

# U.S. Forest Service Transportation Resiliency Guidebook

Addressing Climate Change Impacts on U.S. Forest Service Transportation Assets

September 2018



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## Report notes

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The cover photo is of damage to Sevenmile Road after the 2014 floods in the Arapaho and Roosevelt National Forest.<sup>1</sup>

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<sup>1</sup> <https://www.fs.usda.gov/detail/arp/alerts-notice/?cid=stelprd3792351>

# Executive Summary

The nearly 200 million acres of public lands managed by the U.S. Forest Service (FS) are susceptible to wide-ranging climate change impacts in every region of the country. In addition to impacts that directly affect its lands, such as an increase in wildfires and tree mortality due to drought and higher temperatures, climate change also poses impacts to the roads, bridges, and other transportation infrastructure needed to access and travel within FS lands.

Increasingly, nearby communities rely on this transportation infrastructure to support the transport of tourists and local visitors to sites within National Forests and Grasslands as well as to access economic development opportunities such as timber harvest sites. When a road is out of commission, it impacts not only FS staff but also visitors and the local economy of gateway communities. Although much work has been done to characterize climate change impacts to the Forests themselves, less has been done to analyze impacts to transportation infrastructure in the Forests.

Former FS Chief Tom Tidwell, in a message to all employees, emphasized that every program and unit in the FS has a role to play in responding to hazardous weather and climate change. In fact, the United States Department of Agriculture (USDA) Strategic Plan for 2014-2018 sets a departmental goal to “Ensure our National Forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources.” Furthermore, the FS [National Roadmap for Responding to Climate Change](#) calls for “Protecting infrastructure by modifying or relocating roads, culverts, trails, campgrounds, and other facilities to resist floods and other major disturbances.”

To support these goals, FS and U.S. Department of Transportation (US DOT) staff developed this guidebook to provide the field with a process to assess and address climate change impacts on FS transportation assets at the local and regional levels. The guidebook is intended to strike the balance between being specific enough to be implementable and flexible enough to accommodate a variety of needs and challenges. The target audience is FS staff at the Forest or Regional level who are charged with addressing climate change considerations in transportation systems planning. The guidebook is organized as follows:

**Section 1. Introduction.** This section provides a brief context and an overview of the process, which is then detailed in subsequent sections of the guidebook.

**Section 2. Identifying Climate Change Vulnerabilities within the Forest Service Transportation Network.** This section provides a step-by-step guide for identifying vulnerabilities within the FS Transportation network, including eight systematic steps:

- Step 1. Establish an Interdisciplinary team (IDT) and define objectives
- Step 2. Define the scope: select and characterize relevant assets
- Step 3. Define the scope: identify key climate stressors
- Step 4. Assess vulnerability: develop information on asset sensitivity to climate
- Step 5. Assess vulnerability: collect asset data
- Step 6. Assess vulnerability: develop climate inputs
- Step 7. Assess vulnerability: develop indicators
- Step 8. Assess vulnerability: identify and rate vulnerability “problem spots”



Within this section there are a selection of “toolboxes” to assist in completing the step and “resource-constrained approaches” that provide opportunities for achieving the goals of the steps when resources are limited.

**Section 3. Reducing Transportation Vulnerability to Climate Change.** This section provides a step-by-step guide for preparedness planning to reduce the vulnerability of FS transportation systems.

- Step 9. Select “Problem Spot”/Vulnerable Locations and Assess Risks
- Step 10. Identify and develop adaptation strategies and approaches
- Step 11. Integrate climate change considerations into existing and future programs, projects, and planning processes
- Step 12. Identify and develop adaptation tactics
- Step 13. Evaluate feasibility and likelihood of success
- Step 14. Prioritize strategies and tactics
- Step 15. Identify and develop monitoring options
- Step 16. Adaptive management: revise strategies and tactics

Similar to the section above, within this section, there are a selection of “toolboxes” to assist in completing the steps and “resource-constrained approaches” that provide opportunities for achieving the goals of the steps when resources are limited. Starting with the “problem spots” identified in Section 2, each step in Section 3 is used to work toward the selection of adaptation strategies and tactics to help reduce transportation vulnerabilities.

**Section 4. Implementation Opportunities: Linking to Forest Service Plans and Programs.** This section discusses how to implement climate change vulnerability assessments, preparedness planning, and preparedness projects within existing FS programs and planning processes, as well as funding programs available to the FS. Linking climate change preparedness to other FS goals and leveraging existing programs is an effective way to implement climate change preparedness measures. This section discusses recommendations for enhancing existing programs to better support FS efforts to increase the preparedness of its transportation system to climate change. This section also proposes ways to create new opportunities for climate change technical assistance to help Forests address climate change-related vulnerabilities to their transportation system.

A series of appendices, which are referenced throughout the document, provide supplemental information and resources helpful to FS staff in assessing and addressing climate change impacts to FS transportation infrastructure.

This document is intended to serve as a useful resource for FS staff to identify, evaluate, and prepare for climate change impacts on their transportation system. Though quantitative information driving climate analysis evolves over time, the framework that supports the analysis and discussed in this report is likely to be helpful and robust for years to come. Ultimately, this guidebook seeks to provide a practical and flexible set of tools that FS staff can integrate into their planning and adaptive management strategies to plan for and manage climate change impacts to transportation systems now and in the future.



## Section I. Introduction

Climate change poses many serious threats to National Forests and Grasslands, including impacts to ecosystems and damage to FS transportation systems. Former FS Chief Tom Tidwell, in a message to all employees, emphasized that every program and unit in the FS has a role to play in responding to climate change. In fact, the [United States Department of Agriculture \(USDA\) Strategic Plan for 2014-2018](#) sets a departmental goal to “Ensure our National Forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources.”

This guidebook focuses specifically on how the FS can make its transportation systems more resilient to potential climate change impacts. Reducing climate change vulnerabilities within FS transportation systems is important for maintaining access to National Forests for visitors, supporting community access and economic development, protecting public safety, and maintaining fiscally sustainable transportation networks. This section of the guidebook discusses the policy and legislative context for considering climate change risks to FS transportation systems.

### Relevant Government Orders

*FHWA Order 5520 (December 2014), “Transportation System Preparedness and Resilience to Climate Change and Extreme Weather Events,” states that Federal land management agencies should “develop, prioritize, implement, and evaluate risk-based and cost-effective strategies to minimize climate and extreme weather risks and protect critical infrastructure using the best available science, technology, and information.”*

### I.1. Legislative and Organizational Context

Integrating climate change into transportation planning is important for the FS from a general high level and legislative context. Two government orders, summarized in the text box on this page, are examples of direction that the administration has given to Federal agencies about climate change adaptation. This document is organized in line with these orders.

The FS has completed significant work on climate change to date. The [National Roadmap for Responding to Climate Change](#) and the [Climate Change Performance Scorecard](#) are two important resources to which this document both refers and, where possible, connects. The National Roadmap calls for “Protecting infrastructure by modifying or relocating roads, culverts, trails, campgrounds, and other facilities to resist floods and other major disturbances” and discusses how bridges, culverts, and other infrastructure will be increasingly vulnerable to floods and other climate change impacts in future years. The roadmap points the way to a comprehensive, science-based approach to managing Forests and Grasslands in a rapidly changing climate. Employees in FS units can use the roadmap to chart a course to the future based on local needs. While transportation infrastructure is mentioned in the roadmap, the roadmap does not specifically describe how the FS should prepare its transportation infrastructure for climate change impacts.

According to the Climate Change Performance Scorecard, “Land and resource management are inherently fraught with risk and uncertainty. Climate change exacerbates both. In response, the FS must be nimble, willing to learn from mistakes, and able to incorporate lessons learned into future agency direction.” Between fiscal year (FY) 2011 and FY 2016, the FS administered the scorecard on an annual basis to all National Forests and Grasslands to track each unit’s progress in responding to climate change.

Over this time period, the scorecard helped the agency move forward with research and education on climate change issues and helped the FS adjust land management strategies and tactics accordingly. The scorecard has also been a driver for climate change vulnerability assessments with regions using a variety of different approaches. For example, Region 1 and Region 4 are currently taking a regional approach whereas Region 6 is taking a Forest-by-Forest approach. Region 2 currently has a vulnerability assessment that focuses just on roads.

The scorecard helped units document the steps they have been taking to reduce energy usage, greenhouse gas emissions, water usage, and other environmental footprints. Three of the scorecard's ten elements are particularly relevant to preparing transportation infrastructure for climate change impacts:

6. Assessing Vulnerability: Has the Unit engaged in developing relevant information about the vulnerability of key resources, such as human communities and ecosystem elements, to the impacts of climate change?
7. Adaptation Actions: Does the Unit conduct management actions that reduce the vulnerability of resources and places to climate change?
8. Monitoring: Is monitoring being conducted to track climate change impacts and the effectiveness of adaptation activities?<sup>2</sup>

The FS designed the scorecard to build climate change awareness; the next version, the Climate Action Card, is being designed to implement management decisions through action in all levels of the agency. The FS Office of Sustainability and Climate Change (OSCC) has been piloting the Climate Action Card, and plans to implement it by FY 2022.

2 For engineering, inspections can be considered part of the monitoring process

3 UNDP, #ActNow – Save Later, [http://www.undp.org/content/undp/en/home/ourwork/get\\_involved/ActNow.html](http://www.undp.org/content/undp/en/home/ourwork/get_involved/ActNow.html). Accessed Oct. 24, 2016.

4 Citylab, The Plain Math of Disaster Preparedness: “Every Dollar We Spent Saved 5 Dollars in Future Losses,” <http://www.citylab.com/politics/2013/10/plain-math-disaster-preparedness-every-dollar-we-spent-saved-five-dollars-future-losses/7160/>. Accessed Oct. 24, 2016.

5 The World Bank, Speech by World Bank Group President Jim Yong Kim: “Sending a Signal from Paris: Transforming the Economy to Achieve Zero Net Emissions,” <http://www.worldbank.org/en/news/speech/2014/12/08/transforming-the-economy-to-achieve-zero-net-emissions>. Accessed Oct. 24, 2016.

## 1.2. Climate Change Adaptation as a Fiscal Responsibility

A proactive approach to vulnerability assessments and developing adaptation actions is the most cost-effective way to prepare the FS transportation system for climate change. Studies suggest substantial savings from proactive adaptation planning and implementation.<sup>3,4,5</sup> The potential for increased maintenance, construction, and reconstruction costs due to climate change impacts threatens to put additional pressure on the Forest Service's limited funds for transportation infrastructure. Therefore, it is important for Forests to assess the magnitude of potential impact and develop strategies now to reduce their vulnerability. By taking a proactive approach to identifying climate change vulnerabilities and preparing its transportation infrastructure for future climate change impacts today, the FS can save not only money but can also help minimize the destruction and disruption that climate change can have on National Forests and Grasslands as well as the surrounding communities that rely upon these lands for their economic livelihood.

## 1.3. Purpose of this Guidebook

Recognizing the need to address climate change impacts on FS transportation systems, and the lack of specific guidance on this topic, the FS organized a team to develop this climate adaptation guidebook. Eight regional FS staff with experience in engineering, planning, and climate change as well a representative of the FHWA Western Federal Lands Highway Division met

monthly over the course of this work to provide guidance to the U.S. Department of Transportation John A. Volpe National Transportation Systems Center (Volpe Center), which convened the group, researched the content for this guidebook, and developed this guidebook for the group to review. As part of this work, Volpe Center staff talked to several FS staff in National Forests across the country to learn how climate change is impacting transportation in their Forests and how they are addressing its impacts. Group members and National Forest staff who provided input to this document are listed in the Acknowledgements section.

The guidebook is unique from most other FS climate change related guidance in that it is focused on climate change impacts as they specifically relate to transportation infrastructure within FS lands. As such, more detail is provided where the climate change stressor impacts transportation systems, and less on the climate change induced ecological system impacts that cause these consequences.

The guidebook is intended to be specific to the unique needs of FS staff involved in transportation planning yet flexible enough to accommodate varying climate change impacts, geographical scales, planning horizons, infrastructure needs, available resources and other factors that can differ dramatically across the country. It is also intended to be a succinct manual that FS staff can easily digest and use from planning through implementation; it is not a comprehensive compendium of all known climate change impacts, stressors, data sets, and technologies. As such, it should serve as a starting point for Forests that are confronting the challenges climate change is already placing on their transportation systems through increased wildfire, flooding, and other stressors. Other useful resources that may provide more site- or topic-specific guidance are provided throughout the document. Just like the changing global climate system that is the impetus for this guidebook, the field of climate science and associated adaptation tools are ever-changing as well. FS staff should utilize the

knowledge and expertise of their designated FS climate change coordinators early and often throughout the process to ensure that they are incorporating the most current information and guidance.

The target audience for the guidebook is local staff who are charged with addressing climate change considerations in transportation systems planning. However, the team recognizes that with limited funding many Forests do not have resources to conduct these activities and planning in these areas is coordinated at the regional level. Therefore, the guidebook lays out a process for Forests to get interdisciplinary support to supplement their own capabilities.

## I.4. How to Use this Guidebook

This guidebook can be used to support an independent transportation-specific climate assessment or be part of a larger climate adaptation effort. Many Forests are conducting Forest-wide climate change vulnerability assessments and adaptation strategies in response to the Climate Change Performance Scorecard. This guidebook can support the development of a transportation chapter within a larger climate change adaptation effort, such as those being developed for the Performance Scorecard.

Additionally, the guidebook is distinct from other US DOT climate change related guidance in that it recognizes the unique nature of FS transportation infrastructure, particularly its mostly rural character. As such, the guidebook is tailored to emphasize climate change related transportation impacts that are more prominent on rural FS lands.

To support the understanding and visualization of the steps taken in Sections 2 and 3, the guidebook provides a table in each section that is incrementally filled out as each step is completed. Recognizing limited funding streams and staff resources, the guidebook also provides alternate resource-constrained approaches where practicable.



## Section 2. Identifying Climate Change Vulnerabilities within the Forest Service Transportation Network

This section provides a framework for assessing vulnerabilities to climate change within FS transportation systems using relevant examples of efforts from Federal land management agencies (FLMAs) and the Federal Highway Administration (FHWA). It also provides a summary of projected climate change impacts and a guide to identifying “problem spots,” or areas with relatively high vulnerability, within FS transportation systems.

The 193 million acres of public lands managed by the FS are susceptible to wide-ranging climate change impacts in every region of the country (see Appendix A for impacts by FS Region). In addition to direct impacts to its Forests, such as through an increase in wildfires and tree mortality, climate change also poses impacts to the roads, bridges, and other transportation infrastructure needed to access FS lands. Increasingly, nearby communities rely on this transportation infrastructure to support the transport of tourists and local visitors to sites within National Forests and Grasslands. When a road is out of commission, it impacts these people and the local economy of these communities. Although much work has been done to characterize climate change impacts to the Forests themselves<sup>6</sup>, less has been done to analyze direct impacts to transportation infrastructure.

<sup>6</sup> Visit the [USFS Climate Change Resource Center](#) for more details.

<sup>7</sup> Stressors discussed here include primary, secondary, and tertiary stressors that may impact transportation infrastructure. Primary stressors are measurable changes in climate such as rising temperatures, secondary stressors comprise changes in environmental conditions such as reduced snowpack, while tertiary stressors may include consequences such as wildfire that impact transportation.

<sup>8</sup> Based on research and interviews with National Forests (e.g., Frances Marion NF, National Forests and Grasslands of Texas, Arapaho-Roosevelt NF, Sierra NF) and Regions (e.g., Region 5 Forest Health Protection Group, Region 4 Intermountain Adaptation Partnership).

Climate change will have far-reaching consequences across the nation and world, and the impacts will vary depending on future climatic conditions and the location and sensitivities of transportation infrastructure. As impacts may vary depending on geographic location, Appendix A presents historic and future climate-related exposure and FS transportation impacts by region. Some cross-cutting climate change-related stressors to transportation infrastructure that many Forests are facing include flooding, wildfire, landslides, and tree mortality:<sup>7,8</sup>

- **Heavy Precipitation and Flooding** can inundate roadways interrupting service, washing out roads, causing erosion and compromising underlying soil stability thereby triggering landslides, and plugging or blowing out culverts. Climate change induced sea level rise exacerbates coastal flooding, particularly in low lying areas.
- **Wildfires**, which can be exacerbated by droughts, create additional woody debris that plug culverts, reduce slope stability, and create increased heavy vehicle traffic wear and tear on FS roadways.
- **Landslides** can destabilize roads and trails and cause large-scale damage. The conditions that cause landslides can be exacerbated by water-logged slopes after heavy precipitation, flooding of streams undercutting slopes, and wildfire damage that removes stabilizing vegetation. Because landslides are often caused or exacerbated by flooding and/or wildfires, this guidebook discusses landslides as part of discussions of those climate change impacts.

- **Tree mortality** caused by drought and insect infestations can create a need for clearing hazard trees along roadways and provide forest fuel for wildfires.<sup>9</sup>

There are also climate change-related stressors to transportation infrastructure that are locally significant, such as sea level rise in coastal areas, and permafrost melting particularly in Alaska. All of these climate change-related stressors to transportation infrastructure are affected by changes in weather and climate, such as extreme temperatures and precipitation events. A discussion of these stressors and impacts to FS transportation infrastructure within each Region is included in Appendix A.

The following sub-sections provide a step-by-step guide that FS staff can use to identify vulnerabilities and provides a basic vulnerability assessment table to be populated when each step is completed. This section of the guide is based on the vulnerability assessment methodologies described in Appendix B as well as research and interviews with National Forests (e.g., Frances Marion NF, National Forests and Grasslands of Texas, Arapaho-Roosevelt NF, Sierra NF) and Regions (e.g., Region 5 Forest Health Protection Group, Region 4 Intermountain Adaptation Partnership) that have been working to assess vulnerabilities of their transportation networks to climate change stressors.

In general, the FS has been steadily working on developing transportation vulnerability assessments using a variety of different approaches. For example, currently Region 1 and Region 4 are taking a regional approach whereas Region 6 is taking a Forest-by-Forest approach. Region 2 currently has a vulnerability assessment that focuses just on roads. Other Regions are approaching climate change vulnerability more at the project level than the program level.

This guide is targeted at the Forest level since Forest staff have the strongest knowledge of their key assets and this geographic scale is most suitable for assessing local climatic conditions.

However, there may be cases when the vulnerability assessment will be conducted at the Regional level. If this step-by-step guide is applied at that level, it is important for staff to think critically about which assets (Step 2) and climate stressors (Step 3) to include in the analysis, since the number of assets and variety of climate stressors can increase dramatically at larger geographic scales. Generally, a larger spatial scale translates to a high-level screening analysis that may then target locations to consider for a more detailed vulnerability assessment.

The step-by-step guide proposed here includes eight systematic steps:

- Step 1. Establish an Interdisciplinary Team and define objectives
- Step 2. Define the scope: select and characterize relevant assets
- Step 3. Define the scope: identify key climate stressors
- Step 4. Assess vulnerability: develop information on asset sensitivity to climate
- Step 5. Assess vulnerability: collect asset data
- Step 6. Assess vulnerability: develop climate inputs
- Step 7. Assess vulnerability: develop indicators
- Step 8. Assess vulnerability: identify and rate vulnerability problem spots

Within each step, this section presents a selection of “toolboxes,” which are summarized in text boxes, tables, and figures, that further illustrate how to implement each step. Appendix B provides background and context for the vulnerability assessment framework used in this Guidebook.

<sup>9</sup> Hazard trees are trees with a structural defect such as with the roots, trunk, or branches. These trees are more likely to fall, causing damage and injury.



## 2.1. Step 1. Establish an Interdisciplinary Team and define objectives

A dedicated interdisciplinary team (IDT) of at least a transportation engineer, hydrologist/geomorphologist, and fisheries/aquatic organisms biologist should be included to lead the work of the Forest in identifying vulnerable assets. Other potential disciplines include transportation planners, GIS specialists, asset managers, climatologists, maintenance personnel, and other natural resource agency personnel. The IDT should first identify the study area, as well as a common vision and set of objectives. The IDT should then work together toward achieving this common set of objectives.

## 2.2. Step 2. Define the scope: select and characterize relevant assets

Within this step, the IDT should define the geographic scope of the assessment as well as the types of assets that will be included. The IDT may decide to include all assets or a subset of critical assets. Critical transportation assets for the FS typically maintain some or many of the following functions:

- Provide or support access for recreation;
- Provide or support access for resource management;
- Support watershed restoration;
- Support resource protection to sustain healthy ecosystems;
- Have a high replacement value;
- Have a high average daily traffic (ADT) count; and/or
- Provide the only route to a destination.

A wide range of transportation asset types from road segments to bicycle facilities can be identified as part of this process (see Table I).<sup>10</sup>

<sup>10</sup> Federal Highway Administration (FHWA). December, 2012. FHWA Climate Change Vulnerability Assessment Framework. [https://www.fhwa.dot.gov/environment/climate\\_change/adaptation/publications/vulnerability\\_assessment\\_framework/](https://www.fhwa.dot.gov/environment/climate_change/adaptation/publications/vulnerability_assessment_framework/)

*“It takes a clear vision and strong core group of dedicated people to embark on and complete this type of study.”*  
 - FS Region 4 Staff regarding development of a Climate Change Vulnerability Assessment

Transportation Asset Types
<ul style="list-style-type: none"> <li>• Bridges/tunnels</li> <li>• Culverts/Storm sewers</li> <li>• Road segments</li> <li>• Trails (hiking, OHV, etc.)</li> <li>• Ski lifts and trails</li> <li>• Key evacuation routes</li> <li>• Rail lines</li> <li>• Transit system facilities and vehicles</li> <li>• Bicycle and pedestrian facilities</li> <li>• Maintenance and operations facilities</li> <li>• Signals and traffic control centers</li> <li>• Back-up power, communication, fueling, and other emergency operations systems</li> <li>• Intelligent Transportation Systems (ITS)</li> <li>• Signs and other roadside assets</li> <li>• Pipelines and energy corridors</li> <li>• Stormwater management facilities</li> </ul>
Relevant Landscape Attributes
<ul style="list-style-type: none"> <li>• Wetlands</li> <li>• Floodplains</li> <li>• Roadside vegetation</li> <li>• Areas of potential rock fall</li> <li>• Areas of potential tree mortality</li> </ul>

Table I. Transportation asset types and relevant landscape attributes that may be considered for assessment

Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1							
Asset 2							
Asset 3							
Etc.							

Table 2. Step 2 completes the first column of the vulnerability table

The IDT should carefully consider which assets to include based on the criticality of the assets as highlighted in the bullets above. It can also be useful to identify relevant landscape attributes in the study area, such as wetlands and roadside vegetation that can affect the construction, maintenance, or repairs to transportation asset types (overall life-cycle of the asset).

Table 2 shows how the selected assets can populate the first column of the vulnerability table.

### 2.3. Step 3. Define the scope: identify key climate stressors

Appendix A of this guidebook summarizes the key climate stressors to FS transportation infrastructure (i.e., flooding, wildfire, drought, tree mortality) at a high level by region. The IDT should review Appendix A and other FS or local climate change

impacts assessments to gain an overview of region-specific or local climate change impacts (this may occur after asset identification if specific asset climate-sensitivities are identified or known). The IDT should then select the climate stressor(s) on which it wants to focus and enter them into the vulnerability assessment table (see examples in Table 3). Note that there can be cumulative impacts. For example, tree mortality combined with flooding can lead to plugged culverts.

Under this step, the IDT should also determine the present and future time periods for climate analysis, treatment of uncertainty associated with projections, and scenarios (these decisions should align with the study objectives). To accommodate a variety of planning and programming activities, it may be useful to consider the magnitude of projected changes in climate and system responses in three timeframes: current to short term (less than 10 years), medium term (10 to 30 years), and long term (30 to 100 years).<sup>11</sup>

11 United States Forest Service (USFS). September, 2014. [Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington](#). PNW-GTR-892

Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1							
Asset 2							
Asset 3							
Etc.							

Table 3. Step 3 completes one (or more) column headings of the vulnerability table highlighted in yellow

## 2.4. Step 4. Assess vulnerability: develop information on asset sensitivity to climate

After defining the scope of the vulnerability assessment, the IDT should identify the ways in which the relevant transportation assets are sensitive to the climate stressors (e.g., the kinds of impacts they can experience, and at what thresholds these impacts are experienced) and should enter this information into the vulnerability table (see examples in Table 4). The attributes of the transportation system that may be sensitive to projected climate changes include the location, design, and current condition of the transportation assets as well as recreation use and demand. For example, aging infrastructure that continues to deteriorate, such as culverts that exist beyond their design

lifespan (typically 25 to 75 years), have a higher likelihood of structural failure exacerbating their sensitivity to climate change.<sup>12</sup> The following considerations should be taken into account when determining asset sensitivities:

- Aging infrastructure (is the asset beyond its design lifespan?)
- Design and use considerations (was the asset designed for its current use? For example, a road that was originally designed for timber harvesting may now be primarily used for recreation. Has the change in use degraded its condition?)
- Location and land use (is the asset located in an exceptionally sensitive area, such as on a steep slope? Has past and current land use exacerbated sensitivities? For example, timber harvesting and its associated road network have contributed to the sensitivity of existing infrastructure by increasing storm runoff and peak flows that can affect road crossing structures.)

<sup>12</sup> United States Forest Service (USFS). September, 2014. [Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington](#). PNW-GTR-892

Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	<b>In Floodplain</b>	<b>History of Damage</b>	Cost to Repair	Average Daily Traffic	
Asset 1							
Asset 2							
Asset 3							
Etc.							

Table 4. Step 4 completes one (or more) column headings of the vulnerability table highlighted in yellow

- Maintenance and management of roads and trails (How regularly is the asset managed and maintained? A lack of funding can limit maintenance and management options. For example, replacing a damaged culvert with an “in-kind” culvert that was undersized for the current streamflow conditions leads to continued sensitivity to both the current and projected higher flows).<sup>13</sup>

There are a number of resources that the IDT can use to help identify sensitivities:

- Design standards. Standards or guidelines developed by Federal agencies, State DOTs or other industry organizations, such as standards for designing, constructing, and maintaining infrastructure, can be used to isolate specific climate stressors relevant to a particular asset.
- Design elements or relationships. For example a narrow, steep stream may be more sensitive to increased flow than a relatively flat stream with wide floodplains. The narrow stream may react more quickly and severely with rapidly

rising water surface elevations and increased velocities, whereas a flat wide floodplain may be able to distribute and store the increased flow, effectively dampening the impacts.

- Operation and maintenance records. These records provide a history of the Forest’s experiences with system performance in the past, especially during extreme weather conditions. An assessment of past weather-related disruption and damage might consider:
  - Weather-related sources of disruption to transportation services.
  - Transportation assets currently affected by weather extremes.
  - Damage to roads, bridges, or supporting infrastructure (e.g., culverts).
  - Thresholds at which the system begins to experience impacts (e.g., a specific high temperature or an amount of precipitation within a day or over several days that has led to damage or failure).

<sup>13</sup> United States Forest Service (USFS). September, 2014. [Climate Change Vulnerability and Adaptation in the North Cascades Region, Washington](#). PNW-GTR-892



## TOOLBOX I

EXAMPLES OF TYPES OF ASSET ATTRIBUTE DATA, LEVEL OF IMPORTANCE, AND SITUATIONS WHERE USEFUL

Asset Attribute Data	Level of Importance	Situations Where Useful
Geographic location (geospatial data)	High	Necessary in order to assess risks to climate change stressors
Level of use (traffic counts, forecasted demand)	High	Necessary in order to determine criticality of the asset. Traffic counts specifically before and after a fire events help to quantify the level of fire-related traffic.
Local significance	High	Useful to help identify asset priority. For example, if the route is a school bus route or evacuation route.
Current/historical performance and condition	High	Necessary in order to identify whether the asset is a current risk
Replacement cost	High	Necessary to determine the value of the asset, useful for project prioritization
Age of Asset	Medium	Useful to help assess performance and condition
Elevation	Medium	Can be an important attribute depending on the stressor. For example, roadways at a low elevation (e.g., near or below sea level) may be more susceptible to flooding than those at a higher elevation.
Repair/maintenance schedule and costs	Medium	Useful to support the replacement cost as well as to identify any historic issues with performance/condition
Structural design	Medium	Useful to evaluate current and future performance
Materials used	Medium	Useful to evaluate current and future performance
Design lifetime and stage of life	Medium	Useful to evaluate current and future performance

- Locations within the system that experience impacts.
- Institutional knowledge. Forest engineers and maintenance personnel are very often quite knowledgeable on the weaknesses or vulnerabilities of the current system and should be tapped early on in the process. For example, a vertical gap/waterfall at the terminus of a culvert often caused by erosion due to high velocity flows is an indicator of the culvert being under-sized for high flow events.

#### RESOURCE CONSTRAINED APPROACH FOR UNDERSTANDING FLOOD EXPOSURE RISKS

*Forests should coordinate with local research stations to first identify whether accurate, local sources of data are available.*

*In addition, the National Oceanic and Atmospheric Administration (NOAA) maintains the [Storm Events Database](#), which provides data stretching back to January 1950:*

- *the occurrence of storms and other significant weather phenomena having sufficient intensity to cause loss of life, injuries, or significant property damage;*
- *rare, unusual weather phenomena, such as snow flurries in South Florida; and*
- *other significant events, such as maximum and minimum temperatures.*

*This database is a valuable resource for understanding past weather events and trends for an area.*

## 2.5. Step 5. Assess vulnerability: collect asset data

The IDT should collect data on all relevant assets (e.g., data to inform exposure, sensitivity, adaptive capacity, costs, etc.). The scale, breadth, and depth of the data available drives the level of assessment possible.

There are a number of asset attributes that are useful to collect when conducting a vulnerability assessment. Toolbox 1 provides a prioritized list of asset attributes as well as instances where the attributes might be useful from which the IDT can select. Note that the asset attributes in Toolbox 1 are not prescriptive, and are only examples; the level of importance could vary depending on local conditions, the scope of the study, and other factors. The IDT may wish to add other asset attribute data or create a different priority for different assets/locations.

The IDT should identify which of these data are readily available and which will need to be collected. Depending on the existing asset management system for the study area, many asset attributes may be readily available in an electronic database or may require other means for collection such as map identification or inspection.

Based on the data that are needed, the IDT should consider what resources are needed in the form of budget, staffing, and tools in order to collect necessary data. For example, data collection/modeling tools that might be required include GPS for mapping geospatial data and LiDAR (can be helpful to confirm assets and streams are accurately captured on maps/GIS). Once the IDT has determined the type of asset attribute data to collect, the IDT should enter it into the vulnerability assessment table (see examples in Table 5).

Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1							
Asset 2							
Asset 3							
Etc.							

Table 5. Step 5 completes one (or more) column headings of the vulnerability table highlighted in yellow

**RESOURCE CONSTRAINED APPROACH FOR DEVELOPING CLIMATE INPUTS**

*Because staff time and other resources are often limited, it may be difficult if not impossible for the IDT to do a complete data analysis using the data sources in Toolbox 2. Accordingly, the IDT can gather as much data as is readily available from this list and determine if that is enough to proceed or if more data collection is necessary.*

## 2.6. Step 6. Assess vulnerability: develop climate inputs

Once the IDT has identified the climate-related stressors and the desired future time horizon for the analysis, a compilation can begin of the current and future magnitude, frequency, and duration of these stressors. In general, this is done by averaging 20-30 years of climate data centered on the future time horizon determined in the steps above. If the study area is large, it may be beneficial to break the study area into sub-regions of like stressors and conditions.

Data collection and analysis of climate-related stressors can come from a variety of sources; Toolbox 2 is not exhaustive, but provides a summary of climate- and weather-related datasets from which the IDT can select. Other, more local data may be available, and the IDT should coordinate with the region and research stations to identify available data.

Once a picture of current climate stressors is clear, a literature review, post-processing of available data, and/or computer

modeling are means to obtain projections of how climate stressors may change within the agreed upon future time horizon(s). Toolbox 3 provides a number of resources that are available to assist in estimating future change from which the IDT can select. Other, more local data may be available and useful for the IDT to use. Research station staff or graduate students can help access and use the resources in Toolboxes 2 and 3, but may require funding to do significant work.

For regions that are impacted by tree mortality from beetle infestations, the IDT should delineate areas of tree kill from beetle infestations and tree removal routes to help identify which routes are impacted or will experience particular wear and tear from tree removal. Additionally, to visualize potential problem spots, GIS data, such as hydrologic features, can be overlaid with the locations of transportation assets to help users easily locate these areas and routes.



## TOOLBOX 2

### CLIMATE- AND WEATHER-RELATED DATASETS

#### High Priority (necessary, low cost, typically easily accessible)

- Asset damage records from past extreme events
- FEMA Flood Insurance Rate Maps (FIRMS) maps
- Floodplain and tsunami inundation zone maps
- National Climate Data Center for meteorological observation data (temperature, precipitation, wind, solar radiation)
- USGS stream gage data (stream flow)
- U.S. Drought Portal
- State climatology and weather service websites
- USFS Wildfire Hazard Potential data (firelab.org)

#### Medium Priority (important, but could be higher cost or harder to access)

- LiDAR (Light Detection And Ranging) remote sensing data
- Regional sites providing wildfire risk
- Vegetation and soils surveys
- FEMA Disaster Declaration Records
- NOAA Tides and Currents (sea level rise over the past 50 to 100 years for tide gages)
- Additional information may be found at [climate.gov](http://climate.gov)
- NOAA Storm Events database



## TOOLBOX 3

### RESOURCES FOR ASSISTING WITH ESTIMATING FUTURE CHANGE

- U.S. Global Change Research Program (USGCRP) NCA (2014) report
- USGS Derived Downscaled Climate Projection Portal visualizes future temperature and precipitation projections based on statistically downscaled CMIP5 climate model data.
- DOT Coupled Model Intercomparison Project (CMIP) Climate Data Processing Tool: A user-friendly excel-based tool that provides over 40 temperature and precipitation indicators useful to transportation practitioners based on statistically downscaled CMIP3 and CMIP5 climate model data.
- NOAA Sea Level Rise Viewer: Internet-based viewer that provides coastal inundation for 0 to 6 feet of sea level rise as well as describes current areas that may experience shallow coastal flooding.
- Additional information may be found at [climate.gov](http://climate.gov)



## 2.7. Step 7. Assess vulnerability: develop indicators

The components of an asset’s vulnerability include its exposure, sensitivity and adaptive capacity (Figure 1).

Indicators are useful for conducting an indicator-based vulnerability assessment. Exposure indicators suggest how the climate-related stressor may change in the future. Sensitivity indicators suggest how the FS transportation asset may react to being exposed. Adaptive capacity indicators suggest how well the system can adapt to being exposed to harmful climate-related stressors. Collectively, these indicators suggest whether the assets and the system will be vulnerable to future conditions. This step provides the user of this guidebook a chance to review and revise the indicators previously developed to be sure that the assessment table (Table 6) will yield the results desired.

### a. Exposure Indicators

Exposure indicators are specific to the climate stressors of interest. For example, an indicator for heavy precipitation could be the average number of days per year with heavy precipitation (“heavy precipitation” being regionally defined). Drawing from the efforts in Step 6, a summary cataloging the observed and projected values for the exposure indicators can be developed.

### b. Sensitivity Indicators

Sensitivity indicators include history of damage, bridge elevation, culvert volume or flow data, or other indicators of the extent to which a climate stressor would damage an asset or its services. Sensitivity indicators can be developed based on the efforts in Step 5.

### c. Adaptive Capacity Indicators

Adaptive capacity indicators may include the projected costs of repairs, average daily traffic, or the presence of alternate routes. These indicators help analyze the ability of the transportation system to adjust to climate change, moderate potential damages, or cope with the consequences.

Figure 1. Components of Vulnerability for Transportation Infrastructure

<p><b>1. Exposure:</b></p> <p>Whether a transportation system could be adversely impacted by a climate stressor.</p> <p>(For example, how likely is it that a road could be flooded, under current or future climate conditions?)</p>	<p><b>2. Sensitivity:</b></p> <p>The degree to which a system would be impacted by climate stressors, if exposed.</p> <p>(For example, if a road were exposed to flooding, how much damage would it experience?)</p>	<p><b>3. Adaptive Capacity:</b></p> <p>A system’s ability to adjust to or cope with potential impacts from a climate stressor.</p> <p>(For example, if a road is damaged from flooding, what is the agency’s ability to withstand the damage or repair the system?)</p>	<p><b>RESOURCE CONSTRAINED APPROACH FOR DEVELOPING INDICATORS</b></p> <p><i>While it is ideal to have and use as many of these indicators as possible, if time and resources are limited, selecting or developing one indicator from each of the three types of indicators for each asset type that are tailored to the study area would provide a valuable starting point upon which future analysis can build.</i></p>
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Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1							
Asset 2							
Asset 3							
Etc.							

Table 6. Step 7 provides a chance to review the indicators selected as column headings of the vulnerability table highlighted in yellow

**RESOURCE CONSTRAINED APPROACH FOR IDENTIFYING AND RATING VULNERABILITY “PROBLEM SPOTS”**

*If time and resources are limited, the IDT can develop a list of problem spots based on the operations and maintenance records and institutional knowledge as described under Step 5. These two sources can give the FS enough of an idea about current problem spots that may worsen as the climate changes.*

Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1	+++	++	+++	++	++	+++	2
Asset 2	++	+++	+++	+++	+++	++	1
Asset 3	++	++	++	+++	++	++	3
Etc.							

Table 7. Step 8 fills in the cells of the vulnerability table highlighted in yellow

## 2.8. Step 8. Assess vulnerability: identify and rate vulnerability “problem spots”

After identifying indicators for all of the relevant assets in Step 7, the IDT can create a ranking of relative vulnerabilities within a transportation network to identify which assets or systems are most vulnerable. This can help highlight problem spots and prioritize planning for adapting or increasing the resilience of the transportation network.

During this step, the cells under each column heading (established in previous steps) should be filled out with as much detailed data as possible. However, if no detailed data is available, a rough order of magnitude or basic scoring system can be used (see example in Table 7). Though this time-saving shortcut will not result in as

robust of a ranking process, it enables time- and resource-limited Forests to undertake this process at least at a high level. Other tools, such as [FHWA’s Vulnerability Assessment Scoring Tool](#)<sup>14</sup>, are also available to support the ranking of vulnerable assets.

Section 3 provides a step-by-step guide for adaptation planning based on the vulnerable problem spots identified here in Section 2. It is important to consider the level of uncertainty and confidence in the input data to ensure the vulnerability assessment results are being incorporated appropriately into the adaptation planning process and associated decision making (e.g., if the analysis is considering sea level rise flooding in 2100 for an area with significant changes in projected ocean circulation and subsidence, the range of plausible sea level rise could be quite large and using one specific future rise, opposed to a range, may not be appropriate).

<sup>14</sup> Note that VAST is focused on flooding-related vulnerabilities, and may not be useful for other climate stressors.



## Section 3. Reducing Transportation Vulnerability to Climate Change

This section provides a step-by-step guide for adaptation planning at the Forest level to reduce the vulnerability of FS transportation systems. Adaptation planning involves responding to the impacts of climate change, both proactively and reactively (Table 8). Adaptation planning can include preventative strategies to reduce climate change impacts (e.g., sustain forest ecology to reduce the likelihood of tree mortality or wildfires) and mitigation strategies to reduce the consequences (e.g., reroute traffic flows). Such strategies can be introduced at many entry points of an asset’s lifetime such as during planning, procurement, design, construction, maintenance, repair, and operations.

Climate Change Stressor	Impacts on Transportation	Example Strategies to Reduce Impacts	Consequences of Impacts on Transportation	Example Strategies to Reduce Consequences
Heavy Precipitation / Flooding	Flooded roadways interrupting service Damage/destruction of roads and bridges Pavement buckling Erosion comprising soil stability and transportation assets Slope failures Landslides damaging and disrupting routes Plugged or blown out culverts	Retrofit facilities Relocate facilities Upgrade culverts and drainage facilities Build new facilities to climate ready standards Protect existing infrastructure Divest in assets	Safety risk for transportation users Disrupted access to critical emergency routes Disrupted public access to Forests for recreation and other purposes Disrupted access for FS personnel for Forest management activities	Reroute passenger flows Evacuation strategies Build in network flexibilities Rapid rebuilding of damaged facilities
Wildfires	Additional woody debris that plug culverts Reduced slope stability causing increased landslides Increased heavy vehicle traffic wear and tear on FS roadways	Sustain forest ecology Protect Forests from severe fire and wind disturbance Facilitate Forest community adjustments through species transitions	Higher transportation costs for FS	
Tree Mortality	Fallen trees disrupt access along transportation routes Increased need for clearing hazard trees along roadways Provide forest fuel for wildfire			

Table 8. Role of Adaptation Strategies in Reducing Impacts and Consequences (Adapted from USGCRP, 2009)

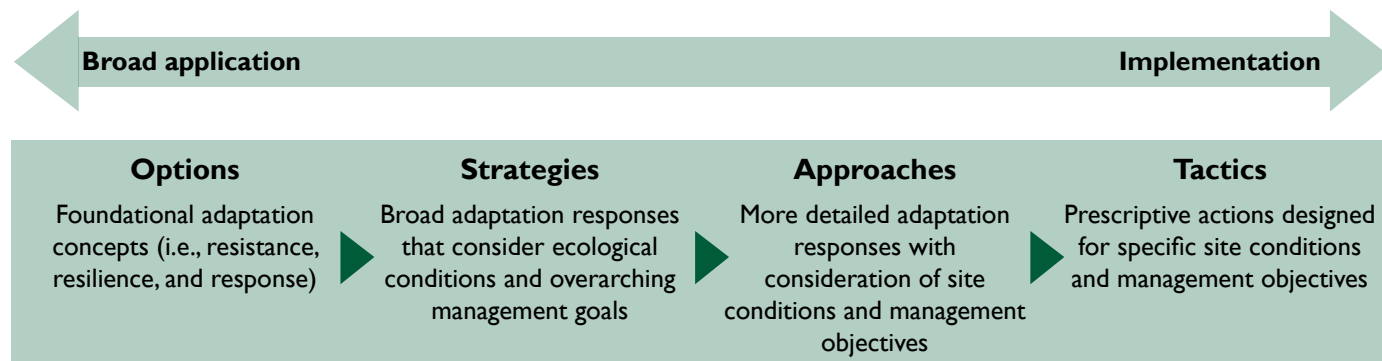
Asset	Exposure Indicator(s)		Sensitivity Indicator(s)		Adaptive Capacity Indicator(s)		Rank
	Increased Flows	More Tree Mortality	In Floodplain	History of Damage	Cost to Repair	Average Daily Traffic	
Asset 1	+++	++	+++	++	++	+++	2
<b>Asset 2</b>	<b>++</b>	<b>+++</b>	<b>+++</b>	<b>+++</b>	<b>+++</b>	<b>++</b>	<b>1</b>
Asset 3	++	++	++	+++	++	++	3
Etc.							

Table 9. The result of the vulnerability assessment table used in Section 2 provides a ranking of assets to address

	<b>Stressors</b>	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	<b>Flooding</b>						
Asset 1							

Table 10. Stressor(s) should populate the first column of the adaptation determination table

Figure 2. Continuum of adaptation actions (adapted from Janowiak et al. 2011)



The step-by-step guide proposed here includes eight steps that follow steps 1 to 8 in Section 2:

- Step 9. Select “Problem Spot”/vulnerable locations and assess risks
- Step 10. Identify and develop adaptation strategies
- Step 11. Integrate climate change considerations into existing and future programs, projects, and planning processes
- Step 12. Identify and develop adaptation tactics
- Step 13. Evaluate feasibility and likelihood of success
- Step 14. Prioritize strategies and tactics
- Step 15. Identify and develop monitoring programs
- Step 16. Revise strategies and tactics

This section also includes a selection of “toolboxes,” that further illustrate how to implement each step and a basic adaptation determination table to be populated when each step is completed.

Since adaptation actions usually take place at the Forest level, this guide is targeted toward Forest staff; however, Regional and other FS staff may also find it useful.<sup>15</sup> This guide has been tailored to specifically address transportation infrastructure threats and impacts; however, it is important to note that these steps can be integrated into a broader Forest-wide adaptation process that addresses transportation infrastructure as a component therein.

The step-by-step guide proposed here is based on several existing best practices and tested methodologies including the FS [Performance Scorecard Guide](#), FS [Climate Change Response Framework \(CCRF\)](#), FS Storm Damage Risk Reduction Guide for Low-Volume Roads, FHWA Climate Change and Extreme Weather Vulnerability Assessment Framework, and other sources.<sup>16</sup> The guide draws from the approach and terminology of the conceptual continuum introduced in Janowiak et al. 2011, which starts with a set of broad adaptation options and moves toward specific on-the-ground tactics (Figure 2).<sup>17</sup>

<sup>15</sup> United States Forest Service (USFS). August, 2016 (accessed). Performance Scorecard: 7- Adaptation Actions. <http://www.fs.fed.us/climatechange/advisor/scorecard/adaptation-actions.html>

<sup>16</sup> E.g., [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers Adaptation Workbook](#), US DOT General Process for Transportation Facility Adaptation Assessments developed for Gulf Coast Study, Phase 2.

<sup>17</sup> The continuum is also used in [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#).

### 3.1. Step 9. Select “Problem Spot”/ Vulnerable Locations and Assess Risks

Based on the ranking of vulnerabilities in Step 8 of Section 2, Identifying FS Transportation Vulnerability “Problem Spots,” Forests should select which high priority problem spots, and associated transportation asset(s), will be the focus of adaptation efforts (see example in Table 9 where Asset 2 scored the highest). Next, the IDT should determine to which climate stressor(s) the asset needs to be resilient (see example in Table 10).

Although Forests should focus on the assets in these problem spots, a systems approach should be taken with regard to implementing the adaptation measures since the impacts of climate stressors cross jurisdictional boundaries. For example, Forests should conduct adaptation planning at the watershed level as it relates to flooding impacts, at the forest ecosystem level as it relates to tree mortality issues, and wildfire prone areas for wildfire impacts. Toolbox 4 offers some other suggestions for getting started on these steps.

To assess the risks to the asset, Figure 3 provides an example of a risk rating matrix that can be used to evaluate the likelihood and consequences of climate change impacts for infrastructure or other resources. The location of conditions within the matrix can vary over time, which allows for an ongoing assessment of risk and development of potential responses for reducing the risk of storm damage.<sup>18</sup>

<sup>18</sup> Keller, G.; Ketcheson, G. 2015. Storm damage risk reduction guide for low-volume roads. Tech. Rep. 1277 1814. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. <https://www.fs.fed.us/t-d/pubs/pdfpubs/pdf12771814/pdf12771814dpi300.pdf>.



#### TOOLBOX 4 TIPS FOR GETTING STARTED

##### Contact your Climate Change Coordinator

Forests are encouraged to consult their [climate change coordinator](#) for support. The climate change coordinator has time allocated for climate change activities and training, and may be able to provide technical or scientific expertise as well as facilitation and communication services that would be helpful in conducting adaptation activities.

For example, Region 4’s Climate Change Coordinator has been working with Forests in the Region as well as the National Park Service, local Universities, and others through the [Intermountain Adaptation](#) Partnership to develop a climate adaptation strategy that incorporates transportation infrastructure impacts.

##### Host a workshop

A workshop is a great way to quickly and effectively identify potential adaptation strategies that will feed into Step 10 of this guide: Review potential adaptation strategies. It can also help foster relationships and collaboration with stakeholders at the outset of the process that will be beneficial throughout the identification, prioritization, and implementation of adaptation strategies and tactics.

Olympic National Forest and Olympic National Park convened a workshop with their agencies’ natural resources and engineering staff as well as local climate scientists and other stakeholders to kick off a discussion of adaptation for road management on the Olympic Peninsula. The workshop resulted in a list of concrete adaptation strategies for road management in the forest and park.

Source: United States Department of Agriculture (USDA). Forest Service Pacific Northwest Research Station. August, 2011. [Adapting to Climate Change at Olympic National Forest and Olympic National Park](#). General Technical Report PNW-GTR-844.



Figure 3. Example of a risk assessment matrix<sup>19</sup>

Probability of Damage or Loss	Magnitude of Consequences		
	RISK		
	Major	Moderate	Minor
Very likely	Very high	Very high	Low
Likely	Very high	High	Low
Possible	High	Intermediate	Low
Unlikely	Intermediate	Low	Very low

**Probability of Damage or Loss:**  
 The following descriptions provide a framework to estimate the relative probability that damage or loss would occur (to reduce the subjectivity of these ratings, develop criteria to express these more quantitatively).  
 Very likely: Nearly certain occurrence (greater than 90 percent).  
 Likely: Likely occurrence (greater than 50 percent to less than 90 percent).  
 Possible: Possible occurrence (greater than 10 percent to less than 50 percent).  
 Unlikely: Unlikely occurrence (less than 10 percent).

**Magnitude of Consequences:**  
 Major: Loss of life or injury to humans, major road damage, irreversible damage to critical natural or cultural resources.  
 Moderate: Possible injury to humans, likely long term, but temporary road closure and lost use of major road or road system, degradation of critical natural or cultural resources resulting in considerable or long-term effects.  
 Minor: Road damage minor, little effect on natural or cultural resources resulting in minimal, recoverable or localized effects.

**Risk and Priority:**  
 A. Very high and High risk: Highest priority of SDRR treatments.  
 B. Intermediate risk: SDRR treatments needed; may be incorporated into annual maintenance.  
 C. Low and Very low risk: SDRR treatments may not be necessary.

<sup>19</sup> Ibid; SDRR = Storm Damage Risk Reduction

	Stressors	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	Flooding	Redesign	A <sub>R</sub>				
			B <sub>R</sub>				
			C <sub>R</sub>				
			D <sub>R</sub>				
		Divest	A <sub>D</sub>				
			B <sub>D</sub>				
			C <sub>D</sub>				
Asset 1							

Table 11. Strategies and approaches should populate the next two columns of the adaptation table

### 3.2. Step 10. Identify and develop adaptation strategies and approaches

Adaptation strategies explain the ways that adaptation options can be applied. Adaptation approaches then provide more detail regarding application of the strategy (Figure 2). For example, an adaptation strategy to mitigate the risks of tree mortality may be: *reduce the impact of existing biological stressors*. Approaches for this strategy could include: (1) *improve the ability of the Forest to resist pests and pathogens* or (2) *prevent the introduction and establishment of invasive plant species*.<sup>20</sup> It is important to note that a plausible adaptation strategy in some cases may be to divest in the transportation asset (e.g., decommission, abandon, lower road prioritization for 10 years for flexibility).

It is ultimately the responsibility of Forest-level staff to identify the strategies and approaches that are most relevant for their geographic area and Forest-level goals. This step cannot be done within a vacuum, however. The IDT will need to coordinate these strategies among relevant stakeholders.

Strategies will relate directly to the climate stressor of concern. For example, adaptation strategies to reduce the risks of transportation infrastructure to tree mortality may relate to preserving forest ecosystem health whereas adaptation strategies for heavy precipitation and flooding may relate to increasing capacity of culverts to handle more extreme flooding events. Table 11 provides an example of how strategies and approaches fit into the adaptation determination table.

Some strategies may be applicable to multiple stressors. For example, ensuring redundancy of critical transportation routes could be a strategy that addresses both wildfire and flooding risks. Toolbox 5 provides a list of some resources that may be helpful in identifying potential adaptation strategies. In addition, Appendix C provides a menu of adaptation strategies and sample approaches that have been tailored to FS transportation infrastructure and the stressors highlighted in this guidebook (heavy precipitation/flooding, wildfire, and tree mortality), and can serve as a good starting point. This menu should be considered illustrative rather than comprehensive.

<sup>20</sup> United States Department of Agriculture (USDA) [Forest Service Northern Research Station. 2012. Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#). General Technical Report NRS-87



## TOOLBOX 5 RESOURCES FOR STRATEGY IDENTIFICATION

### [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#)

See Appendix 2, Synthesis of Adaptation Strategies and Approaches, of the Report for a summary of adaptation strategies and approaches particularly relevant to wildfire and tree mortality stressors.

### [Climate Change Adaptation Library for the Western United States](#)

Library of information from climate change vulnerability assessments conducted by [Adaptation Partners](#) to help integrate climate change in natural resource management, planning, and business operations of federal land management agencies.

### [FHWA Climate Change Resilience Pilots \(2013-2015\)](#)

Between 2013 and 2015 FHWA partnered with 19 State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) for these pilot projects. The purpose of the pilots was to conduct climate change and extreme weather vulnerability assessments of transportation infrastructure and to analyze options for adapting and improving resiliency. The final project reports and case studies provided on this website provide adaptation strategies for a wide variety of geographies (see table below). For example, the [Hillsborough County MPO Final Report](#) (Section 4.4) and the [Maryland State Highway Administration Final Report](#) (Appendix A) each provide a menu of sample adaptation strategies for flooding impacts in their respective regions. Since 2015, FHWA has continued to partner with State DOTs, MPOs, and others for resilience pilots to develop and deploy solutions to current and future extreme weather events. Visit [FHWA's Resilience Pilots](#) website to view all of these pilot projects.

Agency	Adaptation Strategies Provided for Flooding Impacts	Agency	Adaptation Strategies Provided for Flooding Impacts
Arizona Department of Transportation		Michigan Department of Transportation (MDOT)	
California Department of Transportation (Caltrans) District I	•	Minnesota Department of Transportation (MnDOT)	•
Capital Area Metropolitan Planning Organization (CAMPO) and Austin, TX		New York State Department of Transportation (NYSDOT)	•
Connecticut Department of Transportation (CTDOT)		North Central Texas Council of Governments (NCTCOG)	
Hillsborough County MPO and Planning Commission, Florida	•	Oregon Department of Transportation (ODOT)	•
Iowa Department of Transportation (IDOT)		San Francisco Bay Metropolitan Transportation Commission (MTC)	•
Maine Department of Transportation (Maine DOT)	•	South Florida	•
Maryland State Highway Administration (MD SHA)	•	Tennessee Department of Transportation (TDOT)	
Massachusetts Department of Transportation (MassDOT)	•	Washington State Department of Transportation	•

### 3.3. Step 11. Integrate climate change considerations into existing and future programs, projects, and planning processes

Forests should identify how climate change adaptation can be considered within existing and planned programs and projects as well as FS transportation planning processes. For this exercise, Forests should make a list of programs and projects associated with the vulnerable locations identified in Step 9, and analyze how the strategies and approaches identified in Step 10 can be applied to each in order to help reduce potential adverse effects of climate change.<sup>21</sup>

For example, many existing culverts are nearing the end of their useful life and will need to be upgraded. Culvert replacement projects present an excellent opportunity to address climate change impacts through the integration of design criteria that incorporate projected climate change impacts. Channel width or “bankfull width,” as it is often operationally defined, is an important parameter for culvert design. Where climate change projections indicate an increase in heavy precipitation and flooding, there will likely also be an increase in bankfull width. Culverts should be sized to meet these future bankfull width projections.<sup>22</sup>

It is important to note that many culverts across the country are undersized to accommodate current bankfull width conditions.

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21 United States Forest Service (USFS). 2011. [Navigating the Climate Change Performance Scorecard](#).

22 For reference on how future bankfull widths are being considered in the State of Washington: Washington Department of Fish and Wildlife (WDFW). September 2016. [Incorporating Climate Change into the Design of Water Crossing Structures](#).

23 This template was adapted from United States Department of Agriculture (USDA) Forest Service Pacific Northwest Research Station. August, 2011. Adapting to Climate Change at Olympic National Forest and Olympic National Park. General Technical Report PNW-GTR-844.

24 United States Department of Agriculture (USDA) Forest Service Northern Research Station. 2012. [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#). General Technical Report NRS-87.

Culvert replacement projects not only provide the opportunity for climate change adaptation, they also have the potential to offer significant ecological restoration benefits (i.e., improving fish passage, especially if they are bottomless); design criteria to support these ecological goals, which are in line with greater FS goals, should be considered as well.

A sample template that Forests could adapt to assess potential adaptation strategies for their current, ongoing, and anticipated programs and projects is provided as Table 12.<sup>23</sup> Note that the italicized font in the template is example entry data. Forests should also consider how the strategies identified in Step 10 can be integrated into existing planning processes, such as Long Range Transportation Plans, Forest Plans, and Travel Analysis Reports. Section 4 discusses how these planning processes should integrate climate change considerations.

### 3.4. Step 12. Identify and develop adaptation tactics

Adaptation tactics are a set of potential on-the-ground actions that fall under general adaptation strategies and approaches (see Figure 2). For example, for the sample adaptation approach used to address tree mortality in Step 10: *improve the ability of forests to resist pests and pathogens, a site-specific adaptation tactic used to achieve this approach could be: treat selected over-mature paper birch stands with a shelterwood harvest followed by prescribed burning or mechanical site preparation.*<sup>24</sup> Adaptation tactics can consist of one action (e.g., raising a bridge) or a package of actions (e.g., raising

Road Maintenance	Planning	Flooding	Culvert capacity Water diversion Fill-slope failures Stream-adjacent road risk	Prioritize road treatment by watershed risk and road risk (the roads with the most sensitivities and that are most connected to streams)	National Highway Safety Act Fund Requirements (ONF) Maintenance Fund Limitations Need assessments to refine links between stressors and sensitivities.
		Tree Mortality			
		Wildfire			
	Implementation				
	Monitoring				
Road Operations	Planning				
	Design: Water Crossing Fish Passage				

Table 12. Template for Assessing Adaptation Strategies

a bridge and armoring the approach embankments) that address impacts caused by a climate change stressor or set of stressors (see Table 13 for an example of how tactics can fit into the adaptation determination table)<sup>25</sup>. For each adaptation approach, Forest staff should describe one or more specific tactic(s) that can be used to implement the approach using staff experience and expertise. The climate change coordinator can be called on for additional support as needed (see Toolbox 4 for more information).

The Forest Service’s [Storm Damage Risk Reduction Guide for Low-Volume Roads](#) provides a detailed evaluation and list of tactics (which the guide refers to as treatments) primarily for flooding resiliency. Figure 4 provides a sample of one of the tables in that guide. For flooding-related tactics, information from this guide can be used verbatim.

<sup>25</sup> Minnesota Department of Transportation (MnDOT). November, 2014. [MnDOT Flash Flood Vulnerability and Adaptation Assessment Pilot Project](#).

Figure 4. An excerpt table from Table 2 of the Storm Damage Risk Reduction Guide for Low-Volume Roads

MOST COMMON TREATMENTS	Effectiveness		Cost effectiveness	
	Short Term	Long Term	Low	High
<b>EASY, LOW COST, OR MOST COST EFFECTIVE</b>				
<b>Stream Crossing Structures</b>				
Culvert maintenance.	*			*
Minor channel debris removal and clearing.	*			*
Culvert diversion prevention/armored overflow protection.		*		*
<b>Bridge Protection and Improvement</b>				
Channel maintenance and debris/sediment clearing around footings.	*			*
<b>Erosion Protection</b>				
Physical erosion control measures.	*		*	
Vegetating barren areas/deep-rooted native plants.		*		*
Gully prevention (limiting water concentration).		*		*
<b>Slope Stability Measures</b>				
Sidecast fill; pull-back/silver-fill failure prevention.		*		*

	Stressors	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	Flooding	Redesign	A <sub>R</sub>	a <sub>r</sub>			
			B <sub>R</sub>	b <sub>r</sub>			
			C <sub>R</sub>	c <sub>r</sub>			
			D <sub>R</sub>	d <sub>r</sub>			
		Divest	A <sub>D</sub>	a <sub>d</sub>			
			B <sub>D</sub>	b <sub>d1</sub>			
				b <sub>d2</sub>			
C <sub>D</sub>	c <sub>d</sub>						
Asset 1							

Table 13. Tactics should populate the next column of the adaptation table

	Stressors	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	Flooding	Redesign	A <sub>R</sub>	a <sub>r</sub>	++	++	
			B <sub>R</sub>	b <sub>r</sub>	+	++	
			C <sub>R</sub>	c <sub>r</sub>	++	+++	
			D <sub>R</sub>	d <sub>r</sub>	+++	+	
		Divest	A <sub>D</sub>	a <sub>d</sub>	++	+	
			B <sub>D</sub>	b <sub>d1</sub>	+++	+++	
				b <sub>d2</sub>	+++	++	
C <sub>D</sub>	c <sub>d</sub>	+	+				
Asset 1							

Table 14. An evaluation of the tactics should populate the next column(s) of the adaptation table

### 3.5. Step 13. Evaluate feasibility and likelihood of success

A wide range of adaptation tactics may be considered for any given situation. However, Forest staff should consider the feasibility (economic costs, staff time, regulations, and logistics) and likelihood of success for each specific adaptation tactic.<sup>26</sup> For example, as a tactic, an appropriately sized culvert replacement to accommodate projected impacts of climate change might be more expensive than a smaller sized culvert that has been designed considering historical events, but it will likely also be more resilient.<sup>27</sup> Table 14 provides an example of how the evaluation of tactics fits into the adaptation determination table. Figure 4 shows how the guide evaluates each tactic (or treatment) by its potential effectiveness (short term or long term) and cost effectiveness (low or high). A high-level evaluation,

such as the guide performs, suffices if a more detailed evaluation is not possible due to data, time, and/or resource constraints.

Benefits of adaptation tactics, including those related to ecosystem services like wetlands retaining and filtering water, for example, and other hard to quantify costs, should also be taken into account. For example, if the culvert is not replaced at all, what are the potential impacts to the local ecosystem and watershed as a whole? How will this impact the overall goals of the Forest, including those for recreation and environmental protection? Site specific concerns, such as fish passage requirements, water quality requirements, and project permitting requirements should be incorporated into the evaluation of feasibility and likelihood of success. To the extent possible, the evaluation should also incorporate an analysis of corporate risks, such as changing budgets at the asset planning, design or operations phase.

<sup>26</sup> United States Forest Service (USFS). 2011. [Navigating the Climate Change Performance Scorecard](#).

<sup>27</sup> When designing or retrofitting a given culverts, there are a number of considerations that are taken into account that may warrant designing to or not to the projected future conditions (see HEC 17 - <https://www.fhwa.dot.gov/engineering/hydraulics/pubs/hif16018.pdf>).

A benefit-cost analysis, in addition to defining the asset's lifespan, which can determine what impacts the asset may face over time, is an integral piece of the feasibility evaluation. Although the analysis should be calculated to incorporate as many factors as possible, it is important to keep in mind that impacts and associated costs are based on projections. Therefore, similar to the inherent unpredictability of storm events, the preciseness of benefit-cost analyses for adaptation investments is difficult to calculate. However, investing in adaptation strategies as part of regular asset management (e.g., during asset replacement) and forest management activities is likely to reduce impacts and associated economic losses.<sup>28</sup> Toolbox 6 summarizes a set of useful resources for evaluating potential adaptation strategies.

#### RESOURCE CONSTRAINED APPROACH FOR EVALUATING FEASIBILITY AND LIKELIHOOD OF SUCCESS

*A defensible quantitative approach for this evaluation is preferred. However, if resources are not sufficient to conduct a detailed quantitative assessment, a simple qualitative ranking of adaptation tactics based on metrics of interest could be developed to help identify which tactics are “better” than others for a given location.*



#### TOOLBOX 6 STRATEGY AND TACTIC EVALUATION RESOURCES

- [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#): see Chapter 3, Adaptation Workbook, Step 4, Identify adaptation approaches and tactics for implementation, starting on page 49 of this Report for a summary framework and worksheet for evaluating strategies and tactics for consideration.
- [Transportation Research Board Benefit-Cost Analysis Website](#): provides a step-by-step process of benefit-cost analysis, explaining concepts, describing methodologies, and suggesting additional resources.
- [FEMA Benefit Cost Analysis Toolkit](#): Software, written materials, and training to support the calculation of a benefit cost analysis and assist with estimating the expected future benefits over the useful life of a retrofit project.
- [Coastal Adaptation to Sea Level Rise Tool \(COAST\)](#): process that helps users answer questions in regards to the costs and benefits of actions and strategies to avoid damages to assets from sea level rise and/or coastal flooding. This tool was used by MnDOT for their adaptation pilot project (a discussion of their use of the tool is provided in their [final report](#) starting on page 36).
- [FHWA Climate Change Resilience Pilots](#): as previously mentioned, FHWA partnered with 19 State DOTs and MPOs to pilot approaches to conduct climate change and extreme weather vulnerability assessments of transportation infrastructure and to analyze options for adapting and improving resiliency. The final project reports provided on this website provide information regarding how agencies evaluated strategies for their region and associated climate impacts that may be useful to others.
- [Storm Damage Risk Reduction Guide for Low-Volume Roads](#): developed by the US Forest Service, this guide provides a compilation of best management practices that protect water quality while restoring the function of the road. They represent good road design and construction practices that are cost effective in the long run by preventing failures, eliminating repair needs, and reducing maintenance.

28 Hillsborough County Metropolitan Planning Organization (MPO). October 2014. [FHWA Climate Resilience Pilot Program: Hillsborough County Metropolitan Planning Organization](#).



	Stressors	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	Flooding	Redesign	A <sub>R</sub>	a <sub>r</sub>	++	++	
			B <sub>R</sub>	b <sub>r</sub>	+	++	
			C <sub>R</sub>	c <sub>r</sub>	++	+++	
			D <sub>R</sub>	d <sub>r</sub>	+++	+	
		Divest	A <sub>D</sub>	a <sub>d</sub>	++	+	
			B <sub>D</sub>	<b>b<sub>d1</sub></b>	<b>+++</b>	<b>+++</b>	<b>X</b>
				b <sub>d2</sub>	+++	++	
C <sub>D</sub>	c <sub>d</sub>	+	+				
Asset 1							

Table 15. The evaluation results in the selection of a tactic with which to move forward

### 3.6. Step 14. Prioritize strategies and tactics

Once adaptation strategies and tactics are identified in Steps 10 through 12 and then evaluated under Step 13, the Forest should prioritize them in order to narrow the tactics to help focus resources on those that are the highest priority. The highest priority tactics at each location identified under Step 9 can then be further evaluated in terms of potential planning and implementation costs and possible funding sources. Toolbox 7 provides sample

scoring criteria that were used by Caltrans for the evaluation and prioritization of adaptation options for their Resilience pilot with FHWA. Weights can be assigned to each criterion to assist in prioritizing strategies and tactics. Table 15 provides an example of how the prioritization of strategies and tactics fits into the adaptation determination table. Section 4 of this guidebook provides next steps regarding implementation of the selected tactics.



## TOOLBOX 7 SAMPLE SCORING CRITERIA

- **Total Capital Investment:** The estimated total cost of implementing the adaptation option including, but not limited to the costs associated with planning, permitting, design and construction.
- **Average Annual Cost:** The total capital investment cost of implementing the adaptation option with respect to the design service life.
- **Usable Life:** The comparison of the adaptation option's design service life, with respect to the climate change event horizon (e.g., scored on a numerical scale where: 0 = service life is either minimal, temporary or less than the 2050 or 2100 horizon years, 1 = service life extends to the 2050 horizon year, 2 = service life extends to the 2100 horizon year, 3 = service life surpasses the 2100 service year).
- **Level of Performance:** The existing level of protection compared to the anticipated level of protection, at the specified climate change event horizon (e.g., scored on a numerical scale where: 1 = decreased level of performance, 2 = no change in performance, 3 = enhanced level of performance).
- **Flexibility:** The ability of the adaptation option (at any stage in development) to be modified to provide a higher level of protection against impacts or to be updated as new data models for climate change are developed. Flexibility also considers the potential for the adaptation option to be phased or completed in segments over a longer period of time. The benefit to phasing (for the purposes of scoring this criterion) is that the total capital investment cost can be distributed over a period of many years.
- **Environmental Considerations:** The potential of the adaptation option to improve or impact the existing environmental conditions with respect to integrity, diversity, or abundance of the natural ecosystem's functions and/or habitat.
- **Social Considerations:** the potential of the adaptation option to improve or impact the community's social welfare.

Source: California Department of Transportation (CalTrans). December, 2014. District I Climate Change Vulnerability Assessment and Pilot Studies: FHWA Climate Resilience Pilot Final Reports. [http://www.fhwa.dot.gov/environment/climate\\_change/adaptation/resilience\\_pilots/2013-2015\\_pilots/california/final\\_report/caltrans.pdf](http://www.fhwa.dot.gov/environment/climate_change/adaptation/resilience_pilots/2013-2015_pilots/california/final_report/caltrans.pdf)

### 3.7. Step 15. Identify and develop monitoring options

Monitoring plans for evaluating the effectiveness of adaptation options should be developed concurrently with the initial implementation of adaptation strategies and tactics. This step is important to confirm whether specific tactics are working and if they are not, to allow enough time to make revisions.<sup>29</sup>

Forests should identify indicators that will be used to monitor whether adaptation options are being achieved through the implementation of specific tactics. Toolbox 8 offers a template that Forests can use to identify monitoring activities. Once a Forest identifies the monitoring needs, the Forest should incorporate and adapt them into the Forest's overall monitoring program. The National Forest System has established a Monitoring and Evaluation Framework to help FS planners meet monitoring requirements.<sup>30</sup> In order to incorporate these monitoring actions into a Forest Monitoring Program, the "Monitoring Activities" would need to be converted to "Monitoring Questions" and the "Monitoring Metrics" would become "Monitoring Indicators."

#### RESOURCE CONSTRAINED APPROACH FOR MONITORING

*For some Forests, relatively infrequent monitoring may be sufficient for evaluating effectiveness. In addition, monitoring of adaptation effectiveness can be combined with existing monitoring programs. Forests should consider which existing monitoring efforts are available and if these need to be modified to better monitor the results of adaptation tactics. Toolbox 6 offers some example monitoring efforts that may already be performed by Forests to some extent that could be adapted to climate change adaptation efforts. Where resources allow, Forests should consider new monitoring activities to evaluate the effectiveness of adaptation tactics where no existing monitoring activity is available.*

<sup>29</sup> United States Forest Service (USFS). 2011. [Navigating the Climate Change Performance Scorecard](#).

<sup>30</sup> United States Forest Service (USFS). [Monitoring and Evaluation Framework](#).



## TOOLBOX 8 MONITORING

The table below identifies sample monitoring activities for evaluating the effectiveness of adaptation tactics. The format of this table may be used as a template for Forests' use in identifying their own monitoring activities. Each column in the table could be completed as follows:

- **Monitoring Activities:** Identify monitoring activities that will be used to evaluate whether adaptation tactics are being effective in addressing adaptation options under climate change.
- **Monitoring Metric:** Provide at least one metric for each monitoring activity that can be used to evaluate the monitoring activity. Note that facility performance should be monitored and recorded in an asset management database.
- **Criteria for Evaluation:** Identify a criterion (e.g., condition or threshold) to evaluate whether the tactic is being successful in addressing adaptation options under climate change.
- **Monitoring Implementation:** Describe when information on the metric will be gathered and how the information will be collected.

Monitoring Activities	Monitoring Metric(s)	Criteria for Evaluation	Monitoring Implementation
Sample Tactic to address heavy precipitation and flooding: Replace existing undersized culvert with one that has “climate adapted” culvert width	<ul style="list-style-type: none"> <li>• Frequency of overtopping</li> <li>• Duration of closures</li> <li>• Number of injuries resulted from overtopping</li> <li>• Damage costs</li> <li>• Annual costs avoided</li> </ul>	<ul style="list-style-type: none"> <li>• Frequency of overtopping, duration of closures, number of injuries resulting from overtopping and damage costs should be null or reduced.</li> <li>• Annual costs avoided should be similar to historic average annual damage costs</li> </ul>	<ul style="list-style-type: none"> <li>• A post-construction monitoring plan should be developed and facility performance data should be monitored and recorded in an asset management database</li> </ul>
Sample Tactic to address Tree Mortality: Treat selected over-mature paper birch stands with a shelterwood harvest followed by prescribed burning or mechanical site preparation	<ul style="list-style-type: none"> <li>• Treatment acres ÷ over-mature acres</li> <li>• Number of acres prescribed burned</li> <li>• Number of acres mechanically scarified</li> <li>• Number of acres regenerated</li> </ul>	<ul style="list-style-type: none"> <li>• Passes stocking survey</li> <li>• Compare prescribed burn results to mechanical scarification to evaluate paper birch regeneration success</li> </ul>	<ul style="list-style-type: none"> <li>• Review National Environmental Policy Act decision to determine number of over-mature acres that were treated</li> <li>• Monitor seedling success during 1st-, 3rd-, and 5th-year stocking surveys. Identify needed monitoring for any follow-up activities</li> </ul>

Sources: MnDOT, 2014; USDA, 2012

### 3.8. Step 16. Adaptive management: revise strategies and tactics

The outcome of Step 15 is a list of realistic and feasible monitoring activities that can be conducted over time. Step 16 identifies whether strategies and tactics should be modified in the future to account for new information and observations.<sup>31</sup> Table 16 shows how the selection and implementation of a tactic should result in a feedback loop such that the stressors, strategies, and tactics are re-evaluated and perhaps modified over time.

	Stressors	Strategies	Approaches	Tactics	Feasibility	Likelihood of Success	Select
Asset 2	Flooding	Redesign	A <sub>R</sub>	a <sub>r</sub>	++	++	
			B <sub>R</sub>	b <sub>r</sub>	+	++	
			C <sub>R</sub>	c <sub>r</sub>	++	+++	
			D <sub>R</sub>	d <sub>r</sub>	+++	+	
		Divest	A <sub>D</sub>	a <sub>d</sub>	++	+	
			B <sub>D</sub>	b <sub>d1</sub>	+++	+++	X
				b <sub>d2</sub>	+++	++	
C <sub>D</sub>	c <sub>d</sub>	+	+				
Asset 1							

Table 16. The selection of a tactic should lead to a feedback loop to earlier steps of the process

31 United States Department of Agriculture (USDA) Forest Service Northern Research Station. 2012. [Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers](#). General Technical Report NRS-87.



## Section 4. Implementation Opportunities – Linking to Forest Service Plans and Programs

This section discusses how to implement climate change vulnerability assessments, adaptation planning, and adaptation projects within existing FS programs and planning processes, as well as funding programs available to the FS. Linking climate change adaptation to other FS goals and leveraging existing programs is an effective way to implement climate change adaptation measures. Although not discussed in detail here, partnerships with other national, state and local agencies and organizations also provide opportunities for enhancing planning processes and funding.

This section also discusses recommendations for enhancing existing programs to better support FS efforts to increase the resilience of its transportation system to climate change and to create new opportunities for climate change technical assistance to help Forests address climate change-related vulnerabilities to their transportation system.

Although this section discusses FS programs and other opportunities to support or fund adaptation planning and implementation, it does not provide detailed engineering or design strategies for increasing transportation resilience. The Forest Service's [Storm Damage Risk Reduction Guide for Low-Volume Roads](#) provides much more information on maintenance, design, and construction practices that can increase the resilience of low-volume roads with respect to damage from heavy precipitation and flooding.<sup>32</sup>

32 Keller, G.; Ketcheson, G. 2015. Storm damage risk reduction guide for low-volume roads. Tech. Rep. 1277 1814. San Dimas, CA: U.S. Department of Agriculture, Forest Service, San Dimas Technology and Development Center. <https://www.fs.fed.us/t-d/pubs/pdfpubs/pdf12771814/pdf12771814dpi300.pdf>.

### 4.1. Integrating Climate Change into Forest Service Programs and Transportation Planning

Forest Service staff have access to several programs, planning processes, and funding sources that provide Forests and Regions with opportunities to address climate change. Some of these opportunities are listed in Figure 5 and discussed in more detail below. Note that this is not an exhaustive list, and other opportunities may be available at the State and local level.

#### 4.1.1. Leveraging U.S. Forest Service Climate Change Initiatives

The FS has undertaken several initiatives specific to climate change. Of these, two offer the most relevant opportunities to support Forests in assessing climate change vulnerabilities and developing responses for Forest transportation systems:

- Climate Change Performance Scorecard
- Regional Climate Change Coordinators

##### ***Climate Change Performance Scorecard***

The [U.S. Forest Service Climate Change Performance Scorecard](#) is a standardized, qualitative way to measure agency progress in mitigating, preparing for, and adapting to climate change in the National Forest System. This program, which began in Fiscal Year 2011, requires each National Forest and Grassland to use a 10-point scorecard to report accomplishments and plans for improvement on ten Scorecard Elements in four dimensions: organizational capacity, engagement, adaptation, and mitigation. By 2015, each Forest and Grassland was expected to answer yes to at least seven of the Scorecard Elements with at least one yes in each dimension. The goal of the performance scorecard program

Figure 5. Sample of Climate Change Adaptation Implementation Opportunities for the U.S. Forest Service

<b>Forest Service Climate Change Initiatives</b>	<b>Forest Service Planning Processes</b>	<b>Potential Funding Sources</b>
<ul style="list-style-type: none"> <li>• Climate Change Performance Scorecard</li> <li>• Regional Climate Change Coordinators</li> </ul>	<ul style="list-style-type: none"> <li>• National Long-Range Transportation Plan (LRTP) and Regional Collaborative Long-Range Transportation Plan (CLRTP)</li> <li>• Forest Plans</li> <li>• Travel Analysis Reports</li> <li>• Watershed Condition Framework</li> </ul>	<ul style="list-style-type: none"> <li>• Forest Service funding sources</li> <li>• Federal Lands Transportation Program (FLTP)</li> <li>• Federal Lands Access Program (FLAP)</li> <li>• Emergency Relief for Federally Owned Roads (ERFO)</li> </ul>

is “to create a balanced approach to climate change that includes managing Forests and Grasslands to adapt to changing conditions, mitigating climate change, building partnerships across boundaries, and preparing our employees to understand and apply emerging science.”<sup>33</sup>

Although the Climate Change Scorecard does not directly address transportation, it provides a framework for assessing climate change impacts, engaging staff and stakeholders, and managing for climate change that is applicable to all aspects of FS management. It also creates an accountability structure, requiring Forests and Grasslands to take steps to address climate change in their units. The scorecard applies to FS infrastructure and ecosystems. Therefore, it is important for Forests and Grasslands to frame their efforts to prepare for climate change impacts on their transportation systems to meet their scorecard goals.

The FS designed the scorecard to build climate change awareness; the next version, the Climate Action Card, is being designed to implement management decisions through action in all levels of the agency. The Forest Service’s Office of Sustainability and Climate Change (OSCC) has been piloting the Climate Action

Card, and plans to implement it by FY 2022.

#### **Forest Service Climate Change Coordinators**

The FS Climate Change Performance Scorecard says that each FS Unit should have an assigned climate change coordinator, defined as “a permanent staff member with a program of work that includes assisting with climate change-related activities at the Unit level, and coordinating with the Regional Office and other Units on climate change activities. The climate change coordinator should have leadership and communication skills, enough of a technical or scientific background to learn and adopt new concepts related to climate change response, and time for climate change activities and training.”<sup>34</sup> The role of the climate change coordinator is to serve as a resource for climate change questions and issues to help the Unit achieve progress on elements of the Performance Scorecard.

In addition, FS Regions have begun to designate regional sustainability and climate change coordinators. These regional coordinators can provide additional support to Forests and can coordinate FS responses to climate change throughout the Region. The first region to hire a Sustainability and Climate

33 U.S. Forest Service, Office of the Climate Change Advisor. Climate Change Performance Scorecard: <http://www.fs.fed.us/climatechange/advisor/scorecard.html>.

34 U.S. Forest Service, Office of the Climate Advisor. Coordinators: <http://www.fs.fed.us/climatechange/advisor/scorecard/coordinators.html>.



Change Coordinator was Region 4, whose efforts are highlighted below. Region 4 is now advising other Regions on how to develop similar positions. See Case Study I for more information about how Region 4 is preparing for climate change through science-management partnerships.

Designated unit and climate change coordinators can be a valuable resource on climate change, but they may not have expertise in transportation infrastructure. Forest Service transportation staff should work with their climate change coordinators to leverage their knowledge and resources, but also to provide them with the information they need to include transportation infrastructure in the Forest's or Region's range of climate change considerations. Resources on climate change infrastructure and climate change adaptation, such as this Guidebook, can help FS climate change coordinators incorporate transportation into their programs.

### 4.1.2. Incorporating Climate Change into Forest Service Transportation Planning

There are several levels of FS transportation planning, which provide important opportunities to incorporate climate change into future decisions about investments, policies, and management strategies for Forest transportation systems, including:

- National and Collaborative Regional Long-Range Transportation Plans
- Forest Plans
- Travel Analysis Reports (Subpart A of the Travel Management Rule)
- Watershed Condition Framework

Each of these planning processes provides an opportunity to analyze baseline conditions and climate change vulnerabilities and to develop climate resilient strategies for the future. These processes can also provide valuable decision-making support tools for Forests recovering from a climate-related event or stressor.

## CASE STUDY I

### FOREST SERVICE REGION 4: PREPARING FOR CLIMATE CHANGE THROUGH SCIENCE-MANAGEMENT PARTNERSHIPS

The Forest Service's Intermountain Region (Region 4) has embarked on an interdisciplinary project to address climate change by integrating the best available science into land management through a group called the [Intermountain Adaptation Partners](#) (IAP). This project is led by Region 4's Sustainability and Climate Change Coordinator and includes collaboration with Forest-level staff, academic researchers, and other FLMAs, such as the National Park Service.

Like the Performance Scorecard, the IAP focuses on both ecosystems and infrastructure to capture the broad range of anticipated climate change impacts on the Forest Service's ability to accomplish its mission. The project has nine proposed focus areas that elaborate on the Scorecard's broad focus: Physical Resources, Vegetation Resources, Terrestrial Species, Aquatic Species, Infrastructure, Recreational Uses, Cultural Heritage, Ecosystem Services, and Ecological Disturbance. Transportation infrastructure will be a primary focus of the Infrastructure focus area. The IAP is a regional vulnerability assessment that includes adaptation strategies and tactics, which can then inform Forest-level vulnerability assessments and adaptation planning. While the assessment was being developed, the IAP offered training and workshops to increase organizational capacity to address climate change at the Forest level.

### ***National and Regional Collaborative Long Range Transportation Plans***

Long Range Transportation Plans (LRTPs) are an essential element of the Forest Service's transportation planning process. An LRTP is a policy-level document that articulates a vision for a transportation system over the next 20 years. State Departments of Transportation (DOTs) and Metropolitan Planning Organizations (MPOs) develop LRTPs for their transportation networks and update them every four to five years. With the passage of MAP-21 in 2012, FLMAs are now also required to develop LRTPs. An LRTP typically includes the following elements:

- Goals and objectives for the transportation network;
- Analysis of baseline conditions and trends affecting the network;
- Implementation actions to achieve the plan's goals and objectives; and
- Performance measures to track future conditions.

Within the FS, LRTPs are developed at both the National and Regional Level. At the time of the development of this document, the FS is embarking on its first National LRTP. This National LRTP will provide the FS with a better understanding of its challenges and priorities for transportation on National Forests, including those that relate to climate change. It will also include goals, objectives and strategies toward advancing these priorities, including financial components to demonstrate how the recommended transportation plan can be implemented.

At the Regional level, the FS also participates in Collaborative Long-Range Transportation Plans (CLRTPs) in partnership with FHWA's Office of Federal Lands Highway (FLH), other FLMAs, State DOTs, and local and tribal transportation partners.

It is important to note that National LRTPs and Regional CLRTPs do not select projects or establish land management policies, are considered pre-decisional, and are not NEPA documents.

Although the plans do not select projects, they do provide data and analysis to inform specific plans and investment decisions. For example, Forests and Grasslands can use the stated goals and related analyses in the National LRTP or Regional CLRTP, as applicable, as a resource when they develop Forest Plans or site-level transportation studies. The National LRTP and Regional CLRTPs can also result in implementation actions, such as follow-up studies or a collaborative forum to address a specific challenge identified in the National LRTP and Regional CLRTPs.

Because the National LRTP and Regional CLRTPs analyze national and regional trends for FS transportation systems, climate change is a key factor that these documents should address and incorporate. The plans should provide information about how climate change is expected to impact the nation and region and the implications of climate change on Forest transportation systems. They should also consider potential implementation actions, such as Forest-level transportation vulnerability assessments or adaptation plans that the FS and its partners can undertake to increase their resilience. One benefit of the CLRTP is that the collaborative nature (involving other FLMAs and other partners, such as State DOTs and county road managers) can help the FS and its partners work together to prepare for climate change across jurisdictions, for example at a regional or watershed scale. See Case Study 2 for two approaches to planning for climate change at a regional scale.

### Forest Plans

National Forests and Grasslands are required to develop land use management plans (Forest Plans) consistent with the National Forest Management Act (NFMA) of 1976. The NFMA requires Forests to revise their Forest Plans at least every fifteen years, and Forest Plans can be amended at any time it is deemed necessary. The 2012 Planning Rule (36 CFR 219) includes more specific requirements for how to implement the NFMA. Forest Plans include the following:

- Desired Conditions and Objectives for meeting those desired conditions, Goals can also be identified but are optional;
- Standards and Guidelines (constraints or limitations on the development of projects or activities);
- Management Areas or Geographic Areas (areas that describe where various plan components are to be applied);
- Specific limitations on other management activities;
- Recommendations to Congress on special areas, such as wilderness and wild and scenic rivers, or other special areas; and
- A Forest Plan Monitoring Program.<sup>35</sup>

National Forests develop Forest Plans through a public process including public input and collaboration with Forest partners, as well as the preparation of an Environmental Impact Statement (EIS) under the National Environmental Policy Act (NEPA) of 1976.

Forest Plans are important for transportation planning because they provide the set of management direction (desired conditions, objectives, identification of lands suitable for various uses and activities) that define the purpose and need for the Forest's transportation system. It is important for Forest Plans to consider the long-term impacts that climate change may pose to

<sup>35</sup> U.S. Forest Service, Planning Rule 101: <http://www.fs.usda.gov/main/planningrule/101>

## CASE STUDY 2

### TWO APPROACHES TO PLANNING FOR CLIMATE CHANGE AT A REGIONAL SCALE: ALASKA AND THE PACIFIC NORTHWEST

In their CLRTPs, both Region 10 (Alaska) and Region 6 (Pacific Northwest) identified climate change as a crucial element of their plans. However, they took two different approaches to integrating climate change considerations:

- In Alaska, the participating FLMA participants created a goal area specific to climate change, with one objective related to adaptation of the transportation system and another objective related to mitigating greenhouse gas emissions. The plan included a climate change technical report as an appendix, which summarized the state of knowledge on climate change impacts on transportation in Alaska. The CLRTP identified an implementation action for the participating agencies to collaborate on more detailed vulnerability studies of key transportation infrastructure, which the partners have continued to work on after they completed the plan in 2012.
- The Pacific Northwest CLRTP is currently in development. The partners in the Pacific Northwest also agreed that climate change is a crucial challenge to address in the CLRTP. However, instead of addressing it as a separate goal the plan partners chose to “mainstream” climate change by incorporating it into the analysis for a wide range of the plan's goals, especially asset management, safety, and resource protection. The Pacific Northwest CLRTP also includes a Technical Report summarizing climate change projections and their implications for Federal lands transportation systems in the region.

Figure 6. Forest Service Travel Management Regulations

<b>Subpart A: Travel Analysis Report</b>	<b>Subpart B: Motor Vehicle Use Map</b>	<b>Subpart C: Use by Over-Snow Vehicles</b>
<ul style="list-style-type: none"> <li>• Forests determine the minimum necessary road network based on environmental, social, and economic criteria</li> <li>• Helps Forests identify what is possible to remove</li> <li>• Planning tool, no decisions made</li> <li>• No NEPA review required</li> </ul>	<ul style="list-style-type: none"> <li>• Forests designate roads, trails, and areas for motor vehicle use and publish map showing where motorized vehicles are allowed</li> <li>• Requires public involvement and coordination with Federal, state, local, and tribal entities</li> <li>• Requires NEPA review, usually an Environmental Assessment (EA) or EIS</li> </ul>	<ul style="list-style-type: none"> <li>• Forests designate roads, trails, and areas for over-snow vehicle use and publish map showing where over-snow vehicle use is allowed</li> <li>• Public involvement and NEPA requirements similar to Subpart B</li> <li>• Required for areas with adequate snowfall</li> </ul>

Forest transportation systems and the Forest’s ability to provide the access needed to meet the Forest’s desired conditions and objectives. Forest Plans also help to inform the selection of appropriate transportation adaptation strategies because they specify the purpose and needs for specific transportation systems. Therefore, FS transportation planners should consider climate change impacts to transportation systems in future Forest Plans and should use their Forest Plans to inform decisions regarding adaptation options and strategies.

### **Travel Analysis Reports**

In addition to Forest Plans, National Forests must conduct travel management processes in accordance with U.S. Forest Service Travel Management Regulations (36 CFR 212). These regulations include three related subparts, described in Figure 6. Like Forest Plans, travel management planning is conducted by Forests and Grasslands with guidance and review from Regional Offices. Forest-level travel management should be based on the land use management goals, objectives, and policies in the Forest Plans.

The Travel Analysis Report (TAR) in Subpart A can be an especially valuable planning tool for assessing transportation

systems’ vulnerability and developing adaptation options in National Forests. TARs are prepared at the Forest level and require a detailed, asset-by-asset analysis. Subpart A also requires that the minimum road system should “minimize adverse environmental impacts” and that Forests should “give priority to decommissioning those unheeded roads that pose the greatest risk to public safety or to environmental degradation.” This requirement relates well with climate change risk reduction goals and could allow for incorporating climate change considerations into TAR development. Therefore, the TAR’s scope and level of detail is conducive to considering asset vulnerability along with other criteria to inform the TAR’s conclusions. The TAR can also inform the development of adaptation options because it analyzes the criticality of each transportation asset.

Because the purpose of the TAR is to determine the minimum necessary road network to meet Forest goals and requirements, it is also a valuable tool for recovery planning in the case of climate change impacts. For example, when Arapaho-Roosevelt National Forest experienced extensive flood damage to their road network in 2013, they used their recently-completed TAR to help them make decisions during their recovery phase.

Specifically, they prioritized repairs and reconstruction to the assets listed in the TAR's minimum necessary road network and made the decision to decommission some of the roads that were not part of that network rather than rebuilding them. The TAR provided the analysis and necessary to support the difficult decisions they faced during recovery and it allowed them to make more informed decisions during a time when their capacity was stretched thin by the demands of emergency relief.

### **Watershed Condition Framework**

In addition to the transportation planning processes above, the Forest Service's Watershed Condition Framework (WCF) can provide a planning resource for Forests and Grasslands to integrate infrastructure resilience into existing FS programs. The WCF is a comprehensive approach for proactively implementing integrated restoration on priority watersheds on National Forests and Grasslands, and tracking and monitoring outcome-based program accomplishments for performance accountability.<sup>36</sup>

The six steps of the WCF are:

- Step A: Classify the condition of all 6th-level watersheds in the National Forest by using existing data layers, local knowledge, and professional judgment
- Step B: Prioritize watersheds for restoration: establish a small set of priority watersheds for targeted improvement equivalent to a 5-year program of work
- Step C: Develop Watershed Restoration Action Plans that identify comprehensive project-level improvement activities
- Step D: Implement integrated suites of projects in priority watersheds
- Step E: Track restoration accomplishments for performance accountability

- Step F: Verify accomplishment of project activities and monitor improvement of watershed and stream conditions.

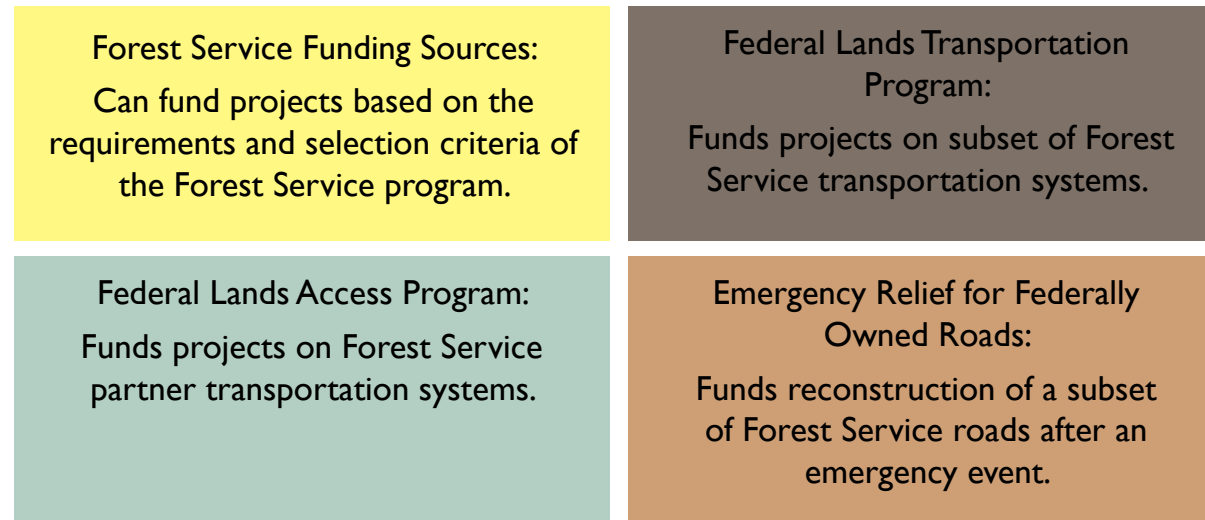
Through the WCF, National Forests and Grasslands have classified and prioritized the condition of watersheds in their units, which are available as [interactive online maps](#). The WCF steps are also integrated into FS TARs, which consider watershed condition criteria. Because of the linkage between transportation infrastructure damage from heavy precipitation and watershed condition, the WCF provides opportunities for Forests and Grasslands to pursue projects that improve transportation infrastructure resilience in priority watersheds.

## **4.2. Linking Climate Change Adaptation to Available Funding Programs**

Another important implementation consideration is how to fund vulnerability assessments, adaptation planning, and project execution. The FS has limited funding and staff resources; finding funding to support climate change adaptation can be difficult. This section provides a summary of the existing FS programs that fund transportation planning and projects (Figure 7) with a discussion of how they can relate to climate change and recommendations for the FS to support climate resilience through these programs. Currently, the majority of the funding for maintenance and construction of FS roads, bridges, trails, and other transportation assets comes from FS funding programs. FLTP, FLAP, and ERFO account for a relatively smaller amount of FS funding for transportation infrastructure.

<sup>36</sup> U.S. Forest Service. 2011. Watershed Condition Framework: [https://www.fs.fed.us/biology/resources/pubs/watershed/maps/Watershed\\_Condition\\_Framework2011FS977.pdf](https://www.fs.fed.us/biology/resources/pubs/watershed/maps/Watershed_Condition_Framework2011FS977.pdf).

Figure 7. Funding sources available for Forest Service transportation resiliency projects



### 4.2.1. Forest Service Funding Sources

Forest Service staff can leverage FS funding programs for climate resiliency projects. Some relevant FS funding sources are summarized below:

- **Road Construction and Maintenance (CMRD):** CMRD funds are used for construction, management, and maintenance of roads on the National Forest System.
- **Legacy Roads and Trails Program (CMLG):** The purpose of CMLG is to direct work towards urgently needed road decommissioning, road and trail repair and maintenance, and removal of fish passage barriers. The program emphasizes areas where FS roads may be contributing to water quality problems in streams and water bodies that support threatened, endangered, and sensitive species or community

water sources.<sup>37</sup> This funding source can be particularly useful for implementing projects that serve the complementary goals of improving watershed function and increasing transportation system resilience.

- **Stewardship Authority (SA):** Under this program, Forests can use revenue from forestry management contracts to fund “treatments to improve, maintain, or restore forest or rangeland health; restore or maintain water quality; improve fish and wildlife habitat; and reduce hazardous fuels that pose risks to communities and ecosystem values.”<sup>38</sup> Since many climate change adaptation strategies, such as increasing culvert sizes or improving roadway drainage, also have benefits for water quality and enhanced aquatic organism passage, these projects can be eligible recipients of Stewardship Authority Funds. The National Forests and

37 U.S. Forest Service, Legacy Roads and Trails Program: [https://www.fs.fed.us/restoration/Legacy\\_Roads\\_and\\_Trails/](https://www.fs.fed.us/restoration/Legacy_Roads_and_Trails/).

38 U.S. Forest Service, Stewardship Contracting Overview: [http://www.fs.fed.us/restoration/Stewardship\\_Contracting/overview.shtml](http://www.fs.fed.us/restoration/Stewardship_Contracting/overview.shtml).

Grasslands of Texas recently used Stewardship Authority funds to clear hazard trees after a drought, an action which improves Forest health and removes a threat to transportation systems.

### **Recommendations for Incorporating Climate Change into Forest Service Funding Sources**

Forests and Regions would benefit from better clarity and guidance on how different internal FS funding sources can be used for vulnerability assessments, adaptation planning, and implementing climate change adaptation strategies for transportation systems. The FS Washington Office could develop a more detailed guide to address this need.

## **4.2.2. Federal Lands Transportation Program (FLTP)**

The [Federal Lands Transportation Program](#) funds program administration, transportation planning, research, preventive maintenance, engineering, rehabilitation, restoration, construction, and reconstruction of transportation assets owned and maintained by FLMAs. FLTP funds must be spent on Federal Lands Transportation Facilities, which are transportation assets on an inventory of FLTP assets. The FS has FLTP inventories for roads and trails. Currently, the FS is limiting its FLTP funding and data collection to the FLTP Subset I network of 5,063 miles of road and 4,002 miles of trails.

Beginning in FY 2015, the FS began receiving a non-competitive amount of \$15 million a year, which increases by \$1 million each year until FY 2020. FLH administers the FLTP program and provides stewardship and oversight. The FS Washington Office submits multi-year Investment Strategies and annual Accomplishments Reports to FLH based on information and priority projects from the Regional Offices.

### **Link to Climate Change**

The wide range of activities that FLTP can fund for assets on the Forest Service's FLTP inventory provides numerous opportunities to address climate change risks to FLTP transportation assets.

These projects may include:

- Research on climate change impacts on FLTP assets;
- Vulnerability assessments;
- FLTP transportation adaptation plans;
- Engineering and design of climate change resiliency projects;
- Preventive maintenance to reduce FLTP asset vulnerability; or
- Repair, reconstruction, or enhancement of FLTP assets to increase their resiliency.

The challenge of the FLTP program is that it already does not provide enough money to meet FS needs. Therefore, FS staff need to make a compelling case for why these limited funds should be spent on preparing for climate change. Two strategies that may help Forests or Regions succeed in competing for funds are:

1. Incorporate climate change resilience elements into identified FLTP projects. For example, consider climate change vulnerability during planning and design of a project and incorporate adaptation strategies into the project as necessary.
2. Demonstrate the co-benefits of climate change adaptation projects, such as enhanced aquatic organism passage, to make them more compelling.

### **Recommendations for Incorporating Climate Change Adaptation into the FLTP Program**

Forest Service Units, Regions, and the Washington Office could consider the vulnerability of a project to climate change impacts when developing the Investment Strategy to avoid investing in a project that is vulnerable to climate change without incorporating adaptation strategies.

### 4.2.3. Federal Lands Access Program (FLAP)

The [Federal Lands Access Program](#) funds projects to improve transportation facilities that provide access to, are adjacent to, or are located within Federal lands. FLAP-eligible assets must be owned or under a long-term maintenance agreement by a FLMA partner, such as a state, local, or tribal government. FLAP can fund transportation planning, research, engineering, preventive maintenance, and capital improvement projects for transportation assets providing access to Federal Lands, including roads, bridges, trails, transit, boat launches, or parking facilities. The program is administered by FLH as a grant program in each state. Funding decisions are made in each state by a Program Decision Committee consisting of FLH, a State DOT representative, and a local government representative. FLMAs cannot apply for FLAP funds, but can work with partner agencies to support their applications. Congress has authorized approximately \$250 million a year for FLAP through FY 2020.

#### **Link to Climate Change**

The FS cannot use FLAP funds for projects on FS-owned and maintained infrastructure. However, FLAP can fund projects on partner assets that have the potential to impact FS lands and FS-owned infrastructure that is maintained, at least in part, by others. This presents an opportunity for Forests to work with adjacent road or trail managers to address climate change vulnerabilities across jurisdictional boundaries. FLAP has the potential to fund a wide range of climate change adaptation projects on FS partner assets, including:

- Transportation and climate change research on a watershed or regional scale incorporating multiple partner agencies;
- Climate change vulnerability assessments on partner's transportation systems;
- Planning and design for climate change adaptation strategies;

- Preventive maintenance practices incorporating climate change adaptation strategies; and
- Capital improvement projects that incorporate climate change adaptation strategies.

As with FLTP there are limited FLAP funds, so FS staff should work with their partners to develop compelling applications. The following strategies can help the FS pursue climate change resilience through the FLAP program:

- Work with FS partners to identify priority FLAP-eligible projects;
- Offer partners technical assistance to improve the quality and competitiveness of applications; and
- Incorporate climate change resilience into projects that meet multiple priorities, and emphasize co-benefits.

#### **Recommendations for Incorporating Climate Change Considerations into the FLAP Program**

In the long term, the FS could ask FLH and its partners to consider adding consideration of climate change vulnerability and resilience into FLAP projects. This could help incentivize climate change adaptation projects and it would increase the resilience of funded projects.



## 4.2.4. Emergency Relief for Federally Owned Roads (ERFO)

The Emergency Relief for Federally Owned Roads Program (ERFO) is administered by FLH and provides funds to assist federal agencies with the repair or reconstruction of tribal transportation facilities, federal lands transportation facilities, and other federally owned roads that are open to passenger cars, which are found to have suffered serious damage by a natural disaster over a wide area or by a catastrophic failure. This program provides the funds to repair transportation systems and re-establish public access after a natural disaster. The minimum threshold for ERFO eligibility is \$700,000. The FS can group multiple damage sites to reach this threshold, including in collaboration with other adjacent FLMAs.

### *Link to Climate Change*

ERFO funds can help the FS rebuild after extreme weather events cause damage to its transportation systems. ERFO is a key program for restoring public access after assets are damaged. ERFO can also be an opportunity to build back in a more resilient fashion through the betterment process.

### *Recommendations for Incorporating Climate Change into the ERFO Program*

Although ERFO is an important tool for addressing climate change impacts to FS transportation systems, there are also challenges that limit its effectiveness in increasing resilience to future climate change impacts:

- ERFO funds are generally limited to building assets back as they were and cannot be spent on enhancing damaged infrastructure. This is a challenge if climate change is projected to increase the severity of future climate stressors, which would necessitate building infrastructure to different standards in the future (e.g., larger culvert sizes, higher bridge

heights, etc.). There is an exception to this rule: ERFO can fund “betterments” if the applicant can demonstrate through a lifecycle cost analysis that it is economically beneficial to the ERFO program to add features that increase the facility’s resilience. The FS can also elect to add other funding to an ERFO-funded project to enhance its design.

- To date, ERFO records do not provide detailed, standardized data about ERFO events, such as geolocated damage locations, extent of damages, or thresholds for damage such as flood height or volume. This makes it difficult to use ERFO data to identify trends in damage. This data could help the FS and FLH identify areas that have repeatedly been damaged, identify trends in severity of damage from different stressors, or identify relationships with additional variables to better inform future vulnerability assessments. This data could also help the FS and FLH evaluate the performance of previous adaptation actions.

To improve the effectiveness of ERFO for increasing transportation resilience, the FS and FLH should partner to study how to develop guidelines or best practices for incorporating adaptation measures into ERFO projects. They should also collaborate to make the case for allowing the use of ERFO funds to rebuild assets to standards that take future climate change vulnerability into account.

The FS and FLH should also collaborate to develop more robust data collection templates and protocols to better capture data on ERFO events. This will provide a valuable dataset for future vulnerability assessments and adaptation planning and it will enable the FS to better anticipate and avoid future ERFO events.

## 4.3. Resiliency Transportation Technical Assistance

This guidebook provides information about climate change impacts on transportation infrastructure, a vulnerability assessment framework, adaptation determination framework, and implementation opportunities for the FS. However, FS staff are very busy and often need help getting started. Resiliency Transportation Technical Assistance could help FS staff identify problems, create priorities, and develop next steps for addressing climate change impacts to their transportation systems.

This assistance could be modeled after the Forest Service's Road Safety Audit (RSA) program, where the Washington Office has committed to funding one RSA in each region every two years and solicits RSA priorities from Regional staff. The RSAs are focused audits by an interdisciplinary team trained to analyze the safety issues in a location and develop recommendations for improvement. The Washington Office also supports a small number of Transportation Assistance Groups (TAGs) each year, which address Forest transportation challenges, such as congestion. These TAGs can be tailored to address the climate change challenges in a Forest but follow the general structure detailed in Toolbox 9.

Under this model, the FS could create a Resiliency TAG consisting of staff from the FS, FLH, and the Volpe Center trained to work with Forests to understand their unique climate change-related challenges and develop short- and long-term actions to address them. This program would be managed by the Washington Office, which would fund a number of Resiliency TAGs each year based on Regional priorities.

This assistance would also help inform the Washington Office about the range of transportation-related climate change impacts, as well as the solutions being developed, further informing future adaptation programs to better meet needs on the ground.

*Arapaho-Roosevelt National Forest used their completed TAR analysis to prioritize ERFO projects after Colorado's 2013 catastrophic floods. This allowed them to make more informed decisions about where and to what extent to rebuild.*



## TOOLBOX 9

### Using a Climate Change Transportation Assistance Group (TAG) to Get Started

The goal of a TAG is to provide transportation-focused technical assistance to Forests. This often includes analyzing existing conditions, identifying transportation problems and needs, making recommendations for future transportation planning and solutions, and scoping implementation steps. TAGs are designed to be efficient, low-effort ways to get started and can provide direction for a Forest's adaptation approach. Through a TAG, a Forest may develop priorities for a vulnerability assessment, evaluate adaptation options, or brainstorm opportunities for implementing adaptation projects.

#### TAG Participants

A TAG is composed of an interagency team that generally includes staff with expertise in a variety of relevant disciplines. The TAG should also include local stakeholders, such as the State DOT or local jurisdictions. For a Climate Change TAG, participants may include:

- USFS Headquarters, Regional Office, and Forest staff (e.g., climate change coordinators, engineers, hydrologists, and other relevant staff)
- FLH and Volpe staff
- Local stakeholders (e.g., other FLMAs, State DOTs, counties, gateway communities)

#### TAG Process

TAGs typically involve a short on-site workshop that culminates in a final report that summarizes findings and next steps. The steps in the TAG include:

- **Step 1: Preliminary Research.** The TAG team reviews existing data and studies prior to the site meeting.
- **Step 2: On-Site Workshop.** During a 2-3 day site visit, the TAG team conducts the following:
  - Meet with Forest Service staff and stakeholders
  - Tour the area of concern
  - Hold a workshop to review existing challenges and brainstorm solutions
  - Review potential solutions and next steps
- **Step 3: Develop TAG Report.** The TAG team develops a concise report summarizing the findings from the on-site workshop and any follow-up research.
- **Step 4: Review the TAG Report.** Follow up with Forest Service staff and stakeholders to confirm report conclusions and discuss any next steps identified.

Source: U.S. Department of Transportation, Volpe National Transportation Systems Center. Forest Service Transportation Assistance Groups (TAGs): <https://www.volpe.dot.gov/transportation-planning/public-lands/forest-service-transportation-assistance-groups-tags>.



# Appendix A: Forest Service Regional Climate Change Profiles

## Introduction

This Appendix provides a high-level summary of observed climate trends and regional climate change projections for each region of the U.S. Forest Service (FS). The primary sources for this Appendix are the U.S. Global Change Research Program's [Third National Climate Assessment](#) (USGCRP 2014) and the [Regional Climate Trends and Scenarios for the U.S. National Climate Assessment](#) (Kunkel et al 2013).<sup>39</sup> Kunkel et al 2013 and USGCRP 2014 provide historical climate trends (based on observed data typically reported for 1895-2011) and future projections (based largely on global climate models).

## Forest Service vs. USGCRP Regions

As Figure 11 shows, FS Regions differ from the USGCRP National Climate Assessment regions. Taking this into consideration, USGCRP regions were determined that best geographically represent each FS region. Then the representative USGCRP regions' climate data and projections were presented for each FS region. In cases where a FS Region includes substantial areas in two USGCRP regions, the Regional profile includes the summary data for both.

Figure A1. U.S. Forest Service Regions (left) and USGCRP Regions (right)



<sup>39</sup> Kunkel et al 2013 provides the detailed analysis of regional climate change trends and scenarios, which USGCRP 2014 uses as the basis for its regional analyses.

### **Understanding the Regional Profiles**

Each regional profile below has two parts: (1) a table summarizing data from Kunkel et al 2013 and USGCRP 2014; and (2) a high-level summary of how the projected changes in climate for the region may affect transportation infrastructure (“where the impacts meet the road”). The information provided in these profiles is not an exhaustive list of all impacts, but highlights of region-specific impacts that are expected to have implications for FS transportation systems. It also serves as a template for Regional staff to consider additional regionally-specific stressors and concerns.

The tables in the regional profiles below are based on the trends and scenarios summarized in Kunkel et al, 2013. The tables primarily draw on results from the Climate Model Intercomparison Project Phase 3 (CMIP3) under the lower (B1) and higher (A2) emissions scenarios used to inform the Intergovernmental Panel of Climate Change (IPCC) Fourth Assessment (AR4). This is supplemented by the North American Regional Climate Change Assessment Program (NARCCAP) dynamically-downscaled climate data under the higher (A2) emissions scenario for projections of extreme temperature and precipitation.

For projected future climate changes, the ranges below represent the median values for the lower and higher emissions scenarios across the region. For example, a range of +2 inches to +4 inches of annual average precipitation would mean that averaging across climate models for one emissions scenario finds a median of 2 inches more per year, while the other emissions scenario finds a media of 4 more inches per year. Values with an asterisk (\*) represent values for which projections are only available for the highest emissions scenario.

Because these tables show median values, they do not represent the full range of projected trends or capture the full extent of uncertainty. The tables also show annual average temperature

and precipitation, which does not capture seasonal variation. For example, climate models may suggest minimal to no change in total annual precipitation for a given region but the timing of that precipitation may change dramatically (e.g., the region may be projected to experience much drier summers and wetter winters).

Historical trends of sea level rise are based on NOAA’s Sea Level Rise viewer, which shows historic trends recorded at tide stations throughout the United States. Relative sea level rise (i.e., sea level rise measured by a tide gage) can vary compared to global sea level rise due to local factors, such as tectonic uplift (particularly in the Pacific Northwest and Alaska) or subsidence (particularly in some areas of the Southeast coast), changes in ocean circulation, salinity and density. For each region with coastal national parks, tide gages representing the range of measured trend for that region are provided in the table. In addition, USACE’s sea level rise calculator is used to project the future sea level rise for 2055 under NOAA’s intermediate-low and high scenarios. Because there is a high range of uncertainty regarding future sea level rise projections, planners should consider a range of possible sea level rise scenarios.

## Projected climate change variables

### Forest Service Region I: Northern Region

The Northern Region encompasses 25 million acres across what is considered the Northern Plains, including 12 National Forests and additional National Grasslands.



Climate variables	USGCRP Region: Great Plains		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.20°F/decade in Northern Great Plains	↑2.8 to 3.0°F	↑3.6 to 4.9°F
<b>Extreme Heat and Cold</b>	No overall trend in heat waves ↓ Shorter freeze season		↑+20 days/year above 90°F* ↓-23 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	No projected change	-2% to +1% change; models show an increase in annual precipitation in the Northern Great Plains and a decrease in the southern Great Plain
<b>Extreme Precipitation</b>	↑ Increased frequency		↑+17% days > 1 inch* ↑+56% days > 4 inches*

Table A1. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher emissions scenarios and across the region; \* indicates higher scenario relative to 1971-2000) (Source: USGCRP 2014; Kunkel reports)

### Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

Projections suggest more frequent and intense flooding and severe storms. Increased snowfall, rapid spring warming, and intense rainfall can combine to produce devastating floods.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Increased tree mortality as a result of insect infestations is expected as increasing temperatures cause heat stress and more overwintering insect populations.

## Projected climate change variables

### Forest Service Region 2: Rocky Mountain Region

The Rocky Mountain Region comprises 17 National Forests and seven National Grasslands.



Climate variables	USGCRP Region: Great Plains		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑ +0.20°F/decade in Northern Great Plains	↑2.8 to 3.0°F	↑3.6 to 4.9°F
<b>Extreme Heat and Cold</b>	No overall trend in heat waves ↓ Shorter freeze season		↑+20 days/year above 90°F* ↓ -23 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	No projected change	-2% to +1% change
<b>Extreme Precipitation</b>	↑ Increased frequency		↑+17% days > 1 inch* ↑+56% days > 4 inches*

Table A2. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario relative to 1971-2000) (Source: USGCRP 2014; Kunkel reports)

### Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

Recent extreme flooding events, including the 2013 Colorado floods, which have caused extensive damage to transportation infrastructure in the Rocky Mountain Region, have recently been attributed to climate change.



**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

In an analysis of nearly 7,000 large wildfires in the Rocky Mountain region, scientists have found a 73% increase in the average annual frequency of these wildfires from 1984 to 2011.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Tree mortality is claimed to be the most significant climate change stressor within the Rocky Mountain Region. The Forest Service estimates the Region is losing 100,000 trees each day partly as a result of climate change-induced beetle infestations.



## Projected climate change variables

### Forest Service Region 3: Southwestern Region

The Southwestern Region is 20.6 million acres of National Forests and National Grasslands.



Climate variables	USGCRP Region: Southwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.17°F/decade (1895 -2011)	↑2.5 to 3.1°F	↑3.6 to 5.0°F
<b>Extreme Heat and Cold</b>	↑Higher frequency of heat waves ↓ Shorter freeze season		↑+30 days/year above 90°F* ↓-29 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	+1% to -2%	↓-2% to -3%
<b>Extreme Precipitation</b>	No overall trend		↑+3% days > 1 inch* ↑+33% days > 4 inches*

Table A3. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)

### Where the impacts meet the road...



**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

Severe droughts combined with increased warming and insect outbreaks, all caused by or linked to climate change, have been increasing wildfires and related impacts across the Southwestern region.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Winter warming has exacerbated bark beetle outbreaks by allowing more beetles to survive and reproduce. Wildfires and bark beetles have killed trees across 20% of Arizona and New Mexico forests from 1984 to 2008.



**Extreme heat waves are expected to increase, which can cause buckling of paved roadways and rail infrastructure.**

Heat waves can also exacerbate other climate change impacts, such as wildfire risk. Heat waves also pose additional risks to Forest Service visitors, such as heat stroke and dehydration, which can make active transportation and recreation more difficult or dangerous.

## Projected climate change variables

### Forest Service Region 4: Intermountain Region

The Intermountain Region encompasses nearly 34 million acres of National Forests. This region encompasses areas in the USGCRP's Southwest and Northwest regions.



Climate variables	USGCRP Region: Southwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
Annual Average Temperatures	↑+0.17°F/decade (1895 -2011)	↑2.5 to 3.1°F	↑3.6 to 5.0°F
Extreme Heat and Cold	↑Higher frequency of heat waves ↓ Shorter freeze season		↑+30 days/year above 90°F* ↓-29 days/year below 32°F*
Annual Precipitation	No overall trend	+1% to -2%	↓-2% to -3%
Extreme Precipitation	No overall trend		↑+3% days > 1 inch* ↑+33% days > 4 inches*
Climate variables	USGCRP Region: Northwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
Annual Average Temperatures	↑+0.13°F/decade (1895 -2011)	↑2.3 to 2.8°F	↑3.2 to 4.1°F
Extreme Heat and Cold	↑ 70% more intense heat waves in the past 20 years than long term average		↑+8 days/year above 90°F* ↓-35 days/year below 32°F*
Annual Precipitation	No overall trend	↑+0% to +3%	↓-3% to -4%
Extreme Precipitation	No overall trend		↑+13% days > 1 inch* ↑+29% days > 4 inches*

Table A4. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)

## Projected climate change variables

### Forest Service Region 4: Intermountain Region (continued)

Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

Reduced snowpack accumulation and advance snowmelt timing in the region will increase the frequency of midwinter flooding, expanding flood conditions into new locations.



**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

Earlier onset of snowmelt and higher temperatures in the region are making a larger portion of the landscape flammable for longer periods of time. populations.



**Extreme heat waves are expected to increase, which can cause buckling of paved roadways and rail infrastructure.**

Heat waves can also exacerbate other climate change impacts, such as wildfire risk. Heat waves also pose additional risks to Forest Service visitors, such as heat stroke and dehydration, which can make active transportation and recreation more difficult or dangerous.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

A warmer, drier regional climate is projected to result in increased tree mortality through beetle infestation and disease.



## Projected climate change variables

### Forest Service Region 5: Pacific Southwest Region

The Pacific Southwest Region manages 20 million acres of National Forests in California.

Climate variables	USGCRP Region: Southwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.17°F/decade (1895 -2011)	↑2.5 to 3.1°F	↑3.6 to 5.0°F
<b>Extreme Heat and Cold</b>	↑Higher frequency of heat waves ↓Shorter freeze season		↑+30 days/year above 90°F* ↓-29 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	↑+1% to -2%	↓-2% to -3%
<b>Extreme Precipitation</b>	No overall trend		↑+3% days > 1 inch* ↑+33% days > 4 inches*
<b>Sea Level Rise</b>	↑ In the last 100 years, sea level has risen along the California coast by 6.7 to 7.9 inches		↑16 inches projected increase over the next 50 years

Table A5. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)

## Projected climate change variables

### Forest Service Region 5: Pacific Southwest Region (continued)

Where the impacts meet the road...



**Flooding is projected to increase, washing out roads and plugging or blowing out culverts.**

Increased atmospheric moisture in California's coastal ranges and the Sierra Nevada are causing "atmospheric rivers," which have contributed to record-breaking floods penetrating inland as far as Utah and New Mexico.



**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

Increased warming, drought, and insect outbreaks, all caused by or linked to climate change, have increased wildfires in the Pacific Southwest Region.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Sierra National Forest has been at the epicenter of a beetle infestation in California, with up to 80% tree mortality in some areas.



**Extreme heat waves are expected to increase, which can cause buckling of paved roadways and rail infrastructure.**

Heat waves can also exacerbate other climate change impacts, such as wildfire risk. Heat waves also pose additional risks to Forest Service visitors, such as heat stroke and dehydration, which can make active transportation and recreation more difficult or dangerous.



**Sea level rise will increase flooding and erosion of coastal infrastructure.**

Sea level along the California coast has risen by 6.7 to 7.9 inches and is expected to rise another 16 inches over the next 50 years. This threatens transportation infrastructure along the coast or low-lying estuaries with inundation and erosion during high tides and coastal storms.

## Projected climate change variables

### Forest Service Region 6: Pacific Northwest Region

The Pacific Northwest Region contains 17 National Forests, two National Scenic Areas, a National Grassland, and two National Volcanic Monuments, all within the States of Oregon and Washington.



Climate variables	USGCRP Region: Northwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.13°F/decade (1895 -2011)	↑2.3 to 2.8°F	↑3.2 to 4.1°F
<b>Extreme Heat and Cold</b>	↑ 70% more intense heat waves in the past 20 years than long term average		↑+8 days/year above 90°F* ↓-35 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	↑+0% to +3%	-3% to -4%
<b>Extreme Precipitation</b>	No overall trend		↑+13% days > 1 inch* ↑+29% days > 4 inches*
<b>Sea Level Rise</b>	Significant variation in sea level trends ranging along the coastline from -1.73mm/year (Neah Bay, Washington) to +2.46mm/year (Garbaldi, Oregon) <sup>40</sup>		Projections suggest an increase of 0.02 to 1.69 feet for Neah Bay, Washington and an increase of 0.43 to 2.45 feet for Garbaldi, Oregon <sup>41</sup>

Table A6. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)

40 NOAA Sea Level Rise Viewer: <http://tidesandcurrents.noaa.gov/sltrends/sltrends.html>.



## Projected climate change variables

### Forest Service Region 6: Pacific Northwest Region

#### Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

Changes in river-related flood risk depends on many factors, but warming is projected to increase flood risk the most in areas that are projected to experience advance snowmelt.



**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

Although wildfires are a natural part of most Northwest forest ecosystems, increasingly warmer and drier conditions are increasing the number and extent of wildfires in the region.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Driven in large part by increased seasonal drought and heat waves, forests will be altered by increasing wildfire risk and insect and tree disease outbreaks, and by forcing longer-term shifts in forest types and species.



**Sea level rise will increase flooding and erosion of coastal infrastructure.**

Global sea levels have risen about 8 inches since 1880 and are projected to rise another 1 to 4 feet by 2100. Regional sea level rise in the Pacific Northwest has been slower than global averages due to regional tectonic uplift. However, this trend could be reversed if a major Cascadia subduction zone earthquake lowers relative elevations. In Oregon and Washington, more than 140,000 acres of coastal lands lie within 3.3 feet of high tide. Major storms or seasonal sea level rise during El Nino events can threaten transportation infrastructure in low-lying coastal areas.

## Projected climate change variables

### Forest Service Region 8: Southern Region

The Southern Region encompasses 13 States and 13.3 million acres of National Forests across what is considered the Southeast and Southern Plains. In addition to the information provided here, the Southern Forest Futures Project may be referenced for more detailed regional climate information.



Climate variables	USGCRP Region: Southeast		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	No overall trend	↑2.3 to 2.8°F	↑3.1 to 4.4°F
<b>Extreme Heat and Cold</b>	No overall trend		↑+31 days/year above 90°F* ↓-17 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	↑+1% to +2%	↑+2% to +3%
<b>Extreme Precipitation</b>	No overall trend		↑+13% days > 1 inch* ↑+60% days > 4 inches*
<b>Sea Level Rise</b>	↑Significant variation in sea level trends along the coastline ranging from +1.92mm/year (Panama City, Florida) to +9.05mm/year (Grand Isle, Louisiana) <sup>42</sup>		↑Projections suggest an increase of 0.51 to 3.94 feet for Grand Isle, Louisiana and an increase of 0.51 to 2.18 feet for Panama, Florida <sup>43</sup>
Climate variables	USGCRP Region: Great Plains		
	Observed Trends (1895-2011)	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.09°F/decade (1895-2011)	↑2.8 to 3.0°F	↑3.6 to 4.9°F
<b>Extreme Heat and Cold</b>	No overall trend in heat waves ↓Shorter freeze season		↑+20 days/year above 90°F* ↓-23 days/year below 32°F*
<b>Annual Precipitation</b>	No overall trend	No projected change	↑-2% to +1% change
<b>Extreme Precipitation</b>	↑Increased frequency		↑+17% days > 1 inch* ↑+56% days > 4 inches*
<b>Sea Level Rise</b>	↑Global sea levels have risen about 8 inches since 1880		↑1 to 4 feet projected increase in global sea levels

Table A7. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)



## Projected climate change variables

### Forest Service Region 8: Southern Region (continued)

Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

There is a particularly imminent threat of increased flooding during heavy rain events in low-lying coastal areas, where sea level rise will impair the capacity of stormwater drainage systems to empty into the ocean.

Projections also show a regional increase in extreme precipitation events, which poses an increased risk of inland flooding independent of sea level rise.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Increasing droughts are causing tree mortality across the region; a 2011 drought caused tens of thousands of trees to die in the National Forests and Grasslands of Texas causing campground and trail closures to clear hazard trees.



**Extreme heat waves are expected to increase, which can cause buckling of paved roadways and rail infrastructure.**

Heat waves can also exacerbate other climate change impacts, such as wildfire risk. Heat waves also pose additional risks to Forest Service visitors, such as heat stroke and dehydration, which can make active transportation and recreation more difficult or dangerous.



**Sea level rise will increase flooding and erosion of coastal infrastructure.**

The Southeast is exceptionally vulnerable to sea level rise, which will also increase the region's vulnerability to hurricanes and storm surges. Low-lying areas along the Gulf Coast that have experienced high levels of subsidence and erosion due to sediment starvation and dredging are particularly vulnerable to future sea level rise and coastal storms.

42 NOAA Sea Level Rise Viewer: <http://tidesandcurrents.noaa.gov/sltrends/sltrends.html>. The greatest increase was measured at Eugene Island, Louisiana; however, this site is not provided in the USACE projections.

## Projected climate change variables

### Forest Service Region 9: Eastern Region

The Eastern Region consists of more than 12 million acres spread across 17 National Forests and one National Tallgrass Prairie in what is considered the Northeast and Midwest regions of the United States.



Climate variables	USGCRP Region: Northeast		
	Observed Trends (1895-2011)	2021-2050	2041-2070
Annual Average Temperatures	↑+0.16°F/decade	↑2.7 to 3.1°F	↑3.6 to 4.9°F
Extreme Heat and Cold	No overall trend in heat waves ↓Shorter freezing season		↑+13 days/year above 90°F* ↓-17 days/year below 32°F*
Annual Precipitation	↑+0.39 inches/decade	↑+3% to +4%	↑+4% to +5%
Extreme Precipitation	↑Increased frequency		↑+21% days > 1 inch* ↑+65% days > 4 inches*
Climate variables	USGCRP Region: Midwest		
	Observed Trends (1895-2011)	2021-2050	2041-2070
Annual Average Temperatures	↑+0.14°F/decade (1895-2011)	↑3.0 to 3.2°F	↑4.0 to 5.1°F
Extreme Heat and Cold	No overall trend		↑+19 days/year above 90°F* ↓-22 days/year below 32°F*
Annual Precipitation	↑+0.31 inches/decade	↑+2% increase	↑+3% to +4% change
Extreme Precipitation	↑Occur twice as frequently as a century ago (heaviest 1% of storms)		↑+23% days > 1 inch* ↑+94% days > 4 inches*

Table A8. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports).

## Projected climate change variables

### Forest Service Region 9: Eastern Region (continued)

Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

Between 1958 and 2010, the Northeast saw more than a 70% increase in the amount of precipitation falling in very heavy events, a greater recent increase in extreme precipitation than any other region in the United States.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Eastern forests are threatened by direct effects of increased heat stress, flooding, drought, and late spring freezes multiplied by changes in pests and disease prevalence, and other ecosystem disturbances.

## Projected climate change variables

### Forest Service Region 10: Alaska

Alaska contains 17 percent of all USFS lands and contains the two largest Forests in the nation.



Climate variables	USGCRP Region: Alaska (Kunkel, et al)		
	Observed Trends	2021-2050	2041-2070
<b>Annual Average Temperatures</b>	↑+0.9 to +4.5°F, varies by sub-region; warming greatest in winter and spring (1949-2011)	↑2.8 to 2.9°F	↑4.1 to 4.7°F
<b>Extreme Heat and Cold</b>	↑ Increase in heat waves ↓ Decrease in cold waves		Current extreme temperature projections do not cover Alaska
<b>Annual Precipitation</b>	↑+10% increase (1949-2011)	↑+7% to +8%	↑+10% to +12%
<b>Extreme Precipitation</b>	↑ Increase in all sub-regions except the Arctic; greatest in the Southeast and West Central		Current extreme precipitation projections do not cover Alaska
<b>Sea Level Rise</b>	Most of Alaska is experiencing tectonic uplift, so most tidal gauges have recorded declining relative sea levels. Trends vary widely from Sand Point, AK, which has experience a +0.92 mm/year sea level rise, to Nikiski, AK, which has seen relative sea level decline by 10.42 mm/year. <sup>44</sup>		Because of regional tectonic uplift, sea level rise in Alaska is projected to be less than global averages. Projections range from +0.45 feet sea level rise at Sand Point to -1.67 feet sea level decline at Nikiski. <sup>45</sup>

Table A9. Observed and projected changes in climate relative to 1971-1999 conditions (based on findings presented in USGCRP 2014 for ensemble average for the lower to higher scenarios and across the region; \* indicates higher scenario) (Source: USGCRP 2014; Kunkel reports)

44 NOAA Sea Level Rise Viewer: <http://tidesandcurrents.noaa.gov/sltrends/sltrends.html>.

## Projected climate change variables

### Forest Service 10: Alaska (continued)

#### Where the impacts meet the road...



**Heavy Precipitation and Flooding are projected to increase, washing out roads and plugging or blowing out culverts.**

The increasing number and intensity of storms, which have already been devastating communities and displacing residents, coupled with glacial melting are expected to increase flooding in the region.



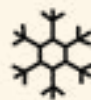
**Wildfires are projected to increase, causing direct damage to infrastructure as well as increased wear and tear on roads as a result of fire response.**

Both wetland drying and the increased frequency of warm dry summers and associated thunderstorms have led to more large fires in the last ten years than in any decade since record-keeping began in the 1940s.



**Tree mortality is expected to increase, creating a greater need for clearing hazard trees along roadways.**

Forest ecosystems are expected to undergo dramatic shifts in distributions and tree mortality as a result of fire and avalanches, and changes to insect or pathogen outbreaks.



**Thawing permafrost in Alaska is expected to continue, causing multiple vulnerabilities through drier landscapes, more wildfire, and increased costs of maintaining infrastructure.**

In Alaska, 80% of land is underlain by permafrost, and of this more than 70% is vulnerable to subsidence upon thawing. Thawing is already occurring in interior and southern Alaska.



## Appendix B: Climate Change Vulnerability Assessment Frameworks

An essential element to preparing for the impacts of climate change is assessing the vulnerability of existing or proposed transportation infrastructure and maintenance practices. These vulnerabilities may be due to a number of climate change-related stressors, such as increased extreme heat events, wildfires, sea level rise, or extreme storm events. Recognizing the relative risks to infrastructure from different stressors, and the potential consequences of damage, it is necessary to develop effective, risk-based adaptation strategies.

This guidebook uses a conceptual framework to consider how the U.S. Forest Service (FS) can reduce the impacts of climate change with respect to transportation infrastructure and prepare for its effects. This framework is based on research from the Intergovernmental Panel on Climate Change (IPCC)<sup>46,47</sup>, the U.S. Global Change Research Program's Third National Climate Assessment,<sup>48</sup> the National Park Service's (NPS) and U.S. Fish and Wildlife Service's (FWS) transportation vulnerability assessment efforts,<sup>49</sup> and FHWA's technical guidance on incorporating climate change mitigation and adaptation into metropolitan area transportation planning.<sup>50</sup> Important concepts from these sources are described below:

- **Adaptation.** Adaptation refers to the process of preparing people and infrastructure for changes in climate. Adaptation may involve physical measures, such as designing or retrofitting infrastructure to function in different climate conditions, or societal measures, such as new operations or procedures for responding to extreme weather.
- **Resilience.** Resilience, a concept originally borrowed from engineering and ecology, refers to the ability of a system to withstand a shock. In the context of FS transportation planning, resilience refers to the ability of the Forest Service's transportation systems to adjust to changes in climate while minimizing stresses to National Forest and Grassland ecosystems, visitors, and neighboring communities. Actions to increase an area's resilience can consist of physical actions, such as infrastructure adaptation, land use, and transportation planning, to reduce vulnerability from extreme weather or other climate change impacts. Resilience could also include maintaining alternate transportation routes to support access or egress in the case of an extreme event and social resilience measures, such as communications and community coordination to ensure that visitors or local residents are not stranded in an extreme weather event.

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46 IPCC, 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability: Summary for Policymakers. [http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5\\_SPM\\_FINAL.pdf](http://ipcc-wg2.gov/AR5/images/uploads/WG2AR5_SPM_FINAL.pdf).

47 IPCC, 2007. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. [http://www.ipcc.ch/publications\\_and\\_data/ar4/wg2/en/contents.html](http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html).

48 Bierbaum, et al., 2014. Chapter 28: Adaptation. Climate Change Impacts in the United States: The Third National Climate Assessment, Melillo, et al. Eds., U.S. Global Change Research Program. <http://nca2014.globalchange.gov/>.

49 FHWA, 2014. "FLMA Southeast Region Climate Change Transportation Tool." FHWA-HEP-14-05. [https://www.fhwa.dot.gov/environment/climate\\_change/adaptation/case\\_studies/southeast\\_region/index.cfm](https://www.fhwa.dot.gov/environment/climate_change/adaptation/case_studies/southeast_region/index.cfm).

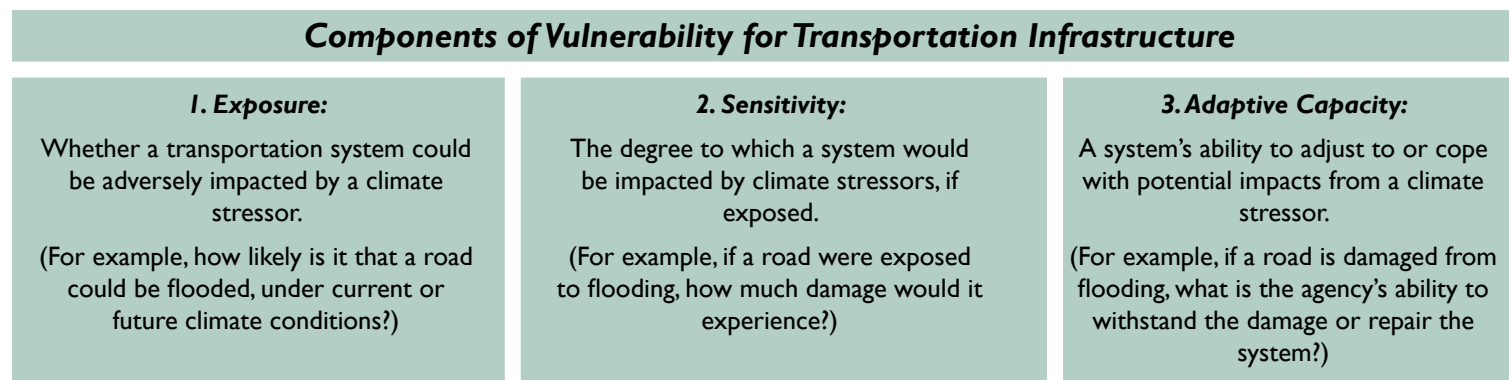
- **Climate Stressor.** A climate stressor is an aspect of the climate that poses potential for damage to a system. Climate stressors may be present now but may be heightened by climate change. Examples of climate stressors include primary climate change stressors, such as extreme heat, drought, sea level rise, and extreme precipitation events, or secondary stressors (influenced by primary stressors) such as wildfires, hydrological flooding, and permafrost thawing. Climate stressors vary by region and location.

## Defining Vulnerability

The IPCC defines vulnerability as “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.”<sup>51</sup> In the case of transportation infrastructure, vulnerability refers to both the likelihood that an asset will be exposed to climate stressors and the potential consequences of that exposure.

The components of an asset’s vulnerability are threefold and are described in Figure B1.

Figure B1. Transportation Infrastructure Vulnerability Framework



## Vulnerability Assessment Methodologies

FHWA, NPS, and FWS have developed vulnerability assessment tools based on the vulnerability framework in Figure 8. These include FHWA’s [Vulnerability Assessment Scoring Tool](#) and the [Southeast Region Climate Change Transportation Tool](#), which NPS, FWS, and FHWA developed to assess the relative vulnerability of transportation infrastructure in national parks and wildlife refuges in the U.S. Southeast. Both of these tools use indicators of exposure, sensitivity, and adaptive capacity to create a composite vulnerability score for a set of transportation assets. These scores can then be used to determine the relative vulnerability of a set of assets so that planners and transportation system managers can prioritize assets to develop adaptation options.

<sup>51</sup> IPCC, 2007.



The general steps for these vulnerability assessments are:

1. **Decide which assets or systems to include in the vulnerability assessment.** An agency may decide to include all assets or a subset of critical assets within a given area.
2. **Identify key climate stressors to analyze.** This may be determined by the stressors most relevant to the location of the assessment, the availability of climate stressor data, and the scope of the vulnerability assessment.
3. **Collect data on assets.** This includes geospatial data, engineering or design data, condition data, and history of previous damage.
4. **Collect data on stressors.** This includes down-scaled climate change projections, sea level rise projections, and other indicators of current or future stressors.
5. **Develop indicators of exposure, sensitivity, and adaptive capacity from existing data sources.** To the extent possible, Forests can use existing FS indicators and corporate data to reduce the burden of data collection.
  - a. Exposure indicators may be location- or elevation-based. These may include bathtub inundation models for sea level rise, Federal Emergency Management Agency (FEMA) flood risk zones, projected temperature increases for a location, and others.
  - b. Sensitivity indicators may include history of damage, bridge elevation, culvert volume or flow data, or other indicators of the extent to which a climate stressor would damage an asset.
  - c. Adaptive capacity indicators may include the projected costs of repairs, average daily traffic, or the presence of alternate routes.
6. **Identify and rate potential vulnerabilities.** Using a tool like [FHWA's Vulnerability Assessment Scoring Tool](#) (described in more detail below), create a ranking of relative vulnerabilities within a transportation network. This can help planners and transportation system managers recognize which assets or systems are most vulnerable, which can help them prioritize planning for adapting or increasing the resilience of the transportation network.

## Other Federal Land Management Agency Approaches

Other FLMA have taken steps to assess vulnerabilities within their transportation systems. For context for the ideas presented in this guidebook, the following projects are examples of their efforts.

### National Park Service

The NPS partnered with FHWA and FWS to develop the FLMA [Southeast Region Climate Change Transportation Tool](#), which was a vulnerability assessment tool for use in the Southeast Region. Through this project, the participating agencies synthesized best practices, developed a standardized vulnerability assessment methodology, calculated relative vulnerability scores for transportation infrastructure in the region, and tested the results in workshops with a small number of park units to review vulnerability findings and discuss adaptation options. This project addressed three relevant stressors for the region: inland flooding, coastal flooding, and wildfire.

In 2014, the NPS Northeast Region undertook a project to better understand the vulnerability of its transportation system to climate

change impacts after experiencing substantial damage from several large storms including Superstorm Sandy. This study focused on flood risk impacts and modeled potential changes to FEMA's flood risk zones to identify those assets currently at risk or potentially at risk under future climate change scenarios. The Region then reviewed its existing asset management practices to strategically incorporate projected future flood vulnerability into its transportation planning and programming process.

## U.S. Fish and Wildlife

FWS has undertaken substantial efforts to assess the vulnerability of its transportation assets to climate change. Along with the NPS, FWS participated in the [Southeast Region Climate Change Transportation Tool](#) described above. They are currently beginning a follow-up project to expand the methodology and apply it to two new Regions: the Pacific Region and another to be determined. The Pacific Region vulnerability assessment, which will cover the Pacific Northwest, Hawaii, and the Pacific Islands, will use a similar methodology but will analyze a different set of stressors more relevant to the region: coastal flooding / sea level rise, inland flooding, landslides, wildfire, and extreme heat.

Figure B2. Map showing current modeled wildfire risk, Rio Puerco Field Office

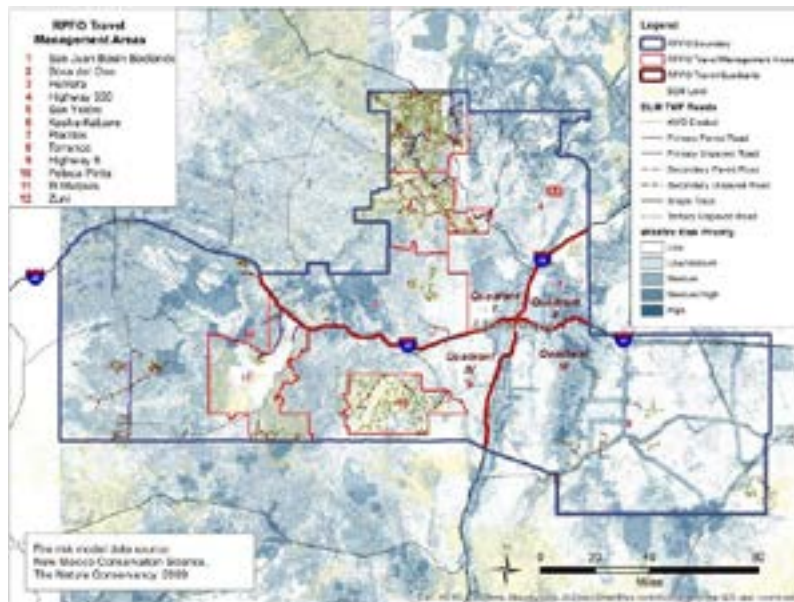
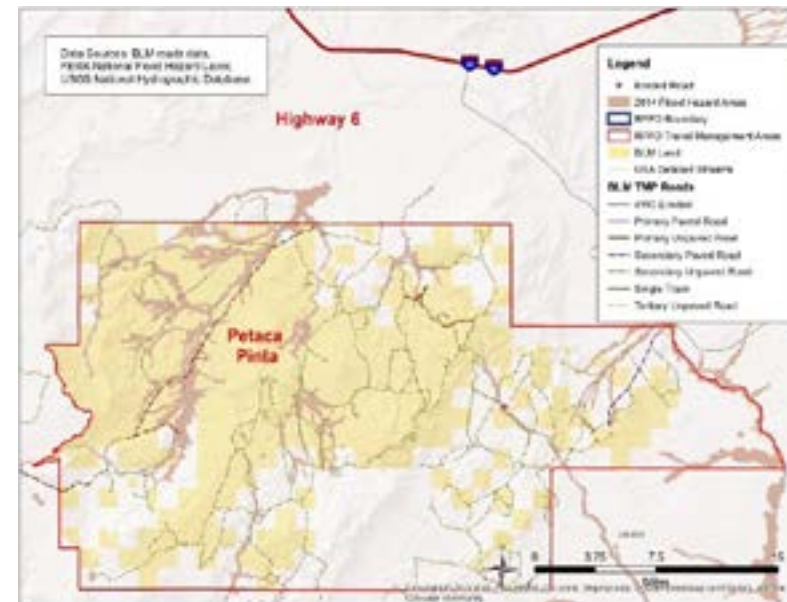


Figure B3. Map showing current transportation assets in FEMA flood risk zones, Rio Puerco Field Office



## Bureau of Land Management

The Bureau of Land Management (BLM) was a partner in the multi-agency FHWA climate change pilot project, the [Central New Mexico Climate Change Scenario Planning Project](#) (CCSP).<sup>52</sup> As part of this project, the BLM developed a report, [Potential Climate Change Impacts and the BLM Rio Puerco Field Office's Transportation System](#), which provided information to inform their upcoming Travel and Transportation Management Plan (TTMP). This report synthesized downscaled climate change projections that had been developed as part of the CCSP by the Volpe Center and focused on how they could impact the BLM's transportation system at the Rio Puerco Field Office, which consists mainly of dirt roads and trails. It focused on the following primary stressors: flood risk, drought, and wildfire risk. Unlike the FWS and NPS examples above, which provided asset-level vulnerability assessments, this report analyzed vulnerabilities at a coarser scale: the Travel Management Areas designated for TTMP planning. Although it does not identify specific roads and trails at risk, the report does summarize the relative proportion of assets at risk by planning area to help the BLM prioritize its attention to climate change risks in the TTMP.

### ***Federal Lands Collaborative Long-Range Transportation Plans***

The NPS, FWS, FS, BLM, and U.S. Army Corps of Engineers are currently collaborating with FHWA's Office of Federal Lands Highway to develop regional Collaborative Long-Range Transportation Plans (CLRTPs). CLRTPs are policy-level plans that establish goals, objectives, and performance measures for FLMA transportation networks in a region and can lead to common implementation actions, such as collaborating for improved data collection and sharing to address a priority topic. In the first two regional CLRTPs, the Alaska CLRTP (completed in 2012) and the Pacific Northwest CLRTP (in progress), the FLMA's involved in the CLRTP have included climate change as a high priority topic.

In the [Alaska CLRTP](#), the plan had a climate change specific goal area, and it provided a climate change technical report in Appendix C that provided regional context on climate change stressors in Alaska, Federal resources for adaptation planning, and a summary of Federal agency actions to address climate change mitigation and adaptation. The primary stressors analyzed in the Alaska plan were permafrost thawing and erosion. The analysis in the CLRTP was at a state level and did not provide unit-level or asset-level details, but it included an action item to develop a statewide Climate Change Action Plan for federal lands.

In the [Pacific Northwest CLRTP](#), the agencies participating in the plan decided not to develop a stand-alone climate change goal area but to “mainstream” it by integrating it into other goals. In the case of this CLRTP, the climate change discussion is primarily in the resource protection, safety, and asset management goal areas. The Pacific Northwest CLRTP will also include a climate change technical report similar in structure to the one in Alaska, but will primarily discuss climate stressors more relevant to the Pacific Northwest: sea level rise and coastal flooding, inland flooding from heavy precipitation events, erosion and landslides, and wildfires.

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52 NPS and FWS also collaborated on different aspects of this project.



## Appendix C: Adaptation Strategies and Sample Approaches to reduce transportation vulnerability to climate change




The table below is intended to provide some example adaptation strategies and approaches that Forests may use to address the climate change stressors highlighted in this guidebook (heavy precipitation/flooding, wildfire, and tree mortality).<sup>53</sup> Adaptation strategies explain the ways that adaptation options (resistance, resilience, response) can be applied. Adaptation approaches then provide more detail regarding application of the strategy. The table should be considered illustrative rather than comprehensive, and strategies should be identified to address each of the impacts associated with the stressors.






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Stressors	Options			Strategies	Sample Approaches
	Resistance	Resilience	Response		
		•	•	Adjust operations and maintenance practices	More frequent maintenance of drainage (culverts, grates, catch basins) and roadway (base, shoulder, pavement) assets
			•	Divest in asset	Place asset in storage Obliterate asset Decommission asset Change maintenance level
		•	•	Retrofit existing assets and engineer new assets to withstand future environmental conditions	Use construction materials better suited to changing climatic conditions Add barriers to prevent water incursion into tunnels Elevate roads and bridges to reduce exposure to flooding To prevent embankment / side slope erosion and possible failure, add robust slope protection such as matting riprap vegetation or possibly a closed drainage system around bridges Provide protections to roadway embankments (i.e. armoring, retaining walls, additional culverts, etc.) Increase the capacity of existing culverts to accommodate future increased precipitation and flooding events Replace the subgrades with materials so that the pavement structure will function during inundation and for multiply inundations Construct sea walls/bulkheads to protect assets from exposure to flooding Construct storm gates to shield assets from flooding Strengthen and stabilize assets (e.g., install approach plates at bridge approaches, enhance resistance to saturation of roadway base)

Stressors	Options			Strategies	Sample Approaches
	Resistance	Resilience	Response		
		•	•	Incorporate climate change considerations into systems planning	Site new facilities outside of expanded flood plains and high wildfire risk areas
					Raise profile of new facilities to reduce exposure to flooding
					Attenuate flooding velocities to reduce impacts of flooding (e.g., through constructed wetlands)
		•	•	Improve operations and post disaster response planning for weather emergencies	Plan for and develop emergency detours
					Ensure redundant critical connectors
	•	•	•	Sustain fundamental ecological functions of forests to mitigate risk of wildfire and tree mortality	Maintain or restore soil quality and nutrient cycling
					Maintain or restore hydrology
					Maintain or restore riparian areas
	•	•	•	Reduce the impact of existing biological stressors causing tree mortality.	Maintain or improve the ability of forests to resist pests and pathogens
					Prevent the introduction and establishment of invasive plant species and remove existing invasives
					Manage herbivory to protect or promote regeneration
	•	•		Protect forests from severe fire and wind disturbance.	Alter forest structure or composition to reduce risk or severity of fire
					Establish fuelbreaks to slow the spread of catastrophic fire
					Alter forest structure to reduce severity or extent of wind and ice damage

Stressors	Options			Strategies	Sample Approaches
	Resistance	Resilience	Response		
			•	Facilitate forest community adjustments through species transitions.	Anticipate and respond to species decline
					Favor or restore native species that are expected to be better adapted to future conditions
					Manage for species and genotypes with wide moisture and temperature tolerances
					Emphasize drought- and heat-tolerant species and populations
					Guide species composition at early stages of stand development
					Protect future-adapted regeneration from herbivory
					Establish or encourage new mixes of native species
			•	Plan for and respond to forest disturbance.	Prepare for more frequent and more severe disturbances
					Prepare to realign management of significantly altered ecosystems to meet expected future environmental conditions
					Promptly revegetate sites after disturbance
					Allow for areas of natural regeneration after disturbance
					Maintain seed or nursery stock of desired species for use following severe disturbance
					Remove or prevent establishment of invasives and other competitors following disturbance







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