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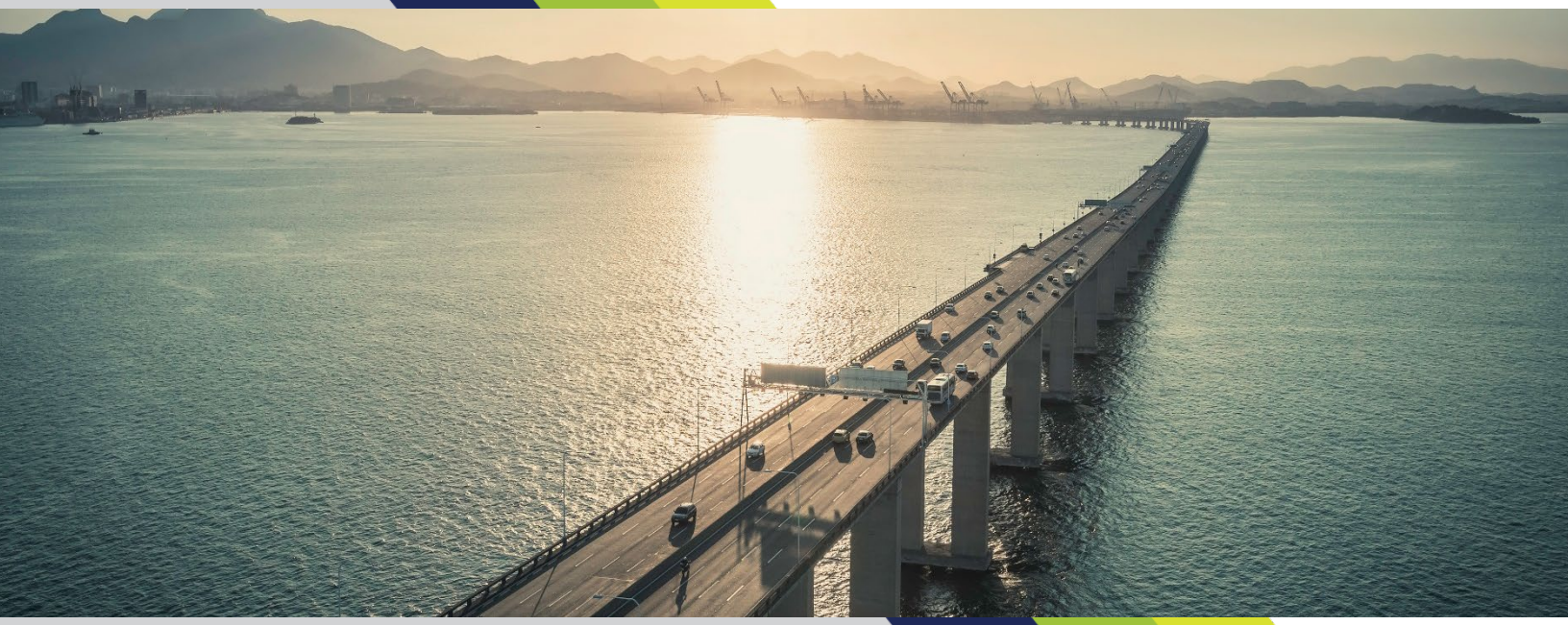

BUILDING RESILIENT INFRASTRUCTURE

How to Create Strong and Adaptable Transportation Systems

U.S. Department of Transportation, Office of the Secretary
www.transportation.gov/Momentum

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WHY CONSIDER CLIMATE CHANGE IN TRANSPORTATION DECISION-MAKING?

Transportation both contributes to and is affected by climate change. Greenhouse gas (GHG) emissions from all modes of transportation contribute to climate change, just as sea level rise and extreme weather events resulting from climate change affect transportation, disrupting networks and degrading infrastructure.

Governments have an important role to play in achieving deep GHG emission reductions and building resilience to the impacts of climate change. This Toolkit explores how climate change affects transportation infrastructure. It provides information about how governments can assess the vulnerability of their transportation infrastructure and systems to the impacts of climate change, and identify and implement adaptation strategies to make their transportation system more resilient to climate change impacts.

The Addressing Transportation's Impact Toolkit in this series explores ways that governments can implement policies that reduce GHG emissions from the transportation sector, which contribute to climate change.

What does the science tell us?

The world is facing a profound climate crisis. The scientific community has made clear that the scale and speed of necessary action is greater than previously understood. The Intergovernmental Panel on Climate Change (IPCC) has warned that significant and potentially dangerous shifts in climate and weather are possible even at 1.5 degrees Celsius (2.7 degrees Fahrenheit) of global warming beyond preindustrial levels.[1] At the 26th UN Climate Change Conference of the Parties (COP26), participating countries reaffirmed the Paris Agreement goal of limiting the increase in the global average temperature to well below 2 degrees Celsius above pre-industrial levels and pursuing efforts to limit it to 1.5 degrees Celsius. The Glasgow Climate Pact recognizes "that limiting global warming to 1.5 degrees Celsius requires rapid, deep and sustained reductions in global greenhouse gas (GHG) emissions, including reducing global carbon dioxide (CO_2) emissions by 45 percent by 2030 relative to the 2010 level and to net zero around midcentury, as well as deep reductions in other greenhouse gases."[2] Climate change is a threat to the global economy. The economic impacts and disruptions caused by climate change will be particularly acute for vulnerable populations. The World Bank estimates that the effects of climate change could push an additional 130 million people into poverty by 2030 and cause over 200 million people to migrate within their own countries by 2050.[3]

[1] IPCC, 2018. Summary for Policymakers, in Global Warming of 1.5°C. An IPCC Special Report. Available at: https://www.ipcc.ch/sr15/chapter/spm

[2] Glasgow Climate Pact. https://unfccc.int/sites/default/files/resource/cma3_auv_2_cover%2520decision.pdf

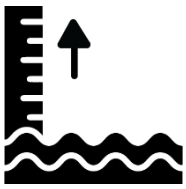
[3] The World Bank. October 26, 2021. World Bank Group COP26 Climate Briefs. https://www.worldbank.org/en/topic/climatechange/publication/world-bank-group-cop26-climate-briefs

WHAT ARE THE IMPACTS OF CLIMATE CHANGE ON TRANSPORTATION INFRASTRUCTURE?

Changes in climatic conditions affect the reliability and capacity of transportation systems in many ways, including:

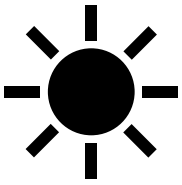
Air Temperature: Temperatures are projected to increase in in the coming decades. Increases in the number of very hot days and heat waves can have severe impacts on the transportation system. Extreme heat can cause stress on expansion joints on bridges and highways, deform rail tracks and runways, cause asphalt pavements to deteriorate more rapidly, limit the ability of airplanes to take off and land safely, and jeopardize customer and worker health and safety.

Precipitation and Flooding: Climate change is predicted to make rainstorms bigger, leading to more flooding and closures of roads, rail lines, tunnels, and airports. Such closures disrupt traffic and freight transport and inhibit emergency response. Exposure to flooding can also shorten the life expectancy of infrastructure. For example, runoff from heavy precipitation events can increase stream and river flows, potentially weakening bridge foundations.

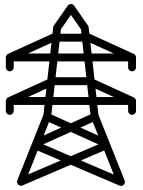


Sea Level Rise: Sea levels are changing along the coastlines at varying rates. Rising sea levels present the risk of permanent or periodic inundation of coastal infrastructure as well as increased coastal erosion, possible loss of coastal vegetative buffers, rising groundwater levels, and changes in salinity. Many airports are located along coastlines, making them particularly vulnerable to sea level rise. Sea level rise may also reduce navigational bridge clearances and jeopardize low-lying access roads to major port facilities.

Storm Surge and Waves: Coastal storms may intensify in the future, leading to larger storm surges and wave heights that can destroy coastal roads, bridges, infrastructure at maritime ports and airports, transit stations, and tunnels. When combined with rising sea levels, storm surges will extend further inland relative to today's coastline, leading to inundation of coastal communities and their transportation assets.



Drought: Prolonged periods with hot temperatures and little rainfall can result in higher rates of evaporation and drier soil, leading to higher rates of pavement degradation. Drought also increases the probability of wildfires, which can affect visibility and lead to road and airport closures or destruction. Wildfires can also significantly alter the hydrologic response of a watershed to the point that modest rainstorms produce dangerous flash floods and debris flows that wash out roads and bridges. Drought also weakens vegetation and makes it more susceptible to pests, which can also lead to issues with debris and limit opportunities to produce alternative fuels. Droughts can also reduce the depth of inland waterways, disrupting barge traffic.



Blackouts: Wildfires, intense storms, and increased electricity demand from air conditioning use during heat waves can cause blackouts. Blackouts disrupting street traffic signals significantly slow traffic and bus operations. Regional blackouts could disrupt supply to transportation systems that rely on electricity, such as rail systems and air traffic control.

WHAT CAN GOVERNMENTS DO TO BUILD RESILIENCE TO CLIMATE CHANGE?

> **Resilience is the capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.**

Transportation systems are already experiencing costly climate related impacts, leading to disruption and damaged roads, bridges, rail systems, and other transportation infrastructure. In the future, these impacts are projected to intensify in magnitude, duration, and frequency across the globe, threatening the long-term investments that governments have made in transportation infrastructure, and, thus, increasing infrastructure costs and requiring different planning, construction, and operational strategies.

Understanding the vulnerability of the transportation system is the first step to making it more resilient. Once vulnerabilities are identified, officials can identify adaptation options to address the vulnerabilities and take action to ensure that transport investments can handle future climatic conditions and deliver their intended immediate and long-term benefits. This Toolkit provides details on assessing vulnerability and risks and identifying solutions to address them.

Addressing climate resilience in the transportation sector requires governments to coordinate at the sub-national, regional, and city level. The resources in this Toolkit are intended for national governments, but all levels of government within a country can work together to assess climate vulnerabilities, plan for future climate change impacts, and build resilient transportation infrastructure.

Roadway damaged by flooding

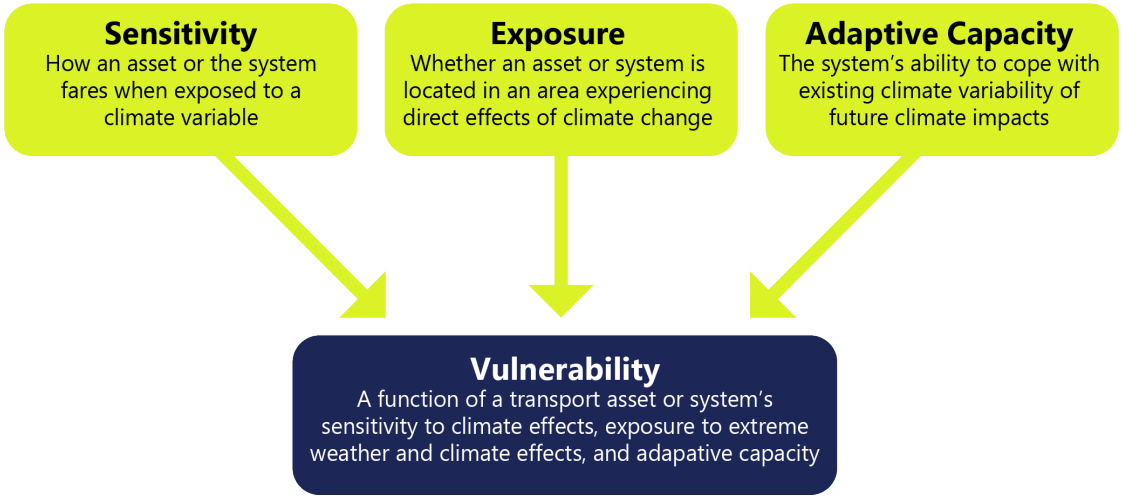
The Steps to Resilience framework describes an approach that governments can use to identify their valuable assets, determine which climate-related hazards could harm them, and then identify and take effective actions to reduce their risk. Following the steps, governments compile a list of the things they care about and explore which climate hazards could harm them. Governments assess what assets are vulnerable, investigate possible solutions, and set priorities to address the highest risks.

The Steps to Resilience framework can help national and sub-national governments, regions, cities, and neighborhoods quantify their vulnerability and risk and integrate considerations of people, ecosystems, and economics into their plans. Given the reality of limited resources and competing options, the framework helps groups produce a prioritized list of projects they can begin implementing to build resilience.

Steps to Resilience framework (Source: U.S. Climate Resilience Toolkit)

HOW CAN GOVERNMENTS IDENTIFY WHICH ELEMENTS OF THEIR TRANSPORTATION SYSTEMS ARE VULNERABLE TO CLIMATE CHANGE?

Vulnerability is the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability in the transportation context is a function of a transportation asset's or system's **sensitivity** to climate effects, **exposure** to extreme weather and climate effects, and **adaptive capacity**.



Government agencies can conduct climate change risk and vulnerability assessments to examine how climate hazards may directly or indirectly affect important transportation assets. Climate change risk and vulnerability assessments involve the following general steps:

1) **Articulate objectives and define study scope**: Often, time and resource constraints will prevent agencies from analyzing every asset in a transportation system. Similarly, not all changes in the future climate will be significant to local or regional transportation networks. The vulnerability assessment should focus on the climate change impacts that will have the greatest effects on the local or regional transportation network. To determine which climate change impacts will affect the transportation network and to what degree, governments should examine the sensitivity of specific transportation assets to various climate and weather hazards, including families of hazards that in combination create a high-risk environment for transportation assets. Governments should also consider the criticality of transportation assets – which transportation facilities, if impacted by a likely climate change event, will cause the most harm to the transportation network, economy, and human life?

2) **Compile Asset Data:** The scope of a vulnerability assessment will determine which asset data need to be collected. Transportation agencies likely track and maintain data on the major assets, such as roadways and bridges, but may not have as much data readily available on smaller assets and support structures, such as culverts. Coordination between internal and external stakeholders, such as local governments and universities, can be a way to identify all

existing data and reduce the need to collect new data or minimize the extent of data collection efforts. Transportation assets that may be useful to collect data on in order to inform the vulnerability assessment include:

- Roadways
- Bridges
- Tunnels
- Airports
- Ports
- Bus routes
- Signals, switches, and track
- Passenger and freight rail
- Evacuation routes
- Floodplains and wetlands
- Culverts and flood control structures

3) **Obtain climate data**: Agencies will need to compile climate data for the study area to establish the projected future climate conditions (e.g., temperature, precipitation, hydrology, sea level, storm surge) to which assets will be (or are projected to be) exposed. Agencies should use the best available climate projections and historical weather data specific to the region or smaller geographic scale. Climate projections associated with a range of emissions scenarios should be examined to ensure that the assessment is considering a range of possible futures rather than relying on any one single climate scenario.

4) **Assess vulnerability**: Practitioners will use the climate variables they developed to identify and evaluate the exposure, sensitivity, and adaptive capacity of a transportation asset or system to determine its vulnerability to climate change. Agencies can draw upon local knowledge and experiences to assess vulnerability, or use a more quantitative, indicator-based approach to score and rank transportation assets for vulnerability. Risk, which considers the probability that an asset will experience a particular impact and the severity or consequence of the impact, should also be incorporated when assessing vulnerability. Identifying and understanding the probabilities and severity of climate change risks can help agencies make more informed decisions about the costs and benefits of potential adaptation and mitigation options in the future.

For more information:

- U.S. Climate Resilience Toolkit
- U.S. DOT Vulnerability Assessment Scoring Tool
- Federal Highway Administration Vulnerability Assessment and Adaptation Framework, 3rd Edition
- Federal Highway Administration Climate Change Adaptation Tools
- Federal Highway Administration Racing for Hard Times Ahead Article
- Federal Highway Administration State of the Practice Scan: Freight Resilience Planning in the Face of Climate-Related Disruption
- Federal Transit Administration Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation Report
- Federal Transit Administration Transit and Climate Change Adaptation: Synthesis of FTA-Funded Pilot Projects
- Federal Aviation Administration Airport Resiliency Research
- Airports Council International Airports' Resilience and Adaptation to a Changing Climate Policy Brief

HOW CAN GOVERNMENT AGENCIES IDENTIFY WHICH TRANSPORTATION ASSETS ARE CRITICAL?

Defining the criticality of transportation assets can be an important step in assessing a transportation system's vulnerability to the impacts of climate change. Criticality assessments enable government agencies to decide which assets, such as roads, railways, or ports, they should prioritize for investments to improve resilience. Criticality considers many factors, including both "traditional" measures (e.g., use as an evacuation route, importance to interstate commerce), as well as community priorities (e.g., access to jobs or healthcare; connecting vulnerable communities). This allows communities to determine how best to use their limited resources to address their unique needs. Because of this subjectivity and the variability of needs in different communities, it is important to use sound professional judgment and a systematic approach when assessing criticality.

Criticality assessments use both quantitative (e.g., traffic volume) and qualitative data (e.g., community input). A typical assessment follows the steps listed below:

- Conduct a desk review to rank assets across a broad range of criteria that consider different transportation modes and systems
    - Potential criteria could include average daily traffic, functional classification, goods movement levels, access to employment/educational/medical facilities, degree of redundancy, and role in emergency management
- Engage stakeholders to verify findings from the desk review and provide additional input
    - Input can be gathered via workshops, public meetings, or similar types of events
- Score assets based on socioeconomic, operational, and safety criteria

For more information:

- U.S. DOT Assessing Criticality in Transportation Adaptation Planning

Example:

Assessing the Criticality of Transportation Infrastructure in Tampa Bay, Florida

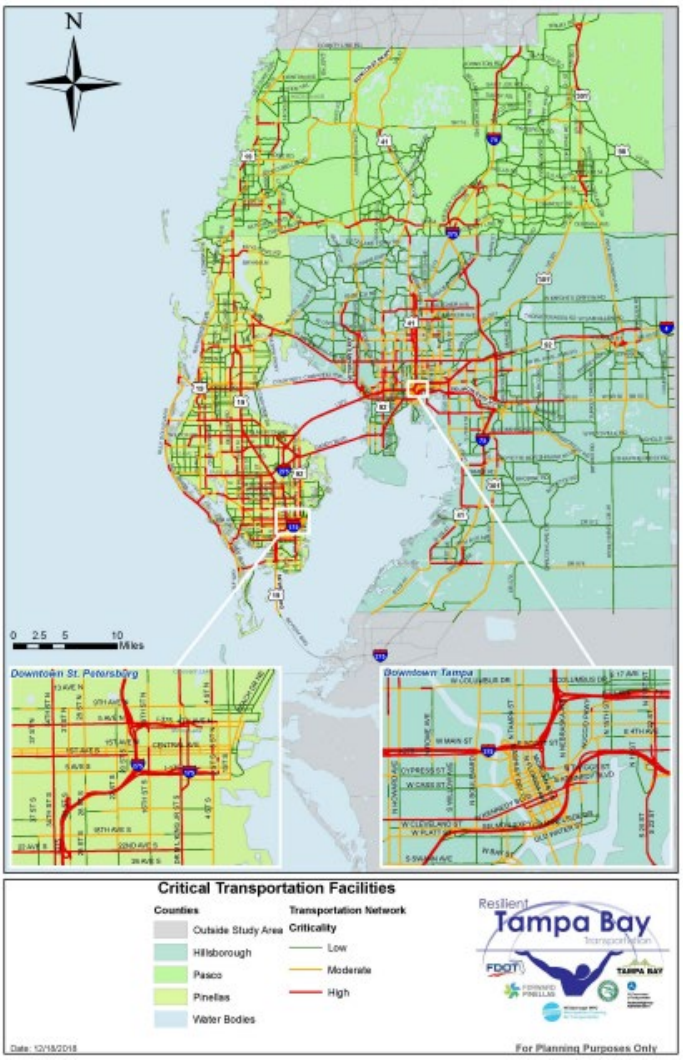
From 2018 to 2020, multiple regional transportation planning organizations in the Tampa Bay region participated in a pilot program to integrate resilience and durability to extreme weather into agency practices and resources. As part of this effort, transportation assets were assessed for criticality using the following factors:

- Whether the asset is part of an evacuation route,
- The projected traffic volume,
- Connectivity to major economic and social activity centers,
- Whether the asset is part of a transit corridor,

- Whether the asset is part of the agencies' long-range plan cost affordable projects,
- Whether the asset supports freight and/or intermodal connectivity,
- The projected population and employment densities,
- The percentage of zero-car households near the asset, and
- Equity areas near the asset.

The assets were then scored based on these factors on a 0-3 scale. High scores indicate the most critical infrastructure and low scores indicate the least critical infrastructure.

This analysis was conducted using a variety of data sources and analysis tools. The agencies engaged stakeholders at every stage of the process to validate the results. Following this analysis, assets were assigned a criticality of high, medium, or low. Assets that were designated as both highly critical and highly vulnerable were prioritized for investments.[4]



Map of critical transportation facilities in the Tampa Bay, Florida region (Source: Plan Hillsborough)

[4] https://planhillsborough.org/wp-content/uploads/2020/07/Resilient-Tampa-Bay-Final-Report-June2020-508_JB.pdf

HOW CAN GOVERNMENTS IDENTIFY ADAPTATION OPTIONS TO IMPROVE SYSTEM RESILIENCE?

Once climate vulnerabilities are identified, government agencies can identify adaptation options to address the vulnerabilities. They can also take action to ensure that transport investments can handle both acute and incremental climate change impacts and be adaptive to manage uncertainty and reduce long-term costs.

Adaptation solutions can be natural, structural, or policy-based and can be at the system level or site-specific. Categories of adaptation options are similar across disciplines:

- **Management and Maintenance**: Maintain existing infrastructure for optimal performance and manage the response to extreme events through advanced preparation. Emergency preparedness plans are one way to anticipate climate change impacts and to be prepared to address when they occur.
- **Increased Redundancy**: Ensure that transportation services provided by infrastructure can be supplied by other alternatives in the event of necessary closures. Providing alternative travel options during extreme weather events and after transportation infrastructure is damaged helps accelerate work to repair damage and keep the economy moving.
- **Protection**: Reduce or eliminate damage by providing transportation assets with protective physical barriers to climate hazards. Governments don't need to repair or replace infrastructure that is damaged or destroyed due to the impacts of climate change, saving money and resources.
- **Accommodation**: Modify or redesign infrastructure for better performance in a climate-stressed environment. Rebuilding infrastructure to be designed to withstand expected climate change impacts can extend the life of a transportation asset and prevent it from being severely compromised.
- **Relocation**: Lessen or eliminate exposure to climate hazards by relocating infrastructure away from the climate hazard. In some cases, building new transportation infrastructure that is in a location where it is less likely to be damaged (e.g., inland or at a higher elevation to avoid sea level rise and storm surges) may be more practical than protecting or adding accommodations to existing vulnerable infrastructure.

Governments can address adaptation in two ways:

- Through **System-Level Adaptation**, governments address climate resilience at a wider scale in the planning process,
- Through **Site-Specific Adaptation**, governments address climate resilience for specific transportation assets in specific locations, and

The next two sections provide additional details about these approaches to adaptation.

System-Level Adaptation

The transportation planning process provides a key opportunity for transportation agencies to proactively identify projects and strategies that address risk and promote resilience at the systems level. Climate resilience should be considered early during the long-range planning process, when options and priorities are considered for investment. The results of a vulnerability assessment provide agencies with useful information to screen projects during the planning phase to avoid making investments in particularly vulnerable areas or to build resilience into project design. Agencies can also use the findings from a vulnerability assessment to inform project prioritization by highlighting projects that can improve the resilience of the transportation system (e.g., identify projects that provide necessary redundancy in a vulnerable area).

Site-Specific Adaptation

Engineers have well-established methods for analyzing historical records to make assumptions about the type of climate a transportation asset will be exposed to over its lifetime. However, planning and designing for a future climate that is different than the past is less straightforward. While the same design standards and engineering equations may still be used, it is more difficult to make assumptions about what the future temperature, rainfall, flood levels, and other climate hazards might be given scenario and scientific uncertainty, and natural variations in the climate system. Many possible adaptation options can be implemented even in the face of uncertainty about future climate impacts. Including flexible options (i.e., those that can be modified as conditions change, or as new data becomes available) as part of a climate adaptation strategy can help reduce uncertainty and manage risk. For example, constructing a flood wall that can be heightened in the future, or taking an incremental approach to stabilizing landslides, can help practitioners ensure that current investments provide value under a range of future conditions.

Once adaptation options are identified, agencies should evaluate each potential option to understand the associated positive and negative impacts. Potential criteria to consider when evaluating are:

- How effective would the adaptation option respond to climate hazards across a range of climate scenarios?
- What are the capital and life-cycle costs of implementing the adaptation option?

Using Nature-Based Solutions to Improve Resiliency

Nature-based solutions can be used to improve system resiliency, with added benefits to the local habitat, water quality and added recreational benefits. Nature-based solutions use natural materials, such as beaches, dunes, mangroves, among others, to protect infrastructure vulnerable to erosion, wave damage or flood risk. Nature-based solutions are often equal or less costly than traditional, structural solutions, with the significant advantage of their ability to naturally adapt to sea level rise. Another advantage of nature-based solutions is that they can be combined with structural solutions to reinforce the resilience of transportation infrastructure. For example, infrastructure that's at risk of storm flooding, such as roads, causeways, bridges, and tunnels, may use structural solutions such as seawalls or flood barriers as a resiliency measure. This infrastructure can be complemented with nature-based solutions such as beaches, dunes, or marshes to provide more robust protection and help reduce initial and maintenance cost of the infrastructure. Successful design and implementation of nature-based solutions often require input from a cross section of expertise, including transportation professionals, coastal engineers, and environmental scientists.

- How will the adaptation option impact the environment?
- Is the adaptation option technically feasible?
- How will the adaptation option impact the community?

Layering these considerations into decision-making will provide a more complete understanding of the full value of adaptation options to the agency and community.

Nature-based solutions can protect transportation infrastructure from sea level rise and extreme weather events (Source: South Coast Engineers)

For more information:

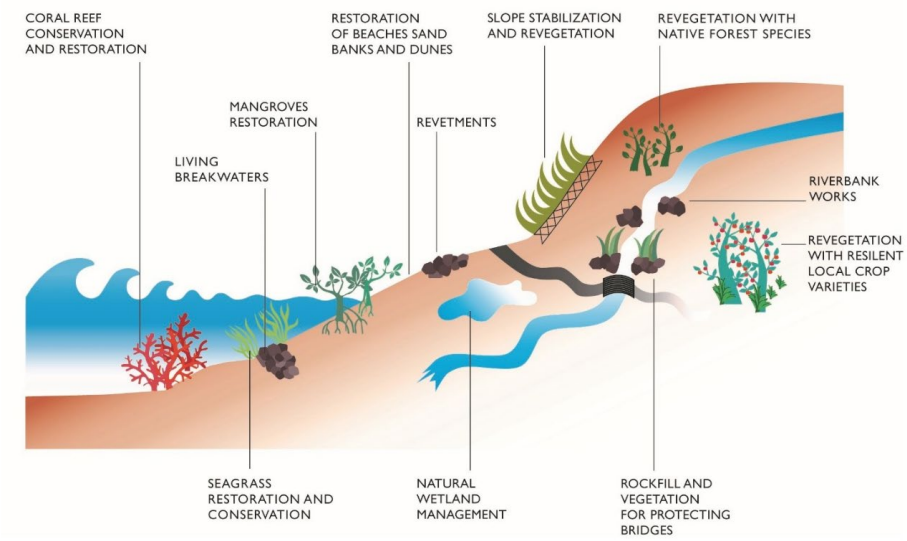
- Federal Highway Administration Hydraulic Engineering Circular No. 17, 2nd Edition: Highways in the River Environment - Floodplains, Extreme Events, Risk, and Resilience, 2nd Edition
- Federal Highway Administration Hydraulic Engineering Circular No. 25, 3d Edition: Highways in the Coastal Environment
- Federal Highway Administration Transportation Engineering Approaches to Climate Resiliency (TEACR) Study

- Federal Highway Administration Resilient and Sustainable Transport – Dutch Style: An interim report on bilateral cooperation between FHWA and Rijkwaterstaat
- Federal Highway Administration Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide
- Federal Highway Administration Climate Change Adaptation for Pavements

Examples:

Nature-based solutions for roadway infrastructure in Haiti

In partnership with the World Bank, Haiti has been implementing nature-based solutions to use its abundant natural resources to protect vulnerable roadway infrastructure. These solutions play a key role in protecting critical infrastructure that is threatened by numerous hazards, including hurricanes, floods, droughts, and earthquakes. Once recent project focuses on a coastal road that is positioned just 20 meters from a beach and 3 meters from a mountain. In order to improve resilience, work is underway to restore mangroves to protect the coastline, and revegetation with native plans will support slope stabilization efforts.



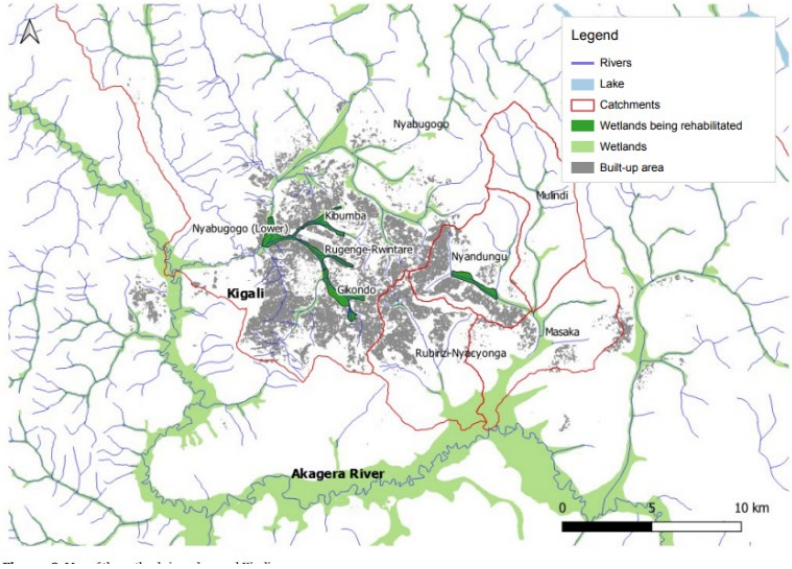
Hybrid NBS solution in Les Zanglais, Sud Department, Haiti (Source: World Bank Group)

Nature-based solutions for coastal resilience in Indonesia

In Indonesia, mangroves are used as a nature-based solution to improve coastal resilience by providing protection against extreme weather and mitigating the risks of flooding and erosion. The World Bank has estimated that the coastal protection provided by mangroves results in an economic value of greater than $10,000 per hectare per year.

Mangroves in Indonesia (Source: Mokhamad Edliadi/CIFOR, CC BY-NC-ND 2.0)

Nature-based solutions for mitigating flooding in Rwanda



Map of wetlands in and near Kigali, Rwanda (Source: WWF)

In Kigali, Rwanda, regular flooding during rainstorms disrupts traffic and prevents all travel among hillside communities. The government of Rwanda is partnering with the World Bank and other entities to restore wetlands to help mitigate the impacts of flooding. These urban wetlands retain stormwater runoff, improve water quality, and increase green urban recreational space.[5]

5 https://wwfint.awsassets.panda.org/downloads/waterways_to_resilience_naturebased_solutions_wwfabinbev.pdf

Nature-based solutions for restoring native forests in the Andes Mountains

In the Andes Mountains, local community members are working with conservation non-profits to plant trees as part of an effort to restore native Polylepis forests. These forests play a critical role in preventing landslides, in addition to protecting the waters that flow into the Amazon River. Since 2000, 1.3 million Polylepis (known as "Queuña" in the indigenous Quechua language) have been planted, and 3 million native trees have been planted through this effort overall.[6]

Communal tree planting across the high Andes of South America. (Source: @Global Forest Generation, Florent Kaiser, 2018)

[6] https://www.weforum.org/agenda/2020/07/reforesting-andes-polylepis-indigenous-people/

HOW CAN GOVERNMENTS IMPROVE SYSTEM RESILIENCE THROUGH OPERATIONS AND MAINTENANCE PRACTICES?

System resilience does not end after the implementation of a transportation project. Transportation operations and maintenance functions play vital roles in increasing the transportation system's resilience to climate change impacts. To increase their resilience to unanticipated shocks to the system, agencies can incorporate climate change considerations into how they plan and execute their management and operations, maintenance, and emergency management programs.

Areas where the impacts of climate change should be considered include:

- **Planning for workforce needs.** Workforce planning includes determining the number of staff required, their locations, and the abilities necessary to monitor, control, report, and maintain the roadway system. An increase in the frequency of extreme weather events may require additional personnel to monitor, control, report, and respond to events. Changes in long-term climate trends may also change seasonal work requirements (e.g., changes in winter weather seasons, construction timing, landscaping timing) and require additional or unique staff expertise to monitor and respond to new types of climate events.
- **Increasing regular maintenance activities.** Regular maintenance helps to prepare transportation to better withstand the impacts of climate change. For example, cleaning debris out of culverts and storm drains, especially before forecasted extreme weather events, can allow more water to flow when increased precipitation or flooding occur.
- **Assessing future technology and system requirements.** Agencies may require different types of monitoring equipment in order to respond to changing climate conditions. Mobile equipment can improve the speed and accuracy of data collection during inspections. Climate change could also affect where agencies choose to site new equipment and communications systems.
- **Determining future maintenance needs and methods.** Maintenance needs, including those related to pavement rehabilitation, bridge maintenance, construction and maintenance work timelines and timeframes, and vegetation control, may be affected by climate change. Climate hazards can lead to increased asset deterioration, requiring more frequent inspections and maintenance.
- **Maintaining mobility and safety.** Changes in the frequency of short-term weather events or the types of events that cause disruptions may require changes in operating procedures, additional resources to prepare for and respond to disruptions, and designated evacuation routes.

Monitoring and Evaluation

Through **monitoring and evaluation**, governments consider how effective implemented adaptation strategies have been and consider this information for future adaptation activities.

Adapting to extreme weather and climate impacts is an iterative process that requires monitoring and evaluation. Once an adaptation option in selected and implemented, agencies should establish monitoring and evaluation processes to assess the success of the adaptation strategies and other initiatives that were established based on the assessment of vulnerabilities. As new climate science

and data become available, agencies may need to reassess their vulnerabilities. The monitoring and evaluation process may identify the need to revisit the assumptions, underlying data, or approaches used in the original vulnerability assessment. The results of the monitoring and evaluation can also be used to periodically revisit and refine adaptation strategies and processes to ensure continued resilience of transportation infrastructure.

For more information:

- Federal Highway Administration Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance
- Federal Highway Administration State of the Practice Scan: Freight Resilience Planning in the Face of Climate-Related Disruption
- Federal Highway Administration Transportation Infrastructure Resiliency: A Review of Practices in Denmark, the Netherlands, and Norway
- Federal Highway Administration Road Weather Management Resources

Example:

Norwegian interactive tools for weather hazards and road conditions

The Norwegian government uses a suite of interactive tools, many on mobile platforms, to inform the traveling public of weather hazards and road conditions. These tools integrate data such as avalanche forecasts, road closures, and reports from the public. Weather station data, stream gauge data, and road condition information can be accessed from a single location. The application, called Xgeo, uses common maps and includes separate access protocols for the public and government employees. Real-time reports from the public can help officials react to road closure events and set up detours.[7]

[7] https://www.xgeo.no/aboutXgeo.html

HOW CAN GOVERNMENTS USE INNOVATIVE FINANCE TECHNIQUES TO SUPPORT THE DEVELOPMENT OF RESILIENT INFRASTRUCTURE?

Governments have many financing tools at their disposal to help reduce the impacts of transportation on climate change (see the "Addressing Transportation's Impact: A Starter Guide to Reducing Transportation Greenhouse Gas Emissions" Toolkit for more information), but they also may use innovative financing techniques to help improve the resilience of their infrastructure. One strategy that many agencies use is value capture, which helps government derive monetary value from transportation improvements and investments to help defray the cost of their implementation. For example, building roads and bridges or improving and expanding transit benefit many different groups, including developers, property owners, employers, businesses, transportation operators and users, investors, and landowners. Local governments can use taxes or other fees to raise revenue from these beneficiaries, and these funds can be reinvested in resilience-focused infrastructure projects.

For more information:

- Federal Highway Administration Center for Innovative Finance Support
- Federal Highway Administration Innovative Finance Video Series
- Federal Highway Administration Value Capture Resources

Example:

Value Capture Strategies in Newberg, Oregon

The city of Newberg, Oregon, uses a transportation utility fee to pay for street repairs, routine maintenance, and pavement preservation. The free is collected from all of the properties throughout the city to help capture the benefits well-maintained roadways, and partial waivers are available for those facing economic hardship or those without personal vehicles. This fee generates approximately $1.2 million annually to be used for road maintenance, which in turn is expected extend the life of streets by almost 50 percent.

PUTTING STRATEGIES INTO ACTION

Despite efforts to reduce worldwide GHG emissions, the impacts of climate change in the form of extreme weather events, sea-level rise, and other impacts will continue to affect the transportation sector. Existing transportation infrastructure will need to be protected from these impacts through many approaches to adaptation, and new transportation infrastructure will need to be built to be resilient to anticipated climate scenarios. Governments can conduct vulnerability assessments to make their transportation systems more resilient to the impacts of climate change. Vulnerability assessments help governments:

- Understand the transportation system's exposure to climate change impacts,
- Assess risks and identify particularly vulnerable aspects of the transportation system,
- Investigate options to making high-risk areas of the transportation system more resilient to extreme weather events and sea-level rise,
- Make plans and prioritize investments to improve transportation system resilience, and
- Implement projects and strategies to make transportation infrastructure more resilient to climate change impacts.

GLOSSARY

Adaptation: The process of adjusting to new (climate) conditions in order to reduce risks to valued assets.

Adaptive Capacity: The ability of a person, asset, or system to adjust to a hazard, take advantage of new opportunities, or cope with change.

Exposure: The presence of people, assets, and ecosystems in places where they could be adversely affected by hazards.

Hazard: An event or condition that may cause injury, illness, or death to people or damage to assets.

Impacts: Effects on natural and human systems that result from hazards. Evaluating potential impacts is a critical step in assessing vulnerability.

Mitigation: Processes that can reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing them from the atmosphere.

Probability: The likelihood of hazard events occurring. Probabilities have traditionally been determined from the historic frequency of events. With changing climate and the introduction of non-climate stressors, the probability of hazard events also changes.

Projections: Potential future climate conditions calculated by computer-based models of the Earth system. Projections are based on sets of assumptions about the future (scenarios) that may or may not be realized.

Resilience: The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.

Risk: The potential for negative consequences where something of value is at stake. In the context of the assessment of climate impacts, the term risk is often used to refer to the potential for adverse consequences of a climate-related hazard. Risk can be assessed by multiplying the probability of a hazard by the magnitude of the negative consequence or loss.

Sensitivity: The degree to which a system, population, or resource is or might be affected by hazards.

Uncertainty: A state of incomplete knowledge. Uncertainty about future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make.

Vulnerability: The propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive

SELF-ASSESSMENT QUESTIONS

Take some time to think through how transportation in your country contributes to climate change through GHG emissions, and how your government is working to reduce GHG emissions. Consider the following questions:

- **What impacts from climate change is your country experiencing?**
  - Where do they occur?
  - How often do they occur?

- **How is your government working with or supporting sub-national or local governments in your country on building climate resilience for transport?**

- **What are some examples of the affects that climate change has had on transportation infrastructure in your country?**
  - How did your government address those impacts?

- **How does your country assess the risks that climate change poses to transportation infrastructure?**

- **What adaptation strategies has your country implemented to make the transportation system more resilient?**
  - How do you measure the success of those strategies?

- **What additional strategies do you think may help your transportation system be more resilient to the impacts of climate change?**

For more information about reducing transportation-related GHG emissions, or to learn more about partnering with Momentum, please contact us at momentum@dot.gov.