

AMERICAN ASSOCIATION OF  
STATE HIGHWAY AND  
TRANSPORTATION OFFICIALS



*Adapting Infrastructure to Extreme Weather Events: Best Practices and  
Key Challenges*

*Background Paper*

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## **Introduction**

The vulnerability of the nation's transportation systems and, in particular, the road network to long-term changes in climate conditions and in the shorter term to changes in weather is a growing concern to many state transportation officials. Infrastructure built today is already experiencing wider climate variations and will likely face very different environmental conditions 30 to 50 years from now. Operational and maintenance strategies could also be affected by these changing conditions. For many reasons, it is important that the transportation community, and especially those responsible for planning and providing for the transportation system, understand risks posed by climate variability and change and how they compare to other risks. Planning, design, operations, maintenance, and emergency management processes may all require adjustments to adequately address current and anticipated changes in climate. With that said, transportation practitioners are well-versed in responding to changing weather conditions, including extreme weather events. The need for new approaches is based on several factors, including the lack of information on which to base future projections, the variety of potential impacts (coastal flooding, inland flooding, heat waves, droughts, extreme winds, storms, etc.); and the wide range of effects anticipated for any one variable (precipitation spanning the full spectrum from flood to drought, for example).

The purpose of this workshop, *Adapting Infrastructure to Extreme Weather Events: Best Practices and Key Challenge*, is to provide a forum for an exchange of information on how states are approaching climate adaptation (from the longer term perspective) and how states have responded to, or are prepared to respond to, extreme weather events. Key questions include:

- What are the most significant weather/climate-related risks your agency faces?
- How are you adjusting your approach/budgeting/activities to address these risks?
- Are these historical risks emblematic of the kinds of risks projected by climate data?
- What has your agency done with respect to considering potential climate change-related impacts in the planning, environmental analysis, project development, operations and maintenance activities?
- In particular, has your state and your agency explicitly linked transportation planning and environmental analysis to potential climate change impacts?
- Has your agency developed a comprehensive strategy for responding to extreme weather events of the nature experienced across the nation in 2011 (e.g., unusually long heat waves, more intense storms, more active tornado systems)? What further information would be useful to your efforts to put in place an effective strategy?

These questions form the core of the discussions that will occur at the workshop. In many ways, they also help form an agenda for further guidance and outreach to the transportation community on desired information relating to potential climate change-related impacts on the nation's transportation system.

The challenges are many:

- The uncertainty associated with expected climate changes and associated changes in weather leads some to question whether it is reasonable to change planning, design, construction, maintenance, and operations practices today, or how to anticipate what might be needed in the future.
- Even if such changes are expected with some certainty, the long-term nature of many of these changes suggests to many that the transportation community will still have time to respond at a future date, and thus why worry today?
- The perception of many is that climate change really means rising sea levels and that if one does not have vulnerable coasts, there is nothing to worry about. In reality, climate change can lead to a wide range of climatic and weather variation that could affect all aspects of transportation system provision and management in all regions of the country.
- Debates about the cause of climate change (e.g., due to human activity or to other cyclical natural causes) have distracted from the recognition that climatic changes are occurring, and that there will be effects on the transportation system. To many, in the short term, the manifestation of a changing climate are found in changes in extreme weather events---more frequent and more powerful hurricanes, tornadoes, drought, etc.<sup>1</sup>
- The bulk of Departments of Transportation efforts related to climate change have thus far been directed towards measuring and ultimately reducing emissions of greenhouse gases (GHGs). Although such a focus is appropriate given the contribution of the transportation sector to carbon emissions, the lifetimes of GHGs in the atmosphere are such that a certain amount of change is locked into the climate system; thus, there is still a need for a strategic perspective on how the transportation sector can be prepared for increased climate variability and change in future years.

These and other challenges will provide institutional challenges for “mainstreaming” strategies to reduce climate risks into state DOT activities. However, these boundaries will likely shift over time as we gain more experience with the exact nature of the climate and extreme weather challenges facing our communities. The purpose of the workshop is to learn what these new boundaries might entail.

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<sup>1</sup> [http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-All\\_FINAL.pdf](http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-All_FINAL.pdf)

## **Anticipated Effects**

It is not the intent of this background paper to provide an extensive review of the scientific studies and reports that have forecast future climatic conditions. Needless to say, there are volumes of studies that have examined likely climatic futures as estimated by global climate models.<sup>2</sup> It is useful, however, as a point of reference, to look at some of the major impacts that are likely to affect the transportation system. The following observations come from the transportation chapter of the 2009 U.S. National Climate Change Research Program, which has a mandate to develop the U.S. National Climate Assessment Plan (note: this plan is now being updated).

- Sea level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels.
- Flooding from increasingly intense downpours will increase the risk of disruptions and delays in air, rail, and road transportation, and damage from mudslides in some areas.
- The increase in extreme heat will limit some transportation operations and cause pavement and track damage. Decreased extreme cold will provide some benefits such as reduced snow and ice removal costs.
- Increased intensity of strong hurricanes would lead to more evacuations, infrastructure damage and failure, and transportation interruptions.
- Arctic warming will continue to reduce sea ice, lengthening the ocean transport season, but also resulting in greater coastal erosion due to waves.
- Permafrost thaw in Alaska will damage infrastructure. The ice road season will become shorter.

A more recent study by the National Cooperative Highway Research Program (NCHRP) concluded that changes in temperature, precipitation and sea level rise could have significant impacts on infrastructure design and system operations in the future.<sup>3</sup> Table 1 presents some of the impacts suggested by this study. These impacts should not be considered an exhaustive list, although note the types of impacts expected in the operations/maintenance category, many of which are linked to extreme weather events.

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<sup>2</sup> Two of the first and most important transportation studies in the United States was Special Report 290, Potential Impacts of Climate Change on the U.S. Transportation System, Transportation Research Board, Washington D.C., 2008, and U.S. DOT, Impacts of Climate Variability and Change on Transportation Systems and Infrastructure -- Gulf Coast Study, Phase 1, March 2008. Phase 2 of the Gulf Coast Study is underway.

<sup>3</sup> Parsons Brinckerhoff, Cambridge Systematics, and Stratus Inc., "Task 2.3 Synthesis Report Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies," NCHRP Project 20-83(5), Transportation Research Board, May, 2011.

Table 1: Summary of Climate Impacts on Highway System

|             | <i>Climatic/<br/>Weather<br/>Change</i>             | <i>Impact to Infrastructure</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <i>Impact to Operations/ Maintenance</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|-------------|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Temperature | Change in extreme maximum temperature               | <ul style="list-style-type: none"> <li>--Premature deterioration of infrastructure;</li> <li>--Damage to roads from buckling and rutting;</li> <li>--Bridges subject to extra stresses through thermal expansion and increased movement.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | <ul style="list-style-type: none"> <li>-- Safety concerns for highway workers limiting construction activities;</li> <li>-- Thermal expansion of bridge joints, adversely affecting bridge operations and increasing maintenance costs;</li> <li>-- Vehicle overheating and increased risk of tire bow-outs;</li> <li>-- Rising transportation costs (increase need for refrigeration);</li> <li>-- Materials and load restrictions can limit transportation operations;</li> <li>-- Closure of roads because of increased wildfires</li> </ul>                                                                                                                                                                                                                                                                                            |
|             | Change in range of maximum and minimum temperatures | <ul style="list-style-type: none"> <li>--Fewer days with snow and ice on roadways;</li> <li>--Reduced frost heave and road damage;</li> <li>--Structures will freeze later and thaw earlier with shorter freeze season lengths;</li> <li>--Increased freeze-thaw conditions creating frost heaves and potholes on road and bridge surfaces;</li> <li>--Permafrost thawing leads to increased slope instability, landslides and shoreline erosion damaging roads and bridges due to foundation settlement (bridges and large culverts are particularly sensitive to movement caused by thawing permafrost);</li> <li>--Hotter summers in Alaska lead to increased glacial melting and longer periods of high stream flows, causing both increased sediment in rivers and scouring of bridge supporting piers and abutments.</li> </ul> | <ul style="list-style-type: none"> <li>--Decrease in frozen precipitation would improve mobility and safety of travel through reduced winter hazards, reduce snow and ice removal costs, decrease need for winter road maintenance, result in less pollution from road salt, and decrease corrosion of infrastructure and vehicles;</li> <li>--Longer road construction season in colder locations;</li> <li>--Vehicle load restrictions in place on roads to minimize structural damage due to subsidence and the loss of bearing capacity during spring thaw period (restrictions likely to expand in areas with shorter winters but longer thaw seasons);</li> <li>--Roadways built on permafrost likely to be damaged due to lateral spreading and settlement of road embankments;</li> <li>--Shorter season for ice roads.</li> </ul> |

|               | <i>Climatic/<br/>Weather<br/>Change</i>                                                      | <i>Impact to Infrastructure</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <i>Impact to Operations/ Maintenance</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Precipitation | <b>Greater changes in precipitation levels</b>                                               | <ul style="list-style-type: none"> <li>--If more precipitation falls as rain rather than snow in winter and spring, there will be an increased risk of landslides, slope failures, and floods from the runoff, causing road washouts and closures as well as the need for road repair and reconstruction;</li> <li>--Increasing precipitation could lead to soil moisture levels becoming too high (structural integrity of roads, bridges, and tunnels could be compromised leading to accelerated deterioration);</li> <li>--Less rain available to dilute surface salt may cause steel reinforcing in concrete structures to corrode;</li> <li>--Road embankments at risk of subsidence/ Heave</li> </ul> | <ul style="list-style-type: none"> <li>--Regions with more precipitation could see increased weather-related accidents, delays, and traffic disruptions (loss of life and property, increased safety risks, increased risks of hazardous cargo accidents);</li> <li>--Closure of roadways and underground tunnels due to flooding and mudslides in areas deforested by wildfires;</li> <li>--Increased wildfires during droughts could threaten roads directly, or cause road closures due to fire threat or reduced visibility</li> </ul>                                                                                                                                                                                                                                                                                                                                     |
|               | <b>Increased intense precipitation, other changes in storm intensity (except hurricanes)</b> | <ul style="list-style-type: none"> <li>--Heavy winter rain with accompanying mudslides can damage roads (washouts and undercutting) which could lead to permanent road closures;</li> <li>--Heavy precipitation and increased runoff are likely to cause significant flood damage to tunnels, culverts, roads in or near flood zones, and coastal highways;</li> <li>--Bridges are more prone to extreme wind events and scouring from higher stream runoff;</li> <li>--Bridges, signs, overhead cables, tall structures at risk from increased wind speeds</li> </ul>                                                                                                                                       | <ul style="list-style-type: none"> <li>--The number of road closures due to flooding and washouts will rise;</li> <li>--Severe erosion at road construction project sites as heavy rain events take place more frequently; road construction activities will be disrupted;</li> <li>--Increase in weather-related highway accidents, delays, and traffic disruptions;</li> <li>--Increase in landslides, closures or major disruptions of roads, emergency evacuations and travel delays;</li> <li>--Increased wind speeds could result in loss of visibility from drifting snow, loss of vehicle stability/maneuverability, lane obstruction (debris), and treatment chemical dispersion;</li> <li>--Lightning/electrical disturbance could disrupt transportation electronic infrastructure and signaling, pose risk to personnel, and delay maintenance activity</li> </ul> |

|                | <i>Climatic/<br/>Weather<br/>Change</i> | <i>Impact to Infrastructure</i>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <i>Impact to Operations/ Maintenance</i>                                                                                                                                                                                                                                                                                                                   |
|----------------|-----------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sea level rise | Sea level rise                          | <ul style="list-style-type: none"> <li>--Higher sea levels and storm surges will erode coastal road base and undermine bridge supports;</li> <li>--Temporary and permanent flooding of roads and tunnels due to rising sea levels;</li> <li>--Encroachment of saltwater leading to accelerated degradation of tunnels (reduced life expectancy, increased maintenance costs and potential for structural failure during extreme events);</li> <li>--Loss of coastal wetlands and barrier islands will lead to further coastal erosion due to the loss of natural protection from wave action</li> </ul> | <ul style="list-style-type: none"> <li>--Coastal road flooding and damage resulting from sea-level rise and storm surge;</li> <li>--Underground tunnels and other low-lying infrastructure will experience more frequent and severe flooding;</li> <li>--Increase in number of road accidents, evacuation route delays, and stranded motorists.</li> </ul> |
| Hurricanes     | Increased hurricane intensity           | <ul style="list-style-type: none"> <li>--Stronger hurricanes with longer periods of intense precipitation, higher wind speeds, and higher storm surge and waves are projected to increase;</li> <li>--Increased infrastructure damage and failure (highway and bridge decks being displaced)</li> </ul>                                                                                                                                                                                                                                                                                                 | <ul style="list-style-type: none"> <li>-- More frequent flooding of coastal roads;</li> <li>-- More transportation interruptions (storm debris on roads can damage infrastructure and interrupt travel and shipments of goods);</li> <li>-- More coastal evacuations</li> </ul>                                                                            |

Source: Parsons Brinckerhoff, Cambridge Systematics, and Stratus Inc., "Task 2.3 Synthesis Report Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies," NCHRP Project 20-83(5), Transportation Research Board, May, 2011.

It is interesting to note how some states are considering the likely impacts of climate change on their transportation system and on agency operations.

*California:* According to the state’s adaptation plan, it is expected that less extreme cold days will reduce frost heave and road damage, but “extreme hot days (including prolonged periods of very hot days), are likely to become more frequent, increasing the risk of buckling of highways and railroad tracks and premature deterioration or failure of transportation infrastructure.”<sup>4</sup> The California Department of Transportation foresees increased damage to transportation infrastructure as a result of flooding of tunnels, coastal highways, runways, and railways and the related economic consequences of such disruptions. Also noted in the plan, “the combination of a generally drier climate in the future, which will increase the chance of drought and wildfires, and the occasional

<sup>4</sup> [http://resources.ca.gov/climate\\_adaptation/docs/Statewide\\_Adaptation\\_Strategy\\_-\\_Chapter\\_10\\_-\\_Transportation\\_and\\_Energy\\_Infrastructure.pdf](http://resources.ca.gov/climate_adaptation/docs/Statewide_Adaptation_Strategy_-_Chapter_10_-_Transportation_and_Energy_Infrastructure.pdf)

extreme downpour, is likely to cause more mud- and landslides which can disrupt major roadways and rail lines. The related debris impacts are historically well known to California, but if they become more frequent, will create greater costs for the state and require more frequent repair.” The plan notes that sea level rise will most likely of greatest concern over the long term affecting ports, coastal roads and airports, in particular. The three San Francisco airports—San Francisco, Oakland and San Jose—are each near sea level. Approximately 2,500 miles of roads and railroads are at risk from coastal flooding and it is expected that sea level rise might require “entirely new drainage systems in low-lying cities with drainage that is pump-driven rather than gravity-driven.”

*Iowa:* The Iowa Climate Change Adaptation and Resilience report identified several changes that are likely to occur in Iowa’s climate over the next 50 years.<sup>5</sup> By 2065:

- “Springtime precipitation is expected to increase, resulting in heavier downpours
- Stream and river flow may increase by 20 percent or more
- Annual temperatures are expected to increase by 2.5 to 7.2°F”

The types and severity of hazards in Iowa are expected to change as well, including:

- “Flood hazards: Changes in precipitation and stream flow have already and will continue to increase the risk of riverine flooding, flash flooding, and damage due to expansive soils, especially during spring and early summer
- Heat waves: Higher average temperatures will lead to more heat waves, resulting in more heat-related illnesses.”

*Massachusetts:* Much of the expected impact of climate change in the Massachusetts strategy relates to extreme weather events.<sup>6</sup> Such events are expected to include “high winds, hurricanes, storm surges, and waves that can damage energy infrastructure, ports, and buildings, and reduce the capability of local agencies to provide emergency response.” The plan also notes that “extreme weather events in the Gulf Coast events could affect natural gas supply in Massachusetts.” Other impacts included:

- “With more frequent large storm events, damage to key infrastructure could become more frequent, take longer to repair, and entail more costly repairs and economic disruption.

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<sup>5</sup> [http://www.epa.gov/dced/pdf/iowa\\_climate\\_adaptation\\_report.pdf](http://www.epa.gov/dced/pdf/iowa_climate_adaptation_report.pdf)

<sup>6</sup> <http://www.mass.gov/eea/docs/eea/energy/cca/eea-climate-adaptation-chapter5.pdf>

- High temperatures and dense air conditions could increase runway length requirements to accommodate typically diminished aircraft performance in such weather situations.
- Massachusetts may not have sufficient alternative transportation modes and routes available in particularly sensitive locations to provide backup and continuity of service in responding to climate change effects.”

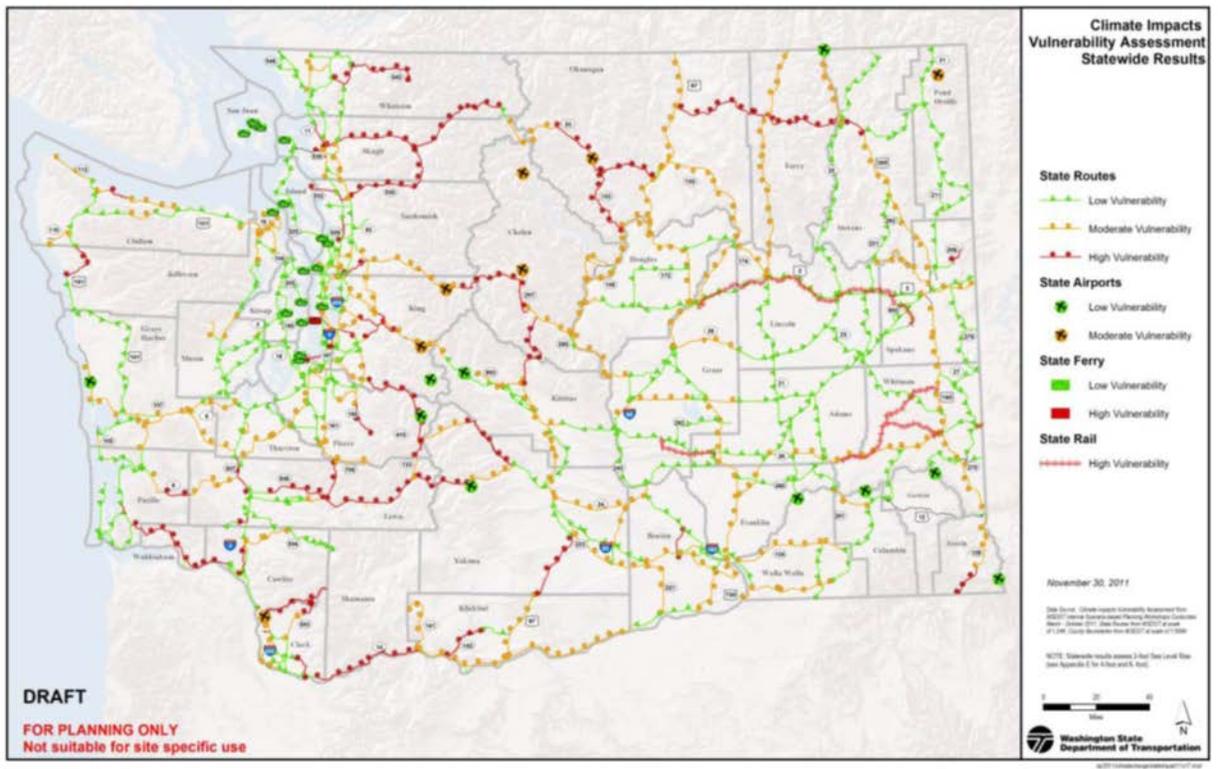
*Michigan:* Michigan DOT has examined a wide range of actions that might be necessary in the future with climate change and that in some cases could be implemented today.<sup>7</sup> The DOT has looked at its snow and ice removal strategies to be better prepared for major winter storm events. Interestingly, part of this effort was examining along with Minnesota and Wisconsin the respective winter activities to determine whether “business as usual” was the best approach in the future. Other activities include improving road weather information systems, enhancing pumping stations along depressed freeways, slope erosion protection, armoring slopes, and reducing mowing in freeway rights-of-way. Consideration was being given to removing piers in new bridge designs so as to reduce the incidence of bridge scour.

*Washington:* Washington State is one of the most advanced in thinking about the possible effects of climate change on transportation systems. The Washington State DOT realizes that climate change “may alter the function, sizing, and operations” of the state’s facilities.<sup>8</sup> To ensure that its system can function as intended over 50, 70, or 100 years, facilities “should be designed to perform under the variable conditions expected as a result of climate change. For example, drainage culverts may need to be resized to accommodate more intense rainfall events or increased flows due to more rapid glacial thawing.” Areas expected to see the greatest impact include locations “in the mountains, either above or below steep slopes, in low-lying areas subject to flooding, along rivers that are aggrading due to glaciers melting, and in low-lying coastal areas subject to inundation from sea level rise.” Interestingly, WSDOT has conducted a vulnerability assessment of its road network and shown where it expects to have the most problems (see Figure 1).

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<sup>7</sup>[http://www.fhwa.dot.gov/environment/climate\\_change/adaptation/workshops\\_and\\_peer\\_exchanges/illinois\\_12\\_2009/peer07.cfm](http://www.fhwa.dot.gov/environment/climate_change/adaptation/workshops_and_peer_exchanges/illinois_12_2009/peer07.cfm)

<sup>8</sup>[http://www.wsdot.wa.gov/NR/rdonlyres/73ADB679-BDA6-4947-93CA-87C157862DD7/0/WSDOT Project GHG Guidance March 2012.pdf](http://www.wsdot.wa.gov/NR/rdonlyres/73ADB679-BDA6-4947-93CA-87C157862DD7/0/WSDOT%20Project%20GHG%20Guidance%20March%202012.pdf)



**Figure 1: WSDOT Vulnerability Assessment**

The above possible implications to the transportation system of changes in climate and weather conditions are at this point conjecture primarily because of the range in uncertainty associated with possible future scenarios. However, with regard to extreme weather events, recent history suggests that transportation agencies are beginning to face more frequent and more intense events that are significantly affecting their operations.

**Extreme Weather Events: The Future Is Now?**

Extreme weather events are symptomatic of the type of weather many climate scientists believe we will see more of in the future, and which will significantly impact state DOT operations. The year 2011 set a record for extreme weather events, with 14 events reaching over \$1 billion each in property damage (\$53 billion total).<sup>9</sup> The National

<sup>9</sup>[http://www.nrdc.org/health/extremeweather/default.asp?utm\\_source=google&utm\\_medium=adwords&utm\\_campaign=ExtremeWeatherMap&gclid=CMrfrpjJz68CFQUHnQodEiBpFw](http://www.nrdc.org/health/extremeweather/default.asp?utm_source=google&utm_medium=adwords&utm_campaign=ExtremeWeatherMap&gclid=CMrfrpjJz68CFQUHnQodEiBpFw)

Resources Defense Council's (NRDC) website on extreme weather noted the following experiences in a sample of states:

Kansas:

- Record-breaking heat in 29 counties and a total of 73 broken heat records
- Record-breaking rainfall in 35 counties and a total of 73 broken rainfall records
- Record-breaking snow in 30 counties and a total of 38 broken snowfall records
- Extreme drought
- Multi-million dollar losses from extreme flooding

Minnesota:

- Record-breaking heat in 13 counties and a total of 16 broken heat records
- Record-breaking rainfall in 21 counties and a total of 34 broken rainfall records
- Record-breaking snow in 16 counties and a total of 21 broken snowfall records
- Extreme flooding

Montana:

- Record-breaking heat in 20 counties and a total of 26 broken heat records
- Record-breaking rainfall in 18 counties and a total of 29 broken rainfall records
- Record-breaking snow in 11 counties and a total of 14 broken snowfall records

Pennsylvania:

- Record-breaking heat in 19 counties and a total of 45 broken heat records
- Record-breaking rainfall in 28 counties and a total of 57 broken rainfall records
- Record-breaking snow in 29 counties and a total of 49 broken snowfall records
- Flooding and damage from the wettest September on record

Perhaps the most devastating events were large hurricane landfalls that impacted several states, including North Carolina, Virginia, Maryland, New Jersey, New York, Connecticut, Rhode Island, Massachusetts and Vermont. Over 7 million homes and businesses lost power; there was over \$7.0 billion in damages/costs and 45 deaths.

Vermont was one of the most devastated states from Tropical Storm Irene, the aftermath of Hurricane Irene that hit the Carolinas earlier (and ironically not one of the states indicated on a FHWA map of states likely to be affected by coastal storms--- Vermont has no coast). According to the Vermont Agency of Natural Resources, "rainfall totals of 3-5" were recorded throughout the state, with many areas receiving

more than 7", especially on higher, eastern slopes."<sup>10</sup> Hundreds of roads were closed, utilities were washed out, many towns were isolated because of washed out roads, a half-mile stretch of the major east-west state highway washed away, 35 bridges were destroyed, 960 culverts were damaged and 200 miles of state-owned railroads were closed with 6 railroad bridges impassable.<sup>11</sup> Interestingly, the Vermont Agency of Transportation, the state's DOT, had in 2007 identified what turned out to be prophetic predictions of what might occur in Vermont with changes in climate and weather. The list (updated after Tropical Storm Irene) included:

- "Flooding and erosion of low lying roads, railroads and other infrastructure
- With changes in the intensity and frequency of storm events, the need for culverts, bridges, erosion controls and storm water systems to be designed and maintained to adequately handle the associated increased flow, sediment and debris transport
- With increased stream flow, comes increased bridge scour
- Increased moisture and corrosion damage on pavements and structures
- Failure of pavement and bridge expansion joints
- The effects on roadbed and pavement longevity from an increase in freeze thaw cycles
- Increased pavement rutting and vehicle hydroplaning potential
- Increases in extreme wind events and associated downed trees, power lines and debris blocking roadways, waterways and ROW. Also higher wind loading on bridges
- Increased emergency preparedness and evacuation demands
- Changing winter maintenance demands due to more or less snow or an increase in freeze events
- Compromised availability and the need to stockpile diesel fuel, salt, and sand
- Effects of new exotic species and longer growing season on ROW vegetative management and stream bank longevity"<sup>12</sup>

VTrans maintenance activities were also discussed, noting such activities as "removing dead and diseased trees in the ROW to avoid wind storm debris blocking roads and

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<sup>10</sup> <http://www.anr.state.vt.us/anr/climatechange/irenebythenumbers.html>

<sup>11</sup> <http://www.burlingtonfreepress.com/article/20110830/NEWS07/108300301/From-Waterbury-Wilmington-Vermonters-shocked-by-Irene-s-destruction> and <http://vtstrong.vermont.gov/Home/RoadRecovery.aspx>

<sup>12</sup> [http://www.anr.state.vt.us/anr/climatechange/Pubs/VTCCAdaptTrans\\_DRAFT.pdf](http://www.anr.state.vt.us/anr/climatechange/Pubs/VTCCAdaptTrans_DRAFT.pdf)

waterways or maintaining ditches, catch basins and other storm water infrastructure to avoid flood damage make sense.”

The Vermont Agency of Transportation’s response to this disaster has been widely acknowledged as being very effective and targeted on the needs of the state. It established two new regional incident command centers to expedite emergency repair work. The agency response was delegated to the command centers so as to expedite road repairs throughout the state (all of the state highway roads closed due to the storm were back in operation within four months). VTTrans received crucial support in the recovery work from the New Hampshire and Maine DOTs, as well as the Vermont National Guard. All communities isolated by washed out roads were reached within three days after the storm; the major east-west roads were put back into operation within weeks; all major rail lines were reopened within five weeks; and a crisis map for mobile phone applications was available within days to inform the public of road conditions.<sup>13</sup>

### **Some Adaptation Examples**

Risk assessments, in the United States and abroad, have identified different types of actions that can be taken to consider how changing climatic and extreme weather conditions can be incorporated into agency decision making.<sup>14</sup>

*Consider in planning.* Florida’s Climate Action Plan, for instance, recommends that the Florida DOT update the Florida Transportation Plan to develop long range goals, objectives, and strategies for adapting to potential impacts from climate change. Likewise, California proposes to incorporate climate change vulnerability assessment planning tools, policies, and strategies into existing transportation and investment decisions (e.g. regional planning, programming, project planning). Similarly, Oregon’s Framework for Addressing Rapid Climate Change recommended that state agencies integrate climate change preparation into existing sustainability plans, agency risk management plans, or other long-range plans. Maryland also recommends integration of adaptation strategies into local comprehensive plans and implementing codes and ordinances; as well as integration of adaptation strategies into state plans and underlying management and regulatory programs. King County, WA is among the most advanced in this respect. There, climate change is incorporated into planning documents such as the Transportation Needs Report and Six Year CIP.

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<sup>13</sup> [http://vtstrong.vermont.gov/Portals/0/Documents/Irene\\_Recovery\\_Report\\_Jan\\_2012.pdf](http://vtstrong.vermont.gov/Portals/0/Documents/Irene_Recovery_Report_Jan_2012.pdf)

<sup>14</sup> Parsons Brinckerhoff, Cambridge Systematics, and Stratus Inc., “Task 2.3 Synthesis Report Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies,” NCHRP Project 20-83(5), Transportation Research Board, May, 2011.

*Consider in environmental analysis efforts.* Several states and the federal government have taken steps to incorporate adaptation considerations into environmental analysis, specifically efforts relating to the National Environmental Policy Act (NEPA) documentation. In 2011, for example, U.S. DOT agencies were given policy direction by the Secretary to consider climate change impacts in their activities.<sup>15</sup> California is operating under a governor's executive order that directs state agencies that are planning to construct projects in areas vulnerable to sea level rise to consider a range of sea level rise scenarios for the years 2050 and 2100.<sup>16</sup> State agencies are "urged to consider timeframe, risk-tolerance and adaptive capacity when determining whether to adapt the project for potential sea level rise impacts."

*More flexible design standards.* A number of plans list changes to design standards as a needed strategy to adapt to climate change – but at this stage few provide specifics. California, for instance, recommends developing transportation design and engineering standards to minimize climate change risks to vulnerable transportation infrastructure. Both Houston-Galveston Area Council and the City of Punta Gorda (FL) recommend using paver blocks (which act as a form of permeable pavement) for parking lots to address storm water runoff and the urban heat island effect (which will be exacerbated by global warming). Among those that do get to a greater level of detail, the Maine DOT recommends upgrading design standards from Q50 to Q100 to build in resiliency in the face of extreme weather events. Again, King County is in the forefront here, and is already incorporating climate change considerations into the project designs of bridges and culverts being rebuilt. Canada's Confederation Bridge, a 13 km bridge between Borden, Prince Edward Island and Cape Tormentine, New Brunswick, is an example of a completed project that took climate change into account during the planning and design phase. The bridge, which replaced an existing ferry connection, consists of a high-level two-lane road structure built on piers over the entire crossing of the Northumberland Strait. It provides a navigation channel for ocean-going vessels with vertical clearance of about 50 meters. During the planning and design process, which was begun in 1985, sea-level rise was recognized as a concern. So that vertical clearance could be maintained into the future, the bridge was built one meter higher than was currently required to accommodate sea-level rise over its hundred-year lifespan.

*Retrofit infrastructure.* The Maryland plan identifies several engineering strategies for retrofitting coastal infrastructure to protect against sea level rise, such as structural

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<sup>15</sup> [www.dot.gov/docs/climatepolicystatement.pdf](http://www.dot.gov/docs/climatepolicystatement.pdf)

<sup>16</sup> [http://www.dot.ca.gov/hq/tpp/offices/orip/Updated\\_Climate\\_Change/Documents/Sea\\_Level\\_Guidance\\_May2011.pdf](http://www.dot.ca.gov/hq/tpp/offices/orip/Updated_Climate_Change/Documents/Sea_Level_Guidance_May2011.pdf)

bulkheads, seawalls, or revetments. However, it also notes that larger decisions on whether to protect, relocate, or abandon infrastructure need to be made as well. In another example, to address flooding, Washington State DOT's strategies focus on restoring natural processes. This includes shoreline armoring, restoring shorelines, and targeted removal of dikes. In response to increased flooding, the Port Authority of New York and New Jersey raised the floodgates at the top of stairways leading to station platforms at the PATH Hoboken Station to account for sea level rise and sealed all gates that were below the one hundred year floodplain. The Washington State DOT has taken an interesting project approach to adaptation by advancing the construction of pontoons to restore the SR 520 bridge over Lake Washington in the event of a catastrophic failure. This project anticipates the failure of this bridge in the event of an extreme storm event and therefore is proactively addressing the issue by constructing and storing the pontoons which are the foundation of the floating bridge and can take several years to construct.

*Maintenance.* The Maine DOT is conducting a pipe and culvert vulnerability assessment, and the Maine DOT Bridge Maintenance Division has completed a scour report. Based on this information, the DOT is preparing bridge-specific scour plans. The Rogue River Basin, Oregon plan recommends expanding road upgrading and maintenance such as the installation of larger culverts and regular culvert clean outs to prevent wash outs during major storms and floods.

*Operations.* Operations-related impacts are associated with both the recovery of the transportation network following an extreme weather event as well as dealing with evacuation planning. California, for instance, recommends incorporating climate change impact considerations into disaster preparedness planning for all transportation modes. The City of Punta Gorda provides a similar recommendation. In a different approach to the issue, the Rogue River Basin, Oregon, plan suggests linking public transportation systems as much as possible to facilitate movement of people and equipment in emergency situations.

*Public Outreach/Communications.* A major challenge with respect to shorter term extreme weather events and longer term climate changes is conveying to the public the actions that can be taken to respond to particular events. This might entail improving road weather information systems (such as being done in Michigan) to providing information on the types of impacts climate change could have to the transportation system (such as being done in California, Maryland and Washington).

*Emergency Response.* Responding to extreme weather events in an effective manner requires not only advanced coordination of the many agencies involved, but also rapid clearing of transportation lifelines, such as roads that lead into devastated areas. As

was seen in Vermont, the response to isolated communities and individual travelers required the coordinated effort of many different groups, with the state DOT playing a key coordinating and information clearinghouse role.

As indicated above, adaptation strategies can be considered in many different parts of an agency's decision making and functional activities. The adaptation strategies under study by King County, WA's Road Services Division provide an illustrative example of the range of adaptation strategies an individual transportation agency might consider:

- Replacing or rehabilitating bridges in order to improve floodwaters conveyance and to avoid scour during high flows;
- Using pervious pavement and other low impact development methodologies to manage storm water through reduced runoff and on-site flow control;
- Modifying existing seawalls to avoid failures in transportation facilities;
- Evaluating roadways to minimize their vulnerability to potential risk from landslides, erosion, or other failures triggers;
- Developing new strategies to effectively respond to increasingly intense storms, including providing alternative transportation access;
- Managing construction and operations to minimize effects of seasonal weather extremes; and
- Identifying opportunities to incorporate habitat improvements that buffer the effects of climate change on ecosystem health into project designs.

## **Conclusions**

An MPO peer review of climate change-related activities concluded that, although mitigation efforts at reducing greenhouse gas emissions were important, perhaps more critical will be MPO efforts to examine adaptation strategies.<sup>17</sup> From a longer term perspective for state DOTs, this means considering climate change adaptation strategies in transportation plans and subsequent efforts, ending with periodic monitoring through asset management programs. This might result in different approaches to facility location, design factors, and operating/maintenance strategies. From a shorter term perspective, many transportation agencies are already beginning to experience significant climate-related impacts in the form of more frequent and more intense extreme weather events. Although many state DOTs have experience in

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<sup>17</sup> [http://www.ampo.org/assets/library/171\\_workshopclimatechgseattle.pdf](http://www.ampo.org/assets/library/171_workshopclimatechgseattle.pdf)

disaster response and recovery, the sheer magnitude and potential destructive nature of these events (e.g., Vermont) suggest that state DOT officials can learn a great deal from the experiences of others. Near term actions may also include opportunistic approaches to reinforce or revisit options to fortify assets to potential impacts of climate change during routine maintenance activities.

### **Useful Resources**

AASHTO Center for Environmental Excellence, Transportation and Climate Change Resource Center, <http://climatechange.transportation.org/>

Center for Energy and Climate Solutions, <http://www.c2es.org/>

FHWA, Climate Change website, [http://www.fhwa.dot.gov/environment/climate\\_change/index.cfm](http://www.fhwa.dot.gov/environment/climate_change/index.cfm)

FHWA Climate Change Adaptation Workshop and Peer Exchange Report  
[http://www.fhwa.dot.gov/environment/climate\\_change/adaptation/workshops\\_and\\_peer\\_exchanges/illinois\\_12\\_2009/peer07.cfm](http://www.fhwa.dot.gov/environment/climate_change/adaptation/workshops_and_peer_exchanges/illinois_12_2009/peer07.cfm)

Intergovernmental Panel on Climate Change Reports, [http://www.ipcc.ch/publications\\_and\\_data/publications\\_and\\_data\\_reports.shtml#SREX](http://www.ipcc.ch/publications_and_data/publications_and_data_reports.shtml#SREX)

U.S. DOT Climate Change Clearinghouse, <http://climate.dot.gov/>

World Resources Institute, Climate, Energy and Transportation, <http://www.wri.org/climate>