Chapter 12

Climate Change Adaptation

Climate Change Adaptation 12-2
Impacts of Climate Change Adaptation on Transportation Infrastructure 12-2
Steps for Assessing Adaptation Needs 12-4
Inventory Critical Infrastructure 12-4
Understand Potential Future Climate Change Impacts 12-4
Assess Vulnerability and Risk 12-4
Adaptation Options 12-5
Maintain, Manage, and Operate 12-5
Protect and Strengthen 12-5
Relocate and Avoid 12-5
Abandon and Disinvest 12-6
Promote Redundancy 12-6
Barriers to Action 12-6
Adaptation Activities 12-6
Interagency Activities 12-6
U.S. DOT Adaptation Activities 12-7
Selected State and Local Adaptation Efforts 12-9

Climate Change Adaptation

Climate change has received increasing attention over the last decade. Policy-makers, scientists, and the public have been increasingly concerned about the impact that climate change will have on people and the planet. For the transportation community, climate change and policies to address climate change can be divided into two categories.

- *Mitigation* (discussed in Chapter 11) focuses on measures to reduce greenhouse gas (GHG) emissions that risk exacerbating climate change from transportation sources including vehicles, construction and maintenance activities, and materials.
- *Adaptation* (discussed in this chapter) focuses on consideration of what potential future changes in a community may be associated with climate change, and what might be the resulting impact of climate change on transportation assets. These considerations can be incorporated into policy and measure development so that transportation planners are adequately prepared to consider impacts of climate change as they become evident.

Impacts of Climate Change Adaptation on Transportation Infrastructure

Research on climate change's potential impacts to transportation infrastructure continues. Two studies published in 2008, the Transportation Research Board's *Special Report 290* and the U.S. Department of Transportation's (U.S. DOT's) *Gulf Coast Study, Phase I* outline the wide range of forecasted impacts to transportation infrastructure. The *Gulf Coast Study, Phase I* includes a comprehensive review of the literature related to the numerous potential impacts of climate change.

In 2002, the U.S. DOT Center for Climate Change and Environmental Forecasting convened a workshop focusing on the issue of climate change impacts to the transportation system, which brought together top transportation and climate change experts to discuss the issue. The U.S. DOT has used geographic information systems to map areas and transportation infrastructure along the Atlantic coast that is potentially vulnerable to rises in sea level. Climate change impacts have the potential to be geographically widespread and modally diverse, and would stress transportation systems in ways beyond which they were designed.

Highway and transit infrastructure is already planned, designed, and maintained in the context of weather-related effects. For example, engineers typically consider the likelihood of an extreme weather event, such as a 100-year storm (which has about a 1 percent chance of occurring in any given year), and incorporate the expected effects of such an event into project designs. However, should climate change proceed as some scientists predict, past weather patterns or environmental conditions would no longer be a good guide to the future. Further, the vulnerability of transportation infrastructure to climate change impacts varies based on location and the environmental context in which they occur. An understanding of how an area may be affected in the future should be informed both by potential changes in climate and by ongoing environmental processes, such as land subsidence/uplift or erosion.

The Gulf Coast Study

The Gulf Coast study, Phase 1 examined the potential impacts of climate change on the central portion of the low-lying Gulf of Mexico coastal zone from Houston-Galveston to Mobile, AL. The study focused on the potential impacts due to changes in temperature and precipitation, relative sea level rise, and storm surge. The impacts of climate change can vary by location in part because each region may have unique environmental characteristics (like land subsidence in the Gulf Coast region) and face varying levels of climate change. The study found that a four-foot increase in relative sea levels could affect 2,400 miles of major highways (arterials and interstates) in the 48-county Gulf Coast study region as well as some of the light rail and bus routes in New Orleans, LA, and Galveston, TX. *Exhibit 12-1* indicates the portion of facilities in the study region vulnerable to the two relative sea level rise scenarios.

Exhibit 12-1

Portion of Gulf Coast Region Highways That Are Vulnerable to Relative Sea Level Rise

Highway Functional Type	Relative Sea Level Rise	
	2 Feet	4 Feet
Arterial	20%	28%
Interstate	19%	24%
Intermodal Connector	23%	43%

Source: Impacts of Climate Variability and Change on Transportation Systems and Infrastructure – Gulf Coast Study, Phase 1 (2008).

Sea-level rise, coastal erosion, tropical storms/hurricanes, and storm surges are major concerns in coastal areas. Impacts on coastal infrastructure include increased risk of bridge scour and bridge failure during storms, periodic or permanent inundation of coastal roads, increased frequency of infrastructure repair after events, and more frequent and/or intense emergency evacuations using a more-fragile and less-resilient network. The *Gulf Coast Study, Phase I* analyzed sea-level rise scenarios on the Gulf Coast region, finding that a rise of 2 feet could affect 64 percent of the region's port facilities, while a 4- foot rise would impact nearly three-quarters of facilities; similarly, approximately "a quarter of" the region's arterials and Interstate System miles, "nearly half of the region's intermodal connector miles, and 10 percent of its rail lines would be affected by a four foot rise in sea level." A University of South Alabama study estimated that there are roughly 60,000 road miles in the United States that are occasionally exposed to coastal waves and surges today. After Hurricane Katrina, the Federal Highway Administration (FHWA) conducted an assessment of coastal bridges potentially vulnerable to failure from coastal storm events. Using very broad criteria, the assessment estimated that there are more than 36,000 bridges within 15 nautical miles of coasts. Of these, more than 1,000 bridges may be vulnerable to the same failures as those associated with recent coastal storms.

Increased variability in temperature extremes; more severe precipitation events; changes in the melting rate of snow pack and permafrost; and increased mudslides, fires, and avalanches—are not confined to coastal or near-lake areas and might be experienced more broadly across the Nation, which could affect transportation infrastructure and services throughout. Compounded effects, such as storm surges *and* sea level rise or temperature increase *and* more severe precipitation, could lead to severe and damaging impacts. These include increased pavement deterioration; an inability to implement or maintain environmental mitigation commitments, such as wetlands or forests; short-term flooding and/or compromised safety.

Our understanding of climate change is steadily improving. While science cannot tell us precisely how much change to expect, it can give us some information now, particularly on the range of future changes in temperature and sea levels. The science of projecting future changes, including precipitation patterns, is expected to improve substantially in coming years. In the meantime, it is prudent to prepare transportation planners to develop appropriate adaptation strategies as the science of projecting future changes improves and likely impacts can be identified.

Steps for Assessing Adaptation Needs

While transportation agencies across the Nation have been addressing climate change mitigation issues on various levels, the issue of adapting transportation infrastructure to climate change impacts has received less widespread attention, beyond the coastal states. The FHWA has developed a framework for analyzing climate and weather-related impacts on highway infrastructure and incorporating risk management approaches into all aspects of highway management. Specific adaptation activities that are currently underway within the U.S. DOT and among the States are discussed later in this chapter.

Adapting to the impacts of climate change starts with inventorying the likely impacts of potential changes in climate. Then, after assessing potential vulnerabilities and risks, adaptation options can be evaluated and prioritized alongside other investments.

Inventory Critical Infrastructure

It is generally good practice for transportation agencies to screen and rank transportation assets based on the relative importance of each asset in meeting local, regional and/or national priorities. Potential metrics include the level of use (e.g., VMT or ridership), freight tonnage or value moved over a facility, road classification (e.g., local verses arterial), a road's importance in linking regions or facilitating national trade flows, the existence of redundant routes, or its role in emergencies for evacuating people or facilitating assistance to a region. Then, agencies can use this information to assemble a list of infrastructure most critical to the region and assess risks posed to that infrastructure.

Understand Potential Future Climate Change Impacts

Assessments of impacts on transportation assets, and any resulting adaptation strategies, should be based on an assessment of climate change effects. Agencies should work with counterparts in the scientific community to collect information on projected changes in regional climate. Relevant information would include projected changes in temperatures, precipitation patterns and frequency, and in coastal areas sea level rise and coastal storm effects. Both the likelihood and potential magnitude of climate changes should be considered. These types of projections are an active area of research, and the ability to make projections with greater levels of certainty and at smaller scales should improve in coming years. Historic information can also inform understanding of the potential impacts of future changes in climate.

Assess Vulnerability and Risk

Assessing vulnerability and risk involves examining how transportation assets have been affected by storms and other weather events in the past, what is the probability that future weather patterns could change, and how assets may fare in the future given likely changes in weather. To start, areas should examine records of weather events—for example, heat waves, intense precipitation and flood events—and related repair and maintenance records to better understand how existing assets can withstand different kinds of climate stressors. Then, by referring to information developed on projected changes in climate, agencies can better understand whether those stressors will become stronger, remain the same, or perhaps lessen. These activities can help agencies assess the vulnerability of individual facilities and the system. Calculating risk involves an additional step of considering both the likelihood of a given impact on a facility, and the consequence of that impact. Such consequences could include costs associated with repairing or replacing a facility, impacts on traffic patterns, or health, safety and environmental consequences. In all cases, the cost of migration must be weighed against the costs of inaction on a present value basis and adjusting for probability.

Adaptation Options

Maintain, Manage, and Operate

With the maintenance adaptation strategy, no changes to the base transportation facility are made. In order to restore operational service, transportation agencies respond to interruptions without necessarily addressing the underlying factors contributing to the damage. Examples of repair and maintenance activities include closures and rerouting; simple damage repairs, such as resurfacing; water and debris clearance; cleaning of storm-drain basins; snow or sand removal; and establishing weight limitations to manage asphalt deficiencies caused by increased temperatures.

Protect and Strengthen

An adaptation strategy that focuses on reconstruction/strengthening is one that entails the application of higher design standards to effectively protect or reinforce a structure. It is a suitable strategy particularly when a facility has reached the end of its service life, is structurally deficient, or has been destroyed. At these times, there can be opportunities to build structures in ways that help them withstand current and potential future global climate change effects, possibly resulting in longer infrastructure life spans.

In areas where problems are occurring or could occur in the future, reconstruction/strengthening can also occur proactively; in these cases, the infrastructure is adapted as a preventative measure. In other cases, reaction to a problem, such as a structural deficiency, might be an impetus to reinforce the facility. Costs for each approach can be high and must weigh the benefits of incurring added cost adjusting for risk and time value. Some reconstruction/strengthening activities include building bridges to greater heights; increasing the size of culverts; considering higher design-events (e.g., using 100-year storm events instead of 50-year storm events) and changing the associated design assumptions; and constructing revetments, embankments, jetties, or other structural fortifications.

One example of reconstruction/strengthening is the application of the FHWA floodplain regulations to coastal bridge design (such as the US-90 and I-10 bridges, which were destroyed during Hurricanes Ivan and Katrina). Although most State DOT design standards are based on the "50-year event," the FHWA's regulations (23 CFR 650 Subpart A) allow engineers to consider the "greatest flood" event. In practice, reconstructed bridges with taller pile caps could be better protected from high stillwater elevations and wave action. Although Hurricanes Ivan and Katrina produced storm surges in excess of a 100-year event, the FHWA has been able to investigate the nature of these "greatest flood" events, develop probabilistic analyses of historic storms, and generate baselines for storm impacts. Using these baselines, the FHWA created the interim guidance "Coastal Bridges and Design Storm Frequency," which contains information about the range of engineering practices that could be applied in anticipation of major storm events.

Relocate and Avoid

Relocation is characterized by the moving of a facility from its existing location to avoid imminent threats. Accomplishing this strategy, the results of which likely have long-term implications, might require environmental review, right-of-way acquisition, new construction, or other related activities. Relocation may be expensive and require years to implement. However, relocation may sometimes be the most effective adaptation strategy because it avoids repeated repair, maintenance, or strengthening actions. Again, planners must weigh the high costs against the likely benefits.

An example of relocation is the proposed realignment of 2.8 miles of Highway 1 near Piedras Blancas Lighthouse, California. In September 2008, the California Department of Transportation released the Draft Environmental Impact Statement for the project, which proposes to relocate a portion of the highway that is subject to bluff erosion caused by high winds and ocean surf. The goal of the project is to protect the highway from bluff erosion for the next 100 years.

Abandon and Disinvest

The abandonment/disinvestment adaptation strategy is a decision to discontinue service on a piece of transportation infrastructure or to make it ineligible for funding based on its condition or location. This decision is based on whether it makes financial sense to continue investing in a facility given likely future threats and its level of use. Although lower in infrastructure costs than other options, this is not a costless decision. Beyond its direct economic costs, abandonment could lead to isolation of communities, political or public opposition, or loss of access. The state of Texas elected to abandon Texas Highway 87 because frequent storm events and erosion led to closure of the highway.

Promote Redundancy

Promoting infrastructure redundancy along key travel corridors is an approach that can reduce service disruption that may result should any one asset run into unanticipated problems.

Barriers to Action

There is a lack of adequate locality-specific information on how the climate will change. Without this type of information, assessment of risk to the infrastructure and development of appropriate adaptation strategies is not possible. For example, without knowing how much sea level will rise in the next 50 years, it is difficult to know whether a transportation facility located near the shoreline will be vulnerable to flooding or inundation. Obtaining this information depends on climate models that are not yet capable of consistently producing reliable results at small scales. The results from the climate models are also highly dependent on assumptions, many of which are in flux and could change significantly based on whether or not effective strategies are taken to reduce GHG emissions. However, climate models are advancing rapidly, and climate scientists hope the next 5 or 10 years will see substantial improvements in the ability of models to predict more localized impacts with a higher degree of certainty.

In some cases, even if adequate information were available, transportation design procedures may not yet be flexible enough to allow areas to consider new information as it becomes available, and instead may be based on historic weather patterns. Ultimately, design procedures, maintenance and replacement schedules, will need to become flexible enough to adequately account for changes in inputs and parameters to reflect assumptions of future temperatures, sea level rise rates, precipitation patterns, etc., once they can be validated. For new infrastructure and/or retrofits to existing transportation facilities, project designs and the choice of materials should reflect our understanding of future climate change impacts as it evolves in coming years.

Adaptation Activities

Interagency Activities

Climate Change Adaptation Task Force. On October 14, 2010, the Climate Change Adaptation Task Force, co-chaired by the White House Council on Environmental Quality (CEQ), the Office of Science and Technology Policy (OSTP), and the National Oceanic and Atmospheric Administration (NOAA), released its interagency report outlining recommendations to the President for how Federal agency policies

and programs can better prepare the United States to respond to the impacts of climate change. The report recommends that the Federal government implement actions to expand and strengthen the Nation's capacity to better understand, prepare for, and respond to climate change. These recommended actions include the following:

- **Make adaptation a standard part of agency planning** to ensure that resources are invested wisely and services and operations remain effective in a changing climate.
- **Ensure scientific information about the impacts of climate change is easily accessible** so public and private sector decision-makers can build adaptive capacity into their plans and activities.
- **Align Federal efforts to respond to climate impacts that cut across jurisdictions and missions,** such as those that threaten water resources, public health, oceans and coasts, and communities.
- **Develop a U.S. strategy to support international adaptation** that leverages resources across the Federal government to help developing countries reduce their vulnerability to climate change through programs that are consistent with the core principles and objectives of the President's new Global Development Policy.
- **Build strong partnerships to support local, State, and tribal decision-makers** in improving management of places and infrastructure most likely to be affected by climate change.

On March 4, 2011, the Task Force released Implementing Instructions and the related Support Document for Federal Agencies to follow. Actions include:

- Establishing an agency climate change adaptation policy and mandate;
- Increasing agency understanding of how the climate is changing;
- Applying understanding of climate change to agency mission and operations;
- Developing, prioritizing, and implementing actions; and
- Evaluating and learning.

The U.S. DOT has been an active member of the Climate Change Adaptation Task Force since its inception and is moving ahead with adaptation efforts.

U.S. DOT Adaptation Activities

This section lists activities in which the U.S. DOT is engaged to better understand the potential impacts of climate change and adaptation best practices.

Conceptual Model for Vulnerability and Risk Assessment. The FHWA has developed a model for conducting vulnerability and risk assessments to help States and local governments identify which assets could be at risk of impacts because of global climate change and to assess the extent of that risk/vulnerability. The model focuses on impacts to both individual assets and the transportation system as a whole. Five agencies have been selected to pilot the model: the Metropolitan Transportation Commission (San Francisco Bay); the New Jersey DOT/North Jersey Transportation Planning Authority (Coastal and Central New Jersey); Virginia DOT (Hampton Roads); Washington State DOT (State of Washington); and Oahu Metropolitan Planning Organization (MPO) (Island of Oahu).

This pilot will (1) help State DOTs and MPOs to more quickly advance existing adaptation assessment activities and (2) assist the FHWA in "test-driving" the model. Based on the feedback received through the pilots, the FHWA will revise and finalize the model for national application. The FHWA's pilots will also be used to test the comprehensive Federal approach to adaptation that is being developed by the interagency Climate Change Adaptation Task Force. The pilots are scheduled to be completed by September 2011.

Adapting Transit to Climate Change Impacts. The Federal Transit Administration (FTA) is undertaking a study and series of workshops on adapting U.S. public transportation assets and services to projected climate change impacts. Climate change has particular impacts on public transportation. Extreme heat can cause deformities in rail tracks, at minimum resulting in speed restrictions and, at worst, causing derailments. Subway tunnels, busways, rails, and roads are vulnerable to an increase in flooding from sea-level rise, storm surge, and more intense rain storms. Public transportation is also called upon to provide evacuation services during the type of extreme weather emergencies that are projected to become more common with climate change. Transit-dependent populations are particularly vulnerable. Knowledge of how best to respond to climate change impacts is critical to attaining a state of good repair, protecting the safety of travelers, and ensuring mobility. The study will provide information and analysis, while the workshops will engage transit agency and the FTA staff in adaptation assessment and planning for public transportation, provide key information and tools to participants, and gather ideas for future action in this area.

Regional Climate Change Effects Report. The FHWA recently released a study on the regional impacts of climate change which focused on information that would be useful to transportation agencies. The goal of the study, which did not involve any new research, was to assemble the most up-to-date science on the regional impacts of climate change. The final report summarizes regional results from hundreds of studies, and includes projected increases in seasonal temperature ranges across nine regions of the country. It also provides a regional summary of background information. The report focuses on climate change at the regional level, but also discusses global, national, and local scales where information exists. More information on this report can be found at: http://www.fhwa.dot.gov/hep/climate/climate_effects/effects00.cfm.

The report reflects substantial uncertainty and will be updated in the coming years as models improve. However, this is a first step in assembling the data needed to make informed decisions regarding climate change, and a good starting point for considering climate change adaptation in transportation plans and project designs.

Gulf Coast Study Phase II. As referenced above, the FHWA and the U.S. DOT completed *Phase I of the Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study* in 2008. This first phase provided an assessment of impacts of climate change on transportation across the region from Houston to Mobile. The U.S. DOT is now proceeding with the second phase of this research study, which will focus on a much narrower piece of the Gulf Coast region—Mobile, Alabama. As part of this study, the U.S. DOT will conduct an in-depth analysis to assess the critical transportation infrastructure; project climate change impacts; evaluate vulnerability; conduct detailed engineering assessments for selected assets; and develop risk management tools to help identify risks and develop adaptation options. From this, the U.S. DOT and the FHWA will derive lessons learned and a process that other MPOs can replicate. This phase of the study is expected to be completed in 3 years.

Selected State and Local Adaptation Efforts

Alaska. The Alaska Department of Transportation and Public Facilities (DOT&PF) is a multimodal agency with ownership of public assets such as roads, bridges, rural airports, and harbors. In 2007, the State established the Alaska Climate Change Sub-Cabinet to focus on adaptation, mitigation, and research needs. In addition, the Governor appointed an Adaptation Advisory Group. The final report was delivered to the Sub-Cabinet in January 2010. Additionally, the Immediate Action Workgroup was established in 2007 to address known threats to communities caused by coastal erosion, thawing permafrost, flooding, and fires.

Documented climate change impacts in Alaska include melting permafrost, increased storm frequency and intensity, coastal erosion due to lack of sea ice, river erosion, sea-level rise, increasing temperatures, and loss of the subsistence way of life for native populations. There has been increased erosion on the coast line and along rivers due to higher amounts of precipitation, the infrastructure in many of Alaska's regions is underlain by ice-rich permafrost, an active layer that is permanently frozen; and, increasingly, the soil layers are experiencing melting cycles causing severe structural damage to infrastructure. The DOT&PF spends about $10 million per year to mitigate melting permafrost, yet this is only a fraction of the need and costs are expected to increase as warming trends continue. Storms are causing avalanches, floods, erosion, and debris flows, which all significantly increase maintenance and operations costs. The loss of shore-fast sea ice is also causing coastal erosion that poses serious threats to infrastructure and is causing entire communities to be displaced.

Alaska is adapting to these extreme impacts with shoreline protection programs, planned evacuation routes, the relocation of infrastructure and communities at risk, improving drainage, and protecting permafrost. There is a need to collect more data on stream flow, precipitation, and hydraulic data, and to investigate alternative design, construction, and maintenance techniques to address the changing environment. The Alaska DOT&PF will also need to continue to collaborate with others to address future impacts of climate change.

California. Executive Order S-13-08 was signed on November 14, 2008, directing state agencies to plan for sea-level rise and climate impacts. This included developing a statewide adaptation strategy for agency responses to climate change impacts. Another key component of S-13-08 directed business, transportation, and housing agencies to develop a report, which was released February 2009, assessing the vulnerability of transportation systems to sea-level rise. Additionally, the State government established the Climate Action Team (CAT) under Executive Order S-3-05 in June 2005. CAT is required to release a biennial science assessment report on climate change impacts and adaptation options for California. The current report was released in March 2009.

Florida. The Florida Energy and Climate Commission created by Florida Legislature in the 2008 Legislative session, is the primary organization for State energy and climate change programs and policies. Executive Order 07-128 created a Governor's Action Team on Energy and Climate Change in July 2007. The action team was tasked with creating a comprehensive Energy and Climate Change Action Plan for the State. One of the six Action Teams focused on Adaptation was tasked with developing "adaptation strategies to combat adverse impacts to society, public health, the economy, and natural communities in Florida."

Maryland. Executive Order 01.01.2007.07 was signed on April 20, 2007, establishing the Maryland Climate Change Commission (MCCC) and charging them with developing a state climate action plan that addresses both mitigation and adaptation. The State released a final Climate Action Plan in August 2008.

Maine. In April 2009, the State legislature passed a resolution charging the Department of Environmental Protection to initiate a stakeholder-based process evaluating options and actions available to state businesses and people to prepare for "the most likely" impacts of climate change.

New Hampshire. Executive Order 2007-3 was issued in November 2007, creating the Climate Change Policy Task Force. The Task Force comprises six working groups, with one dedicated to Adaptation, and was tasked with creating a New Hampshire Climate Action Plan. The final plan was released in March 2009.

New York. The Office of Climate Change was created within the Department of Environmental Conservation, and is tasked with leading the development of programs and policies to address both adaptation and GHG mitigation. Executive Order 24 was signed in August 2009, creating the New York Climate Action Council. The Council is charged with creating a draft Climate Action Plan by September 2010. The Plan is to cover both mitigation and adaptation for all economic sectors in the state.

New York Metropolitan Transportation Authority (MTA). New York MTA operates the Nation's largest public transportation system, serving the New York City metropolitan area. In conjunction with MTA's Blue Ribbon Panel on Sustainability Commission in 2008, the agency developed an initial assessment of key vulnerabilities of MTA assets and operations. MTA also identified temporary fixes, mid- to longer-term solutions, and more radical long-term solutions to these vulnerabilities. Finally, the agency outlined a plan for a more comprehensive vulnerability/risk assessment and identification of adaptation priorities.

Virginia. In March 2009, the State finalized a Climate Change Action Plan which was created by the Governor's Commission on Climate Change, Adaptation and Sequestration workgroup. The workgroup developed recommendations spanning public and human health, coastal and shoreline management, local planning, infrastructure protection and planning, floodplain management and insurance industry participation, emergency planning response and recovery, multi-State natural resource plans, and water resource management. The plan also calls for a separate Sea Level Rise Adaptation Strategy to be developed by 2011.

Washington. In 2007, Preparation Adaptation Working Groups were formed as part of the State's overall Climate Advisory Team (CAT). Vulnerabilities and recommendations for adaptive actions and research were released in the February 2008 CAT report for agriculture, forestry resources, human health, water resources, and quality sectors. Legislation E2SSB 5560 was signed on May 15, 2009, requiring an "integrated climate change response strategy" to better enable State and local governments, businesses, nongovernmental organizations and individuals to better prepare for, address, and adapt to climate change impacts. A draft Strategy is scheduled for Spring 2011, with the final report to the Legislature by December 2011.