PHOTO: MICHIGAN DOT

# Climate Change Adaptation in Michigan

## *Preparations, Strategies, and Examples*

GREGORY C. JOHNSON, NILES ANNELIN, AND KRISTIN SCHUSTER

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(*Above*:) Michigan DOT is developing stronger contingency plans for responding to severe winter storms. Some studies indicate that warmer lakes and less ice cover may cause more lake-effect snows.

Climate has become increasingly variable throughout the world. Michigan and other states in the interior of the continent face different climate-related changes from those of the coastal states. In ocean coastal states, sea-level rise and hurricanes are concerns. In the Midwest, questions about climate involve the increased variability of precipitation and temperature extremes. These changes are likely to have negative and unexpected impacts on industry and infrastructure across the region.

### Climate and Economy

Michigan is located in the heart of the Great Lakes, which influence the state's climate. No location in Michigan is more than 85 miles from one of the lakes, and with 3,000 miles of shoreline—second only to Alaska—water is important to the state's economy. Economic activity related to the Great Lakes accounts for 823,000 jobs, or approximately one-quarter of Michigan's payroll. The lakes contribute to the state's tourism, transportation, manufacturing, and agricultural industries.

PHOTO: MICHIGAN DOT

Freighters passing through the Soo Locks between Lake Superior and Lake Huron in Michigan. The Great Lakes are vital to the state's economy—and a major influence on its climate.

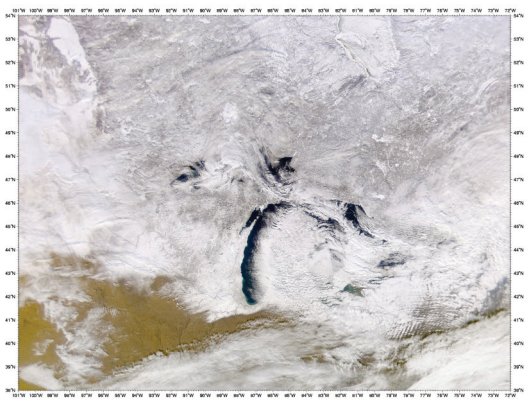

Photo: National Aeronautics and Space Administration

Satellite photo of lake effect over Lake Michigan: clear dry air moving eastward from Wisconsin picks up moisture in crossing the lake, forming dense clouds as it reaches the eastern shore. Downwind areas often experience heavy snowfalls.

### *Lake Conditions*

The health of the lake ecology and the impacts of climate variability therefore are a concern to Michigan residents and businesses. As global temperature rises, the water level in the lakes could decrease, and the average water temperature could increase. Lower lake levels would have a negative effect on the state's waterborne freight industry, which handles approximately 95 million tons of bulk cargo annually. The Detroit–Wayne County Port Authority generates more than 10,000 direct and indirect jobs and $550 million in personal income for state residents.

This industry is linked to freight operations throughout the country; maintaining operation with shallower shipping lanes would require reductions in the weight of cargo loads, making shipping in the Great Lakes less effective and less efficient. The U.S. Army Corps of Engineers spends more than $80 million annually to dredge the harbors and waterways of the Great Lakes to maintain functional depths for ports and channels.

Changing lake conditions also could influence local weather patterns. The surface area of the lakes, as well as the considerable volume of water, moderates Michigan's weather. In the winter, the overnight low temperatures are often warmer than temperatures in Wisconsin, for example, because of the insulating effect of the water.

Photo: Michigan DOT

An intense heat spell caused pavement to buckle on a section of I-69 in southern Michigan. Higher summer temperatures and other effects of climate change pose new challenges for transportation infrastructure.

The lakes also generate heavy lake-effect snows in downwind areas. Some studies indicate that warmer lakes and less ice cover in the winter will increase evaporation and precipitation, potentially causing more snow in areas prone to lake-effect snow. In addition, warmer winter weather can cause more rapid deterioration of roadways through more frequent freezes and thaws of the soil.

### *Effects on Infrastructure*

The Great Lakes are important to Michigan tourism and to the transportation network that supports the tourism industry. Changes that affect the lakes as a tourist attraction also would affect travel on Michigan roadways.

More frequent and intense rainfall events are expected, posing a significant threat to the transportation network. Road washouts raise safety concerns, and restoration is expensive for the responsible transportation agency and for the local economy. Closure of a typical freeway section during peak traffic periods can lose up to $200,000 in economic activity per hour. In addition, the potential for changes in the water table would require an analysis of the structural integrity of much of the state's infrastructure.

Michigan is predicted to experience higher summer temperatures lasting for longer periods. Prolonged high temperatures can increase the rate of deterioration of road and rail infrastructure and can cause rutting, buckling, and other pavement damage. On June 8, 2011, after several days of warm weather, the pavement buckled on a southbound section of I-69 in Calhoun County. Worker safety is another key concern during high temperatures, and a strategy to protect workers needs to be developed.

## Case-by-Case Approach

Michigan DOT is managing its system to increase motorist safety, protect the infrastructure, address changing conditions, and communicate with system users about weather events. The department is tackling these issues case by case, taking into account site conditions, costs, and changes over time.

Michigan DOT is preparing for altered climate conditions throughout the state. For example, to minimize infrastructure damage from intense precipitation events, changes are needed in the design of drainage systems and bridges. Bridges over waterways may require larger hydraulic openings. Designing structures to avoid scour-critical features and installing pump stations with greater capacity for below-grade freeways and culvert systems are on the agenda for increased attention—including monitoring and maintenance—as are modifications to culvert sizes, locations, and numbers.

## Fighting Slope Erosion

With funding from the American Recovery and Reinvestment Act (ARRA), Michigan DOT recently undertook a project to address ongoing slope erosion in sections of below-grade freeway on I-696, which crosses Oakland and Macomb Counties in suburban Detroit. Steep slopes and high volumes of traffic make this section of the road difficult to maintain. In addition to the slope instability problems, intense rain events have damaged the freeway, and heat and drought have caused loss of vegetation.

The department explored options beyond the selection of turf species to address the poor growing climate and the high maintenance costs from the difficult access for mowing. The department required a vegetation mix that would provide a variable-depth root structure to stabilize the slopes, would reduce runoff volume and velocity, and would trap and filter sediment and pollutants.

To accomplish these goals and still provide an attractive roadside, Michigan DOT selected 55,000 trees, plants, shrubs, and vines capable of withstanding heat, drought, and adverse roadside conditions. The ARRA-funded project has stabilized more than 9 miles of steep slopes and has improved water quality by incorporating green technologies and infrastructure. The department will monitor the pilot project to gain information for managing other steep slopes.

## Construction Challenges

Michigan DOT also is considering how climate changes may affect construction practices. The strategy will address the need to protect motorists, workers, and the environment from hazards created in work zones by extreme weather events. For example, stronger specifications can require contractors to develop response plans to protect work under way from flooding.

### *Concrete Materials*

The department also is concerned about the integrity of construction materials during days of prolonged high temperatures and will encourage conducting different phases of construction at night or during cooler periods. For example, Michigan DOT already uses night pours for bridge decks on steel beams because the daytime temperature of the steel beams is warmer than that of the adjacent concrete. Pouring at night, when the steel has cooled to the temperature of the concrete, allows for a better bridge deck.

Altering workday hours for paving operations also may be necessary, to stagger the peak hydration temperature of newly finished concrete in relation to the peak ambient temperature. This would help minimize the risk of early and excessive tensile stress cracking in the pavement.

PHOTO: MICHIGAN DOT

Michigan DOT conducts some construction activities—such as bridge concrete pours—at night, when temperatures are cooler.

The temperatures during various phases of pavement construction can affect the outcome of a project significantly. For example, high temperatures can cause slab curling during construction and in service, and the loss of moisture in the earliest stages can cause warping in concrete pavements. If fluctuations in daily temperatures increase, the response reaction in the pavement from the edge stresses of curling could accelerate decay, increase fatigue, and raise the likelihood of load-related cracking.

Other pavement issues related to higher temperatures include plastic shrinkage cracking and the instability of fresh concrete mixtures. These may jeopardize the effectiveness of the entrained air void system, making the pavement susceptible to early deterioration from freezing and thawing.

The department also may have to monitor the moisture content of the aggregates more closely during concrete production, as well as the temperature of the fresh concrete during placement, to ensure the levels are not detrimental to the quality of the finished product. Although more costly, innovative materials that have the potential to render concrete less sensitive to extreme fluctuations in temperatures should be investigated.

### *Asphalt Mixtures*

Hot-mix asphalt pavement can be susceptible to rutting if temperatures after construction are high. During construction, high temperatures may cause delays in opening to traffic while the new pavement cools to a temperature ideal for achieving density. Agencies may try warm-mix asphalt to avoid the negative outcomes associated with asphalt paving during excessively warm periods. Warm-mix asphalt also reduces the energy input for construction—as well as the greenhouse gas emissions.

Photo: Michigan DOT

Roadside weather information systems increase the accuracy of traveler information systems and allow more efficient management during weather events.

## System Operation

System operation is a critical activity of transportation departments; closing roads because of infrastructure damage, snow, or flooding hurts local, state, and national economies. In the winter of 2011, 40 miles of Canada's 402 Highway—a critical link between Toronto, Southwest Ontario, and Michigan—was closed for parts of three days because of a blizzard. The inability to reroute traffic cost days of delay and hurt industries that depend on just-in-time delivery.

The closure of Michigan roadways for one day would cost the state's economy approximately $250 million. Michigan DOT's strategy is to continue to improve real-time traveler information systems to inform motorists about risks and closures and to minimize economic loss.

To improve the effectiveness of traveler information systems, Michigan DOT is investing in roadside weather information systems (RWIS). Remote sensors and weather equipment have been installed in key locations throughout the Upper Peninsula and the Northern Lower Peninsula.

The RWIS sensors collect real-time information that enables the department to react appropriately and rapidly to changing road and weather conditions. The system ensures that the department can dispatch the correct maintenance vehicles to plow or to treat the roadways as needed, reducing waste and boosting efficiency.

With this information, Michigan DOT also can develop stronger contingency plans for responding to severe winter storms. During heavy snowfalls, for example, more frequent snow removal is needed along roadside barriers, which can create a hazard as snow accumulates. A major issue, however, is the inability to fund a maintenance budget that supports response to multiple snowstorms in accordance with public expectations.

Even routine maintenance activities, such as ditch and drainage structure cleanout, are difficult with stretched budgets. Nonetheless, completing these activities can reduce the likelihood of failure during an intense rainfall. Removal of vegetation, debris, and sediment that can build up and hinder function allows the department to maintain the effective, efficient conveyance of water through the right-of-way.

Photo: Michigan DOT

The necessary relocation of US-41 away from the lake's edge cost $3 million and placed several planned construction projects on hold.

## US-41 Relocation

Erosion produced by long-term fluctuations in lake levels threatens some coastal routes in Michigan. A section of US-41 along Lake Superior was located on an 80-ft sandstone cliff approximately 7 miles north of Baraga in Michigan's Upper Peninsula. Cliff recession had advanced to undercut the guardrail system and was threatening the stability of the highway. Contributing phenomena included the following:

- Rock weathering,
- Surface water from highway runoff eroding the top of the cliff,
- Groundwater flowing through the permeable sandstone above less permeable layers within the cliff rock, and
- Removal of weathered cliff materials, known as talus material, at the base of the cliff by longshore currents and wave action.

Unable to address the various contributors to the cliff recession, Michigan DOT relocated the two-lane roadway in 2010, moving it more than 100 feet inland for 2 miles at a cost of approximately $3 million dollars. Because of the urgency of the project, the region had to adjust its planned construction program.

Michigan Route 25 on the east side of the Lower Peninsula, along Lake Huron, is facing similar threats from erosion caused by long-term lake level fluctuations and the consequent instability. A 40-mile stretch of Route 25, located along a 30- to 40-ft cliff, is being undercut. In the 1990s, Michigan DOT closed a park along the road because of the instability of the shoreline. Many measures have been taken at another roadside park to slow the rate of localized erosion.

The department is monitoring the conditions and is commissioning a study to explore how the rate of erosion affects the road and to identify measures that can slow the erosion and allow the roadway to remain in place. The long-term solution is unclear, and the funds necessary to address the stability of the roadway have yet to be determined.

## Risk Assessment

Michigan DOT is continuing to explore the risks from extreme weather events for infrastructure and operations. This will require an analysis of a regional climate model and detailed information about the location and condition of state transportation assets. These asset management data are available for Michigan's major infrastructure but are incomplete for many of the roadside features that potentially are at risk. Elements such as culverts and stormwater management infrastructure, for example, will need to be inventoried to determine the points of greatest risk to the transportation system.

Michigan DOT is participating in a National Cooperative Highway Research Program project to examine risk assessments related to climate change.[1] The project is using Michigan Route M-222 as a case study in developing a risk assessment tool. M-222 passes along a slope above a sharp bend in the Kalamazoo River, which reaches high velocities during peak flow. Scouring of the toe of the slope has caused deterioration, intensified by river migration and possibly by dam operations. Aerial photographs revealed slope recession for many years; although identified in 2006, the problem was mistakenly believed to be caused by a culvert outlet eroding the slope.

[1] NCHRP Project 20-83 (05), Climate Change and the Highway System: Impacts and Adaptation Approaches, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2631.

PHOTO: MICHIGAN DOT

Erosion of cliffs near Baraga, Michigan, threatened US-41; Michigan DOT moved the road more than 100 feet inland.

In 2011, Michigan DOT determined that the slope had become unstable. Slope failure would damage the roadway and would affect travel around the City of Allegan; M-222 is a primary arterial road to the city from the east. Closure of the route would have had huge economic impacts for the city and would have impeded access to many residences. In 2009 the receding slope had damaged a home that the city later removed for safety reasons; as part of the project to restore the slope's stability, another home had to be razed.

The NCHRP project expects that data on the natural factors affecting the safety of the M-222 roadway can be integrated into the predictive model for the impacts of increased precipitation events on roadways.

## Implementing Strategies

As these various examples from Michigan show, extreme weather events can have a significant impact on the transportation system of an entire state or region, causing the interruption of commerce locally—and sometimes nationally and internationally. Transportation agencies must investigate, plan, design, construct, and operate their systems recognizing the risks and applying proactive strategies to mitigate extreme impacts.

A robust knowledge of transportation assets and their vulnerability to extreme weather events is a key to implementing adaptation strategies that balance risk while recognizing budget realities. Discussions with state and regional climatologists have proved to be vital to Michigan DOT in planning for adaptation strategies.

Agencies also should create an organizationwide awareness of long-term climate trends for their jurisdictions and for the surrounding regions. This awareness is indispensable in developing adaptation strategies that sustain local and regional commerce during an extreme event.

# State Activity on Climate Change and Energy

## *A Whirlwind Tour*

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PHOTO: TOM SAUNDERS, VIRGINIA DOT

(Photo above:) *In-place pavement recycling on I-81 is part of Virginia DOT's Green Initiatives program. Other measures include LEED-certified rest areas and enhanced signal timing for efficient traffic flow.*

To find out what state departments of transportation (DOTs) are doing related to climate change and energy, take a quick tour of the interactive U.S. map posted on the website of the Transportation and Climate Change Resource Center of the American Association of State Highway and Transportation Officials (AASHTO).[1] Selecting a particular state on the map provides access to a variety of information and documents. Some examples follow:

- Colorado: "Assessment of Colorado DOT Rest Areas for Sustainability Improvements and Highway Corridors and Facilities for Alternative Energy Source Use";
- Massachusetts: "Interagency Transportation, Land Use, and Climate Change: Cape Cod Pilot Project";
- Michigan: "Climate Change Adaptation Issues in Highway Operations";
- Missouri: "Alternative Energy Resources for Missouri DOT";
- New York: "Climate Change and Energy Efficiency Initiative of the New York State DOT";
- Oregon: "ODOT Solar Highways";
- Pennsylvania: "Pennsylvania Climate Adaptation Report: Risks and Practical Recommendations";
- Tennessee: "Tennessee DOT Biofuel Green Corridor Network";
- Virginia: "Green Initiatives in Virginia Transportation"; and
- Washington: "WSDOT Sustainable Transportation Folio."

The map was launched in 2011, and is updated continually. Nonetheless, the map represents only a portion of the climate change and energy activities undertaken by state DOTs. Many climate adaptation, energy conservation, and greenhouse gas mitigation activities by state transportation agencies are not recorded in documents that are web-accessible. The AASHTO map is a work in progress that is evolving as new activities unfold and information becomes available. A "contact us" feature on the website allows states to provide additional material for the map; states also can send new information and updates via e-mail to climatechange@aashto.org.

In addition to the interactive map, the Transportation and Climate Change Resource Center website contains a wealth of information for state DOTs, metropolitan planning organizations (MPOs), and other transportation professionals interested in climate change and energy. The site is well populated with research reports, a calendar of meetings and events, and other topical information, covering key topics such as

- Federal actions and legislation;
- State, local, and MPO activities;
- GHG mitigation;
- Climate adaptation;
- Climate science;
- Energy;
- Communications and public opinion;
- Litigation;

[1] www.transportation.org/tools/state_by_state.

◆ Future research; and
◆ Web links.

The website home page displays recent activities at a glance under Current Topics and Events.[2] This feature is updated monthly with timely information relevant to DOTs.

Links are provided to the briefing materials from the climate change workshops at 17 state DOTs, along with links to 12 national climate change webinars sponsored by AASHTO and the Federal Highway Administration. The site also provides resources for members of AASHTO's Sustainable Transportation: Energy, Infrastructure, and Climate Solutions Technical Assistance Program, including the monthly *Climate Briefing* newsletter and a peer-to-peer forum.

AASHTO is working to keep the site practical and useful for state DOTs and others and solicits suggestions and material from users to ensure that the posted information maintains its freshness and value.

[2] http://climatechange.transportation.org.


*The AASHTO Transportation and Climate Change Resource Center's website features an interactive map of the climate change–related measures employed by state DOTs.*

## Climate Change and the Highway System

### *Project Explores Impacts and Adaptation Approaches*

The potential impacts of climate change on the highway system are many. Higher greenhouse gas concentrations are likely to increase the Earth's average temperature and to alter patterns of precipitation and the incidence and severity of storms. According to a 2007 report from the Intergovernmental Panel on Climate Change, the recent increases in coastal erosion and flooding are results of sea-level rise caused by climate change; global mean sea level is projected to rise by 0.09 to 0.88 meters between 1990 and 2100.

Research is needed to provide a sound foundation for practitioners to address the impacts of climate change on the highway system for the period 2030 to 2050. National Cooperative Highway Research Program (NCHRP) Project 20-83(05) is working to produce the first layer of information necessary for assessing potential impacts, identifying vulnerable infrastructure by region, and recommending institutional arrangements and technical tools that can address the future interactions of climate change and highway systems.

The objectives of the research are as follows:

◆ Synthesize the state of knowledge worldwide to ascertain the probable impacts of climate change on highway systems by U.S. region for the period 2030 to 2050;

◆ Recommend institutional arrangements, tools, approaches, and strategies that state departments of transportation can use in system planning, design, construction, operations, and maintenance to adapt infrastructure and operations; and

◆ Identify research and activities needed to close gaps in knowledge and to implement effective adaptive management.

The research team is led by Michael D. Meyer of PB Americas, Inc. Randell Iwasaki, Executive Director of the Contra Costa Transportation Authority, chairs the project advisory panel. Two interim reports are available for download:

◆ *Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies*[a] and

◆ *Synthesis of Information on Projections of Change in Regional Climates and Recommendation of Analysis Regions.*[b]

The final report for the project is expected in late 2012.

[a] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-83%2805%29_Task2-3SynthesisReport.pdf.
[b] http://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-83%2805%29_Task2-4TechnicalReport.pdf.

# The Transportation and Climate Initiative

## *An Innovative State Collaborative*

LOIS NEW

The Transportation and Climate Initiative (TCI) is a regional collaboration of transportation, energy, and environment officials in 11 Northeastern and Mid-Atlantic states and the District of Columbia. The initiative seeks to promote a clean energy economy and reduce greenhouse gas emissions in the transportation sector. Specifically, TCI focuses on the following tasks:

1. Developing clean vehicles and alternative fuels,
2. Creating sustainable communities,
3. Adopting innovative communication technologies, and
4. Advancing more efficient freight movement.

The initiative was launched in June 2010 by agency heads in energy, environment, and transportation and already is demonstrating the benefits of regional action.

In fall 2011, participating TCI jurisdictions formed the Northeast Electric Vehicle Network and were awarded a nearly $1 million planning grant from the U.S. Department of Energy to prepare the region for the mass market rollout of electric vehicles. Work on the project, including efforts to remove barriers to the deployment of plug-in cars and trucks, is under way, and the effort has engaged a diverse group of stakeholders—utilities, vehicle and charging manufacturers, fleets, large employers, and other interested parties.

In 2011, the TCI jurisdictions agreed to a set of regional sustainability principles that make sustainable development a top transportation goal. TCI work groups have commissioned several substantive research projects to inform further action. The projects include the following:

- A literature review on removing barriers to the deployment of electric vehicles;
- A survey of what TCI jurisdictions are doing to achieve sustainable community outcomes;
- A workshop and report on potential metrics of progress toward the goals for sustainable communities;
- A series of webinars with leading experts on developments in information and communication technologies; and
- A report on freight flows within the TCI region.

TCI also offers an innovative model for collaboration among states and jurisdictions. At a time when states are working to overcome budget shortfalls, the initiative fosters important regional strategic planning to maximize environmental benefits, increase energy efficiency, and bolster economic development in the transportation sector.

The heads of environment, energy, and transportation agencies for the 12 TCI jurisdictions convened in June 2012 for an annual summit, during the annual meeting of the Northeast Association of State Transportation Officials in Baltimore, Maryland. Regular operations of TCI are guided by a steering committee of agency staff and managers, who meet biweekly via conference call. Four larger, topic-oriented work groups—corresponding to the four core tasks—involve energy, environment, and transportation staff from all 12 jurisdictions; the work groups meet via monthly conference calls.

PHOTO: TCI

*The Transportation and Climate Initiative explores strategies for fuel efficiency, data application, and technology—such as electric vehicle charging stations—to reduce GHG emissions.*

Although decision-making within TCI is generally consensus-based, any jurisdiction can choose not to participate in specific efforts or policy deliberations. The four work groups generally develop projects, initiatives, and policy proposals, which are vetted by the steering committee and then directed to the agency heads for review and consideration.

Participating in TCI are Connecticut, Delaware, the District of Columbia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont. The Georgetown Climate Center, housed at Georgetown Law in Washington, D.C., facilitates the initiative. In addition to the grant from the U.S. Department of Energy, the efforts are supported by the Rockefeller Foundation, the Emily Hall Tremaine Foundation, the Rockefeller Brothers Fund, Oak Foundation, and the Barr Foundation.

For more information about TCI, visit www.georgetownclimate.org/tci.

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# Facing Up to Climate Change

## *Planning and Implementation at the Vermont Agency of Transportation*

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Vermonters have been conservation-minded for decades. Vermont led the nation in banning billboards, requiring bottle deposits, and adopting a statewide land use law. Climate change, the latest environmental challenge facing the state, has been on the agenda since the late 1990s, when Vermont joined the other New England states and Eastern Canadian provinces to set aggressive goals for reducing regional greenhouse gas (GHG) emissions.

Vermont's GHG policies are closely linked to energy policy. The Vermont Agency of Transportation (VTrans) is working with other state agencies through the Vermont Climate Cabinet to implement the Comprehensive Energy Plan (CEP). The CEP sets an ambitious goal of meeting 90 percent of the state's energy demand—including the needs for transportation—with renewable sources by 2050. The state will achieve this goal by focusing on the following objectives:

- Increase the share of Vermont-registered vehicles powered by electricity from renewable sources to 25 percent by 2030,
- Increase transit ridership by 110 percent,
- Quadruple Vermont-based rail passenger trips,
- Triple the number of state park-and-ride spaces by 2030, and
- Hold per capita VMT to 2011 levels.

The state's commitment to reach these objectives includes the following steps:

- VTrans, the Agency of Natural Resources, and the Department of Public Service equally support a staff position as the single point of contact for the state's utilities, car dealers, local officials, and other partners.
- Key issues on the policy agenda for the coming year include removing barriers to the deployment of infrastructure for alternative fuels, establishing state incentives to support green vehicle purchases, examining the effects of fuel switching on transportation revenues, and identifying strategies to address revenue losses.
- The governor's recommended budget for 2013 increases transit funding by 9 percent and funding for park-and-ride facilities by 27 percent.
- More than $52 million dollars obtained in the past two years from federal sources was combined with $15 million in private funding to improve track on the Amtrak *Vermonter* line.

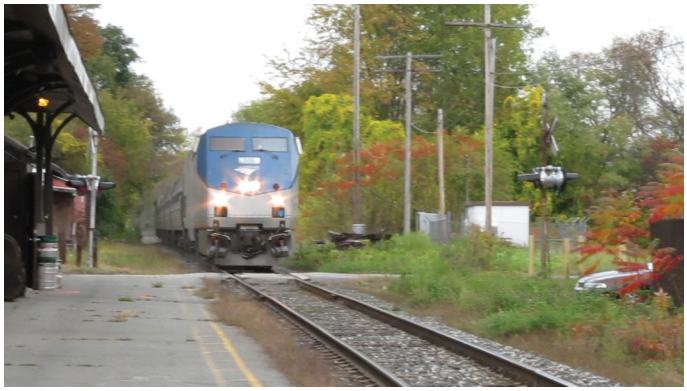

PHOTO: LEONORA ENKING

*An Amtrak train pulls into the station in Windsor, Vermont. The state has set goals—such as quadrupling the number of passenger rail trips—to decrease the use of nonrenewable energy sources.*

Changing travel demand in a rural state is a difficult task, but Vermont has a strong tradition of concentrated, mixed-use town and village centers of economic growth. These have continued to prosper as job centers, in part because of state programs promoting smart growth; in addition, the centers are amenable to walking, biking, and transit.

VTrans is also planning for climate adaptation. In 2011, Vermont's transportation infrastructure experienced major climate-related impacts with two 500-year flood events. Water levels in Lake Champlain broke all records, with unprecedented spring flooding, and Tropical Storm Irene hammered the state in August 2011. For more than 200 years, much of the state's transportation network had grown along winding valley floors and scenic rivers. More intense and frequent storm events, which scientists associate with a changing climate, are causing the rivers and adjacent mountain streams to wreak havoc on the state's bridges, culverts, roadways, trails, and rail lines.

*(continued on next page)*

PHOTO: VERMONT AGENCY OF TRANSPORTATION

*With many transportation facilities adjacent to rivers and streams, VTrans is adapting to mitigate the devastating effects of extreme weather events, such as Tropical Storm Irene in 2011.*

PHOTO: JOHN BLYBERG

*Record-breaking water levels at Lake Champlain in 2011 caused extensive flooding and infrastructure damage.*

Tropical Storm Irene washed out more than 2,000 roadway segments, undermined more than 1,000 culverts, and damaged more than 300 bridges; the price tag was several hundred million dollars. As VTrans rebuilds and works to make the transportation network more flood resilient, it is pursuing short- and long-term approaches to climate change adaptation.

In the short term, VTrans is evaluating the hazard risk from fluvial floods for roads and bridges, as well as the vulnerability of the transportation infrastructure throughout the state, and is developing a suite of measures to address risk and vulnerability. The measures run the gamut from engineering solutions—such as bridge and culvert retrofits—to wetlands conservation, to keep floodwaters away from developed areas, and include the evaluation of alternative routes.

In the long run, the agency intends to establish flood resiliency criteria to help in prioritizing transportation project funding. In addition, the agency will work with state and federal natural resource agencies to collect data and information to improve understanding of the effects of climate change in Vermont.

VTrans has reinvigorated its relationship with the Natural Resources Agency, recognizing that river science is critical to its work. The agencies are sharing several positions, as well as resources, and executive-level staff are meeting weekly. Vermont cannot afford to forgo this collaborative approach or the preparations for a new weather normalcy.

PHOTO: FEDERAL EMERGENCY MANAGEMENT AGENCY

*Tropical Storm Irene washed out more than 2,000 roads and damaged hundreds of bridges in Vermont.*

## Adaptation with Rapid Bridge Replacement

Recovering from the damage of Hurricane Irene in 2011, the Vermont Department of Transportation (VTrans) already is planning for climate change adaptation. When Chris Williams, a senior project manager for VTrans, learned of a new toolkit that speeds bridge design and construction—saving time both for the agency and for travelers—he took prompt action to implement standard bridge designs and construction methods developed by TRB's second Strategic Highway Research Program (SHRP 2).

The SHRP 2 rapid bridge-building toolkit integrates standard concepts for accelerated construction of all bridge components into designs that local contractors can build using their own equipment. During a pilot test of the design toolkit in Iowa, local contractors replaced a three-span bridge in two weeks.

Local resources are important, especially during emergencies. Not only is quick response critical—at a time when arranging for outside constructors and delivery of equipment may not be feasible—but local economies benefit from work done by local businesses. Developing local expertise in applying plans and methods from the toolkit is one way VTrans and other highway agencies can prepare for the challenges of adapting to climate change.

For more information, contact Monica Starnes at mstarnes@nas.edu. For related videos, visit www.trb.org/StrategicHighwayResearchProgram2SHRP2/SHRP2Videos.aspx.

*—Linda Mason, SHRP 2*