Transportation System Resilience, Extreme Weather and Climate Change

A Thought Leadership Series

Final Report
September 2014

Prepared by the Office of Strategic Initiatives for Research and Innovation, Volpe

U.S. Department of Transportation
Volpe, The National Transportation Systems Center

Volpe

Notice

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 2014	Final Report

4. TITLE AND SUBTITLE
Transportation System Resilience, Extreme Weather and Climate Change: A Thought Leadership Series

5a. FUNDING NUMBERS
YM205/G228A

6. AUTHOR(S)
Bahar Barami, Ph.D.

5b. CONTRACT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
John A Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-14-04

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Department of Transportation
John A Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
This document is available to the public on the Volpe website: http://www.volpe.dot.gov.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
This report summarizes key findings from the Transportation System Resilience, Extreme Weather and Climate Change thought leadership series held at Volpe, the National Transportation Systems Center from fall 2013 to spring 2014.

14. SUBJECT TERMS
Climate change, resilience, mitigation, adaptation, transportation planning, national climate assessment, thought leadership

15. NUMBER OF PAGES
39

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

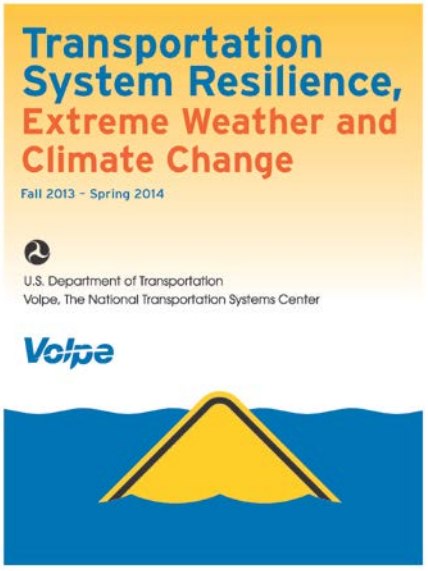
Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

Contents

Executive Summary

September 2014

Global transportation infrastructure today is confronted with significant vulnerabilities, including the escalating threats of our changing climate. The infrastructure and systems that we use to move people and goods are particularly vulnerable to the impacts of climate change, from rising sea levels to rising temperatures to more intense storms to extreme drought.



This report summarizes the Volpe, The National Transportation System Center's recent thought leadership speaker series on *Transportation System Resilience, Extreme Weather and Climate Change*. From October 2013-April 2014, Volpe, part of the U.S. Department of Transportation, convened notable and influential voices in transportation system resiliency and climate change to present the current state of climate science and to discuss challenges, opportunities and fresh approaches related to these pressing multi-modal, multi-sector issues.

Transportation decision makers representing a broad spectrum of the transportation community from across the country and around the world participated in this series and joined Volpe in person and via webinar to learn about transportation adaptation and resilience and to engage in the dialogue.

The insights, research, and experiences of Volpe's guest lecturers provide a framework for tackling transportation challenges arising from the escalating threats of our changing climate. This report summarizes the strategies and realities within this framework that emerged from Volpe's recent thought leadership series.

Volpe's Transportation System Resilience, Extreme Weather and Climate Change series reached more than 1,000 transportation stakeholders and decision-makers across the transportation enterprise including leaders in federal, state, and local government, academia, the transportation industry, non-profit organizations, and international entities.

Appendix A provides links to selected video clips as well as full videos of each presentation. Appendices B and C provide stakeholder engagement statistics as well as the state, regional, and local stakeholders that participated in these climate discussions.

Transportation System Resilience, Extreme Weather and Climate Change: Driving Forces

Several landmark reports on climate change were recently released or were in development at the time of the Volpe Center thought leadership series on Transportation System Resilience, Extreme Weather and Climate Change.

Recent Landmark Climate Change Reports and Initiatives

1 - *The President's Climate Action Plan*, June 2013, released by the Executive Office of the President, outlined a broad spectrum of executive actions and a plan structured around three key pillars: Cutting Carbon Pollution; Preparing the U.S. for the Impacts of Climate Change; and Leading International Efforts to Combat Global Climate Change and Preparing for Its Impacts.

2 - The *United States Climate Action Report 2014* was issued as the first Biennial Report of the U.S. under the United Nations Framework Convention on Climate Change (UNFCCC), and consistent with the Intergovernmental Panel on Climate Change (IPCC) Working Group III recommendations on meeting the challenges of reducing greenhouse gas emissions from fossil fuel.

3 - *National Climate Assessment*, May 2014. The National Climate Assessment summarizes the impacts of climate change on the United States, now and in the future. A team of more than 300 experts, guided by a 60 member Federal Advisory Committee, produced the report. Dr. Jerry Melillo, one of the Volpe thought leadership series' speakers, chaired the Committee.

4 - The Intergovernmental Panel on Climate Change (IPCC) Working-Group Reports. The IPCC is the leading international body for the assessment of climate change, established by the United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts.

5 - *Risky Business: The Economic Risks of Climate Change in the United States*, June 2014. This report documents the economic risks from damage to coastal property and infrastructure from rising sea levels and increasing story surge, climate-driven changes in agricultural production and energy demand, and the impact of higher temperatures on labor productivity and public health.

With the input of hundreds of experts that contributed to this set of major climate change reports, assessments, and plans providing a backdrop, Volpe brought together thought leaders to focus on the challenges related to transportation system resilience, extreme weather and climate change. U.S. Department of Transportation's Assistant Secretary for Transportation Research and Technology Gregory Winfree and Associate Administrator and Volpe Director Robert Johns kicked off the series on October 8, 2013.

Program of Events and Speakers

Series Kick-Off: October 8, 2013

Gregory D. Winfree
Assistant Secretary for Research and Technology
U.S. Department of Transportation

Robert C. Johns
Associate Administrator and Director, Volpe
U.S. Department of Transportation

Steve Winkelman
Director of Transportation and Adaptation Programs
Center for Clean Air Policy
Can We Get There from Here? Transportation and Climate Adaptation: Prospects for the Future

November 19, 2013
Dr. Klaus H. Jacob
Research Scientist, Lamont-Doherty Earth Observatory
Adjunct Professor, Columbia University
Pre-Sandy Impact Modeling of Storm Surge

December 4, 2013
Susanne E. DesRoches
Assistant Chief, Resilience and Sustainability
Port Authority of New York and New Jersey (PANY/NJ)
Super Storm Sandy

December 17, 2013
Gregg Fleming
Director, Center for Environment and Energy Systems
Volpe Center
U.S. Initiatives to Reduce Transportation-Related Global Greenhouse Gas Emissions

February 25, 2014
Dr. Kerry Emanuel
Cecil and Ida Green Professor of Atmospheric Science
Massachusetts Institute of Technology
Extreme Weather and Climate

March 11, 2014
William M. Lyons
Principal Technical Advisor, Transportation Planning
Volpe Center
The Challenges of Transportation Planning for Resilience

March 18, 2014
Vinn White
Senior Policy Advisor for Transportation Policy
U.S. Department of Transportation
Federal Program Adaptation Post Sandy

April 10, 2014
Dr. Jerry Melillo
Distinguished Scientist and Director Emeritus
Marine Biological Laboratory, Woods Hole, MA
Professor of Biology at Brown University
The Third National Climate Assessment: Lessons Learned, Paths Forward

The ideas, observations, and findings documented in this summary report capture the four dominant forces that drive global climate-change research and planning:

1. Assessment of climate-change risks and vulnerabilities;
2. Adaptation strategies;
3. Mitigation of the consequences; and
4. Planning for resilient infrastructure systems.

1. Assessment of Climate-Change Risks and Vulnerabilities

Understanding the current state of climate change begins with risk assessment. What are the potential outcomes of climate change? What happens to our natural environment if we do not take action? What happens if we take aggressive action?

Researchers estimate climate change risks, consequences and vulnerabilities. Several speakers pointed out that before presenting research evidence on climate change risks they first document past trends in changing climate indicators, such as air and water temperatures, sea levels, and precipitation rates. After researchers understand existing vulnerabilities and risks they can begin charting a course for future strategies and preventive measures.

Indicators of a Warming World

Dr. Jerry Melillo, chair of the National Climate Assessment and Development Advisory Committee (NCADAC), summarized the 10 key indicators (see Figure 1) of a warming world documented in NCADAC's 2014 report Climate Change Impacts in the United States:

- Rising air temperature near the earth's surface;
- Rising water vapor;
- Rising temperature over oceans;
- Rising sea levels;
- Rising sea surface temperatures;
- Rising temperature over land;
- Rising ocean heat content;
- Declining sea ice levels;
- Declining glaciers and ice sheets; and
- Declining levels of snow-cover.

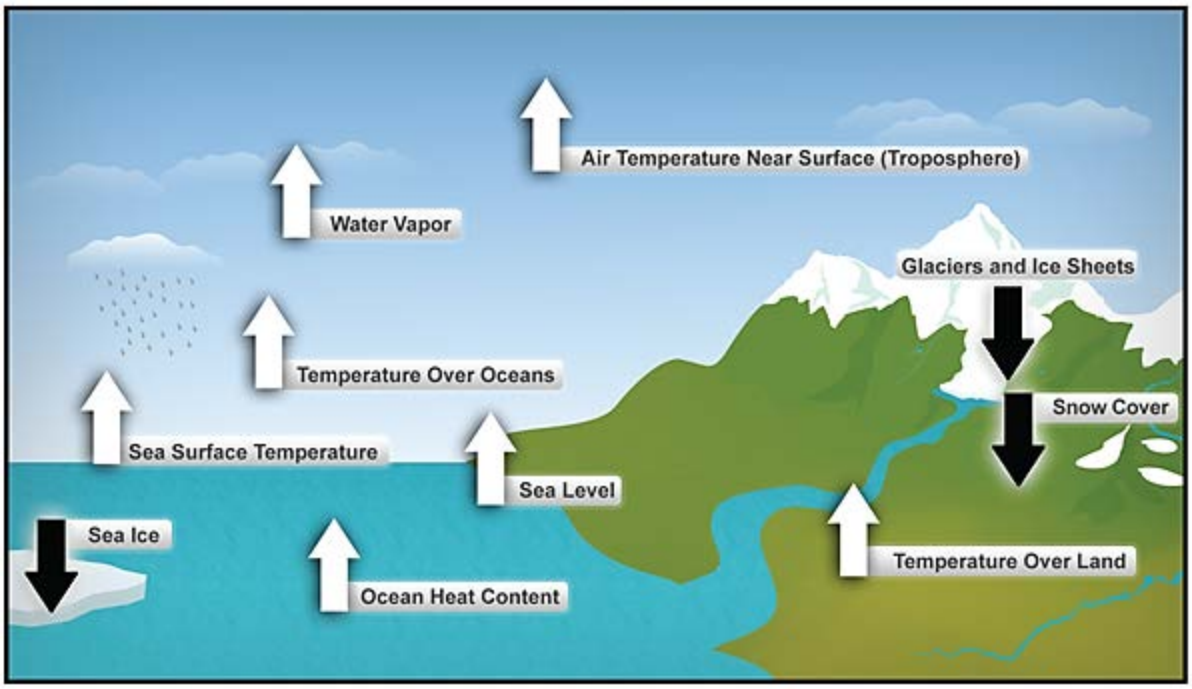


Figure 1. Ten indicators of a warming world.[1]

Changes in Sea Levels

Dr. Melillo detailed the historical trends of several of these climate change indicators, including historical changes in sea level from 1800 to 2100, with actual and projected data (see Figure 2). By 2100, sea levels are forecast to rise from 1 to 4 feet. Dr. Melillo pointed out that while the 19th century data were based on proxy records, the early 20th century data were based on tidal-gauge data. Since mid-century, satellite signals have improved the overall quality of data and made them more precise.

[1] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

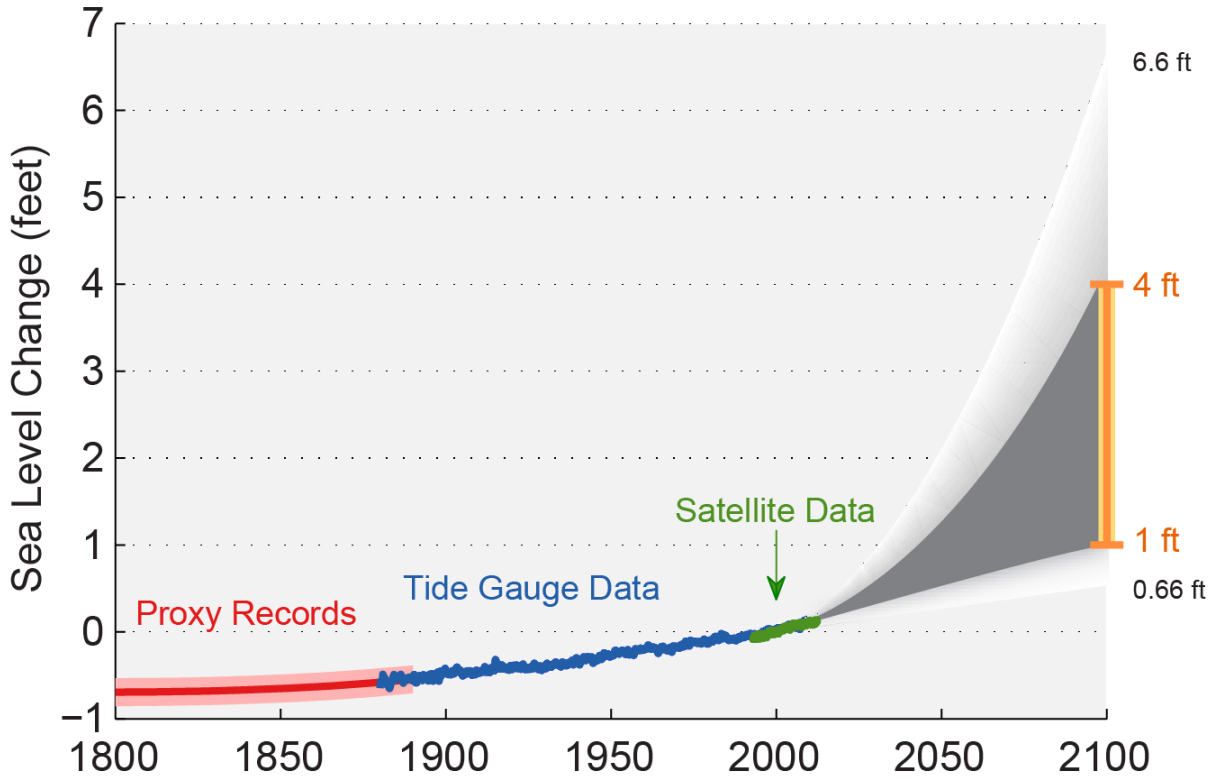


Figure 2. Past and projected changes in global sea level, 1800-2100.[2]

Changes in Average Temperature and Rainfall

Dr. Melillo presented evidence on temperature trends over the past 100 years showing regional variations in temperature change. Heavy precipitation, too, has changed. Some U.S. regions—such as the Northeast—have seen heavy precipitation swell by more than 70 percent, and other regions—such as Hawaii—have seen heavy precipitation decline by 12 percent over recent decades (see Figures 3 and 4).

[2] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

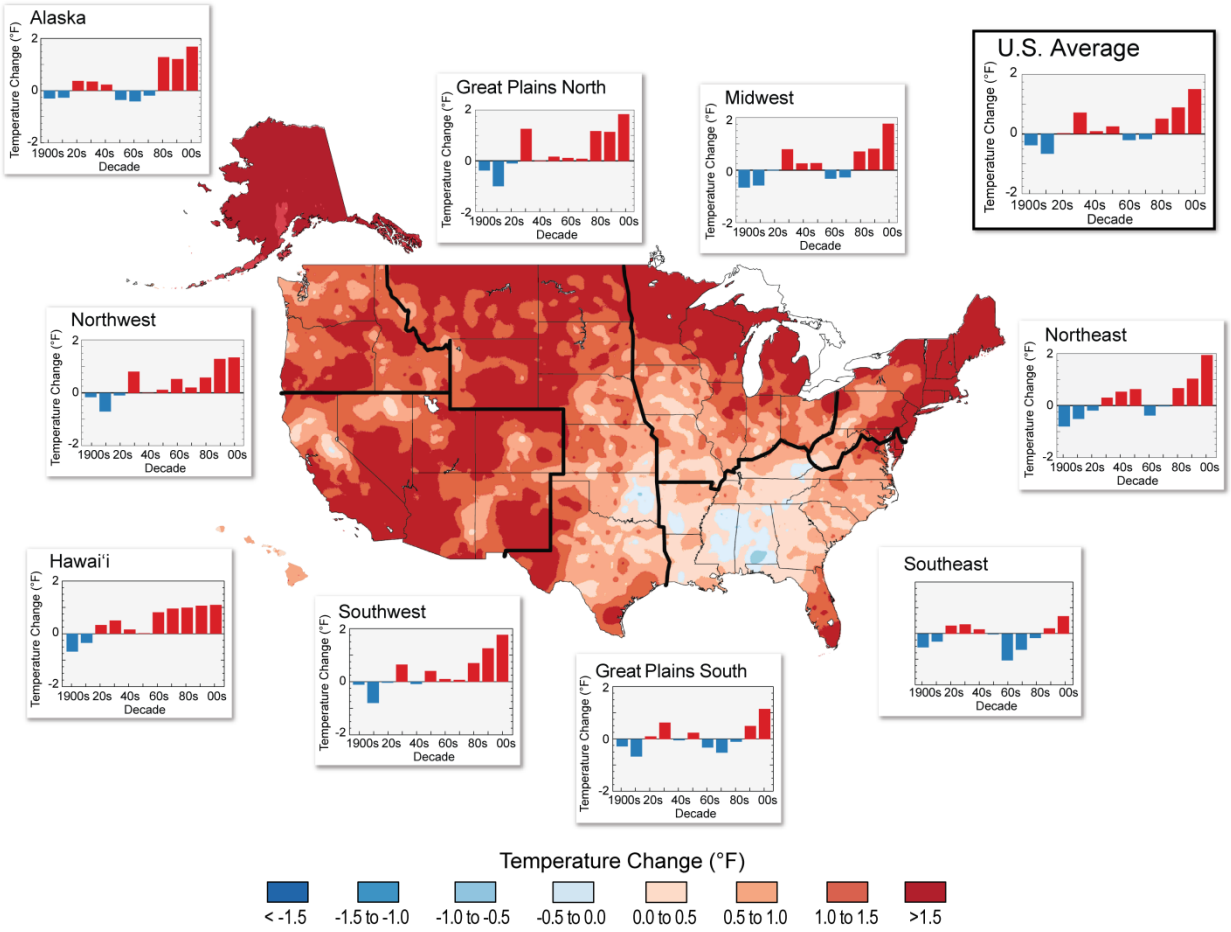


Figure 3. Observed U.S. Temperature Change, 1900s-2000s.[3]

[3] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

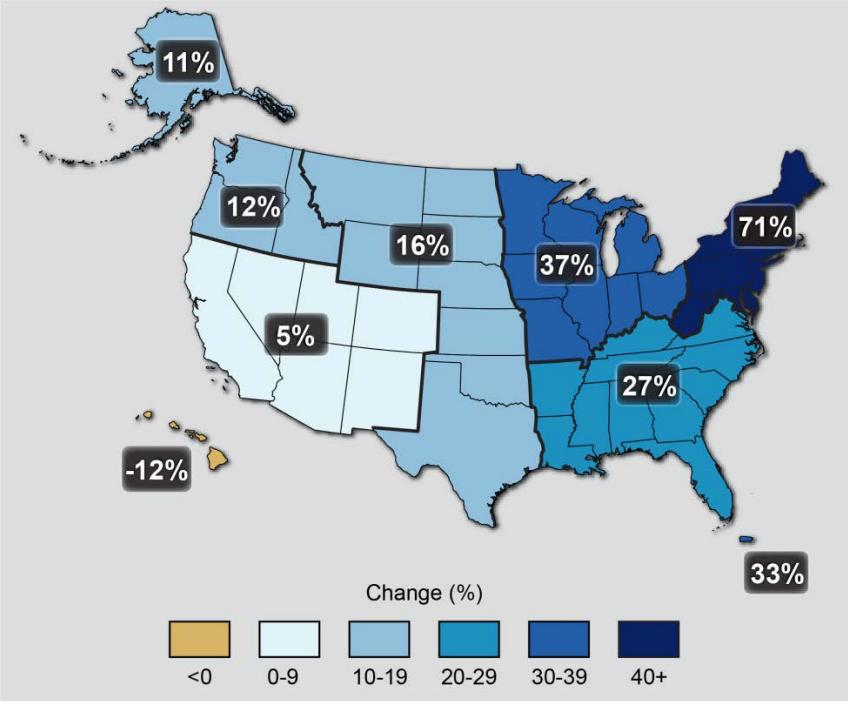


Figure 4. Observed change in very heavy precipitation, 1958-2012.[4]

What's Causing Climate Change?

"There is not really any dispute in my field about the relationships between CO_2 and the environment," said Dr. Kerry Emanuel, professor of atmospheric science at the Massachusetts Institute of Technology (MIT). According to Dr. Emanuel, our climate is generally warming and today the concern isn't another Ice Age—it's that someday there might be no ice at all. Emanuel, whose research at MIT focuses on atmospheric science and intense meteorological events, traced trends in changing temperatures, rising sea-levels, and other manifestations of climate change to growing levels of greenhouse gases.

[4] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

Dr. Emanuel's data on climate trends from 1880 and 2000 showed that changes in carbon dioxide (CO_2) rose in tandem with changes in mean global surface temperatures. The trend data showed that CO_2 concentrations began to increase much more rapidly at the dawn of the industrial era, around 1900, and suggest that by 2020 the rates are on track to double or triple (see Figure 5).

> *"Any doubling of the percentage of carbon dioxide in the air would raise the temperature of the earth's surface by 4°C; and if the carbon dioxide were increased fourfold, the temperature would rise by 8°C."*
>
> The relationship between rising temperatures and CO_2 was recognized more than a century ago by the Swedish scientist Svante Arrhenius, who stated the above in his groundbreaking 1908 book, *Worlds in the Making*.
>
> Source: Svante Arrhenius. *Worlds in the Making: The Evolution of the Universe*. Translated by Dr. H. Borns. New York and London: Harper & Brothers Publishers, 1908.

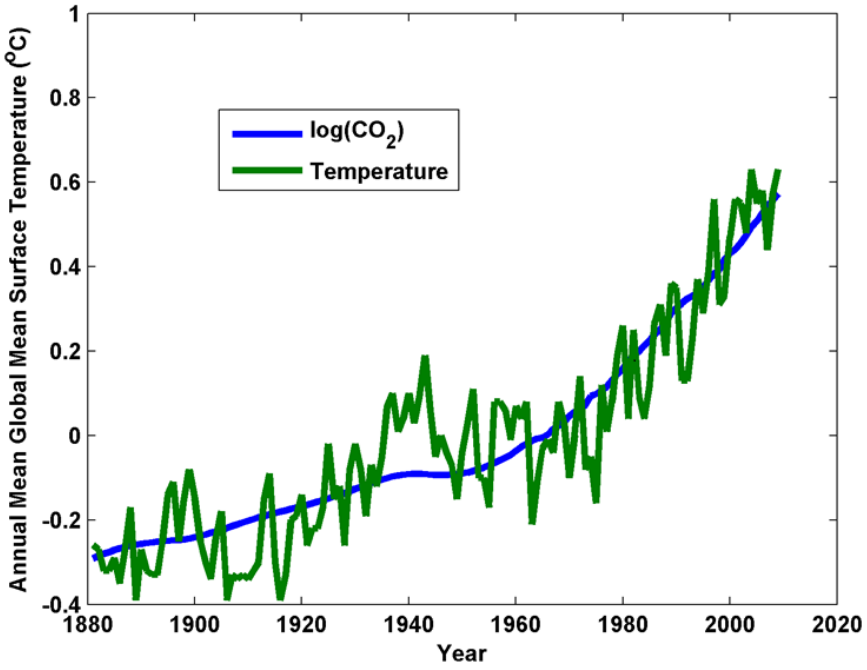


Figure 5. Relationship between mean surface temperature and CO_2 levels.[5]

[5]Emanuel, Kerry, "Extreme Weather and Climate" (lecture, Volpe, The National Transportation Systems Center, Cambridge, MA, February 25, 2014).

CO_2 emissions are likely to double over the coming decades, according to Dr. Emanuel, citing the latest estimate from the Intergovernmental Panel on Climate Change, which states that CO_2 concentrations by 2100 are likely to raise the global temperature from 1.5°C to 4.5°C. He pointed out that the majority of Earth's surface heat goes into the ocean, not into the atmosphere, and that the exchange of heat between the atmosphere and ocean is an important part of the internal variability of the climate system—this interplay, for instance, causes El Niño weather systems (see Figure 6).

According to Dr. Emanuel, the following scenarios are likely in the near future:

- Heat waves will be more frequent and cold spells will be less frequent;
- More floods and drought;
- More intense, destructive hurricanes with increased flooding due to rising sea levels; and
- More very strong storms and rainfall.

As oceans heat up, they become less effective *heat sinks*. They do not absorb heat as well as they used to. The loss of oceans as heat sinks is a key cause of overall global warming. Dr. Emanuel stressed that, "higher temperatures are just the tip of the proverbial melting iceberg—extreme climate events are also becoming more common." A 4.5°C increase in global temperatures would represent an increase of "existential" proportions, with "potentially devastating consequences," Dr. Emanuel said.

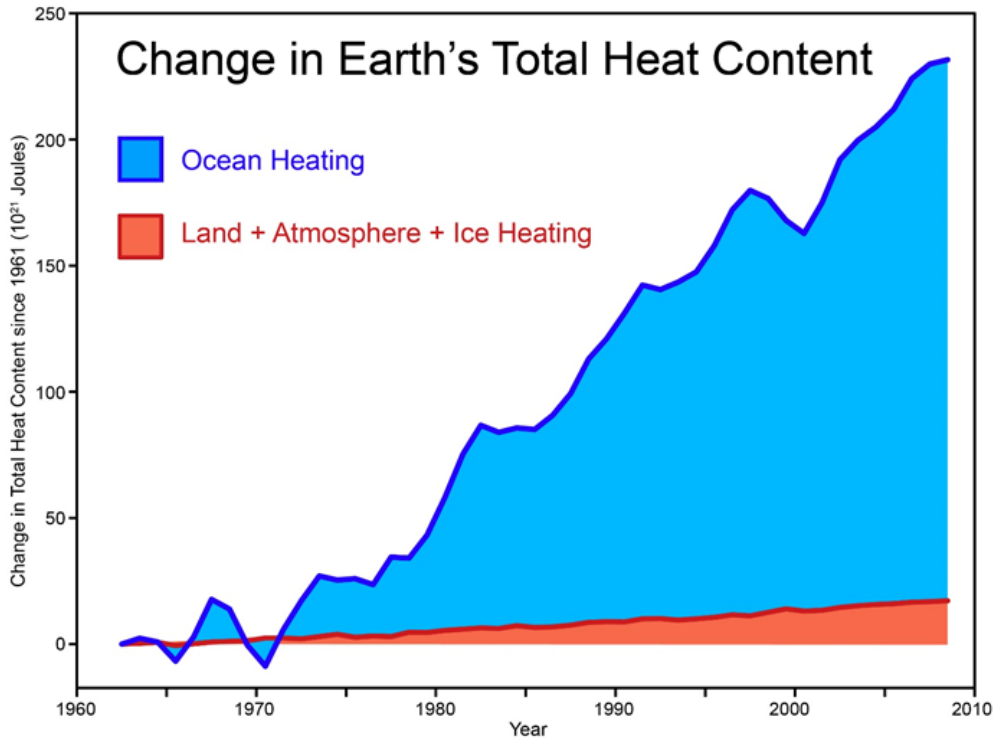


Figure 6. Rising land temperatures compared to rising ocean temperatures.[6]

[6] Emanuel, Kerry, "Extreme Weather and Climate" (lecture, Volpe, The National Transportation Systems Center, Cambridge, MA, February 25, 2014).

But he also made clear that climate change is not just about global warming. Climate change means that dry areas become drier, wet areas become wetter, and hurricanes in the Atlantic get stronger—although there is no direct link yet between higher sea temperatures and more intense hurricanes.

> *"You start seeing temperatures you never saw before. Hot temperatures occur much more frequently. Really cold temperatures occur far less frequently. Drought is one of the big issues we worry about when we think about the consequences of climate change. There will always be weather. There will always be El Niño, but it's really important to distinguish the signal from the noise. You have to look at a large amount of data to see that signal."*
>
> - Dr. Kerry Emanuel
> Massachusetts Institute of Technology

Impacts of Climate Change on Transportation Infrastructure

Every facet of daily life is affected by our environment. A changing climate can change the types and quantity of food we eat, where we live, the types of available jobs, and, critically, how people and goods move. The following table summarizes five of the ten key indicators of climate change, with consequences for transportation infrastructure if each indicator continues unchecked. [7]

[7] Table adapted from "Department of Defense 2012 Climate Change Adaptation Roadmap."

Climate Change Indicator	Transportation System Impacts and Consequences
Rising Temperatures - More days with temperatures above 95° F - Melting permafrost and ice sheets - Changes in incidence or distribution of vector-borne diseases - More wildfires - Warmer soil	- Degrading transportation infrastructure and increased maintenance costs - Increased energy costs for transport facility operations - Creating infrastructures that can stand weather extremes - Stress on electrical grids - Opening of Arctic waters - Longer ice-free seasons - More seasonal Arctic commerce and transit
Changes in Precipitation Patterns - Seasonal increases and decreases in precipitation - More drought, and more severe drought - More extreme precipitation events	- Higher maintenance costs - Higher costs for flood control and erosion prevention - Stream bank erosion - Desertification—the creation of new deserts - Soil and water supply loss - Poorer quality groundwater - Spread of invasive species
Increasing Storm Frequency and Severity - Changes in flood patterns, soil, and vegetation	- Increased coastal and inland flooding - Poorer water quality - Loss of soil and vegetation - Wind damage - Damage to coastal infrastructure - Increased costs of flood control and erosion prevention
Rising Sea Levels and Storm Surges - Loss of coastal land - Reduced capacity of protective barrier islands and coastal wetlands against storm surges	- Degradation of coastal infrastructure - Increased cost of retrofit structures - Supply chain impacts - Scarcity of available land for transportation services - Road and rail infrastructure damage - Equipment damage from salt water
Changes in Ocean Temperatures - Coral reef losses - Loss of ocean protection from storm surge and wave damage.	- Coastal stations and infrastructure more vulnerable to severe weather - Reduced commercial fishing

Source: Table adapted from "Department of Defense 2012 Climate Change Adaptation Roadmap."

2. Climate Change Adaptation Strategies

There is no simple definition for the term *adaptation*. In the past decade or so, *adaptation* has come to be viewed as closely aligned with *infrastructure resilience;* in fact, many current definitions use the two terms interchangeably, with the definition of one embedded in the other.

Adaptation has come to denote a reactive posture to the onslaught of man-made and natural disasters that threaten our transportation infrastructure. Volpe developed a framework for infrastructure resilience that emphasizes the *proactive* function of adaptation as a risk-management strategy.

The IPCC defines adaptation as an "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities." That definition mirrors the concepts that guided Volpe's infrastructure resilience framework (see Figure 7).

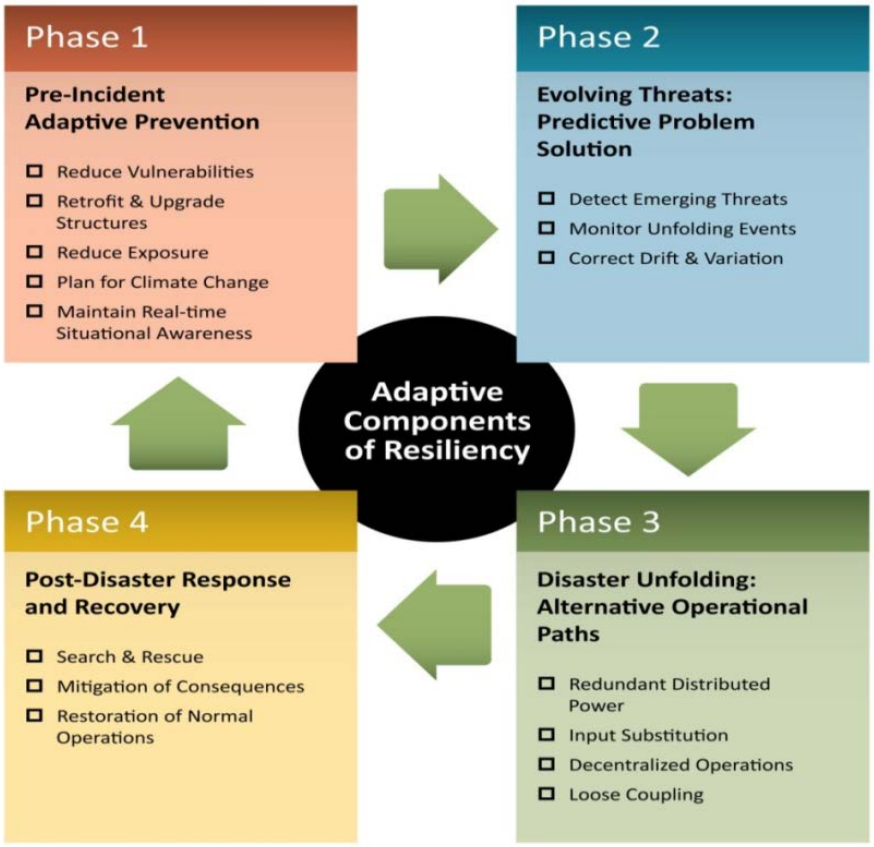


Figure 7. Lifecycle adaptive components of a resiliency framework.[8]

[8] Volpe, The National Transportation Systems Center, "Infrastructure Resiliency: A Risk-Based Framework."

Speaking on transportation and climate adaptation, Steve Winkelman, director of Transportation and Adaptation Programs at the Center for Clean Air Policy, encouraged those involved in land use and infrastructure decisions to always "ask the climate question" to be clear how those decisions impact greenhouse gas emissions and resilience to climate change impacts. He noted, "We have a lot of challenges. We have a lot to learn on transportation and climate adaptation," and offered that his talk would "help frame what kind of problems we're facing, what solutions we know about, and some of our needs going forward."

Winkelman argued that as a nation, we need to invest in ways to reduce greenhouse gas emissions and also invest in ways to help our systems adapt to climate change. "It used to be that working on adaptation was giving up," he said, but "it is clear that there is enough warming built into the system that we are going to need to do both. "

NCADAC's report, *Climate Change Impacts in the United States,* further describes adaptation as "not a stepwise or linear process," but a concurrent improvement process (see Figure 8) in which, "various stages can be occurring simultaneously, in a different order, or be committed completely."

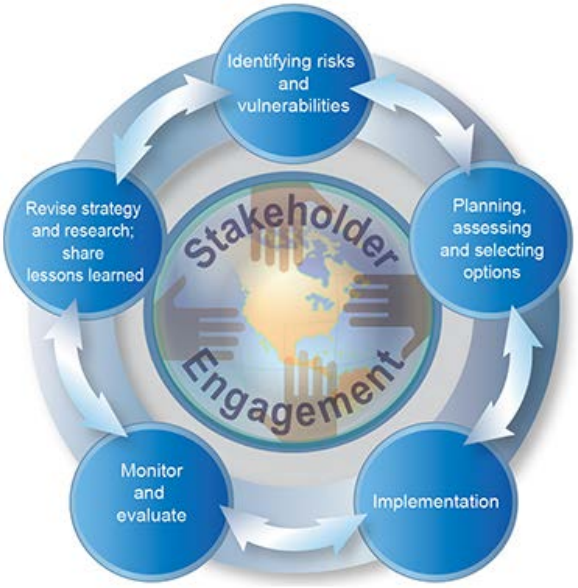


Figure 8. The clockwise adaptation process.[9]

Dr. Melillo provided examples of two adaptation strategies—rezoning and ecosystem restoration—that are being implemented in several regions:

- *Adaptation through rezoning.* In Iowa, a new floodplain ordinance in Cedar Falls expanded zoning restrictions from the 100-year floodplain to the 500-year floodplain to better reflect the

[9] Melillo, Jerry M. , Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

flood risks experienced by this and other Midwest cities during flooding in 2008. Cedar Rapids has also taken significant steps to reduce future flood damage by buying more than 1,000 properties and retrofitting numerous buildings with flood protection technology.

- *Adaptation through ecosystem restoration.* An ecosystem restoration project in New York City has integrated re-vegetation with bulkheads and built infrastructure. Coastal ecosystem conservation and restoration have protected waterfronts and infrastructure, while providing improved habitats for commercial and recreational fish, birds, and other animal and plant species.

Susanne DesRoches, assistant chief of Resilience and Sustainability at the Port Authority of New York and New Jersey (PANYNJ), indicated that, in the wake of increasing storm surge, elevation is now considered critical. She discussed how the PANYNJ is going to add up to 55 inches of height to certain assets, which is an example of one of the important, risk-based approaches being undertaken.

Adaptation Benefits, Co-Benefits, and Challenges

Climate change adaptation has many benefits, but also many challenges and unintended consequences. Dr. Melillo pointed out that the benefits from adaptation often generate additional benefits, or co-benefits—for example, sustainable development, disaster risk-reduction, and improvements in quality of life. Co-benefits make it easy to justify incorporating adaptation measures into decision making processes.[10] However, Dr. Melillo noted challenges that come with adaptation. There are often *multiple stresses* at work that compound damages; key among them pollution and habitat fragmentation. Adjusting to these challenges requires that planners assess composite threats, as well as tradeoffs amongst costs, benefits, and risks of available options.

> *"There is a gap in our knowledge of how the adaptation measures we have undertaken affected the environment. Many of these adaptive actions have only recently been initiated and comprehensive evaluation metrics do not yet exist. Because of this gap, the effectiveness of climate change adaptation has seldom been evaluated."*
>
> - Dr. Jerry Melillo
> The Ecosystems Center
> Marine Biological Laboratory,
> Woods Hole, MA

Adaptation Success Metrics

Given the complexity of climate change causes and stressors, it can be difficult for researchers to develop indicators and consistent metrics for climate change adaptation. To improve the process of adaptation, Dr. Melillo proposed the following goals for climate assessment indicators:

- Provide meaningful, authoritative climate-relevant measures about the status, rates, and trends of key physical, ecological, and societal variables and values;
- Inform decisions on management, research, and education at regional and national scales;
- Identify climate-related conditions and impacts to help develop effective mitigation and adaptation measures; and
- Provide analytical tools for communities to develop their own indicators.

Dr. Melillo proposed that adaptation efforts that are successful would have the following characteristics:

- Widespread use by decisionmakers on an ongoing basis;

[10] The concept of "multiple benefits" from a single climate-change adaptation action has been referred to in the international climate-change literature as a "co-benefit." This concept is emphasized in the IPCC Technical Summary report of Working Group III, as referenced in Section 4 of this report.

- Advance knowledge or understanding on topics of scientific or societal interest;
- Improve coordination of federal activities, or added value from the interagency process;
- Engage stakeholders;
- Achieve objectives from NCADAC strategy documents;
- Increase awareness and accessibility of agency data;
- Produce credible and actionable climate-related information;
- Create high-quality U.S. Global Change Research Program-branded products;[11]
- Have utility for communication documents, or potential for citation; and
- Have an adaptive management and learning process.

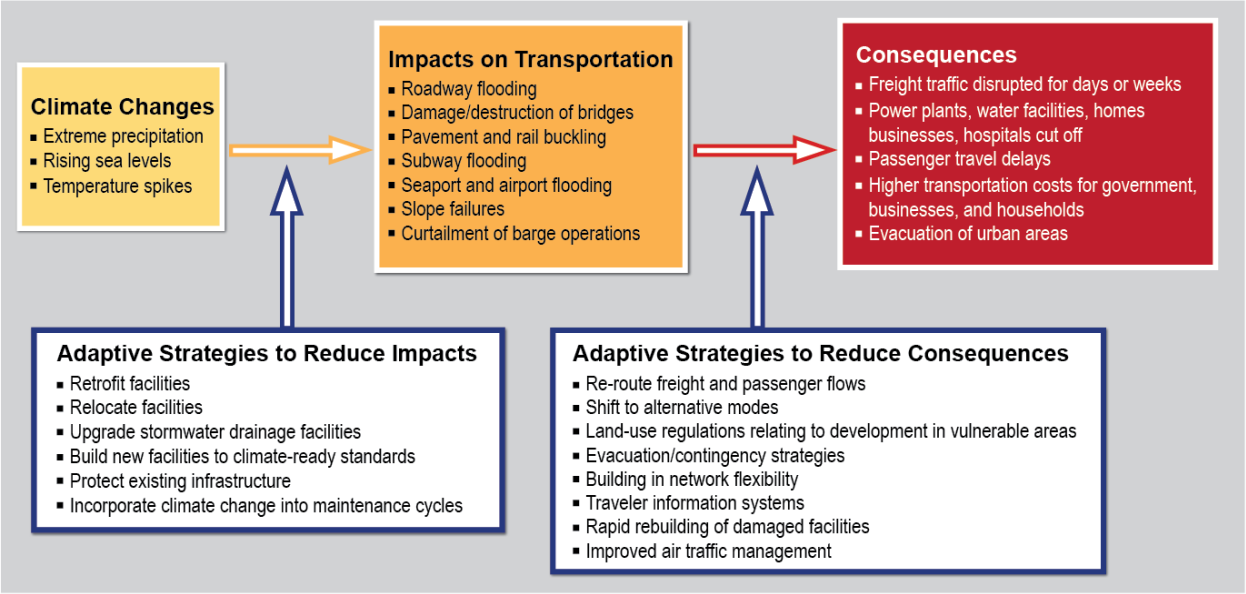


Figure 9. Adaptation impacts identified by NCADAC.[12]

Climate Change Adaptation in New York City

Professor Klaus Jacob described his service as a member of the *Climate Change Adaptation Task Force* of the *New York City Panel on Climate Change (NPCC).* NPCC was convened by former New York City Mayor Michael Bloomberg as an independent advisory body composed of climate change scientists and experts in law, insurance, and risk management.

[11] The U.S. Global Change Research Program (USGCRP) coordinates and integrates federal research on changes in the global environment and their implications for society. USGCRP began as a presidential initiative in 1989 and was mandated by Congress in the Global Change Research Act of 1990, which called for, "a comprehensive and integrated United States research program which will assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change."

[12] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

Established in 2008, the NPCC Task Force produced a foundation report and tools to identify infrastructure adaptation strategies. The product was called ClimAID, a computerized model of the pre-Sandy storm surge in New York City. The Task Force created ClimAID to model growing climate change risks to New York City from the following impacts:

- Accelerating temperatures and sea level rise by 2100 of more than 6 feet above year 2000 levels;
- Nor'easter winter storms;
- Hurricanes that severely flood coastal infrastructure;
- Increases in severe rain events causing street and subway floods; and
- Increases in heat waves, affecting power usage, operational costs, and creating health risks.

The NPCC Task Force recommended adaptation actions that ranged from incremental to large-scale strategies, with planning horizons that ranged from short-term projects of less than 5 years to long-term projects of over 15 years. Closely following the 5 facets of adaptation depicted in Figure 9, the NPCC recommended an 8-step adaptation process:

1. Identify current and future climate hazards;
2. Conduct risk assessment and develop an inventory of built assets to identify vulnerabilities;
3. Characterize risks of climate change on built areas;
4. Develop an initial list of adaptation strategies;
5. Prioritize strategies and identify opportunities for coordination;
6. Link strategies to development cycles and prepare adaptation plans;
7. Implement adaptation plans; and
8. Monitor progress and reassess strategies.

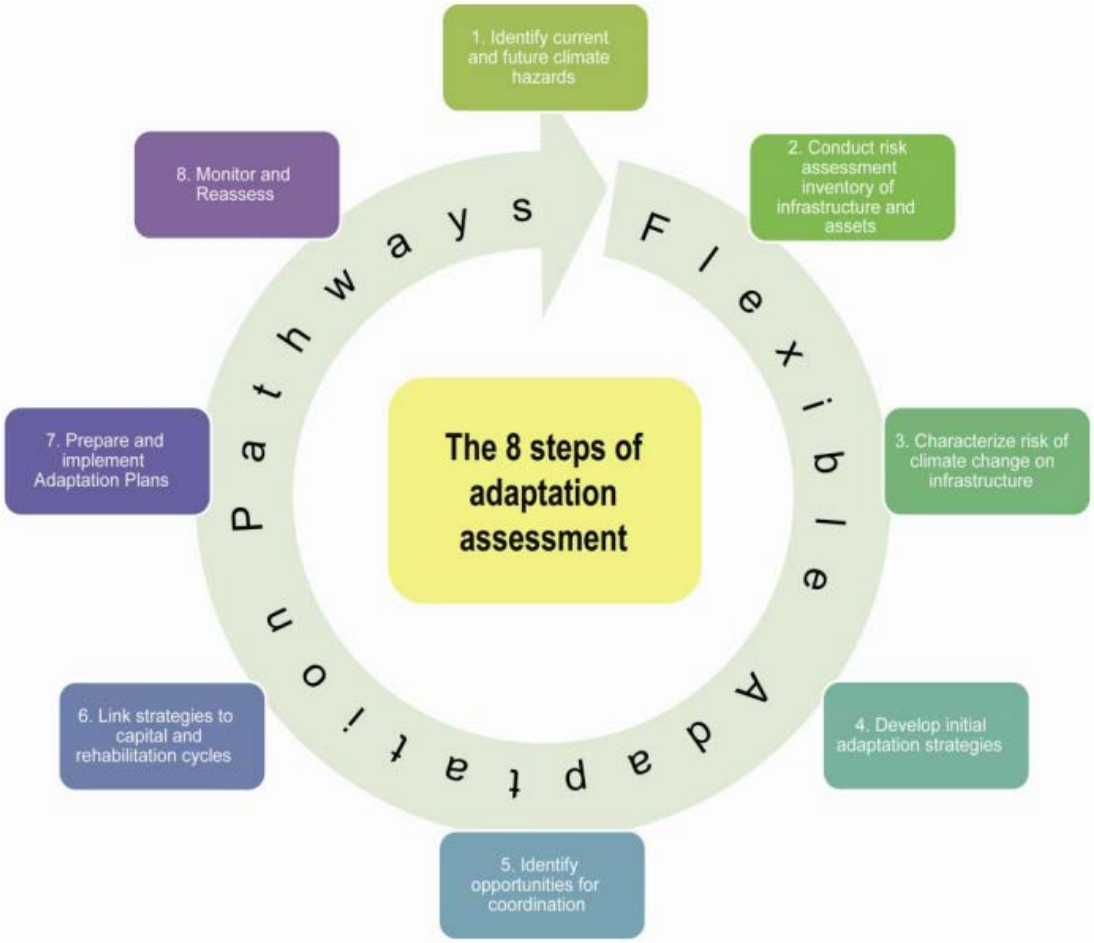


Figure 10. New York City NPCC Task Force adaptation impacts.[13]

[13] New York City Panel on Climate Change, "Adaptation Assessment Guidebook."

Pre-Super Storm Sandy NYC Task Force Climate Risk Assessment

The ClimAID project identified three ways for New York City to adapt:

1. *Protection*—primarily for infrastructure
2. *Accommodation*—primarily for high-rise buildings
3. *Strategic retreat*—primarily for residential assets.

ClimAID produced the following adaptation solutions for New York City:

- Seal ventilation street grates for subway systems in flood zones, and replace passive open ventilation with forced closed vents;
- Install flood gates at vulnerable entrances;
- Build berms and levees;
- Update flood maps to show flood elevation for 100- and 500-year recurrences and add projections on sea level rise;
- Implement design and retrofit transportation infrastructures for adaptive resilience;
- Update emergency response plans.
- Develop alternative plans, including barriers to protect the entire New York harbor and estuary, similar to London's Thames barriers.

The ClimAID report estimated the following consequences if adaptive strategies are not implemented:

- $10 billion in damage to transportation infrastructure from the 100-year flood projections;
- $50 billion in potential economic losses from transportation and utility outages and extended restoration times, plus loss of building stock; and
- Approximately 3 weeks of restoration time at $4 billion per day for various components of infrastructure to resume services.

Post-Sandy Damage Assessment and Lessons Learned

Susanne DesRoches shared the Port Authority of New York and New Jersey's experiences in the aftermath of Superstorm Sandy.

DesRoches described the effects of the storm on airports, seaports, train tunnels, train stations, and vehicle bridges and tunnels. She discussed how the port authority collected lessons learned from Sandy, set up a storm mitigation and resilience office, and began to implement protective measures.

"We had several weeks of just getting through the emergency part of Sandy, getting back up and running, making sure that everything was functional. Then we in the engineering department took a

hard look at what we would need to do cross-agency to increase our flood protection, our generation capacity, etc.," said DesRoches.

DesRoches discussed how resiliency needs to be part of how the transportation community does business. After Sandy, the port authority put together a list of strategies that could potentially be implemented throughout the agency. DesRoches provided examples of some of those strategies including the installation of a variety of water intrusion protective systems.

Over the long term, the PANYNJ is looking at how to improve its design guidance. So, considering climate stressors such as sea level rise and increased frequency and severity of storms, officials are looking at how to factor this knowledge into improved design of infrastructure, such as airfields or pumping stations.

Dr. Jacob also outlined the losses and damages after Sandy, confirming the risks and impacts for roads, ferries, tunnels, rail airports, and ClimAID's warnings of the gradual risks of increased yearly precipitation, higher average temperatures, storm surges, heavy downpours, heat waves, and high winds. Dr. Jacob said that the post-Sandy destruction, "eerily verified ClimAID impact forecasts—with two exceptions." These exceptions, below, demonstrate the effectiveness of adaptive measures:

- Temporary barriers at the Harlem River Tunnel prevented flooding of subway lines between Manhattan and the Bronx;
- Removing sensitive signal and control systems from most tunnels expected to be flooded, and reinstalling them after the storm was highly effective in keeping signals free of damage from salt water, saving 1 to 2 weeks of recovery time and an estimated $10 billion in damages.

Dr. Jacob wrapped up his talk with the following conclusions:

- Make risk-based benefit-cost assessments at the right time using updated flood maps and flood vulnerabilities as a function of sea level rise, while also accounting for changing physical and social asset configuration and vulnerabilities and optimal *resiliency pathway* is reached;

> *"All modes of transportation need to take into account a robust climate and sea level rise projection for all their capital spending projects...Not investing in these resilience measures will be more expensive by factors of four to ten in incurred, direct, and economic losses combined."*
>
> -Dr. Klaus H. Jacob
> Lamont-Doherty Earth Observatory
> School of International and Public Affairs,
> Columbia University

- Develop sea-level rise adaptation policies with public-private stakeholders and create land-use plans that balance the merits of temporary protection and medium-term protection, accommodating for sea-level rise, with long-term, sustainable retreat to safer neighborhoods;
- Incorporate climate change data and risk estimates for various time horizons into all strategic planning and capital decisions;
- Use each climate change and sea-level rise challenge as an opportunity for improvement and renewal of urban infrastructure. The costs for the NYC metro region will be upward of $100 billion—some $30 billion of which for the transportation sector alone—but not investing in these resilience measures would be more expensive by factors of 4 to 10 in post-disaster costs;
- Ensure robust planning for interim operational emergency and business continuity of operations.

Perspective on Federal Response to Super Storm Sandy

Vinn White described the challenges the federal government faced after some $68 billion in damages from Sandy and transportation-specific damages of more than $12.4 billion, including the following:

- $5.1 billion in damages to transit;
- $2 billion of damaged pipelines, primarily natural gas;
- $400 million in damages to highways;
- $70 million in damages to Amtrak and freight rail; and
- $40 million in damages to aviation.

White described the activities of the Sandy Rebuilding Task Force, consisting of 14 federal agencies and 9 White House offices. The Task Force was asked to inform the National Disaster Recovery Framework and to, "identify and work to remove obstacles to resilient rebuilding in a manner that addresses existing and future risks and vulnerabilities." The Task Force's activities included the following:

- Creating an Executive Order to revise floodplain elevation guidelines, floodplain maps, and raise Advisory Base Floodplain Elevation by 1 foot;
- Adding language to the TIGER Discretionary Grants program so that project plans consider State of Good Repair criteria for minimized life-cycle maintenance costs, and criteria for considering environmental sustainability improvements that enhance resilience of transportation assets;

> *"These are the principles that guide us: adopting integrated approaches, which I think you've actually seen done well in the Sandy context; prioritizing the most vulnerable of infrastructure; and then this third one here is probably the most referred to in the Sandy context, is the use of best-available science or data."*
>
> -Vinn White
> Senior Policy Advisor for
> Transportation Policy
> U.S. Department of Transportation

- Funding transportation agency rebuilding efforts:
  - Federal Aviation Administration rebuilding infrastructure to elevated standards;
  - Federal Railroad Administration providing redundancy for major rail projects;
  - Federal Highway Administration integrating climate change resilience consideration into programs and guidance that include climate adaptation activities eligible for funding, including vulnerability assessment and risk-based asset management;
  - Federal Transit Agency incorporating resilient buildings into notices of funding, issuing a $3 billion notice of data availability for Resilience Projects in Response to Hurricane Sandy, and promoting a benefit-cost estimation process with quantitative and qualitative metrics.

3. Mitigation of Climate Change Consequences

In climate change planning, mitigating impacts is about addressing the anticipated consequences of climate change by taking preventive measures that will reduce the probability or severity of an adverse climate-related consequence. The IPCC has defined mitigation as a form of "intervention to *reduce the sources* or enhance the sinks of greenhouse gases."[14] Mitigation is often part of a broader policy framework that includes adaptation and emission-pricing policies, such as carbon taxes and cap-and-trade policies to cut carbon pollution. Climate change mitigation can be viewed as a two-pronged process of reducing short-term impacts and taking longer-term actions to reduce future consequences.

- *Short-term actions* include updating flood maps, installing gates at subway entrances, and draining flooded subways;
- *Medium- and long-term actions* include carbon pricing as well as new zoning and building codes, floodplain buyouts, analyzing hazard-related data to determine where it is safe to build or locate temporary facilities, or developing technologies that could be used to support mitigation strategies.

> *"The International Civil Aviation Organization (ICAO) has endorsed ambitious emission reduction efforts…requesting that the Council make a recommendation for a global scheme for developing market-based measures applicable for international aviation. The ICAO assembly called for implementing technical measures for: monitoring, reporting and verifying emission levels, establishing acceptable levels of carbon credits, and agreeing on allocation of emission levels for international operators in order to close the CO_2 gap and provide a blueprint for other transportation sectors."*
>
> - Gregg Fleming
> U.S. Department of Transportation
> Volpe Center

Beneficial Effects of CAFE Standards as a Mitigation Measure

Gregg Fleming characterized the first pillar of the White House's 2013 Climate Action Plan—cutting carbon pollution—as a key mitigation measure for combating global climate change. He noted that this first pillar should be augmented by two other pillars of the Climate Action Plan—preparing for impacts and leading international efforts. Fleming described how these mitigation measures can be implemented in clean energy programs, building a 21st century transport system, cutting energy waste, and federal leadership. The Climate Action Plan will mitigate climate change by enforcing emission

[14] Intergovernmental Panel on Climate Change. *Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability. Available:* http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch18s18-1-2.html. 30 September, 2014.

standards for new and existing power plants, new fuel efficiency standards for heavy-duty vehicles, and new goals for doubling electricity generation from wind and solar power. Fleming pointed out that the U.S. passenger vehicle standard of 54.5 miles per gallon by 2015, and new heavy-duty standards for model year 2014-18 are positive steps on top of existing Corporate Average Fuel Economy (CAFE) standards. See Figure 11.

- CAFE standards have saved an estimated 1 trillion gallons of fuel and 14 billion tons of CO_2 emissions since the 1970s.
- By 2021 consumers may save $660 to $860 billion at the pump as a result of CAFE standards—through 2050, new CAFE standards could save 1.1 trillion gallons of fuel and 12 billion tons of CO_2 emissions.

Fleming also described how market-based measures (MBMs) can mitigate climate change. The aviation sector has committed to developing MBMs in international aviation to effectively provide incentives for low-cost CO_2 reduction strategies.

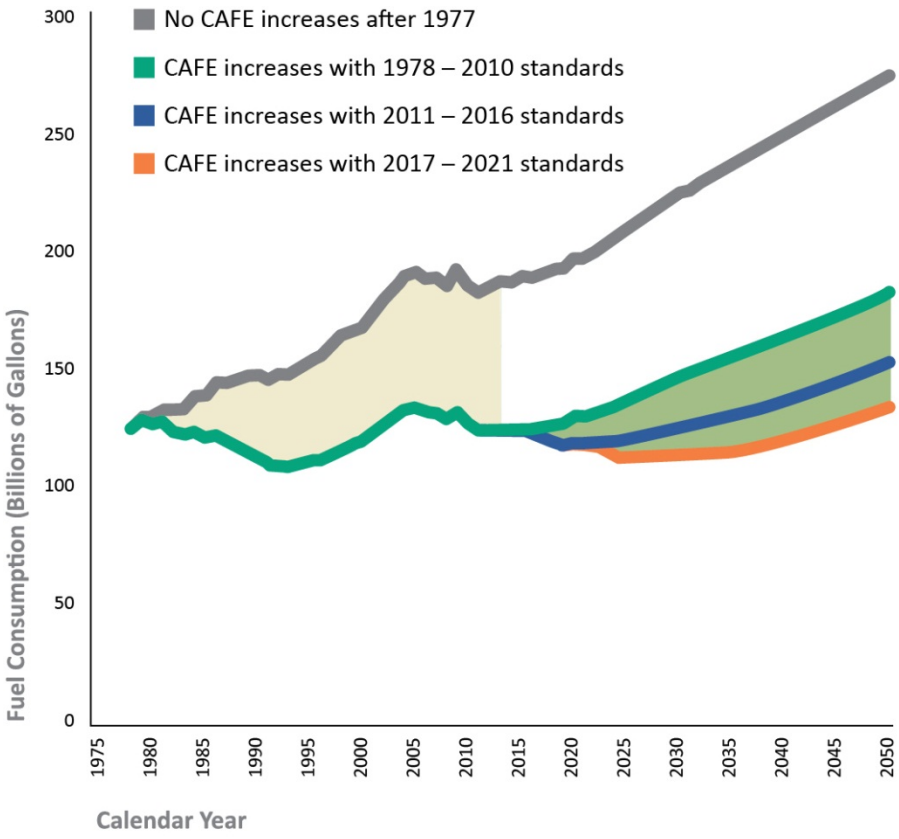


Figure 11. Mitigating the impacts of climate change by reducing fuel consumption.[15]

[15] U.S Department of Transportation, Volpe Center image.

Adverse Impacts of Fossil Fuels on Rates of CO_2 Concentration

The transportation sector's heavy use of fossil fuels exacerbates the impact of carbon sinks lost to deforestation and warming oceans. Between 1880 and 2010, deforestation and fossil fuel usage were the primary sources of the growth in CO_2 emissions trends that have coincided with the shrinking of the size of the carbon sinks. See Figure 12.

> *"In 2010, The U.S. transportation sector accounted for 27% of total U.S. GHG emissions, with cars and trucks accounting for 65% of that total. Petroleum accounts for 93% of the nation's transportation energy use."*
>
> *- Climate Change Impacts in the United States*, 2014

Dr. Melillo, in an effort to under-score the significance of combining adaptation and mitigation, observed that, "current implementation efforts are modest, but growing." He cautioned that it is, "critical to link mitigation and adaptation. With more mitigation there is less need for adaptation, because adaptation has its limits."

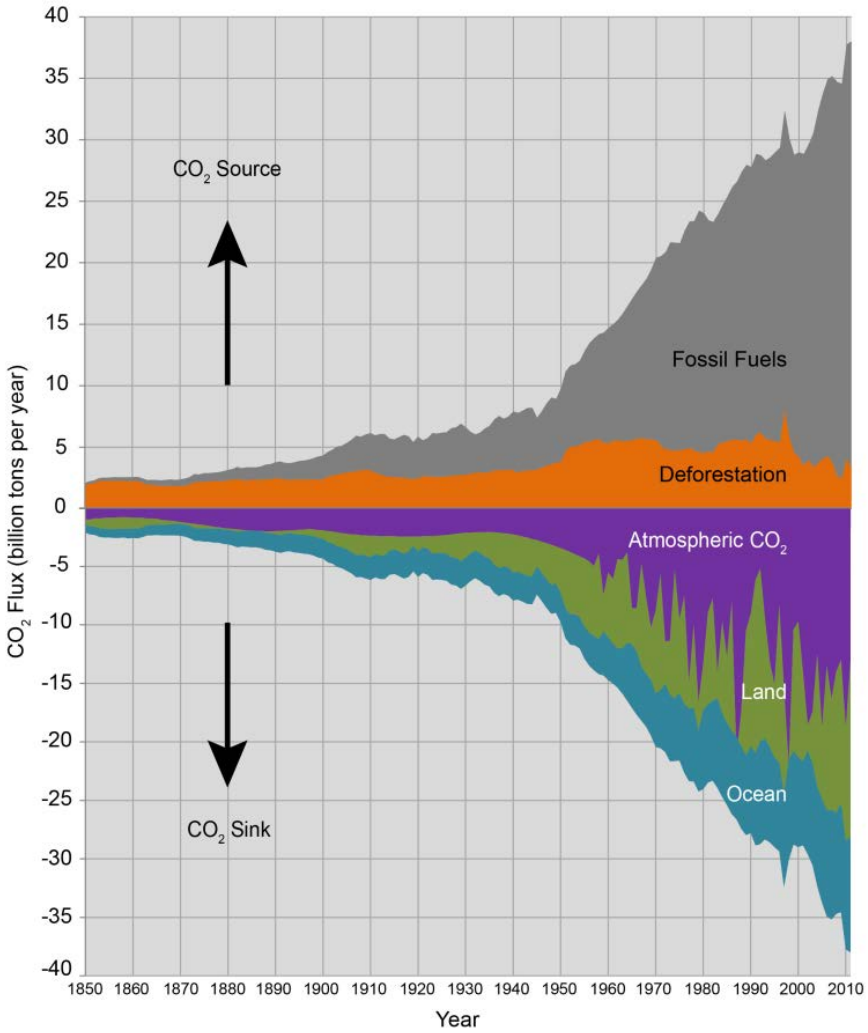


Figure 12. Influence of human activities on the accumulation of global carbon dioxide.[16]

[16] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

4. Resilience in the Face of Climate Change Impacts and the Importance of Planning

Planning for climate change-resilient infrastructure requires a coordinated process of assessing risks, formulating adaptation and mitigation strategies, and coordinating implementation. As previously noted, the climate change literature has intertwined resilience and adaptation, often using the two terms interchangeably. However, resilience connotes more than adaptation. Planning for climate change resilience involves taking steps to prevent disruption, prepare to withstand damages, and rapidly recover from consequences. In this respect, resilience to climate change is a byproduct of a well-planned and efficiently executed process of risk assessment, damage prevention, adaptation to change, and effective mitigation measures to remedy damages and learn to better deal with the risks that threaten our complex infrastructure systems.

The Volpe framework for infrastructure resilience (see Figure 13) depicts resilience as an overarching concept linking infrastructure fault-tolerance and event-monitoring capabilities with elements of adaptation and mitigation of adverse consequences to ensure functional continuity.

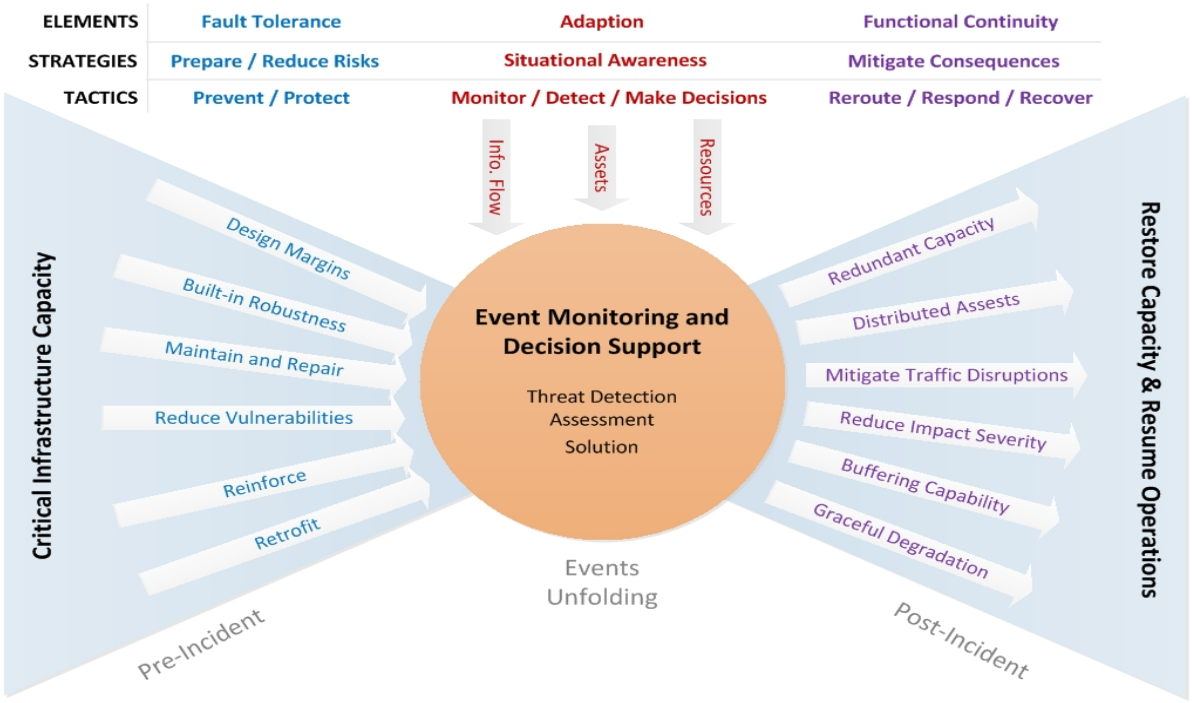


Figure 13. Key attributes of infrastructure resilience.[17]

[17] Volpe, The National Transportation Systems Center

A climate change-resilient infrastructure has adaptive properties that derive not only from the system's ability to absorb damages and disruptions, but its abilities for constructive change and learning. Resilience does not mean automatically bouncing back, fully resuming life as it was before adverse impacts of climate change. Instead, a resilient system is one that *learns and adapts*, can correct past errors, self-organize, and forge new solutions that minimize climate change impacts.

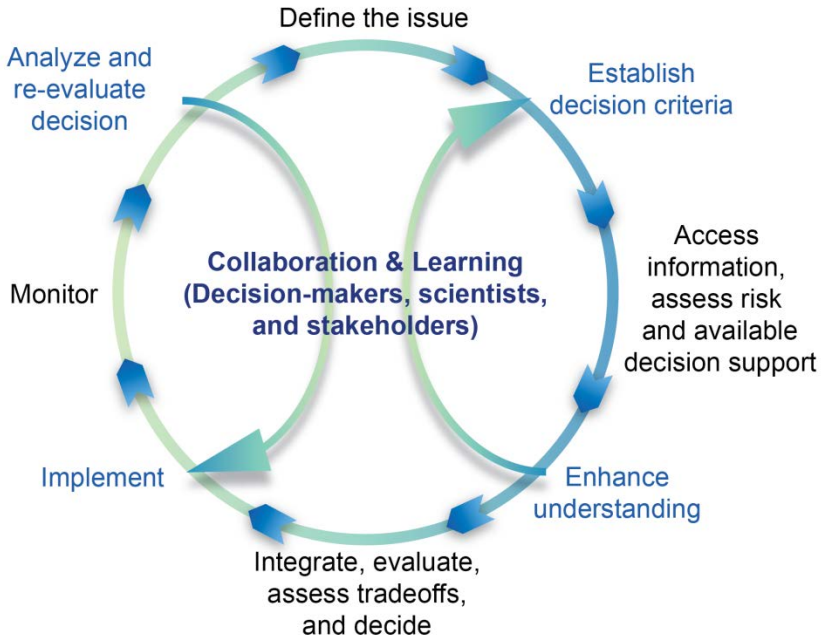


Figure 14. The climate change decision making process.[18]

Importance of Planning

Three of Volpe's climate change lectures emphasized that the process of planning for climate change is closely associated with resilience planning in general, and adapting to and mitigating adverse consequences of climate change.

[18] Melillo, Jerry M., Teresa (T.C) Richmond, and Gary W. Yohn, Eds., 2014: *Climate Change Impacts in the United States: The Third National Climate Assessment,* U.S. Global Change Research Program.

- Steve Winkelman has been active in climate adaptation since 2006. He directed the Urban Leaders Adaptation Initiative, helping city governments consider climate issues when making infrastructure and land use decisions to improve their resilience to the effects of climate change. Partners included New York City, Chicago, Miami-Dade County, Los Angeles, San Francisco, King County, Phoenix, Milwaukee and Toronto. Mr. Winkelman's team provided technical and policy assistance to help these locations develop and implement climate adaptation plans and policies and produced a paper on green infrastructure and urban climate adaptation.

> *"What we build, where, and how, makes a big impact both on emissions, whether we're talking about buildings or transportation, as well as resilience or vulnerability to climate change impacts. So ask the question when you're making that kind of decision."*
>
> -Steve Winkelman
> Center for Clean Air Policy

  Mr. Winkelman described CCAP efforts to mitigate climate change impacts and help regional stakeholders plan for resilience by promoting a Mitigation Action Implementation Network (MAIN) in the U.S., Latin America, and Asia. The MAIN initiative helps participants design and implement nationally appropriate mitigation actions. As part of this process, CCAP helps regional stakeholders develop strategies to identify best practices and regional and national resources to support implementation.

  The long-term solution to transportation system resiliency is not just about cleaning up after events and repairing the infrastructure, but planning for and designing infrastructure with the current and future climate in mind. This will ensure that the nation's transportation infrastructure can withstand more severe weather events. Winkelman provided some examples:

  - Collecting information on local, non-climate factors like infrastructure state of repair is a proactive measure that can be part of the solution.
  - Updating flood maps to include climate scenarios can better prepare local, state, and federal agencies to deal with extreme weather.
  - Educating stakeholders and decision makers from a central location eases communication and allows for everyone to be on the same page.

- Susanne DesRoches served in the lead role for the Hurricane Sandy immediate recovery and future climate resiliency efforts within the PANYNJ's engineering department. DesRoches manages the sustainable design program for the Port Authority's capital projects, overseeing the

sustainability and climate resiliency of large-scale projects such as the LaGuardia Modernization Program and Newark Terminal A Redevelopment. She led the development and adoption of the PANYNJ's Sustainable Infrastructure Guidelines, a sustainability rating system for infrastructure projects.

In her lecture, Susanne described post-Sandy measures to improve resilience in the New York City area. Actions taken included short-term protective measures to reduce water intrusion, and assembling a series of high-level estimates of the costs of mitigation measures, such as emergency generators, flood control barriers, drainage improvements, and electrical system protection. PANY/NJ established an internal mitigation team that works with the PANY/NJ Storm Mitigation and Resilience Office, the U.S. Office of Emergency Management, and representatives from municipal business, finance, and engineering departments.

> *"We did not have a deep bench of architectural and electrical engineers available right after the storm. We were able to find people, but that was a lesson learned that we'll have a much broader discipline base of inspectors in the future."*
>
> -Susanne DesRoches
> Port Authority of New York and New Jersey

- William Lyons is a Principal Technical Advisor in transportation planning at the U.S. Department of Transportation's (USDOT) Volpe Center. His research interests include transportation planning and policy, sustainability and innovative ways to incorporate considerations of climate change mitigation and resilience in transportation decisions.

> *"Resilience is a much more open-ended topic. It does need to be distinguished. It's related to adaptation but to me it's not really the same thing. It's the focus on the system that's not only the multimodal transportation system but it's the broader community system."*
>
> -William Lyons
> U.S. Department of Transportation
> Volpe Center

Mr. Lyons stressed the difference between specific mitigation measures, such as reducing emissions, or adaptation strategies focused on infrastructures and IPCC recommendations, and how the transportation planning process can consider climate change resilience. Planning for resilience, he pointed out, must focus on system-level strategies that seek to enhance an entire network's capacity to withstand shocks, respond, and rebuild. Such a process requires a collaborative, multi-sector approach that offers multiple options that can be integrated into existing institutions and infrastructure investment plans. He pointed out that under federal law, Metropolitan Planning Organizations (MPOs) conduct long-range transportation planning in metropolitan areas over 50,000 population. With federal encouragement, MPOs are currently

developing performance-based planning processes, including for asset management. This consistent planning process provides a flexible foundation for considering climate adaptation and resilience, supporting sound technical analysis, community participation, and collaboration with other sectors. This is illustrated by the San Francisco Bay Area Metropolitan Transportation Commission planning process, Adapting to Rising Tides. This process assesses the risk of sea-level rise for the BART transit, airport, port, Bay Bridge, and interstates by preparing for multi-modal options to respond to various SLR scenarios, with adaptation plans that include consideration of redundant resources and mitigation measures.

Appendix A: Video Library

Steve Winkelman
Part I Part II
Part III Part IV

Dr. Klaus H. Jacob
Selected clips
Full presentation

Susanne E. DesRoches
Selected clips
Full presentation

Gregg Fleming
Selected clips
Full presentation

Dr. Kerry Emanuel
Selected clips
Full presentation

William M. Lyons
Selected clips
Full presentation

Vinn White
Selected clips
Full presentation

Dr. Jerry Melillo
Selected clips
Full presentation

Appendix B: Stakeholder Engagement Statistics

More than ***220*** state, regional, and local transportation professionals attended or viewed the speaker series via the web.

Attendees from ***40*** states, and from cities including Atlanta, Boston, Houston, San Francisco, Seattle, and New York.

Representatives from more than ***40*** universities, including professors, research directors, and doctoral students from dozens of universities such as Clemson, Harvard University, MIT, Penn State, Stanford, UCLA, and the University of Southern Florida's National Center for Transit Research.

Nearly ***200*** large and small business executives, planners, project managers, consultants, scientists, and journalists from outlets such as Amtrak, Bloomberg News, Booz Allen Hamilton, CDM Smith, McClatchy, Raytheon, and Southwest Airlines.

Numerous **Non-profits** also joined the conversation, including the **Center for Clean Air Policy**, **the RAND Corporation**, the **American Association of State Highway and Transportation Officials**, the **Rails to Trails Conservancy**, and the **Sierra Club**.

The world showed up at Volpe virtually, with government officials and researchers from the **Canada**, **China**, **England**, the **European Union**, **Fiji Islands**, the **Netherlands**, and **Senegal**.

More than ***150*** Volpe staff members took advantage of the opportunity to engage with thought leaders and learn how climate and system resiliency applies to their work supporting the U.S. Department of Transportation and other sponsors.

Nearly all U.S. DOT modes and several Secretarial offices linked in to the series including Federal Aviation Administration, Federal Highway Administration, Federal Transit Administration, Federal Railroad Administration, Federal Motor Carrier Safety Administration, Pipeline and Hazardous Materials Safety Administration and the Maritime Administration.

Because transportation is woven into nearly every facet of our national interests, this series also attracted widespread participation from over 60 Federal officials outside of DOT: Department of Defense, Department of Homeland Security, Environmental Protection Agency, Department of Energy–including Argonne and Idaho National Laboratories, the Department of Interior, the U.S. Department of Agriculture, National Oceanic and Atmospheric Administration, the Government Accountability Office, and Congressional staff.

Appendix C: Stakeholder Engagement

Volpe
The National Transportation Systems Center

Fall 2013 – Spring 2014

U.S. Department of Transportation

Volpe's Transportation System Resilience, Extreme Weather and Climate Change series informed hundreds of transportation practitioners nationwide and around the globe.

State, Regional and Local stakeholder engagement

State DOTs

Arizona
California
Colorado
Connecticut
Delaware
D.C.
Florida
Georgia
Illinois
Indiana
Maryland
Massachusetts
Michigan
Minnesota
Montana
Nevada
NH
New Jersey
New York
Ohio
Oklahoma
Oregon
Rhode Island
Tennessee
Texas
Vermont
Virginia
Washington
Wyoming

Other state agencies, transit agencies and local government

Alameda-Contra Costa Transit District, CA
Bay Area Rapid Transit, CA
Charlotte Area Transit System (CATS), NC
City of Cambridge, MA
City of Newport, RI
City of Seattle, WA
Executive Office of Health and Human Services, MA
Galveston Island Transit, TX
Maine Emergency Management Agency
Metro. Transportation Authority, NY
New Jersey Transit
New York City DEP
Town of Mashpee, MA
MBTA, MA
Prairieland Transit System, Southwestern MN
Port Authority of NY, NJ
Authority, VA
Port of Portland, WA
RI Dept. of Envir. Mgt
Seattle DOT, WA
Triangle Transit, Durham, NC
Utah Transit Authority
VT Division of Emergency Management and Homeland Security
VIA Metropolitan Transit, San Antonio, TX
Williamsburg Area Transit
Washington Metropolitan Area Transit Authority

MPOs

Adirondack/Glens Falls Transportation Council, NY
Atlanta Regional Commission, GA
Baltimore, Metropolitan Council, MD
Boston Region MPO, MA
Broward MPO, FL
Capital Area Metropolitan Planning Organization, TX
Central Mass Regional Planning Commission, MA
Cobb County Regional DOT, GA
Delaware Valley Regional Planning Commission, DE
Fresno Council of Governments, CA
Genesee Transportation Council, NY
Greater Buffalo Niagara Regional Transp. Council, NY
Houston-Galveston Area Council, TX
Ithaca-Tompkins County Transportation Council, NY
Kern County MPO, CA
Kings County Association of Governments, CA
Metropolitan Area Planning Council, MA
Mid-America Regional Council, KS
Mid-Ohio Regional Planning Commission, OH
Mobile County Commission, AL
MD-National Capital Park and Planning Commission
Mid Region Council of Governments of NM
New Orleans Metro Region MPO, LA
New Bern Area MPO, NC
NJ Transportation Planning Authority, NJ
New York Metropolitan Planning Council, NY
North Slope Borough, Arctic Regions, Alaska
Northeast Ohio Area-wide Coordinating Agency, OH
Northern Shenandoah Valley Regional Commission, VA
Oahu MPO, Hawaii
Red Cliff Band of the Lake Superior Chippewa Indians, WI
Regional Transportation District for Denver, CO
Rockingham Planning Commission, NH
Sacramento Area Council of Governments, CA
Southwest Michigan Planning Commission, MI
Southwestern Pennsylvania Planning Commission, PA
Syracuse Metropolitan Transportation Council NY
Ulster Country Transportation Council, NY

Non-Profits

AASHTO
American Council for an Energy Efficient Economy
ACI-NA
APTA
Association of Metropolitan Planning Organizations
Center for Clean Air Policy
Climate Protection Camp.
Coalition of NE Governors Policy Research Center
Environmental and Energy Study Institute
Enterprise Community Partners

ITS America, Minnesota Center for Environmental Advocacy, National Association of Regional Councils, National Transportation Research Center, Inc., Rails to Trails Conservancy, RAND Sierra Club

Appendix C: Stakeholder Engagement (continued)

Volpe
The National Transportation Systems Center

Fall 2013 – Spring 2014

U.S. Department of Transportation

Volpe's Transportation System Resilience, Extreme Weather and Climate Change series informed hundreds of transportation practitioners nationwide and around the globe.

Academia, Private Sector, and Global stakeholder engagement

Academia

Carleton College
Clemson University
Cleveland State University
Columbia University
George Mason University
Georgetown University
Harvard University
Jackson State University (MI)
Massachusetts Institute of Technology
Michigan Technological University
New York University
Northeastern University
Oregon State University
Penn State
Purdue University
San Jose State University
Stanford University
University of Colorado
University of Iowa
University of Maryland
University of Massachusetts – Amherst
University of Massachusetts - Boston
University of Minnesota
University of Michigan
University of Pittsburgh
University of Southern Florida
University of Rhode Island
University of Vermont
University of Wisconsin
Virginia Tech

Private sector

Abt Associates
AECOM
Atkins Global
Amtrak
Azymuth Telecon
Battelle
BEM Systems, Inc.
Bloomberg Media
Booz Allen Hamilton
Bosch
BTG Ventures LLC
Cadmus Group
Cadmus Sustainable Transportation Practice
Cambridge Systematics
CDM Smith
CDR Maguire
CEVA Logistics
Chevron
CINSA
Clary Corporation
Clean Tech Strategy Group
ClimateProgress (media)
Coleshill Associates
Collins Engineering
Coral Sales Company
CSC
ee Publishing's ClimateWire (Media)
Efecto Verde Engineering (Mexico)
ERG
Global Innovative Solutions

Private sector cont.

Greenman-Perderson, Inc.
Gresham, Smith and Partners
Hatch, Mott McDonald
HDR Alaska, Inc.
HDR, Inc.
Hitachi Consulting
HNTB
iBiz
ICF International
Jacobs
JT Environmental Consulting
KAG Engineering, PLLC
Kleinfelder
Leverage Information Systems
LF Consulting
LTK
LWV
McClatchy Washington Bureau (Media)
Meadow Networks
Nakanishi Research & Consulting
Parsons Brinkerhoff
Raytheon
Research Systems Group
RSG
RTGR Consulting
SGT
Southwest Airlines
SRTA
Stahl Sheaffer Engineering
Stantec
Strategic Technology Assessment
STV Incorporated
Taminco US, Inc.
Toole Design Group
TPRG
TransCore
TREDIS Software
Truline
TY Lin International
Urban Engineers of NY, PC
URS Corporation
Venner Consulting
VHB
Vionics
WeatherStrategy LLC
Weir Environments

International

British Columbia Ministry of Trans. China
Canadian Trucking Alliance
China
City of Toronto, Canada
Civil Aviation Authority of Fiji
Government of the Northwest Territories
EU Delegation to the United States
Imperial College, London
Ministry of Transport, Public Works and Water Management, The Netherlands
Ministry of Transportation, Ontario, Canada
Port Metro Vancouver
Railway Association of Canada
Royal Netherlands Embassy
TELCOM Bretagne, France
Transport Canada
University of Nottingham
Ville de Montreal
Ministry of Sustainable Development and the Environment, Canada

For further information on this series and
Volpe's thought leadership activities, please contact:

Ellen E. Bell, Director of Strategic Initiatives
for Research and Innovation

U.S. Department of Transportation

John A. Volpe National Transportation Systems Center

55 Broadway

Cambridge, MA 02142-1093

(617) 494-2491

www.volpe.dot.gov

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center

Volpe