

## **Assessing Vulnerability and Risk of Climate Change Effects on Transportation Infrastructure: Pilot of the Conceptual Model**

This document outlines a conceptual Risk Assessment Model that will be piloted by three to four State Departments of Transportation (DOTs) or Metropolitan Planning Organizations (MPOs) (hereafter, “transportation agencies”) selected by the Federal Highway Administration (FHWA). Using feedback and lessons learned during this pilot phase, FHWA will refine this draft conceptual model and develop a final version for all transportation agencies.

The goal of the Risk Assessment Model is to help transportation decision makers (particularly transportation planners, asset managers, and system operators) identify which assets (a) are most exposed to the threats from climate change and/or (b) could result in the most serious consequences as a result of those threats. Assets in this context refers primarily to infrastructure assets (such as bridges and roads), but could include other assets that benefit the transportation system such as a coastal wetland buffer.

The conceptual model consists of three primary components, as shown in Figure 1:

1. Develop inventory of assets;
2. Gather climate information; and
3. Assess the risk to assets and the transportation system as a whole from projected climate change.

Each of these components is described in more detail below. The conceptual model is intended to be broad and flexible in how it is applied. FHWA will provide limited support to the selected transportation agencies to implement the model, and will collect feedback and lessons learned; this information will feed into a revised version of the model.

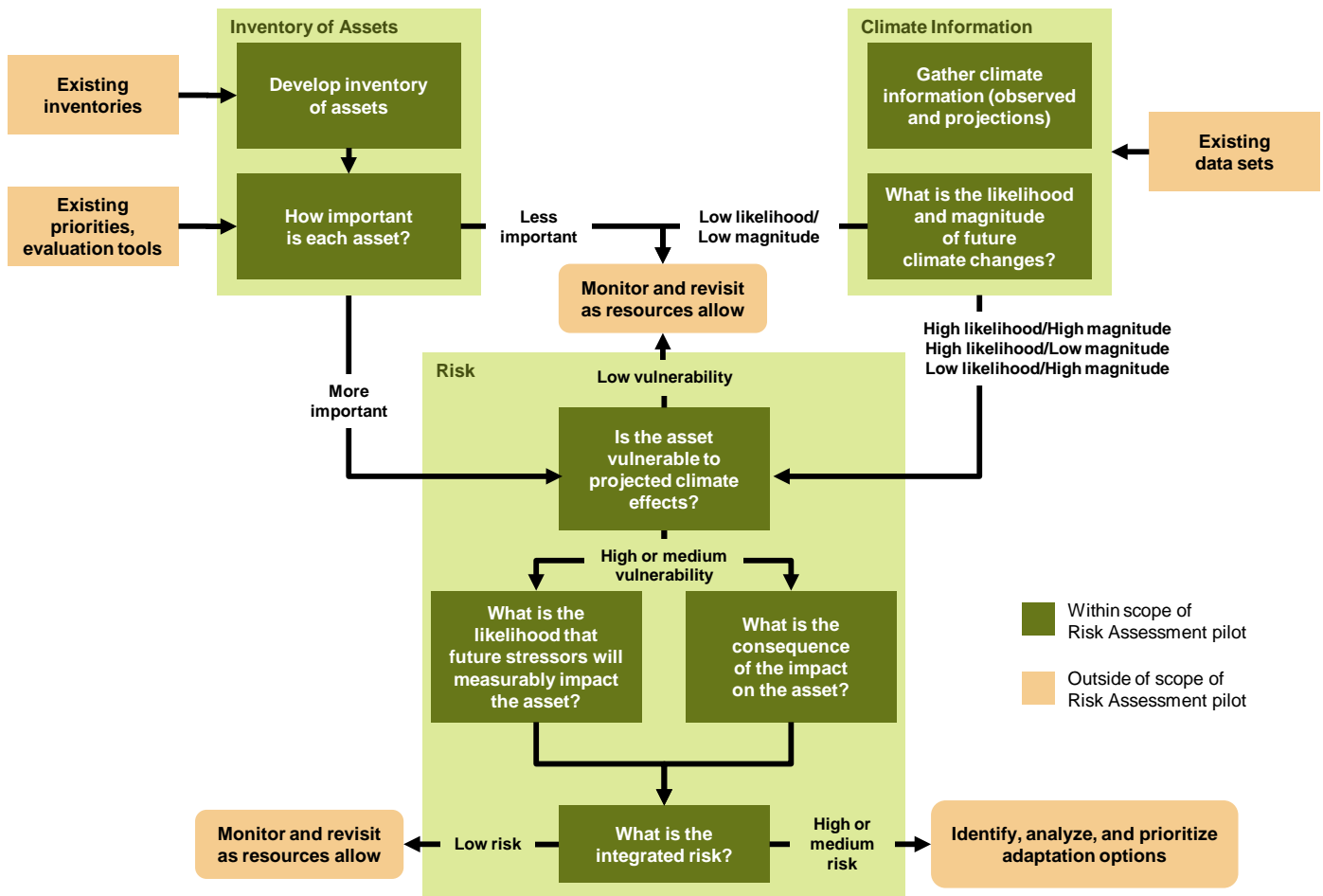


Figure 1: Structure of the conceptual Risk Assessment Model that will be piloted by State DOTs and MPOs

## Asset Inventory and Prioritization

### Develop Inventory of Assets

Transportation agencies selected for the pilot will first compile an inventory of all assets they wish to evaluate during this pilot phase. Example asset categories are provided below, although each pilot area should select asset categories that correspond to their planning priorities. When compiling this inventory, agencies should also gather any information that may help to later evaluate how resilient the asset is to climate stressors, and how costly damage to the asset could be. Example information types are provided below.

This inventory should include, but not be limited to, all assets that fall under the selected asset categories. Existing state and MPO inventories of assets will be the primary source of this information.

FHWA understands that inventory datasets may not be available in all cases, and that some data compilation may occur during this pilot study, although data collection is outside of the scope of this Conceptual Risk Assessment Model.

FHWA will also work with the agencies to identify potential sources of relevant data. National databases, such as those identified in the Appendix, can serve as a starting point for inventory development; state and local agencies may have more comprehensive records and knowledge of assets beyond what is included in national datasets. FHWA is interested in feedback on which datasets could be used in this step, and which ones the agencies found particularly helpful.

#### Box 1: Example Criteria for Identifying Important Assets

The DHS National Critical Infrastructure Prioritization Program (NCIPP) uses consequence-based criteria to identify national critical infrastructure. Capacity-based criteria can also indicate the importance of assets.

Examples of consequence-based criteria include:

- Loss of life,
- Economic costs,
- Ability to re-route, and length of detour, and
- Time to rebuild if damaged.

Examples of capacity-based criteria include:

- Annual average daily traffic volume,
- Ridership (mass transit), and
- Span or tunnel length.

#### Example Asset Categories

- Bridges and tunnels
- Key road segments (and evacuation routes)
- Rail (passenger and freight)
- Transit system assets
- Port and airport assets
- Signals and traffic control centers
- Back-up power, communication, fueling, and other emergency operations systems
- Intelligent Transportation Systems (ITS), signs
- Pipelines
- Wetlands
- Floodplains
- Vegetative Cover

#### Example Information Types

- Age of asset
- Geographic location
- Elevation
- Current/historical performance and condition
- Level of use (traffic counts, forecasted demand)
- Replacement cost
- Repair/maintenance schedule and costs
- Structural design
- Materials used
- Design lifetime and stage of life
- LIDAR (Light Detection And Ranging) remote sensing data
- Federal Emergency Management (FEMA) maps
- Vegetation survey

### How Important is Each Asset?

Transportation agencies should initially “screen” the assets located in their jurisdiction based on the relative importance of each asset. Using existing priorities and metrics (such as traffic flow, emergency management, movement of goods), agencies should consider which assets are most important for meeting those priorities.

Many transportation agencies have existing evaluation tools or guidelines they use to prioritize assets for maintenance or repair. For example, after a snowstorm, how are roads prioritized for snow removal? Other criteria used to prioritize assets could include the level of usage (annual average daily traffic), class (local road versus arterials), ownership (a road is privately owned, and not under the entity’s jurisdiction), the importance of an asset within the larger transportation network (including potential for adverse network effects), its value in emergency situations (e.g., for evacuation), and/or

redundancy. The loss of a particular asset may have ripple effects through the network that make an asset important to include in the Risk Assessment Model. Box 1 describes “consequence-based” and “capacity-based” criteria used by the Department of Homeland Security (DHS) to identify national critical infrastructure and provide asset prioritization guidance to states and territories. During this pilot phase, FHWA is interested in how assets are currently prioritized by transportation agencies when making decisions related to safety, reliability, mobility, emergency management, and ultimately, climate change. To streamline the process, agencies should initially set aside “less important” assets, and then revisit them later if resources permit; see “Monitor and Revisit as Resources Allow” for more information.

## Climate Information

### Gather Climate Information

As agencies develop their asset inventory, they will also gather local- or regional-level information on past changes and projections of future climate. Agencies should use this information to assess impact. In later steps, FHWA may assist agencies in using this information to translate projected climate changes into tangible climate-related impacts on the transportation system. Agencies should revisit this step as new information becomes available.

**Historical** climate and weather information will provide clues as to how assets may withstand future climate stressors. **Projected** climate information, is important for estimating future climate conditions to plan for. Both of these types of information will be used later in this risk assessment.

### What is the likelihood<sup>1</sup> and magnitude of future climate changes?

Each climate dataset will have associated uncertainties<sup>2</sup>. Uncertainties are generally smaller with observational data than with projections of future climate conditions. The range of uncertainty associated with future projections has been characterized for major U.S. regions in the Climate Change Effects Report developed by FHWA [http://www.fhwa.dot.gov/hep/climate/climate\\_effects/index.cfm](http://www.fhwa.dot.gov/hep/climate/climate_effects/index.cfm) (see Box 2). There are several sources of uncertainty in projections, including: (1) uncertainties with physical processes and their representation in global and regional climate models; (2) uncertainties with future greenhouse gas emissions; and (3) the stochastic and

### Box 2: Resources for Climate Data

#### Historical Data

Historical weather and climate data are available from the NOAA National Climatic Data Center:

- Comprehensive U.S. climate data available at: <http://www.ncdc.noaa.gov/climate-monitoring/index.php#us-icon>
- U.S. climate maps available at: <http://cdo.ncdc.noaa.gov/cgi-bin/climaps/climaps.pl>
- Other State or Local weather and climate data may be available.

#### Projected Data

Transportation agencies can use the Climate Change Effects Report developed by FHWA as a starting point for understanding future climate. Agencies may want to supplement this information with sources of local or regional data and/or input from climate change experts familiar with state and regional climate details.

Data sources that have projections of future climate change from many different models for various emissions scenarios include:

- Statistically downscaled data from the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3): [http://gdo-dcp.ucllnl.org/downscaled\\_cmip3\\_projections/dcpInterface.html#Welcome](http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/dcpInterface.html#Welcome)
- Dynamically downscaled data from the North American Regional Climate Change Assessment Program (NARCCAP): <http://www.narccap.ucar.edu/>
- A new project funded by USGS is developing a comprehensive web-based dataset of high-resolution (downscaled) climate change projections for the entire U.S.

<sup>1</sup> In this document, “likelihood” refers to the general probability of occurrence and is used preferentially over the term “probability,” because it colloquially denotes a probability range, rather than a single value. As discussed in the climate assessments from the Intergovernmental Panel on Climate Change and the U.S. Global Change Research Program, it is generally not possible to assign a single integer of the percent probability to a particular future climate effect.

<sup>2</sup> “Uncertainty” is an expression of the degree to which a value (e.g., the future state of the climate system) is unknown. In general terms, uncertainty can result from lack of information or from disagreement about what is known. (From IPCC, 2007, Glossary of Terms. <http://www.ipcc.ch/pdf/glossary/ar4-wg1.pdf>)

unpredictable aspects of the climate system. Therefore, it is important to consider a range of future climate scenarios, such as done by the Climate Change Effects Report. The larger the range of uncertainty, the smaller the likelihood that the mean of the projected range will be near the actual future value. Thus, in the absence of explicit likelihood information for a particular variable, the range of uncertainty may be used to approximate the likelihood.

A screening analysis should be conducted at this stage to set aside potential climate change effects that are both relatively uncertain (e.g., the sign of the change is unknown) and small in magnitude. These potential effects may be revisited at a later time. Potential changes that should not be screened out at this stage are those that are relatively uncertain but possibly large (e.g., changes in hurricane characteristics), and those that are relatively certain but small in magnitude (e.g., regional temperature changes). Judgments about the significance of the magnitude will be subjective since a change in one climate variable may be significant to one region or transportation mode, but insignificant to another. FHWA will work with the agencies to provide guidance on how to take uncertainty and magnitude into account.

## Assessing Risk

Risk is the potential for an unwanted outcome resulting from an event—in this case, a climate stressor. It is determined by the product of: (a) the likelihood of the impact; and (b) the consequence of the impact.<sup>3</sup> The likelihood of an impact is, in part, a function of the likelihood of the climate stressors. It is also a function of the vulnerability of the transportation element to climate change. Vulnerability also affects the magnitude of the impact.

In this phase, agencies will: (1) screen assets that are less vulnerable to projected climate effects; (2) assess the likelihood of a particular impact resulting from a defined set of stressors, (3) assess the consequence of the impact, not just in terms of what it does to a particular asset, but in terms of how it affects the surrounding community and beyond, and (4) assess the integrated risk of the consequence and likelihood.

### Box 3: Risk Assessment of Bridge Assets – An Example

Transportation agencies already document, prioritize, maintain, and repair bridge assets using tools that can assist with this conceptual Risk Assessment model. This example shows how the National Bridge Inspection Program (NBIP) could be used.

1. Use existing information required by the NBIP to develop an initial inventory of bridge assets, including other non-highway bridge assets using available regional, state, and local records.  
Consider data such as average daily traffic, length/width of bridge, scour criticality, and the bridge's sufficiency rating to assess the importance of each bridge according to consequence- and capacity-based criteria (see Box 1) or other state or regional priorities.
2. Once less-important bridge assets have been screened, assess the risk to the remaining assets. First, assess the vulnerability of each asset to climate impacts. Consider the following vulnerability assessment examples for bridge assets:
  - a. Analyze previous bridge failures resulting from weather events;
  - b. Identify current weather-related stressors and their impact on bridge performance using bridge inspection reports and maintenance records;
  - c. Identify scour-critical bridges; evaluate their performance, and maintenance requirements;
  - d. Review weather-related specifications that are already incorporated into bridge design. For example, design flood and storm frequency (e.g., 50-, 100-, or 500-year frequencies), drainage, and material selection;
  - e. Of those assets with a low vulnerability to current climate impacts, review projected climate changes to identify those assets that could become vulnerable to future climate impacts.Assets with low vulnerability to projected climate effects should be monitored and reassessed as resources permit.
3. For assets with a medium or high vulnerability, evaluate the likelihood of measurable impacts in the future.  
Assets can be sorted into high- and low-likelihood categories. For example, bridges with historical drainage problems, overtopping, or scour-critical bridges may be assessed with a high likelihood of impacts from sea level rise, storms, and/or increased precipitation.  
Consider cumulative effects. Heavier rainfall coupled with sea level rise may not only increase the risk of flooding, but may also increase scour and weaken embankments and bridge supports.
4. Next, assess the consequence of impacts on each asset.  
Consequence- and capacity-based criteria that were used to screen less-important assets can be applied at this step to each type of climate impact. Assets should be categorized into high- and low-consequence groupings.  
Finally assess the risk to each asset by group assets by high/low likelihood and high/low consequence.

<sup>3</sup> As defined by the Department of Homeland Security in its 2009 *National Infrastructure Protection Plan*. See [www.dhs.gov/xlibrary/assets/NIPP\\_Plan.pdf](http://www.dhs.gov/xlibrary/assets/NIPP_Plan.pdf), p. 27.

## **What is the vulnerability of the asset to projected climate change?**

### *Assess vulnerability using historical weather information*

By understanding how weather events had previously affected an asset, transportation agencies will be better able to understand how weather events in the future may affect that asset, or similar assets. Furthermore, historical experience may provide information on the significance of the impact to the transportation system if a certain asset is damaged or destroyed.

To address this question, agencies should consider the historical performance of assets during specific weather events. For example, agencies could consider:

- the repair costs or retrofits caused by past weather events,
- budgets and spending for services that respond to weather events (e.g., snow plowing),
- effects of past weather events on services provided by an asset (e.g., changes in VMT, the value of the goods transported), and
- role of the asset in emergency response and evacuations required in past weather events.

By comparing historical weather events with historical maintenance and repair needs, agencies can estimate how well specific assets withstand certain climate stressors. In doing so, they may be able to identify physical or environmental characteristics that make a structure more or less vulnerable to a given climate stressor. If a specific climate stressor does not appear to have a significant effect on a given asset, agencies may screen that climate stressor-asset combination from the assessment, record it, and revisit it as resources allow.

Each agency should identify information sources that could be consulted or compiled to evaluate the effects of current climate stressors on assets, and will assist agencies in identifying climate stressors that are already taken into account in the design, operation, and maintenance of existing assets.

### *Assess whether future climate change introduces additional climate vulnerability*

At this point, agencies will have a good sense of how well assets can withstand specific climate stressors, many of which may be present (and perhaps be more/less frequent) in the future. However, projected climate scenarios may include stressors to which assets are currently not exposed. For example, climate projections may indicate that an asset will likely be exposed to extreme temperatures not previously experienced. The projected extreme temperatures may exceed certain thresholds at which the asset material is compromised. Or, some assets may have been exposed to temporary flooding, but projected climate information may indicate longer-term inundation, which can have very different impacts on an asset. Finally, agencies must consider the cumulative impacts of more frequent climate stressors; a particular asset may be able to withstand the first and second flood (for example) but not the 20<sup>th</sup> flood.

## **What is the likelihood of a particular impact resulting from a defined set of stressors?**

Agencies will need to apply climate projections to evaluate the likelihood of future impacts, including cumulative effects from changes in several climate stressors. To the extent that information is available, impacts will be split into high- and low-likelihood groupings. Transportation agencies will have the flexibility to define what a “severe” climate effect means for them, and effects that are determined to be less severe can be recorded and revisited as resources allow. Projected changes in climate that are so uncertain that it is not possible to determine whether future stressors will measurably impact the asset can also be set aside and revisited later.

## **What is the expected consequence of the impact on society?**

When an asset sustains a particular impact, what is the consequence to society? Transportation agencies may wish to consider the level of use of an asset, the degree of redundancy in the system, or the value of an asset (in terms of cost of replacement, economic loss, environmental impacts, cultural value, or loss of life) to determine consequence. FHWA will assist in categorizing assets into high- and low-consequence groupings.

This step will take into account the criticality assessments conducted earlier. Transportation agencies can use the criteria listed in Box 1 as a starting point for assessing the consequences of an impact. Approaches that are currently used by transportation agencies to define and prioritize important system components may help identify high-

consequence assets. For example, approaches and metrics are used to determine road maintenance and construction priorities. FHWA is interested in determining what approaches already exist.

Transportation agencies may have models, computer software, or other methodologies available to them to assist in identifying consequences of changes in climate. For example, the American Association of State Highway and Transportation Officials (AASHTO) is currently testing a new pavement design model (the Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures) that will allow input of alternate climate scenarios to determine how pavement will hold up under those conditions. Analyses including environmental assets can help determine how environmental conditions may alleviate impacts to infrastructure assets.

**What is the integrated risk of climate change to the asset?**

For assets deemed “vulnerable”, the integrated risk assessment for an asset should jointly consider the likelihood that the asset will experience a particular impact, and the consequence of that impact on the surrounding community or region (from a health/safety, economic, environmental, cultural, or other point of view). Assets that have a low likelihood of being impacted by future climate *and* a low consequence of that impact occurring will be screened, recorded, and revisited as resources allow. The remaining assets, grouped according to high/low likelihood and high/low consequence of impact, is the outcome of the Risk Assessment Model. As a result of this analysis, agencies will have a prioritized list of assets at risk from future climate change impacts, developed according to their own criteria. The integrated risk is often represented by a two-dimensional matrix that classifies risks into three categories (low, moderate, high) based on the combined effects of their likelihood and consequence. An example matrix from the 2006 FHWA document *Risk Assessment and Allocation for Highway Construction Management* is provided in Figure 2

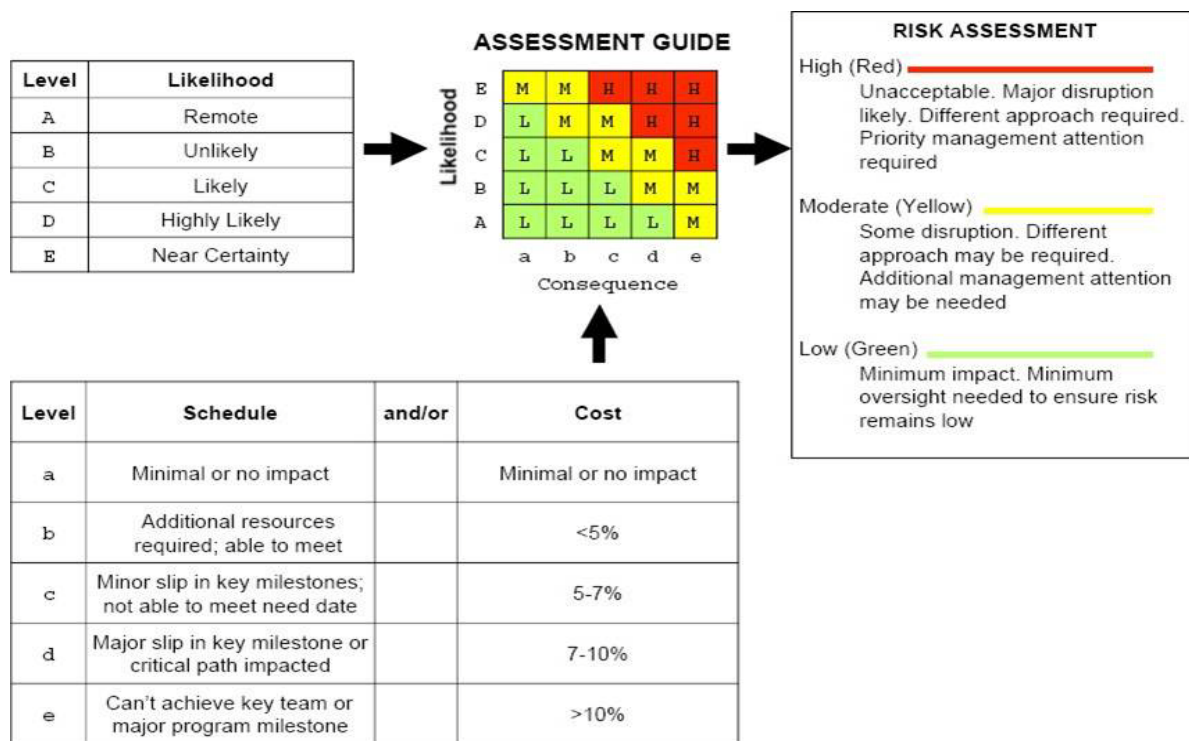


Figure 2 illustrates the classification of risks to an asset according to categories of likelihood and consequence.

**Monitor and Revisit as Resources Allow**

At various points in the conceptual model, transportation agencies will apply screens to separate (i) less-important assets, (ii) unlikely and low-magnitude changes in climate, (iii) less-vulnerable assets, and (iv) vulnerable assets facing a low integrated risk of climate change, according to their own existing methods and priorities. These screens will help prioritize assets according to vulnerability and consequence, based on the most current and relevant data available.

These screens are important to apply and document so that agencies have the option of revisiting and re-classifying assets. Changes in asset inventories, refinements in future climate projections, and improved understanding of the relationships between changes in climate, asset vulnerability, and infrastructure and environmental assets may alter categorization of some assets in future years. FHWA is interested in tracking the elements that have been initially set aside, and in identifying monitoring mechanisms—either existing or potential—that can be used to evaluate whether such assets should be revisited, depending upon available resources.

Agencies may also identify elements where data is unavailable, or the impacts and/or consequences of future climate changes are unknown and cannot be assessed. It may be important to also monitor and revisit these assets, climate changes, stressors, and impacts once more data is available. Tracking these elements for monitoring can also help agencies set priorities for data collection and research as resources are available.

## Next Steps: Identify, Analyze, and Prioritize Adaptation Options

At the conclusion of this pilot, transportation agencies should have identified the assets that are most critical to their transportation priorities, and most at-risk to climate change. The ultimate purpose of identifying these critical vulnerable assets is to inform decisions on how to prepare for and adapt to climate change. Although not a part of this conceptual model, the next step involves making decisions about what to *do* about the risks that climate change poses to the transportation system.

This step will eventually help transportation agencies identify risk reduction options (adaptation strategies) for assets that scored either medium or high risk based on an integrated assessment of likelihood and consequence. Although identifying and implementing adaptation options is not included in the pilot program, adaptation measures can occur in two timeframes:

1. Opportunistic adaptation measures, or measures that take advantage of scheduled or necessary equipment planning, maintenance, repair, or end-of-life cycles to respond to identified risks from future climate stressors.
2. Proactive adaptation measures, or measures that are implemented before scheduled or necessary equipment planning, maintenance, repair, or end-of-life cycles to prevent impacts from climate stressors from occurring.

Not all adaptation measures are proactive, as shown in the example in Box 4. The benefits of opportunistic measures are that they can be integrated with existing activities that are already being undertaken. For transportation agencies with constrained budgets and limited resources, implementing adaptation options opportunistically at planning or budgeting stages, intervals of maintenance or repair, and at the end of life of assets can be less costly than pursuing options proactively.

### Box 4: Proactive and Opportunistic Adaptation Measures – An Example

*Problem:* Extended periods of extreme heat can impact the integrity of pavement, causing softening and rutting.

Opportunistic options might include:

- Enhancing existing maintenance operations (e.g., increasing the frequency of maintenance, milling out ruts), and
- Retrofitting roads with rut-resistant asphalt at scheduled maintenance periods.

Proactive options could involve:

- Developing new, heat-resistant paving materials,
- Overlay existing roads with more rut-resistant asphalt, and
- Abandoning roads before the end of their expected service life.

Sources:

*Climate Change Science Program (CCSP). 2008. Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. Washington, DC: Department of Transportation.*

*NRC. 2008. Potential Impacts of Climate Change on U.S. Transportation. Transportation Research Board Special Report 290. Washington, DC: Transportation Research Board.*

## **Appendix 1: Existing Resources that can Assist Transportation Planners in Evaluating the Risks and Vulnerability from Climate Change Effects on Transportation Infrastructure**

FHWA recognizes that the best, most comprehensive data for developing inventories and assessing the risk and vulnerability of assets often exist at regional, state, and local levels. At the same time, datasets and guidelines exist at the national level that can serve as a good starting point for developing inventories. These resources can serve to help identify data elements that agencies may wish to collect on their assets.

Databases, guidelines, and other resources identified at the national level that can help build asset inventories are listed below. This is not a comprehensive list, but provides examples of the resources that are available for various transportation infrastructure types. During the pilot phase, FHWA is interested in hearing feedback on which of these sources are particularly useful, as well as which resources should be added to this list.

### **Existing National Databases and Tools that can Assist in Developing Asset Inventories**

- Federal Highway Administration:
  - FHWA Highway Statistics (highways)
  - Long Term Pavement Performance DataPave Online (road surfaces)
  - National Bridge Inventory (bridges)
  - Highway Tunnel Inventory (tunnels)
  - Major Tunnel Projects (tunnels)
- U. S. Geological Survey:
  - National Bridge Scour Database (bridges)
- Bureau of Transportation Statistics:
  - National Transportation Statistics (transportation system)
- Federal Emergency Management Agency:
  - Hazards U.S. Multi-hazard assessment tool (HAZUS-MH) (infrastructure)

### **Existing Design Guidelines that can Assist in Assessing Risk and Vulnerability from Climate Change Effects on Transportation Infrastructure or other resources.**

- American Association of State Highway and Transportation Officials (AASHTO):
  - Highway Drainage Guidelines, Volume III, Erosion and Sediment Control in Highway Construction (highways)
  - Guide for Design of Pavement Structures and 1998 Supplement (pavement and road surfaces)
  - A Policy on Geometric Design of Highways and Streets (5th ed.) (highways)
  - AASHTO Model Drainage Manual (3rd ed.) (drainage)
  - Manual for Bridge Evaluation, First Edition (bridges)
  - AASHTO Load and Resistance Factor Design (LFRD) Bridge Design Specifications with 2008 and 2009 Interim Revisions (4th ed.) (bridges)
- Federal Highway Administration:
  - Evaluating Scour At Bridges, Fourth Edition. FHWA Circular No. 18 (bridges)
  - Highways in the Coastal Environment (2nd ed.). Hydraulic Engineering Circular 25 (bridges)
  - Integrating Climate Change into the Transportation Planning Process

<http://www.fhwa.dot.gov/hep/climatechange/index.htm>

- Technical Manual for Design and Construction of Road Tunnels - Civil Elements, available at <http://www.fhwa.dot.gov/Bridge/tunnel/pubs/nhi09010/index.cfm> (tunnels)
- Road Tunnel Design Guidelines, available at <http://www.ntis.gov/search/product.aspx?abbr=PB2006100660> (tunnels)
- Transportation Research Board (TRB)
  - TRB Superpave Committee, *Superpave: Performance By Design, Final Report of the TRB Superpave Committee*, available at: [http://www.trb.org/Publications/Blurbs/Superpave\\_Performance\\_by\\_Design\\_156426.aspx](http://www.trb.org/Publications/Blurbs/Superpave_Performance_by_Design_156426.aspx) (pavements and road surfaces)
- National Cooperative Highway Research Program (NCHRP)
  - NCHRP 1-37A: Guide for Mechanistic-Empirical Design of New & Rehabilitated Pavement Structures, available at <http://onlinepubs.trb.org/onlinepubs/archive/mepdg/home.htm> (pavement and road surfaces)
- The Asphalt Institute:
  - State Binder Specs Database (road surfaces)