released a climate adaptation report or are at the beginning stages of considering the impacts of climate change. Those states that have released some sort of adaptation report are Florida, Hawaii, and Connecticut. These reports are considered preliminary frameworks for addressing climate change and briefly identify some strategies for adaption in the transportation sector.

7.1 Florida Climate Change Adaptation Efforts

Florida has focused most of its attention on the impacts of sea level rise and is actively assessing vulnerabilities by working on sea level rise projection models and developing regional, land use response strategies. A couple of regions that have completed sea level assessments include the Florida Keys [32] and South Florida (including Miami-Dade County) [33]. There is also mention of climate change adaptation in Florida's 2060 Transportation Plan. One of the long range objectives mentioned in the report is to improve resilience of critical infrastructure to the impacts of climate change. Also, part of its implementation strategy is to develop refined data and decision-making tools to integrate climate change adaptation into designing, constructing, maintaining, and operating transportation infrastructure [34].

7.2 Hawaii Climate Change Adaptation Efforts

Hawaii has put together an adaptation framework as a tool for assisting the state in forming an adaptation team and developing a long-term vision for assessing climate change. The report identifies all the sectors that will be impacted and identifies what agencies must be included in the team. Once the team is created, its goal will be to conduct vulnerability and risk assessments so that it can prioritize areas for adaptation planning and ultimately implement a plan [35].

7.3 Connecticut Efforts

Connecticut has released an adaptation report that briefly looks at implications on the transportation infrastructure. The state's main concern is increased flooding and the report suggests incorporating green designs, much like low-impact development that can increase ground infiltration and slow precipitation runoff [36].

CHAPTER 8: OTHER COUNTRIES ADAPTATION EFFORTS

Many countries across the globe have been facing the impacts of climate change and have taken strides towards creating adaptation plans. Much like the United States, they see climate change impacting many parts of their country including the transportation infrastructure. Two countries in particular, which have been adapting their transportation infrastructure to the impacts of climate change, are Canada and United Kingdom. It is apparent, from the review of their efforts, that these countries sees climate change impacts as a serious threat to the economy and the safety of its inhabitants, and believes that adaptation should be consider as a major means of mitigating these impacts.

8.1 Canada Climate Change Adaptation Efforts

Canada has recognized that adaptation to climate change is an important issue and has responded by developing the Climate Change Impacts and Adaptation Division under the Natural Resources department. The division has assisted adaptation efforts by listing varieties of reports regarding latest assessments on climate change, case studies, guidelines and decision-making tools. Many local governments and universities across the country are also responding to adaptation needs by providing assistance and guidance to areas that are at major risks due to climate change.

The major concerns facing the transportation sector in Canada are sea level rise, storm surge, temperature, and permafrost. Many bridge designs have begun accommodating for sea level rise by raising the height above water. For example, the Confederation Bridge located between Prince Edward Island to New Brunswick incorporated into its design a meter rise in sea level that is estimated to occur within the 100 year life span. Research has been dedicated to new design of asphalt cements that will reduce thermal cracking caused by cold temperatures and rutting caused by high temperatures. Also, new modeling techniques for predicting changes in permafrost have been development and have assisted transportation agencies' decision making for planning new roads and pipeline routes. Other examples of adaptation include the Clyde River's community climate change adaptation plan which has helped the community deal with melting permafrost and ice roads, metro Vancouver's stormwater management program which has taken into account increased precipitation, and storm surge preparation plans in Annapolis Royal, Nova Scotia to deal with coastal flooding [37].

One of the reasons why Canada has been so successful at implementing adaptation is by the collaboration between university researchers, local residents, and policymakers putting together discussions and determining the most effective options for adaptation. In the following section is a presentation of a case study where adaptation was implemented due to this collaboration.

8.1.1 Le Goulet Climate Change Adaptation Efforts

Le Goulet, New Brunswick is a small finishing community, located in a low-lying area next to the Gulf of Saint Lawrence, which began feeling the impacts of climate change with more frequent floods from storm surge. Before all the flooding events, the town was protected by a 6.5 foot above-sea-level sand dune, but due to the erosion from the storm surges, the sand dunes were lowered to just 1.5 feet. This was putting the town's infrastructure more at risk to major floods and so the residents decided that adaptation must be implemented. The village hired engineering consultants and university lead researchers to develop a local plan to adapt to the increased storm surges and sea level rise. The researchers developed three methods for coastal adaptation: 1) relocate assets located in flooding prone areas, 2) accommodate assets with modifications such as higher foundations, or 3) protect assets by implementing new construction measures such as sea walls, dikes, beach nourishment, and wetland restoration. For the village's case, they determined two options: construct a $3.3 million sea wall that would extend over 2 miles long or relocate homes in the at-risk flooding zone. Before choosing an option, the researchers engaged in several risk analysis studies and discussions with the village that would determine where the flooding zones were located and assess the costs of various adaptation measures. After the results of the discussions, the local planning commission decided to enact a zoning bylaw that would prevent development in the designated flood prone areas unless the developer implements adaptation measures into the design and ensure its resiliency to climate change. The New Brunswick Department of Natural Resources also decided to provide its own assistance by leading a effort to create a high-resolution elevation map that can be used to further assess the coastline in order for the community to located more flood prone areas and make necessary adaptation decisions [38].

This case study shows that collaboration between local residents, researchers, and policymakers are important when striving to make adaptation considerations. For the small village Le Goulet, they were able to garner support from the local leaders and receive assistance from university led researchers to develop a comprehensive plan for adapting to the issues of flooding caused by increased storm surge events appearing from climate change.

8.2 United Kingdom Climate Change Adaptation Efforts

The United Kingdom is at the forefront of climate change adaptation because of the government's role in encouraging research and work towards the development of tools, guides, and strategies to use in adaptation. This role can be seen by the Climate Change Act 2008, which was enacted by the Parliament in November 2008 and includes a provision to report climate change impacts and create programs for adapting to climate change [39]. In the transportation sector, the Department of Transport, Highways Agency has been in charge of developing adaptation strategies for the country's transportation network. The agency has been progressing forward with adaptation by releasing its latest report, "Climate Change Risk Assessment," which lays out its climate change risk assessment report, adaptation framework, and goals for implementing adaptation into plans [40].

The Highways Agency follows a basic, systematic approach to adaptation for its transportation assets. The framework, shown in Figure 9, uses seven steps that identifies climate change impacts, assesses vulnerabilities and risks, and creates preferred options that can be used to approach adaptation for each asset. The role of each step is to contribute to the overall adaptation program. In this last step, all the adaptation plans and prioritization lists from each asset are fully assessed so that the entire plan can be distributed to different transportation sectors and provide assistance in their adaptation efforts.

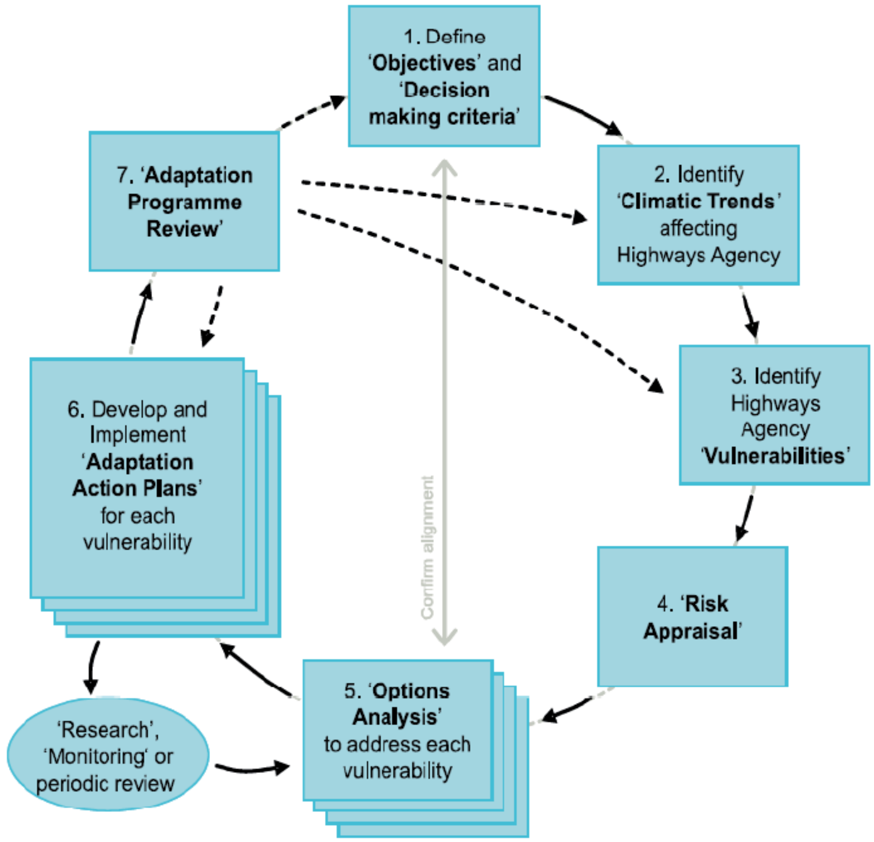

Figure 9. Adaptation process for Highways Agency [40].

8.2.1 Adaptation Framework: Risk Appraisal

One of the important aspects of this adaptation framework is the prioritization of vulnerabilities within the risk appraisal stage. There are four criteria used to prioritize vulnerabilities: uncertainty, extent of disruption, severity of disruption, and rate of climate change. The uncertainty analysis uses a matrix, similar to California's assessment of consequences shown in Table 2, which rates the uncertainty level by a high, medium, low. The measure of uncertainty is based on the effects of climate change on the asset and climate change predictions. Figure 10 shows how the ranking is given.

Uncertainty level – climate change predictions		Uncertainty level – effects of climate change on asset/activity		
		High	Medium	Low
	High	H	H	M
	Medium	M	H	L
	Low	M	L	L

Figure 10. Identifying uncertainty levels [40].

The extent of disruption uses a high, medium, and low ranking to gauge how much of the transportation asset will be affected by climate change. Different climate impacts can have a varying extent of damage on an asset. For example, sea level rise impacting a small section of a local road is small compared to it inundating a major highway. In order to assess the extent of disruption, criteria are given for each ranking: if more than 80% of the network is affected, then it is considered high, if 20-80% is affected, it is considered medium, and if less than 20% is affected, it is considered low.

Severity of disruption can be a very important aspect in prioritizing vulnerabilities because certain aspects, such as emergency responses, are essential and depended heavily on the transportation network. The severity of disruption, exactly like extent of disruption, uses a high, medium, and low ranking to measure how long it takes for the transportation asset to be restored. For determining its rank, the criteria follows: if the disruption time is greater than one week, then it is considered high, if the disruption time is between one day and one week it is considered medium, and if the disruption time is less than one day it is considered low.

One of the uncertainties surrounding climate change is when it will begin to take effect. For some climate change impacts, they have already begun to occur, such as rising temperatures. However, for other impacts, such as sea level rise, there are a lot of uncertainties when predicting when and how much will rise. That is why uncertainty can be prioritized by rate of change. This analysis uses high, medium, and low rankings to measure the level of uncertainty based on a short term or long term design life and the timeframe of the effects of climate change. Figure 11 shows how each level is ranked based on these criteria.

		Uncertainty level – effects of climate change on asset / activity	
		Short term < 30 years	Long term > 30 years
Time horizon for climate change effects to become material	Short term	H	H
	Mid to longer term	M	H
	Longer term	L	M

Figure 11. Risk level assessment for rate of change [40].

There is no one set way of weighing uncertainty, extent of disruption, severity of disruption, and rate of climate change for prioritization of vulnerabilities. It is possible to use equal or different weights, but it mainly depends on the type of transportation asset being assessed. Even if there is a low ranking risk given for a particular vulnerability, it does not mean it should have the lowest priority. The bases of the risk appraisal approach should be for suggesting where priorities should be set. Engineering judgment may be used to emphasize one risk as being more important than another or may find early action as the only suggestive mean for adapting to climate change.

8.2.2 *Continuing Efforts in Climate Change Adaptation*

So far, there have been few adaptation efforts in the United Kingdom, but there have been several case studies implemented to study how climate change has been impacting the region. Atkins, one of the United Kingdom's largest transportation firms, has been commissioned to several of these case studies. Some of the works they have completed include developing sustainable principles and options for Lincolnshire's coast communities to adapt to increasing flood risks, and assessing London's transport system with adaptation recommendations for improving the resilience of many of its transit stations to the possibility of flooding [41].

Another significant contributor to much of the United Kingdom's climate change adaptation efforts is the United Kingdom Climate Impacts Programme (UKCIP), an environmental group based at the Environmental Change Institute at the University of Oxford. Since its establishment in 1997, they have been providing policymakers and stakeholders with information on frameworks and tools to help them develop climate assessments and plans for adaptation [42]. This includes many government agencies, such as the Department of Transport, Highways Agency, who have contracted the UKCIP to provide assistance in developing their adaptation plans.

CHAPTER 9: APPLICATIONS OF ADAPTATION IN GEORGIA

States that do not have adaptation plans may benefit from the work states with adaptation plans have taken to offset the impacts of climate change. One particular state that does not have a climate action plan or adaptation plan is Georgia. If Georgia decides to progress towards adaptation in transportation, then it is recommended that it takes four comprehensive steps to achieve this goal: determine the impacts of climate change, create a vulnerability and risk assessment plan, determine applications for adaptation, and provide a framework for implementation. Before any of these steps can be taken, the state must put together a team of experts consisting of political state officials, agency officials, local government officials, businesses, university researchers, and environmental groups to collaborate on the adaptation planning process. For transportation adaptation purposes in Georgia, this team should, at a minimum, include representatives from Georgia Department of Transportation (GDOT) including each district, Georgia Environmental Protection Division including Coastal Resource Division, university-lead researchers, specific Georgia environmental groups, transportation design and engineering firms familiar with adaptation and green designs, and transportation engineers from major cities in Georgia.

9.1 Impacts of Climate Change in Georgia

Assessing the impacts of climate change in Georgia may be a difficult task. To this date, there has been no statewide study conducted to assess how climate change is impacting the state. However, a few university studies have been conducted, identifying observed climate change impacts. The greatest impacts that are believed to be experienced in Georgia are extreme heat, intense precipitation events, and sea level rise [43]. The severities of these impacts can already be seen by studying recent disasters, such as the 2007 Georgia drought crisis or the 2009 Atlanta flood. These climatic changes can have several effects on the transportation network in Georgia. Extreme heat can cause rail lines and pavement to buckle; intense precipitation events can cause major flooding to roadways and increase bridge scour; and sea level rise can inundate Georgia towns and structures located in close proximity to the coast. Once a complete assessment of impacts has been realized then Georgia can move on towards the vulnerability and risk assessment study which will identify what areas in particular need to be adapted.

9.2 Vulnerability and Risk Assessment

The vulnerability and risk assessment will be the most complicated and time consuming stage of adaptation. According to a guidebook developed by researchers in King County and the University of Washington entitled, "Preparing for Climate Change: A Guidebook for Local, Regional, and State Governments", a vulnerability assessment requires conducting a sensitivity analysis of the area and evaluating adaptive capacities of the systems [44]. The purpose of the sensitivity analysis is to locate areas that may be indirectly affected by changes in climate. For Georgia, there should be three types of sensitivity analysis: 1) An analysis of extreme temperature to determine areas with rail and roadway infrastructure that could receive abnormally long number of days of high temperatures, 2) an analysis of intense precipitation events in high populated areas that are susceptible to flooding, and 3) a coastal assessment to locate populated, low lying areas and structures that could be inundated by certain rises in sea levels or areas susceptible to beach erosion from storm surge. After the sensitivity analysis locates vulnerable areas, then an evaluation of adaptive capacity can determine if the existing infrastructure is fit to handle the impacts. This may require 1) evaluating the type of pavement material used to construct roadways and determining if it has resilience to withstand different climates; 2) analyzing drainage areas and storm events to determine actual flow rates for drainage systems; and 3) evaluating wetlands and costal storm buffers to determine if there are enough natural or man-made structures to withstand sea level rise or storm surge. After completing the vulnerability assessment, the risk assessment can be conducted. This step is necessary in order to prioritize which areas need to be adapted first. Table 2 in this report can be used to develop the risk assessment (risk = impact x adaptive capacity). Each area in the sensitivity analysis should be ranked by impact (high, medium, low) along with a rank for the adaptive capacity so that a list of priorities can be developed. Once the areas of impact are indentified, it will be possible to move on towards developing transportation adaptation strategies.

9.3 Applications for Adaptation

Since the main areas of concern for Georgia will be extreme temperatures, flooding, and sea level rise, several strategies will need to be developed to adapt to these impacts. There are many ways that Georgia cities can reduce flooding caused by increased precipitation events. The least costly would be low impact development or green designs, similar to what cities in Washington are doing. These techniques would be very applicable to many urban neighborhoods located in the city of Atlanta. Natural drainage systems or swales with planted vegetation can be very effective in maximizing stormwater time of concentration which reduces the possibility of floods during intense precipitation events. A more costly approach would be to update drainage design standards to require designs for larger storm events, for example, designing state highways for 100 year storm rather than 50 year storm as stated in GDOT Drainage Manual [45].

For adapting to extreme temperatures, GDOT can conduct more research in advanced pavement technologies or implement new mixes in concrete and asphalt pavement. The goal would be to create a mix that is durable enough to retain pavement structure during long periods of heat.

Although costly, there are options for reducing vulnerability of the Georgia coastline to sea level rise. Some temporary options include beach replenishing projects such as refurbishing existing dunes and beaches, or wetland restoration projects. If sea levels rise to the levels that have been predicted in the next 100 years, then the only possible solution may be to relocate transportation infrastructure. That is why it is important to manage land use and oversee population growth in areas susceptible to sea level rise. Once all possible transportation adaptation options are established, then it would be necessary to create a framework to implement the strategies.

9.4 Implementation Framework

Once all possible transportation adaptation options have been established, the next step would be to create a framework to implement the strategies into action. The best way to complete this action is to integrate adaptation into existing policies. This could be through modifying design standards, adding additional permitting and zoning rules, or applying tax incentives. Because there is a lot of risk involved in implementing adaptation, the best approach of action to avoid community disagreement is by developing a "no-regrets" plan. A "no-regrets" adaptation plan uses actions that will benefit the community in other ways while creating resiliency to climate change. An example of "no-regrets" could be a traffic calming project. By using low impact develop designs, you can force cars to reduce speeds, which improves safety, and also reduce impervious areas and increase aesthetics with greenery, which improves drainage. An action that GDOT can take to assist in adaptation is providing a guidance tool around planning and design for projects to use. By implementing a guide similar to Caltrans guide to sea-level rise, GDOT can provide steps for engineers to assess projects in need of adaptation such as conducting a vulnerability and risk assessment.

CHAPTER 10: CONCLUSIONS

10.1 Summary of State Adaptation Efforts

The overall purpose of this thesis is to develop a synthesis for researchers and policymakers to use in understanding all the adaptation efforts that are underway in the United States. Even countries who the United States share a majority of research with are implementing adaptation and should be seen as an example by the efforts being undertaken. It should also be noted that a majority of the work in this thesis came from analyzing a wide range of resources from states with adaptation efforts. Most of the information was obtained by the latest reports released by many of the states (which can be seen in the Appendix) or by information received by contacting several state agencies.

The conclusion that can be taken by this research is that there are many states participating in climate change adaptation activities at all levels. From the information received from those states, California, Washington, and Oregon appear to be the closest to fully implementing adaptation at the project level. This can be seen in several ways. Caltrans already has a transportation guide developed for adaptation which is expected to be integrated into planning for all transportation projects. Many local counties in the state of Washington, especially King County, highly recommend projects for green designs or LID which reduces impervious areas and maintains existing drainage flows so as to avoid flooding in the future when storms are more frequent and intense. The state has also considered applications to climate change designs in many of its bridges, much like the Tolt Bridge that was built with larger spans to withstand increased flooding. Along the east coast, states such as North Carolina, Delaware, and Maryland have invested in extensive studies on the threat of sea-level rise and are developing frameworks for adaptation. These states are using advanced modeling techniques and LIDAR to create inundation maps that can be used to assess vulnerabilities for land and critical transportation infrastructure. Maryland is also approaching its state legislation with enacted policies toward adaptation. This includes smart growth policies that will keep population growth out of vulnerable areas along the coast and policies to enhance coastal buffers to prevent sea-level rise from infiltrating the mainland. Alaska has increasingly seen the effects of climate change by the melting of permafrost which is causing damage to a large portion of its highways and airports. The state has been fairly successful at mitigating these issues with applications from research to highway design. Research in air cool embankments, heat drained embankments, and longitudinal culverts have been tested out in Alaska and the short-term results have shown that these techniques work in maintaining colder temperatures in the ground and preventing permafrost from melting.

Since global climate change has become a realistic threat throughout the country, many states have gone as far as researching and developing adaptation plans and applying them to transportation. However, this is only a small step in the overall goal of understanding all that needs to be done for full implementation. Although several states have introduced adaptation measures into projects, they will have to encourage it by applying “no-regret” actions or integrating adaptation into policies. If they can garner support for adaptation related projects, then strategies and applications can be fully realized and the risks of climate change can be reduced. But there are still many states that have not considered climate change adaptation in transportation. These states must not fall behind because the risks have proven to be real and the economic and social costs of not adapting could be substantial.

10.2 Understanding Adaptation in Georgia

Although Chapter 9 gives a list of steps to be taken for adaptation in transportation, it is only a short analysis of what Georgia can do. Georgia is far from implementing adaptation and will require much time and commitment in researching and understanding the effects of climate change. However, there are many guidelines, frameworks, and resources that are at Georgia's disposal. Federal agencies such as FWHA and AASHTO are constantly sponsoring pilot programs and releasing useful tools and many states are providing answers to the adaptation needs of this country. With all these analysis and tools in place, Georgia and other states without adaptation measures should have no problem adapting their transportation infrastructure to climate change.

10.3 Future Research

With the United States only at the beginning stages of adaptation, more research will have to be conducted in order to understand all possible options for states to use in adapting to climate change. Although this analysis found an exhaustive list of states pursing adaptation in transportation, there may be some states in discussions of pursuing adaptation. If this is the case, then in the next few years this list will have to be updated. There will also be a continual need to conduct research in other fields directly related to adaptation, such as "green" designs. This research indicates that the future in climate change adaptation may not necessarily be in relocating or modifying transportation assets, but accommodating current designs with greater environmental and safety concerns.

APPENDIX: LIST OF ADAPTATION REPORTS BY STATE

Washington: *Washington State Climate Change Response Strategy Interim Recommendations of the Built Environment: Infrastructure & Communities Topic Advisory Group*

California: *2009 California Climate Adaptation Strategy,*
Caltrans' *Guidance on Incorporating Sea Level Rise*
State of California Sea-Level Rise Interim Guidance Document

Hawaii: *A Framework for Climate Change Adaptation in Hawaii*

Alaska: *Alaska's Climate Change Strategy: Addressing Impacts in Alaska*

Florida: *Florida's Resilient Coasts: A State Policy Framework for Adaptation to Climate Change*

Maryland: *Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change - Phase 1: Sea-Level rise and coastal storms*
Comprehensive Strategy for Reducing Maryland's Vulnerability to Climate Change – Phase 2: Building societal, economic, and ecological resilience

Delaware: *Level Rise Initiative Project Compendium*

Pennsylvania: *Pennsylvania Climate Adaptation Planning Report: Risks and Practical Recommendations*

Connecticut: *Adapting to Connecticut's Changing Climate*

Massachusetts: *Massachusetts Climate Change Adaptation Report*

Vermont: *Climate Change Adaptation White Paper Topic Outline*

Maine: *Climate Change and Transportation in Maine*

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