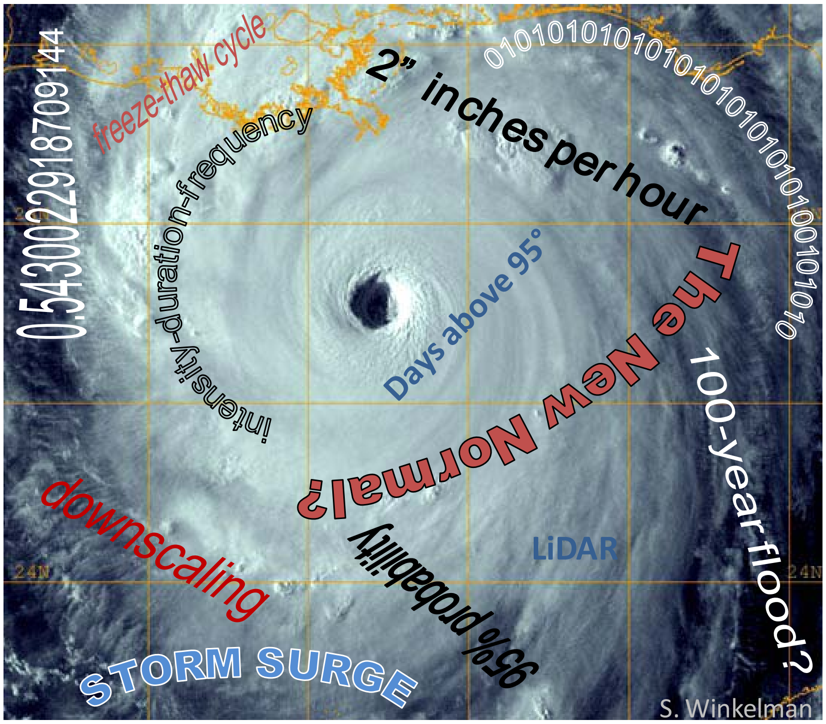
CLIMATE ADAPTATION & TRANSPORTATION

Identifying Information and Assistance Needs

Summary of an Expert Workshop held November 2011



Center for Clean Air Policy

Environmental and Energy Study Institute

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About CCAP

Since 1985, the Center for Clean Air Policy (CCAP) has been a recognized world leader in climate and air quality policy working at the local, U.S. national and international levels. Headquartered in Washington, D.C., CCAP helps policy-makers around the world develop, promote and implement innovative, market-based solutions to major climate, air quality, energy, infrastructure and land use problems that balance environmental and economic interests. www.ccap.org.

CCAP's work on transportation and climate adaptation connects infrastructure and land use planning, economics and climate policy. Recent reports include, "Ask the Climate Question: Adapting to Climate Change Impacts in Urban Regions," "The Value of Green Infrastructure for Urban Climate Adaptation," "Lessons Learned on Local Climate Adaptation," and *Growing Wealthier: Smart Growth, Climate Change and Prosperity*. CCAP's new program and blog, Weathering Climate Risks addresses corporate and urban climate preparedness, emphasizing risk management, critical infrastructure and the economics of adaptation.

About EESI

The Environmental and Energy Study Institute (EESI) is a 501(c)3 non-profit organization that advances innovative policy solutions that set us on a cleaner, more secure and sustainable energy path. EESI was founded by a bipartisan Congressional caucus in 1984, and today is governed by a diverse Board of Directors made up of environmental, business, academic, and former political leaders. Now an independent organization that receives no Congressional funding, EESI maintains its strong relationship with Congress and serves as a trusted source of credible, non-partisan information on energy and environment solutions. www.eesi.org

EESI's work on climate adaptation includes, "Planning for a New Energy and Climate Future," a report prepared with, the American Planning Association (APA), and the University of North Carolina, which explores the role that planners can play in meeting energy needs, reducing GHG emissions, and adapting to climate change**.**

Cover Art

Designed by Steve Winkelman. Background photo of hurricane Katrina from www.hurricanekatrina.com.

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INTRODUCTION

This report summarizes the presentations, discussions and recommendations from a workshop, "Climate Adaptation & Transportation: Identifying Information and Assistance Needs," held November 16-17, 2011. Funded by the National Oceanic and Atmospheric Administration (NOAA) Sector Applications and Research Program, the workshop was designed and facilitated by the Environmental and Energy Study Institute (EESI) and the Center for Clean Air Policy (CCAP).

The workshop brought together transportation and climate professionals to identify the critical support needs of surface transportation professionals as they adapt their practices to climate change and shifting trends in extreme weather. Previous workshops have examined and characterized the physical impacts of climate change and extreme weather on the transportation sector. [1, 2] This gathering focused on assessing the operational needs of transportation practitioners for evaluating and implementing adaptation measures and how the climate science community can help meet needs for:

- Data and information
- Analytic and decision support tools
- Technical assistance
- New research
- Communications and outreach support

The workshop presentations are available for download here: www.ccap.org/adaptation.html.

Economic Context

Severe weather in the US caused more than $50 billion in damages in 2011, a year that saw record-breaking extreme weather across the country.[3] Already 2012 has been a challenge for many communities, from the latest intense tornados in Kentucky, Indiana and Ohio, to the record 15-inch rainstorm in Louisiana. The transportation sector often bears significant losses from extreme weather events – at a time when transportation agencies are already faced with failing infrastructure and major budgetary constraints. There are numerous examples of higher than usual weather-related maintenance and repair costs from all over the country in recent years. Here are just a few:

- Rhode Island experienced losses of $1.5 billion in 2010 from the worst flooding in state history.
- Flooding in North Dakota in 2011 cost $195 million in road repairs. On the Souris River, the floods exceeded the 130-year-old record for flood crests by almost 4 feet.
- Vermont suffered millions of dollars of damage to transportation infrastructure from Tropical Storm Irene. Damage to the state highways system alone was between $175 and $250 million dollars.

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[1] FHWA, "Peer Workshop on Adaptation to Climate Change Impacts," December 2008. http://www.fhwa.dot.gov/planning/statewide/pwsacci.htm
[2] AASHTO, "Climate Change Adaptation Strategies Workshop," November 2010. http://climatechange.transportation.org/about/products_programs.aspx
[3] NOAA Billion Dollar U.S. Weather/Climate Disasters, http://www.ncdc.noaa.gov/oa/reports/billionz.html#chron.

Participant Organizations

The workshop was attended by a variety of experts from all levels of government, research institutions, consulting and NGOs. Participants included planners, engineers, climate scientists, environmental experts, program administrators, project managers, and others. See Appendix A for full participant list.

Federal

- Federal Highway Administration, USDOT
- Federal Transit Administration, USDOT
- National Climatic Data Center, NOAA
- National Environmental Satellite, Data, and Information Service, NOAA
- US Geological Survey
- US Global Change Research Program

State, Regional & Local

- California DOT (by phone)
- Chicago Transit Authority
- Maryland DOT
- Massachusetts DOT
- Metropolitan Transportation Commission (San Francisco Bay Area)
- Miami-Dade County MPO
- New York City Metropolitan Transportation Authority
- North Jersey Transportation Planning Authority
- Portland Metro
- Virginia DOT
- Washington State DOT

University/Research

- Georgetown Climate Center
- National Center for Atmospheric Research
- Oregon Climate Change Research Institute, Oregon State University (by phone)
- Oregon Transportation Research and Education Consortium, Portland State University
- RISA-Southern Climate Impacts Planning Program, University of Oklahoma

Consulting

- Cambridge Systematics
- CH2M Hill
- ICF
- Parsons-Brinkerhoff

NGO

- American Association of State Highway and Transportation Officials (AASHTO)
- Center for Clean Air Policy
- Environmental and Energy Study Institute

Background

This study was undertaken to advance efforts to adapt the planning, design, operation, and maintenance of transportation infrastructure to changing patterns of climate and extreme weather. Transportation planning has been typically been conducted based on historical data – with the underlying assumption that existing climatic conditions will continue into the future. However, as documented in recent studies[4,5,6] and several conferences and workshops convened within the transportation community, climate change portends to have far-reaching impacts on transportation infrastructure and associated systems.

Extreme weather events, including coastal storm surges, flooding, heating and freezing, and severe rain, snow, ice, and wind events, as well as changing average conditions and seasonal weather patterns – including, sea level rise, precipitation totals, mean temperatures, evapotranspiration rates, and ecosystem changes, are projected to affect safety, cost-effectiveness, efficiency, and technical feasibility of transportation investment and asset management decisions.

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[4] Transportation Research Board, "Potential Impacts of Climate Change on U.S. Transportation--Special Report 290," National Academy of Sciences, 2008. http://www.nap.edu/catalog.php?record_id=12179

[5] U.S. Climate Change Science Program, "Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I," 2008. http://www.gcrio.org/library/sap-final-reports.htm

[6] Transportation Research Board,"Adapting Transportation to the Impacts of Climate Change," National Academies, June 2011. http://onlinepubs.trb.org/onlinepubs/circulars/ec152.pdf

These impacts will vary from region to region and may even vary at the local and site scale. Anticipating the consequences of such disruptive changes and planning prudent responses before they become reality will help transportation agencies protect the transportation infrastructure upon which communities, regions, and the national economy depend for the movement of goods and people. The general nature of potential climate change impacts on transportation has been reasonably well-defined. The specific operational implications for transportation agencies and the broader transportation community, however, are not well understood. Transportation agencies and professionals will need to respond in all of their major activities, including:

- Policy
- Planning
- Budgeting
- Siting
- Design and engineering
- Maintenance
- Operations

It is unclear how prepared and equipped transportation agencies are to adapt each of these practices to the changing climate, especially in today's challenging budget environment. This workshop aimed to inform and address actions to increase the adaptive capacity of transportation officials.

Transportation planners, project designers, budget managers and others will need specific guidance on how to translate climate change projections into actionable, quantitative decision parameters and criteria. Transportation officials will need information on the magnitude, frequency, and timeframes of different climate change variables. They will need to know how climate change will affect specific regions, locations, and sites, as well as natural features, such as individual rivers and streams. They will need information regarding the probabilities and uncertainty of different climate scenarios in order to factor climate information into broader financial evaluations and risk analyses. Policymakers will need cost estimates of the impacts of climate change on transportation infrastructure. Then, they will need to be able to integrate climate information with other criteria and processes for making planning, project, budget, and other critical decisions.

Meanwhile, the weather information community – and, to some degree, the climate science community – are well-versed in providing data and guidance to transportation system managers regarding extreme weather events, and they are pioneering new approaches to weather monitoring that will support enhanced weather-based decision making. However, how existing and future climate research and data gathering efforts need to targeted, tailored, and packaged in order to be specifically useful to the transportation community has not yet been adequately examined. There are considerable gaps in climate research and data resources at scales relevant to transportation decisions. There are continuing challenges for researchers in understanding the climate information requirements of the transportation sector, and in translating that science on climate impacts into useful guidance. In addition, different activities and different types of decision analyses within the transportation community may have different or more specific information needs than other transportation decisions. Understanding those differences and its implications for the collection and delivery of climate information and the development of data analysis tools is also critical.

Transportation agencies, like all human institutions, have imperfect decision making processes as well as organizational obstacles and inertia to incorporating new information and adapting to new challenges. Different areas of the transportation community may not only have different information needs, but also different challenges in terms of integrating that information into existing information flows and decision making processes. Climate information may not be effectively used if transportation professionals are not sufficiently engaged and motivated to apply such information. Evolution and adaptation of institutional cultures and procedural norms likely need to accompany the provision of new data and development of new decision making tools. Information and data tools from the climate science community may also need to be provided in ways that respond to and help address these organizational issues. As a starting point, climate information providers may want to emphasize changes in extreme weather events that DOTs are already encountering.

SUMMARY OF MAJOR FINDINGS AND RECOMMENDATIONS

Over two days of presentations, information exchange, and intensive discussion, participants in a November 2011 workshop organized by EESI and CCAP, in collaboration with NOAA, sought to answer these two questions:

- **What kinds of information and assistance do transportation professionals need to more effectively adapt the transportation system to climate change and extreme weather?**
- **How can the climate science community help meet those needs?**

The workshop examined key challenges facing transportation officials in making climate adaptation decisions. The workshop identified several key issues that had been identified by the organizers through prior research, but presentations and subsequent discussions throughout the workshop also uncovered a number of additional issues and clarified several misconceptions regarding the role of climate and weather science in transportation decision-making.

Here are the major findings and recommendations that emerged. Note that these reflect CCAP's and EESI's best effort to summarize meeting outcomes, but are *not* intended to represent the specific views of any individual, agency or organization.

1. Better information on local, non-climate factors is often equally or more important to adaptation decisions than climate science information.

One of the fundamental findings of the workshop is that **understanding local conditions and context** is crucial. Some of the most important data for assessing vulnerabilities and adaptation opportunities are not directly related to climate science. "On-the-ground" information regarding, infrastructure elevation, state of repair, capacity of culverts, land development trends and natural resource conditions –soil, land cover, land use change, and hydrology – are dominant factors in decisions regarding climate and extreme weather adaptation. Uncertainty and variability in non-climate data often outweigh uncertainty regarding future climate projections.

Adaptation starts with determining how well critical infrastructure is adapted to current climate and weather conditions. Records on infrastructure age, maintenance history, impacts from past storms are all important for determining current and future vulnerabilities. Natural factors such as **soil saturation**, **tide levels**, **river flows and sediment levels** can make the difference between moderate and severe flooding. Most climate models do not provide such information, but local parameters and conditions can be used to define a range of climate impact scenarios. In some cases local hydrologic and river flow models may prove more useful than downscaled climate models.

Similarly, **interactions among local factors** can significantly exacerbate the effects of climate change and extreme weather but need to be considered off-model. Such chains of interactions can be physical or operational and have 2nd, 3rd and 4th order dimensions. For example, severe rain may cause a dam to fail which, in turn, inundates nearby transportation infrastructure. Or, an extreme storm, combined with heat-stressed forest cover could lead to more trees falling into a stream, which results in a clogged culvert and a collapsed roadway, which, in turn, brings down power lines, thereby reducing rail traction power or interfering with rail service in corridors also used for utility lines. Such potential vulnerabilities are best identified through common-sense discussions among infrastructure operators and service providers (energy, transportation, water, telecommunications) to provide a basic mapping of key interactions and interdependencies. Climate and weather information are an important input to this analysis, but again, understanding local factors can be even more important in analyzing scenarios that could trigger such cascading impacts. Discussions with local experts can identify these factors, and shed light on what keeps maintenance staff up at night, without waiting for further data improvements.

Recommendations

➔ **Enhance data on local contextual factors:**
- Infrastructure elevation, condition and capacity
- Land cover, land use change and development trends
- Natural factors: soil saturation, hydrology, tide levels, river flows and sediment levels

➔ **Develop extreme weather impact scenarios based on recent events, climate forecasts and local conditions to identify vulnerabilities and potential cascading effects**

2. Certain climate and weather information products are particularly important to adaptation efforts for transportation. Much of this information can be developed or significantly improved using current climate models.

Areas where key information is in need of improvement and updates include:

Precipitation

➔ ***Finish updating NOAA Atlas 14 for all regions; update them more frequently***

➔ ***Compile data on projected changes in precipitation in the same format as NOAA Atlas 14, taking climate change into account***

- Seasonal and monthly precipitation
- Extreme events – with enhanced spatial and temporal resolution
- Snow melt, change in snow cover, ice storms
- Seasonal trends (and projections) in reservoir volumes

Flooding

➔ ***Updated flood maps – taking climate change scenarios into account***

- Runoff data and projections

Temperature

- Seasonal and monthly
- Daily extremes (very hot, very cold)
- Frequency/intensity of heat waves
- Changes to freeze/thaw cycles
- Remote sensing of transportation infrastructure

Coastal Storms

- Projected changes in intensity and frequency
- Projected storm surge
- Probability of a given location being hit by hurricane

Sea Level Rise

- Range of projected SLR increases
- Projected rates of local change that account for SLR projections and local geologic factors (subsidence, erosion, local variations in sea level)
- LiDAR data for coastal areas
- Baseline Digital Elevation Model data (DEMs) for all coastal areas, with Infrastructure
- ➔ **Standardization of DEMs so that they can be meshed**
- DEMs with layers for different scenarios of SLR
- DEMs for all areas around lakes and rivers (for flooding analyses)

3. The form in which climate and weather information is communicated and delivered is as important as its availability.

Workshop participants repeatedly emphasized that the way in which information is communicated and delivered bears directly on its value and usefulness. In particular, they highlighted the importance of:

- Clear guidance on **where** to look for information, including the need for a central clearinghouse for climate and weather information relevant to transportation officials.
- Clear guidance on **how** information should and should not be used.
- Using clear, plain language and graphics.

Improving Communication

Climate data and information – in raw form or even processed information – are not typically accessible to non-climate scientists such as transportation planners, engineers and policy makers. Workshop participants identified the need for improved two-way communication, identifying responsibilities for both climate information providers and users. Transportation practitioners need to become more informed about the forms, quality, applications and uncertainties in climate information. Climate information providers need to understand how to present their findings in a way that's accessible and meaningful to users.

Lost in Translation

- ➔ **Scientists and engineers do not speak the same language**
  - Need Climate-to-English translation.
    - De-wonkify terminology
    - Use familiar units (°F not °C, inches not cm)
  - Rethink terms– e.g., a 100-yr storm is a magnitude and frequency issue. Would it be more accurate and accessible to refer to 1% probability events?

- Promote communication among

- Climate modelers (NOAA, universities)
- Hydrologists, statisticians, weather experts (National Weather Service, state climatologists)
- Engineers, planners, environment staff

- Differences in data needs and translating data used by the different fields
  - Annual series (hydrologists, engineers) verses partial duration (climate modelers)
  - Different assessment of what constitutes "robust" data

- Comfort with applying projections versus following trends in historic data

Where to Find What You Need

Participants emphasized the need for guidance on where to find climate information. The NOAA Climate Portal was seen as a valuable resource and good starting point. For most participants it is not obvious who to contact for what they need, be it data, information, models or technical assistance. Or, as Bill Murray and Dan Aykroyd put it:

➔ **Who Ya Gonna Call?**

Recommendations

➔ **Establish a central clearinghouse of information sources and guidance including:**

- **Information on what agencies are doing**
  - "Producers" of climate info (NOAA, NWS, USGS, EPA, state climatologists)
  - "Consumers" (USACE, FEMA, USDOT, etc.)
  - General responsibility, available assistance
  - Research results
  - Relevant regulatory development, guidance, outreach, etc.
  - State and local efforts/results
  - Existing federal inter-agency coordination
    - FHWA and USGS
    - Army Corps and NASA: engineers, scientists, planners
  - Outreach to track developments, post status updates, contacts, etc.
  - Academic and other research results
  - **Who to call** for additional guidance

- **Best management practices** (e.g., reliability centered maintenance)
  - For each step in adaptation planning (e.g., risk assessment, prioritizing responses)
  - For key sectors (transportation, electricity, water, telecommunications, etc.)
  - Examples from international experience
    - E.g., Rotterdam working "with" water
    - Engineers Canada is developing a triple-bottom line study of adaptation solutions that should be ready around the end of 2012

- **Guidance management on navigating and using available datasets**
    - How to weigh and integrate projections with historic/observed data
    - Understanding data quality and applicability—e.g., strengths, weaknesses, recommendations
    - Provide enough information for consumers who are not climate scientists to understand what they are using

- **Guidance management on how to select, use and interpret models**
    - Challenges and benefits of different models
    - Different levels and types of uncertainty
    - Use and limitations of downscaling
    - Example: The NOAA and NCAR climate modeling partnership with water utilities is a model that should be applied to other sectors, such as transportation.

- **Need consistency and clarity in available information products** to be able to use data in transportation decision support systems
    - Translation from uncertainties and ranges to specifics to which transportation professionals are accustomed

Other Communication Issues

➔ **It's Not the Heat, It's the Probability**

Climate scientists tend to talk about "climate change" as opposed to "global warming" to more accurately convey the complexity of the climate system and the multitude of impacts. Workshop participants noted that it's typically the second order impacts from climate change that affect the transportation system. Some of these observations and a few others are captured below.

- It's not the sea level rise, it's the storm surge that really gets you
    - Hurricane Irene taught us that Vermont is a coastal state (Irene went coastal on VT)
- It's not the precipitation, it's the run off
- It's not the average, it's the extreme
    - Infrastructure fails one storm at a time, until one above-average storm comes along
- It's not the variability, it's the change in variability
- Is it the 'new normal' yet?
    - Past performance is no guarantee of future returns
    - How long until the next 100-year storm?

4. Education, in addition to information, is critical to sound decision-making and effective use of climate and weather information by the transportation community.

All agencies addressing climate adaptation, including transportation agencies, need to focus on education and "science"—i.e. not information alone, but a coherent understanding of how different knowledge and data fit together. Transportation professionals don't need to become scientists, but they do need to be science-literate. Some areas where better understanding and clearer definitions are needed include:

- The concept of "Ask the Climate Question" across all areas of transportation practice
- Definition of "critical" assets
- Definition of extreme events

➔ **Education needs to support an evolution in the culture and paradigms of transportation and engineering practice**
  - Increase comfort level in applying projections instead of historical data
    - Looking at *recent* trends (e.g., last decade) as an initial tangible proxy for the "new normal" under climate change?
  - Updating engineering standards and design inputs
    - Developing **trending standards** that reflect recent trends and climate change projections (the 100-year flood isn't static, sea level is rising, floodplains are expanding)
  - Develop a "Green Pavement" selection tool for different climate conditions tool, balancing albedo, permeability and fly ash content
  - Use of tools for project analysis as well as system-wide analysis

Peer Exchange and Education

There is also an important role for government and NGO providers of climate information, including peer exchanges and affinity groups.

- DOTs could collect and share quantified impacts and photos from flooding, increased intensity and frequency of record-breaking extreme events that can be associated with climate change.
- Best management practices and standards can be developed through existing affinity groups
  - E.g., APTA's sustainability committee
  - International rail operators (e.g., Tokyo, London)
- Learn from places that already have that weather
  - Exchanges could be useful
  - Some northern US cities have already asked southern cities about things like appropriate concrete mix and tree species
- The National Climatic Data Center (NCDC) is planning Dataset Discovery Days
- Climate change adaptation should be included in curricula for engineers, planners and students of all ages (K-12)
- Participants proposed developing a "Linked In" group on critical infrastructure and climate adaptation (transportation, electricity, water, telecommunications)
- CCAP's new program and blog, Weathering Climate Risks addresses corporate and urban climate preparedness, emphasizing risk management, critical infrastructure and the economics of adaptation.

5. Transportation officials need more and better tools for integrating climate and weather information with other multiple factors to make sound decisions.

➔ **Tools and guidance for scenario analysis and planning**
  - Scenarios = climate-weather variability + development patterns + population growth + growth by economic sector...
  - Guidance on how to address community values (priorities, risk tolerance, etc.)

- Making use of Decision Theaters

➔ **Integration of contextual factors and assessment of multi-sector interdependencies**
  - Analysis of public and private infrastructure
  - Cascading impacts
  - Multiple events and threats
  - Business continuity: supply chain, customers, employees

Key Issues for Decision Making

➔ **Ask the Climate Question: Integrate climate decision making into existing processes over the full transportation lifecycle**
  - Planning, design, siting, construction, operations, maintenance
- Evaluating costs and benefits of adaptation options
  - New design, retrofits, manage, harden, abandon/retreat, etc.
- Determining **thresholds**, decision points
- Determining **timing** of decisions, actions
- Funneling: conducting sketch analysis to identify hot spots and criticalities to determine where more detailed analysis is needed
- Responding to major risks vs. smaller ones
- Making the world safe for risk-based decision making

Managing Uncertainties and Risk

➔ **When does uncertainty matter, when are directionally-correct measures enough?**
  - Sometimes it may suffice to know that it will be wetter or hotter as many adaptation response measures cannot be fine tuned to a specific level of inundation or temperature
- Guidance on operationalizing responses to probabilities, ranges and worst case scenario s
- Integration with other uncertainties
  - spread between emissions scenarios is greater than climate model uncertainties
  - sometimes the dominant source of uncertainty is not even climate related
- Draw from risk analysis best practices in other fields

6. There are areas where more research and higher-resolution climate and weather information would be very useful for transportation planning, particularly information on rainfall intensity during extreme events and more information about small events.

Research Needs

- Projection of extreme events provided at 24-hour level, but hydraulic engineers are interested in events of 6-hour or less duration
- Small scale events don't get enough attention – they may be significant in terms of storm water management
- Need to develop ways to relate projected model results (for precipitation) to flow/runoff
  - Also need to integrate with land use changes and other projected changes that will affect runoff to get a true picture

7. Climate adaptation efforts for transportation need to be addressed in the context of other management, economic, and institutional issues

Climate adaptation is as much a management and economic issue as it is an engineering one. Urban governments have found that Asking the Climate Question can go a long way to identifying appropriate adaptation solutions: if you plan it, fund it, build it or do it, ask how your decision affects resilience to climate change impacts.

➔ **Integrate climate adaptation into existing management systems**

- Explore non-engineering solutions, which may be less expensive
  - Can't fix, harden, or replace everything

Economic Analysis

Participants noted that maintaining the existing system is challenging even in good economic times. Transportation practitioners will need new tools and guidance to assess which climate impacts are most threatening to the local economy and to assess the costs and benefits of different adaptation measures in order to prioritize use of limited resources:

- Tools and guidance to analyze
  - Impacts of climate change
    - Opportunity costs of inaction
    - Total economic value of asset at risk
  - Costs of preparedness measures
    - Preventative costs, new design, retrofitting…
  - Economic and social benefits of preparedness measures
    - For different stakeholders: households, businesses, governments (as in the *Growing Wealthier* matrix)
- Guidance on incorporating climate impacts into asset management processes
- Guidance on how to direct funds in the most cost-effective manner
- Policies, strategies, standards to reduce future risks, economic losses

Participants mentioned the Coastal Adaptation to Sea Level Rise Tool (COAST) tool from the New England Environmental Finance Center that allows for assessment of economic losses from sea level rise and flooding.

Engaging the Public

Workshop participants noted that it is much easier to prepare for and respond to climate change impacts if the public has a better of understanding of the likely threats and effective responses. They noted that it is also critical that adaptation solutions resonate with local values and key concerns, such as quality of life and the economy. The following ideas were put forward for "selling" adaptation.

➔ **Address core community values**

➔ **Is there an app for that?**

  - Whether it's severe weather alerts or real-time updates on transit schedules and power outages, social media outlets will be an important resource in the adaptation tool kit

➔ Use images and data to illustrated the existential threat that climate change poses to critical infrastructure

Rt. 131, Vermont outside of Cavendish Village, 10 days after tropical storm Irene.
Source: Vermont Agency of Transportation.

- Identify cherished community amenities at risk
    - Where does the mayor golf?!
- Approach from national security, emergency preparedness, risk management perspectives
- Responses should be integrated with other functions, such as flood management, long-range planning, economic development

➔ Find sources of information to which local stakeholders can relate

- Private sector studies on bottom line impacts, such as Entergy's work on Building a Resilient Energy Gulf Coast

➔ Look for common sense, compelling stories and tangible examples

- Recent financial losses from extreme weather
- Juxtapose images of problems and solutions

Problem

NYC subway flooding after a 2007 storm.

Solution

Raised ventilation grates in New York City help prevent subway flooding.

Problem

Solution

A 2005 storm in **Toronto** caused $647 million in damages including destruction of this culvert (left), which was replaced with a larger, more resilient culvert (right). Source: Toronto Environment Office).

Photo credit for damaged culvert: Jane-finch.com. Photo credit for new culvert: City of Toronto Transportation Services.

- o Make the connection between climate changes and major local impacts, such as when early snow melts coincide with increased wild fires

Source: Climate Central

➔ **Convey the economic impacts for a diversity of stakeholders**: businesses, households, local governments (as in the *Growing Wealthier* matrix)

Business	Household	Municipal & Regional	National
Return on Investment			
Access to new markets Reduced investment risks Construction & transit jobs Higher property values Productivity enhancements due to agglomeration	Enhance or preserve housing values Better access to jobs	Higher public revenues Reduced citizen opposition to development Attracts private investment More efficient economy	More efficient use of transportation investments Construction & transit jobs
Savings on Expenditures			
Employee health care savings Better information & decision making Reduced parking requirements Reduced energy & water use	Save on travel costs Reduced energy & water use Health care savings Lower taxes for infrastructure services	Infrastructure savings (construction & operation) Reduced costs from urban decline Green infrastructure (such as natural filtration) replaces gray infrastructure	Energy security Health care savings
Improved Quality of Life			
Quality places attract high quality workers Improved environment for small businesses	Better access to services Affordable housing Access to nature & recreation Increased physical activity	Reduced exposure to congestion Thriving public spaces Growth reflects community values Protects natural resources	Reduced GHGs

The Growing Wealthier Matrix: Economic Benefits of Smart Growth
Source: CCAP

8. Federal agencies should continue to enhance state and local capacity to prepare for severe weather and a changing climate.

US Federal agencies are actively engaged in climate change adaptation efforts, with the Interagency Climate Change Adaptation Task Force providing regular progress updates.

CCAP provides the following recommendations on federal transportation climate change adaptation efforts.*

Research and Analysis

- Conduct detailed analysis of the **costs and benefits** of climate change preparedness measures (economic, social, environmental), including cross-sector interactions among infrastructure (transportation, energy, water, telecommunication) and natural systems (e.g., rivers)
- Convene a multi-agency effort (USDOT, NOAA, USGS, NASA, EPA) to determine and provide appropriate **data** for climate preparedness analyses in the transportation sector

* While some meeting participants provided input on these recommendations after the workshop, these are not meant to reflect the views of any specific individuals, agencies or organizations.

- Develop a hierarchy of **risk management methods** that can be used for different levels of decision-making
- Conduct a study on transportation structure, component, and material vulnerabilities to a variety of climate stressors

Capacity Building[7]

- Provide **technical assistance** and guidance to help states, MPOs and local governments to "Ask the Climate Question" when planning, siting, designing and constructing transportation infrastructure by assessing vulnerabilities to climate change impacts and the costs and benefits of adaptation measures (economic, social, environmental). Continue to develop and enhance technical assistance and guidance on:
  - Integrating climate preparedness into asset management and planning processes
  - Identifying critical assets and vulnerabilities
  - Selecting and applying analytic tools, climate models and visualization software
  - Selecting and applying appropriate data for climate preparedness analyses
  - Best practices in emergency response and evacuation
  - Design, maintenance and operations (e.g., for culverts)
  - Material selection and engineering standards
  - Analyzing costs and benefits of adaptation measures (economic, social, environmental)
  - Statistical and hydrological flood plain projection methods taking climate scenarios into account (with NOAA and FEMA)
  - Public and stakeholder engagement in adaptation planning
- Support enhanced **climate preparedness pilots** integrated with MPO long-range transportation plans
  - Integrate climate scenarios into a public planning process that considers multiple transportation and land use scenarios
  - Include targeted capacity-building (per categories above)

Policy

- Explore options for integrating climate preparedness into transportation planning processes and asset management
- Consider how to integrate climate adaptation with other environmental goals and efforts such as GHG mitigation and streamlining
- Consider potential performance management guidelines for climate change vulnerability and adaptation preparedness in the transportation sector

[7] Note that the Senate Transportation bill, MAP 21, includes a new section (33008), "Capacity Building for Natural Disasters and Extreme Weather," which calls for USDOT to issue guidance and design standards to help states, MPOs and local governments prepare for a greater frequency of extreme weather events.

Conclusions

Transportation practitioners need tools and methodologies for making decisions with imperfect data and perpetual uncertainty. A significant portion of the data and uncertainty has to do with imperfect information on non-climate factors and the variable nature of climate and weather events in general, more so than the limits of climate science.

> Workshop participants took solace from the insight provided by Mick Jagger's lyrics:
>
> ➔ **You Can't Always Get What You Want**
> *but if you try sometime,*
> *you just might find*
> *you get what you need*.

The good news is that transportation experts already have much of the relevant experience needed to prepare for climate change impacts through their experience in hazard mitigation, emergency response, flood management, and land use planning. Thus, focusing on things that are knowable at the local level goes a long way. And, while climate science is complex, it is certainly not beyond useful understanding. Thus, it is important for transportation practitioners to educate themselves on climate science, and to articulate their unique data and technical assistance needs. Similarly, adaptation efforts would be improved by using experiential input from transportation experts. We hope that this report is a constructive step in that direction.

MEETING SUMMARY

The full workshop agenda appears in Appendix B. This section provides highlights of the presentations, which are available for download here: www.ccap.org/adaptation.html.

Jan Mueller (EESI) kicked things off with an overview of workshop goals and key questions to guide the discussion.

Goals

1. Identify priority needs for information and analytic tools
2. Identify priority technical assistance, training, and communications needs
3. Identify priority research needs
4. Identify principles, guidelines, and institutional changes to enhance collaboration regarding climate adaptation and transportation

Key Questions

1. How can climate information be most effectively translated for use by transportation practitioners? What can be done to help the transportation and climate professionals "share a common language"?
2. What are the critical thresholds for different transportation decisions related to climate adaptation? Where and how does climate information intersect with these decision thresholds?
3. How can uncertainty and risk be most effectively integrated into transportation decision-making? What concepts and tools are most useful or important for managing uncertainty, risk, and error?
4. How are states and cities similar or different in their information and assistance needs for climate adaptation? What issues cut across different transportation users and disciplines?
5. How can we help transportation users best integrate evolving climate information and science?

Key Issues and Examples

In preparation for the workshop, the project team reviewed a number of studies on climate adaptation relevant for the transportation sector. Appendix D provides brief annotated summaries of some of the key studies. The project team also conducted interviews with a variety of transportation and climate experts to inform workshop goals, design and content. **Steve Winkelman** (CCAP) summarized key issues revealed during the background research:

Data

- It's all about the **water**
    - Too much, too little, wrong place, wrong time
- Need **ranges** on sea-level rise, precipitation, etc.
- **Weather** data are key
- Need **LIDAR** data to geocode infrastructure elevation and map vulnerabilities
- Need help **navigating** all of the climate data and information

Decision Making

- How well adapted are we to the **current climate** and recent extreme weather events?
- Which **worst case** should you plan for?
- What's the right **timing** of adaptation responses?
    - What are the key opportunity points?
    - Design of new infrastructure vs. retrofit of existing
- What are key decision **thresholds** and trigger points?

Navigating Uncertainty

- **Multiple sources** of uncertainty
    - Emissions scenarios
    - Development patterns
    - Climate science
    - Modeling
- When is **precision** most important vis-à-vis decision thresholds?
- When are **directionally-correct** responses appropriate?
    - Many adaptation "dials" cannot be finely tuned to X" of rain, Y° of temperature change

Costs and Economic Impacts

- How to allocate **scarce funds**?
- **Upfront** costs vs. longer-term savings
    - Opportunity costs of inaction
- New design vs. **retrofit**
- **Cost/Benefit** of adaptation measures
- **Green vs. grey** infrastructure
- **Who** bears costs, reaps benefits?

What we build – where and how – affects emissions and resilience

Decisions on infrastructure design and placement impact GHG emissions from transportation and buildings, as well as community vulnerability or resilience to impacts from extreme weather and climate change. Steve summarized some key lessons learned from CCAP's Urban Leaders Adaptation Initiative , a partnership that included Chicago, King County, Los Angeles, Miami-Dade County, Milwaukee, Nassau County, NYC, Phoenix, San Francisco, and Toronto.

- ***Like breathing and eating*** – We must reduce GHG emissions *and* prepare for climate impacts.
- **Ask the Climate Question** – How do our transportation and land use decisions impact our resilience to climate change impacts?
- **You're doing it already** – Local governments already have much of the relevant experience needed to prepare for climate change impacts through their experience in hazard mitigation, emergency response, flood management, , and land use planning.
- **Climate Extension Services** – CCAP recommends the development of networks to provide local governments with technical assistance on implementation of adaptation solutions, building upon the 150-year old agricultural extension model of federal-state-university partnerships for research and training.

Visualizing and Communicating Adaptation

John Holdren, science advisor to President Obama, speaks of the three choices when it comes to climate change: mitigation, adaptation and suffering. As a society, we can minimize suffering by doing a lot on mitigation (reducing emissions) and adaptation (enhancing our preparedness and resilience to climate impacts). Common sense solutions and iconic images can help enhance public understanding and engagement on climate change. While images on mitigation and suffering are plentiful, images of adaptation solutions are now coming to the fore.

Mitigation

Suffering

Adaptation!

Notes: The green roof on Chicago's City Hall; a cooling center in Toronto; launch of the Brightwater sewage treatment plant in King County Washington; storm-hardened library at Florida International University; green infrastructure; Thames river flood defence barrier in London.

Economic Benefits of Climate Adaptation

Climate adaptation is all well and good, but if proposed measures do not appeal to community self-interest – improving quality of life and enhancing the local economy – they are unlikely to garner the public support necessary for large scale implementation. Steve Winkelman described CCAP's *Growing Wealthier* matrix that examines returns on investment, cost savings and quality of life improvements for individuals, business and governments.[8] He presented a few examples of how preventative measures yield long-term returns.

Plan Now or Pay More Later

Preventative measures are cheaper than recovering from a disaster – preparedness is a least-cost strategy. While it might be tempting to climate-proof every community and piece of infrastructure for the worst-case event, we don't need to and we can't afford it. Risk-based decision making requires that preventative measures be prioritized based upon risks and available budget.

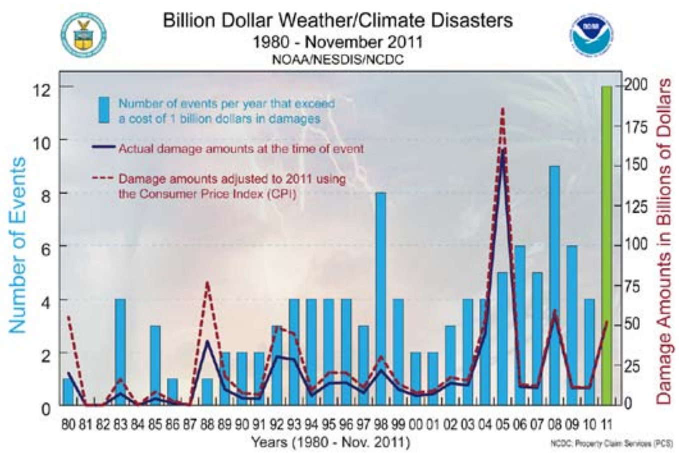
A dollar spent on hazard mitigation saves society an average of $4. *Multihazard Mitigation Council*

- **New Orleans**
  - Cost of Amsterdam-style flood controls: $ 30 billion
  - Estimated losses from Hurricane Katrina: $150 billion
- **San Francisco Bay Area**
  - Flood defense for 1.4 m sea level rise: $ 5 billion
  - Replacement value of assets at risk: $ 62 billion
- **FEMA 2012 Budget Request**
  - Pre-disaster hazard mitigation: $ 0.1 billion
  - Disaster relief: $ 1.5 billion
  - National Flood Insurance: $ 3.1 billion

Of note, the Federal Emergency Management Agency budgets much less for pre-disaster hazard mitigation than for disaster relief and National Flood Insurance. In years with multiple major disasters, actual emergency appropriations for disaster relief may be higher than budgeted. This is especially

[8] C. Kooshian, and S. Winkelman, *Growing Wealthier: Smart Growth, Climate Change and Prosperity*, CCAP 2011. www.growingwealthier.info

relevant given that 2011 has been a record year weather/climate disasters with 14 separate billion dollar events in 2011, causing more than $50 billion in damage (see chart).[9]



Green vs. Grey Infrastructure

Green infrastructure practices such as green roofs, urban forestry, permeable pavement, open space preservation and water conservation are familiar to local governments as strategies to enhance sustainability and quality of life and they are increasingly being seen as best practices in climate adaptation.[10] Benefits include better management of storm-water runoff, flood prevention, storm-surge protection, reduced urban heat island effects, improved human health and lower energy demand. Green infrastructure measures can reduce capital and operating costs from traditional "hard" or grey infrastructures such as expanding storm-sewers or building storm-water storage tunnels.

- **Catskills, NY**
  - New York spent $1.5 billion to protect the Catskills, rather than $6 billion for a water filtration plant with annual operating costs of $300 million.
- **Portland, OR**
  - $8 million spent on green infrastructure saves $250 million in grey infrastructure. For example, bio-swales on one street cost $15,000 and cut peak runoff flow by 88%, whereas the average claim for flooded basement is $4,000.
- **Houston, TX**
  - Trees in Houston provide an estimated $1.3 billion in stormwater management benefits.
- **Philadelphia, PA**
  - The net present value of green infrastructure to reduce combined-sewer overflows is $2.6 billion higher than for grey infrastructure

[9] NOAA, "U.S. sets record with a dozen billion-dollar weather disasters in one year," December 7, 2011. http://www.noaanews.noaa.gov/stories2011/20111207_novusstats.html. See also: http://www.ncdc.noaa.gov/oa/reports/billionz.html#chron.

[10] CCAP, "The Value of Green Infrastructure for Urban Climate Adaptation," 2011. www.ccap.org/adaptation.html

Culvert inspection and maintenance can save millions of dollars

A 2005 storm in Toronto caused more than $647 million in damage. It cost $4 million to replace one culvert that was clogged and damaged a major section of roadway and other critical infrastructure. Standard engineering practice has been to properly design culverts, build them and leave them. With climate change, inspection and maintenance has become far more important due to the increased frequency of extreme weather events.

Source: David MacLeod, City of Toronto

A Review of Current Climate Science and Information Resources

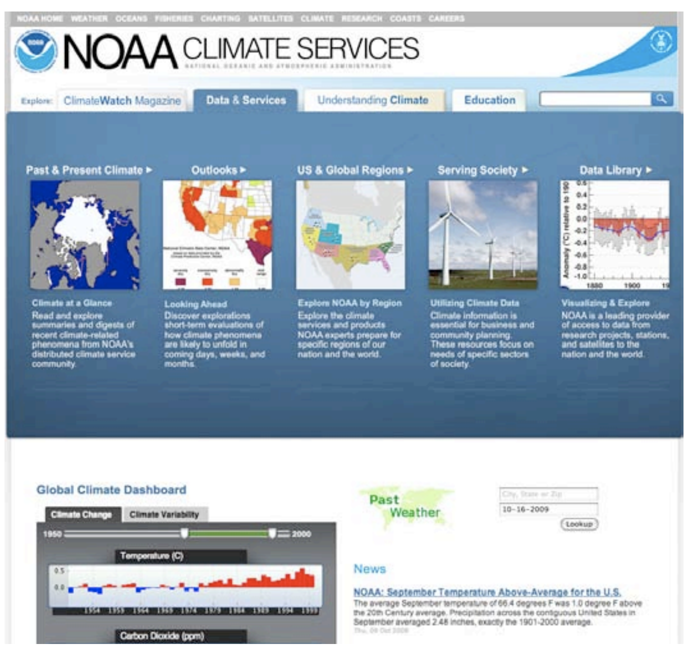
Ellen Mecray, NOAA's Regional Climate Services Director, Eastern Region noted that demand for climate services has been increasing in recent years from a variety of public and private sector stakeholders. NOAA provides a wide variety of climate services to the public, private sectors and other federal agencies through observation and monitoring, assessments of climate change and impacts, research, and modeling. NOAA provides information such as seasonal forecasts of temperature, precipitation, extreme weather and drought. Current climate service efforts focus on marine ecosystems, coastal resilience, water resources and changes in extreme weather.

NOAA Climate Services Portal [11]

NOAA unveiled its Climate Services Portal prototype (www.climate.gov) in January 2010 to provide a single, authoritative online location where the public can access the agency's, and its partners', climate data and information. The Climate Portal is a focal point through which NOAA's offices, labs, centers, and partners could work collaboratively to serve our priority publics. It consists of four elements:

(i) Understanding Climate – peer-reviewed resources for policy leaders and decision makers
(ii) Data & Services
(iii) Education – serves educators with ready-to-use lessons and resources
(iv) ClimateWatch Magazine – non-fiction stories, narratives and data visualizations

The Portal Team has been evaluating the prototype, gathering feedback from each of its target publics, and working on a complete site redesign that will mark the site's transition from a prototype to operational phase in late 2012. The site will be re-branded as "Climate.gov" with improved navigation, expanded scope and functionality. NOAA will add a new section called "Climate Conditions," to present a data-driven digest of recent and near-future climate trends of interest and relevance to society.



[11] Source: David Herring, NOAA

➔ ***Workshop participants suggested that the federal government develop a click-able map to identify key resources and contacts across agencies working on climate change adaptation.***

Marjorie McGuirk, meteorologist at NOAA's National Climatic Data Center (NCDC), discussed NOAA resources and efforts including weather records, climatology and adaptation. She noted that weather affects transportation system operations while climate affects transportation infrastructure planning and design.[12] The NCDC website (http://www.ncdc.noaa.gov/oa/ncdc.html) allows users to access past weather and climate data from a variety of sources (surface, satellite, radar, models) by time, place and type. Surface weather data are important to transportation because factors such as wind speed, precipitation, water level, fog and pavement condition affect road safety and efficiency. State DOTs make use of this information to examine relationships between weather and accidents.

NCDC data are useful for generating average climatologies for specific places, and assess factors such as: visibility by time of day; distribution of rain, snow, freezing rain; and drought index. NOAA's new storm inventory risk assessment data allow for analysis of all storms within GIS grid boxes. National Weather Service data inform frequency-duration-intensity design criteria. The Climate Atlas of the United States (CD-ROM) includes data on temperature, precipitation, snowfall, and fog in GIS format for all 50 states.

NOAA Atlas 14 and Intensity Duration Frequency Curves [13]

NOAA Atlas 14, Precipitation-Frequency Atlas of the United States contains precipitation frequency estimates for the United States, its associated territories and selected Pacific Islands. These climatic estimates are accompanied by additional information such as probabilistic temporal distributions, seasonality, and extensive documentation and meta information. Precipitation frequency estimates prepared by NWS on behalf of the Federal Government for over 60 years are de-facto national standards. They are included or referenced in Civil Engineering design standards of a wide variety of agencies at federal, state, and local levels, and are used in the design of traditional civil works to environmental management in general. The estimates are available at a spatial resolution of 30 arc-sec for 5-minute through 60-day durations at average recurrence intervals of 1-year through 1,000-years.

NOAA Atlas 14 is a web-based publication available through the Precipitation Frequency Data Server. It presents the estimates as tables, graphs, maps and GIS compatible grids. It recognizes the difference between average recurrence interval and annual exceedance probability and provides both forms of the data as well as in depth or intensity terms. For the first time NWS has also provided error bounds on the estimates in the form of the upper and lower 90% confidence limits. The information can be retrieved for any location based on latitude and longitude or by observing location. The figure on the next page is an example of the two classic intensity graphs; intensity-duration-frequency (IDF) and intensity-frequency -duration (IFD) for the Washington DC area.

NOAA Atlas 14 replaces a variety of previous publications dating as far back as 1963. It is published as volumes as it is expanded across the U.S. Seven volumes have been published covering twenty states, the District of Columbia, Puerto Rico and the U.S. Virgin Islands, and selected Pacific Islands. Two additional volumes covering seventeen Midwest and southeast states are being developed and will be published late in 2012. Volumes are developed as funds become available. Most of the work has been

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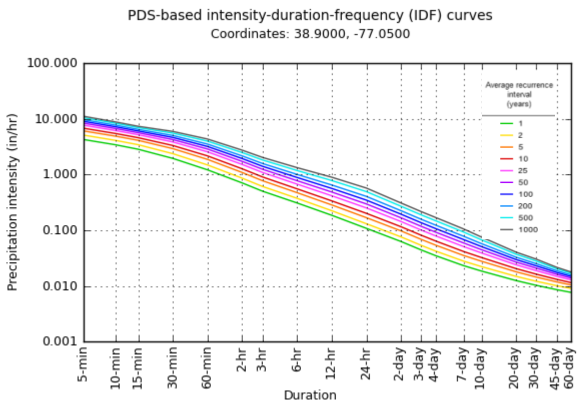
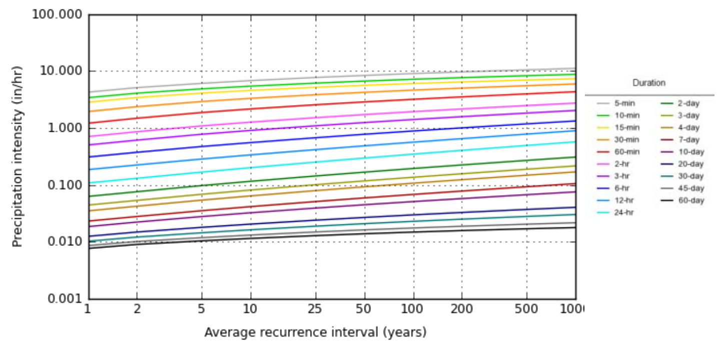
[12] McGuirk, M., S. Shuford, T.C. Peterson, and P. Pisano, 2009, "Weather and climate change implications for surface transportation in the USA," *Bulletin of the World Meteorological Organization*, 58, 84-93.

[13] Source: Geoff Bonnin, NOAA

funded by state and local agencies with supplemental funding from NWS and the U.S. Army Corps of Engineers (USACE). NOAA provided roughly half the funds to develop estimates for Alaska. NWS has been working with the Federal Highway Administration (FHWA) using their "pooled fund" mechanism to identify resources to develop estimates for seven northeastern states. Funds have not been identified to expand the Atlas to Texas and the five northwestern states.

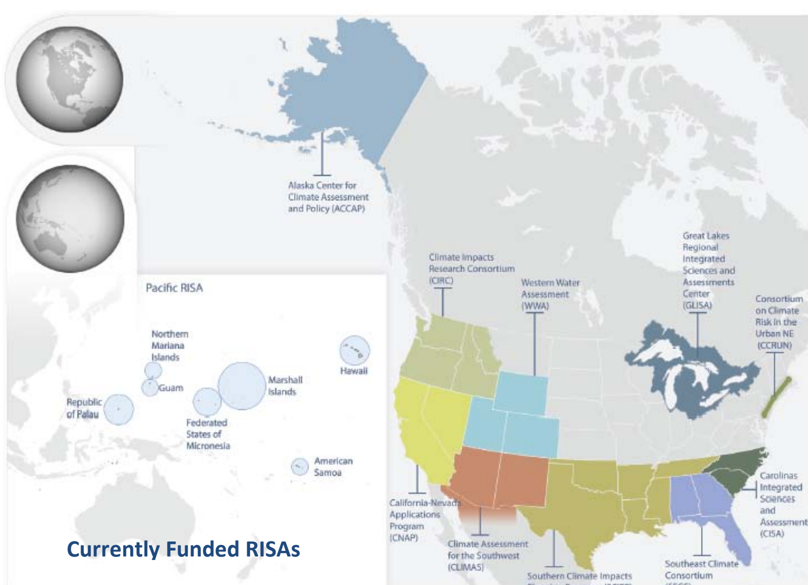




➔ ***Participants in the EESI-CCAP workshop proposed that NOAA develop a forecast version of Atlas 14 that takes climate change scenarios into account.***

Regional Integrated Sciences and Assessments [14]

NOAA's Regional Integrated Sciences and Assessments (RISA) program supports interdisciplinary, user-inspired climate research that is used to develop decision-support tools, products, and services. Eleven RISA programs are currently funded across the country to help build the nation's capacity to prepare for and adapt to climate variability. Some RISAs focus on particular sectors such as water resources or agriculture; other RISAs focus on climate-related issues that span multiple sectors including but not limited to transportation, energy, public health, and forestry. The climate issues on which each RISA focuses depends on what is relevant to their region and local communities. While RISAs conduct physical science research, social science research is also a vital component to each program. As such, RISA teams have built and continue to build a network of decision-makers with which they work and communicate. The Alaska RISA and Northwest RISA have been active in transportation sector climate adaptation efforts (see Appendix C for more on the latter – Oregon Transportation Research and Education Consortium).

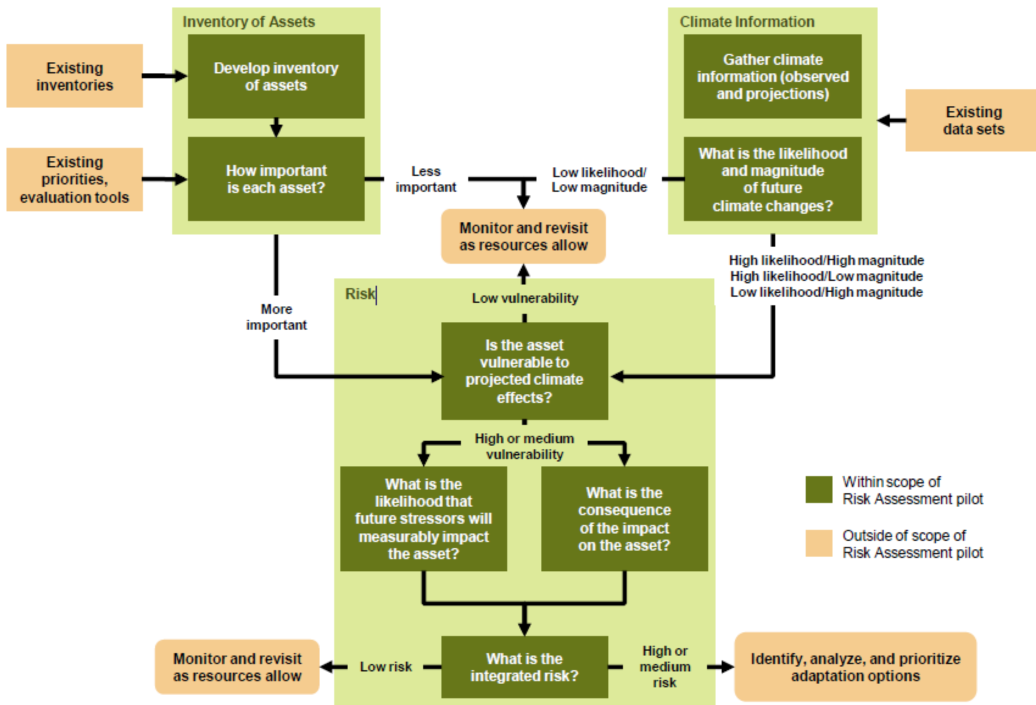


[14] Source: Rachel Riley, Southern Climate Impacts Planning Program

Decision Making Frameworks

FHWA Framework

FHWA developed their conceptual Risk Assessment Model to help transportation decision makers identify which assets are most exposed to the threats from climate change and/or could result in the most serious consequences as a result of those threats. Assets in this context refers primarily to infrastructure assets (such as bridges and roads), but could include other assets that benefit the transportation system such as a coastal wetland buffer. The conceptual model consists of three primary components, as shown in the figure below: 1. Develop inventory of assets; 2. Gather climate information; and 3. Assess the risk to assets and the transportation system as a whole from projected climate change. For more information: www.fhwa.dot.gov/hep/climate/conceptual_model62410.pdf.



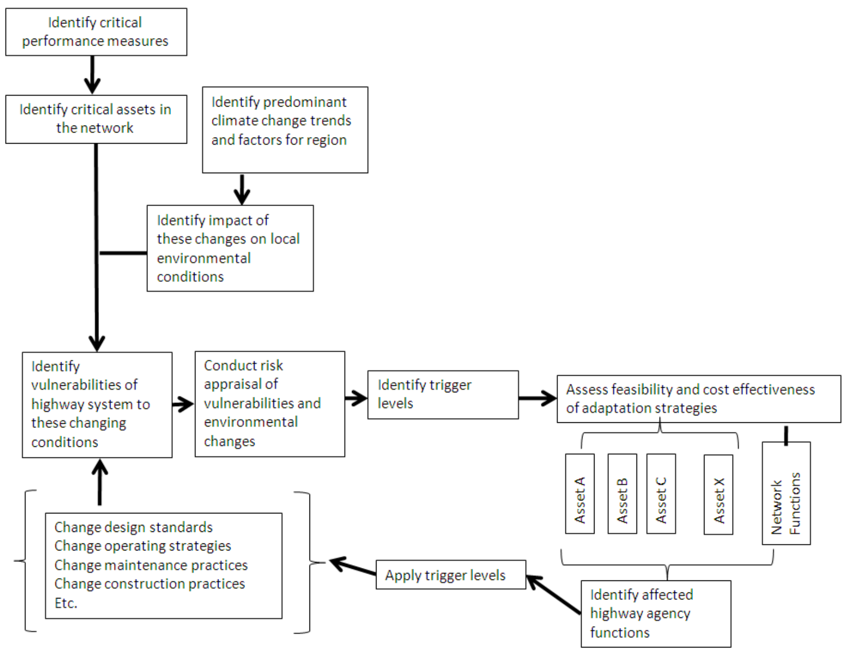
FHWA conceptual Risk Assessment Model

Professor Michael Meyer's Framework

Professor Michael Meyer of Georgia Tech[15] has proposed a diagnostic framework for climate adaptation planning. Prof. Meyer proposed that a diagnostic framework should:

- Determine what you are trying to accomplish
- Account for possible climate scenarios
- Identify transportation system vulnerabilities
- Understand risk to vulnerable assets
- Know when to "kick in" mitigation strategies
- Identify organizational responsibilities
- Focus on program and project-level strategies

[15] http://www.ce.gatech.edu/people/faculty/821/overview



Proposed Diagnostic Framework for Climate Adaptation Planning – NCHRP 20-83(5)

NOAA and NEMAC's Decision Theater[16]

From Data to Decisions, the Use of a Structured Process with the Right Technology Support

NOAA and the University of North Carolina Asheville's National Environmental Modeling and Analysis Center (NEMAC) partnered to create a decision theater with other federal and state partners. The decision theater combines a process and linked tools, which allows a group to interact with all of their data in a theater-like setting while being led through a structured decision process by a group of trained facilitators.

The decision theater enhances the decision-making process by linking it to risk and uncertainty related to climate variability and climate change impacts, and then to the vulnerability of key services and resources valued by the general population. NOAA and NEMAC have created numerous decision theaters across multiple scales, from local watersheds to regional evaluations and support of the National Climate Assessment.

The decision process focuses on a well-defined problem with associated goals and objectives, approached in a four step process:

1) **Data Integration** – The process first creates data that integrates climate data with non-climate data.
- Climate conditions include: warm and cold spells, heavy precipitation, drought, tropical cyclones, high and low temperature days, cool and warm seasons, sea-level rise, among others.

- Non-climate factors include: population, topography, land use, soil type, governing policies, and

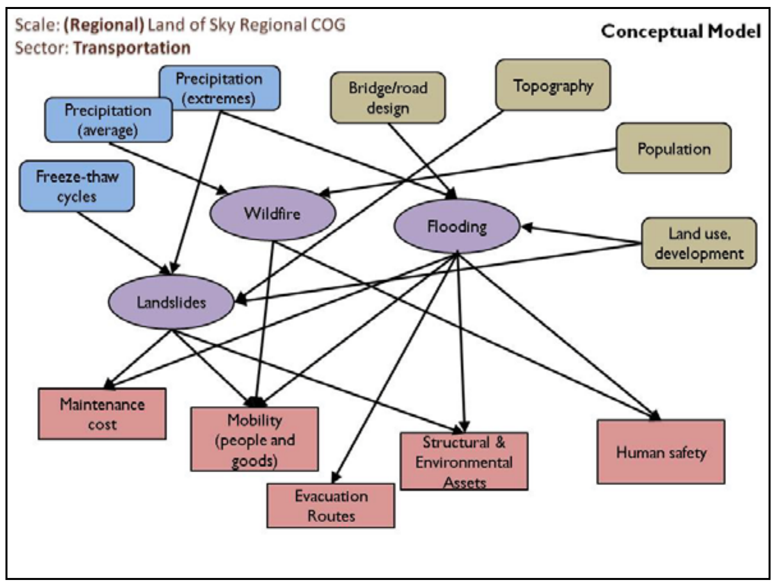
[16] Source: Jim Fox, University of North Carolina, Asheville, National Environmental Modeling and Analysis Center

the economy. Together, the climate conditions and non-climate factors combine to cause a climate impact on a system, which result in various forms, including, flooding, reduced water availability, inundation, reduced agriculture production, increased wildfire, and salt infiltration. Climate impacts affect how a system provides transportation, reservoirs, water supply, human health, clean air, etc., and this system is what stakeholders and decision makers are most concerned about.

2) **Visualization** – The climate and non-climate sectors data are then put into meaningful visuals and linked narratives, such as online GIS viewers with multiple layers, or a complex three-dimensional gaming engine that allows for interaction with the data to see how factors apply directly to a respective local scale. These visualizations must also be provided in formats that work well in group settings (the decision theater) but also accessible at private workstations and computers.

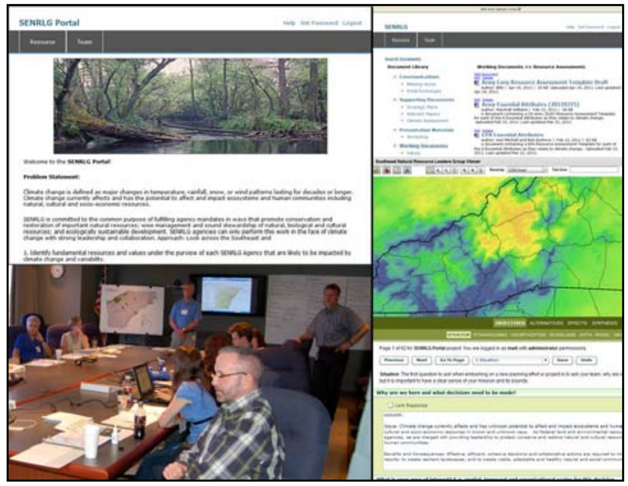
3) **Storytelling** – Storytelling is a critical step since it enables decision makers who are not sector experts to interact with the right data and understand its significance to the key problem being addressed, and insures that all members of the decision-making group understand the true value drivers for each case. This can be conveyed through printed handbooks, dynamic websites, short videos and interactive media.

4) **Decision Making** –The data, visuals and narratives are used to construct conceptual models to address risk and uncertainty through risk modeling. In general, a conceptual model is a graphical model that indicates the principal cause-effect relationships that explain why a problem exists. A good model can help clarify problems, expose unconsidered opportunities, reveal ambiguities and uncertainties in how a system works, and lay critical groundwork toward the quantitative probabilistic model that will be developed later. This approach allows decision makers to explore their understanding of the problem and formulate decision statements of "what to do" and have a more informed understanding of "what could happen."



Step 4 – Decision Making. Regional Conceptual Model used for transportation sector in the North Carolina Climate Adaptation Plan. Shows cause and effect relationships that explain how key resources and services in the state of North Carolina are impacted by climate change. Red boxes are key resources and services valued by the transportation sector, purple boxes are climate related impacts, blue boxes are climate factors and brown boxes are non-climate factors.

Facilitation and Decision Support Tools – These tools include “online workspaces” for team collaboration and interactive GIS for application in a geospatial context. The best tools can only be developed if you know the actual ***decisions*** being faced by our society, which highlight the importance of partnerships. The decision theater helps facilitate team member involvement. Ultimately, decision support tools should allow collaboration and provide transparency to the decision process.



Facilitation and Decision Support Tools – A group actively using the decision theater, with screen captures from an “online workspace.”

➔ ***Workshop participants were intrigued by the decision theater as a potential tool for evaluating climate adaptation opportunities in the context of community values.***

Those interested in using the decision theater on site, or in a mobile application should contact Marjorie McGuirk: Marjorie.McGuirk@noaa.gov.

Arizona State University also has a decision theater that can be used to assess climate scenarios.

Arizona State University’s Decision Theater

The Decision Theater enables better decision making through system-science and technology-based collaborative experiences. The Decision Theater and the Global DT Alliance are places where academics, leaders and decision makers come together to address real-world challenges.

Case Study: WaterSim has been implemented in a highly interactive framework to explore in real-time the sustainability of managing a regional water budget (supply and demand) under various conditions of drought and climate change.

See additional research and projects here.

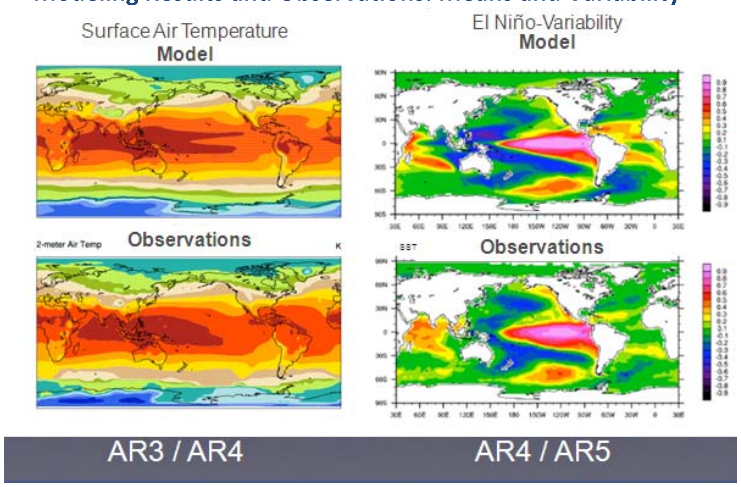
Climate Modeling and Uncertainty

Dr. Caspar Amman, of the National Center for Atmospheric Research (NCAR) provided an overview of climate modeling, including sources of uncertainty and how to navigate them. Dr. Amman provided time scale definitions to set the context: weather predictions can range from minutes up to one to two weeks, whereas climate predictions can range from weeks to centuries. Climate change analyses often use downscaling to take into account changing boundary conditions on local scales.

Dr. Amman explained how climate modeling is improving and evolving overtime with increasing sophistication and complexity and computing power. For example, climate models have incorporated progressively more feedback systems over the last several decades, such as sulfate aerosols, the carbon cycle, vegetation and biogeochemical cycles and now the leading models include ice sheets as well. Today a range of models exist; some seek to explain a single phenomenon (Simple Climate Models), others run quickly but attempt to capture some of the important phenomenon (Earth Models of Intermediate Complexity, EMICs), and finally generalized circulation models (also known as general climate models, or GCMs) have the highest resolution and include a comprehensive set of parameterizations.

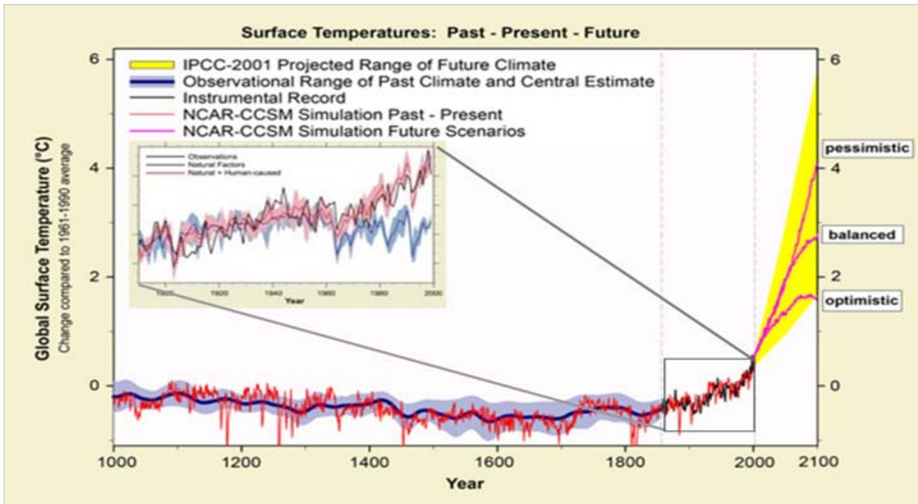
Dr. Amman noted that EMICs and GCMs can do a good job modeling averages (such as temperature) and variability (such as El Niño), as per the figure below. But it is more challenging to assess how variability will change – e.g., how will El Niño cycles change in a warmer climate?

Modeling Results and Observations: Means and Variability



Source: C. Amman, NCAR

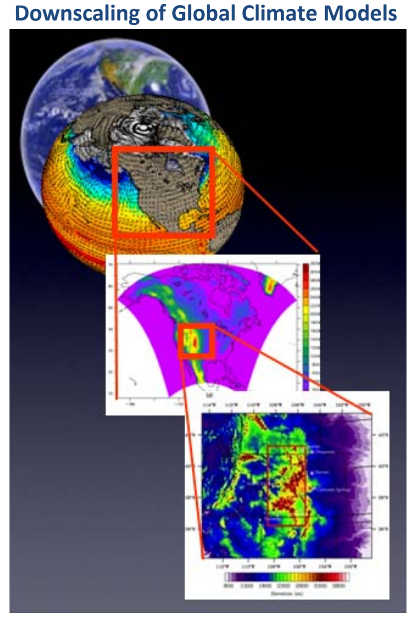
Dr. Amman presented temperature historic temperature data and projections under a variety of IPCC emissions scenarios. He noted that emissions forecasts have tended to be too conservative due to the underestimates in emissions, sea ice retreat, and melting of ice sheets compared with reality. Moreover, factors such as potential methane releases in polar areas are not included in the scenarios.



Source: C. Amman, NCAR

Different models can yield different forecasts on precipitation due to factors such as topography (e.g., mountains block moisture), treatment of clouds, and tropical dynamics. Ensembles of multiple models are often compiled to characterize the range of likely impacts. Dr. Amman noted that while climate change is a global problem, the impacts are local. In order to understand local impacts, a few methods are available to "**downscale**" the global climate models to a higher resolution in a local area. The "dynamic" approach is physics based and calculates regional predictions (20-35 mile grid cell resolution) based on the interaction between the global model and specific local factors. Dynamic downscaling tends to require major computing power, which can make it impractical to consider outputs from multiple global models or multiple emissions scenarios.[17]

Downscaling of Global Climate Models



Source: C. Amman, NCAR

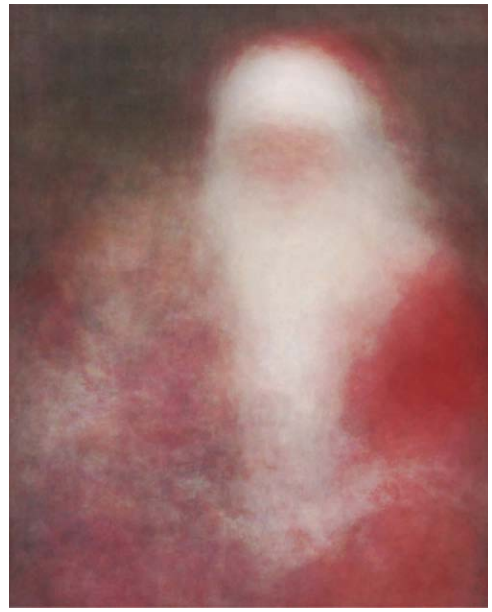
In "statistical" downscaling, equations are generated to characterize relationships among large-scale factors from global models and local level climate conditions. A key disadvantage is the assumption that the statistical relationships between specific model variables and the local climate remains constant – that may not be true under climate change. [18] Statistical approaches require less computational effort than dynamic approaches and can thus be used to test multiple scenarios and ensembles of multiple global models over many decades. Another statistical approach uses weather generators to predict local conditions based upon global model outputs.[19]

Dr. Amman emphasized the importance of understanding the challenges of climate modeling and the use of model outputs. It is crucial to understand the assumptions, sources, biases and limitations of specific models and ensembles. For example, some earth models of intermediate complexity are known

[17] M. Lenart, "Downscaling Techniques," http://www.southwestclimatechange.org/climate/modeling/downscaling
[18] Michael Meyer et al, "Synthesis of Information on Projections of Change in Regional Climates," National Cooperative Highway Research Program, NCHRP #20-83 (5)
[19] "Downscaling Climate Data," http://www.climate-decisions.org/2_Downscaling%20Climate%20Data.htm

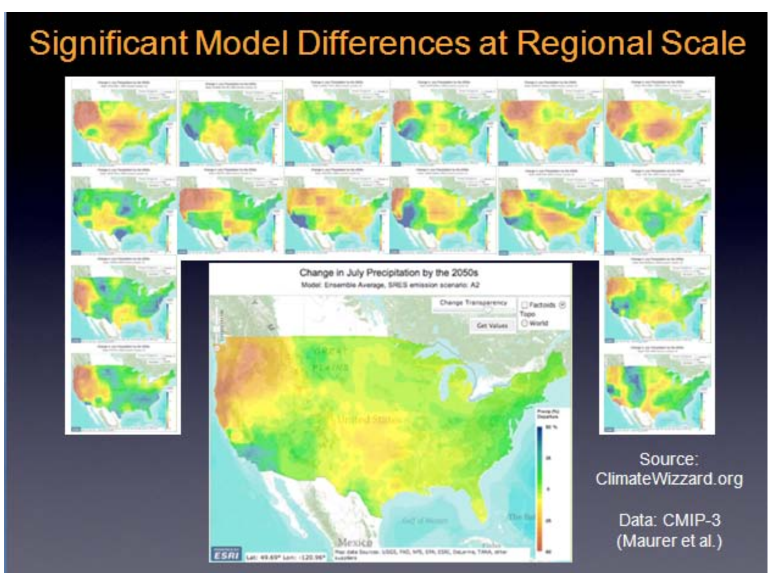
to be "too warm" when compared with past paleoclimate data, so statistical techniques called flux adjustments are introduced to correct that bias. However, such a correction assumes a stationary situation, which may not be the case. It is also important to keep in mind averages, variability and extremes. For example, as high-intensity, short-duration precipitation events may be masked in mean values, but, especially if they occur at rush hour they can have major traffic impacts.

Modelers look for "robust" results in which different models yield similar as outputs (e.g., increased precipitation). To illustrate how robust patterns can be revealed through ensemble averages, Dr. Amman referred to the interesting work of Jason Salavon in which he downloaded 100 images of Santa Claus with a child on his right knee and generated composite images using both mean and median images. Dr. Amman posed the challenge as to how to interpret the results if in some of the photos the child was on Santa's left knee, or if there was no child. While the composite image still conveys the dominant pattern, that doesn't negate the reality of those outlier photos. Thus when uncertainty is high because of fundamentally different model results, composite results will capture some but not necessarily all of the detail to provide a picture adequate for policy needs.



Composite image composed of 100 photos of Santa Claus.
Source: J. Salavon
http://legacy.salavon.com/SpecialMoments/KidsWithSanta.shtml

A similar challenge can arise when interpreting downscaled climate information. Using the Climate Wizard website (www.climatewizard.org), Dr. Amman presented outputs from 16 different climate models. As can be seen in the following images, while trends are clear in some parts of the country, some models predict increased precipitation (green or blue) for southern California, some predict less precipitation (yellow or red). This introduces challenges for local planners trying to prepare for climate change impacts, and calls for examination of specific models and assumptions in pursuit of better understanding.



Expert guidance is indispensable for interpreting climate model outputs and in navigating variations. NOAA and NCAR have worked closely with the water sector to help utilities and resource planners understand uncertainties and downscaling options (see box). Dr. Amman noted that NCAR is considering developing such a pilot program for the transportation sector.

Case Study: Climate modeling tools applied to the Water Sector

In collaboration with Water Utility Climate Alliance members, NOAA and NCAR established the Piloting Utility Modeling Applications (PUMA). It is a collaborative venture bringing together the Water Utility Climate Alliance (five utilities across the Northwest, Cal-Neva, Southeast, and Northeast regions), Regional Integrated Sciences and Assessments (RISA) leaders, and selected representatives of the climate science and applications communities to assess climate impacts on water resources.

The purpose of the pilot program is to indentify climate tools for WUCA members to conduct climate change assessments for their systems, articulate uncertainties in modeling results, and how to best use downscaled and other climate modeling data in planning. For example, through acquired climate project data, this can be used by utility hydrologic models to generate watershed and/or urban runoff information to be utilized in impacts assessment, water planning processes, and decision making.

Other benefits include bridging and enhancing conversations between climate scientists, users and providers to exchange best practice approach to downscaling and climate modeling in the water sector.

➔ ***Workshop participants were interested in technical assistance for transportation planners and engineers in understanding climate models, uncertainties and applications.***

➔ ***Dr. Amman invited the transportation community to propose collaboration opportunities to promote best practices.***

National Center for Atmospheric Research: From Climate Models to Adaptation Tools

Dr. Amman provided some more information about NCAR's services.

Objectives

- Provide climate services (better local data and information on extreme events)
- Bridging disciplines
- Cross-Disciplinary Modeling
- Engagement – Translation
- Educating about the ***correct*** inputs for models (if inputs are wrong, the model is wrong)

New tools and data to study climate

The National Climate Predictions and Projections (NCPP) platform is an open-source, community platform and problem-solving environment which provides comprehensive regional and local information about the evolving climate and will facilitate its use to support decision making and adaptation planning. The purpose is to provide: 1. data access, 2. science and tools, 3. knowledge translation – to provide assessments of impacts, assessments of risk, and adaptation.

Ongoing activities at NOAA and NCPP

- Defining best practices (NCAR invites transportation community to define best practices in which to extend to other areas)
- Web 3.0 service which combines static web pages, blogs, and social sites, to explore given climate scenarios, and to initiate interaction.

Examples of Transportation Climate Adaptation Efforts

In order to shed more light on information and assistance needs, several workshop participants presented their experience on climate adaptation in the transportation sector. Highlights are presented below. A number of participants also presented "wish lists" for data and assistance needs on climate adaptation; these are reflected in the Summary Recommendations and their presentations are available online (www.ccap.org/adaptation). Additional information from other participants is included in Appendix C.

Federal Highway Administration Climate Adaptation Efforts[20]

Rob Kafalenos (FHWA) provided an overview of the Federal Highway Administration's climate adaptation work.

Adaptation to climate variability and extreme weather events is critical to ensure the continued integrity and resilience of our nation's highway system, and can help promote safety and good stewardship of federal transportation funding. FHWA aims to promote systematic consideration of climate change vulnerability and risk in transportation decision making, at the system and project levels. FHWA is developing and sharing information on tools and methodologies that states and MPOs can use to assess risk and prioritize actions: climate projections, critical asset identification and vulnerability assessment methodologies.

To this end, FHWA has conducted research focused on investigating potential climate impacts on the highway system and approaches to adapt to these impacts. FHWA's 2010 report Regional Climate Change Effects: Useful Information for Transportation agencies provided a snapshot of information on climate change projections for transportation users. The report synthesizes information on climate change projections for transportation decision makers. It provides projected changes by region of:

- Annual, Seasonal Temperature (change in ^{o}F)
- Seasonal Precipitation (% change)
- Sea level rise, Storm activity (where information exists)

The 2008 Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study, Phase I provided an examination of climate impacts on transportation networks across the central Gulf Coast region.

FHWA has two efforts underway designed to help MPOs and State DOTs prepare their transportation systems to deal with climate change. FHWA developed a vulnerability and risk assessment framework that has been piloted by five transportation groups across the US: New Jersey, Hampton Roads (VA), San Francisco, Washington State, and Oahu (HI). Similarly, FHWA and US DOT have completed the first half of the Gulf Coast Phase 2 study; which is assessing the vulnerability of critical infrastructure in Mobile, Alabama and developing tools for transportation authorities to use in assessing vulnerability and developing adaptation options. The findings of the pilots and the Gulf Coast 2 study will help FHWA establish future direction in terms of development and implementation of adaptation approaches and techniques. More information can be found at: http://www.fhwa.dot.gov/hep/climate/activities.htm

[20] Source: Rob Kafalenos, FHWA

Federal Transit Administration Climate Adaptation Efforts [21]

Adapting public transportation to the impacts of climate change

FTA is partnering with transit industry to address impacts of climate change and adaptive responses to reduce vulnerability. Across extreme weather patterns, impacts on subway tunnels, busways, rail tracks and maintenance facilities vulnerable to increased flooding from more frequent and intense rain storms, rising sea level, and storm surges. Extreme heat can deform rail tracks, stress materials, reduce asset life, and jeopardize customer and worker health and safety.

Rail buckle from extreme heat

FTA Selected Initiatives and Strategies

FTA issued a Policy Statement in May 2011 explaining the impacts of climate change on key FTA goals such as safety and state of good repair and its commitment to addressing climate change impacts in its policies, programs, procedures, and grant programs. FTA publicized the statement and FTA's adaptation initiative with a dear colleague letter sent to public transportation agency grantees.

NYC Transit Green Roof

Climate Adaptation Pilots/Grants

FTA is funding several transit agencies and partnerships with transit agencies to assess the vulnerability of their assets and services to climate change hazards such as heat waves and flooding. FTA plans to make four agreement awards with the total amount of funding of $525,000. This year's application deadline has passed, however more info can be found here.

The pilots will also assess initial adaptation strategies and link these strategies to transit agency organizational structures and activities. One of the pilots will focus on demonstrating the integration of adaptation assessment within an asset management system. Each pilot will submit to FTA a final report on the activities conducted, main findings, and applicability to other transit agencies.

More Tools and Resources

- Recent report examines projected climate impacts on U.S. transit, climate change adaptation case studies by domestic and foreign transit agencies, transit adaptation strategies, lists risk management tools, and incorporation of adaptation into transit agency organizational structures and processes. See Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation.

[21] Source: Tina Hodges, FTA

- Recent and upcoming **workshops and webinars** engage transit industry in adaptation process. FTA held its first two workshops in 2011, respectively in Los Angeles and New Orleans; the third workshop was held in March 2012 in Arlington, VA. Live recordings of webinars are available here.

Toronto Climate Change Risk Assessment Tool [22]

Background

Toronto's infrastructure assets—including our electrical supply, water supply and transportation network—are worth billions of dollars. Critical to local wellbeing and the economy, these assets are also vulnerable to more frequent severe weather events resulting from climate change. Toronto's government is dedicated to delivering customer service excellence, creating a transparent and accountable government, reducing the size and cost of government and building a transportation city. Taking all these factors in account, the City of Toronto developed a climate change risk assessment process and tool to understand how extreme weather could put key infrastructure and services at risk, and how those risks could be reduced. In 2011, the process and tool was applied to the City's roads department known as the Transportation Services Division.

What Was Done

In 2010, City staff developed a first-of-its-kind **Environmental Risk Assessment Process and Tool** that facilitates due diligence and enables City service and infrastructure providers to identify and prioritize environmental and climate change risks, and assess the benefits of various protective actions. The development of the process and tool was a key component of Toronto’s Climate Change Adaptation Strategy: *Ahead of the Storm*.

Toronto's Transportation Services Division (TSD)—one of the first City divisions to pilot the new tool—has assets with a replacement value of about $12.1 billion. While TSD staff had some insight into how a changing climate might affect its infrastructure and services (damaging roads, culverts and bridges, and increasing maintenance costs, for example) the new tool brought a high level of rigor to the process and provided a deeper understanding of what is at risk and why.

The TSD pilot involved 14 experienced staff trained in the risk assessment process. With more than 90 assets and services critical to its operations, seven extreme weather event types were identified and various risks were examined over two time horizons. Through the process, more than 1,600 impact scenarios were generated and assessed, and new ideas for risk control were generated and documented. A software tool was definitely needed to handle this volume of data.

The frequency and intensity of extreme weather events in the 2040-2050 time period is expected to quadruple the number of extreme risk scenarios and more than double the number high risk scenarios. Having completed its risk assessment, TSD is better positioned to determine which actions will improve the adaptive capacity of Toronto's transportation infrastructure and reduce the risk of costly damage and disruption.

[22] Source: David MacLeod, City of Toronto

Toronto's Climate Change Risk Assessment Tool

Toronto's climate change risk assessment process and tool captures the knowledge and expertise of experienced staff in order to prioritize risks and corrective actions. Toronto's process requires an assessment of the magnitude/severity of potential risks and consequences, and the likelihood of an occurrence within a defined time period. The process and tool follow four major steps:

1. **Set the context:** Define the internal/external factors which influence the scope of the assessment, and the criteria against which risks will be assessed; such as internal policies, regulatory requirements and risk tolerance levels.
2. **Identify risks:** Identify the sources and causes of climate change risks, the vulnerabilities and controls to limit risks, and the potential impacts on assets and services such as financial, social, supply chain and reputational impacts.
3. **Risk analysis/ranking:** Assign magnitude and likelihood ratings for risks (based on defined assessment criteria) and determine overall risk rankings from low to extreme.
4. **Prioritize:** Prioritize risks on the basis of significance, identify potential measures to reduce risk consequence/ likelihood, and assess the effectiveness of potential risk reduction measures.

Toronto's tool is designed in accordance with the ISO 31000 (international management standard), takes into account elements of ISO 14001 (the international environmental management system standard), insights derived through a benchmarking study on approaches to climate risk assessment around the world, as well as stakeholder engagement and practical experience. It can be used to assess climate risks and identify adaptive actions in any jurisdiction or sector. The tool also can be configured to address other types of risks such as environment, health and safety.

For more information, contact David MacLeod, Senior Environmental Specialist, Dmacleo2@toronto.ca.

TORONTO

A Tale of Two Storms – the MTA Response in the NYC Region [23]

Post-2007 storm subway flooding

On August 8, 2007, the New York City metro area suffered a severe and largely unpredicted storm that brought in heavy rains and flooding, and the first tornado to hit parts of Brooklyn in more than 100 years. New York City Transit, an operating agency of the Metropolitan Transportation Authority (MTA), was forced to shut down much of the transit system after disruptions occurred on 19 major segments of the subway.

As a result of flooding at a critical junction in the Bronx, MTA Metro-North Railroad was forced to stop all service into and out of Grand Central Terminal. Service on the Port Washington Branch of MTA long Island Rail Road was disrupted for approximately six hours due to flooding above the third rail. The amount of rainfall varied throughout the city and suburbs, from 1.4 inches to 3.5 inches in two hours, overwhelming regional drainage systems and the MTA's pumping capacity, ultimately inconveniencing 2.5 million customers.

Both the amount of rainfall (concentrated in short periods of less than 3 hours), and the storm's timing (during a weekday morning rush hour), resulted in increased difficulty of response and severely disrupted MTA operations. Recovery time varied throughout the MTA network, with NYCT Subways being most severely affected, with some segments requiring eight hours to resume normal service. After the storm, the MTA formed a task force to assess the agency's performance and vulnerability to future storms. The August 8, 2007 Storm Report catalogued system deficiencies and identified priorities. The Storm Report assessed MTA's performance and future vulnerabilities and provided recommendations for improving early warning weather prediction capabilities, emergency response management, storm operations, engineering, and both internal and external communications. The MTA has since begun retrofitting its infrastructure in flood-prone locations, raising subway entrance stairs and ventilation grates to prevent runoff from entering the system and increasing pumping capacity.

On August 28, 2011, Tropical Storm Irene hit New York City, but resulted in a different outcome due in large part to the precautionary steps undertaken by the MTA. The MTA, a public benefit corporation of the State of New York, operates subways, buses, regional rail and bridges and tunnels in a 5,000-square-mile service territory covering New York City, Long Island, the Hudson Valley and southern Connecticut. Midday on August 27th, a weakening Hurricane Irene approached New York City, the MTA implemented the first pre-emptive service shutdown in its history. In addition, the MTA assisted New York City in evacuating senior centers, hospitals and other at-risk populations in the city.

> *"Our hundred-year storms seem to be happening every 3 years now"*
> *– Fred Chidester, NYC MTA*

Bernstein, Andrea. "Climate Change Is Adding A Premium To Infrastructure Costs." *Marketplace*, Dec. 7, 2011.

The MTA relied on its longstanding Hurricane Plans (for category 1-4 hurricanes) to determine how to best protect subway trains, commuter trains, bus and other critical transport assets and infrastructure. In addition, the MTA blocked off at-risk subway and rail tunnels to prevent intrusion of

[23] Source: Dana Coyle, Ernest Tollerson, NYC MTA

water. During a system shutdown scenario, such as Tropical Storm Irene, trains were stored on tracks that are not expected to flood.

Responses to Climate Change (addressing adaptation and mitigation initiatives)
Since 2007, the MTA has been involved in partnerships with research centers, local universities and climate adaptation taskforces coordinated by New York State and New York City. The MTA and its partners at the state, county and city levels are identifying and addressing vulnerabilities in the system and the MTA is building and procuring new assets to higher standards (i.e., the Second Avenue Subway will be built to 100-year flood plain standards). The MTA is also developing and refining its weather plans (i.e., the Winter Operations Plan, the Hurricane Plan, and the Flood Plan), advancing strategies for predicting events and preparing and protecting assets.

The MTA has been, and continues to be, an active participant on both city- and state-led climate change task forces. In 2008, NYC launched a Climate Change Adaptation Task Force and the NYC Panel on Climate Change, a combination of public and private sector authorities advised by a panel of scientists, to adapt critical infrastructure to the environmental effects of climate change. The NYC Panel on Climate Change issued a report in 2010 with recommendations on adaptation strategies.

Climate Resilient Infrastructure

In the locations that were identified as the highest-priority flooding locations, the MTA has begun retrofitting its infrastructure, raising ventilation grates to control the amount of water entering the system. Since the 2007 Flood Report, MTA New York City Transit has retrofitted 25 priority locations, raising over 5,300 linear feet of ventilation gratings, installing 30 stair pads at subway entrances, and allocating nearly $90 million towards this initiative. In many cases, the raised ventilation grates serve a dual purpose by also providing street seating and bicycle racks. In addition, NYC's Green Infrastructure Plan aims to manage runoff from impervious areas, thereby improving water quality and reduce storm water management costs by $2.4 billion.

Raised ventilation grates

Chicago Transit Authority Climate Adaptation Efforts [24]

In September 2008, the City of Chicago unveiled the Chicago Climate Action Plan, which outlines the city's strategy to reduce Chicago's greenhouse gas emissions to 25% below 1990 levels by 2020. In addition to its efforts to mitigate greenhouse gases, CCAP is preparing for anticipated impacts of climate change by adapting in three primary areas: Chicago's built environment, natural environment, and human population. Research conducted for the action plan outlines projected Chicago-specific climate impacts that are likely to increase in frequency and intensity, and affect CTA assets and operations:

- ***Temperature***: The number of 100-plus degree days could increase from the current two to as many as 31 days annually
- ***Precipitation***: Projections of 20% more precipitation in the winter/spring could lead to more intense rain and snow storms and increased flooding
- ***Combined Impacts***: Projected impacts with increases in both temperature and precipitation include greater volatility in electrical grid and compromised customer access and convenience:

Based on the projected impacts, CTA and the City of Chicago have made initial strides toward climate-adaptive implementation strategies:

- ***Bus/Rail Right-of-Way Flooding:*** Ongoing measures to address flooding are largely stopgap (e.g. sealing subway tunnel walls, deploying bus shuttles during rail flooding). A comprehensive analysis of bus and rail ROW vulnerabilities would help CTA define more proactive and cost-effective approaches to flooding.
- ***Rail Traction Power Reliability:*** A preliminary CTA analysis estimates that an increase in average temperature of 5° F could increase heat-related failure rates by 5-10%. With additional analysis, initial estimates can be refined to make strategic decisions to increase the reliability of CTA traction power.
- ***Transit Ridership:*** Adverse climatic impacts to transit ridership can be addressed in the short term with enhanced communication strategies (e.g. deployment of real-time information signs), and in the long-term with investments to increase weather protection (e.g. extended/expandable rail canopies).

[24] Source: Karl Peet, CTA

Conclusions

Transportation practitioners need tools and methodologies for making decisions with imperfect data and perpetual uncertainty. A significant portion of the data and uncertainty has to do with imperfect information on non-climate factors and the variable nature of climate and weather events in general, more so than the limits of climate science.

Workshop participants took solace from the insight provided by Mick Jagger's lyrics:

➔ **You Can't Always Get What You Want**
but if you try sometime,
you just might find
you get what you need.

The good news is that transportation experts already have much of the relevant experience needed to prepare for climate change impacts through their experience in hazard mitigation, emergency response, flood management, and land use planning. Thus, focusing on things that are knowable at the local level goes a long way. And, while climate science is complex, it is certainly not beyond useful understanding. Thus, it is be important for transportation practitioners to educate themselves on climate science, and to articulate their unique data and technical assistance needs. Similarly, adaptation efforts would be improved by using experiential input from transportation experts. We hope that this report is a constructive step in that direction.

Appendix A: Participant List

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National Center for Atmospheric Research

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APPENDIX B: WORKSHOP AGENDA

Climate Adaptation & Transportation
Identifying Information and Assistance Needs
EESI-CCAP-NOAA
Hall of States, 400 North Capitol St. NW, Washington DC
November 16-17, 2011

AGENDA

Day 1, November 16, 2011

12:00 – 12:45 pm	**Welcome**, Lunch	Introductions	
12:45 – 1:30 pm	**Overview**	Jan Mueller, EESI Steve Winkelman, CCAP	• Goals, Agenda Review • Key Questions to Address
1:30 – 2:00 pm	**Climate Information Products and Services**	Marjorie McGuirk, NOAA Ellen Mecray, NOAA	• Current Data, Tools, and Services • How Information Is Being Used • Future Research and Products
2:00 – 2:30 pm	**Transportation Outlook**	Rob Kafalenos, USDOT/FHWA Climate Change Team	• Lessons Learned • Obstacles and Challenges • The Transportation Wishlist
2:30 – 3:30 pm	**Examples**	David MacLeod, Toronto Ernest Tollerson, NYC/MTA Karl Peet, Chicago Transit Auth. Jeff Perlman, North Jersey TPA Amanda Anderson, NCAR	• How Climate Trends Affect Transportation Practice • Connecting Climate Data to Key Planning and Design Criteria
3:45 – 5:15 pm	**Defining the Task**	Facilitated Discussion: Key Information and Assistance Needs	• Defining Impacts, Vulnerabilities, and Risks • Defining Operational Challenges, Opportunities, and Responses
7:00 – 9:00 pm	Dinner, Informal Discussion		

(AGENDA)

Day 2, November 17, 2011

8:00 – 8:45 am	Breakfast		
8:45 – 9:15 am	**Day 1 Synthesis**		• Priority Issues to Address • Initial Recommendations
9:15 – 10:30 am	**Uncertainty, Scale, and Time in Climate Models**	Caspar Ammann, NCAR	• Climate Model Variables • Limits of Spatial and Temporal Resolution • Factors Affecting Precision, Confidence in Climate Projections
10:30 – 10:45 am	Break		
10:45 – 12:15 pm	**Integrating Climate Data into Transportation**	Facilitated Discussion: Working with Evolving Climate Science	• Downscaling • Managing Uncertainty
12:15 – 1 :30 pm	Lunch		
1:30 – 2:45 pm	**Setting Priorities**	John MacArthur, Portland State University	• Identifying Hotspots • Budget Constraints • Weighing Options
2:45 – 4 :15 pm	**Recommendations**	Facilitated Discussion: Designing Programs, Building Capacity	• How Can We Build on Existing Programs and Resources? • What New Tools, Programs, and Resources are Needed?
4:15 – 4:30 pm	**Wrap-Up**		
4:30 pm	Adjourn		

Appendix C: Additional Information on Participant Adaptation Efforts

Massachusetts Department of Transportation – Highway Division [25]

In August 2008, Governor Deval Patrick signed into law the Global Warming Solutions Act (GWSA), making Massachusetts one of the first states in the nation to move forward with a comprehensive regulatory program to address Climate Change.

Two documents were filed with the state Legislature as required by the GWSA. This was done in consultation with other state agencies and the public. The Massachusetts Clean Energy and Climate Plan for 2020 set economy-wide greenhouse gas (GHG) emissions levels at 25 percent below the statewide 1990 GHG emission level using a series of clean energy policies. The Massachusetts Climate Change Adaptation Report (Adaptation Report) includes a sector by sector look at how climate change may impact Massachusetts and presents likely climate change scenarios.

Five technical subcommittees provided forums for in-depth examination of Natural Habitat, Key Infrastructure, Human Health and Welfare, Local Economy and Government, and Coastal Zone and Oceans. The Adaptation Report discusses key predictions and impacts, the scope and scale of the challenge, the costs and risks associated with climate change common strategies across all sectors and sector specific strategies. MassDOT was highly represented on the Key Infrastructure Technical Subcommittee. MassDOT outlined a series of strategies in the categories of No Regret, Short-Term and Long-Term to help address coastal and inland asset vulnerabilities to local climate change events.

[25] Source: Steven Miller, MassDOT

Pacific Northwest and Alaska - Climate Change Impact Assessment for Surface Transportation[26]

The states in the Pacific Northwest and Alaska share interconnected travel networks for people, goods, and services that support the regional economy, mobility, and human safety. The rising costs of building and maintaining reliable transportation infrastructure place tremendous pressure to deliver resilient transportation systems. Regional climate change has and will continue to affect the physical condition and serviceability of these networks. Yet the nature of the changes and their potential impacts on the regional transportation system and its use are very poorly understood. Researchers from Portland State University, Oregon State University and University of Alaska – Fairbanks completed an OTREC project on the Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska. The project is sponsored by The Region X Transportation Consortium, which is comprised of the four Departments of Transportation and the four University Transportation Centers from Alaska, Idaho, Oregon and Washington. The research addresses the potential impacts of climate change to the region's surface transportation infrastructure.

OTREC
OREGON TRANSPORTATION RESEARCH AND EDUCATION CONSORTIUM

www.otrec.us

The objective of this research project was to conduct a preliminary vulnerability assessment of the risks and vulnerabilities climate change poses to the surface transportation infrastructure system in the Pacific Northwest and Alaska region. The report, was published in February 2012:

- Synthesizes data to characterize the region's climate,
- Identifies potential impacts on the regional transportation system,
- Identifies critical infrastructure vulnerable to climate change impacts, and
- Provides recommendations for more detailed analysis and research needs as appropriate to support managing risks and opportunities to adapt multimodal surface transportation infrastructure to climate change impacts.

Transportation professionals and policy makers will be able to use the results of this report to build a breadth of knowledge and information on regional climate change impacts, understanding vulnerabilities of the transportation system and begin creating more quantitative risk assessment models.

The final report, "Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska," can be downloaded here: http://otrec.us/project/383.

[26] Source: John MacArthur, OTREC

San Francisco Bay Area Transportation Vulnerability and Risk Assessment Pilot Project: Adapting to Rising Tides [27]

The San Francisco Bay Conservation and Development Commission (BCDC) has partnered with the National Oceanic and Atmospheric Administration Coastal Services Center to work with San Francisco Bay Area shoreline communities on planning for sea level rise (SLR) and other climate change–related impacts. The overall goal of the project, called Adapting to Rising Tides (ART), is to increase the preparedness and resilience of Bay Area communities to SLR and other climate change–related impacts while protecting ecosystem and community services. It involves evaluating potential shoreline impacts, vulnerabilities, and risks; identifying effective adaptation strategies; and developing and refining adaptation planning tools and resources that will be useful to communities throughout the Bay Area.

As part of the project, the Metropolitan Transportation Commission (MTC), California Department of Transportation (Caltrans) District 4, and BCDC collaborated on a subregional planning pilot project to test the conceptual Risk Assessment model developed by the Federal Highway Administration (FHWA) to assess the climate change–related SLR risks to transportation infrastructure in a select portion of the San Francisco Bay Area.

The purpose of the pilot project is to enable the region's transportation planners, including those at the MTC, Caltrans, congestion management agencies, and local governments, to improve vulnerability and risk assessment practices and to help craft effective adaptation strategies. If both existing and planned transportation infrastructure is assessed, vital infrastructure can be protected, and future investments can be guided by the best available information about future climate and SLR conditions.

For more information, please see the ART website: http://risingtides.csc.noaa.gov/index.html.

[27] Source: Stefanie Hom, MTC

Washington State Department of Transportation Climate Change Adaptation[28]



The Washington State Department of Transportation (WSDOT) is working to create an integrated 21st century transportation system that is reliable, responsible, and sustainable. Understanding future conditions is essential to WSDOT's mission to keep people and business moving. It is also required to meet our longer-term sustainability goals, which are designed to meet society's needs today without compromising the ability of future generations to meet their needs.

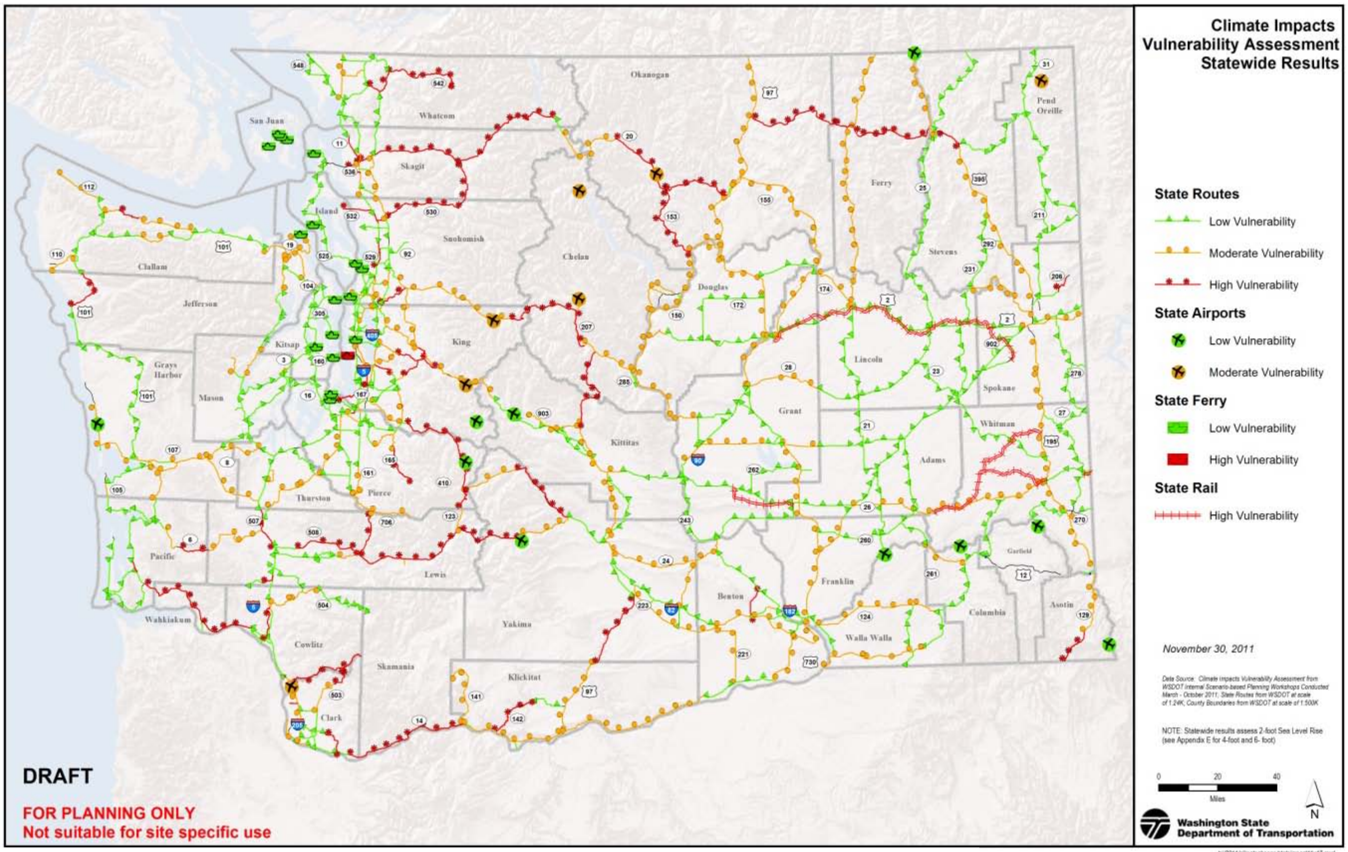
Like other risks we plan for, such as retrofitting bridges against earthquakes, we plan to take action, including updating planning and design policies, to protect our transportation infrastructure from climate impacts. This is responsible asset management. We build highways, bridges, and state ferries to last decades, so the need to improve structure resiliency to better adapt to weather extremes is essential to reducing risk.

To understand our vulnerabilities to climate impacts, WSDOT participated in a national pilot to test the Federal Highway Administration's climate risk model. We used climate projections from the University of Washington's Climate Impacts Group to develop scenarios which we used in workshops with field staff from across the state to assess possible impacts to WSDOT owned and managed assets: highways, rail, aviation, and ferries. We asked the question: What keeps you up at night now, and what happens if we have more extreme weather events, or sea levels rise?

What did we find?

Many Washington State highways and ferry terminals are fairly resilient to extreme weather events now and likely in the future. In general we found that climate change will intensify existing conditions, such as unstable slopes, areas prone to flooding, fire, or dust storms, and facilities susceptible to coastal erosion or inundation. The areas where impacts were anticipated are areas already experiencing problems.

[28] Source: Sandy Salisbury, Washington State Department of Transportation



Statewide Results based on Integrated Climate Scenario (with 2 foot SLR)

We learned through this assessment that most of our newer bridges are resilient to climate changes; some can withstand sea level rise of up to 4-feet. While this is good news, we did find that in some areas road approaches may be more vulnerable than previously thought.
This information gives our agency a strong starting point to help WSDOT and our partners prepare ahead of time for potential roadway and infrastructure changes due to weather affects or rising tides.

WSDOT's pilot project team will assist WSDOT regions and modes in the use of this assessment. Contact Carol Lee Roalkvam at 360-705-7126, Sandy Salisbury at 360-705-7245, or Mark Maurer 360-705-7260. More information is available on-line: www.wsdot.wa.gov/SustainableTransportation/adapting.htm

Cambridge Systematics[29]

Now in its 40th year, Cambridge Systematics (CS) has worked with a variety of federal, state, and regional agencies to assess the potential impacts of climate change on transportation infrastructure, operations, and long-range planning and investment. The Cambridge Systematics approach integrates region-specific environmental trend information, climate model scenarios, and transportation data to assess risks from climate factors and consider adaptation strategies– helping to ensure that the investments we make today will result in reliable and robust transportation networks for decades to come. CS's environmental practice also supports transportation climate change policy, mobile source greenhouse gas (GHG) emissions analysis and reduction strategies, air quality analysis, and sustainable transportation and land use coordination.

Cambridge Systematics Climate Change Adaptation Activities

- *North Jersey Transportation Planning Authority – Climate Change Vulnerability and Risk Assessment of NJ Transportation Infrastructure.* For the North Jersey Transportation Planning Authority and agency partners including NJDOT, NJ Transit, NJDEP, the Delaware Valley Regional Planning Commission, and the South Jersey Transportation Planning Organization, CS led a climate change vulnerability and risk assessment of transportation infrastructure in selected regions of New Jersey, using FHWA's pilot conceptual model. CS is currently developing an adaptation strategy implementation framework to help NJTPA incorporate climate change considerations into its planning and project development processes.

- *Caltrans Addressing Climate Change Adaptation in Regional Transportation Plans.* For the California Department of Transportation (Caltrans), CS is developing a manual to support California's planning agencies in incorporating the risks of climate change impacts into their decision-making processes.

- *NCHRP 20-83 (Task 5) – Climate Change and the Highway System: Impacts and Adaptation Approaches.* For NCHRP, CS, as part of the Parsons Brinckerhoff team, is providing insights, guidance, and tools to mitigate the risks of climate change impacts on the nation's highway systems and related intermodal facilities.

- *A Preliminary Study of Climate Adaptation for the Statewide Transportation System in Arizona.* For the Arizona Department of Transportation (DOT), Cambridge Systematics is conducting a research study on climate adaptation for the statewide transportation system in Arizona. This effort is providing a framework for the DOT to help departments responsible for infrastructure planning, design, operations, and maintenance effectively incorporate the risks of climate change impacts into their decision-making processes.

- *Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.* For this seminal study, CS coordinated interagency research to study the impacts of climate change on transportation in the Gulf Coast. Analysis was performed for the impacts of sea-level rise, storm surge, and temperature and precipitation changes. The resulting report was released under the auspices of the U.S. Climate Change Science Program.

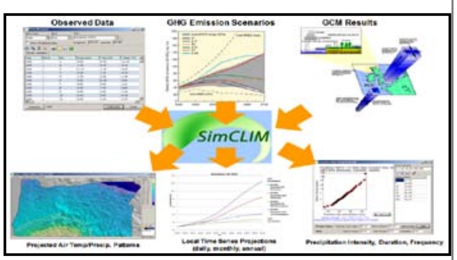
[29] Source: Joshua DeFlorio, Cambridge Systematics

CH2MHill - Climate Change Planning[30]

COLORADO RIVER BASIN WATER SUPPLY AND DEMAND STUDY (ONGOING)
U. S. Bureau of Reclamation

The study is addressing the uncertainty in supply and demands over the next 50 years, and will develop and analyze adaptation and mitigation strategies to resolve the imbalances. CH2M HILL is leading the consultant team to support the supply and demand assessments, evaluate future water management actions and prepare a strategic roadmap for management of the basin resources. Key project elements:

- Hydrology and hydroclimatic variability
- Climate science and water supply-demand integration
- Integrated water supply and ecosystems planning
- Water management strategy development
- Bi-national and interstate watershed



SimCLIM
CLIMATE MODELING TOOL

CH2M HILL formed a strategic partnership with CLIMSystems. The SimCLIM modeling tool enables the integration of global climate change data with actual local observed data to rapidly, and with scientific rigor, guide development of practical, implementable adaptation actions and strategies. SimCLIM is an integrated modeling system for assessing climate risk and resilience for water, agriculture, transportation, energy, ecosystems, human health, sea level and coastal issues, and much more.

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Increasing climatic uncertainty has serious implications for sustainable water supplies and is making unprecedented demands on infrastructure and ecosystems. Among the most important consequences of changing climate conditions are increasing temperatures, changes in seasonal patterns of precipitation and runoff, sea level rise, and the resulting effects on the overall water cycle. Effects include:

- Increased frequency and intensity extreme weather events,
- Early snowmelt,
- Sea level rise, and
- Temperature extremes.

These effects can adversely affect infrastructure of all types; water management; drainage management systems for transportation and urban areas; facility locations; agricultural demands and land use; energy production; ecosystem function; and other infrastructure and social, environmental, and economic factors.

Climate Change Planning Approach

Climate risk and resilience entails more than suggesting sea walls, higher levees, bigger tunnels, and more reservoirs. CH2M HILL employs a scenario planning process and work with clients to understand how (if at all) climatic changes could influence their business. The scenario planning process considers all elements that influence the client's future (regulations, population, rates, etc). Using this process, followed by robust modeling tools (such as SimCLIM) and our climate scientists and engineers' expertise, CH2M HILL is on the cutting edge of assessing region-scale climate risk.

Strategic partnership with CLIMSystems and SimCLIM tool capabilities distinguishes us from our competitors.

A Record of Success

Important strategic projects include basin-wide projects for the Salton Sea and Bay Delta in California, and the Colorado River Basin Supply and Demand Study, which covers seven states and addresses all water users to support long-term ecosystem management strategies. We have created community-specific plans, including Alexandria, VA, where drainage design criteria are being updated based on projected changes in rainfall intensity, and Onondaga County, NY where we developed climate risk projections for extreme precipitation event to guide development of green infrastructure program for sewer and stormwater compliance.

[30] Source: Laurens van der Tak, CH2MHILL, www.ch2m.com

Georgetown Climate Center [31]

The Georgetown Climate Center (GCC) focuses on the nexus of state and federal law and policy for climate change mitigation and adaptation. GCC works to distill, analyze, and communicate adaptation policies in a way that is responsive to the needs of state and local officials. GCC works with state and local policymakers to plan for flooding in coastal communities, to address water shortages in already dry regions of the country, and to offset the public health dangers related to climate change.

Tools

- The Adaptation Clearinghouse: GCC recently launched an extensive online database and networking tool that supports state and local efforts to adapt to climate change. The website is an adaptation "data hub" for policymakers and planners across the country. One section of the Clearinghouse specifically focuses on resources related to adapting transportation infrastructure. Other topics include sea-level rise, law & governance, urban heat, public health, water and coasts.

- Adaptation Tool Kit: Sea-Level Rise and Coastal Land Use: the tool kit provides local and state governments and their citizens with practical knowledge to help adapt to sea-level rise. It offers an assortment of generally used legal devices that can reduce future harms of climate change, and shows how local governments have significant legal authority and tools to plan for future changes, now. Further it supports varied approaches depending on the needs for each local and state government.

Sea Walls (Dothan, Alabama) The sea wall reflects wave energy and exacerbates erosion on the adjacent properties.
Source: Advanced Coastal Technologies, LLC, Dothan, Alabama

Case Study: Adaptation and Sea Level Rise

GCC is working with state and federal experts to analyze some of the potential legal issues in adapting transportation infrastructure to impacts from sea level rise. Specifically researching the potential legal barriers to using federal funding (allocated through the Federal-Aid Highway Act (FHWA)), ways to use the FHWA program to promote adaptation at a state and local level, potential opportunities to promote adaptation through capital improvement planning, and potential liability for implementing certain adaptive measures, such as abandonment of highly vulnerable bridges and roadways.

GEORGETOWN CLIMATE CENTER
A Leading Resource for State and Federal Policy
www.georgetownclimate.org

[31] Source: Jessica Grannis, GCC

ICF International [32]

ICF International partners with national governments, federal agencies, state and local governments, transportation organizations, private sector clients, academia, and NGOs to promote climate-resilient decision making. ICF has over 30 years of experience in climate change policy and research. ICF's team includes climate scientists, policy analysts, economists, engineers, and planners, with experience on every continent, conducting assessments, supporting development, and building resilience. Across the globe, ICF's impacts, risk, and adaptation experts are developing strategies and technical tools, forging partnerships, and helping organizations cope with the uncertainty of climate change.

ICF has been working on vulnerability, impacts, and adaptation for over 20 years. ICF works in every major sector, including transportation and infrastructure, and covers the full range of services, including:

- **Climate analysis**
- **Risk & vulnerability assessment**
- **Adaptation planning**
- **Monitoring & evaluation**
- **Programmatic & strategic support**
- **Decision support**
- **Outreach & communications**

A few examples of ICF's climate change adaptation activities are described below.

- For the ***U.S. Department of Transportation***, ICF is performing an in-depth assessment of transportation assets across all modes for Mobile, AL, as part of the Gulf Coast Study, Phase II. This assessment will identify critical assets, assess climate impacts on those assets, assess vulnerability, and perform detailed engineering assessments of vulnerable infrastructure, including an analysis of adaptation options. Members of ICF's staff led Phase I of the same study.
- For the ***U.S. Agency for International Development***, ICF is leading an effort to incorporate into everyday planning the potential risk that climate change poses to infrastructure and ways to manage it. In the first phase of this effort, ICF is developing a series of fact sheets that include infrastructure-specific information on importance to USAID programming, potential climate impacts, and adaptation options. ICF is also summarizing key lessons learned by practitioners on infrastructure-related risk assessment and how these are applicable to USAID.
- For the ***Federal Highway Administration***, ICF developed a conceptual model to guide transportation officials through the vulnerability assessment process and helped administer five agency pilots to test it. ICF produced Regional Climate Change Effects, a report that synthesizes relevant climatological studies into a format readily accessible for transportation professionals. In addition, ICF planned and facilitated peer exchanges with state DOTs to discuss how climate adaptation efforts can be integrated into DOT planning and operations.
- For ***transit agencies***, including the Southeastern Pennsylvania Transportation Authority (SEPTA), ICF is assessing the climate vulnerability of transportation assets. For SEPTA, ICF is assessing, in detail, the weather and climate impacts on one flood-prone rail line under an FTA grant.
- For the ***National Climate Assessment***, ICF contributed leadership and expertise as lead authors for two Technical Reports on infrastructure vulnerabilities. These reports, one for the Department of Energy and the other for NASA and the City University of New York, are designed to inform the 2013 National Climate Assessment. They examine system interdependencies and analytical methods, with a particular focus on transportation in metropolitan areas.

[32] Source: Joanne Potter, ICF

Parsons Brinckerhoff [33]

Parsons Brinckerhoff (PB) is an engineering firm with over 125 years of experience in helping public and private-sector clients plan, develop, design, construct, operate, and maintain infrastructure systems. PB incorporates climate adaptation into their work to deliver quality products that will stand the test of time. Over the past decade, PB has become an industry leader in helping transportation sector clients assess potential impacts of climate change and plan and design systems that remain resilient as conditions change. Their involvement in climate adaptation work began overseas in Australia and the UK. PB aims to continue moving adaptation towards the project level to help clients manage and build resilient transportation infrastructure in the face of profound changes to our environment.

Parsons Brinckerhoff Climate Change Adaptation Activities

- In Australia, PB helped the federal government develop the National Infrastructure Climate Change Adaptation Risk Assessment, addressing direct and indirect impacts on infrastructure out to 2070 and the capacity of current and future infrastructure owners and managers to adapt to climate change.
- In the UK, PB helped the UK Highways Agency develop the Highways Agency Adaptation Strategy Model (HAASM). A seven-stage process for assessing the risks climate change poses to the agency, prioritizing action on the highest risks, and assigning responsibility to various parties within the organization for execution of adaptation actions.
- At the national level, PB has provided planning and engineering support for the US Department of Transportation's Gulf Coast Study Part II, focused on a detailed engineering-level assessment of critical infrastructure in the Mobile, AL region.
- PB is also working on the National Cooperative Highway Research Program's (NCHRP) Climate Change and the Highway System project (20-83(5)), providing guidance and tools for planners and engineers to incorporate adaptation into their transportation work.
- At the regional scale, PB worked with the Western Federal Lands Division of the Federal Highway Administration to provide guidance on incorporating adaptation into engineering designs.
- Recently, PB has begun working with Maryland State Highway Administration and the District Department of Transportation (Washington, DC's DOT) to develop policies for embedding adaptation into their work processes.

PARSONS BRINCKERHOFF

www.pbworld.com

[33] Source: Chris Dorney, PB

Appendix D: Selected Bibliography and Resources

AASHTO, FHWA and FTA

- Transportation Climate Change Symposium

APA and EESI

- Planning for a New Energy and Climate Future

Bipartisan Policy Center

- Transportation Adaptation to Global Climate Change

Center for Clean Air Policy

- Climate Adaptation & Transportation: Identifying Information and Assistance Needs
- Urban Leaders Adaptation Initiative
    - "Ask the Climate Question: Adapting to Climate Change Impacts in Urban Regions"
    - "The Value of Green Infrastructure for Urban Climate Adaptation"
    - "Lessons Learned on Local Climate Adaptation"
- *Growing Wealthier: Smart Growth, Climate Change and Prosperity*
- Weathering Climate Risks – blog addresses corporate and urban climate preparedness, emphasizing risk management, critical infrastructure and the economics of adaptation.

Climate Central

- Climate change science news, graphics, videos and data. www.climatecentral.org

FHWA

- Literature Review: Climate Change Vulnerability Assessment, Risk Assessment, and Adaptation Approaches.
- Climate Adaptation Conceptual Model Pilots.
- Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: The Gulf Coast Study.
- Applications of Geographic Information Systems (GIS) for Transportation and Climate Change

FTA

- FTA Climate Change Adaptation Initiative.
- Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation.

National Academies / TRB

- Potential Impacts of Climate Change on U.S. Transportation: Special Report 290.
- Adapting Transportation to the Impacts of Climate Change
- Climate Variability and Change with Implications for Transportation
- Climate Change and the Highway System: Impacts and Adaptation Approaches (in progress)
  Includes two interim reports:
  - Review of Key Climate Impacts to the Highway System and Current Adaptation Practices and Methodologies
  - Synthesis of Information on Projections of Change in Regional Climates and Recommendation of Analysis Regions

NOAA

- NOAA Climate Services: www.climate.gov

USDOT

- Climate Change Impacts and Adaptation.
- The Potential Impact of Global Sea Level Rise on Transportation Infrastructure (2008)

US Global Change Research Program

- USGCRP publications

World Meteorological Organization

- Weather and climate change implications for surface transportation in the USA
- Climate Change Impacts and Adaptation.

Center for Clean Air Policy

www.ccap.org

Environmental and Energy Study Institute

www.eesi.org

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