FTA Report No. 0265

FTA
FEDERAL TRANSIT ADMINISTRATION

Transit Resilience Guidebook

PREPARED BY
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U.S. Department of Transportation
Federal Transit Administration

MAY 2024

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Metric Conversion Table

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC

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14. ABSTRACT
The Federal Transit Administration (FTA) developed the Transit Resilience Guidebook to support transit agencies, local government officials, metropolitan planning organizations, and other entities responsible for operating, funding, or coordinating on public transportation in their efforts to anticipate, adapt to, and recover from service disruptions that current and future extreme weather event and other natural hazards can cause. The Guidebook presents recommendations for and examples of how to identify and address vulnerabilities and build resilience throughout the agency decision-making and project life-cycle processes, from planning through design and construction, asset management, to operations and maintenance.

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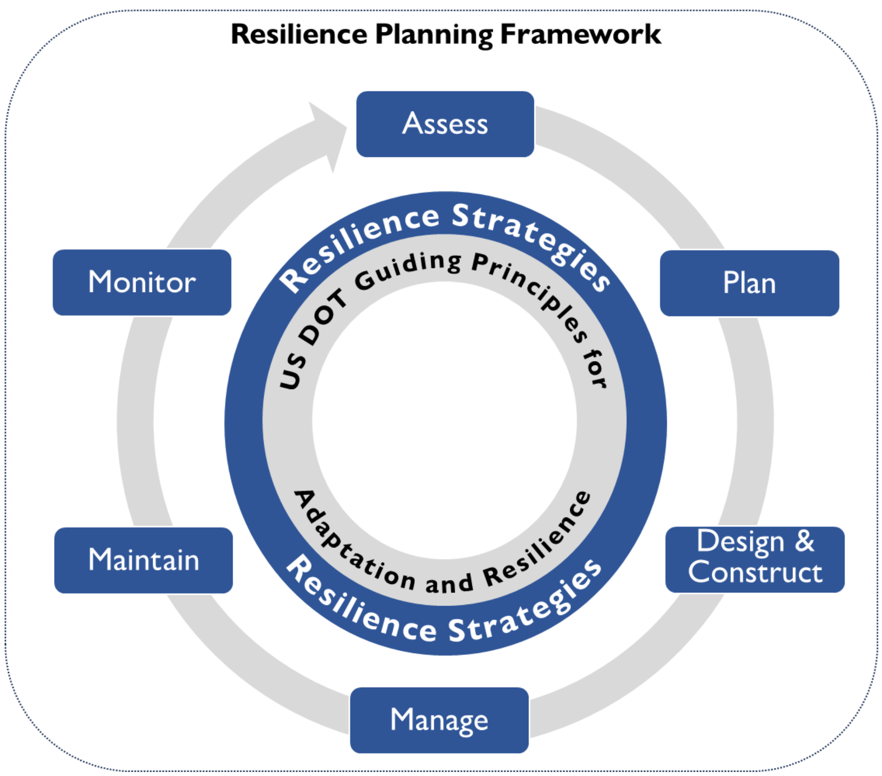
Executive Summary

The Federal Transit Administration (FTA) prepared this Transit Resilience Guidebook (Guidebook) to assist transit agencies, local government officials, metropolitan planning organizations, and other entities responsible for planning, funding, operating, or coordinating with public transportation agencies to anticipate, adapt to, and recover from service disruptions caused by extreme weather events, natural disasters, and climate change impacts. The Guidebook presents recommendations for and examples of how to identify and address climate vulnerabilities and risks and build resilience into transit assets throughout the agency's project life-cycle process, while ensuring priority is given to protecting vulnerable populations. The Guidebook also provides links to resources and references where additional information on implementation of resilience measures into transit planning may be found.

Resilience planning is an iterative process to identify and address the weather events and natural hazards and risks that threaten an agency's transit systems. Resilience cannot be achieved through the actions of any one department within a transit agency. Instead, resilience efforts must be considered and implemented, as appropriate, throughout an agency's project life-cycle and decision-making processes.

The Guidebook presents a resilience planning framework overlaid onto agency processes using six phases: "Assess," "Plan," "Design and Construct," "Manage," "Maintain," and "Monitor." Additionally, the Guidebook outlines best practices for incorporating resilience in each phase and identifies commonly used transit resilience strategies grouped into four general categories of "Avoid," "Maintain and Manage," "Strengthen and Protect," and "Enhance Redundancy." These adaptation measures may be implemented at each phase of the Resilience Planning Framework to enhance the overall resilience of transit systems.



Introduction

The American public in communities large and small, urban, and rural, depends on public transportation to access jobs, schools, health care, and other critical services. Weather events and natural hazards, such as sea-level rise, extreme precipitation, flooding, and extreme heat, are threatening public transit agencies and the transit systems they manage at increased frequencies and intensities. Since 2012, FTA has provided $11 billion[1] in emergency relief funding to transit agencies to assist with recovery from and enhancing resilience to natural disasters, emergencies, or significant events that disrupt transit services. The impacts of these major disasters, as well as more routine weather events and climate hazards, undermine the reliability, safety, and efficiency of public transportation systems, with the effects being particularly acute for vulnerable or transit-reliant populations.

Many transit agencies are challenged with maintenance and repair backlogs for their aging infrastructure, a problem that budget shortfalls exacerbate. Extreme weather and other climate hazards are additional stressors that can hasten the deterioration of assets, shortening their useful lives and further increasing the costs of maintaining, repairing, and replacing infrastructure. Efforts to make transit systems more resilient to the impacts of current and future natural hazards are imperative to ensuring transit fulfills the critical role it plays across American communities. Resilience refers to the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability to resist hazards or withstand impacts from weather events and natural disasters; or to reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster on a project (23 United States Code (U.S.C.) 101(a)).

FTA invests more than $20 billion annually through its various funding programs to support and expand subway, light rail, passenger rail, bus, trolley, and ferry systems. FTA has also long understood the need to make public transportation infrastructure and operational systems more resilient to protect long-term Federal investments and the safety of transit riders. By proactively embedding resilience into all aspects of decision making, from assessment through planning, design and construction, asset management, to operations and maintenance, and monitoring, transit agencies can increase rider safety and day-to-day reliability in an increasingly unpredictable climate, ensure services continue during emergency situations, and save money on maintenance, repair, and disaster recovery activities.

Purpose of the Guidebook

FTA’s Office of Environmental Policy and Programs prepared this Transit Resilience Guidebook (Guidebook) to support transit agencies, local government officials, metropolitan planning organizations (MPOs), and other entities in their efforts to increase the resilience of transit systems. The Guidebook presents recommendations and examples on how to identify and address vulnerabilities and build resilience to current and future extreme weather events, natural disasters, and climate change impacts while ensuring priority is given to protecting vulnerable populations.

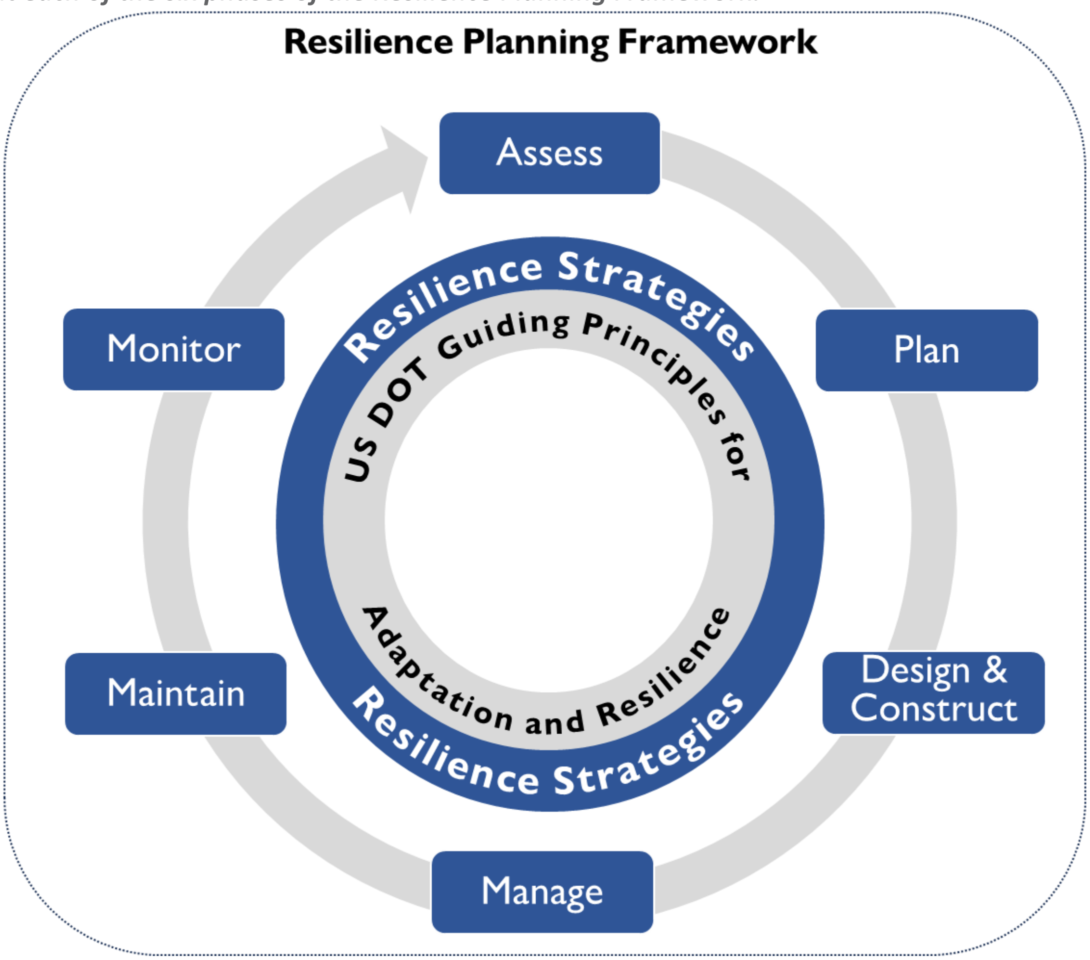
[1] This figure does not include funding associated with preventing, preparing for, and responding to the Coronavirus Disease 2019 (COVID-19).

The Guidebook presents a resilience planning framework overlaid onto agency processes using six resilience phases: “Assess,” “Plan,” "Design and Construct,” "Manage,” “Maintain,” and “Monitor.” The Guidebook presents resilience planning as an iterative process to identify and address the weather events, natural hazards, and risks that threaten an agency (Figure 1). It acknowledges that resilience cannot be achieved through the actions of any one department within a transit agency. Instead, resilience efforts must be considered and implemented, as appropriate, throughout an agency’s decision-making and project life-cycle processes, including coordination with a diverse set of stakeholders, such as environmental agencies, emergency response organizations, and local communities.

The Guidebook provides resources and tools for integrating equity into resilience planning and the transit project life cycle since climate hazards are known to disproportionately impact low-income individuals, people of color, other marginalized groups, and historically underserved neighborhoods.

Finally, the Guidebook promotes the integration of the USDOT’s Guiding Principles on adaptation and resilience. These include using the best-available science, prioritizing the most vulnerable, preserving ecosystems, and building community relationships into the six phases of the Resilience Planning Framework. See the text box below for more information on the USDOT guiding principles.

Figure 1 ***Resilience Planning Framework. FTA recommends incorporation of the Resilience Strategies and US DOT Guiding Principles for Adaptation and Resilience throughout the project life-cycle process at each of the six phases of the Resilience Planning Framework.***



The six phases of the Resilience Planning Framework are:

- **Assess** – In order to make informed decisions on how to enhance resilience, transit agencies need a solid understanding of which assets and populations are most at risk and to which current and future weather events and natural hazards they are most vulnerable. Evaluation and incorporation of the best-available science is an important component of the assessment phase.

- **Plan** – Transit agencies should incorporate resilience into each level of transit planning to ensure that it is considered at the earliest stages of setting agency priorities and site selection considerations. By evaluating and incorporating science-based and nature-based adaptation solutions, as appropriate, into agency-specific planning efforts, agencies can increase resilience, while preserving ecosystems, building community relationships, and protecting vulnerable populations.

- **Design & Construct** – When designing and developing major construction and rehabilitation projects (capital projects), as well as undertaking smaller construction or retrofit activities, transit agencies should consider potential hazards that may affect an asset and its ridership over the course of its anticipated useful service life and develop, evaluate, and re-evaluate, as needed, potential adaptation measures to reduce possible damage, economic loss, or safety impacts. It is critical that transit agencies evaluate projects to ensure they incorporate cost-effective adaptation measures at the design and construction phases. A variety of adaptation measures within the four resilience strategy categories ("Avoid," "Maintain and Manage," "Strengthen and Protect," and "Enhance Redundancy") should be considered. Additional information on these categories is provided later in the Guidebook.

- **Manage** – Extreme weather events are increasing in frequency. Therefore, it is critical that transit agencies integrate resilience into their overall transit asset management (TAM) approach. Doing so can help reduce costs associated with damage repairs, asset replacement, or emergency evacuation, for example. It can also help prevent service disruptions and safety hazards, while extending an asset's useful service life, resulting in a more resilient transit system.

- **Maintain** – The integration of adaptation measures into operations and maintenance (O&M) activities and processes is critical to continuing service and preventing hazardous conditions during and after disruptive events. It can also ease the process of rebuilding infrastructure and re-establishing service when necessary.

- **Monitor** – Transit agencies should develop a framework to monitor and quantify the performance and effectiveness of resilience actions and investments under various conditions. They can use this framework to determine what, if any, mid-course corrections might be needed to enhance and further improve resilience outcomes. Agencies are encouraged to reassess vulnerabilities and risks when updated data become available and to revise priorities and plans accordingly, as needed.

U.S. DOT's Guiding Principles for Adaptation and Resilience

Excerpted from U.S. Department of Transportation Climate Action Plan (2021): Revitalizing Efforts to Bolster Adaptation and Increase Resilience.

- **Use Best-available Science.** Adaptation and resilience strategies will be grounded in the best adaptive actions will not be delayed—all plans and actions will be continuously reevaluated as our understanding of climate impacts evolves.
- **Prioritize the Most Vulnerable.** Adaptation and resilience plans will prioritize helping people, communities, and infrastructure that are most vulnerable to climate impacts—this includes underrepresented groups, low-income communities, communities of color, limited English proficient communities, and individuals with disabilities. These plans will be designed and implemented through a transparent process with meaningful involvement in decision making from all parts of society. Issues of inequality and environmental justice associated with climate change impacts and adaptation will be addressed.
- **Preserve Ecosystems.** Protecting biodiversity and ecosystem services through adaptation strategies will increase resilience of human and natural systems to climate change and other risks, providing benefits to society and the environment (e.g., in a coastal setting, wetlands serve as buffers to transportation assets and can minimize the impacts of storm surge).
- **Build Community Relationships.** Adaptation and resilience require coordination across multiple sectors, geographical scales, and units of government. Our actions will build on existing efforts, knowledge, and meaningful engagement of communities that are impacted. Because impacts, vulnerabilities, priorities and needs vary by region and locale, adaptation will be most effective when driven by local and regional risks and needs.

How to Use This Guidebook

The information within this Guidebook is based on an extensive review of transit agency climate resilience plans and other literature, as well as interviews with transit agency personnel. The Guidebook is organized as follows:

Phase 1: Assess provides an overview of the steps involved in recognizing vulnerabilities and the climate risks they pose. This section of the Guidebook identifies the relevant transit assets and common natural hazards to consider, and industry-standard data sources and tools to understand and assess changing climate conditions. It also showcases example approaches that transit agencies have taken to better understand which of their assets were most vulnerable to current and future extreme weather events, natural disasters, and climate stressors.

Phases 2 through 6 of this Guidebook provide recommendations on how to use the results of a vulnerability and climate risk assessment to address and promote resilience across all phases of the transit project decision-making and life-cycle processes, as follows:

Phase 2: Plan outlines opportunities to incorporate resilience into agency planning efforts to align planning priorities and ensure actions at the various levels of transit planning increase resilience.

Phase 3: Design & Construct provides recommendations on how to consider potential hazards as part of the design and development of new capital projects, as well as smaller retrofits, and how to evaluate potential adaptation measures that would reduce possible damage to the newly constructed assets.

Phase 4: Manage outlines best practices for integrating resilience into transit asset management to reduce costly damage, prevent service disruptions, and extend the assets' useful lives for a more resilient transit system.

Phase 5: Maintain presents opportunities to integrate resilience considerations into operations and maintenance activities to enhance the agency's ability to prepare for and respond to weather events and natural hazards.

Phase 6: Monitor provides information on the importance of and how to establish a monitoring and evaluation approach to track progress toward resilience goals and to assess the impact of resilient strategies.

Each section features examples in practice to demonstrate how transit agencies across the country and in a variety of contexts are addressing resilience in practice. Additional examples are included in the Appendix.

Resources and References provides recommended climate data sources and community vulnerability screening tools that can be used to inform a vulnerability assessment. It also provides references to detailed primers and step-by-step guidance on conducting a vulnerability assessment, as well as information on available training and potential funding sources for supporting resilience planning and project implementation.

Transit agencies should consider the policies listed in Table 1 when incorporating resilience into the decision-making and project life-cycle processes.

Table 1 *Relevant Regulations and Policies*

Citation	Title	Summary
Executive Order 14008	Tackling the Climate Crises at Home and Abroad	Calls for domestic and international actions to address climate change impacts and increase climate resilience. Also created the Justice40 initiative to direct 40 percent of certain Federal investments towards disadvantaged communities. Led to the development of the USDOT Equitable Transportation Community Explorer and the Climate and Economic Justice Screening Tool to support the Justice40 initiative and actions outlined under the Executive Order.
FTA Circular 4703.1	Environmental Justice Policy Guidance for FTA Recipients	Provides guidance on incorporating environmental justice principles into plans, projects, and activities that receive funding from FTA. Clarifies existing requirements.
DOT Order 5610.2(a)	Actions to Address Environmental Justice in Minority Populations and Low-Income Populations	Sets forth the USDOT policy to consider environmental justice principles in all USDOT programs, policies, and activities, as well as steps to prevent disproportionately high and adverse effects to minority or low-income populations through Title VI analyses and environmental justice analyses. Describes measures to be taken to address disproportionately high and adverse effects.
49 CFR Part 602	Emergency Relief Program	Describes eligibility and requirements for FTA's Emergency Relief program. Refer to Emergency Relief Manual as a supporting guidance document.
49 CFR Part 673	Public Transportation Agency Safety Plan (PTASP)	Establishes requirements for rail transit agencies to include an emergency preparedness and response plan within their PTASPs.
23 CFR Part 450 (Subparts B and C)	Planning Assistance and Standards	Provides guidance for implementing transportation planning and programming processes, with guidance for States under Subpart B and guidance for metropolitan planning organizations under Subpart C. Regulations cover metropolitan transportation plans, transportation improvement program, long-range statewide transportation plans, statewide transportation improvement plans, and unified planning work programs.
23 U.S.C. 176	Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) program	Provides guidance on eligibility and requirements for the PROTECT program which provides funding to support efforts that increase resilience of surface transportation to natural hazards.
Executive Order 11988 (as amended by Executive Order 13690)	Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input	Directs Federal agencies to consider and address both short and long-term flood impacts of their proposed actions and take measures to prevent or mitigate the impacts. Also establishes the Federal Flood Risk Management Standard, a framework designed to help agencies identify and address current and future flood impacts.
88 FR 1196	National Environmental Policy Act Guidance on Consideration of Greenhouse Gas Emissions and Climate Change	Provides guidance to assist Federal agencies on how to analyze greenhouse gas and climate change impacts of proposed actions under the National Environmental Policy Act (NEPA).
USDOT Order 5650.2	Floodplain Management and Protection	Prescribes policies and procedures for ensuring that proper consideration is given to the avoidance and mitigation adverse floodplain impacts in agency actions, planning programs, and budget requests.
23 CFR part 771	Environmental Impact and Related Procedures	Provides guidance for the FTA, Federal Highway Administration, and Federal Rail Administration for implementing NEPA for highway, public transportation, and railroad actions.
49 CFR part 625	Transit Asset Management	Establishes requirements for public transportation providers to develop and implement Transit Asset Management (TAM) plans. Also provides guidance on the required components of a TAM plan.

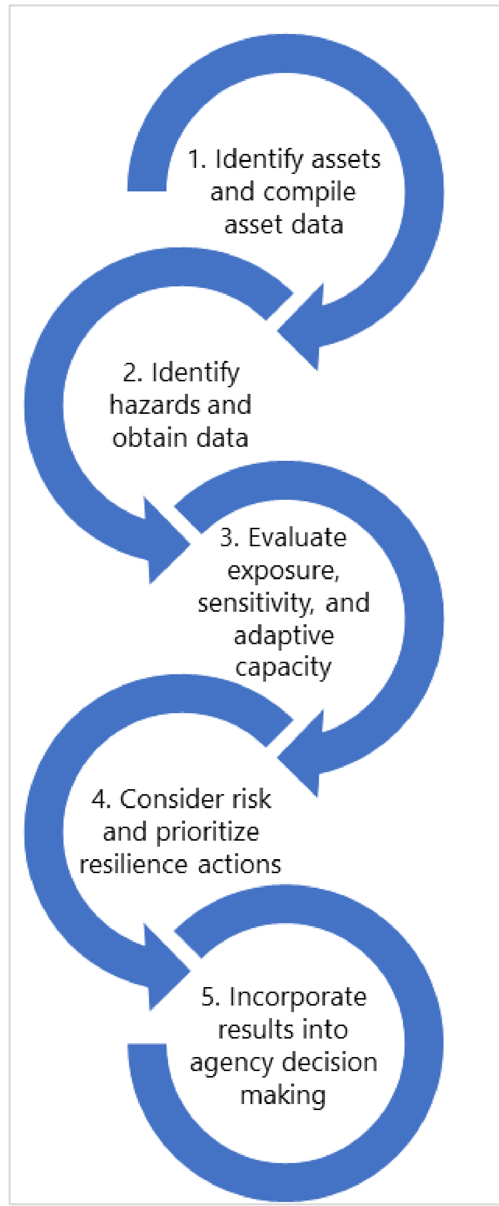
Assess

Overview of Assessing Vulnerability and Risk

Transit agencies need a solid understanding of which assets and populations are most at risk and to which hazards they are most vulnerable to make informed resilience decisions. Once an agency understands its vulnerabilities and risks, it can prioritize actions to prepare and adapt.

In the transit context, a vulnerability assessment is a process to evaluate how natural hazards may impact public transportation systems. It can help agencies to better understand current vulnerabilities and to anticipate how changing climate conditions may affect those vulnerabilities in the future.

Figure 2 Vulnerability Assessment Steps



Vulnerability assessments vary in their scopes, objectives, and timelines. These characteristics are driven by the type of decisions the assessment will inform, the level of detail required to support those decisions, and the resources available to support the assessment. For example, a vulnerability assessment could focus on just one asset type or hazard, or provide a broader, comprehensive view of the total risk confronting the agency across all known natural hazards.

The methodology for conducting a vulnerability assessment as described in this section draws upon two primary sources: the Federal Highway Administration's (FHWA) [Vulnerability Assessment and Adaptation Framework] and the National Oceanic and Atmospheric Administration (NOAA) Climate Program Office's [Implementing the Steps to Resilience: a Practitioner's Guide].

Key vulnerability assessment steps are to:

1. Identify the relevant assets to include in the assessment and compile asset data.
2. Identify relevant weather events and natural hazards and obtain climate data to understand how changing climate conditions may impact hazard conditions.
3. Evaluate the exposure, sensitivity, and adaptive capacity for the selected asset(s) or system(s) to determine vulnerability.

4. Consider risk and prioritize resilience actions.
5. Incorporate assessment results into agency decision making.

Approaches and the resources required to accomplish these steps are not uniform, (i.e., qualitative vs quantitative). Agencies can choose an appropriate approach based on the technical and financial resources currently available, while anticipating datasets or analytical capabilities expected to be helpful in preparing future assessments.

Step 1: Identify assets and compile asset data

The first step in a transit vulnerability assessment is to identify the specific asset types or system services to address in the assessment. Relevant transit assets may include:

- Linear assets, including tracks, bridges, tunnels, guideways, associated utilities, and stormwater management systems;
- Rolling stock, including buses, vans, cars, railcars, locomotives, trolley cars, trolleybuses, ferry boats, and support and maintenance vehicles;
- Facilities, including bus shelters, stations, terminals, parking facilities, garages, maintenance and repair facilities, storage facilities, fuel storage, environmental mitigation facilities, and stormwater management systems; and,
- Power supplies, signals, revenue collection systems, and communication systems.

Agencies should also consider which personnel are essential to operating the transit services.

Recognizing that transit agencies have limited resources and may not be able to focus on all assets, a subset of assets to include can be prioritized based on considerations such as data availability and asset or service criticality. Regarding the latter, a “critical asset” is one that has the potential to significantly impact the achievement of the agency’s objectives. Aspects of criticality to consider are degree of redundancy of the asset or service, its role in emergency management and evacuation, and whether the service supports a transit-dependent or socioeconomically vulnerable community (APTA, 2021).

Ideally, the assessment team will have the resources necessary to compile relevant data for all assets included in the study along with attributes such as:

- Asset location
- Elevation information
- Condition and age of asset
- Level of use (ridership counts)
- Replacement costs
- Maintenance schedule and cost

While some transit agencies may have asset management systems that provide comprehensive datasets needed to inform the vulnerability assessment (see Phase 4), for others, the necessary data may be housed in multiple databases that different departments or agencies manage. For example, inspection and maintenance records, work orders, environmental management systems, and financial management systems can be valuable sources of information to inform a vulnerability assessment. If resources are unavailable to develop a comprehensive database, or if an asset database does not contain necessary information, firsthand accounts from maintenance and operations staff can serve as rich sources of input.

Agencies that find they do not have all the desired data should note those gaps. Agencies that lack a unified database should consider creating a plan for updating it and collecting the relevant data to prepare for future vulnerability assessments such as collaborating with internal or external stakeholders. (See Phase 4 of this Guidebook for recommendations on data to include in capital asset inventories to support future vulnerability assessments).

Step 2: Identify hazards and obtain data

The next vulnerability assessment step is to select the natural hazards and climate stressors to consider (see text box for definitions). Relevant potential natural hazards will depend on the region's climate and topography, among other factors. Hazards that are not currently experienced in an agency's service area may become relevant in the future due to climate change.

Assessment teams should also consider the timeframe the vulnerability assessment is covering when identifying hazards to include. Natural hazards may be chronic, in that they are ongoing and occur over the long-term, or acute, meaning they are sudden (EPA, 2023). The former typically result from gradual changes in climate patterns. In contrast, an acute stressor is typically related to extreme weather events, such as hurricanes, heatwaves, or heavy storms. These events can damage infrastructure and lead to significant transportation service interruptions.

Weather events and natural hazards that may impact public transportation assets and services are listed in Table 2.

Key Terms

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

Climate Stressor: A condition, event, or trend related to climate variability and change that can exacerbate hazards.

Non-climate Stressors: A change or trend unrelated to climate that can exacerbate hazards.

***Photo credit** Leah-Anne Thompson – stock.adobe.com*

Table 2 *Example Natural Hazards and Associated Impacts to Transit Infrastructure and Operations*

Hazard/Weather Event	Potential Impacts to Infrastructure / Disruption of Service (TRB, 2017 and NCA, 2023)
Sea level rise	• Higher water tables and permanently flooded infrastructure • Infrastructure exposure to salt water, tidal flooding, and storm surge • Flooding of waterside ferry terminals, docks, and piers
Coastal storm surge	• Flooded infrastructure • Damaged electrical transmission and signal systems • Bridge, pier, and abutment scouring • Damage from saltwater intrusion • Failure of overwhelmed drainage systems
Hurricanes/tropical storms and other extreme wind events	• Power failures due to high winds, tree, and debris damage • Damage to signage and other overhead structures • Vehicle damage from blowing debris
Coastal erosion	• Bank erosion and destabilization
Inland/riverine/stormwater flooding and erosion	• Flooded infrastructure • Damaged electrical transmission and signal systems • Failure of overwhelmed drainage systems • Landslides, washout land subsidence and erosion along/adjacent to infrastructure
Severe winter storms	• Power failure • Damaged electrical infrastructure from accumulating snow/ice • Need for snow/ice removal operations
Extreme cold	• Rail fracturing • Asphalt heaving/potholes from freeze-thaw • Frozen air lines on locomotives and gelling of diesel engine fuel • More rapid degradation of batteries
Extreme heat/heat waves	• System downtime, derailments, and slower travel speeds due to rail buckling • Overheated electrical equipment and power failures • Sagging and/or failure of catenary systems • Vehicle overheating • Worker/customer health and safety concerns
Drought	• Changes in soil stability affecting track geometry and integrity
Wildfire	• Damaged equipment • System disruption and rerouting of services

Existing hazards are often well understood based on agency experiences. In such cases, resources may be better spent on mitigation efforts then on a multi-system assessment of vulnerability and risk. However, changing conditions, such as changing climate conditions or changes in land use, can create new hazard conditions or exacerbate the effects of hazards in the future.

As part of the vulnerability assessment, the team will need to collect information and data to understand how exposure to hazards may change as a result of changing climate conditions.

Obtain climate data

The assessment team should rely on the best available science to understand and assess the changing climate conditions. The White House Office of Science and Technology Policy's (OSTP) Selecting Climate Information to Use in Climate Risk and Impact Assessments: Guide for Federal Agency Climate Adaptation Planners provides detailed guidance on selecting resources for climate information. The OSTP document provides background information on climate models and projections, scenarios that drive climate model projections, and downscaling techniques. See text box below for an overview of climate projections and scenarios.

Understanding Climate Projections and Scenarios

A global climate model is a mathematical representation of the interactions between and within the ocean, land, ice, and atmosphere. They are used to develop projections for a variety of climate variables, such as temperature and precipitation. Climate models use scenarios to explore different possible climate futures based on a combination of policy, economic, and climatic variables. These futures include the level of emissions over time and their associated impacts. Using multiple, plausible, and decision-relevant scenarios and considering the range of projections within each scenario helps to address the uncertainty in future climate projections. The decision of which climate scenarios to consider for projects can have major implications for the vulnerability assessment; it is always recommended that agencies work with experts, such as Federal and state environmental agencies or universities and research centers, to determine the appropriate scenarios for use. The Federal Flood Risk Management Standard Climate-Informed Science Approach (CISA) State of the Science Report (March 2023) is another helpful source of information on using climate scenarios for flood risk management that assessment teams should consult.

One key consideration is the appropriate timeframe of the climate projections to use in the assessment. A practicable approach would be to use a timeframe that encompasses the useful service life of the asset(s) included in the study, and to include both near- and long-term timeframes, such as 20, 50, and 80 years, that span the useful service life.

Other important considerations are the geographic scale and the level of detail needed to inform the vulnerability assessment. For vulnerability assessments focused on larger areas or more general questions, broad geographic information on projected changes in climate conditions available through national or regional climate assessment reports may be sufficient. Other types of analyses, such as those related to decisions about assets in a specific location, may require more detailed, downscaled climate data. Downscaling refers to using climate data for a larger geographic area to model the expected impacts on a smaller area at a higher resolution: for example, climate data for a region can be downscaled to model the future hazards for a specific city or state.

Data Sources

There are a wide variety of Federal and state resources, many of which are free and easily accessible, that can help practitioners obtain climate projections and to understand how the projected changes will exacerbate coastal flooding, drought, and other hazards.

Table 3 lists three helpful Federal information portals for climate data and additional tools and resources to consider when developing a vulnerability assessment. See the Climate Data Resources and Tools section of this Guidebook for more recommended data sources and tools. Additionally, the FHWA Vulnerability Assessment and Adaptation Framework provides useful information on resources to obtain projections relevant to transportation infrastructure.

If the necessary information and data are not available from existing resources, transit agencies should work with subject matter experts, such as Federal and state environmental agencies or universities and research centers, to develop the needed climate data as resources allow.

Table 3 *Information Portals for Climate Data Resilience Information*

Data source	Description	Author	Geographic extent	Time scale	Hazard(s)
U.S. Climate Resilience Toolkit	Stepwise approach to resilience projects, access to climate projections and indicators, 500+ resources based on region and sector	U.S. Global Change Research Program	U.S.	Varies	Extreme heat, extreme precipitation, drought, sea level rise
Heat.gov	Web portal for the National Integrated Heat Health Information System (NIHHIS)	NIHHIS Federal Partners	U.S.	Varies	Extreme heat
U.S. Global Change Research Program Indicator Platform	High-level indicators of climate change at a broad geographic scale	U.S. Global Change Research Program	Worldwide, Continental U.S.	1900-present	Extreme heat, extreme precipitation, hurricanes, sea level rise

Step 3: Evaluate exposure, sensitivity, and adaptive capacity

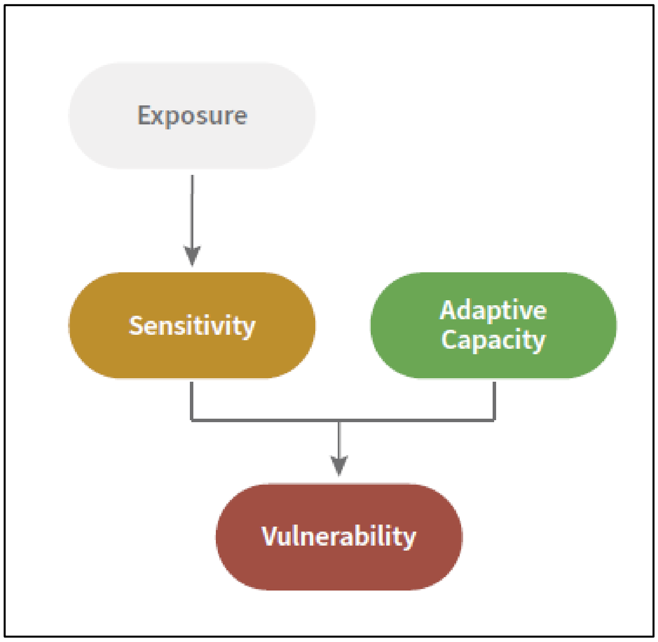
Once an assessment team has collected the relevant asset, hazard, and climate data, the next step is to use the data to identify and evaluate transit assets' or systems' exposure, sensitivity, and adaptive capacity to determine vulnerability (Figure 3).

Exposure refers to the presence of assets and systems in places where hazards could harm them. If an asset is not currently exposed to a hazard, then it is not vulnerable; however, vulnerability assessments should also consider exposure under expected future conditions.

Sensitivity refers to the degree to which an asset or system is or might be affected by its exposure. If an asset could experience a serious impact when exposed to a hazard, then it is considered sensitive to the hazard.

Adaptive capacity refers to the ability of an asset or system to adjust to a hazard, take advantage of new opportunities, or cope with change. In the transit context, adaptive capacity characteristics or design elements could involve the built environment, such as sea walls or nature-based solutions to attenuate flooding; organizational preparedness, such as alternate schedules; and redundancies in infrastructure and service. Increased adaptive capacity can reduce asset or system vulnerability.

Figure 3 Components of Vulnerability. Source: U.S. Climate Resilience Toolkit



The following section describes two approaches assessment teams can take to evaluate an asset's or system's exposure, sensitivity, and adaptive capacity to assess its vulnerability.

Qualitative Approach to Assessing Vulnerability

A qualitative approach to conducting a vulnerability assessment generally involves harnessing stakeholders' past experiences, expert knowledge, and professional judgment to identify and rate potential vulnerabilities. Interviews, online surveys, or workshops are all useful tools to gather information from those with subject matter expertise and local knowledge. Group exercises can be used to gather participants input on how the study assets are used, to map locations of assets that have experienced negative impacts from weather events or natural hazards, to identify thresholds for the types and severity of damages observed and categorize and to weight assets in terms of sensitivity and adaptive capacity to assess vulnerability.

Involving the general public, particularly vulnerable populations, such as older adults, low-income communities, and communities of color, may help agencies to identify system vulnerabilities that are already affecting passengers.

See example below of how Sound Transit used a stakeholder-based approach to assess its vulnerability to extreme weather events and natural hazards.

Example In Practice: Assess Vulnerability

Sound Transit Use of a Qualitative Approach to Assess Vulnerability

The Central Puget Sound Regional Transit Authority (Sound Transit) was one of nine transit agencies that received FTA research funding for pilot projects to identify and address climate change impacts. As part of the project, Sound Transit used a stakeholder input approach to assess vulnerability. The project team held a series of workshops attended by more than 50 technical staff and senior managers. During the workshops, which were organized by Sound Transit, staff identified and qualitatively rated how extreme events affect Sound Transit services including bus, light rail, commuter rail, and paratransit services, and how projected changes in those events could affect operations and planning. Staff also discussed adaptation options, such as retrofitting or replacing infrastructure and changes in maintenance frequencies, as well as approaches to integrating climate change considerations into agency processes, such as implementing tools to gather information related to climate impacts on the transit system and capacity-building activities. Results from the project's workshops were summarized in detail by type of service (bus and rail) and analyzed to assess how climate change may affect Sound Transit. The analysis included a relative ranking of climate change impacts across services as well as a relative ranking of services based on impacts (FTA, 2013). More information about Sound Transit's Climate Risk Reduction Project, including detailed information on the methodology, is available at the following website: https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0075.pdf.

***Photo credit** Sound Transit*

Indicator-Based Assessment

An indicator-based approach provides a way to score and rank assets to determine vulnerability to the identified hazards (FHWA, 2017). Under the indicator-based approach, the assessment team would develop an approach to assign an exposure, sensitivity, and adaptive capacity score for each asset and each hazard included in the study. To do so, the assessment team would need to identify appropriate indicators to use. An indicator is a characteristic of an asset that suggests whether that asset is likely to be vulnerable to a given stressor, either through being exposed, being sensitive, or having low adaptive capacity. The selection of indicators to use is a critical component to the success of this approach. When possible, the indicators selected should be based on complete and consistent datasets across all assets being evaluated (FHWA, 2017).

Example indicators for each category include:

- Exposure indicators:
  - Change in total number of days per year above/below a threshold temperature
  - Presence in a Federal Emergency Management Agency (FEMA) flood zone
  - Modeled sea level rise inundation depth
  - Observed wind speed records
- Sensitivity indicators:
  - Ballast type
  - Rail curvature
  - Age of fleet
  - Condition of asset
- Adaptive capacity indicators:
  - Ability to reroute service
  - Cost of replacement
  - Existence of flood protection features
  - Existence of back-up generators

One overall vulnerability score for each pair of asset and climate hazard is then developed by weighting and combining the exposure, sensitivity, and adaptive capacity scores.

The U.S. DOT developed the Vulnerability Assessment Scoring Tool (VAST) to assist users with conducting a quantitative, indicator-based vulnerability screen of large numbers of assets. VAST is a spreadsheet tool designed to take users through the scoring process in a systematic, results-driven manner.

See the example below of how the Massachusetts Bay Transportation Authority (MBTA) used an indicator-based approach to assess its climate vulnerability.

Example in Practice: Assess Vulnerability using an Indicator-Based Assessment

MBTA Climate Change Vulnerability Assessment Methodology

The MBTA conducts vulnerability assessments to better understand which assets are the most vulnerable to climate stressors in the short-term and long-term and to identify possible adaptation measures to improve overall climate resilience. The agency uses the results of the vulnerability assessment to inform future capital improvement plans for its transit assets.

The agency initially conducted a system-wide assessment in 2018 and has since conducted numerous additional assessments focused on specific aspects of the MBTA system, including its heavy rail and light rail lines; power, signals, and communication systems; pump systems; bus facilities; rolling stock; and commuter rail facilities.

The MBTA created a standardized vulnerability assessment methodology based on the U.S. DOT's VAST tool but tailored the tool to meet specific agency needs. The methodology provides a high-level, indicator-based, screening assessment approach where vulnerability is defined as a function of exposure, sensitivity, and adaptive capacity.

- **Exposure:** Each asset assessed receives an exposure score from 1 to 4 for each of the following climate stressors: extreme heat, precipitation, sea level rise/storm surge, wind, and winter weather. A score is given for each stressor for the years 2030 and 2070. The exposure scores for each stressor and each time period are summed to generate a total exposure score.
- **Sensitivity:** Each asset receives a sensitivity score based on four indicators: asset complexity, critical system sensitivity, past impact/failure, and asset location. The four sensitivity indicator scores are averaged and added together to generate one, scaled sensitivity score from 1 to 4.
- **Adaptive Capacity:** Each asset receives an adaptive capacity score based on four indicators: distance from the central point of the MBTA system, redundancy, presence of backup generators, and flood protection systems. The adaptive capacity score for each climate stressor is calculated by summing the equally weighted scores to generate one adaptive capacity score from 1 to 4.

Vulnerability scores for each climate stressor are calculated for both 2030 and 2070 by summing the exposure, sensitivity, and adaptive capacity scores at equal weights. The vulnerability scores for each climate hazard are then averaged and scaled to generate an overall vulnerability score for each time horizon (see Table 4).

Table 4 *Example of Exposure, Sensitivity, and Adaptive Capacity Scoring for an Asset*

	Exposure 2030	Exposure 2070	Sensitivity	Adaptive Capacity	Vulnerability 2030	Vulnerability 2070
Extreme Heat	2	3	1.75	2.75	1.92	2.25
Precipitation	2	4	3	2	2.33	3.00
SLR/Storm Surge	3	4	3	2	2.67	3.00
Wind	1	1	1.75	2	1.58	1.58
Winter Weather	2	2	1.75	2	1.92	1.92

2030 Vulnerability Score	2070 Vulnerability Score
2.08	2.35

The vulnerability scores for each asset are entered into the MBTA's asset management system for the purpose of informing the Asset Management Department as to which assets are most at risk from climate change stressors and therefore need to have their vulnerabilities addressed through Operations & Maintenance activities or Capital Projects. See the Appendix of this Guidebook for an example of how the MBTA uses the information on vulnerability to inform its Capital Investment Plan.

More information on the MBTA's vulnerability assessments is available on the MBTA's Climate Change Resiliency website.

Integrating Equity Considerations in Vulnerability Assessments

Climate hazards are known to disproportionately impact low-income individuals, people of color, other marginalized groups and historically underserved neighborhoods that already experience chronic economic, social, and environmental challenges. The non-climate stressors these communities face can worsen the impacts of climate hazards and decrease their abilities to adapt to or recover from climate hazards (a lower adaptive capacity).

One example of a non-climate stressor is socioeconomic vulnerability. For example, the impact of a service outage on a low-income community may be greater than on a high-income community, due to higher transit dependency, less job or schedule flexibility, or other factors. Similarly, service disruptions in a food desert may

Refer to the following for further guidance around environmental justice and equity in the context of this Guidebook:

- Executive Order 14008
- FTA Circular 4703.1
- DOT Order 5610.2(a)

negatively impact food access, while it might not in an area with many grocery stores in walking distance. Such stressors may make assets near socially vulnerable communities more critical than other assets.

FTA stakeholders are encouraged to use FTA Circular 4703.1, the U.S. DOT's Equitable Transportation Communities Explorer and the Council on Environmental Quality's (CEQ's) Climate and Economic Justice Screening Tool to explore the cumulative burden communities experience. See Table 10: Non-Climate Stressor and Community Vulnerability Screening Tools in this Guidebook for a detailed list of additional data sources to assess community vulnerability. See text box below for additional guidance on addressing environmental justice and equity, and the example below of how the Los Angeles County Metropolitan Transportation Authority (LA Metro) is integrating equity into vulnerability assessment and resilience planning.

Robust public involvement can also help agencies understand vulnerabilities in disadvantaged communities. Not all socioeconomic vulnerabilities are captured in the above resources. The size of census tracts can obscure small or dispersed vulnerable populations. Furthermore, the limited set of statistical measures may not always reflect communities' experiences of vulnerability. The U.S. DOT's Promising Practices for Meaningful Public Involvement in Transportation Decision Making describes best practices for public involvement, including both in-person and virtual public involvement, that substantively include underrepresented and disadvantaged communities in planning processes. Transit agencies can also partner with MPO, municipal and state governments, and community organizations when conducting public involvement to inform its vulnerability assessment.

Example in Practice: Integrate Equity into Vulnerability Assessment

LA Metro Use of Data to Assess Socioeconomic Vulnerability

People are at the center of the LA Metro's climate change, sustainability, and resiliency program. In addition to Federal sources, the LA Metro uses the California Environmental Protection Agency's database of disadvantaged communities based on CalEnviroScreen, which identifies socio-economically vulnerable communities burdened by multiple sources of pollution. LA Metro has also developed its own vulnerability index and visualization tool to assess socio-economic vulnerability. The Metro Equity Need Index (MENI) considers the concentration of low-income households, Black, Indigenous, and other People of Color residents, and households with no access to a car. The Equity Information Hub allows LA Metro staff and the public to view the MENI index for all census tracts in Los Angeles County as well as current public transportation lines, projects under construction, and planned transit and highway projects. The Rapid Equity Assessment (REA), developed in 2020 in response to the COVID-19 pandemic, allows LA Metro to assess the equity implications of urgent, short-term changes and serves as a starting point to consider equity in longer-term Metro projects, programs, services, and decisions. Two other equity tools, the Metro Budget Equity Assessment Tool and the Equity Planning and Evaluation Tool Pilot, support equitable outcomes in LA Metro's budgeting process, planning efforts, and large-scale, multi-year projects.

LA Metro proactively engages with its stakeholder groups for input and feedback to ensure that programs and projects also provide a platform to enhance community resiliency goals. Some examples of advisory groups and network of community-based organizations the agency engages with include the Metro Sustainability Council, Metro Youth Council, Metro Community Advisory Council, Women and Girls Governing Council, and the aging and disabled communities.

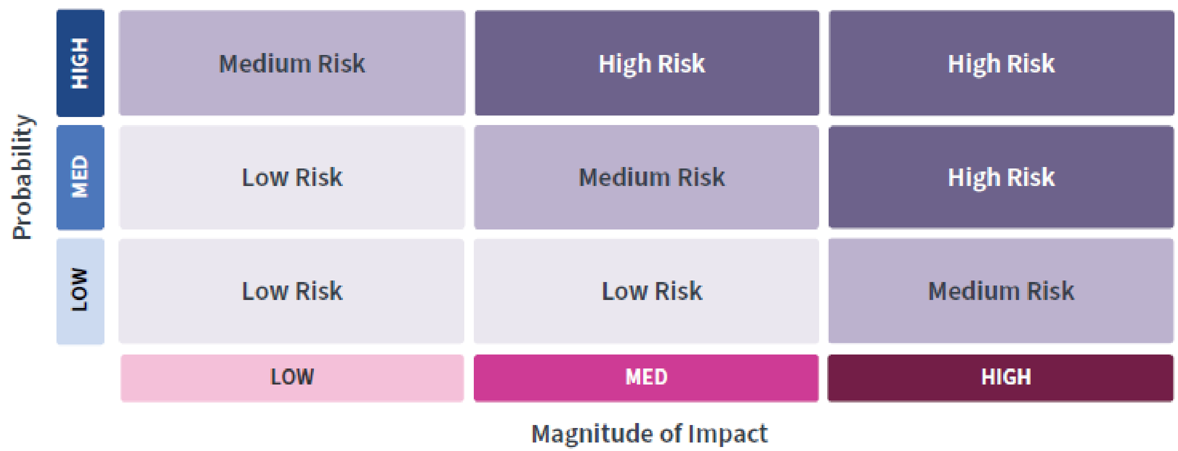
***Photo credit** LA Metro*

Step 4: Consider risk and prioritize resilience actions

Risk refers to the potential for negative consequences where something of value is at stake. It can be assessed by multiplying the probability of a hazard by the magnitude of the negative consequence or loss (NOAA, 2022). Considering risk allows an assessment team to screen for the highest priority assets and transit services exposed to a given hazard, and also to consider options according to different levels of risk.

A risk matrix (Figure 4) is a key tool for any risk assessment. It prompts agencies to assign values for the likelihood and impact of a given hazard. Calculating risk provides for a common scale for comparing different risks even if they affect different assets, have very different probabilities, or result from different natural hazards. A risk assessment may be useful to shed light on transportation assets or services that have low vulnerability, but for which any negative impact would have a high consequence.

Figure 4 Classification of Risk. Source: Gardner et al.



Criticality is one way to consider the magnitude of the consequence or loss and to prioritize assets for resilience improvements. Critical assets may be those that:

- Have the highest negative impacts on safety should they fail;
- Have the highest potential for impacting service;
- Account for the greatest portion of maintenance funds;
- Have a high operational consequence of failure, even if the likelihood is low;
- Serve the most transit-dependent users (APTA, 2021).

See below for two examples of how transit agencies considered risk as part of their vulnerability assessment. See the Guidebook's Phase 3 for further discussion on considering risk in project development and Phase 4 for information on how risk can inform asset management investment decisions.

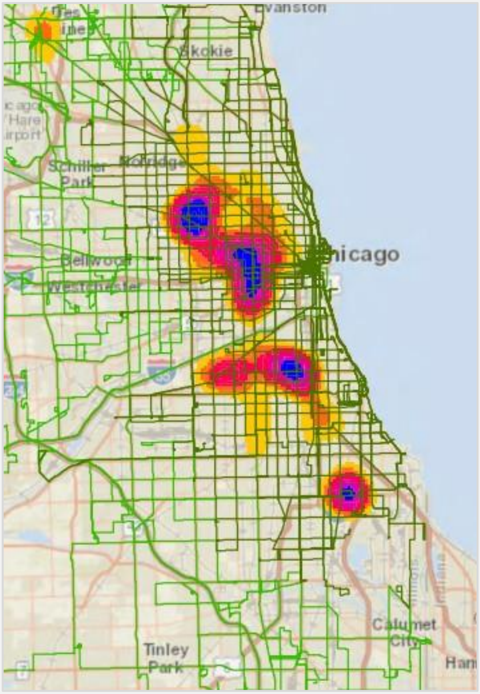
Examples in Practice: Assess Vulnerability and Incorporate into Planning

RTA Flood Resilience Plan for Bus Operations

In Fall 2015, the Regional Transportation Authority of Northeast Illinois (RTA) initiated the Flooding Resilience Plan for Bus Operations project to prepare a bus route flooding resilience plan for the RTA service area in northeastern Illinois. The RTA serves as the governing body and has oversight of Chicago Transit Authority (CTA), Metra, and Pace Suburban Bus (Pace). The objective of the plan, which was developed by a private consultant, was to identify CTA and Pace bus routes that are prone to flooding during both average rain events and extreme weather events and to develop recommendations to address flooding issues and reroute service during flooding to minimize impacts and inconvenience to riders. The study consisted of the following tasks:

1. **Identifying Current Flooding Hazards in the Chicago Area.** The team collected a robust set of quantitative and spatial data focused on existing floodplains, floodways, and socioeconomics as a starting point for identifying high-risk areas that are vulnerable to riverine and overbank flooding. Datasets included:
   - Geospatial data on the location and characteristics of FEMA flood risk zones.
   - Geospatial data on the locations of viaduct and road closures on County roads.
   - Socio-economic geospatial data for the RTA service area.
   - Shapefiles and General Transit Feed Specification data on CTA and Pace bus routes and stops.
   - CTA data on historic flooding incidents (date, time, location, and type of event, along with additional notes from the operator, the route number, and the disposition of the event). These data were plotted in GIS and the density of flooding incidents was calculated to generate flooding incident hot spots (Figure 5).

***Figure 5** Bus Routes with CTA-Reported Flood Incident Hot Spots. **Source** RTA LA Metro*



The team also incorporated public participation and outreach by conducting a series of stakeholder interviews to collect input from CTA and Pace bus drivers, operations management, riders, emergency management stakeholders, and local departments of stormwater management to identify additional areas of known flood prone areas.

2. **Identifying Critical Service Routes to Assess Risk.** The team then assessed CTA and Pace bus routes across the following scenarios to prioritize bus routes for further analysis.
    - Scenario A - Routes with reported flooding and located in flood zones, ranked by ridership.
    - Scenario B - Routes with reported flooding, ranked by ridership.
    - Scenario C - Routes in flood zones, ranked by ridership.
    - Scenario D - Routes with reported flooding or located in flood zones, ranked by ridership.
    - Scenario E - Routes with reported flooding, ranked by system connectivity and ridership.

    CTA and Pace each selected specific routes to focus on to conduct more detailed flooding impact analysis. CTA selected the "workhorses" of the CTA network, routes associated with moving large volumes of passengers across the city and making vital connections between transit modes, as well as routes connecting residential communities to downtown and other employment centers. Pace selected the routes from Scenario E. The prioritized bus routes were then analyzed according to the socio-economic characteristics of the populations they traverse.

3. **Examining Impact of Climate Change on Flood Hazards.** The project team examined the effects of changing climate patterns on the flood risk landscape in the region. The team solicited input from stormwater and water resource engineers and scientists to assess whether forecasted increases in precipitation are likely to worsen risk conditions for the prioritized bus routes identified.

4. **Identifying Adaptation Options Prepare a Resilience Plan.** The project team prepared responses to the identified flooding risks in three major categories: reroute plans for impacted bus routes, communications strategies for updating impacted stakeholders of service interruptions, and inventories of potential mitigation projects and recommendations, with suggested next steps for items outside an agency's control. As part of developing the reroute plan, the team quantified the potential impacts on CTA and Pace service and operations due to bus reroutes to avoid impassable flooding on street or under viaducts due to severe rain events. Quantifying the impacts of rain-related reroutes enables the agency to understand the benefit-cost ratio associated with potential investments in infrastructure projects to mitigate, minimize, or reduce flooding, now and in the future under expected climate change scenarios.

Since developing the flood resilience plan for bus operations, neither CTA nor PACE have experienced flooding events that resulted in long-lasting detours.

LA Metro Risk Assessment

The LA Metro conducted a risk assessment to identify potential risks that climate change might pose to its systems and riders. The risk assessment included a wide variety of assets from the agency's Enterprise Transit Asset Management database, including bus rapid transit, light rail, subway, park and ride lots, bike share stops, terminals, stations, and other facilities. For each asset, Metro assigned a risk level associated with seven climate hazards:

- Extreme heat
- Electrical outages
- Landslides and mudslides
- Heavy precipitation events
- Riverine flooding
- Sea level rise and coastal flooding
- Wildfires

Risk was measured as a function of two components:

1) **Vulnerability**: Measured as a function of exposure, sensitivity, and adaptive capacity. The specific indicators used to assess exposure varied based on the climate hazard. Individual scores for exposure, sensitivity, and adaptive capacity for each asset were averaged to generate a vulnerability score on a scale of 0 to 5.

2) **Criticality**: Measured based on eight indicators of an asset's role in contributing to LA Metro's mission. The criticality indicators used were ridership, transit dependency, connectivity, lack of redundancy, role in emergency response, joint development site, economic impact, and priority economic zone (i.e., how much the asset contributes to enhancing economic opportunity in the region). Each asset received a rating of 1 to 5 for each indicator; the ratings were then averaged to develop an overall criticality score for each asset.

A risk score was computed for each asset as the product of its vulnerability score and criticality score, by hazard (see Figure 6 for an illustrative example). The overall risk scores are on a scale of 1 to 25. See Figure 7 for the risk matrix and risk rating assigned to each risk score.

***Figure 6** LA Metro's Formula for Calculating Risk Scores of Assets. Source: LA Metro Climate Action Plan*

Underlying Indicators	Value	Score (1-5)	
Expected increase in very hot days	32 more hot days by 2050	5	Vulnerability Score 4.3
Sensitivity to extreme heat	High; may be severely damaged or subject to costly and extended repair	5	
Adaptive capacity to extreme heat	Medium; Minor engineering modification to asset possible to avoid impact	3	×
Ridership	5 million boardings	5	Criticality Score 3.5
Serves transit-dependent populations?	Yes	5	
Connectivity	52 connections to other modes	5	
Lack of redundancy	43 replacement assets	1	=
Role in emergency response?	Yes	5	
Joint development site near asset?	No	1	Risk Score 15.2 (High)
Jobs served	1,000	5	
Serves priority economic zone?	No	1	

Figure 7 Metro Risk Rating Matrix. Source: LA Metro Climate Action Plan

Criticality \ Vulnerability	0	1	2	3	4	5
5	0	5	10	15	20	25
4	0	4	8	12	16	20
3	0	3	6	9	12	15
2	0	2	4	6	8	10
1	0	1	2	3	4	5

Risk Score Range	Risk Rating
Risk = 0	Negligible
1 ≤ Risk < 6	Low
6 ≤ Risk < 11	Medium
11 ≤ Risk < 17	High
Risk ≥ 17	Extreme

In addition to the quantitative risk assessment, LA Metro also conducted interviews with employees across a wide range of departments and specialties to collect data on current climate vulnerabilities and progress made toward addressing these risks. These discussions supplement the risk analysis and provide important information on incorporating current climate risks with future projections.

Based on the results of the risk assessment, LA Metro has implemented several projects to increase the resilience of its system to climate hazards. Highlighted activities include:

- Implement pre-emptive inspection and maintenance of the bus fleet to ensure air conditioning units are working properly to minimize impacts to passengers during heat wave season.
- Tested new technology to replace balance weight component of the overhead catenary system to minimize impacts of extreme heat on system operations.
- Revised design criteria to incorporate thresholds and requirements based on climate change projections.

See LA Metro's Climate Action and Adaptation Plan for more details on its risk assessment methodology and results.

Step 5: Incorporate results into agency decision making

Ideally, the outcomes of a vulnerability and risk assessment process include:

- Information on the level of hazard exposure for agency assets and activities.
- A clear understanding of the vulnerabilities of agency assets, activities, and the communities they serve.
- Prioritized list of vulnerable assets based on risk;

Practitioners can use these outputs to identify resilience and adaptation options to address vulnerabilities.

Improving transit infrastructure resilience cannot be achieved through the actions of any one agency department. Instead, resilience must be considered and implemented throughout an agency's decision-making processes. In addition, there is no one size fits all approach to resilience. Rather, the appropriate adaptation measure and strategy is driven by the specific assets and services impacted and the nature of the vulnerabilities to be addressed. An agency-wide approach to building resilience will likely require a suite of solutions, including short-term actions that may be relatively easy to implement with minimal financial resources, as well as long-term solutions that require planning and design and more robust financial investments to complete.

There are four broad categories of resilience strategies: avoid, maintain and manage, strengthen and protect, and enhance redundancy (see Figure 8). Each category should be evaluated and re-evaluated throughout every phase of the decision-making and project life-cycle processes.

See Table 5 for example resilience and adaptation measures organized by hazard type and relevant transit infrastructure and operational component.

Figure 8 *Categories of Resilience Strategies*
Photo credit *Getty images*

Avoid: Avoid locating new transit systems and assets in areas with known vulnerabilities. Remove transportation infrastructure located in extremely vulnerable locations or relocate infrastructure away from the hazard.

Example: Locate HVAC systems on rooftops to protect from potential flood damage.

Maintain and manage: Conduct scheduled maintenance to preserve the usefull life of assets and mitgiate impacts of stressors. Manage the response to extreme events and hazards through advanced preparation and emergency prepardedness.

Example: Conduct scheduled maintenance inspections to ensure assets are operating at most efficient capacity.

Strengthen and protect: Design/retrofit infrastructure and assets to withstand future climate conditions. Build protective features – either conventionally engineered or through nature-based solutions - to reduce or eliminate exposure to the hazard.

Example: Install riprap along embankment.

Enhance redundancy: Ensure that systems and services can be supplied by alternatives in the event of an interruption or failure along with emergency evacuation.

Example: Install back up power.

Table 5 *Example Resilience and Adaptation Measures*

	Vehicles	Stations and Facilities	Streets, Transit Routes, and Corridors	Mechanical and Electric Equipment
Flooding and sea level rise	• Move vehicles and other portable assets out of harm's way areas prone to flooding when extreme rainfall is predicted.	• Modify/raise ventilation grates. • Install physical barriers and floodgates. • Enhance stormwater management i.e., rain gardens, green roofs, stormwater ponds, pervious pavements. • Elevate bus and train stations and entrances ensuring safe access for all with ramps. • Avoid underground or low-lying depots prone to flooding for bus fleets. • Assess salinity and lateral force impacts on buildings and infrastructure from sea water intrusion. • Create living shorelines, alone or in combination with sills and berms.	• Avoid new mass transit corridors in flood prone areas. • Raise track elevation in flood prone areas. • Install watertight maintenance hole covers. • Consider the use of porous pavements for streets in flood-prone areas. • Build water tanks, catchment, and drainage when building new streets or transit infrastructures. • Develop evacuation re-route plans for bus routes that are frequently impacted by flooding. • Develop emergency evacuation plans for all transit routes and establish emergency response relationships with adjacent communities. • Develop communication strategies to update impacted stakeholders of service interruptions or route changes. • Enhance protective measures along coastal routes, such as marsh vegetation, dune restoration, sea walls, etc. Update service interruption plans to accommodate more service interruptions.	• Elevate or floodproof power houses, switch houses, and other electrical equipment to accommodate flooding/sea level rise. • Ensure watertight sealing of duct banks, conduits, or other penetrations to a structure. • Create system redundancy for increasing frequency of extreme weather. • Acquire back-up power sources to support critical systems for multiple days. • Install submersible de-watering and pumping systems. • Make electrical infrastructure (plants and distribution) flood proof. • Thoroughly insulate electric infrastructure, or avoid installation altogether, within coastal land impacted by high tide, storm surge or sea level rise. Install backup power for subway de-watering pumps and for charging electric fleets in case of damage.

	Vehicles	Stations and Facilities	Streets, Transit Routes, and Corridors	Mechanical and Electric Equipment
Extreme Heat	• White paint on bus roofs. • Tinted windows to shade off the sun. • Installation of thermometers displayed inside vehicles, for easy user monitoring of transit conditions. • Energy-efficient air conditioning in facilities and rolling stock. • Implement pre-emptive inspection/maintenance of vehicles' air condition systems.	• Shaded bus shelters and misters. • Shading & greening of transit stations (e.g., green walls, cool roofs). • Misting systems of waiting areas. • Drinking water fountains. • Reflective roofs on facilities. • Higher performing building insulation.	• Cool pavements (with higher solar reflectance) on bus routes and waiting areas to lower surface temperature. • Greening of transit routes: e.g., grass on tramlines to lower surface temperature, or street trees to create shade. • Greening and shading of walking and cycling main access routes. • Directly monitor rail temperature through use of thermocouples to determine when to issue slow orders. • Make structural changes to track or track bed to reduce the potential for rail buckling.	• Enhance ventilation systems for electrical equipment.
High Wind		• Higher wind-rated roofs. • Higher wind rated windows, bus shelters, kiosks, and other stations and facility infrastructure.	• Higher wind-rated bus shelters, signage, emergency preparedness and evacuation route signage. • Installation of cameras and/or wind sensors.	• Stronger equipment supports for wind loads.

The next Guidebook sections examine how transit agencies can incorporate vulnerability- and risk assessment-informed resilience decisions at each stage of a project's life cycle, as follows:

Phase 2: Plan

Phase 3: Design and Construct

Phase 4: Manage

Phase 5: Maintain

Phase 6: Monitor

Each section provides detailed guidance on how to address and promote resilience during the given project phase and features examples in practice to demonstrate how transit agencies across the country are addressing resilience in practice.

***Photo credit** Getty Images*

Phase 2

Plan

Overview of Integrating Resilience into Transit Planning and Project Selection

Once a vulnerability assessment is completed, the next phase of the resilience planning framework is to incorporate that knowledge into the day-to-day decisions of the agency during all phases of a project lifecycle, beginning with planning.

Many of the natural hazards and climate stressors that threaten transit assets and systems also threaten surrounding communities. Instead of working in silos, FTA encourages transit agencies to collaborate with local, State, and Federal partners to share information regarding their known vulnerabilities and risks and to coordinate on how to effectively address those issues to ensure an efficient use of public resources. The transportation planning process provides a venue for such coordination at a regional scale. In addition, incorporating resilience into transit agency-specific planning efforts can help ensure that resilience is considered at the earliest stages of setting agency priorities.

Relevant Regulations and Policies for Considering Resilience in Planning

Transportation planning is a cooperative, performance-driven process by which short- and long-range transportation improvement priorities are determined. Federal transportation planning regulations require the development of various planning and programming documents for metropolitan areas, non-metropolitan areas, and statewide settings. These include:

- Metropolitan Transportation Plan
- Transportation Improvement Program
- Long-Range Statewide Transportation Plan
- Statewide Transportation Improvement Plan
- Unified Planning Work Program
- State Planning and Research Work Program

> FTA and FHWA published "A Guide to Transportation Decision Making" which details different transportation plans and programs and the roll the public plays in the decision-making process.

Federal transportation planning regulations also require the transportation planning process to consider projects, strategies, and services that will improve the resilience and reliability of the transportation system and reduce or mitigate stormwater impacts of surface transportation (23 CFR 450.206 and 450.306). By actively participating in the transportation planning process at the metropolitan and state level, transit agencies can help ensure their resilience needs are considered.

FTA, in coordination with FHWA, included "Tackling the Climate Crisis" among the updated Planning Emphasis Areas in 2021. This planning emphasis area includes ensuring that transportation plans and infrastructure investments increase resilience to extreme weather events and other disasters resulting from the increasing effects of climate change (FTA and FHWA, 2021).

Under the Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) Program, State DOTs and MPOs are encouraged to develop Resilience Improvement Plans as part of their transportation planning processes. Resilience Improvement Plans are risk-based plans, with immediate and long-term planning horizons, that address vulnerable transportation and demonstrate a systemic approach to surface transportation system resilience (23 U.S.C. 176(e)). While not required, having a Resilience Improvement Plan can reduce non-Federal match by up to 10 percent for both PROTECT Formula and Discretionary Grant projects (23 U.S.C. 176(e)(1)(B)). Transit agencies can work with their respective MPO or DOT to ensure transit is incorporated into the Resilience Improvement Plans. In addition, transit agencies can apply for funding under the PROTECT discretionary grant program to fund resilience planning activities (see text box).

PROTECT Discretionary Grant Program

The PROTECT Discretionary Grant Program provides $1.4 billion in funding through competitive grants over a five-year period (FY22 – FY26). The vision of the PROTECT Discretionary Grant Program is to fund plans and projects that address the climate crisis by improving the resilience of the surface transportation system, including public transportation. For information on applicant eligibility, current awards, and future grant rounds, please visit the PROTECT Program website.

Transit agencies also conduct a variety of other planning efforts to inform their investment decisions, including developing strategic plans, vision documents, climate action plans, capital improvement plans, etc. Transit agencies are encouraged to incorporate resilience into these various planning efforts to align planning priorities and ensure actions at the various levels of transit planning increase resilience.

Integrating Resilience into Transit Planning and Project Selection

Practitioners have multiple opportunities to integrate resilience considerations into existing transit planning processes:

- **Vision and goal statements** – The vision and goals are the foundation of the planning process and inform the policies, programs, and projects that derive from the plan. These statements represent the key priorities and desired end state for the transportation system. Agencies can integrate resilience, either as a standalone goal or as part of the objectives related to a goal, to ensure that resilience is considered during the analysis and decision-making process. Example resilience goals and related objectives include:
  - Ensure that new transportation infrastructure is designed to withstand projected future environmental conditions.
  - Improve the resilience of the transportation system to withstand extreme conditions.
  - Create equitable, reliable, and resilient multimodal infrastructure.
  - Reduce weather-related delays in the transportation system.
- **Resilience-focused performance metrics** – When developing performance metrics within short-term and long-term planning

processes, such as asset management plans, safety plans, capital plans, and long-range transportation plans, consider the inclusion of resilience-focused metrics. Including resilience-focused performance metrics can help drive implementation of resilience strategies across agency departments, provide insight on the performance of resilience strategies, and illustrate the need for further improvements or alternative strategies. Examples include:

  - Frequency of Extreme Weather Events: Measure the occurrences of extreme weather events impacting transit operations to assess the effectiveness of existing measures and need for further investment in resilience strategies.
  - Downtime and Service Disruption Duration: Track the duration, location, and costs of service disruptions caused by weather-related events, providing insight into the system's ability to recover.
  - Costs associated with repairs, loss in fare collection, and emergency services resulting from extreme weather events: Track the costs resulting from extreme weather events.

- **Use of future climate conditions to inform alternate investment strategies/scenarios** – Considering future climate conditions rather than relying only on historical data ensures that planning is more proactive, rather than waiting for future destructive events to dictate changes in practice. One method for effectively incorporating resilience into planning efforts is scenario planning. The technique assesses risks over a range of plausible futures, incorporating potential changes in socioeconomic and climate trends and assists agencies in selecting actions that are robust across potential futures.

- **Use of resilience as a metric when scoring projects for inclusion in Transportation or Capital Improvement Plan** – Agencies often establish a set of evaluation criteria to determine which projects to prioritize for the limited available funding. Including resilience as a criterion in project prioritization enables the formal consideration of whether a project supports or detracts from achieving the agency's resilience goals. For example, projects can receive points if they increase the agency's climate resilience, or alternatively, be disqualified if they would construct new facilities in high-risk areas. See Phase 4 in this Guidebook for more information on how resilience criteria can be used in investment prioritization.

- **Coordination and communication with stakeholders on resilience activities and areas of concern** – Establishing a dedicated communication framework to engage transit users, particularly those from vulnerable populations, local communities, regional planning agencies, environmental agencies, emergency response organizations, and other stakeholders in resilience planning will allow transit agencies to foster transparency and collaboration. By regularly engaging with stakeholders to share data and knowledge on vulnerabilities and to plan collective action can help enhance transit system resilience for all users and support community resilience.

Examples in Practice: Integrating Resilience into Planning Activities

LA Metro Multifaceted Approach to Inclusion of Resilience in Planning Activities

LA Metro has woven climate resilience priorities, programs, and goals into its strategic planning efforts to ensure a comprehensive integration of resilience and adaptation throughout the agency's operations. The agency's 2020 Long Range Transportation Plan is a financially constrained plan that examines how LA Metro's future transportation investments can be leveraged to achieve the maximum mobility benefits for all of LA County. The plan recognizes that Southern California is facing threats from a changing climate, such as increasingly frequent and severe fires, mudslides, rising urban temperatures, and the associated impacts on the public health and livelihood of its residents. It also acknowledges that LA Metro must improve the sustainability and resilience of its system through active asset management, life-cycle cost analysis for transportation projects, and proactive planning for severe climate events. One of the key strategies in the plan is the "Improve the resiliency of Metro's transportation system" (LA Metro, 2020). LA Metro has been addressing this strategy through risk assessments, decision making that considers all hazards, and climate adaptation plans and policies.

LA Metro developed the 2019 Climate Action and Adaptation Plan (CAAP) and 2020 Sustainability Strategic Plan, *Moving Beyond Sustainability*, to inform and align the agency's long-term priorities around climate resilience, environmental sustainability, and improve agency operations. These plans outline specific resilience goals, targets, and planned strategies and actions that support the agency's broader goals and priorities as outlined in its Long Range Transportation Plan. In 2022, LA Metro also completed its Hazard Mitigation Plan that further enhances its approach to managing the resiliency of current and future assets. The Hazard Mitigation Plan provides a detailed discussion of how climate change is an essential consideration in an all-hazards planning process. These three documents provide a comprehensive approach to identify all acute and chronic stressors that affect the resilience of critical or vulnerable areas at or near Metro infrastructure.

Like many major transit agencies, LA Metro is contending with how to keep assets in a state of good repair and minimize recovery times when addressing the higher and more intense frequencies of different stressors. The agency continually identifies the need to establish pro-active holistic best practices, especially when systems, operations, and services are interrupted. For example, in 2023, the Los Angeles area has recently experienced significant wet weather events fueled by atmospheric rivers that resulted in widespread flooding across the region, including flooding of LA Metro's Union Station. The lessons LA Metro learned from this event helped the agency significantly reduce the chance of another flooding event and service disruption at the same location when the region experienced another atmospheric river event in 2024. Another example is on electric vehicles integration into their revenue and non-revenue fleets.

The agency is also continually including the flexible adaptation pathways framework in all planning, procurement, asset management, and operations. The flexible adaptation pathways framework calls for each project to have a sustainability plan.

Through a collaborative approach that is sensitive to the project and program delivery method, the framework integrates vulnerability considerations, alternative options, and decision points into project and program design and development to encourage adaptability and flexibility to mitigate hazard risks. For example, when building a new Metro Rail station, the agency and its engineers opted to increase the height of the platform based on the 50- and 100-year storm event data rather than the 25-year storm. LA Metro also established a sustainable acquisition program that is designed to involve and engage contractors and staff on environmental compliance, sustainability, resiliency, and environmental justice principles to ensure new designs and projects incorporate the agency's equity, environmental, climate change, sustainability, and resiliency goals.

Finally, LA Metro has taken an active approach to prioritizing investments towards equity-focused communities. First developed in 2019 and updated in 2022, LA Metro's 2022 Equity Focus Communities (EFCs) interactive map serves as an internal tool to assess the needs, burdens, and opportunities for transit-dependent populations and how the agency can prioritize investments in those populations. As a part of resilience and adaptation efforts, the agency also released a Climate Change Resilience Map to further support the visualization and analysis of climate risk identification for existing and planned Metro assets, and to address the intersection of climate resilience and equity in Metro's service area. Additional information of this map as well as other related resources could be found at on Metro's Sustainability Program and Equity Hub sites.

Integration of renewable energy into bus stops. Photo credit: LA Metro

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Yuba-Sutter Transit Authority Consideration of Resilience in Facility Planning

The Yuba-Sutter Transit Authority received an Adaptation Planning Grant from Caltrans in 2019 to develop the Resilient Next Generation Transit Facility Plan for a replacement maintenance, operation, and administration facility. The Yuba-Sutter Transit Authority worked with a planning and engineering firm to identify, analyze, rank, and study the potential sites, study the resilience of potential sites, and provide design criteria for the future facility. Each potential site was evaluated against 40 criteria, which included: wildfire risk/resilience, flood risk, emergency response to extreme events/natural disasters, levee protection rating, use as an evacuation center, and drainage. The original 16 sites were narrowed down to the top three. For each of the three recommended sites, the team reviewed potential hazards associated with climate change and their effects, with a particular focus on flooding, heat waves, and wildfire. The team also identified potential adaptation strategies for these hazards. Potential strategies identified include development of temporary disaster-related vehicle relocation plan and practice, floodproof server room, requiring HVAC and other cooling measure to meet specific future climate scenarios, installing an emergency backup power generator, and use of defensible space zones (Figure 9 **Defensible Space Zones. Source: Cal Fire**).

Figure 9 Defensible Space Zones. Source: Cal Fire

The team conducted a cash flow analysis to forecast the funding and capital costs associated with the three potential sites. Based on the financial analysis, Yuba-Sutter Transit Authority identified a preferred site – Site 3 in the Facility Plan (WSP, 2021). The plan for the new facility includes the development of a renewable energy DC microgrid based on a significant amount of onsite photovoltaic energy production and storage to meet the agency's current and future energy needs for battery electric bus and agency vehicles, maintenance and operations facilities, and employee and public charging stations. While the agency has not yet completed final design for the new facility, current plans include climate-appropriate and drought-resistant landscaping, elevated charging cabinets and overhead charge dispensers that would protect critical infrastructure during a flooding event, emergency backup batteries/power generators, and microgrid management software with switch controllers to maintain continuous power for essential services during power outages and natural disasters. Additionally, the site plans include defensible space to serve as a buffer around the site facilities to protect critical infrastructure from threats of wildfire (Yuba-Sutter Transit, 2022).

Integrating Resilience into Emergency Preparedness and Recovery

The frequency and severity of extreme weather events has increased and will likely continue to increase due to climate change in most regions of the United States and its territories. When developing emergency preparedness plans, agencies should consider changing conditions instead of relying on baseline data and past experiences. This type of planning would specifically consider how the transit agency can prepare for potential future disasters and what actions they would take post-disaster.

Future conditions relevant to emergency planning can include change to seasonality, such as hurricane season lasting longer, and change to location, such as flooding occurrences in entirely new areas or increasing wildfire risk in areas that have not traditionally been considered high-risk or have not burned in decades.

Emergency Preparedness in Statute:

The Public Transportation Agency Safety Plan (PTASP) Final Rule (49 CFR Part 673) requires rail transit agencies to include an emergency preparedness and response plan within its PTASP:

> *49 CFR 673.11(a)(6) – A rail transit agency must include or incorporate by reference in its Public Transportation Agency Safety Plan an emergency preparedness and response plan or procedures that addresses, at a minimum, the assignment of employee responsibilities during an emergency; and coordination with Federal, State, regional, and local officials with roles and responsibilities for emergency preparedness and response in the transit agency's service area.*

Future conditions relevant to emergency planning can include change to seasonality, such as hurricane season lasting longer, and change to location, such as flooding occurrences in entirely new areas or increasing wildfire risk in areas that have not traditionally been considered high-risk or have not burned in decades.

The following considerations may be appropriate when integrating resilience measures into emergency planning:

- Existing standard operating procedures for emergency events may not account for changing conditions and therefore should be updated to reflect current and future risk.
- Plans should integrate new measures to maintain, strengthen, protect, and secure assets critical to emergency response or evacuation procedures, such as moving a bus fleet to higher ground, dispersing the fleet across multiple facilities to reduce flood risk, increasing maintenance of stormwater management areas (i.e., clearing debris), or other efforts which enhance redundancy of the transit system. Ensure that agency plans that require the evacuation of equipment or assets are addressed through new or updated agreements with operators, facility management teams, or other partners.
- Existing assets may need to be replaced or updated to handle changing conditions, such as procuring high-water vehicles for evacuation support.
- Due to the interconnected nature of emergency planning, creating strong

community relationships and clear lines of communication with state and local partners must remain a priority when considering changing hazards. Transit agencies are encouraged to maintain close relationships with their State Emergency Management Agency. This group, which is responsible for coordinating the activities of State agencies who assist local governments, voluntary organizations, and private industry, provides a variety of emergency management programs, such as hazard identification, loss prevention, training operational response to emergencies, technical support, and disaster recovery assistance.

See FTA's Emergency Relief Manual (Section 2) for additional disaster preparation recommendations and guidance.

For more information on incorporation of emergency preparedness and response plans and procedures refer to FTA's National Public Transportation Safety Plan website and Emergency Preparedness and Response Plans workshop.

MTA Subway station closure Photo credit Getty Images

Example in Practice: Resilience in Emergency Preparedness

Houston Metro Emergency Planning Activities

Transit not only provides a critical service during normal operations, but it also has significant value during natural disasters. In August 2017, Hurricane Harvey brought historic amounts rainfall over Southeast Texas (NOAA, 2017). In large part due to careful planning in the aftermath of previous disasters, the Metropolitan Transit Authority of Harris County (Houston Metro) was able to demonstrate how vulnerabilities can be assessed, and longer-term strategies designed to address future weather events. Before, during, and after Hurricane Harvey, Houston Metro's agility allowed it to minimize possible damage to its vehicles so it could resume service as soon as possible, while avoiding repair or replacement costs.

As Harvey loomed, Houston Metro relied on checklists of extreme weather event responsibilities that it had previously developed based on learning from previous floods. The checklists describe approaches to and responsibilities for securing vehicles, assuring essential staff are on duty, and coordinating communication protocols with emergency managers, first responders, the public, and the news media (Gurley, 2018). Houston Metro Operations staff thought quickly about where its low-lying facilities and routes were and acted accordingly. The agency moved 120 buses parked in a low-lying depot near downtown Houston to an elevated section of a high-occupancy vehicle lane in the center of Interstate 69 (Left photo). The queue of buses extended more than a mile. Other assets were similarly relocated in efforts to protect them. Additionally, the agency had purchased highwater vehicles (Right photo) after floods in 2015 and 2016 (Transit Center, 2017). These were called into action during Harvey along with school buses borrowed from neighboring Harris County Transit that were also able to drive through flooded areas. During the storm, Houston Metro staff worked with emergency managers and first responders to decide where to deploy the vehicles to help with evacuations (Gurley, 2018).

After the storm, Houston Metro knew which service it wanted to restore first and had pre-existing agreements for services like tree removal to help limit competition with other organizations to secure contractors after a major storm. Except for a few detours, the system was mostly up and running a little more than a week after the hurricane (Gurley, 2018).

Staging of Metro buses
***Photo credit** Houston Metro*

Metro High water vehicle
***Photo credit** Houston Metro*

Resilience in Recovery

FTA's Emergency Relief program (49 CFR Part 602) enables FTA to aid public transit operators in the aftermath of an emergency or major disaster. FTA Emergency Relief Program funds can be used for capital projects to protect, repair, or replace facilities or equipment in danger of or impacted by serious damage as a result of an emergency, including natural disasters, such as floods or hurricanes. FTA encourages recipients to incorporate cost-effective resilience measures into their replacement and repair projects. FTA can also make funding available under the Emergency Relief Program for projects that improve the resilience of transit systems. The FTA Emergency Relief Manual serves as a comprehensive guide for eligible recipients, offering detailed instructions on the application process, eligible expenses, and compliance requirements to streamline and expedite the recovery efforts.

Since 2012, FTA has provided billion[2] in emergency relief funding to transit agencies to assist with recovery from and enhance resilience to natural disasters, emergencies, or significant events that disrupt transit services. This funding included support for resilience projects for transit agencies in the Northeast affected by Hurricane Sandy, which caused the worst transit-related disaster in U.S. history, as well as other agencies across the U.S. that experienced damage earthquakes, winter storms, typhoons, landslides, flooding, and high winds.

Example resilience projects made available by the Disaster Relief Appropriations Act of 2013 (Pub. L. 113-2) as FTA Emergency Relief Program funds include:

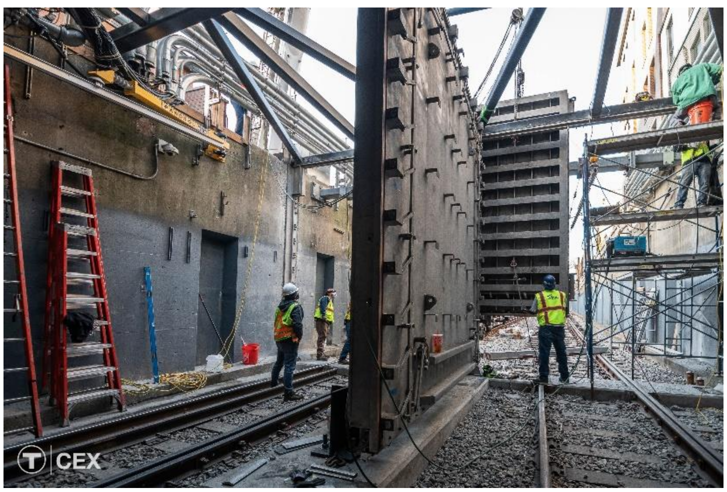
- FTA provided NJ Transit with Emergency Relief Program funding for the Hoboken Long Slip Fill and Rail Enhancement Resilience Project. The project will modify the Long Slip, a 2,000-foot former barge canal adjacent to the Hoboken Terminal Yard, to eliminate it as a conduit for flood water. The canal will be filled to an elevation above the FEMA base flood elevation, and six new tracks will be constructed on the filled area to serve three high-level ADA-accessible boarding platforms. The elevated position of tracks and platforms will permit the rapid recovery of commuter rail services to and from Hoboken Terminal and its associated Hudson Bergen Light Rail and ferry services, while the main terminal and yard infrastructure are being restored following a storm, and the continuation of services when the terminal and yard are taken out of service in advance of an impending storm.
- FTA provided NJ Transit with Emergency Relief Program funding for the Delco Lead Safe Haven Storage and Re-inspection Facility Project. The purpose of the project is to mitigate the risk of damage to NJ TRANSIT equipment as a result of severe weather events and maintain continuity of operations for as long as possible before and after a storm. NJ Transit will acquire and construct a rail storage and re-inspection facility in an inland area not susceptible to flooding to safely store vehicles in an emergency.
- FTA provided MBTA with Emergency Relief Program funding for resilience improvements to the existing Green Line Fenway Portal. The Fenway Portal Flood Protection Project, completed in 2020, included the construction of barriers,

[2] This figure does not include funding associated with preventing, preparing for, and responding to the Coronavirus Disease 2019 (COVID-19).

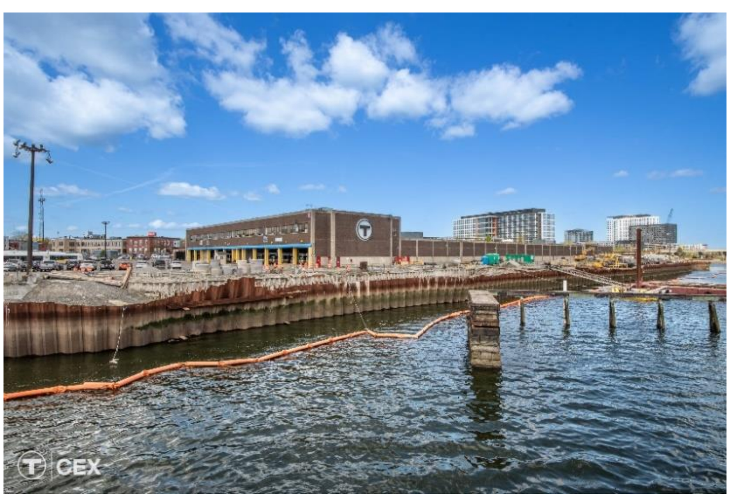
floodgates, steel doors (Top photos) raising a retaining wall, and the installation of new and expanded capacity pumping station, along with the installation of new cameras to monitor potential flooding and other resilience measures for MBTA's Green Line tunnel near Fenway Station. The flood resilience measures will allow MBTA to respond more quickly and efficiently in future flooding events and enable a rapid return to service when flood waters recede.

- FTA provided MBTA with Emergency Relief Program funding for resilience improvements to the existing MBTA Charlestown Seawall surrounding the Charleston Bus Garage. The project included reconstruction of the sea wall adjacent to the existing Charlestown Bus Garage to protect the facility from waterfront erosion and future sea level rise. The Emergency Relief funding assisted MBTA in replacing the failing sheet pile seawall with rip rap embankment and landscaping (Bottom photos).

Fenway Portal Flood Protection Project Steel Flood Door
***Photo credit** MBTA*




Seawall at MBTA Charlestown Bus Garage. Before (Right) and After (Left)
***Photo credit** MBTA*




Phase 3

Design and Construct

Overview of Integrating Resilience into Design, Project Development, and Environmental Review

When designing and developing new capital projects, transit agencies should consider potential hazards that may affect an asset over the course of its anticipated useful service life and develop and evaluate potential adaptation measures that would reduce possible damage. This is especially important when developing major construction and rehabilitation projects to ensure resilience is incorporated into site selection and design decisions. It is typically much more cost effective to design and build resilient infrastructure compared with retrofitting infrastructure in the future.

Relevant Regulations and Policies for Considering Resilience in Project Development

The National Environmental Policy Act (NEPA) of 1969, as amended (42 U.S.C. §§ 4321-4327) and the Council on Environmental Quality (CEQ) implementing regulations at 40 C.F.R. Parts 1500-1508, require federal agencies to evaluate and disclose the environmental effects of their proposed actions. In January 2023, the CEQ issued guidance to assist agencies in analyzing greenhouse gas emissions and climate change effects of their proposed actions under NEPA (88 FR 1196). The CEQ guidance advises agencies to assess the effects of climate change on proposed actions. The CEQ guidance states:

> "To illustrate how climate change may impact proposed actions and alternatives and to consider climate resilience, NEPA reviews should consider the ongoing impacts of climate change and the foreseeable state of the environment, especially when evaluating project design, siting, and reasonable alternatives. In addition, climate change resilience and adaptation are important considerations for agencies contemplating and planning actions…The analysis [of climate change effects] also should consider how climate change can make a resource, ecosystem, human community, or structure more vulnerable to many types of effects and lessen its resilience to other environmental effects. This increase in vulnerability can exacerbate the environmental effects of potential actions, including environmental justice impacts." (88 FR 1196).

Additionally, all FTA funding recipients must comply with Executive Order 11988, Floodplain Management, as amended by Executive Order 13690, Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input (80 FR 6425) and the DOT Order 5650.2, Floodplain Management and Protection, both of which require assessment of flood risk associated with proposed projects in floodplains. EO 11988 requires that FTA program recipients avoid adverse impacts associated with the occupancy and modification of land within floodplains if a practicable alternative exists and to the extent possible. Additionally, if no practicable alternative exists, development in a floodplain must be designed to minimize adverse impact to the floodplain's natural and beneficial values as well as to minimize the potential risks for flood-related property loss and the loss of human life.

Integrating Resilience into Design, Project Development, and Environmental Review

If a proposed project site or asset type is vulnerable to existing and future extreme weather events and natural hazards, agencies should work to identify and evaluate plausible resilience strategies and adaptation measures to reduce the risks. The identification of appropriate resilience strategies and adaptation measures is a process driven by the specific asset and the nature of the impact and vulnerabilities to be addressed.

Depending upon the scope of any vulnerability assessments previously conducted, more detailed analysis may be needed to inform design and engineering decisions for a specific asset or site. A system-wide assessment can serve as a foundation for understanding what hazards may be appropriate to consider, but some project decisions may require a more detailed, engineering-informed assessment of asset and site-specific data to inform the appropriate adaptation measure(s) to select.

The FHWA Adaptation Decision-Making Assessment Process (ADAP) (FHWA, 2016) provides a risk-based framework to aid decision makers in determining adaptation measures and project alternatives for a project. As outlined in the ADAP framework, if it is determined that future climate conditions would negatively impact the proposed project/asset, agencies should identify and evaluate appropriate adaptation measures, as follows:

- **Develop adaptation options and assess performance against climate scenarios** – One or more adaptation options should be developed that enable the asset to perform as intended against the projected climate conditions through the asset's useful service life. Adaptation options may consist of a single action implemented as part of the design of the project, such as use of alternate right of way or the incorporation of nature-based solutions, the development of thresholds that trigger when specific actions will be taken, such as raising station platforms over a period of time, or a combination of both (see Table 5). When developing adaptation options, agencies should consider an adaptive (flexible) design approach that allows for resilient design features to be implemented over time as the likelihood of the impact becomes more certain.

  Additional factors to consider when developing adaptation options for a specific project include:
  - What is the useful service life of the project? Are there planned rehabilitation points in the future where resilience could be addressed as part of the scheduled retrofit or rehabilitation?
  - Is there a resilience project planned by another entity that will impact the resilience of the proposed project?

- **Consider benefits and costs of adaptation options and select a course of action** – Agencies need to consider the prospective benefits and life-cycle costs to inform which adaptation measures and resilience investment(s) are most appropriate. Questions to consider when evaluating adaptation measures include: Do the benefits of avoiding the impact outweigh the costs? Can the impact be managed and maintained sufficiently for its useful service life, or does the assessment indicate a need to strengthen or protect the asset, or enhance redundancy by providing other modal alternatives?

The USDOT maintains guidance on estimating benefits and costs that is applicable to DOT discretionary grant programs. The benefit-cost analysis (BCA) guidance (US DOT, 2023), which is updated each fiscal year, contains an overview of BCA, discussion of BCA methodologies, recommended values for key parameters, and sample calculations of BCA.

While cost considerations are important, the decision on which adaptation measure(s) to choose should look beyond cost-effectiveness as the sole consideration. Additional factors, such as equity and the preservation of biodiversity and ecosystem services, should also be incorporated into the decision-making process

- Frequency of Extreme Weather Events: Measure the occurrences of extreme weather events impacting transit operations to assess the effectiveness of existing measures and need for further investment in resilience strategies.
- Downtime and Service Disruption Duration: Track the duration, location, and costs of service disruptions caused by weather-related events, providing insight into the system's ability to recover.
- Costs associated with repairs, loss in fare collection, and emergency services resulting from extreme weather events: Track the costs resulting from extreme weather events.

See the examples in practice below for descriptions of how agencies are incorporating resilience into project development.

Examples in Practice: Resilience in Design to Strengthen and Protect

NJ TRANSIT Raritan River Bridge Replacement Project

In 2014, FTA awarded the New Jersey Transit Corporation (NJ TRANSIT) $446 million in Federal Emergency Relief Program funds for resilience in response to Hurricane Sandy to increase the resilience of the aged and deteriorated Raritan River Drawbridge, which was originally built in 1908. The drawbridge was severely damaged in October 2012 during Super Storm Sandy when a 13-foot tidal surge completely submerged the bridge and caused the bridge's superstructure to shift on its piers. Several of the pier capstones that support the approach span girder were dislodged or broken and the motors that operate the bridge's movable swing span were damaged. The Raritan River Bridge is a critical rail link along the NJ TRANSIT's North Jersey Coast Line (NJCL), a commuter rail line that carries almost 10,000 customers to job centers in Newark, Jersey City, and Manhattan.

NJ TRANSIT initiated the Raritan River Bridge Replacement Project to address the vulnerability of the existing Raritan River Drawbridge to major coastal storm events. The agency developed goals and objectives to guide the development and evaluation of alternatives for the project (see Table 6**Error! Reference source not found.**).

Table 6 *Raritan River Bridge Replacement Goals and Objectives*

Goal	Objectives
Improve resilience of the Raritan River Drawbridge to severe storms	Improve bridge's resistance to ocean surges
	Raise tracks and electrical and mechanical systems above NJ TRANSIT's Design Flood Elevation (2.5 feet above the Federal Emergency Management Agency's Base Flood Elevation) to the extent practicable
	Design vulnerable components to better withstand saltwater and ocean surge
	Provide adequate structural capacity to comply with current code requirements
	Minimize loss of service on the NJCL during and following storm event
Provide rail improvements that minimize service disruption and optimize operations	Optimize design speeds for trains on the bridge, up to 60 mph
	Avoid substantial compromises to existing NJCL timetables
	Accommodate heavier freight trains of 286,000 pounds and potentially up to 315,000 pounds
	Minimize capital and operating and maintenance costs
	Implement within a reasonable timeframe
	Avoid impacts to NJCL and Conrail operations during construction
Maintain and improve marine navigation beneath the bridge	Minimize delays to marine traffic due to bridge malfunctions
	Widen channel to minimize the risk of collisions with marine vessels
	Enable the safer and faster passage of boats beneath the structure
	Avoid impacts to marine traffic during construction
Minimize adverse impacts on the built and natural environment	Avoid property acquisition to the maximum extent feasible
	Avoid, minimize, or mitigate adverse impacts on historic resources
	Avoid impacts on parklands, open space, natural features, aquatic species, and coastal waters
	Maintain access to nearby residences and businesses during construction
	Minimize construction impacts to the extent feasible

As part of the project's environmental review process, NJ TRANSIT used evaluation criteria aligned with the proposed project's goals and objectives to identify and evaluate numerous reasonable alternatives, including rehabilitation and bridge replacement alternatives, and to address the vulnerability of the existing drawbridge to major coastal storm events (NJ Transit, 2017).

After evaluating the alternatives, the agency decided to replace the existing bridge with a movable lift bridge (photos below) on an alignment adjacent to the west side of the existing bridge as the Preferred Alternative. To increase resilience to flood damage and improve rail service, the new bridge will be constructed with new reinforced concrete piers on piles; new steel superstructure; new drive motor and electrical controls; tie-ins to existing track; vertical adjustment of existing track; and electrical catenary relocation. NJ TRANSIT's Resilience Program also includes plans to elevate electrical substations and signal structures, raising electrical, signal, and interlocking apparatus, and replacing wooden catenary poles with steel structures less vulnerable to wind and falling trees.

The post-Sandy Base Flood Elevation (BFE) is 18.0 feet (NAVD 88) in the vicinity of the bridge near the shorelines of both Perth Amboy and South Amboy. NJ TRANSIT has implemented a 2.5 feet freeboard above the FEMA-designated BFE for determination of the Design Flood Elevation (DFE). Using this criterion, the DFE for the Raritan River Bridge Replacement project is EL 20.5 (NAVD 88).

The new bridge deck at the new lift span is approximately 10 feet higher than that of the existing deck at the existing swing span. The bottom of steel members at the lift span and the flanking spans is set at 20.75 feet, which is 3 inches above NJ TRANSIT's design flood elevation of 20.50 ft (NAVD88). The bridge control house and machinery house are located significantly higher than the design flood elevation (DFE). The bridge control house will be cantilevered off the new steel truss tower (approx. 45' above DFE) and the machinery house will be on the top of the lift span (approx. 65' above DFE at closed position). The mechanical equipment that operates the vertical lift will be located on the towers and the moveable span well above the FEMA BFE. All bridge components, including the superstructure and mechanical and electrical equipment, will be resilient to ocean surges and saltwater.

Construction of the new bridge started in September 2020 and is projected to be completed in June 2029.

Rendering of movable lift bridge – closed (L) and open (R)
***Source** NJ Transit*

MTA Adaptation and Resiliency Toolbox (ARToolbox)

In 2016, the Maryland Department of Transportation (MDOT) Maryland Transit Administration (MTA) developed a Climate Change Vulnerability Assessment to identify sensitive locations and assets vulnerable to hurricane storm surge, flooding, sea level rise, and extreme temperatures. In the years since, MTA has continued to collect new data to identify assets at risk across MTA's local and commuter bus, light rail, subway, and commuter rail systems.

MTA staff developed the Adaptation and Resiliency Toolbox (ARToolbox), a web-based resource, to aid MTA staff in understanding the hazards across its system and to assist staff in identifying potential adaptation measures to incorporate at the project planning and design level.

The ARToolbox serves as the central repository for MTA's resilience planning, data, and project information. The ARToolbox provides various pathways to guide staff to identify resiliency solutions at the asset level. Toolbox users can select a specific mode (e.g., Metro, bus, etc.) and asset class to view assets deemed to be at high or very high risk for vulnerability. The toolbox then suggests resiliency solutions that can be implemented across various time frames, from low-cost solutions that can be deployed immediately to longer-term that require higher levels of planning and design. For each resilience solution presented, the toolbox lists the project phase in which the solution can be implemented, the implementation timeline, the solutions anticipate useful service life, cost ranges, and the benefits and limiting factors for selecting the solution (Figure 10). The information on resilience solutions was developed through an extensive research effort on industry best practices, which involved input from numerous transit agencies nationwide.

Figure 10 *Screen Shot of ARToolbox*
Source Maryland MTA

The ARToolbox also provides MTA staff with a resource for comprehensive information necessary to apply for grant funding from external sources. The ARToolbox was used to successfully obtain FEMA grant funding to complete a Metro tunnel pumping/dewatering study and accompanying 30 percent design. Staff used the information available in the toolbox to map the most vulnerable areas of the Metro system, identify appropriate adaptation measures, and provide the project engineering team with an understanding of the FEMA grant funding process.

While the ARToolbox was developed for MTA staff, many of the resources on resilience solutions are applicable to the broader transit community. Those outside MTA can explore the suite of adaptation and resiliency measures included in the tool here.

Example in Practice: Economic Analysis of Adaptation Measures

OCTA Facility-Level Assessments to Inform Adaptation Options

The Orange County Transportation Authority (OCTA), in partnership with the State of California Department of Transportation (Caltrans) District 12, completed a study in January 2021 about how climate change affects the Orange County rail corridor. The OCTA Rail Defense Against Climate Change Study used a two-tiered approach to assess exposure. An initial scan identified systemwide climate change-related hazards, including coastal and inland flooding, high heat, wildfire, and drought. The second tier of analysis involved more detailed facility-level assessments in three areas identified to be of high risk and high priority to the OCTA system. These facility-level assessments tailored future climate projections to specific aspects of the OCTA system and identified adaptation strategies OCTA and partner agencies can adopt to mitigate these risks. Through each of the facility-level assessments, OCTA evaluated the efficacy and cost-effectiveness of the adaptation strategies and recommended actions to implement.

The systemwide scan identified the OCTA coastal alignment as one of the three high-risk, high-priority areas. OCTA owns a portion of ROW and rail that follows along the Pacific Ocean shoreline in the cities of Dana Point and San Clemente. Given the study area's proximity to the coast, sea level rise and its attendant effects on wave heights and beach erosion are some of most prominent climate stressors posing risks to OCTA infrastructure in this area. Likewise, increased precipitation, both in terms of seasonal totals and during short-duration events, has the potential to trigger landslides on the bluffs. The facility-level assessment focused on (1) sea level rise coupled with storm surge and (2) precipitation change (short-duration events).

The study team identified numerous adaptation options, including for both the coastal and the landward side of the tracks. Coastal adaptation options included maintaining the current revetment, improving the revetment by increasing its height and installing new revetment where needed, installing an impermeable seawall with wave deflector on top of the revetment, and relocating the rail away from the coastline. Each adaptation alternative was assessed against a set of performance criteria under different sea level rise scenarios. This process allowed OCTA to develop estimates for installation costs and hazard-related costs (i.e., damage repair costs) under different sea level rise scenarios. Through this economic analysis, OCTA compared the cost and benefits of the adaptation alternatives across a range of scenarios and over several different timeframes.

The study includes detailed recommendations on which adaptation options to pursue and also includes 'adaptation triggers' – rules about actions to take once certain conditions or events occur – along the corridor. The recommendations indicate which strategies should be prioritized in the near-term to mitigate climate risks and which strategies can be implemented in the long-term to further strengthen the resilience of the rail system.

Resilience Design Standards

FTA does not have regulations governing the design and specification of transit infrastructure. Instead, most transit agencies and localities have developed design standards that outline criteria for designing and constructing transit infrastructure and systems in their jurisdictions. These standards typically include provisions to address a variety of factors, including floodplain standards, wind load, seismic conditions, and temperature conditions.

To standardize the consideration of how changing climate conditions will impact natural hazards as part of project design, agencies are encouraged to develop resilience design standards that specify the climate change projections and decision parameters for evaluating climate impact risks and adaptation options. Resilient design guidelines support a consistent application of resilience measures at an agency level and also minimize the need to conduct resilience analysis on a project-by-project basis for smaller, more routine projects.

For examples of resilience informed design standards, see the examples of the MBTA and the Port Authority of New York (NY) and New Jersey (NJ) below.

Examples in Practice: Avoid, Strengthen, and Protect

MBTA Resilient Design Standards

The MBTA has developed two resilience guidance documents – the Design Guidelines for Bus Maintenance Facilities (2023) and the Flood Resilience Design Directive (2019) – to set baseline resilience requirements, standards, and preferences for MBTA as they relate to resilience. Both documents assist designers in constructing projects that can withstand and recover from extreme weather events, maintain functionality and longevity, and minimize downtime of facilities and services.

MBTA's Design Guidelines for Bus Maintenance Facilities outlines design criteria for running repair and/or preventative maintenance on both new construction and major rehabilitation on facilities that provide daily bus service and maintenance operations. The guidelines present considerations to help make site design elements resilient and establish resilience performance requirements to assist designers in creating facilities that will experience little to no service disruption from extreme weather events and will quickly recover under future climate conditions. Finally, the guidelines also include example adaptation strategies, including both physical design and operational strategies, for various climate hazards, including extreme storms, coastal flooding, extreme precipitation, and extreme temperatures.

The Flood Resilience Design Directive is intended to provide direction for all new construction, repair projects, and replacement projects to protect assets and operations from flood-related impacts. It lays out a design hierarchy to minimize risk to MBTA assets and maximize the resilience of MBTA systems, as follows:

"The first priority shall be to avoid flood risks wherever possible through siting decisions. When siting within an area of potential flood cannot be avoided, the project shall elevate assets above the potential flood elevation...When neither avoidance nor elevation change measures are feasible, the asset shall be protected from flood risk through dry or wet floodproofing and/or appropriate material selection. Finally, if an asset cannot be protected through any of these means, the project shall be designed for operational recovery within a set number of hours commensurate with the criticality of that asset to system operation and/or human safety. "

The Directive outlines a preferred approach to meet the design hierarchy and cites specific climate projections to use depending upon whether the project is vulnerable to coastal versus inland flooding.

MBTA flood protection system at Aquarium station
***Photo credit** MBTA*

MBTA green roof on Orient Heights Station reduces the amount of stormwater runoff entering the municipal storm system
***Photo credit** MBTA*

PANYNJ Climate Resilience Design Guidelines

The Port Authority of NY and NJ (PANYNJ) established Climate Resilience Design Guidelines that outline a science-based methodology for incorporating risks into project design criteria. These guidelines include sea level rise in the project design criteria, ensure climate-related risks are proactively addressed in the design process, and prioritize resiliency of the Port Authority's assets. They also provide a "code-plus" approach to supplement other applicable codes and standards related to flood resilience design in two ways:

- **Adjustment of the FEMA BFE for Sea Level Rise:** The guidelines augment the applicable FEMA BFE by adding the relative increase in future sea levels over the project's expected useful service life based on the New York City Panel on Climate Change projections.
- **Consideration of future floodplain expansion:** Rising sea levels may also lead to expansion of the 100-year tidal floodplain over time. Therefore, the guidelines apply to projects sited in or proximate to today's 0.2% annual chance ("500-year") floodplain or in the projected future tidal 100-year floodplain, in addition to the current FEMA 100-year floodplain.

To help ensure that the guidelines are considered early in the project development process, the Port Authority requires that the Climate Resilience Guidelines be included in project proposals, consultant service requests, design criteria/performance criteria/basis of design documents, and requirements and provisions for work.

Sustainable and Resilient Design Rating and Certification Programs

Many transit agencies participate in third party rating and certification frameworks, such as Leadership in Energy and Environmental Design (LEED) and Envision. LEED primarily targets green building projects, whereas Envision can be applied to civil infrastructure projects. Since these systems are born from a foundation of green building and infrastructure, both LEED and Envision include credits focused on encouraging resilient planning, design, and construction.

Resilience through LEED

The U.S. Green Building Council promotes sustainable infrastructure through a LEED certification as a "cornerstone of enhancing community resilience." LEED offers three LEED pilot credits for resilient design that address a project's overall resilience performance. The three resilience credits are:

- **Assessment and Planning for Resilience**, which encourages teams to determine potential vulnerabilities at the project location.
- **Designing for Enhanced Resilience** to ensure project teams address the top hazards via mitigation measures.
- **Passive Survivability and Back-Up Power During Disruptions** to support the concept that buildings are able to safely shelter occupants during a power outage and be able to provide back-up power.

Other credits within the LEED framework are also relevant to resilience. These include assessments and impact measuring for choices such as: utilizing materials that can withstand climate-related events and disasters, inclusion of on-site renewable energy generation, use of sites that are less vulnerable to environmental change, and other mitigation techniques to ensure reliability of services during and post-disaster.

Resilience through Envision

Envision, supported by the Institute for Sustainable Infrastructure, seeks to establish resilience within all types and sizes of civil infrastructure with "informed, resourceful, robust, redundant, flexible, integrated, and inclusive" aspects. Similar to LEED, credits are obtained when design choices promote services that are reliable, experience minimal disruption in the wake of climate-related events, incorporate natural systems, and utilize materials that prevail against disaster. The Envision rating system includes 64 sustainability and resilience indicators, or credits, within 5 categories. The category dedicated to Climate and Resilience has 10 credits, including credits for minimizing or avoiding development on sites prone to hazards and credits for conducting risk and resilience evaluations.

For more information about LEED and Envision resilience credits see:

- **USGBC Page on LEED Resilience**
- **Envision Webpage and Introductory Packet**

Phase 4

Manage

Overview of Integrating Resilience into Transit Asset Management

Current and future extreme weather events and natural hazards can disrupt transit services and decrease the useful service life of assets. For this reason, it is critical that transit agencies integrate resilience into transit asset management (TAM) to reduce costly damage, prevent service disruptions, and extend the assets' useful service life for a more resilient transit system.

TAM is a business model that uses the condition of assets to guide the optimal prioritization of funding at transit properties to keep transit networks in a state of good repair (SGR). Per the TAM Final Rule (49 CFR part 625), transit providers are required to develop a TAM plan, to be updated every four years. A TAM plan helps transit providers evaluate the current condition of capital assets; identify the unacceptable risks in continuing to use an asset that is not in an SGR; and decide how to best balance and prioritize reasonably anticipated funds toward improving asset condition. The latter can ensure a sufficient level of performance within those means. This section of the Guidebook offers potential strategies and considerations for resilience that can be incorporated into TAM plans.

Relevant Regulations and Policies for Considering Resilience in Transit Asset Management

TAM ensures that systems are functioning at high levels and are maintained in SGR throughout their useful service life. The TAM Final Rule, promulgated in 2016, encourages transit agencies to consider climate resilience in their investment prioritization processes and integrate climate vulnerability analyses as part of the overall asset management approach. The TAM Final Rule also requires transit agencies to develop a TAM plan, to establish a system to monitor and manage public transportation assets to improve safety and increase reliability and performance, and to establish performance targets for national performance measures.

The TAM Final Rule applies to all transit providers that are recipients or subrecipients of Federal financial assistance under 49 U.S.C. Chapter 53 and own, operate, or manage transit capital assets used to provide public transportation. However, the requirements vary between Tier I and Tier II transit providers. Tier I agencies are required to include all TAM plan elements, while Tier II agencies are required to include a subset of the elements (see Table 7).

Table 7 *TAM Plan Requirements for Tier 1 vs Tier 2* Agencies*

Tier	Element	Description
Tier I & II	Inventory of Capital Assets	List of capital assets and information about the assets
	Condition Assessment	Evaluation of the physical conditions of assets
	Decision Support Tools	Process or tool that is used to support investment prioritization and/or decision making
	Investment Prioritization	List of prioritized projects/activities/programs to support SGR
Tier I only	TAM and SGR Policy	Policies and strategies to support SGR and the TAM plan
	Implementation Strategy	Strategy to carry out the TAM plan (e.g., performance measures)
	List of Key Annual Activities	Activities that will be taken to implement the TAM plan
	Identification of Resources	List of resources that are needed to implement the TAM plan
	Evaluation Plan	Framework for monitoring and evaluating the TAM plan

* Tier I provider means a recipient that owns, operates, or manages either (1) one hundred and one (101) or more vehicles in revenue service during peak regular service across all fixed route modes or in any one non-fixed route mode, or (2) rail transit. Tier II provider means (1) a recipient that owns, operates, or manages one hundred (100) or fewer vehicles in revenue service during peak regular service across all non-rail fixed route modes or in any one non-fixed route mode, (2) a subrecipient under the 5311 Rural Area Formula Program, (3) or any American Indian tribe. (49 CFR 625.5).

Integrating Resilience into Transit Asset Management

Current and future weather events and natural hazards can greatly impact the condition and performance of transit assets and systems. For this reason, agencies are highly encouraged to integrate considerations of natural hazards and climate resilience into each element of transit asset management. Opportunities to address resilience as part of asset management include:

- **Incorporating data on vulnerability in inventory of capital assets and condition assessments** – Transit agencies can leverage the capital asset inventory to identify assets that may be vulnerable to current and future climate conditions and to inform resilience planning. To do so, transit agencies can include information that reflects the vulnerability and criticality of an asset, including the type of natural hazards each capital asset is vulnerable to and/or has been impacted by previously, as well as whether resilience measures were incorporated into an asset. In addition, because current and future natural hazards impact asset conditions, transit agencies should include relevant information from vulnerability assessments as part of their condition assessment processes. Doing so can provide a more comprehensive understanding of asset conditions to help determine which assets are most at risk, inform asset replacement schedules, and evaluate the useful service life of assets.

- **Considering resilience in investment decisions** – A resilience criterion could be built into the decision support tool/process to guide investments towards assets that are most at risk and vulnerable. FTA developed the Transit Economic Requirements Model (TERM)-Lite tool to help transit agencies assess their SGR backlog and identify and prioritize programs and projects in need of investment. The TERM-Lite tool uses the inventory of an agency's capital assets to assess potential investments for their ability to advance an agency's goals.

- **Considering hazards as part of prioritization of investments** – While not required, FTA recommends that transit agencies should consider current and future climate and weather-related hazards as part of their prioritization of investments, since such hazards impact asset-replacement schedules and the expected useful service duration of capital assets (81 FR 48890). To do so, transit agencies can integrate the results of their vulnerability assessments with data on system performance and asset condition to focus financial resources on the assets whose failure(s) would present the highest risk to the system (see Step 5: Consider Risk). Assets deemed to be at higher risk could be prioritized for rehabilitation or replacement.

Refer to FTA's Transit Asset Management website for more details on incorporating resilience in the TAM process.

Phase 5

Maintain

Overview of Integrating Resilience into Transit Operations & Maintenance

Transportation operations and maintenance functions play vital roles in increasing the transportation system's resilience to current and future extreme weather events and natural hazards. Operations includes programs and day-to-day activities focused on improving the efficient use of the transportation network and infrastructure. Operational functions include:

- Facilities management
- Rolling stock management
- Location and storage of vehicle fleets
- Vehicle operation
- Route operator scheduling and coordination
- Coordination during interruption of service
- Implement bus bridge plans
- Implement emergency preparedness, response and recovery, and evacuation plans
- Signaling operations
- Management of splits, interlockings, etc.
- Fare collection management
- Ridership and demand management
- Asset inspections
- Operational testing

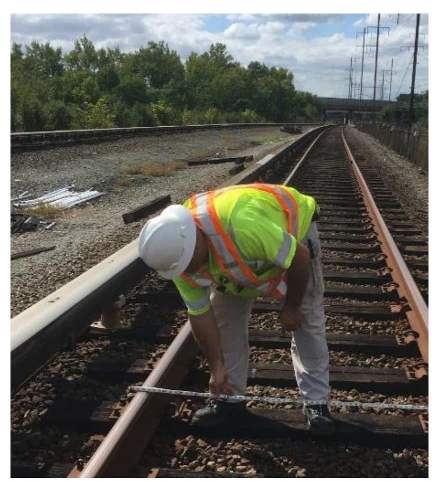
Maintenance, repair, and replacement activities are designed to preserve and extend the useful service life of transit infrastructure and assets and mitigate the impacts of naturally occurring stressors (e.g., weather) or imposed processes (e.g., traffic). Maintenance functions include:

- Depot management
- Asset maintenance, repair, and replacement
- Track inspection
- Work zone management
- Surveillance and security system management
- Stormwater management and maintenance, clearing debris

NYC Transit weather preparations
Photo credit *Ray Raimundi / MTA*

LA Metro staff inspect photovoltaic systems
Photo credit *LA Metro*

WMATA inspectors inspect track
Photo credit *WMATA*



Extreme weather events and natural hazards can physically impact transit infrastructure and cause track and road closures, interrupt or limit transit service, and cause transit diversions (see Table 2). Given that severe weather events are increasing in frequency and severity, transit agencies will be challenged with existing, emerging, or escalating natural hazards that require different planning approaches or responses. Operations and maintenance (O&M) staff, units, and assets will be critical to the rebuilding of infrastructure and re-establishing service following a disruptive event.

Additionally, cascading impacts, also referred to as cascading failures, are increasingly common as severe weather events become more commonplace. Cascading impacts occur when critical damage to one key system directly impacts other key systems. During severe weather events, the interdependencies between key community services like telecommunications, power, water and wastewater, and transportation, can result in cascading failures (TCRP, 2017). For example, most rail systems rely on electricity to power the trains and their maintenance and repair facilities. Furthermore, emergency management plans often assume functioning transportation systems, such as transit systems and service, for evacuation purposes. Ensuring the transit system's O&M units are prepared for response and recovery, for example, by procuring backup power, or planning for redundant evacuation routes and vehicles can lessen the impacts on interdependent services and the community.

Integrating Resilience into Transit O&M

Transit agencies are encouraged to assess their current O&M vulnerabilities and the likely solutions and associated costs of reducing them. O&M units are traditionally reactive: they manage, maintain, replace, and repair the ongoing operations. With resilience inherent throughout the system, transit agencies can provide more reliability to their riders. Transit services can also be a comfort and lifeline for communities adversely impacted by an extreme weather event or natural hazard.

Practitioners have multiple opportunities to integrate resilience considerations into O&M activities, through implementing adaptation measures to avoid, manage and maintain, strengthen and protect, and enhance redundancy, as follows:

- **Data Collection and Information Sharing** – O&M staff witness the ground-level consequences of system vulnerabilities and disruptions. O&M staff need to be provided opportunities and supporting infrastructure to report on resilience-related issues to help document vulnerability conditions and spur dialogue on solutions. Transit agencies can strengthen O&M personnels' abilities to do this by establishing requirements and schedules for information-sharing expectations or proactively requesting reports on the nature, severity, and cause of disruptions. Transit agencies can also use real-time cameras, weather stations, or drones to obtain or strengthen data collection/information sharing. Such data can be instrumental to providing a comprehensive picture of the system's vulnerabilities and to establishing a culture of transparency and proactivity in managing disruptive events. Data collected from emergency events and service disruptions should be recorded and used in the Monitoring Phase to assess the effectiveness of resilience measures under various conditions and, by extension, to inform future resilience planning.
- **Key Partnership Coordination and Communication** – Transit agencies often rely on outside stakeholders or third-party contractors to carry out essential O&M services. A clear understanding of the internal and external O&M

interdependencies can improve and optimize resource, information, and service sharing prior to and in response to an extreme weather event. Some key stakeholders might include communication providers, power utilities, highway departments, other transit agencies, state emergency management agency, and local government representatives.

Transit agencies should be proactive in establishing and maintaining information-sharing protocols about travel conditions, closures, service disruptions, infrastructure damage, etc. To establish an effective regional information-sharing network, begin by identifying key points of contact for all relevant partner agencies and a regular cadence for check-ins and sharing updates. Agencies may opt to establish mutual aid agreements to share resources in a disaster response scenario. Partnership agreements between transit agencies and local municipalities, other transportation providers, and other entities for the storage of buses and railcars outside of hazard areas to avoid/protect from hazardous events, or for backup bus services for evacuation procedures, etc. during extreme weather events, are examples of how use of key partnerships can enhance redundancies for transit resilience. Creating and maintaining partnerships can reduce loss of life and property during extreme weather events and can smooth the way for returning essential services back to regular functionality.

- **Build Operational Redundancies and Capacities** – Operational resilience is most effective when it integrates enhanced redundancy into all parts of the O&M units and systems to respond to extreme weather events. Operational activities that transit agencies can make to optimize their existing O&M processes and position themselves to quickly resume service include.

    - **Reevaluate** the scope of contracts to include a broader range of conditions, including severe weather response. Agencies may require additional personnel to monitor, avoid, report, manage, and respond to events.
    - **Ensure** procurement specifications and inspection standards encourage versatile and durable materials and design to manage, protect, and strengthen assets during extreme weather events.
    - **Examine** costs of asset repairs and replacements to identify potential future costs incurred by increasing and different hazards and risks over time.
    - **Develop** a plan to strategically stockpile and locate key materials and equipment to facilitate efficient response.
    - **Involve** O&M units in emergency planning and regional stakeholder coordination.
    - **Conduct** exercises specific to develop O&M unit recovery and response capacities.
    - **Allocate** resources for specialty training and capacity building. Unique staff and skillsets may be required to respond to different types of hazard events.
    - **Provide** dedicated funding for repairs and maintenance in anticipation of increasing weather events and natural disasters to increase the capacity of the agency to protect assets and recover from such events.

    Building resilience into O&M systems can also improve customer experiences, cut down on costs, and ultimately keep services running smoothly.

- **Promoting O&M Resilience through Environmental Management Systems (EMS)** – Transit operators can infuse resilience into O&M units by incorporating resilience considerations into their EMS systems. The primary function of EMS systems is to assess and control the environmental impact of a transit system and inform future designs to achieve a transit agency's environmental goals. EMS systems can help transit agencies to implement adaptation measures to avoid impacts from extreme weather events, to manage, maintain strengthen and protect assets, and to provide enhanced redundancy. These systems can also support the tracking of emergency preparedness and resilience performance metrics. EMS systems can also act as a source of data on resilience gaps and performance to communicate with the public and decision makers, implement cost saving measures, and increase operational efficiency. See FTA’s Environmental and Sustainability Management Systems website.

- **Resilience Considerations for Electric Vehicles** – Many transit agencies are currently transitioning their bus fleets from fossil-fuel-powered vehicles to electric vehicles (EVs) to reduce greenhouse gas emissions and improve local air quality. As transit agencies plan for fleet electrification, they should consider how current and future hazards may impact their EV bus operation and maintenance activities.

  For example, electric buses rely on the electric grid or an agency’s own electricity generation, transmission, and distribution infrastructure for power, which have different risk exposure profiles than the supply chain for fossil fuels. Agencies will need to consider how to maintain continuity of operations in the event of power outages. Similarly, fossil fuel-powered buses are often used to bridge service gaps that may occur during power outages on electrified rail lines. Electric buses may not be able to provide the same flexibility. On the other hand, electric buses offer options not possible with fossil fuel-powered buses. For example, they can be used as mobile power banks in the event of smaller power outages.

  See examples below and in the Appendix of how transit agencies are building resilience in their O&M activities.

Electric Bus Chargers
***Photo credit** Rhode Island Public Transit Authority (L) and King County (R)*

Example in Practice: Enhance Redundancy

Montgomery County Department of Transportation Establishes Resilient Energy Supply for EV Buses

The Montgomery County Department of Transportation (MCDOT) Division of Transit in Maryland operates the Ride On bus system consisting of nearly 400 County owned and operated buses. The County has been transitioning its diesel buses to electric buses and has a goal of converting the entire fleet to zero-emission vehicles. In support of this effort, the County entered into a public-private partnership with AlphaStruxure to build a microgrid at the Brookville Smart Energy Bus Depot to charge county-owned electric buses. Through the partnership, the entities are developing a 5.6 MW microgrid and 2 MW of solar canopies at the Depot (see photo below), as well as 0.5 MWH of battery energy storage capacity. The energy from the solar panels will be used to charge the electric buses. The microgrid system is designed to support up to 70 buses without support from the electric grid. However, as the fleet grows and power demands increase, electricity from the grid will be used to support over 140 electric buses. Using energy that originates from solar panels at the bus depot rather than the traditional electricity grid will allow the County to provide a sustainable, resilient, and reliable energy supply for bus charging and site operations during grid outages. Public transportation serves as a lifeline for many marginalized communities. Many bus riders in Montgomery County depend on the service to get to work, school, medical appointments, and make other essential trips. The microgrid project helps ensure reliable transit services to its riders following a long term grid disruption and helps mitigate the 42 percent of greenhouse gas emissions that are generated from the transportation sector in Montgomery County.

Solar Panel - 3D Canopy
Source Montgomery County

Example in Practice: Avoid
SEPTA Resilience in Operations & Maintenance

Southeastern Pennsylvania Transportation Authority (SEPTA) is taking an integrated approach to mitigating risk and managing the system's ability to respond to severe weather events. This approach focuses on bringing corridor-wide assets and infrastructure to higher resilience standards instead of one project or asset at a time to allow for a more comprehensive reduction of the system's vulnerability.

SEPTA considers its O&M units to be critical in the advancement of system resilience. Management strives to communicate consistently with those working on the front lines – those who are addressing the issues on the ground – to have a more complete understanding of operations issues. During emergencies, SEPTA redirects routes and stages vehicles in different areas less prone to damage (often in higher ground particularly for flooding risks). This can be challenging as there can storage and space constraints to how many of their assets can be contained in previously identified facilities. Nevertheless, using this strategy, SEPTA has not experienced any vehicle damage due to storm conditions since Hurricane Sandy.

On the infrastructure side, SEPTA has reconstructed portions of the rail system's interlocking to allow some parts of the system to restore service after flooding events rather than render the entire system inoperative. Similarly, SEPTA relocated an interlocking from the Miquon station, a location near the Schuylkill River that can be susceptible to flooding, to a location closer to the city center. A SEPTA study of historic flooding conditions on the Schuykill River evaluated the position of the interlockings. Findings ultimately led SEPTA to reconfigure the interlocking to allow for more frequent and extended services during flooding events.

Phase 6

Monitor

Overview of Monitoring Progress of Resilience Efforts

Building a resilient transit system is an iterative process that requires monitoring and evaluation to track progress toward resilience goals and to assess the impact of resilience strategies. By monitoring the benefits resilience strategies and adaptation measures are having on reducing damage to assets and improving safety and economic outcomes, agencies can assess the effectiveness of resilience measures under various conditions and determine what, if any, mid-course corrections might be needed to enhance and further improve resilience outcomes (TRB, 2017a).

Transit agencies should develop a framework to monitor the performance of resilience actions and investments. As part of the framework, agencies will need to develop performance measures and reporting metrics (i.e., a quantifiable indicator of performance) to track progress. Agencies can use the resilience-focused performance measures established as part of short-term and long-term planning processes (see Phase 2) and/or create additional performance measures and metrics to track the inputs, outputs, and outcomes related to resilience activities (see text box for definitions and example metrics).

Type of Performance Metrics

Input metrics pertain to the amount of resources put into an activity, process, or program. An example of a resilience-focused input measure is the dollars invested in resilience projects.

Output metrics pertain to the number of services or products produced by an activity, process, or program. An example of a resilience-focused output measure is the percent of stations located in a floodplain.

Outcome metrics pertain to the impact of the activity, process, or program. An example of a resilience-focused outcome measure is the hours/days to return to full service after a weather event.

Transit agencies will need to establish a process to collect the data and information needed to evaluate progress. As is the case for the data needed to inform the vulnerability assessment, the data needed to evaluate the performance of resilience actions and investments may come from a variety of disparate sources. Potential sources of data include (TRB, 2017a):

- Customer surveys
- Inspection and maintenance records
- EMS systems
- Frontline worker observations
- Asset management systems
- After action reports

Staff leading the monitoring process should seek input and feedback from all departments responsible for resilience strategies and adaptation measures to understand potential challenges to success, including challenges internal to the agency (such as administrative structure, institutional processes, or a lack of adequate funding).

Transit agencies should also periodically assess whether there is a need to revisit the assumptions, underlying data, or approaches used in the original vulnerability assessment (FHWA, 2017). The following are key factors that may warrant an update to the vulnerability assessment:

- Availability of new or improved climate data or new observations of weather events and natural hazards impacting the region.
- A change in asset condition, either due to investments in state of good repair, transit asset management updates, new facilities coming online, budget shortages, unexpected events, or operational issues.
- The identification of new resilience measures resulting from advancements in technology, materials science, engineering, to strengthen and protect assets and regulatory changes, and/or from actions by other units of government or stakeholders.
- Opportunities that new resources, community relationships, stakeholders, or partnerships create (NOAA 2024).

Key Partnership Coordination and Communication – Transit agencies often rely on outside stakeholders or third-party contractors to carry out essential O&M services. A clear understanding of the internal and external O&M interdependencies can improve and optimize resource, information, and service sharing prior to and in response to an extreme weather event. Some key stakeholders might include communication providers, power utilities, highway departments, other transit agencies, state emergency management agency, and local government representatives.

Transit Rail Inspection
***Photo Credit** FTA*

Community Feedback
***Photo Credit** North Central Regional Transit District, NM*

Examples in Practices: Monitoring Progress

King County's Strategic Climate Action Performance Measurement Framework

King County's Strategic Climate Action Plan (SCAP) is a five-year blueprint for County climate action that outlines King County's priorities and commitments for climate action. The *Preparing for Climate Change* section includes climate preparedness actions focused on operationalizing climate action by incorporating a broad range of climate change considerations into decision processes. The section also includes a performance management framework for tracking progress in each of the section's five strategies. See Table 8 for the performance measures and targets associated with two of the strategies: mainstreaming climate preparedness and technical capacity. The plan also outlines priority actions that will be taken to achieve each strategy and identifies the King County department responsible for and role (e.g., implement, convene, support/ advocate) in the action.

King County reports on its progress towards the SCAP actions, goals, and targets every two years. This process provides transparency by showing if and how SCAP actions are delivering on intended outcomes. The SCAP notes "[p]erformance measurement can help identify when it is time to set new goals and targets. Performance measurement can also identify barriers that limit progress. In both cases, the knowledge gained from performance measurement helps the County know how to move forward with its work in order to achieve SCAP goals." (King County, 2021). King County's progress update on the 2020 SCAP is available at your.kingcounty.gov/dnrp/climate/documents/2024/2401-13286w-SCAP-biennial-rpt.pdf.

Table 8 *Excerpt from SCAP Climate Preparedness Performance Measurement Framework (King County, 2021)*

Focus Area 1: Mainstream Climate Preparedness	
Strategy 1: Account for climate impacts in policies, plans, practices, and procedures, and implement climate-resilient decisions.	
Performance Measures	**Reporting Metric or Target**
1. King County policies, plans, practices, and procedures require consideration of climate impacts, where relevant, as part of decision processes.	*By 2025*: King County programs have successfully delivered updates identified in the 2020 SCAP actions. *By 2030*: King County programs have identified and updated remaining relevant policies, plans, practices, and procedures.
2. King County is accounting for climate impacts in decision processes and implementing climate resilience actions.	Qualitative assessment (comparative over time) of if/how King County programs are making progress on: • Clearly articulating if/how climate change affects a planned activity or other type of decision; • Adjusting decisions or actions to account for climate impacts; and Implementing climate-resilience actions.
3. SCAP climate preparedness actions are achieving their expected outcomes.	Target for *completed* actions: 100% Combined quantitative and qualitative assessment (comparative over time) of if/how King County's climate preparedness actions are delivering on the expected outcomes identified for those actions. The time frame for when SCAP action outcomes will be achieved will depend on the action and may extend beyond any single five-year SCAP window.

Focus Area 2: Technical Capacity	
Strategy 2: Invest in and use best available science and other technical information to inform climate preparedness work at King County.	
Performance Measures	**Reporting Metric or Target**
1. King County staff are accessing and applying relevant research, data, guidance, and other technical information related to climate impacts and climate preparedness.	King County staff report knowing where to find relevant climate information and feel they have the technical guidance needed to consistently apply that information in decisions.
2. King County is funding or otherwise pursuing the technical information and research needed to inform climate-resilient decision-making and share that technical information with others.	Examples and qualitative assessment of if/how King County is making progress on identifying, funding, and/or participating in the development of research and technical assessments, and what they are learning from that work.

Resources and References

Climate Data Resources and Tools

Table 9 *A Selection of Tools and Data Available to Evaluate Climate Exposure*

Data source	Description	Author	Geographic extent	Geographic scale	Time scale	Hazard(s)
Climate Risk and Resilience Portal	Localized models and projections for climate hazards using downscaled climate models	Argonne National Laboratory	Continental U.S. and Alaska	1/8th degree resolution	Present - 2100	Temperature, wind, wildfire, precipitation
Climate Data Processing Tool	Processed downscaled CMIP5 climate data for transportation planners	DOT	Lower 48 U.S.	Up to 1/16th degree resolution	1950 - 2100	Temperature, precipitation
FEMA Flood Maps	Online application to find all flood hazard mapping products created under the National Flood Insurance Program	FEMA	U.S.	Various	Present	Flooding
FEMA National Risk Index	Information on historical annualized hazard frequencies	FEMA	U.S.	County or Census Tract	Present	Climate & non-climate natural hazards
Resilience Analysis and Planning Tool	Mapping tool comparing census data to hazards, weather, and historic disasters	FEMA	Various	Various	Historic, present, and future conditions	Climate & non-climate social and natural hazards
Heat-Related EMS Activation Surveillance Dashboard	Map of heat-related emergency medical service activities	HHS and DOT	U.S. and Territories	State or County	Present	Extreme heat
NASA Earth Exchange Global Daily Downscaled Projections	CMIP5 downscaled climate model data access	NASA	Global	¼ degree resolution (25km^2 grid)	1950 - 2100	Temperature, precipitation
NASA IPCC AR6 Sea Level Projection Tool	View and download updated sea level projections and extrapolated observations	NASA	U.S. and Territories	Global, regional, or individual tidal gauge	Present - 2150	Coastal inundation

Data source	Description	Author	Geographic extent	Geographic scale	Time scale	Hazard(s)
Urban Heat Island Effect Solutions and Funding	Tool to identify bus stops located in high heat risk areas with low tree canopy	National League of Cities	U.S.	City	Present	Temperature
NOAA Sea Level Rise viewer	View impacts of sea level rise across the United States	NOAA	U.S. and Territories	10m resolution	Present - 2100	Coastal inundation
Climate Explorer	Projections of climate hazards through 2100 for high or low emissions futures	NOAA	U.S. & Territories	City and County level	Present - 2100	Temperature, precipitation, and related climate variables
2022 NOAA State Climate Summaries	Indicators and vulnerability summaries specific to each state	NOAA	U.S. & Territories	State level	Present - 2100	Temperature, precipitation, sea level rise, wildfires
Application Guide for the 2022 Sea Level Rise Technical Report	Guidance for sea level rise vulnerability assessments with updated scenarios as of 2022	NOAA	U.S. and Territories	Various	Present - 2150	Coastal inundation
Locating and Selecting Scenarios Online	Spatial data, climate models, and projections for states or regions of the U.S. available to download	U.S. EPA	Lower 48 U.S.	Up to $1/16^{th}$-degree resolution	Present - 2100	Temperature, precipitation
Fifth National Climate Assessment, Interactive Atlas	Considered the Nation's most authoritative source on climate change and its impacts. Summarizes key information and data about climate vulnerability, impacts, and adaptation by region and by sector	U.S. Global Change Research Program	U.S.	Regions of U.S.	1900 - 2150	Wildfire, drought, extreme heat, sea level rise, storm surge, inland flooding, extreme precipitation, extreme storms
Scenarios for the NCA: Localized Constructed Analogs Viewer	Projections for temperature and precipitation under low, mid, and high emissions scenarios downscaled to $1/16^{th}$ degree spatial resolution	U.S. Global Change Research Program	U.S.	$1/16^{th}$-degree resolution	Present - 2099	Extreme temperature, extreme precipitation
Climate Mapping for Resilience and Adaptation	Maps and tables of present and future exposure to climate hazards and resources on federal funding opportunities	U.S. Global Change Research Program	U.S. & Territories	Census tract, county, or tribal land	Present - 2100	Extreme heat, drought, wildfire, flooding, coastal inundation

Data source	Description	Author	Geographic extent	Geographic scale	Time scale	Hazard(s)
USGS Hazard Exposure Reporting and Analytics	Hazard exposure reports on a variety of assets such as railroads and roads with multiple future scenarios	USGS	CA, FL, GA, NC, SC, VA	County or census tract	Present - 2100	Sea level rise, coastal groundwater, shoreline change
USGS Coastal Change Hazards Portal	View and download coastal hazard data from various USGS resources	USGS	U.S.	Various	Present - 2100	Extreme storms, shoreline change, sea level rise

Table 10 *Non-Climate Stressor and Community Vulnerability Screening Tools*

Data source	Description	Author	Geographic extent	Geographic scale	Time scale	Hazard(s)
Climate and Economic Justice Screening Tool	Map of census tracts designating disadvantaged communities using many risk indicators	CEQ	U.S. and Territories, Federally Recognized Tribes	Census Tracts and Federally Recognized Tribes	Present	Climate & non-climate social and natural hazards
DOT Equitable Transportation Community Explorer	Map of 2020 census tracts exploring community vulnerability for transportation, climate, environmental, health, and social indicators	DOT	U.S. and Territories	Census Tract	Present	Climate & non-climate social and natural hazards
EJScreen	Maps and reports of environmental and demographic indicators	EPA	U.S. and Territories	Varies	Varies	Flood, wildfire
FEMA Social Vulnerability Index	Map of community level social vulnerability scores and rankings	FEMA	U.S. and Puerto Rico	County	Present	Social vulnerability

Table 11 *Transportation-Focused Tools*

Data source	Description	Author	Geographic extent	Geographic scale	Time scale	Hazard(s)
DOT Equitable Transportation Community Explorer	Map of 2020 census tracts exploring community vulnerability for transportation, climate, environmental, health, and social indicators	DOT	U.S. and Territories	Census Tract	Present	Climate & non-climate social and natural hazards
FHWA's Infrastructure Voluntary Evaluation Sustainability Tool	Self-evaluation tool for transportation agencies to evaluate sustainability practice across the life cycle of a transportation system	FHWA	Any	N/A	N/A	Social, economic, and environmental considerations
TERM Lite	Analysis tool to support transit agencies in assessing state of assets	FTA	Any	N/A	N/A	Economic considerations
Hazard Mitigation Cost Effectiveness Tool	Tool for conducting cost-benefit analyses of resilience projects being considered for funding	FTA	U.S. and Territories	Various	N/A	Flooding, extreme storms, and other non-climate hazards
Resilience and Disaster Recovery Tool Suite	Tools to estimate the return on investment of resilient infrastructure across a range of uncertain future hazards (flooding, earthquake, etc.) for long-range transportation planning	Volpe Center DOT	N/A	N/A	N/A	Various

Reports & Guidance Materials

Assessing Vulnerability and Risk

American Public Transportation Association (September 28, 2021). Using Asset Criticality to Make More Informed Decisions in a Transit Agency. https://www.apta.com/wp-content/uploads/APTA-SUDS-TAM-RP-010-21.pdf

Environmental Protection Agency (November 2023). Climate Risks and Opportunities Defined. https://www.epa.gov/climateleadership/climate-risks-and-opportunities-defined

Gardiner, Ned, ed., Matt Hutchins, Jim Fox, Aashka Patel, and Kim Rhodes (2022). *Implementing the Steps to Resilience: a Practitioner's Guide.* Climate-Smart Communities Series, Vol. 6. NOAA Climate Program Office, 2022. https://repository.library.noaa.gov/view/noaa/46456

FHWA (2023). Geohazards, Extreme Weather Events, and Climate Change Resilience Manual. https://www.fhwa.dot.gov/engineering/geotech/pubs/hif23008.pdf

FHWA (2017). Vulnerability Assessment and Adaptation Framework, 3rd Edition. https://www.fhwa.dot.gov/environment/sustainability/resilience/adaptation_framework/climate_adaptation.pdf

National Climate Task Force. (March 2023). Federal Flood Risk Management Standard Climate-Informed Science Approach (CISA) State of the Science Report. https://www.whitehouse.gov/wp-content/uploads/2023/03/Federal-Flood-Risk-Management-Standard-Climate-Informed-Science-Approach-CISA-State-of-the-Science-Report.pdf

Office of Science and Technology Policy (2023). Selecting Climate Information to Use in Climate Risk and Impact Assessments: Guide for Federal Agency Climate Adaptation Planners. White House Office of Science and Technology Policy. Washington, D.C. https://www.whitehouse.gov/wp-content/uploads/2023/03/Guide-on-Selecting-Climate-Information-to-Use-in-Climate-Risk-and-Impact-Assessments.pdf

Terando, A., Reidmiller, D., Hostetler, S.W., Littell, J.S., Beard, T.D., Jr., Weiskopf, S.R., Belnap, J., and Plumlee, G.S., 2020, Using information from global climate models to inform policymaking—The role of the U.S. Geological Survey: U.S. Geological Survey Open-File Report 2020–1058, 25 p., https://doi.org/10.3133/ofr20201058

Integrating Resilience into Transportation Decision Making (Cross-Cutting)

American Public Transportation Association. 2021. Using Asset Criticality to Make More Informed Decisions in a Transit Agency https://www.apta.com/wp-content/uploads/APTA-SUDS-TAM-RP-010-21.pdf

FTA (2011). Flooded Bus Barns and Buckled Rails: Public Transportation and Climate Change Adaptation. https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_0001_-_Flooded_Bus_Barns_and_Buckled_Rails.pdf

FTA (August 2014). Transit and Climate Change Adaptation: Synthesis of FTA-Funded Pilot Projects. https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0069_0.pdf

Lempert, R., J. Arnold, R. Pulwarty, K. Gordon, K. Greig, C. Hawkins Hoffman, D. Sands, and C. Werrell, 2018: Reducing Risks Through Adaptation Actions. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 1309–1345. https://nca2018.globalchange.gov/chapter/28/

Transportation Research Board. National Cooperative Highway Research Program. 2021a. *Mainstreaming System Resilience Concepts into Transportation Agencies: A Guide.* https://doi.org/10.17226/26125

Transportation Research Board. 2021b. *Investing in Transportation Resilience: A Framework for Informed Choices*. https://doi.org/10.17226/26292.

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Southern California Association of Governments (SCAG). Adaptation and Resilience Planning for Providers of Public Transportation. https://scag.ca.gov/transit-adaptation-and-resilience-planning

U.S. DOT. Office of the Secretary of Transportation. 2021. Climate Action Plan. https://www.transportation.gov/sites/dot.gov/files/2022-04/Climate_Action_Plan.pdf

Integrating Resilience into Transit Planning and Project Selection

FHWA and FTA. 2021. 2021 Planning Emphasis Areas for use in the development of Metropolitan and Statewide Planning and Research Work programs. https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-01/Planning-Emphasis-Areas-12-30-2021.pdf

FHWA. Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation Program. https://www.fhwa.dot.gov/environment/protect/

State Emergency Management Agencies. https://www.usa.gov/state-emergency-management.

Integrating Resilience into Project Development and Environmental Review

FHWA. 2019. Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide. https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/implementation_guide/

FHWA. 2017. Synthesis of Approaches for Addressing Resilience in Project Development. https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/teacr/synthesis/fhwahep17082.pdf

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U.S. DOT Volpe Center. Resilience and Disaster Recovery Tool Suite. https://github.com/VolpeUSDOT/RDR-Public

US DOT. December 2023. Benefit-Cost Analysis Guidance for Discretionary Grant Programs. https://www.transportation.gov/sites/dot.gov/files/2023-12/Benefit%20Cost%20Analysis%20Guidance%202024%20Update.pdf

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Integrating Resilience into Transit Operations & Maintenance

FHWA. 2015. Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance. https://ops.fhwa.dot.gov/publications/fhwahop15026/fhwahop15026.pdf

FTA. FTA Environmental and Sustainability Management Systems. https://www.transit.dot.gov/regulations-and-programs/environmental-programs/environmental-and-sustainability-management-systems

Resources for Examples in Practice

The resources below lead to additional information on the examples referenced throughout the Guidebook.

King County

- King County 2020 Strategic Climate Action Plan (May 2021): https://your.kingcounty.gov/dnrp/climate/documents/scap-2020-approved/2020-king-county-strategic-climate-action-plan.pdf

Los Angeles County Metropolitan Transportation Authority (LA Metro)

- Metro Sustainability Plan (2020): https://www.transit.dot.gov/sites/fta.dot.gov/files/2022-03/LA-Metro-Sustainability-Strategic-Plan-2020.pdf
- Metro Climate Action and Adaptation Plan (2019): https://media.metro.net/projects_studies/sustainability/images/Climate_Action_Plan.pdf
- Metro Equity Information Hub: https://equity-lametro.hub.arcgis.com/
- Metro Climate Change Adaptation Pilot Project Report (2013): https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0073.pdf

Maryland Department of Transportation (MDOT) Maryland Transit Administration (MTA)

- Adaptation & Resilience Toolbox: https://www.resilientmdotmta.com/

Massachusetts Bay Transportation Authority (MBTA)

- Focus40, the 2040 Investment Plan for the MBTA (2019): https://static1.squarespace.com/static/57757a3cff7c50f318d8aae0/t/5c9042690852294993eae62b/1552958096600/F40+Final+Book+Layout_V9-2019_03_13-508compliant.pdf
- MBTA Design Guideline for Bus Maintenance Facilities Second Edition (2023): https://cdn.mbta.com/sites/default/files/2023-04/2023-03-31-bus-maintenance-facility-design-guideline-second-edition_accessible.pdf
- MBTA Flood Resiliency Design Directive (2019): https://cdn.mbta.com/sites/default/files/2019-12/2019-11-18-flood-resiliency-directive-accessible.pdf
- Vulnerability Assessments: https://www.mbta.com/sustainability/climate-change-resiliency

Metropolitan Atlanta Rapid Transit Authority (MARTA)

- Transit Climate Change Adaptation Assessment/Asset Management Pilot for the MARTA (2013):https://www.transit.dot.gov/sites/fta.dot.gov/files/FTA_Report_No._0076.pdf

Metropolitan Transit Authority of Harris County (Houston Metro)

- National Weather Service. Hurricane Harvey 2017: https://www.weather.gov/lch/2017harvey#:~:text=Harvey's%20rainfall%20was%20the%20most,60.54%20inches%20near%20Groves%2C%20Texas.

- Gurely, G. (January 12, 2018). What Cities Can Learn from Houston Metro's Hurricane Harvey Experience. *The American Prospect.* https://prospect.org/environment/cities-can-learn-houston-metro-s-hurricane-harvey-experience/

- Transit Center. (October 26, 2017). Houston Metro Shines During Hurricane Harvey. https://transitcenter.org/houston-metro-shines-during-harvey/

Montgomery County Transit

- Montgomery County DOT Press Release (2022): https://www2.montgomerycountymd.gov/mcgportalapps/Press_Detail.aspx?Item_ID=42341&Dept=50
- Project Profile: Montgomery Microgrid Charging Depot P3, Maryland: https://www.fhwa.dot.gov/ipd/project_profiles/md_montgomery_micrgrid.aspx#:~:text=Montgomery%20County%2C%20Maryland%20leveraged%20its,charge%20county%2Downed%20electric%20buses.

New Jersey Transit

- Raritan River Bridge Replacement Project website: https://njtransitresilienceprogram.com/raritanriveroverview/

- Raritan River Bridge Replacement Project Environmental Assessment/Draft Section 4(f) Evaluation (2017): https://njtransitresilienceprogram.com/wp-content/uploads/2017/06/RaritanRiverBridge-Replacement_EA-Text_20170614.pdf

Orange County Transportation Authority (OCTA)

- OCTA Rail Defense Against Climate Change Plan (2021): https://www.octa.net/pdf/OCTA_RailDefAgainstCC_FinalReport_wAppendix.pdf?n=202103

Regional Transportation Authority of Chicago

- Flooding Resilience Plan for Bus Operations (May 2018): https://www.rtachicago.org/uploads/files/general/Drupal-Old/documents/plansandprograms/RTA%20FRPBO%20Full%20Report%20With%20Appendices.pdf

San Francisco Bay Conservation & Development Commission

- Community Vulnerability Mapping website: https://bcdc.ca.gov/data/community.html

- Adapting to Rising Tides Adaptation Planning Process: https://www.adaptingtorisingtides.org/howto/art-approach/

Southeastern Pennsylvania Transportation Authority (SEPTA)

- SEP-TAINABLE 2020 Sustainability Plan: https://planning.septa.org/wp-content/uploads/2022/06/SEPTAINABLE-2020.pdf

- SEPTA Transformation Office Annual Report: https://planning.septa.org/wp-content/uploads/2023/03/TransformationOfficeAnnualReport_final.pdf
- SEPTA Forward Strategic Plan: https://planning.septa.org/wp-content/uploads/2021/02/SEPTA-Forward_StrategicPlan2021-2026.pdf

Yuba-Sutter Transit Authority

- Yuba-Sutter Transit (2022). 2022 Grant Application Rebuilding American Infrastructure with Sustainability and Equity (RAISE): Next Generation Zero-Emission Bus Operations, Maintenance, and Administration Facility: https://www.yubasuttertransit.com/files/12f9045db/Narrative.pdf
- WSP. February 2021. Yuba-Sutter Transit Next Generation Transit Facility, Working Paper #1 Site Selection: https://www.yubasuttertransit.com/files/6bbda1bbd/Yuba+Sutter+Transit+Working+Paper+%231+Site+Selection+10-8-20.pdf
- WSP. February 2021. Yuba-Sutter Transit Next Generation Transit Facility, Working Paper #2: Final Design Criteria: https://www.yubasuttertransit.com/files/3772a7c24/Yuba-Sutter+Transit+Working+Paper+%232+-+Final+Design+Criteria+10-8-20.pdf
- WSP. February 2021. Yuba-Sutter Transit Next Generation Transit Facility, Working Paper #3: Funding Plan and Cash Flow Analysis: https://yubasuttertransit.com/files/3b39261d3/WSP+NextGen+Section+3+Final+with+Appendix+A+Costs.pdf

Trainings

National Highway Institute (NHI) Trainings

- NHI-142081 Understanding Past, Current and Future Climate Conditions https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=142081&typ=3&sf=0&course_no=142081
- NHI-142082 Introduction to Temperature and Precipitation Projections https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=142081&typ=3&sf=0&course_no=142082
- NHI-142083 Systems Level Vulnerability Assessments https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=142081&typ=3&sf=0&course_no=142083 https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=142081&typ=3&sf=0&course_no=142084
- NHI-142084 Adaptation Analysis and Project Decision Making https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=142081&typ=3&sf=0&course_no=142084
- NHI-142085 Addressing Climate Resilience in Highway Project Development and Preliminary Design https://www.nhi.fhwa.dot.gov/course-search?tab=0&key=NHI%20142085%20&sf=0&course_no=142085

DOT Climate Change Center Trainings

- Climate and Transportation 101: Recording Passcode: so*bDP5z
- 2024 Webinar Series: Webinars | US Department of Transportation

Potential Funding Sources

FTA Programs

FTA funding: https://www.transit.dot.gov/funding
FTA Emergency Relief Program: https://www.transit.dot.gov/funding/grant-programs/emergency-relief-program

Other US DOT Programs

FHWA PROTECT Discretionary Grant Program:https://www.fhwa.dot.gov/environment/protect/discretionary/

Neighborhood Access and Equity Grant Program
https://www.transportation.gov/grants/rcnprogram/about-neighborhood-access-and-equity-grant-program

FEMA Programs

FEMA Building Resilient Infrastructure and Communities Program:
https://www.fema.gov/grants/mitigation/building-resilient-infrastructure-communities

FEMA Flood Mitigation Assistance Grant Program:
https://www.fema.gov/grants/mitigation/flood-mitigation-assistance

FEMA Hazard Mitigation Grant Program:
https://www.fema.gov/grants/mitigation/hazard-mitigation

Appendix

Additional Examples in Practice

The following presents additional examples in practice to demonstrate how transit agencies across the country are addressing resilience. The examples are organized within the six phases of the Resilience Framework.

Phase 1: Assess

BCDC Regional Approach to Assessing Community Vulnerability

The San Francisco Bay Conservation and Development Commission (BCDC) led an effort to assess various socioeconomic, demographic, and environmental factors at a regional scale using high resolution data and localized economic information. The resulting Community Vulnerability Mapping effort provides a method for social equity to be actively incorporated into resilience planning and permitting processes in the San Francisco Bay Area. The vulnerability assessment framework promoted by BCDC's Adapting to Rising Tides program includes:

- A socio-economic analysis of vulnerable communities
- A description of historic exposure and response to past hazards
- An understanding of community needs, resources, and opportunities for cross-jurisdictional cooperation

These efforts provide guidance on considering additional stressors that communities may face that may need to be addressed in adaptation planning. BCDC's ongoing Regional Shoreline Adaptation Plan draws on the lessons learned from these efforts and has a robust public engagement program to complement the regional analysis.

Phase 2: Plan

MBTA Integration of Resilience in Long-Range Planning and Project Prioritization

The MBTA's Focus40 is its long-range investment plan for meeting the needs of the Greater Boston region in 2040 and ensuring that the MBTA becomes the reliable, robust, and resilient transit system the region requires. To develop the plan in the face of uncertainty, the MBTA used a scenario planning approach looking at a range of possible futures to develop a robust investment strategy that can be successful regardless of how current trends evolve. The scenario planning looked at four key trends, one of which was the policies and behaviors around climate change (MBTA, 2019).

Focus40 also identifies a systemwide resilience program area that aims to "[r]etrofit priority MBTA assets to withstand severe weather and sea level rise and ensure all new construction meets strict resilience standards" (MBTA, 2019). (See the MBTA Resilience Design Standards example in Phase 3 of this Guidebook). The plan identifies resilience investments that are programmed in the five-year Capital Investment Plan as well as investment options that are important to meet the needs of the region in 2040. A key step in the development of that plan was the evaluation, scoring, and prioritization of capital funding requests. One of the CIP's criteria –Policy Support –evaluates the extent to which the project is aligned with MBTA policy priorities, including Focus40. Another criterion – System Preservation – considers the extent to which the project contributes to a state of good repair, including system resilience. The result was a FY23-27 Capital Investment Plan that includes resilience projects such as vulnerability assessments and flood protection measures (MBTA, 2022).

Phase 3: Design and Construct

California Sea Level Rise Guidance Considers Risk Tolerance

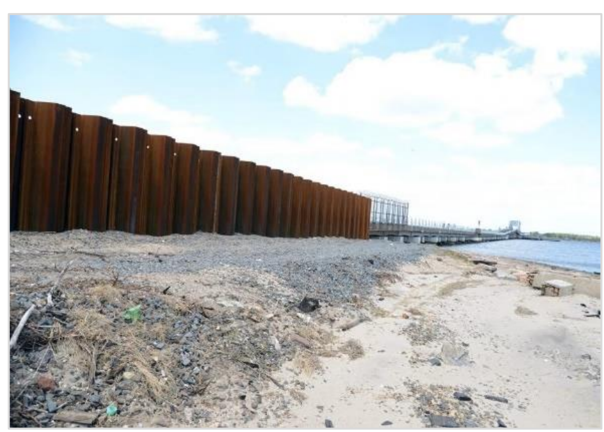
The State of California publishes sea level rise guidance for selecting design conditions and risk aversion scenarios for any project within California's Coastal Zone Management Program. The guidance suggests specific sea level rise scenarios based on a combination of emissions scenarios and the level of risk aversion the project type requires. The guidance provides the user with a set of sea level rise projections based on both low and high emissions pathways, encouraging the user to choose pathways based on the needs of the project. For example, projects with smaller consequences, such as low-use coastal parking lots, may be classified as low risk and be expected to consider the likely range of sea level rise scenarios. Projects with larger consequences, like transit depots or highways, may be expected to consider sea level rise scenarios tied to higher emissions pathways due to the higher consequences of flooding in these areas.

MTA Climate Resilience Projects

After Hurricane Sandy, the New York Metropolitan Transit Authority (MTA) set out not only to repair damage from the storm, but to strengthen NYC's transit system for the future, by keeping water out of tunnels, protecting and rebuilding where necessary infrastructure such as train yards, maintenance shops, power and signal systems not only to be able to rebound quickly after future storms, but to also run more trains when the weather is good. Shown below are MTA's rebuild of the St. George Terminal which has raised signals and enhanced flood protection and Floodwalls installed in the Rockaways.

Example MTA Resilience Projects. St. George Terminal rebuild, including raised signals (R). Enhanced flood protection and floodwalls installed in the Rockaways (L)

Photo Credit MTA



Phase 4: Manage

MARTA Enterprise Asset Management System

The Metropolitan Atlanta Rapid Transit Authority (MARTA) created a new component in its Enterprise Asset Management System (EAM) to document climate resilience, sustainability, and environmental factors. This component was designed to link with MARTA's capital improvement planning software, so that resilience considerations could be seamlessly transferred throughout the investment and decision-making processes.

Phase 5: Maintain

MARTA Maintenance Work Order and EMS Systems

MARTA has adapted its maintenance work order system to include an identification code for weather-related issues. This capability allows staff to signal weather as a cause or stressor related to a maintenance issue. Building in this information piece to the work order system allows for MARTA managers, planners, and procurement staff to more clearly evaluate the costs and impacts associated with severe weather events on transit system assets and services and plan for future repairs, replacement, and other service improvement considerations (TRB, 2017a).

MARTA has also integrated resilience considerations into its EMS to guide O&M activities and investments. MARTA considers emergency preparedness as a key element in their EMS progress, especially regarding tank management and the threat of environmental release. The agency believes that tank management is likely to evolve for transit operators in the coming years as more fleets adopt zero-emissions leading to reduced and reimagined fuel storage systems.

Key Terms

The following terms appear frequently throughout this Guidebook. Their definitions are taken from the U.S. Climate Resilience Toolkit except where noted otherwise.

Adaptation: FTA's equity projects and programs are designed to improve public transportation services for communities that have historically had more limited access to public transportation. The program provides for transportation activities for lower-density and lower-income portions of metropolitan areas and adjoining rural areas.

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

Climate-informed Science Approach (CISA): The elevation and flood hazard area that result from using a climate-informed science approach that uses the best available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding based on climate science. This approach will also include an emphasis on whether the action is a critical action as one of the factors to be considered when conducting the analysis – *National Climate Task Force*.

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

Federal Flood Risk Management Standard: The national flood risk management standard established by Executive Order 13690 to be incorporated into existing processes used to implement Executive Order 11988.

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

Nature-based solutions/Natural Infrastructure: Nature-based solutions or natural infrastructure means a project that "uses, restores, or emulates natural ecological processes and "(A)" is created through the action of natural physical, geological, biological, and chemical processes over time; "(B)" is created by human design, engineering, and construction to emulate or act in concert with natural processes; or "(C)" involves the use of plants, soil, and other natural features, including through the creation, restoration, or preservation of vegetated areas using materials appropriate to the region to manage stormwater and runoff, to attenuate flooding and storm surges, and for other related purposes" –23 United States Code (U.S.C.) 101(a).

Resilience: With respect to a project, resilience means a project with the ability to anticipate, prepare for, or adapt to conditions or withstand, respond to, or recover rapidly from disruptions, including the ability--``(A)(i) to resist hazards or withstand impacts from weather events and natural disasters; or`(ii) to reduce the magnitude or duration of impacts of a disruptive weather event or natural disaster on a project; and``(B) to have the absorptive capacity, adaptive capacity, and recoverability to decrease project vulnerability to weather events or other natural disasters –23 United States Code (U.S.C.) 101(a).

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 hazard.

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

Acronyms and Abbreviations

ADAP	Adaptation Decision-making Assessment Process
ARToolbox	Adaptation and Resilience Toolbox
BCA	Benefit-cost Analysis
BCDC	San Francisco Bay Conservation and Development Commission
BFE	Base flood elevation
CEQ	Council on Environmental Quality
CISA	Climate-informed Science Approach
CTA	Chicago Transit Authority
DFE	Design flood elevation
DOT	Department of Transportation
EMS	Environmental management system
ETC	Equitable Transportation Community
EO	Executive Order
EV	Electric vehicle
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FR	Federal Register
FTA	Federal Transit Administration
FY	Fiscal year
GHG	Greenhouse gas
LA Metro	Los Angeles County Metropolitan Transportation Authority
LEED	Leadership in Energy and Environmental Design
MARTA	Metropolitan Atlanta Rapid Transit Authority
MBTA	Massachusetts Bay Transportation Authority
MPO	Metropolitan planning organization
MTA	Maryland Transit Administration
NEPA	National Environmental Policy Act
NIHHIS	National Integrated Heat Health Information System

NJCL	New Jersey Coastal Line
NJ TRANSIT	New Jersey Transit Corporation
NOAA	National Oceanic and Atmospheric Administration
NTD	National Transit Database
O&M	Operations and maintenance
OCTA	Orange County Transportation Authority
OSTP	White House Office of Science and Technology Policy
PANYNJ	Port Authority of New York and New Jersey
PROTECT	Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation
PTASP	Public Transportation Agency Safety Plan
RTA	Regional Transportation Authority of Northeast Illinois
SEPTA	Southeastern Pennsylvania Transportation Authority
SGR	State of good repair
SLR	Sea level rise
TAM	Transit asset management
TERM	Transit Economic Requirements Model
USC	United States Code
VAST	Vulnerability Assessment Scoring Tool

U.S. Department of Transportation
Federal Transit Administration

U.S. Department of Transportation
Federal Transit Administration
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