

# Workshop Summary

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By **Joanne R. Potter**

In October 2002 the U.S. Department of Transportation Center for Climate Change and Environmental Forecasting (the Center) hosted a workshop of leading experts and decision makers in transportation and climate change. The purpose was twofold: to discuss the potential impacts of climate change on transportation, and to gain input and perspectives on the research necessary to better understand these impacts. The workshop marked a new area of investigation for the Center, which, since its creation in 1998, has concentrated on understanding and mitigating the effects of transportation on our global climate. The Center is now expanding its research to consider the implications a changing climate might have for the future of transportation and how the transportation community might be better prepared to avoid or adapt to any potential impacts.

The Center enlisted the support of key Federal partners in this effort: the Environmental Protection Agency, the Department of Energy, and the U.S. Global Change Research Program (under the auspices of the U.S. Climate Change Science Program). An interagency working group provided technical support and guidance to the Department of Transportation and was instrumental in the workshop's success.

The *Potential Impacts of Climate Change on Transportation Research Workshop* was held October 1-2, 2002, at the Brookings Institution in Washington D.C. The sixty-four invited participants included transportation professionals, regional and national stakeholders, and experts in climate change and assessment research, the environment, planning, and energy (Table 1). Appendix A provides a complete list of participants and their affiliations. Throughout the day and a half long event, participants explored the key challenges climate change may pose for transportation in specific regions and for specific modes, and identified priority areas for research, through interdisciplinary breakout sessions.

This report provides a summary of the workshop and the research recommendations generated by participants. This summary is followed by eighteen discussion papers that address various aspects of the relationship between climate change and transportation, and suggest opportunities for further study.

*Table 1. Workshop participants.*

|   |  |
|---|--|
| <b>U.S. Federal Agencies</b>  |  |
| U.S. Climate Change Science Program<br>U.S. Department of Energy<br>U.S. Department of Transportation<br>U.S. Environmental Protection Agency | National Aeronautics and Space Administration<br>National Oceanic and Atmospheric Administration<br>U.S. Army Corps of Engineers<br>U.S. Geological Survey |
| <b>State and Local Governments</b>  |  |
| Alaska Department of Transportation and Public Facilities<br>Chicago Area Transportation Study  | Delaware Valley Regional Planning Commission<br>New York State Department of Transportation  |
| <b>International Government Agencies</b>  |  |
| Environment Canada  | Transport Canada   |
| <b>Non-Governmental Organizations</b>   |  |
| Researchers<br>Consultants<br>Industry representatives  | Environmental non-profit organizations<br>Transportation non-profit organizations  |
| <b>Expertise Represented</b>  |  |
| <i>Climate and Environment</i><br>Air quality<br>Climate change<br>Environmental impact assessment<br>Meteorology<br>Water resources          | <i>Transportation</i><br>Economics<br>Emergency management<br>Engineering<br>Transportation operations<br>Transportation planning<br>Urban planning        |
| <b>Transportation Modes Represented</b>   |  |
| Aviation<br>Highway<br>Marine   | Rail<br>Transit  |

## Summary of Workshop Findings

Workshop participants strongly agreed that there is significant need for research to build understanding about the connections between climate change and transportation. The results of further research – if appropriately focused – will help transportation planners and managers better prepare for and manage the impacts of climate change on the transportation system. In addition, greater attention should be given to making current research findings available to inform trans-

portation decision makers. The key themes that emerged through the workshop discussions are summarized below.

### *Key Research Needs*

- *Climate and Weather Projections at Regional and Local Levels.* Because transportation decisions and investments are most often made at local and regional levels, a regional research approach is essential to provide information at a level of specificity that is meaningful to local and regional decision makers, and to reflect the different

risks to transportation in different parts of the country.

- *Assessment of Potential Impacts on Critical Infrastructure Locations and Facilities.* Planners and transportation managers require research that helps identify the key facilities and locations that may be impacted by climate change. Impacts of particular interest to transportation could result from hydrologic changes, changes in the patterns and location of extreme events, changes in coastal geography and storm activity, and changes in prevailing climate and weather.
- *Analysis of Impacts on Operations, Maintenance, and Safety.* Long-term climate change may affect adverse weather conditions, shift temperature patterns, and alter seasonal precipitation. Future research is needed to better understand what these shifts may mean for safe and efficient management and operation of the transportation network.
- *Improved Tools for Risk Assessment and Decision Making.* Transportation managers need improved tools to effectively incorporate climate change data and projections into their planning, asset management, and operations decisions. Decision makers need techniques and methods that can be used to assess the relative risks of climate change to different aspects of the transportation network, to evaluate response strategies, and to target limited resources.
- *Integration of Climate Change Assessment with Other Transportation Decisions.* Transportation decision makers need frameworks to integrate consideration of climate changes with other key dynamics, including development patterns, technological advances, economic trends, and ecological changes. Tools are needed to

integrate impacts assessment with environmental assessments and transportation planning processes across all modes of transportation.

- *Assessment of Response Strategies.* Research is needed to better understand the range of potential response strategies available to transportation managers to avoid or adapt to the potential impacts of climate changes. Research should also develop new responses, evaluate tradeoffs among strategies, and assess the benefits, disbenefits, and costs of these options.

#### ***Coordination, Communication, and Public Awareness***

- *Improved Sharing of Data and Knowledge.* Increased focus should be given to the dissemination and customization of existing data and knowledge for use by transportation managers, policy makers, the broader research community, and the general public.
- *Integration into CCSP Strategic Priorities.* DOT and other Federal agencies should coordinate the research priorities identified through this workshop with the activities of the U.S. Climate Change Science Program (CCSP). DOT, a Federal partner in CCSP, plays an active role in the development of the federal strategic plan for climate change research.<sup>1</sup>
- *Leveraging Existing Research Activities.* The transportation community should work more closely with the climate and weather research communities to share knowledge and resources in this emerging field of research. DOT should collaborate with research partners to tap expertise in other fields, to provide transportation perspectives and expertise, and to leverage the research investments of other Federal agencies, international agencies, industry, and academia in climate change research.



*Emil Frankel, Assistant Secretary for Transportation Policy at the Department of Transportation, addresses the importance of DOT research on climate change impacts in his opening address.*

- *Public Education and Outreach.* Public access to and awareness of research findings needs to be improved. Information needs to be disseminated using formats readily understandable by the general public. Improved availability of information on the range of potential climate changes will provide the basis for the public to more effectively participate in transportation planning processes.

The following report gives a brief background on climate change research as it relates to transportation, provides an overview of the background papers and activities of the workshop, and summarizes the findings and recommendations of the *Potential Impacts of Climate Change on Transportation Research Workshop*.

## **Background**

### **Current Research on Climate Change Impacts**

Considerable research is being conducted on the effects that climate change might have on the U.S. and on the world. At the request of Congress, the U.S. Global Change Research Program (USGCRP) organized the U.S. National Assessment, a multi-year research effort to understand and assess the potential consequences of climate variability and change on the nation. In November 2000, the USGCRP



*Panelist David Easterling, NOAA, makes a presentation on climate changes in the United States.*

released the National Assessment Report: *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*.<sup>2</sup> This report provides a national level snapshot of potential impacts of climate change on the US and the relative degree of certainty researchers have in their projections, based on current scientific understanding. Table 2 provides a summary of the range of potential impacts identified in this report. In addition, under the auspices of USGCRP, various partnerships of universities, government agencies, and stakeholders have undertaken impact assessments on regional and sectoral levels. As of February 2003 reports on 11 regional assessments have been published that examine the potential impacts of climate change on specific regions of the United States; additional studies are forthcoming.<sup>3</sup> Five sectoral assessments have also been completed, exploring impacts on water resources, human health, coastal areas and marine resources, forests, and agriculture.<sup>4</sup> Other USGCRP research initiatives are profiled in *Our Changing Planet: The Fiscal Year 2003 U.S. Global Change Research Program and Climate Change Research Initiative*.<sup>5</sup>

Elaborating on the USGCRP assessments, other studies have explored various aspects of climate change impacts.<sup>6</sup> For example, the National Research Council provided an overview of potential impacts as part of a larger examination in *Climate Change Science: An Analysis of Some Key Questions*.<sup>7</sup> A related series of studies has been sponsored by The Pew

**Table 2.** *Projected impacts of climate change on the United States, adapted from Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change, by the National Assessment Synthesis Team.*<sup>8</sup>

1. Increased warming and more intense precipitation will characterize the 21<sup>st</sup> century.
2. Differing regional impacts will occur, with greater warming in the western US, but a greater rise in heat index in the east and south.
3. Vulnerable ecosystems, particularly alpine areas, barrier islands, forests in the Southeast, and other vulnerable ecosystems will be significantly impacted.
4. Water will be a concern across the country, with increased competition for available resources, and the potential for more droughts and floods and reduced winter snowpack in some areas.
5. Food availability will increase because of increased crop productivity, although lowered commodity prices will stress farmers in marginal areas.
6. Forest growth will increase in the near-term, but some forests will be threatened over the long-term by increased susceptibility to fire, pests, and other disturbances.
7. Increased damage is very likely in coastal regions due to sea-level rise and more intense storms, while damage in other areas will result from increased melting of permafrost.
8. Adaptation will determine the importance of health outcomes, so that strengthening of the nation's community and health infrastructure will become increasingly important.
9. The impacts of other stresses will be magnified by climate change, with multiple factors causing adverse impacts on coral reefs, wildlife habitats, and air and water quality.
10. Uncertainties remain in current understanding and there is a significant potential for unanticipated changes.

Center on Global Climate Change, including reports discussing changes in precipitation patterns and the water cycle, sea-level rise, forests, and agriculture.<sup>9</sup> Finally, studies such as the Federal Emergency Management Agency (FEMA) study on the effects of shoreline erosion in coastal communities and the Great Lakes regions<sup>10</sup> have investigated the possible effects of climate and weather phenomena on emergency preparedness and property loss.

Impacts have been the subject of studies outside the United States as well, such as assessments prepared in Canada<sup>11</sup> and the United Kingdom.<sup>12</sup> On an even larger scale, the Intergovernmental Panel on Climate Change (IPCC), an organization formed by the United Nations (UN) and the World Meteorological Organization (WMO) to provide international assessments of climate change issues, published an examination of global impacts in *Climate Change 2001: Impacts, Adaptation, and Vulnerability*.<sup>13</sup>

### Implications for Transportation

Few studies of climate impacts have been conducted that focus primarily on transportation concerns in the United States, but assessments such as those discussed above suggest potentially far-reaching implications for transportation. For example, changing coastlines and rising sea levels could, over the long-term, require the relocation of roads, rail lines, or airport runways, and could have major consequences for port facilities and coastal



*Center Steering Committee member James Shrouds, Federal Highway Administration, introduces the speakers in the second panel.*



*Panelist Virginia Burkett, United States Geological Survey, speaks about climate impacts and transportation in the Gulf region.*



*Michael Savonis, Federal Highway Administration.*

shipping. Underground tunnels for transit systems, roads, and rail could be subject to more frequent or severe flooding.<sup>14</sup> In Alaska, thawing permafrost could damage roads, rail lines, pipelines, and bridges. Declining water levels in the Great Lakes could adversely impact shipping operations. A possible increase in the number of hurricanes and other extreme weather events would have implications for emergency evacuation planning, facility maintenance, and safety management for surface transport, marine vessels, and aviation. Changes in rain and snowfall and in seasonal flooding patterns could affect safety and maintenance operations as well.

In addition to these direct implications for planning, siting, design, and management of transportation facilities, the prospect of climate change raises other, less obvious, questions. For example, some research suggests that increasing temperatures could exacerbate near-surface ozone concentrations, making it more difficult for metropolitan areas to maintain air quality standards. Shifts in climate that affect ecosystems and the viability of natural resources are projected to impact agriculture, fisheries, and forestry production, which could, in turn, have long-term implications for freight transport. If climate change causes the relocation of major industrial and business activities, this would be expected to require significant investments in transportation and other infrastructure.



*James Mahoney, Assistant Secretary of Commerce and Director of the Climate Change Science Program Office, delivers remarks on the importance of research on climate change and transportation.*

Because of the many possibilities, assessing the implications of climate change for transportation will not be a straightforward task. Social and economic factors – including technology development, demographic shifts, and the rate of economic growth or contraction – will influence our future transportation needs, where transportation networks are located, and our investment in sustaining the nation’s infrastructure. Furthermore, while the state of science in modeling climatic changes has advanced rapidly, there remain significant uncertainties about how global climate change will ultimately unfold. As studies attempt to project what could happen at specific regional and local areas, the level of uncertainty increases. In addition, the National Assessment notes that there is a high potential for “surprises” – major, unexpected events that will have significant impacts.

### **Need for Research on Transportation Impacts**

The complexity of projecting the potential impacts of climate change presents a huge challenge for transportation decision makers. Ultimately, managers may need to incorporate a range of possible effects into their transportation investment decisions and management strategies. These decisions need to be informed by solid information about the range of potential effects on the transportation system and the



Panelist Martin Wachs, University of California at Berkeley, discusses the future of transportation.

probability of these effects. Further, long-range transportation plans and investment strategies must be sufficiently robust to accommodate unanticipated future events. Transportation decision makers need to know what policy and management options they have to prepare for these possible effects, and be able to assess the strengths and weaknesses of these options.

Recognizing transportation decision makers' need for more comprehensive projections of coming changes in climate, the DOT Center for Climate Change has decided to initiate research in this area and to encourage others in the research community to consider transportation concerns in their own research. The *Potential Impacts of Climate Change on Transportation* workshop launched this new research focus.

## The Potential Impacts of Climate Change on Transportation Research Workshop

### Discussion Papers

In preparation for the workshop several experts developed papers providing background information and introducing case examples of issues and current research related to climate changes and infrastructure. Final versions of these discussion papers are included in this report. These eighteen informative and thought-provoking papers provide both the research community and transportation decision makers an introduction to the wide variety of potential



Panelist Brian Mills, Meteorological Service of Canada, addresses the intersection of climate change and transportation.

connections between climate change and transportation, and open the door to further interdisciplinary study and dialogue.

### Overviews

The first five papers provide summary background information on current climate change science and transportation services. In *Global Warming: A Science Overview*, Michael MacCracken presents six key aspects of the scientific findings on global warming. David Easterling then discusses the observational evidence for climate change in the United States and globally, in his paper *Observed Climate Change and Transportation*. Next, in *National Assessment of the Consequences of Climate Variability and Change for the United States*, MacCracken describes the process used to conduct the National Assessment, and summarizes the climate concerns for different regions of the United States as identified in the Assessment Report. Donald Trilling takes a look at the future of transportation in his paper *Notes on Transportation into the Year 2025*. Brian Mills and Jean Andrey then offer an introduction to the ways that trends in climate change and transportation may intersect in their paper *Climate Change and Transportation: Potential Interactions and Impacts*, which is based on studies conducted as part of Canada's national assessment.

### **Regional Case Studies**

Following these overviews, six researchers provide more detailed examinations of regional effects of climate change in the United States, and what future changes may mean for transportation systems in these areas. Rae Zimmerman discusses climate change implications for infrastructure in the metropolitan New York region in *Global Climate Change and Transportation Infrastructure: Lessons from the New York Area*. Virginia Burkett describes how climate change dynamics may play out in the Gulf Coast / Mississippi Delta region – and the risks for transportation of these changes in storm events, sea level, precipitation, and other factors – in her paper *Potential Impacts of Climate Change and Variability on Transportation in the Gulf Coast / Mississippi Delta Region*.

In *The Potential Impacts of Climate Change on Great Lakes Transportation*, Frank Quinn provides an overview of how climate variability and change are projected to affect water levels in the Great Lakes – “one of the most intensively used fresh water systems in the world” - and discusses the implications for ports and marine transport. Turning to the west, Pierre duVair, Mary Jean Burer, and Douglas Wickizer discuss some of the ways climate change can be expected to impact transportation networks in California in their paper *Climate Change and the Potential Implications for California's Transportation System*. Jim Titus takes an East Coast perspective, posing the question *Does Sea Level Rise Matter to Transportation Along the Atlantic Coast?*. Finally, Orson Smith and George Levasseur examine the ongoing and potential effects of climate change in arctic regions in their discussion, *Impacts of Climate Change on Transportation in Alaska*.

### **System Impacts**

The next group of papers looks at the potential implications of climate change for specific aspects of transportation, examining the issue either through an operational lens or modal perspective. In their paper *Surface Transportation Safety and Operations: The Impacts of*

*Weather within the Context of Climate Change*, Paul Pisano, Lynette Goodwin and Andrew Stern explain how adverse weather affects the safety and effectiveness of surface transportation operations, and how these effects may become even more important under climate change. Freight and transportation specialists Harry Caldwell, Kate H. Quinn, Jacob Meunier, John Suhrbier, and Lance Grenzeback examine the potential effects of climate change on the reliability and efficiency of freight transport in their discussion *Impacts of Global Climate Change on Freight*. Gloria Kulesa discusses how weather affects the safety and operations of airports and aviation and describes current research activities in the aviation community in her paper *Weather and Aviation*. Michael Rossetti considers the effects of weather and climate factors on rail operators in his paper *Potential Impacts of Climate Change on Railroads*.

### **Environment and Planning**

The final group of papers addresses some of the environmental implications of climate change for transportation, and suggests considerations the transportation planning process may need to incorporate. In *Climate Change and Air Quality*, Anne Grambsch discusses the interaction between rising temperatures and air quality concerns in metropolitan areas and the implications of these effects on transportation. Paul Marx considers how climate changes may affect agriculture, industry and commerce, and residential land uses – and the issues that these effects may raise for transportation – in *Potential Climate Impacts on Land Use*. Finally, Erika S. Mortenson and Fred G. Bank explain the environmental roles and responsibilities of federal and state highway agencies, and explore how climate change may affect transportation agencies' efforts to protect water quality, wetlands and ecosystems in their paper *Potential Impacts of Climate Change on Transportation: Water Quality and Ecosystems*.

These background papers offered workshop participants an array of thoughts to spark discussion when they arrived at the workshop on October 1, 2002.



### Opening Session and Panel Presentations

Emil Frankel, Assistant Secretary for Transportation Policy, Department of Transportation, welcomed the distinguished group of experts. In the opening presentation, James Mahoney, Director of the Climate Change Science Program Office, Department of Commerce, stressed the importance of cooperation across Federal agencies on climate change research, and expressed his enthusiasm for research that would inform policy makers about the connections between climate changes and transportation. The full group then engaged in a brainstorming discussion, led by workshop facilitator Douglas Brookman, to explore the broader context for future research. The context map that quickly evolved through this dialogue highlighted the connections of transportation to broader social, political and economic drivers, the key roles of science and technology to the future of transportation, and the multiple challenges facing both the research and transportation communities (Figure 1). The

group recognized that we face significant uncertainties about the future – ranging from how technology is likely to unfold to the prospects of terrorism and international conflict. Potential changes in climate need to be considered as one factor among many in this dynamic context. The reality of an unpredictable future increases the challenges inherent in planning for a reliable and resilient transportation system.

### Panel A – Overview of Trends

Joel M. Szabat, Deputy Assistant Secretary for Transportation Policy, Department of Transportation, moderated the first panel. Panelists provided an overview of trends in both the climate science and transportation communities as a starting point for workshop discussions.

David R. Easterling, of the National Climatic Data Center, summarized key observational data on temperature and precipitation in the U.S. and presented model-



**Figure 1.** Climate impacts on transportation context map. This chart was used to brainstorm lists of relevant issues for the workshop, highlighting: seasonal trends, political factors, the economic climate, accessibility and mobility trends, technology factors, customer needs, and uncertainties.



*Panelist Rae Zimmerman responds to a question following her presentation on New York area impacts.*

derived projections for future changes in climate. Measurements of near-surface temperature for the twentieth century document warming of approximately 0.6 degrees Celsius since 1880, both globally and in the United States. More significant is the change in daily maximum and minimum temperatures: minimum temperatures have warmed at a rate approximately twice that of maximum temperatures. Changes also appear to be occurring in the hydrologic cycle. Observations indicate that precipitation has increased in higher latitudes, and heavy rainfall events have become more common across the United States. Easterling also summarized the findings of the National Assessment, focusing particularly on potential changes in hydrological regimes and risks to coastal communities and marine resources.

Martin Wachs, from the University of California at Berkeley, provided a picture of what lies ahead for transportation. Much of the change in transportation is expected to come from outside the United States, as other countries develop and as globalization increasingly influences what U.S. consumers purchase. Critical issues include growth in international air travel and goods movement, increases in non-commuting travel, and environmental concerns. Demands on transportation facilities and services are growing prodigiously in both the passenger and freight sectors, placing strains on a network already beyond capacity in some areas. Much of the nation's infrastructure is aging and obsolete, and



*Panelist John Gambel, Federal Emergency Management Administration, gives an overview of FEMA's National Hazard Programs.*

as funds are used to maintain the existing network there will be fewer resources for new capital investment. Transportation agencies are challenged to maintain and optimize the use of existing infrastructure even as demands for access and services grow and costs increase. Information technologies may help to increase the capacity of the US transportation system, but the need is already large and growing. Finally, a new emphasis on safety and security places additional challenges on the transportation community.

Brian Mills, from the Meteorological Service of Canada, presented an analytic approach that Jean Andrey and he developed to examine the potential interactions between climate change and transportation. In order to identify and evaluate possible impacts, one must first define the scale and scope of the transportation system or activity, and determine its sensitivities to weather and climate. It is then possible to explore how anthropogenic climate change and variability might alter those interactions, and the implications for future vulnerability. Adaptation options can then be considered based on this assessment of risk. In weighing the priority that should be given to research on a potential impact, both the significance of the impact and the level of confidence in the climate change projection should be considered. Mills illustrated the approach by presenting examples of climate change impacts that have been experienced recently in northern Canada and the Great Lakes-St. Lawrence River Watershed.

***Panel B – Assessing the Impacts of Climate Change and Variability on Transportation***

James Shrouds, Director of the Office of Natural and Human Environment for the Federal Highway Administration (FHWA), moderated the second panel. This panel provided examples of the implications of climate change for two regions of the United States and on Federal emergency management programs.

Rae Zimmerman, of New York University, described the findings of the regional assessment of the New York metropolitan area, including specific vulnerabilities of infrastructure to flooding and storm surges. Climate change model projections for increases in sea level and temperature as well as for changes in precipitation patterns indicate that much of the metropolitan area's transportation infrastructure will be at risk of more frequent flooding, and higher flood levels. Higher temperatures also pose risks to pavement and structures. These potential impacts call for multiple mitigation and adaptation responses that may include redesign or retrofitting of critical infrastructure, operational strategies, relocation of facilities, and land use planning. Zimmerman emphasized the interrelationships between development patterns, transportation's contributions to greenhouse gas emissions, and the impacts of climate change on transportation. She argued that climate change needs to be considered as a factor in urban development and infrastructure management. Zimmerman noted the research challenges inherent in translating global projections of climate change phenomena to local levels and the institutional challenges of developing adequate response strategies when multiple local governments and agencies must be involved.

John Gambel of the Federal Emergency Management Administration (FEMA) presented the connections between emergency management and transportation, and gave an overview of FEMA's National Hazard Programs. FEMA has studied the hazards of erosion in coastal areas, along with the significant – and growing – economic impacts of these hazards. Gambel indicated that insurance

rate structures for high-risk areas are already insufficient to cover the projected costs of property losses in erosion hazard areas. This situation could be exacerbated by the increase in erosion due to rising sea level and increased storm surge projected by climate change models.



*Center Steering Committee Chair Joel Szabat, Office of the Secretary of Transportation.*



*Center Steering Committee members engaged in discussion. From left: Linda Lawson (Office of the Secretary), Robert Tucillo (Federal Transit Administration), and James Shrouds (Federal Highway Administration).*

Furthermore, FEMA’s National Hurricane Program is working to improve hurricane emergency planning, including mitigation, preparedness, and response and recovery activities. As seen in recent emergencies, inland flooding from hurricanes is a serious public safety concern requiring improved coordination between states and communities during evacuation. Use of real-time technology in managing transportation systems during evacuations could serve to improve this communication, but closer coordination between emergency management and transportation agencies is needed and will become even more necessary in the future.

Virginia Burkett, of the USGS National Wetlands Research Center, discussed the implications of climate change for transportation in the Gulf Coast. She highlighted several key climate change variables, described the impacts of these factors for the transportation sector, and explored adaptation strategies that could be considered. She noted that more frequent and intense rainfall events, higher storm surges, loss of coastal wetlands and barrier shoreline, and land subsidence all pose significant risks for transportation in many areas of the Gulf Coast. Surface roads and rail networks, ports, offshore and near-shore oil and gas production facilities, and onshore processing and pipeline systems may each be affected. The risks to the densely populated city of New Orleans – which is located below sea level and has limited evacuation routes – are particularly high. According to Burkett, Gulf Coast transportation managers need to incorporate weather and climate change projections into mitigation and adaptation strategies. These strategies may include changes in construction and design, hurricane preparedness plans, wetland and water quality mitigation planning, and energy transport. Given the vulnerability of the Gulf Coast to extreme weather events, significantly worse weather could lead to disastrous conditions.

**Breakout Sessions: Creating a Framework for Research Analysis**

Following these plenary sessions, the participants broke into interdisciplinary working groups to discuss in detail specific aspects of the research challenge. Six groups were defined, each with a particular geographic and modal perspective. This framework, illustrated in Figure 2, enabled the workshop as a whole to cover a broad spectrum of research concerns. Each working group was asked to address three questions:

- What are the most significant potential problems that climate change poses for transportation?
- Based on this, what are the priority research topics?
- Who should take the lead in this research?

| Modal Focus                         | Regional Focus |          |                        |
|-------------------------------------|----------------|----------|------------------------|
|                                     | National       |          |                        |
|                                     | Coastal        | Interior | Great Lakes and Rivers |
| Marine                              | X              |          | X                      |
| Rail, Road, and Pipeline            | X              | X        |                        |
| Aviation                            | X              |          |                        |
| Transportation Systems Perspectives | X              |          |                        |

**Figure 2.** A research framework for regional and modal analysis.

Two groups considered the research needs raised for transportation in coastal areas; one focused on marine issues and the other on surface transportation. A third group looked at the issues raised for surface transportation in interior regions. A Great Lakes and rivers group examined research issues raised for marine transportation on waterways throughout the country, as well as the related implications for surface modes. The aviation breakout group

considered research needs related to aviation on a nationwide basis. The sixth group was asked to consider the “big picture” by exploring the research challenges posed by climate change for the nation’s transportation systems as a whole.

A summary of the research recommendations of each group is provided in the following section.

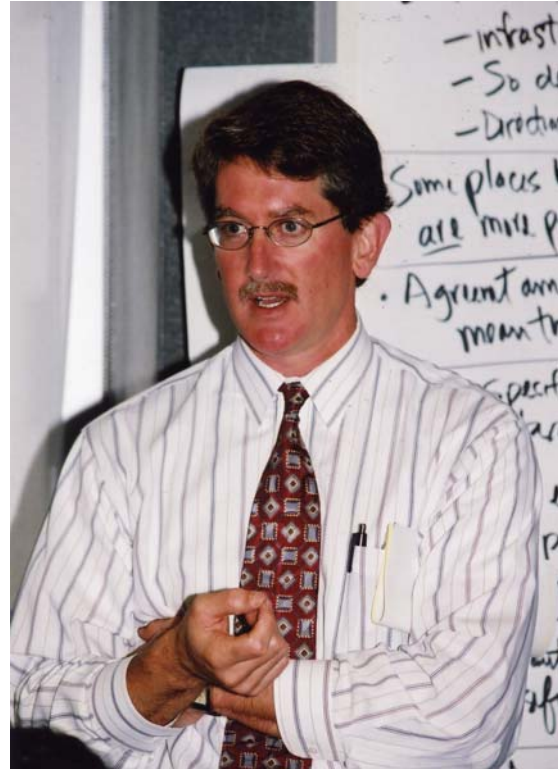
## Research Recommendations

### Analysis Focus Area: Coastal Regions/Marine

The group addressing marine issues in coastal areas identified six major research topics (Table 3). Several research challenges must be met to achieve a better understanding of the potential effects on ports and marine shipping of storms, sea level rise, sedimentation and erosion rates and mechanisms, and changes in key variables such as prevailing winds, waves, currents, and precipitation rates. Research should improve projections of the most likely changes with local and regional resolution. Participants emphasized that the need for research on climate variability is just as important as research on long-term climate change.

Specific research needs include enhancing climate models to simulate storm events, identifying the impact of severe events on ports and shipping, and modeling local sea level rise near ports and shipping channels. Participants recommended studies to identify the most likely impacts of climate change on river hydrology and sedimentation rates (including how varying rainfall could affect erosion into waterways), and case studies of actual sedimentation rates and impacts. Additional research on changes in Arctic shipping should detail the changes in sea ice extent and thickness that may result in longer shipping seasons or new routes.

These advances in scientific modeling and projections would provide the information transportation planners and managers need to prepare or respond to changes in coastal weather and coastline geography. The group also recognized the need for improved tools for



*Michael Carter, Maritime Administration, presenting the findings of the Coastal Regions / Marine breakout group.*



*Orson Smith, University of Alaska at Anchorage.*

**Table 3. Summary of research priorities - coastal/marine.**

| <b>Coastal / Marine</b>   |  |
|---|--|
| <b>Research Challenge</b>   | <b>Specific Research Needs</b>   |
| <ul style="list-style-type: none"> <li>• Storms and sea level rise</li> </ul>                                       | <ul style="list-style-type: none"> <li>– Climate change effects on storm intensity, location, track</li> <li>– Clarification of projected trends</li> <li>– Exploration of local sea level changes and land movements</li> <li>– Simulation of storm events</li> <li>– Impact of severe events at different geographic scales</li> </ul> |
| <ul style="list-style-type: none"> <li>• Sedimentation and erosion</li> </ul>                                       | <ul style="list-style-type: none"> <li>– Impact on wave- and current-induced sedimentation</li> <li>– Changes to rainfall and river hydrology; sedimentation rates</li> <li>– Case studies at ports</li> <li>– Dredging disposal options</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Changes in prevailing winds, waves, currents, and precipitation</li> </ul> | <ul style="list-style-type: none"> <li>– Improved monitoring, modeling</li> <li>– Relation to shipping, port design</li> </ul>   |
| <ul style="list-style-type: none"> <li>• Shipping routes</li> </ul>   | <ul style="list-style-type: none"> <li>– Monitor extent and thickness of sea ice – Arctic and Great Lakes</li> </ul>   |
| <ul style="list-style-type: none"> <li>• Decision making and policy tools</li> </ul>                                | <ul style="list-style-type: none"> <li>– Improved models, elevation maps, GIS; communication tools</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Socio-economic patterns, legal issues</li> </ul>                           | <ul style="list-style-type: none"> <li>– Localized land use, watershed, transport development trends</li> </ul>  |

decision making – improved models, geographic information systems (GIS), and communications that could enable planners and policy makers to better understand and incorporate scientific data. They further recommended that research be conducted to better understand socio-economic patterns – including land use and development trends – and the implications of these trends for marine transport.

**Analysis Focus Area: Coastal Regions/Rail, Road and Pipeline**

The second group turned landside, to consider the key research questions concerning surface transportation in coastal areas. Participants identified four major research challenges that examine the potential impacts of weather events and climate changes on the full range of transportation decision making, from short-term operational decisions to long-range planning and investment decisions.

At the operational level, research should consider the effects of weather-related travel

delays on rail and road system performance. Participants noted that studies to date on weather delays have focused on aviation, rather than on surface transportation. Research on the effects of weather on travel times, and on travelers’ responses to adverse weather can help inform real-time operational and maintenance decisions of transportation managers. A better understanding of weather activity and its effects on surface transportation could support better planning and investment for longer-term climate impacts, reducing delays and enhancing user satisfaction with the transportation network.

The group also highlighted the need for a better understanding of the potential impacts of climate change on both infrastructure and ecosystems, coupled with efforts to capture best practices in road design and construction that respond to these changes. The effect of sea level rise on coastal infrastructure provides one striking example of these impacts. Growing development on coasts compounds the risks of sea level rise. Because of the inter-relationships

of development, sea level change, and changes in severe weather, research is needed to enable transportation decision makers to incorporate these factors into planning for coastal development and transportation infrastructure. These efforts should include assessments of the economies of coastal development and the impacts of climate change, and development of local planning tools, such as GIS tools to create location-specific overlays of sea level rise on critical infrastructure and services.

As coastal conditions change, the impacts of existing coastal roads and other infrastructure on

local environments can change as well. Border roads can, for example, become barriers to wetland migration, acting as unintended dikes. Suggested research includes the identification and development of best practices for the construction and modification of coastal roads to avoid or mitigate environmental damage. This could include GIS overlays of coastal roads and elevations and regional case studies.

Finally, the group suggested measures to improve public understanding of the consequences of climate change. These could include better dissemination of existing information about climate change – and options for state and local responses – as well as research to develop improved methodologies for public education on this topic.

*Table 4. Summary of research priorities – coastal/rail and road.*

| <b>Coastal / Rail and Road</b>  |   |
|---|---|
| <b>Research Challenge</b>   | <b>Specific Research Needs</b>  |
| <ul style="list-style-type: none"> <li>• Weather-related travel time delays</li> </ul>                      | <ul style="list-style-type: none"> <li>– Regional effects on transportation system performance</li> <li>– Travel behavior response to delays</li> </ul>   |
| <ul style="list-style-type: none"> <li>• Impact of climate change on roads and ecosystems</li> </ul>        | <ul style="list-style-type: none"> <li>– GIS overlay of coastal roads and elevations – impacts of sea level rise on roads and habitat</li> <li>– Regional case studies of road design that minimize environmental impacts</li> <li>– Best practices for road construction and location</li> </ul> |
| <ul style="list-style-type: none"> <li>• Smart growth</li> </ul>  | <ul style="list-style-type: none"> <li>– Economies of coastal development and impacts of climate change</li> <li>– Analysis of anticipated sea-level rise and local development plans, using GIS technologies</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Lack of public awareness of climate change consequences</li> </ul> | <ul style="list-style-type: none"> <li>– State and local case studies</li> <li>– Website development on potential climate change impacts</li> </ul>   |



*Stanley Riggs, East Carolina University.*

### **Analysis Focus Area: Interior Regions/Rail, Road and Pipeline**

This expert group focused on research to address projected climate changes in interior regions and their implications for surface transportation and pipelines. The group identified four priority research challenges.

A lack of tools to support decision making related to local and regional scale impact projections creates a significant challenge. The group felt that it is currently very difficult to get useful information developed through climate research to transportation planners. They recommended the development of tools to specifically support transportation decision making at the local and regional level, and tools that integrate climate and impact models at comparable resolutions of current transportation planning. These tools should include risk analysis information and the ability to translate impact research findings into meaningful data used by decision makers. The availability of such tools and information would enable transportation managers to better project and plan for service interruptions, develop design parameters to accommodate expected impacts, and make improved decisions about the location and scale of new infrastructure.

The experts also recognized the need to understand how climate change is likely to affect the hydrologic cycle, and the implications of



*John Zamurs, New York State Department of Transportation.*

such changes on road, rail and pipeline infrastructure. For example, changes in precipitation, soil moisture, groundwater, and flooding may indicate the need to adjust engineering standards, location of infrastructure, maintenance schedules, and safety management. Suggested research includes the evaluation of existing hydrologic models under climate change scenarios, with a particular focus on groundwater issues, landslides, flooding, and sediment transport.

The group also recommended a focus on research to better understand and project risks from potential changes in the frequency and intensity of extreme events. Specifically, because projections based on historic trend lines are expected to be increasingly less accurate as the climate changes, research to develop methods to characterize risks *without* complete reliance on historical data becomes increasingly necessary. In addition, models need validation at multiple geographic and temporal scales.

Finally, the participants noted that there could be shifts in demand for natural resources due to changes in climate. These shifts may have impacts for transportation, depending on the timeframe over which these changes occur and the useful life of the related infrastructure. The group recommended evaluations of the timing and location of shifts in demand, and their intermodal implications.



*Table 5. Summary of research priorities - interior/rail, road and pipeline.*

| <b>Interior / Rail, Road, and Pipeline</b>   |  |
|--|--|
| <b>Research Challenge</b>  | <b>Specific Research Needs</b>   |
| <ul style="list-style-type: none"> <li>• Tools to support local / regional scale impacts projection and decision making</li> </ul> | <ul style="list-style-type: none"> <li>– Service interruptions</li> <li>– Development of appropriate design parameters for new facilities</li> <li>– Integration of climate and impact models at comparable resolution</li> <li>– Data “info mining”</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Hydrologic impacts on road, rail and pipeline infrastructure</li> </ul>                   | <ul style="list-style-type: none"> <li>– Evaluation of existing hydrologic models (under climate change scenarios)</li> <li>– Effects of hydrological changes on groundwater table / quality</li> <li>– Landslides / washout, flooding impacts on transportation facilities</li> <li>– Effects of sediment transport on infrastructure, and response strategies</li> </ul> |
| <ul style="list-style-type: none"> <li>• Extreme events and impacts on roads, rail and pipelines</li> </ul>                        | <ul style="list-style-type: none"> <li>– Methods to characterize risks without complete reliance on historical data</li> <li>– Validation of climate, hydrological and impacts models at multiple scales</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Spatial and temporal shifts in demand</li> </ul>  | <ul style="list-style-type: none"> <li>– Timing and location of shifts in transportation demand, relative to life of infrastructure</li> <li>– Impacts on port facility capacities and inter-modal flows</li> </ul>  |

**Analysis Focus Area: Great Lakes and Waterways/All Modes**

The Great Lakes and Waterways group considered potential climate change impacts on the nation’s waterway system, including the Great Lakes and the Ohio, Mississippi,

Columbia, and Missouri river basins. This network of waterways provides the basis for intermodal transport systems for both freight and passenger movement. In addition, these lakes and rivers support fisheries, industries, and recreation, and have important ecological functions. Recognizing the diverse set of



*George Levasseur, Alaska Department of Transportation and Public Facilities.*



*Roger King, Mississippi State University.*

interests involved, the group focused both on the specific research priorities and on the need to promote improved communication and systems for sharing information among all interests and stakeholders. The group identified three priority challenges for research: projection and analysis of future climate events; analysis of potential responses to these events; and comprehensive analysis of competing interests for water.

Researchers project that climate change may result in lower water levels throughout the Great Lakes system. Lower water levels would have significant implications for freight transport and recreational boating. The group suggested that the effect of climate changes on rainfall and fisheries should also be examined. Continuing to improve modeling and projections of changes in seasonal water levels will be an important ongoing research activity. In addition, further research is recommended that could help to indicate how the characteristics of extreme events are likely to change. Given the number of diverse interests involved, a special effort should be made to develop a common architecture with customers to disseminate research results in usable formats to the range of users of the lakes and rivers.

The results of these modeling efforts should be used to analyze the advantages and costs of possible responses to these events, including assessments of alternative passenger and freight

routes, redundancy, recovery time, and longer shipping seasons. These analyses should include market research, and should have the capability to model intermodal responses to climate changes and events. Research should be initiated to help inform governmental responses to climate changes and events, including the identification of critical infrastructure needs for public sector investment.

Experts stressed the need for a greater understanding of competing interests in the Great Lakes system – particularly regarding the long-term viability of the freight network – as climate changes take place. Lowered water levels would be expected to dramatically change the important parameters used in determining water distribution, creating additional stress in the process of allocating water resources. In making these decisions, more definitive data and model results will be required, as well as an understanding of the legal regulations affecting water management, the impacts on ecosystems, and projections of economic impacts on different industries.

Finally, the group noted the importance of appropriate coordination of any research that is conducted. For research on the Great Lakes, DOT should work with the International Joint Commission (IJC) and ensure Canadian involvement on research topics of joint interest.



*Donald Trilling, Office of the Secretary of Transportation, presenting the findings of the Great Lakes and Waterways breakout group.*



*Harry Caldwell, Federal Highway Administration.*

**Table 6.** Summary of research priorities - Great Lakes and waterways/all modes.

| <b>Great Lakes and Waterways / All Modes</b>  |  |
|---|--|
| <b>Research Challenge</b>   | <b>Specific Research Needs</b>   |
| <ul style="list-style-type: none"> <li>• Future events that will impact the waterway system</li> </ul>  | <ul style="list-style-type: none"> <li>– Projection of extreme events: severity, frequency, variability</li> <li>– Global and regional modeling to forecast: low flows, high rainfall events, impact on fisheries, impacts on navigation</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Responses to events; government management of impacts</li> </ul>   | <ul style="list-style-type: none"> <li>– Identification of alternative passenger and freight routes, modal splits, redundancy, recovery time</li> <li>– Modal interaction down river with events on the Great Lakes</li> <li>– Identification of demand network, supply network, defense network</li> <li>– Development of intermodal simulation capability to model changes, severe event frequency</li> <li>– Designation of critical infrastructure for investment decisions, and for government support</li> </ul> |
| <ul style="list-style-type: none"> <li>• Understanding of competing interests for water after long-term climate changes, as related to freight viability</li> </ul> | <ul style="list-style-type: none"> <li>– Legal analysis of moving water between basins</li> <li>– Impact on environment, endangered species, stakeholders</li> <li>– Comprehensive basin studies</li> <li>– Prediction of climate impacts</li> </ul>   |

### **Analysis Focus Area: National/Aviation**

The aviation breakout group discussed the relative needs of the industry for improved information regarding long-term changes in climate versus an improved understanding of near-term weather phenomena and climate variability. Research related to climate change and aviation has generally been regarded as a lower priority by both industry and government due in part to other, more immediate concerns confronting aviation, as well as to a lack of familiarity with the potential aviation risks posed by climate variability and change. Increased dialogue and communication among researchers, the FAA, and the range of public and private sector interests involved in aviation – owners and managers of airport facilities, airlines, manufacturers, and suppliers – will improve understanding of the aviation challenges stemming from climate change. The participants explored opportunities to advance research related to climate change and variability by building upon existing research activities in weather, environmental effects, safety, and technology. Five priority research challenges were identified.

The group identified achieving a better understanding of the relationships between high altitude emissions and climate chemistry as the first major research challenge. This will require additional data collection through monitoring and field campaigns, building upon the ongoing observational work conducted by the Department of Defense, NOAA, NASA, and the National Science Foundation. These data need to be incorporated into global air quality models for analysis. Sensitivity studies are required to assess the potential efficacy of policy and technology options, in collaboration with FAA and industry.

The second major research challenge lies in improving predictability of weather phenomena (i.e. timing, confidence, location, frequency) in the face of a changing climate. Advances in weather prediction will support aviation decision making regarding location of facilities, flight paths, operations, and safety. Research in this area should build upon the substantial weather research already underway through the FAA and Federal science agencies. Additional research is needed to understand the potential effects of

climate change on convection, jet streams and turbulence, extreme events, winter weather conditions, visibility, and radiation.

The group also recommended research to identify technical strategies that will reduce aviation contributions to climate change. Research is needed, in particular, on the potential of advanced aircraft and engine technologies – both of alternative airframe and engines and improvements to existing technologies – to reduce greenhouse gas emissions from aviation, and research to promote higher efficiency and cleaner fuels.

Recognizing that the aviation community faces a range of environmental issues, the group highlighted the need to develop an integrated framework to assess these factors and the interaction of potential strategies intended to improve individual environmental effects, such as emissions, noise, and climate impacts. This analysis could assess costs and benefits of various strategies, reveal unintended counter-effects of some strategies, and potentially identify synergistic approaches to address multiple environmental needs.

Similarly, the group discussed how best to link ongoing research to improve aviation safety and efficiency with research and development to address environmental impacts. Research in this area needs to be conducted in close collaboration with industry, academia, and the FAA, and should be informed by an assessment of user needs, including identification of potential incentives to encourage research and development in this area. The group recommended that this assessment include examination of the potential effects on insurance costs. The experts stressed the importance of working with the entire aviation community to understand their priorities and concerns related to climate change – and to consider ways to integrate research on climate change with analysis of other concerns – including environmental issues, efficiency, and safety.

The experts also suggested several additional topics for specific research to provide aviation planners and operators improved data to support decision making. These topics include

the potential effects of more hot days on lift pavement, the implications of sea level rise and storm surges on airport facilities and operations, the effects of climate variability and change on location and aviation route decisions, and the potential interaction between changing climate and aviation in the spread of diseases.



*Linda Lawson, Office of the Secretary of Transportation, presenting the findings of the Aviation breakout group.*



*Anne Grambsch, Environmental Protection Agency.*

*Table 7. Summary of research priorities - national/aviation.*

| <b>National / Aviation</b>   |   |
|--|---|
| <b>Research Challenge</b>  | <b>Specific Research Needs</b>  |
| <ul style="list-style-type: none"> <li>• High altitude aviation emissions and climate chemistry</li> </ul>                                 | <ul style="list-style-type: none"> <li>– Monitoring of high altitude emissions, field campaigns</li> <li>– Incorporation of emissions data into global air quality models</li> <li>– Analysis of high altitude emissions impact on climate</li> <li>– Sensitivity and policy studies</li> </ul> |
| <ul style="list-style-type: none"> <li>• Improved predictability of weather phenomena (timing, confidence, location, frequency)</li> </ul> | <ul style="list-style-type: none"> <li>– Convection</li> <li>– Jet stream / turbulence</li> <li>– Extreme events</li> <li>– Winter weather conditions</li> <li>– Visibility / ceiling</li> <li>– Radiation</li> </ul>   |
| <ul style="list-style-type: none"> <li>• Aircraft and engine technology</li> </ul>   | <ul style="list-style-type: none"> <li>– Alternative engines</li> <li>– Improvements to current engines</li> <li>– Fuels</li> <li>– New lightweight materials</li> <li>– Multidisciplinary design for operations</li> </ul>   |
| <ul style="list-style-type: none"> <li>• How to tie research and development in environment to safety, efficiency</li> </ul>               | <ul style="list-style-type: none"> <li>– Use existing FAA network to assess user needs</li> <li>– Identification of incentives (e.g. potential increased insurance costs)</li> </ul>  |
| <ul style="list-style-type: none"> <li>• Integrated framework to incorporate climate into environmental analysis</li> </ul>                | <ul style="list-style-type: none"> <li>– Tradeoffs between emissions, noise</li> <li>– Portfolio management tool to inform decision makers</li> </ul>   |

### **Analysis Focus Area: National/Transportation Systems**

The final breakout group examined the overriding topics of concern from a nationwide, transportation systems perspective. This group identified research priorities related to climate variability and change that would inform effective planning and investment decisions and support a strong and viable intermodal transportation network. The group identified four key challenges requiring research: improved understanding of weather effects, integration of climate change factors with environmental and transportation planning, institutional barriers and decision making processes involving multiple organizations and stakeholders, and risk assessment techniques to support sound decisions.

An increased research focus on regional and local effects of weather and climate variability would build an improved understanding and predictive capacity of weather impacts at a level appropriate and useful for transportation decision makers. This will require significant, long-term research, including development of data and models to support regional and local estimates; better scenario development; and study of the specific effects of weather and climate variability on infrastructure, patterns of development, transportation operations and services.

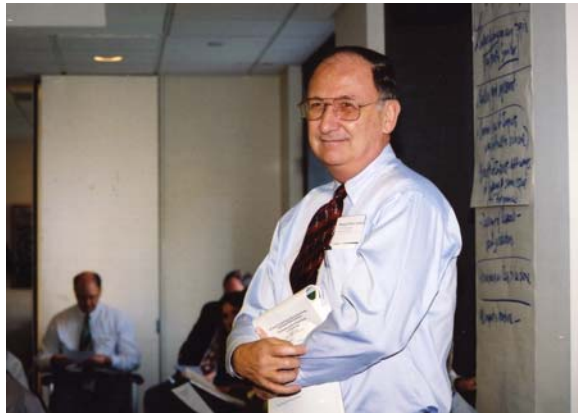
The participants identified a need for tools to integrate environmental and transportation plans to better understand and assess the interactions among climate change, air, and water quality in transportation decisions. They

called for applied research to define and share best practices among transportation practitioners, focusing on win-win strategies that reduce risks associated with climate change,

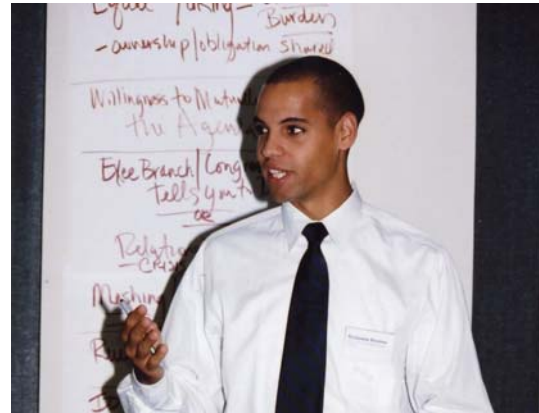
support sound transportation, and are environmentally beneficial.

*Table 8. Summary of research priorities - national/transportation systems.*

| <b>National / Transportation Systems</b>   |   |
|--|---|
| <b>Research Challenge</b>  | <b>Specific Research Needs</b>  |
| <ul style="list-style-type: none"> <li>• Uncertainties about science of climate variability and weather effects</li> </ul> | <ul style="list-style-type: none"> <li>– Data and models for regional / local estimates</li> <li>– Better climate scenario development</li> <li>– Effects on infrastructure, patterns of development, operations and services</li> </ul>                              |
| <ul style="list-style-type: none"> <li>• Integrating environmental and transportation plans</li> </ul>                     | <ul style="list-style-type: none"> <li>– Enhanced understanding of interactions, changes in air and water quality</li> <li>– Identification and dissemination of best practices</li> <li>– Search for environmentally-beneficial transportation strategies</li> </ul> |
| <ul style="list-style-type: none"> <li>• Institutional barriers and decision making</li> </ul>                             | <ul style="list-style-type: none"> <li>– Comparative analysis across government, private sector</li> <li>– How to elevate climate awareness in transportation</li> <li>– Better communication with decision making public</li> </ul>                                  |
| <ul style="list-style-type: none"> <li>• How to do risk assessment</li> </ul>  | <ul style="list-style-type: none"> <li>– Scenario building, testing</li> <li>– Identification of vulnerable assets</li> <li>– Exploration of reinsurance industry experience</li> </ul>   |



*Michael MacCracken, U.S. Global Change Research Program (retired).*



*Benjamin Preston, Pew Center on Global Climate Change.*

The group recognized that transportation decision making occurs at various levels of government, and involves multiple government agencies with different mandates and priorities, private sector entities, and the general public. Research to address institutional barriers would support improved communication and analysis across institutions. The group also recommended research to identify ways to elevate climate awareness both within the transportation community and with the public at large.

The ability to understand and evaluate levels of risk lies at the core of effective decision making. The group highlighted the need to advance the transportation community's capacity to assess risks associated with climate variability and change. This will involve scenario development and testing, development of modeling techniques, and identification of vulnerable transportation assets. The group recommends collaborating with the reinsurance industry in this work.

## Conclusions

The research workshop on the *Potential Impacts of Climate Change on Transportation* helped spark a new level of dialogue between the climate change and transportation communities – the beginning of a multi-disciplinary discussion that can enrich scientists and practitioners working in both arenas.

## Key Research Needs

There is a significant need for research to build knowledge and capacity about the connections between climate change and transportation. Such research holds great potential to help transportation planners and managers better prepare for and manage the impacts of climate change on the transportation system. At the same time, the research and transportation communities need to make existing research findings available to transportation decision makers. While a broad range of research challenges and needs were identified, some key themes for future research emerged through the day and a half of discussions.



Virginia Burkett, U.S. Geological Survey.



Center Steering Committee Chair Joel Szabat, Office of the Secretary of Transportation, addressing the workshop participants at the close of the event.

## *Climate and Weather Projections at Regional and Local Levels*

The need for improved regional-level modeling and scenario development was a recurring theme in the recommendations of the breakout groups and in the full-group discussions. Because transportation decisions and investments are most often made at local and regional levels, a regional approach is essential to provide

information at a meaningful level of specificity. Further, analysis at the regional and local level can best reflect the variation in risks to transportation systems in different parts of the country. While better use of existing information can inform some transportation decisions today, transportation planners and managers need more refined models and projections.

#### ***Assessment of Impacts on Critical Infrastructure Locations and Facilities***

The results from improved regional-level climate and weather projections would support improved modeling and analysis of the range of potential climate impacts on transportation infrastructure. This will help planners and transportation managers identify the key facilities and locations that may be impacted. Impacts of particular interest to transportation could result from hydrologic changes, changes in the patterns and location of extreme events, changes in coastal geography and storm activity, and changes in prevailing climate and weather.

#### ***Analysis of Impacts on Operations, Maintenance, and Safety***

Changes in climate have implications not only for the built transportation infrastructure but also for the safe and efficient management and operation of the transportation network. Research to understand the potential effects of long-term climate change on adverse weather conditions, temperatures, and seasonal precipitation patterns – and the meaning of these shifts for seasonal and real-time management of the transportation system – will improve our understanding of challenges to system operation.

#### ***Improved Tools for Risk Assessment and Decision making***

Transportation managers need improved tools to effectively incorporate climate change data and projections into their decisions regarding planning, asset management, and operations. Techniques to assess the relative risks of climate change to different aspects of the transportation network will allow decision makers to

appropriately target resources to the most significant infrastructure and systems. Use of geographic information system technologies and scenario modeling could assist in identification of key concerns and evaluate response strategies.

#### ***Integration of Climate Change Assessment with Other Transportation Decisions***

Transportation decision makers need frameworks to integrate consideration of climate changes with other key dynamics, including development patterns, technological advances, economic trends, and ecological changes. Tools are needed to integrate impacts assessment with environmental assessments and with transportation planning processes across all modes of transportation.

#### ***Assessment of Response Strategies***

Research is needed both to better understand the range of potential response strategies available to transportation managers to avoid or adapt to the impacts of climate changes on transportation, and potentially to develop new responses. Decision makers will need tools to evaluate an array of potential strategies – including changes in infrastructure location, engineering and design responses, operational strategies, and modal shifts – and to assess the direct costs and benefits, long-range effects on ecological systems, economic and social effects, and economic implications of each option.

#### ***Coordination, Communication, and Public Awareness***

In addition to their recommendations on research priorities, workshop participants identified key actions that would advance the state of knowledge, help support transportation managers in making sound decisions, and enable researchers to be more effective. These include the following recommendations:

##### ***Improve Sharing of Data and Knowledge***

Workshop discussions highlighted the considerable amount of research that has been accomplished by numerous Federal agencies and



private research organizations. This research has already produced a significant amount of valuable data and research products that transportation decision makers could use; yet much of this information has not reached transportation managers or the general public. Increased focus should be given to the customization and dissemination of existing data and knowledge so that it can be used both by policy makers and by other researchers.

### ***Integration into CCSP Strategic Priorities***

Participants noted that the research priorities identified for DOT and other Federal agencies through the workshop should be coordinated with the U.S. Climate Change Science Program, which is developing the interagency strategic plan for federal climate change research. DOT is a Federal partner of CCSP, and plays an active role in the development of the federal research strategic plan.<sup>15</sup>

### ***Leveraging Existing Research Activities***

Participants emphasized both the opportunities for the transportation community to work more closely with the climate and weather research communities to share knowledge and resources in this emerging field. In addition, they emphasized the importance of multi-disciplinary

approaches to research. They encouraged DOT to collaborate with research partners to tap expertise in other fields, and to leverage the investments of other organizations in climate change research. Working with other Federal agencies, international agencies, industry, and academia can help make the best use of limited DOT resources.

### ***Public Education and Outreach***

Participants stressed the need to improve public access to and awareness of research findings, and the responsibility of the transportation and research communities to provide this information to the general public through formats and tools that are readily understood. There is a broad diversity of economic, social and environmental interests that must be addressed as adaptation or mitigation strategies are developed. Outreach and education efforts will assume a growing importance as research produces results and the outlines of potential adaptation strategies begin to form. Improved availability of information on the range of potential climate changes and adaptation options will help the public effectively participate in transportation planning processes and support sound community decisions and investments.

<sup>1</sup> For further information, see: US Climate Change Science Program, 2003. *Strategic Plan for the U.S. Climate Change Science Program*. <http://www.climatechange.gov/Library/stratplan2003/final/default.htm>. A National Research Council evaluation of an earlier draft of the plan is also available: National Research Council, 2003. *Planning Climate and Global Change Research: A Review of the Draft U.S. Climate Change Science Program Strategic Plan*, Washington, DC: The National Academies Press.

<sup>2</sup> National Assessment Synthesis Team, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, Cambridge, UK: Cambridge University Press, 2001. See: <http://www.usgcrp.gov/usgcrp/Library/nationalassessment/foundation.htm>.

<sup>3</sup> See USGCRP National Assessment webpage for links to regional assessment homepages: <http://www.usgcrp.gov/usgcrp/nacc/default.htm>. Links to regional assessment reports can be found at <http://www.usgcrp.gov/usgcrp/nacc/allreports.htm>.

<sup>4</sup> See USGCRP National Assessment webpage for links to sectoral assessments; <http://www.usgcrp.gov/usgcrp/nacc/default.htm>.

<sup>5</sup> Climate Change Science Program and the Subcommittee on Global Change Research, *Our Changing Planet: The Fiscal Year 2003 U.S. Global Change Research Program and Climate Change Research Initiative*, 2003.

<sup>6</sup> For example, several studies of impacts on the New York City area have been released. See Gornitz, V., S. Couch, and E.K. Hartig, 2001, "Impacts of sea level rise in the New York City metropolitan area." *Global Planetary Change* 32, pp 61-88. See also Bloomfield, J., Smith, M. and Thompson, N., *Hot Nights in the City: Global Warming, Sea-Level Rise and the New York Metropolitan Region*, Environmental Defense, 2001.

<sup>7</sup> National Research Council, *Climate Change Science: An Analysis of Some Key Questions*, Washington DC: National Academy Press, 2001.

<sup>8</sup> Condensed and adapted from the National Assessment Synthesis Team, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, Cambridge, UK: Cambridge University Press, 2001.

<sup>9</sup> See the Environmental Impacts Reports series on the Pew Center website for a complete listing, at [http://www.pewclimate.org/projects/index\\_environment.cfm](http://www.pewclimate.org/projects/index_environment.cfm).

<sup>10</sup> *Evaluation of Erosion Hazards*, prepared for the Federal Emergency Management Agency by the H. John Heinz III Center for Science, Economics and the Environment, April 2000.

<sup>11</sup> See *The Canada Country Study: Climate Impacts and Adaptation*, conducted by Environment Canada.

<sup>12</sup> See the many regional reports of the United Kingdom Climate Impacts Programme, <http://www.ukcip.org.uk/>.

<sup>13</sup> IPCC, *Climate Change 2001: Impacts, Adaptation, and Vulnerability*, Cambridge, UK: Cambridge University Press, 2001.

<sup>14</sup> See for example, *Climate Change and a Global City: An Assessment of the Metropolitan East Coast Region*, Assessment Synthesis, [http://metroeast\\_climate.ciesin.columbia.edu/sectors.html](http://metroeast_climate.ciesin.columbia.edu/sectors.html).

<sup>15</sup> For further information, see: U.S. Climate Change Science Program, 2003. *Strategic Plan for the Climate Change Science Program*. <http://www.climatechange.gov/Library/stratplan2003/final/default.htm>. A National Research Council evaluation of an earlier draft of the plan is also available: National Research Council, 2003. *Planning Climate and Global Change Research: A Review of the Draft U.S. Climate Change Science Program Strategic Plan*, Washington, DC: The National Academies Press.

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