

Transit Climate Change Adaptation Assessment/Asset Management Pilot for the Metropolitan Atlanta Rapid Transit Authority

AUGUST 2013

FTA Report No. 0076
Federal Transit Administration

PREPARED BY
Adjo Amekudzi, Ph.D.
Matthew Crane
Georgia Institute of Technology

David Springstead
Metropolitan Atlanta Regional
Transportation Authority

David Rose, Ph.D.
Tiffany Batac
Parsons Brinckerhoff, Inc.



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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	liter	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	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)				
°F	Fahrenheit	$\frac{5}{9}(F-32)$ or $(F-32)/1.8$	Celsius	°C

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ABSTRACT

Public transit agencies play an important role in the provision of safe, reliable, and cost-effective transportation for the communities they serve. With the growing intensity and frequency of extreme weather events, such as hurricanes Irene and Sandy, several public transportation agencies have begun to adapt their systems to make them more resilient to the changing climate conditions. This report applies transit asset management principles to climate change adaptation using the Federal Transit Administration’s “Asset Management Guide.” Climate change adaptation generally involves understanding potential impacts of the changing climate on an agency’s services and assets and taking necessary actions to avoid, reduce, or manage anticipated impacts. For transit agencies, this involves identifying vulnerable assets and their associated risks and prioritizing improvements to develop more resilient systems while achieving other system performance objectives. Principles from the “Asset Management Guide” are applied to demonstrate how a public transit agency can adapt to extreme weather events or changes in climate using the Metropolitan Atlanta Regional Transit Authority (MARTA) as a case study. The report outlines procedures for identifying the climate hazards and vulnerable assets and their associated risks in a transit agency’s service area. It identifies opportunities to integrate climate adaptation strategies in a transit asset management system at the enterprise and asset levels and then link the resulting information to appropriate business units to manage risks while undertaking continual improvement and updates in the life cycle management of assets. Addressing climate change through asset management programs can help agencies achieve system resilience simultaneously with other system performance objectives such as safety, mobility and the state-of-good-repair.

EXECUTIVE SUMMARY

This report demonstrates a progression of improvements made by the Tri-County Metropolitan Transportation District of Oregon (TriMet) to better serve Limited English Proficiency (LEP) customers. This initial investment afforded the agency the opportunity to focus more on meeting the needs of diverse populations, resulting in the development of practical guidelines and protocols. However, the agency is still learning how to improve its delivery of service to LEP communities. This will be an ongoing, iterative process.

Public transit agencies play an important role in the provision of safe, reliable, and cost-effective transportation for the communities they serve. With the growing intensity and frequency of extreme weather events, such as hurricanes Irene and Sandy, several public transportation agencies have begun to adapt their systems to make them more resilient to the changing climate conditions. This report applies transit asset management principles to climate change adaptation using the Federal Transit Administration's "Asset Management Guide." Climate change adaptation generally involves understanding potential impacts of the changing climate on an agency's services and assets and taking necessary actions to avoid, reduce, or manage anticipated impacts. For transit agencies, this involves identifying vulnerable assets and their associated risks and prioritizing improvements to develop more resilient systems while achieving other system performance objectives. Principles from the "Asset Management Guide" are applied to demonstrate how a public transit agency can adapt to extreme weather events or changes in climate using the Metropolitan Atlanta Regional Transit Authority (MARTA) as a case study. The report outlines procedures for identifying the climate hazards and vulnerable assets and their associated risks in a transit agency's service area. It identifies opportunities to integrate climate adaptation strategies in a transit asset management system at the enterprise and asset levels and then link the resulting information to appropriate business units to manage risks while undertaking continual improvement and updates in the life cycle management of assets. Addressing climate change through asset management programs can help agencies achieve system resilience simultaneously with other system performance objectives such as safety, mobility and the state-of-good-repair.

The report is divided into the following sections:

- Section 1 makes a case for applying asset management principles to climate change adaptation.
- Section 2 provides a framework for addressing climate adaptation in transit asset management based on FTA's "Asset Management Guide." The framework is applied to MARTA at an enterprise level as a case study example and described in Sections 3 through 5.
- Section 3 discusses the process for identifying climate hazards in the Metro Atlanta area and the MARTA service area.

- Section 4 provides an overview of MARTA's Asset Management System and outlines opportunities to incorporate climate change adaptation considerations in the system.
- Section 5 discusses integration of climate adaptation into MARTA's decision-making processes. It outlines possible adaptation strategies based on the climate hazards identified for the transit system service area and maps these strategies to transit agency divisions where action can most appropriately be taken to adapt to climate change.

Introduction: Making a Case for Applying Asset Management to Climate Change

The New Climate Era and Transit System Performance

Recent decades have shown that modern climate hazards can affect transit operations and assets significantly. For example, initial recovery and rebuilding cost estimates (including infrastructure repair and replacement costs) of Hurricane Sandy have been placed in the tens of billions of dollars by the Associated Press, at once highlighting the potentially significant impacts of climate change on societies and civil infrastructure, the vulnerability of our older infrastructure systems and traditional designs to modern climate patterns; the significant financial, economic and social costs and risks associated with climate hazards particularly in the context of human life and basic infrastructure services; the opportunity to rebuild smarter after disaster events with improved designs and design standards; and the wisdom in taking a measured and systematic approach to developing infrastructure resilience in response to modern climate patterns. Indeed, New York's Metropolitan Transit Authority (MTA), with a daily ridership of more than five million, has referred to the impact of Hurricane Sandy as unprecedented in the history of the nation's largest transit system. Over several decades in the recent past, other major storms, such as Hurricanes Katrina, Ike, and Ivan, have had similarly significantly adverse impacts on the infrastructure, including public transit, and devastating effects on the quality of life of various communities, amounting to billions of dollars in losses, recovery, and rebuilding.

MAP-21 and FTA Requirements for Transit Asset Management

Asset management is defined as a strategic and systematic process of operating, maintaining, upgrading, and expanding physical assets effectively throughout their lifecycle. It focuses on business and engineering practices for resource allocation and utilization, with the objective of better decision making based on quality information and well-defined objectives [1]. Public Transit Asset Management

(TAM) systems ideally use quality inventory and condition data and well-defined objectives to provide a systematic process for improving resource allocation decision-making. Maintaining transit systems in a state of good repair (SGR) is critically important to improving the social quality of life and local, regional and national economic competitiveness. SGR may be defined as a state that results from the application of asset management concepts in which a transit agency maintains its physical assets according to a policy that minimizes asset life-cycle costs while avoiding negative impacts to transit service. It involves the following [2]:

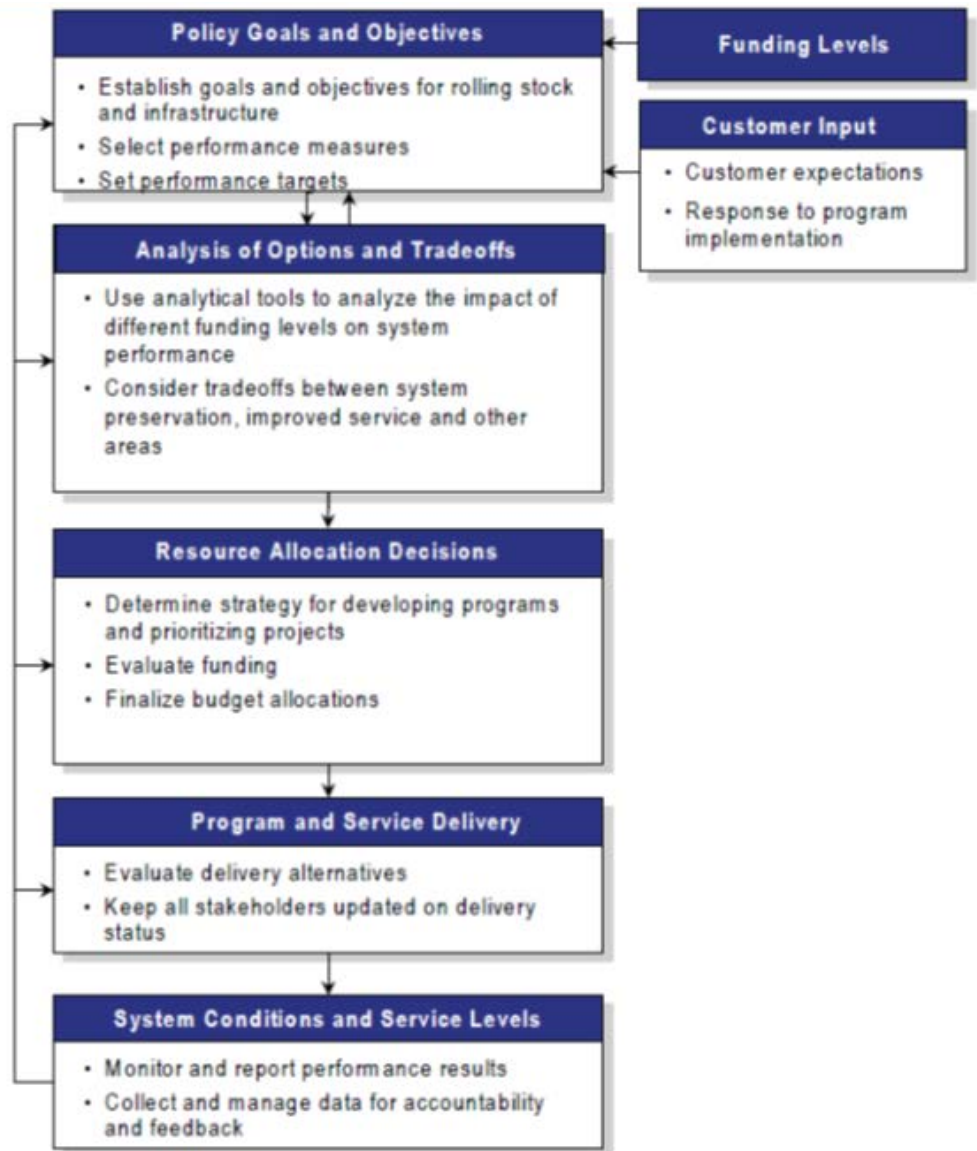
- Maintaining an agency’s rolling stock and infrastructure as needed to meet a certain level of service (e.g., avoiding slow zones on a rail system),
- Performing maintenance, repair, rehabilitation and renewal according to agency policy (e.g., replacing buses according to a set time interval), and/or
- Reducing or eliminating an agency’s backlog of unmet needs.

The generic asset management process in transit agencies involves the following [2]:

1. Collecting inventory and condition data for rolling stock and infrastructure
2. Establishing a lifecycle policy for system preservation, including maintenance repair, rehabilitation and renewal activities, and modeling application of the policy on physical assets
3. Developing alternative capital programming scenarios that use the above steps together with projections of agency funding to characterize predicted future conditions and maximize the effectiveness of agency investments

Figure I-1 depicts the generic asset management process for public transit agencies. Each step of this process offers opportunities for integrating climate change considerations in the context of the existing decision support framework of a transit agency.

Figure 1-1
 Transit asset
 management process
 [3]



MAP-21 Requirements for Transit Asset Management and State of Good Repair

Section 20019 of the 2012 reauthorization of the national surface transportation law, Moving Ahead for Progress in the 21st Century (MAP-21), establishes new requirements for transit asset management by grantees of the Federal Transit Administration (FTA) as well as new reporting requirements to promote accountability. Indeed, the goal of improved transit asset management is to implement a strategic approach for assessing needs and prioritizing investments for bringing the nation's public transit systems into a state of good repair. MAP-21 calls for a national transit asset management system which does the following:

1. Defines the state of good repair
2. Sets objective standards for measuring the condition of capital assets (including equipment, rolling stock, infrastructure, and facilities)
3. Establishes performance measures for state of good repair, under which all FTA grantees will be required to set targets.

In addition, FTA grantees are required to develop asset management plans that include the following at a minimum:

1. Capital asset inventories and condition assessments
2. Estimation of capital investment needs
3. Asset Investment prioritization.

Each grantee would also be required to report on (1) system condition, (2) any change in condition since the last report, (3) targets set under the designated performance measures, and (4) progress toward meeting those targets [3].

The MAP-21 requirements for transit asset management (TAM) indicate that TAM systems that are not at the required level of maturity will undergo developments to meet the requirements. In the context of the MAP 21 requirements for transit asset management, there are several opportunities to proactively develop or modify transit asset management systems to address climate change considerations as they are being developed to address SGR considerations. However, it also opens the door for agencies to take leadership in identifying potentially high-severity, high-impact scenarios, identifying alternative sources of funding and developing shorter-term strategies for addressing these scenarios proactively and preemptively.

FTA's "Asset Management Guide"

There is considerable focus on improving transit asset management, as evidenced through national policy, FTA's National State of Good Repair Assessment, and the enactment of MAP-21, requiring transit agencies to prepare a transit asset management plan. FTA's "Asset Management Guide" [4] provides a transit-specific asset management framework for managing assets individually and as a portfolio of assets that comprise an integrated system. Through lessons learned from those with first-hand experience with each asset class, the guide does the following:

- Explains what transit asset management is and what the business benefits to an agency are.
- Provides an enterprise asset management framework and business model that agencies can refer to as "best practice."

- Describes the elements of a transit asset management plan.
- Details the primary components of asset management for each major asset class (e.g., inventory, condition assessment, performance analysis and modeling, risk assessment, and lifecycle cost management).
- Guides organizations through the migration from their current baseline to higher-performing asset management.

Risk-Based Transit Asset Management: Climate Change Adaptation in the Context of Asset Management

Climate change adaptation strategies are actions taken to adapt to expected changes in the climate. While adaptation measures deal with the effects of climate change, mitigation measures deal with the causes of climate change. From the viewpoint of the Metropolitan Atlanta Rapid Transit Authority (MARTA), climate change adaptation involves understanding the potential impacts of the changing climate on the agency's services and assets and taking the necessary actions to avoid, reduce, or manage anticipated impacts. This process can be thought of as building resilience to climate change. In essence, climate change adaptation can be viewed as building resilience to climate change [5].

In transit and other transportation agencies, a systematic approach to addressing climate hazards is likely to be developed in the context of ongoing systematic decision-making at the agencies on the SGR of their assets. This indicates that several transit agencies may begin to consider climate change in the context of their asset management programs and practices. Commissioned by the U.S. Congress, the Rail Modernization Study [6] assessed capital investment needs for the nation's seven largest transit operators—Chicago Transit Authority (CTA), Massachusetts Bay Transportation Authority (MBTA), Metropolitan Transportation Authority of New York (MTA), New Jersey Transit Corporation (NJ TRANSIT), San Francisco Bay Area Rapid Transit (BART), Southern Pennsylvania Transportation Authority (SEPTA), and Washington Metropolitan Area Transit Authority (WMATA)—agencies that collectively account for 80 percent of annual passenger boardings, 51 percent of track miles, 57 percent of passenger stations, and 74 percent of fleet vehicles. The study showed that \$50 billion (2008 dollars) would be needed to replace all assets exceeding their useful life and to rehabilitate all stations, with an additional \$5.9 billion (2008 dollars) per year to maintain the assets in good condition beyond that. The study also

found that all seven transit agencies had asset management processes in place at different levels of maturity [6].

The Rail Modernization Study has at least four implications in the context of climate change impacts to public transit agencies, systems and services:

1. A significant inventory of transit capital is potentially vulnerable to climate changes or hazards nationwide
2. Climate change considerations will largely be made in the context of SGR and budgetary considerations, in a competitive and/or complementary manner
3. Asset management programs are a logical platform to consider systematic climate change risks for an entire public transit system
4. With budgetary limitations and competing objectives, risk (i.e., probability of a hazard occurring and its level of impact) is a useful construct for climate change adaptation considerations using existing asset management systems

Based on the vulnerability of the assets to climate hazards, the relative criticality of those assets to the agency achieving its goals, the potential magnitude of the impacts on the system users and surrounding community, and the costs of appropriate retrofits, appropriate climate-change retrofits can be prioritized to make the system more resilient. While agencies may take a more progressive approach to addressing lower-impact scenarios, they may find it ultimately more beneficial to their customers and the surrounding community to take a more aggressive stance toward identifying and addressing higher-impact scenarios where assets have relatively high criticality. An asset management framework will facilitate such assessments.

Transit has multiple benefits—moving people safely, reliably, and affordably in various metropolitan areas, cities, and towns nationwide. Transit systems support economic development, improve the societal quality of life, provide mobility and accessibility to those who need it, and help to protect and sustain our environment by offering alternative mode choices to highway travel [6]. Ultimately, transit agencies that can proactively deliver cost-effective climate risk management stand to protect these benefits for their customers and the broader community in which they provide service, and to preserve their ability to continue to build and expand upon their significant cumulative investments in transit systems thus far. At the same time, agencies would want to be cautious and wise in how they expend limited funds on climate-related issues in the face of other critical priorities such as SGR backlogs and operational safety. This is where an asset management platform can be a very useful and effective approach to providing appropriate decision support in the face of multiple decision-making objectives.

Report Objectives and Outline

This report makes a case for using transit asset management programs to adapt to climate change, discusses key elements of the process using Metro Atlanta’s public transit system as a recurring example, and presents guidelines and a case study for using risk-based transit asset management procedures to adapt to climate change, using FTA’s “Asset Management Guide.” Following this introduction, the report is divided into the following sections:

- Section 2 provides a framework for addressing climate adaptation in transit asset management based on FTA’s “Asset Management Guide.” The framework is applied to MARTA at an enterprise level as a case study example and described in Sections 3 through 5.
- Section 3 discusses the process for identifying climate hazards in the Metro Atlanta area and the MARTA service area.
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Understanding Climate Adaptation Terminology Used in this Report

Throughout this report, there are a number of terms used to describe and address climate challenges in a transit asset management framework. They include:

- *Vulnerability assessment* refers to the process of identifying, quantifying, and prioritizing the vulnerabilities in a system. Asset vulnerability assessment to adapt for climate change or extreme weather events involves understanding the climate hazards or stressors in the public transit system service area and understanding the relative exposures of the assets/system and their users to these stressors in an extreme weather event.
- *Risk assessment* refers to an integrated evaluation of the likelihood and consequences of climate change impacts on the performance of the transit asset or system.
- *Climate change adaptation or climate risk mitigation strategies* are actions taken to adapt to expected changes in the climate. From MARTA’s viewpoint, climate change adaptation involves understanding the potential impacts of the changing climate on the agency’s services and assets and taking the necessary actions to avoid, reduce, or manage anticipated impacts. This process can be thought of as managing associated risks and building resilience to climate

change. In essence, climate change adaptation can be viewed as building resilience to climate change [5].

- *Resilience* represents the ability of a system to react to stresses that challenge its performance [8]. A resilient system is able to adjust its functioning prior to, during, or following changes and disturbances, so that it can continue to perform as required after a disruption or a major mishap, and in the presence of continuous stresses [9]. Resilient systems have the ability to recover from sudden and severe stresses in a dynamic environment. Robust systems can 1) absorb effects from disturbances that are caused due to several reasons and 2) ensure operational continuity. Designing to achieve these goals is resilience engineering [8].
- *Criticality* relates to how critical an asset is to the fulfillment of the agency's objectives. In providing safe, reliable, and cost-effective transit, a transit agency may rank various assets according to the extent to which they are critical to the safety of customers and the reliable operation of their system. Table I-1 shows MARTA's prioritization scheme for critical infrastructure.

Table 1-1
*MARTA Lifecycle/
Priority Definitions*

	Lifecycle/Priority	Definitions
1	Life Safety-Critical	Equipment and capital projects with this priority perform a function(s) that when faulty could cause injury or death.
2	Operation Critical	Equipment and capital projects with this priority perform a function(s) that when faulty directly impacts our ability to provide revenue service.
3	Operation Support	Equipment and capital projects with this priority perform a function(s) that when faulty could, over time, have an impact on revenue service operations.
4	Operation Enhancement	Equipment and capital projects with this priority perform a function(s) that serves to plan and/or enhance revenue service operations.
5	Operation Expansion	Equipment and capital projects with this priority perform a function(s) that serves to plan and/or expand revenue service operations.
6	Decommissioned	Equipment with this priority has been taken out of use/ service.
7	Salvage	Equipment with this priority is no longer in use and is awaiting salvage.

SECTION
2

Applying FTA's “Asset Management Guide” to Address Climate Adaptation in a Transit Agency

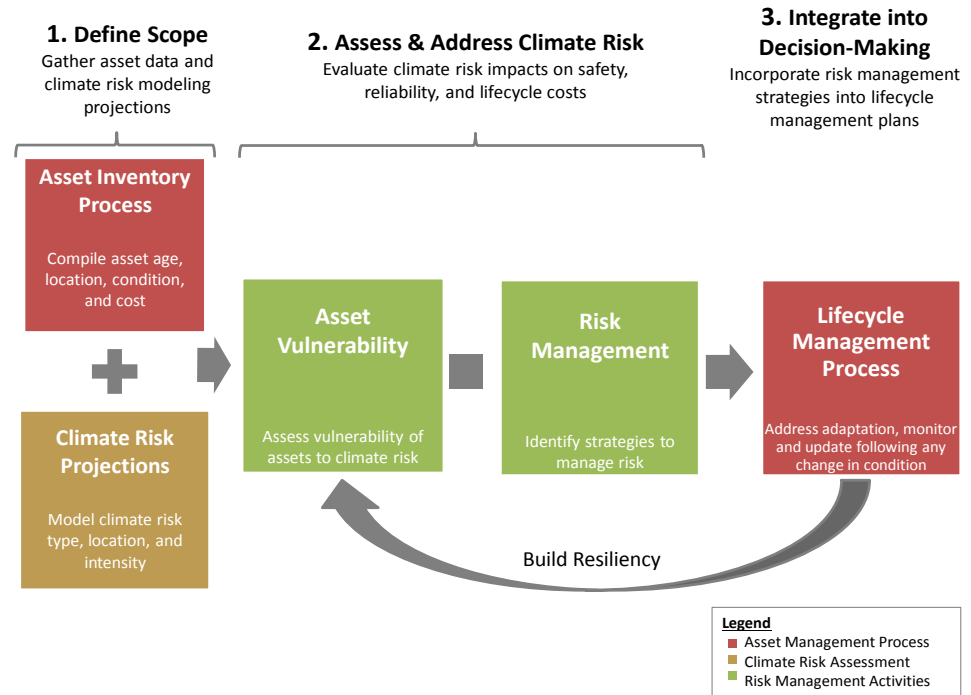
Context for Climate Adaptation in Transit Asset Management

The Intergovernmental Panel on Climate Change (IPCC) defines climate adaptation as the, “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.” A transit agency adapting to climate change refers to adjusting its assets, systems, and management practices in a way that moderates potential damage, copes with consequences, or finds opportunities to build system resiliency and maintain a minimum level of service. These constitute a set of climate risk mitigation actions that require capital expenditures for which the evaluation of risk and mitigation costs creates a business case for the investments. In fact, an independent study assessing the future savings from natural hazard mitigation activities, commissioned by the Federal Emergency Management Agency (FEMA), found that, in some cases, four dollars can be saved for every one dollar invested.

To identify the capital expenditures required to adapt to climate change involves a systematic, business-driven analysis to ensure the most effective use of funding. The general approach is to assess the criticality of transit assets to the regional economy, accessibility, and mobility in an extreme weather event and identify thresholds above which climate risks to asset performance are severe. In an extreme weather event, it also involves assessing the damage done and what actions are to be taken to restore service as quickly as possible.

An asset management focused adaptation process can be characterized by three broad steps: 1) define scope of climate adaptation, 2) assess and address climate risk, and 3) integrate into decisionmaking. Figure 2-1 illustrates these broad steps and is described in further detail below.

Figure 2-1
Addressing climate adaptation in transit asset management



Step 1: Define Scope of Climate Adaptation

In this first step, two key actions are involved:

- Identification of current and future climate risks.
- At the asset level, this also entails identification of critical transit assets based on number of people affected, mobility, or access needs in the event of an emergency or extreme weather event.

An assessment of the agency's climate stressors (e.g., high winds, intense precipitation, drought, etc.) is conducted either in conjunction with or after the agency's assets have been inventoried. The asset inventory should include, at a minimum, the asset location, condition, age, and cost. In Step 2, this asset inventory will be built upon with climate risk data.

Climate information obtained should include, at a minimum, the current and projected climate stressor (type and level of risk) in the service area, location, and intensity.

Critical assets should be identified (based on mobility or accessibility needs and exposure to risk – e.g., how many people would be affected) and mapped against locations vulnerable to specific climate stressors to determine which assets are likely to be affected and by which climate stressor.

Step 2: Assess and Address Climate Risk

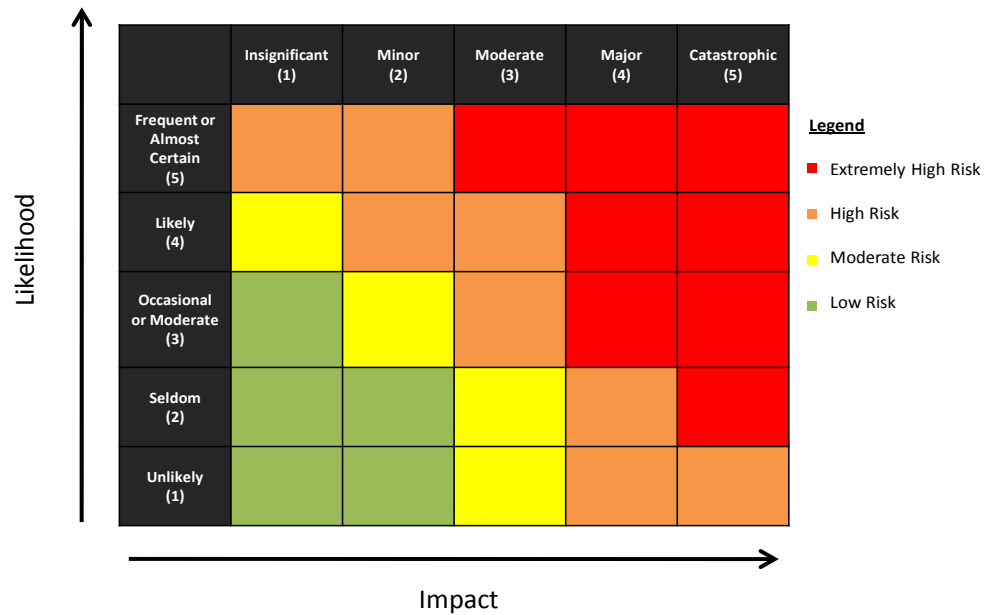
Step 2 focuses on the evaluation of climate risk impacts on the safety, reliability, and lifecycle costs of transit assets and system operations. Two key actions include:

- Assess the vulnerability (in other words, sensitivity or level of exposure) of the asset to a particular climate stressor and understand how it performs under those conditions.
- Conduct a risk assessment, evaluating the severity or consequences of a climate impact in combination with the likelihood that the asset will experience that particular impact.

Building upon the asset inventory in Step 1, performance under different climate conditions should be understood and included. For example, if increased temperatures are expected, how will intense heat affect the transit service and associated assets in that location? Will the risks of intense heat affect performance of air conditioning systems on trains? If so, at what temperature point would the air conditioning system malfunction?

Asset vulnerability is determined using a general risk matrix based on the likelihood and consequences of climate change impacts on the performance of the transit asset or system. Low to high characterizations can be made on a scale of 1 to 5, where 5 equates to catastrophic impact of risk or frequent/ almost certain likelihood of the climate risk impacting a particular asset (see Figure 2-2). With the absence of information on the likelihood of specific climate impacts, climate impact studies will often use separate risk matrices for a range of possibilities with a "low emissions" scenario and a "high emissions" scenario or a range of emissions scenarios. To determine consequence, transportation agencies may wish to consider the level of use of an asset, the degree of redundancy in the system, or the value of an asset (in terms of cost of replacement, economic loss, environmental impacts, cultural value, or loss of life). The combination of these risk characterizations can help rate or identify a transit agency's most vulnerable assets.

Figure 2-2
Climate risk matrix



Upon conducting a vulnerability and risk assessment, an agency can then develop appropriate risk mitigation strategies and prioritize projects based on short- and longer-term needs as part of a broader adaptation plan. For vulnerable or critical assets identified, cost should also be considered. If quantitative values are not available, a rating of high, medium, or low may be used to assess the cost to replace or retrofit the asset.

Risk mitigation strategies generally fall under four major categories as identified by FTA [10]:

- **Maintain and Manage:** Absorb increased maintenance and repair costs and improve real-time response to severe events for existing assets. Incorporate “smart” technologies such as sensors that detect changes in pressure and temperatures in materials; these can set off alerts of approaching damage thresholds for bridges and other structures, or of rising water levels and potential flooding.
- **Strengthen and Protect:** Retrofit existing structures and facilities or replace with newly-designed infrastructure/assets to withstand future climate conditions (larger drainage capacity, stronger structures to withstand high winds, materials suited to higher temperatures). Build protective features such as retaining walls, levees, and vegetative buffers.
- **Enhance Redundancy:** Identify system alternatives to maintain mobility and accessibility, or return to service as quickly as possible, throughout the region in the event of an emergency or extreme weather event. Examples include increased bus service in the event of rail interruption or increased ferry service in the event of a major bridge shutdown.

- **Retreat or Avoid:** Abandon transportation infrastructure located in extremely vulnerable or indefensible areas. Potentially relocate. Avoid developing new facilities in areas vulnerable to high climate risk.

A later section describes different types of risk mitigation strategies in further detail.

Step 3: Integrate into Decision-Making

Step 3 focuses on implementation of the adaptation plan and risk management strategies. Addressing climate adaptation in transit asset management occurs at two levels: the enterprise level and asset level. At the enterprise level, the adaptation plan is the overall strategy providing direction for cross-asset business processes. It also provides information on the overall capital expenditure needs required to accomplish climate change adaptation objectives.

At the asset class level, it provides direction to business unit managers regarding the incorporation of capital improvements that strengthen and protect and/or enhance redundancy. These lifecycle management plans address the overall implication of climate change adaptation to preventive and corrective maintenance required and provide guidance for rehabilitation/replacement of projects over the asset lifecycle. These plans are integrated into the agency's annual planning and budgeting cycles.

Once the climate risk mitigation strategies are identified, they can be linked to the appropriate department in the agency's organizational structure and incorporated into lifecycle management planning and budgeting processes. Investment portfolios may vary across transit agencies depending on a variety of factors such as geography, asset types, etc. In some areas, for example, investment decisions may be driven by climate stressors specific to the geography, such as earthquakes or high winds. After an adaptation plan has been implemented, the actions taken should be monitored for performance and the adaptation plan and risk management strategies should be reassessed as conditions change.

Addressing Climate Adaptation in Transit Asset Management: An Enterprise Level Strategy

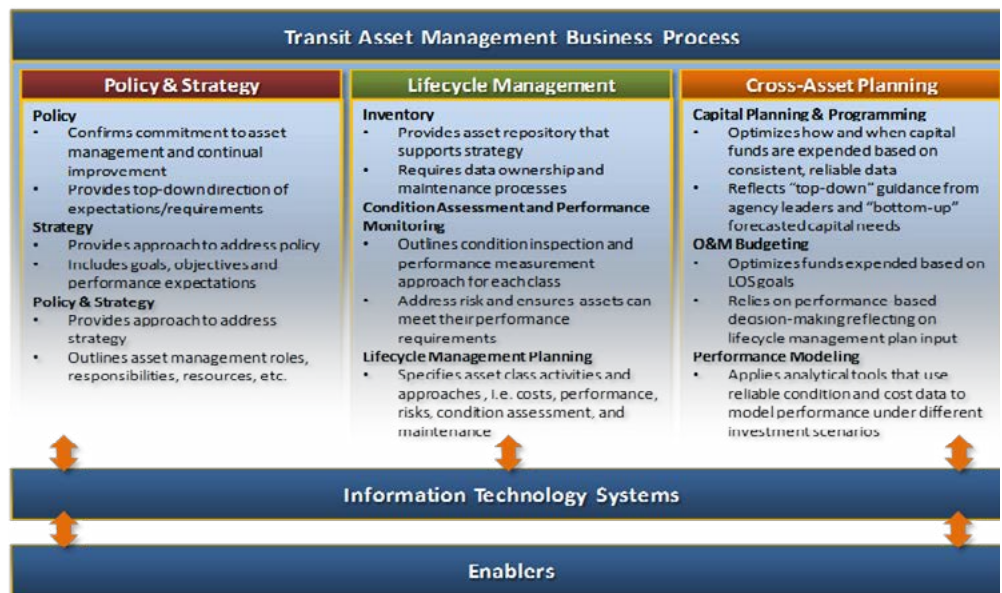
In a high-performing transit agency, asset management is a core strategic management process, along with risk management and performance management. None of these processes can be entirely effective without the other, and together, they help the agency accomplish its goals and objectives. Although adapting to climate changes primarily intersects asset management and

risk management processes, if done successfully, it will also improve performance by encouraging a “predict and prevent” as opposed to a “find and fix” approach. By taking a whole lifecycle approach from design specifications, through procurement, and into maintenance practices, the future operating environment and conditions are better addressed.

There are three major components of a transit asset management business process that can be categorized by 1) Policy & Strategy, 2) Lifecycle Management, and 3) Cross-Asset Planning (see Figure 2-3). At the enterprise level, a transit adaptation plan provides direction for cross-asset business processes primarily through policy and strategy.

Figure 2-3

Transit asset management business process



Source: http://www.fta.dot.gov/documents/FTA_Report_No._0027.pdf

There are five key components of transit asset management planning:

- 1. Asset Management Policy and Strategy:** States the asset management policy and strategy and describes process for developing these, including relationship to agency-wide policies and strategies. It also explains the past year’s accomplishments and planned progress towards goals and objectives.
- 2. Implementation Strategy:** A plan and schedule with roles, responsibilities, accountabilities, tasks, and dependencies showing activities necessary to achieve the asset management goals (including all aspects of change management).
- 3. Key Asset Management Activities:** Key asset management activities that are planned to be accomplished in the upcoming year. Examples of activities include combining three departments’ asset inventories, developing a lifecycle management template, or hiring asset management program manager.

- 4. Financial Requirements:** Resources (including internal staff time, consultant time, technology requirements, and materials) needed to develop and implement the asset management plan. The information should be easily transferred to the agency's capital program or operations and maintenance budget, as required.
- 5. Continuous Improvement:** The asset management plan and all related business processes should be revisited and updated, as needed, to ensure that the organization is embracing continuous improvement of the asset management initiative.

For each asset management component, opportunities exist to address climate change adaptation. Key climate adaptation considerations and opportunities for each component are outlined in Table 2-1.

Addressing climate change at the enterprise level provides an overall strategy for the agency. The climate risk data collected can help identify which assets are most vulnerable and inform decision-making in the development of enterprise-level risk management strategies. The level to which this data is built into the agency's business procedures will depend on resources and the level of resiliency the agency intends to plan for. Climate adaptation considerations at the enterprise level then inform the coordination needed among various business units and asset managers. Climate change considerations at the asset level are described in a later section through a lifecycle management framework.

Table 2-1 *Opportunities to Integrate Climate Change Adaptation into Asset Management Plans*

Asset Management Component	Key Climate Adaptation Consideration	Opportunity to Integrate Climate Change Adaptation
Asset Management Policy and Strategy	<ul style="list-style-type: none"> • Has the agency considered climate change in asset management goals, policies, and/or plans? 	Incorporate climate change considerations into asset management goals and policies; these could be general statements concerning adequate attention of potential issues, or targeted statements at specific types of climate risk (e.g., heat waves, flooding, etc.)
Integration Strategy with Asset Management Implementation Plan	<ul style="list-style-type: none"> • Has the agency mapped areas vulnerable to projected climate risks? • Has the agency inventoried critical assets, created risk profiles, and developed risk mitigation strategies? 	Identify vulnerability of infrastructure assets in areas susceptible to climate change impacts. Inventory critical assets and identify and implement appropriate adaptation strategies (e.g., updated design guidelines, etc.)—short- and long-term—for these assets or asset classes. These strategies should be mapped to the appropriate business unit that will oversee the lifecycle management activities of that asset or asset class.
Key Asset Management Activities	<ul style="list-style-type: none"> • Has the agency considered adaptation strategies at the enterprise, asset-class or lifecycle asset management planning level? 	Required adaptation strategies in the near term should be identified. Key asset management activities required within the next year can be based on condition assessments where preventive maintenance is warranted to avoid exacerbation of wear and tear or damage due to anticipated climate impacts. It can also involve reactive maintenance activities due to an extreme weather event.
Financial Requirements	<ul style="list-style-type: none"> • Has the agency incorporated climate risk mitigation strategies into its short- and long- range plans? Capital and/or O&M budgeting process? 	Costs associated with the key asset management activities (e.g., replacement parts, retrofits, labor, etc.) identified above should be estimated and incorporated into the agency's capital improvement plan and/or operations and maintenance budgets.
Continuous Improvement	<ul style="list-style-type: none"> • Has the agency begun monitoring asset condition in conjunction with climate change indicators to determine if/how climate change affects performance? 	Monitor asset condition in conjunction with climate-related conditions (e.g., temperature, precipitation, winds, etc.) to determine how it affects performance; incorporate risk appraisal into performance modeling and assessment; flag highly vulnerable assets. Monitor asset management system to ensure effective response to climate change; possible use of climate-related performance measures or thresholds to identify when an asset has reached a critical level. Revisit lifecycle management plans for asset as appropriate based on performance monitoring.

Managing Climate Risks in the Lifecycle Management Process: An Asset Level Strategy

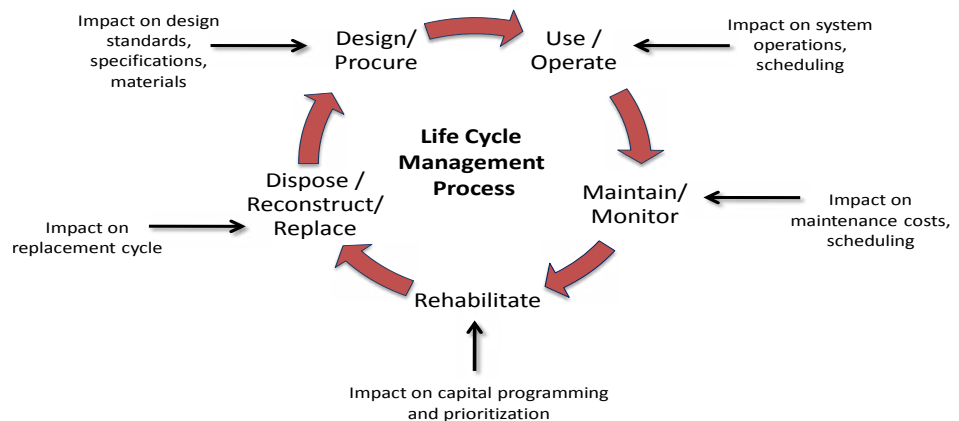
FTA's "Asset Management Guide" defines lifecycle management planning as:

... intended to drive successful service delivery and financial performance by minimizing the cost to procure, operate, maintain, rehabilitate, dispose of, and replace an asset while meeting or exceeding established service and reliability commitments for both the asset and the transit system as a whole.

Depending on the level of climate risk and its impacts on the asset performance, it may or may not change the activities in the lifecycle management process. As depicted in Figure 2-4, the five key lifecycle management steps include:

1. Design/procure.
2. Use/operate.
3. Maintain/monitor.
4. Rehabilitate.
5. Dispose/reconstruct/replace.

Figure 2-4
Climate adaptation considerations in asset lifecycle steps



Critical assets and those most vulnerable to climate change are likely to undergo changes in the lifecycle management of the asset in order to mitigate the risks to safety, reliability, or performance. These changes may affect design standards, specifications, or materials to adapt the asset to changing climatic conditions. They may also include changes to system operations or scheduling in the case of emergency response to an extreme weather event. Depending on condition

assessments and operating in changing climate conditions, this could also lead to more corrective maintenance or required changes to an asset's replacement cycle. These risk mitigation activities should be incorporated into the asset's lifecycle management plan and ultimately asset management system and budgeting processes.

Lifecycle Management Plans

An asset's lifecycle management plan will document the costs, performance, and risks associated with a specific asset class throughout its life. These asset classes will fall under one of the four major asset categories: Vehicles, Facilities and Stations, Guideway Elements, or Systems. Ideally, lifecycle management plans are developed at the design/procurement stage to ensure that the asset is designed and/or manufactured in a way that considers its performance requirements (including resilience to extreme weather and climate risks) and total cost of ownership.

The contents of a lifecycle management plan may vary based on the asset management maturity level of an asset class. A fully matured lifecycle management plan, however, would include the following components outlined in Table 2-2. Also included in this table are opportunities to integrate climate adaptation in each respective component of an asset's lifecycle management plan.

Table 2-2 *Opportunities to Integrate Climate Adaptation in an Asset's Lifecycle Management*

Lifestyle Management Component	Component Description	Opportunity to Integrate Climate Change Adaptation
Roles and Responsibilities	Outlines roles, responsibilities, and accountabilities for the asset's lifecycle management, including the "Asset Owner."	Identify resource (person, organization, or program) for climate risk data and how it will be maintained.
Asset Inventory	Introduces the asset class, including inventory process overview, asset risk assessment (including climate risk impacts on asset reliability or performance), challenges the agency faces with maintaining the asset class.	Overlay or relate inventory to climate-related data. This would include information like age, location, elevation, materials used, design lifetime and stage of life. FEMA flood maps and information on vegetation, soil type and average daily ridership should also be documented where available.
Condition Assessment and Performance Monitoring	Outlines the asset class' current condition and historical performance if available. It references the documented asset class-specific approach to condition assessments and performance monitoring. This includes outlining when the asset should be inspected, how inspections will be conducted and condition measured and what actions should be taken based on the rating assigned.	Condition and performance monitoring should be documented in conjunction with climate conditions to understand how an asset performs under various climate extremes and if a climate risk mitigation strategy that has been implemented is effective and responsive. To facilitate condition assessment and performance monitoring, smart technologies can be used to detect critical levels.
Preventive Maintenance Plan	Outlines the predictive and preventive maintenance approach to maximizing the performance and minimizing the lifecycle costs of this asset class. This describes the resources needed (costs, staffing, materials, etc.) and links to performance.	Maintenance practices could change given changing climate conditions. See Figure 5 for examples of preventive maintenance strategies that reduce the impacts of climate change on transit.
Reactive Maintenance Plan	Outlines the rehabilitation and replacement approach to maximizing the performance and minimizing the costs of this asset class. It may also identify operational redundancies or alternatives required in response to system disruptions as a result of an extreme weather event. This describes the resources needed (costs, staffing, materials, etc.) and links to performance.	Corrective maintenance may be needed due to assets functioning more frequently in climate conditions they were not originally designed for. See Figure 2-4 for examples of reactive maintenance strategies that reduce the consequences of climate change impacts.
Asset Policy and Strategy	Outlines any policies and strategies related to this asset class. It also explains how the asset's lifecycle management activities support the broader asset management policies and goals.	This would include goals for level of service requirements and climate change-related outcomes.
Asset Lifecycle Management	Outlines all lifecycle management activities, including considerations and strategies regarding procurement, warranties, operations, maintenance (preventive and reactive), rehabilitation, and disposal. This section identifies the total cost of ownership for this asset class, with the focus on lifecycle management activities that maximize the asset's performance (including climate change-related outcomes) while minimizing risk and costs.	Climate risks to the asset should be considered throughout each major phase of the lifecycle management process: <ul style="list-style-type: none"> • Design/procure • Use/operate • Maintain/monitor • Rehabilitate • Dispose/reconstruct/replace

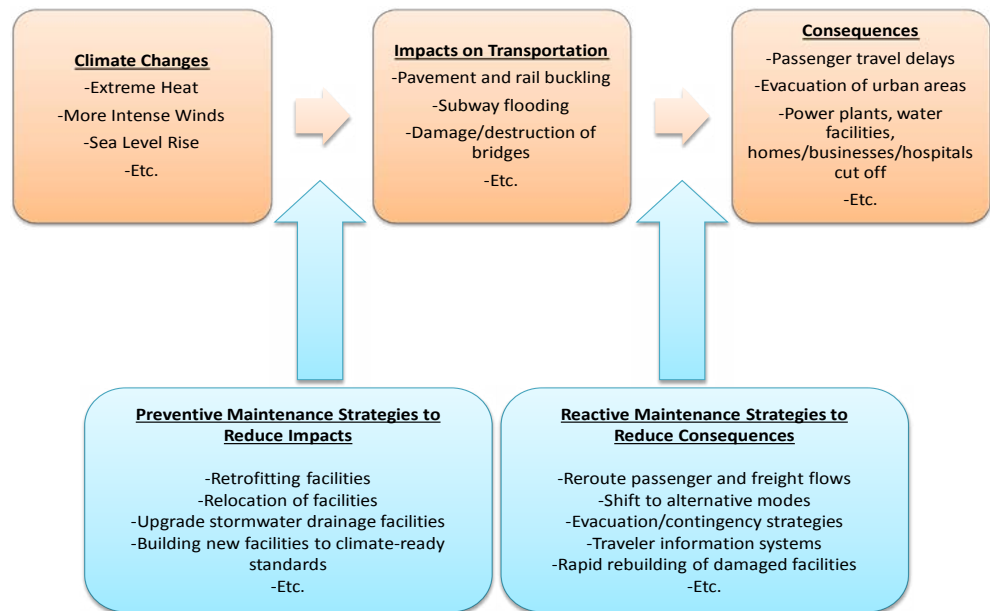
Lifestyle Management Component	Component Description	Opportunity to Integrate Climate Change Adaptation
Capital Programming and Operations and Maintenance Budgeting	Forecasts the capital and operations and maintenance budget needed to address the lifecycle needs of this asset class. The budgeting timeframe should match the agency's overall capital and operations and maintenance budgeting timeframes.	For climate-related strategies, the cost of the measure should not only be considered but also the value or benefit of the measure to facilitate prioritization. When considering the cost to replace an asset, the cost to retrofit it should also be assessed as a possible alternative.
Performance Modeling	Identifies how available data can be used to evaluate how well an asset class is achieving its level of service, sustainability, and other performance goals. Historic data (compiled into decay curves) and current data can be used to monitor performance over time and forecast how different funding levels can impact performance in the future.	Performance modeling should be conducted in conjunction with climate conditions to understand how an asset performs under various climate stressors and if a climate risk mitigation strategy that has been implemented is effective and responsive.
Continuous Improvement	Outlines how the asset owner should be monitoring the performance of this asset class to ensure that this plan is being followed and, ultimately, the asset class' performance is being maximized. Lessons learned should be captured associated with managing the lifecycle of this asset class. Additionally, it should reflect the process for maintaining the lifecycle management plans.	Asset lifecycle management plans should be updated as conditions and performance change. This also includes new climate data as it becomes available.

Preventive and Reactive Maintenance

Preventive and reactive maintenance plans and strategies play a key role in adapting a transit asset or system to changes in the climate (see Figure 2-5). As the climate changes and places certain risks on transit asset performance, safety, or reliability, preventive maintenance plans and practices may need to change to improve resiliency and minimize the lifecycle costs of this asset class. The preventive maintenance strategies can also be characterized by risk mitigation or adaptive strategies that reduce the impacts of climate change on the transit asset or system as a whole.

When transit systems have been impacted by climate change (e.g., through flooding or other extreme weather events), there are consequences that can affect the region's mobility and accessibility. For example, a subway system can be flooded, which would halt or delay passenger rail service, which could also cut off access to jobs or other key destinations. Reactive or corrective maintenance plans and strategies can provide a response approach in the event of an extreme weather event. It could include rehabilitation, replacement, or identification of operational redundancies or alternatives required in response to system disruptions. The strategies included in a reactive or corrective maintenance plan can be characterized by risk mitigation or adaptive strategies that reduce the consequences of climate change impacts.

Figure 2-5
Role of preventive and reactive maintenance strategies in climate adaptation for transit



Source: Adapted from NCHRP 20-83 (05), "Practitioner's Guide to Climate Change Adaptation"

Additional examples of preventive and reactive maintenance measures to reduce the impacts and consequences of climate change are illustrated below. Costs for each vary on a case-by-case basis and therefore are not specified here. Identified costs of specific adaptation strategies to be implemented or already implemented by MARTA are included in Section 5 of this report.

- Preventive Maintenance Strategies
 - Explore integration of real-time video feeds from agency vehicles into operations decisions.
 - Incorporate technology, such as sensors, that can detect changes in pressure and temperatures in materials to alert when damage thresholds are near approaching.
 - Review and augment cross-training in emergency response and maintenance tasks.
 - Review and update culvert maintenance, storm water management, and tree trimming programs.
 - Design for larger drainage capacity.
 - Maintain and update automated system for detecting traffic signals affected by power outages, and monitor the battery back-ups at the intersections that would require traffic officers in case of outages.
 - Adjust design parameters based on detailed asset-specific vulnerability analyses for the most critical assets and layout the possible effects on of the transportation system.
 - Establish a bus rerouting procedure for flood prone areas and a communication plan for affected customers.
 - Establish modified railcar and bus washing plans for varying degrees of drought.
 - Update design standard for new railcars to have heat resistant materials where feasible, increased ventilation for electrical components, and more durable air conditioning systems.
 - Identify potential landscape designs (natural or manmade) that can reduce or better withstand greater wind velocities.
- Reactive Maintenance Strategies
 - Revisit the design or location of an asset to be replaced or rehabilitated if damaged due to climate change or extreme weather events.
 - Provide real-time detour route information to drivers during incidents, and explore establishing a 511 travel service (especially for trucks and buses).
 - Build protective features such as levees, retaining walls, etc.
 - Review and update truck and bus parking accommodations during snowstorms and other extreme conditions and convey information to drivers.
 - Programmatic correction of failures that are being responded to but whose root cause is climate change-related.

Incorporating Climate Risk Mitigation Strategies in Lifecycle Management Plans

There is a broad range of preventive and reactive maintenance strategies addressing climate change adaptation for specific asset classes and climate stressors (e.g., drought, extreme heat, flooding, increased precipitation, more frequent high winds, etc.). At a more detailed level, these adaptation strategies are often linked to specific business unit operations, asset classes, specific climate risks, and other details such as when and where will the strategy be implemented, and how much will the strategy cost. They should also be prioritized to identify short-term versus longer-term strategies. Table 2-3 provides an illustrative template of the types of lifecycle management information that can be documented for vulnerable assets or asset classes. When quantitative cost information is not available, a ranking of high, medium, or low may be used. This information should be integrated into the lifecycle management plan of the asset.

In most cases, the intent behind these strategies is to maintain, manage, strengthen and protect, or enhance redundancy. In some cases, however, strategies exist that focus on locating new facilities in less vulnerable areas or abandoning critical infrastructure located in extremely vulnerable or indefensible areas. The latter case would generally occur when the benefits gained from the rehabilitation do not outweigh the costs.

Table 2-3 *Illustrative Template Incorporating Climate Risk Mitigation Strategies into Lifecycle Management Planning*

Business Unit	Asset Or Asset Class(Es) Affected	Location	Climate Risk To Asset	Climate Risk Mitigation Strategy	Preventive Or Reactive	Lifecycle Step Impacted	Timing	Cost Of Risk Mitigation Strategy
Short-Term Strategies								
Bus O&M-1	CNG Bus Fleet	Systemwide	Performance of AC systems impacted by extreme heat.	Establish explicit policies for conducting more frequent inspections of air conditioning systems and CNG buses during summer months and establishing temperature thresholds for increased inspections during other months.	Preventive	Maintain/Monitor	Fall 2013	Low
Long-Term Strategies								
Bus O&M-2	Maintenance Facilities	ABC Maintenance Facility	Heat waves affecting indoor air temperature.	Retrofit or redesign maintenance facilities to utilize natural air flow to cool facilities during summer months where air conditioning is unfeasible.	Reactive	Rehabilitate	2018	Medium

SECTION
3

Defining Scope of Climate Adaptation: Climate Hazards

Several climate hazards have become increasingly evident in the recent decades. Sea-level rise and storm surges are some of the climate-related stresses that have received much of the attention of climate change researchers. There is also evidence of the increasing frequency and severity of several climate hazards such as heat waves, hurricanes, blizzards, droughts, hailstorms, ice storms, and tornadoes. The most critical climate hazards may vary from region to region. In addressing climate change adaptation issues, an important point of departure is identification of the prevailing climate hazards in the region. This chapter discusses the climate hazards in the Atlanta Metro Region and MARTA service area.

Climate Hazards in the Atlanta Metro Region/MARTA Service Area

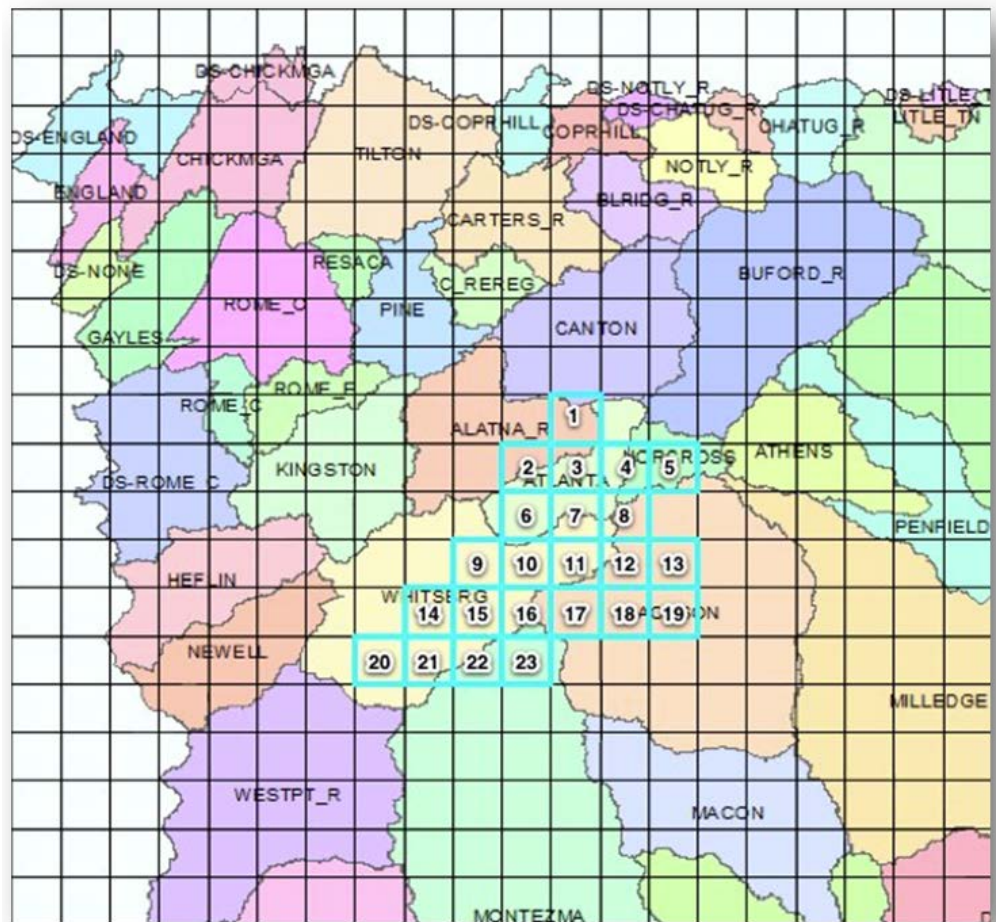
Identifying present and future climate hazards in the transit agency's service area is an important starting point for adapting to climate changes. Climate data can be obtained from various sources, including the National Oceanic and Atmospheric Administration (NOAA) and the National Climatic Data Center (NCDC), and used in making future projections. Rainfall and temperature forecasts for the Atlanta Metropolitan Region and the MARTA service area were obtained from the Georgia Water Resources Institute (GWRI) at the Georgia Institute of Technology. Figure 3-1 shows the grid system that was used in modeling and forecasting selected climate factors for the Atlanta region and MARTA service area. A total of 23 cells (12 km by 12 km) were identified from the model as being most relevant for the analysis, selected to cover the MARTA service area. Longitude/latitude data were provided for each cell. The climate variables estimated included precipitation, average temperature, maximum temperature, and minimum temperature (the temperature was measured in Celsius and the precipitation in millimeters/day). There was no capability for estimating the number of extreme weather events. Historical data from 1972 to 2010 for every day in each of the 23 cells had been obtained and analyzed. The historic data indicate that in general average temperature, maximum temperature, and the number of days over 95°F have increased over this 29-year period. Precipitation levels are less certain, with a serious drought over the past several years in northern Georgia skewing precipitation trends toward no

net change over prior decades (where prior trends tended to be toward higher precipitation levels).

Identification of Hazards

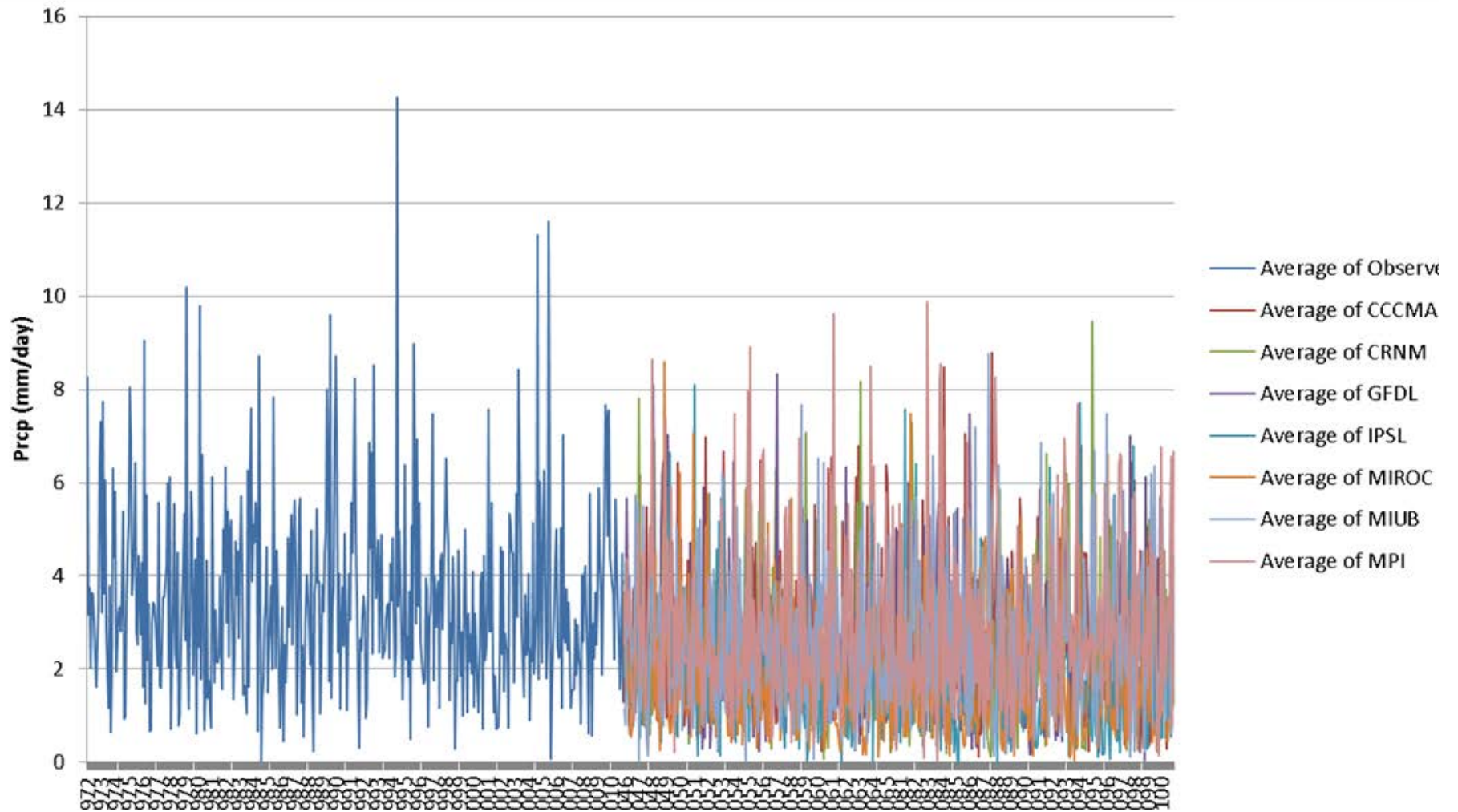
MARTA personnel indicated that higher extreme temperatures for longer periods of time, as well as higher-intensity rainfall in storm events, have been an issue for the agency’s operations and assets in the past. Atlanta will most likely not experience sea-level rise nor storm surge given its location, two of the climate-related stresses that have received much of the attention of climate change researchers. The types of climate/weather stresses that could affect MARTA’s operations (and those related to bus operations of other transit properties in the region) include higher levels of more intense precipitation (and thus flooding), higher maximum temperatures and a wider range of temperature, higher-strength winds related to more intense storms, and, possibly, the opposite of more precipitation—drought.

Figure 3-1
Grid system used for climate variable forecasting, MARTA region



For the 23 cells, the Georgia Water Resources Institute (GWRI) provided data on average annual maximum temperatures, average annual minimum temperatures, and average annual precipitation values from 1972 through 2100. Daily values for the three different types of data were averaged to determine average annual values. For example, the maximum daily temperatures for the different cells were collected beginning from 01/01/1972 through 12/31/2010. Seven Global Climate Models (GCMs) were then used in estimating the maximum daily temperatures through 12/31/2100: CGCM3.1 (Canada); CM3 (France); CM2 (USA); CM4 (France); Medres (Japan); ECHO (Germany/Korea), and ECHAM5 (Germany). The maximum daily temperatures were then averaged to estimate the annual average maximum temperature for each year. Figure 3-2 shows average annual precipitation from 1972 through 2100.

While the GWRI data forecasts are based on averages rather than extremes, these findings indicate that possible climate hazards in the MARTA service area this century include high temperatures with the possibility of heat waves, below-freezing temperatures, a wider variation or fluctuation in temperatures, and droughts. Other sources including the ongoing National Climate Assessment have projected decreased water availability. It is also expected that higher-intensity storms in the southeastern region will likely be associated with higher levels of more intense precipitation (and hence flooding) and higher-strength winds.



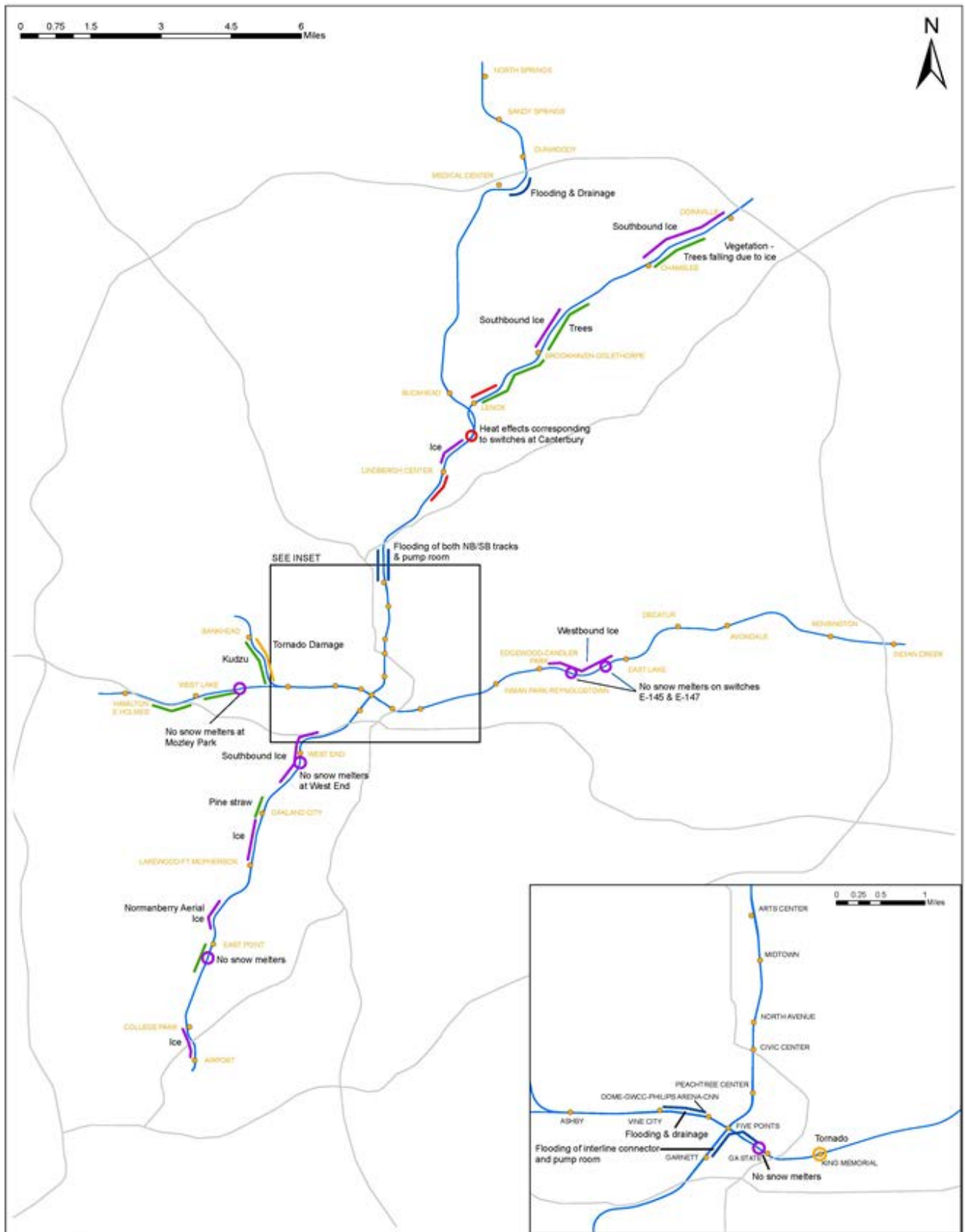
Courtesy: Georgia Water Resources Institute

Figure 3-2 Average annual precipitation (observed 1972–2010, forecasted 2011–2100)

Data Limitations

Climate forecasts in general have some uncertainty and the processes used in developing data forecasts must be understood to enable forecast data to be understood and used appropriately. As the science of climate change continues to evolve, climate forecasts should reflect the most current approaches. Map of Historic Hazards

Data were also obtained on historic climate hazards on the bus and rail systems from experts at MARTA. GIS maps of the bus and rail systems were developed showing various hazards that had occurred over the past several decades. Figures 3-3 and 3-4 show historic climate hazard locations in the MARTA service area based on expert knowledge. Such data can be a useful component of the climate hazards assessment information used by the agency in conducting a vulnerability analysis for climate change adaptation decisionmaking.



MARTA Rail System Legend

By Matthew Cairns - 10/1/12

- MARTA Rail
- MARTA Stations
- Interstates
- Flooding Issues
- Wind Issues
- Heat Issues
- Vegetation Issues
- Other Issues

Figure 3-3 Historic climate hazards for MARTA rail system

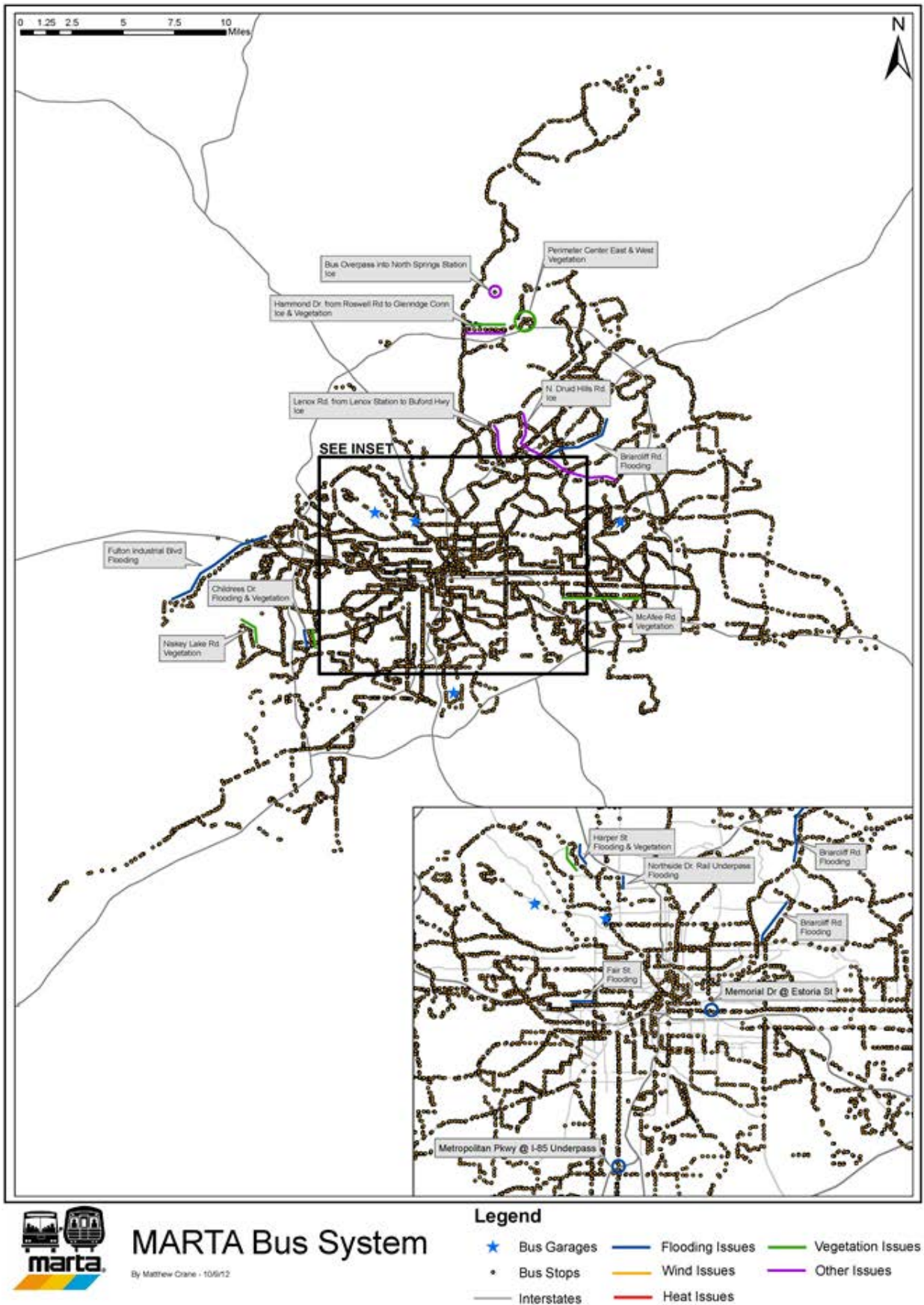


Figure 3-4 Historic climate hazards for MARTA rail system

What We Can Expect in the Future

Climate-related forecasts for the MARTA service area in the Atlanta metro region indicate the increased likelihood of higher temperatures with heat waves, below-freezing temperatures, a wider variation in temperatures, and droughts. More general climate-related forecasts for the Atlanta and North Georgia region also indicate that average temperatures will rise from now to 2100, and the range in high to low temperatures will likely increase. The more general information also indicates the possibility of flooding from high-intensity precipitation, as well as higher-intensity tornadoes. From discussions with MARTA staff on examples of weather-related incidents that have affected operations in the past, the two climate stressors that stand out as most importance to MARTA's operations and assets are the following:

- *Higher extreme temperatures for longer periods of time:* The consensus of the analysis efforts reviewed indicate that the Atlanta region will experience higher temperatures on average over the next 70 to 80 years, but that it will also experience longer periods of extreme temperatures, defined as greater than 95°F (i.e., possible heat waves). This could potentially affect MARTA operations in two major ways. First, the high levels of heating of key electrical instrumentation (signals, communication relays, passenger information systems, etc.) could lead to a higher level of failure of these devices. Second, heat-related passenger and worker comfort could become more of an important factor in how MARTA schedules and protects its labor force, and the way it assures a comfortable traveling experience to its passengers. Given that climate modeling is much more precise with respect to temperature (than precipitation), there is a high likelihood that projections associated with this climate stressor will indeed occur over the next several decades. It will be important to consider how higher fluctuations in temperatures can affect MARTA operations and assets.
- *Higher-intensity precipitation in storm events:* As noted earlier, the forecasts for average precipitation levels in the MARTA service area are less certain than forecasts for temperature increases. However, several scientific studies have concluded that the number of higher-intensity storms will likely increase in future decades, with this particularly being the case in the southeastern United States. MARTA has experienced some flooding in several track and facility locations from intense storms over the past several years. It is likely that with the larger number of intense storms expected in the future, more flooding will occur. Many of MARTA's most critical assets, however, have been built in such a way that flooding from nearby creeks, streams, or drainage facilities will not affect operations. Nevertheless, there are some assets where potential flooding risks do exist, and for bus operations on local streets and roads, the interruption of service due to the flooding of these facilities will impact service provision.

Another implication of higher-intensity storms relates to the design and maintenance of drainage facilities, primarily culverts, channels and retention ponds. One of the lessons learned in Vermont from Tropical Storm Irene is that poorly-maintained culverts—culverts blocked by debris and other material that substantially reduce the flow capacity—were primary reasons for road failures. For long-lived MARTA assets in high runoff areas where drainage capacity has been designed taking into consideration historical data, the risk of overflow and runoff backup into service-sensitive areas (given higher-intensity downpours) could be an important vulnerability. Such areas should be one focus of subsequent efforts for climate change adaptation.

One aspect of this climate variable that is nearly impossible to forecast is the potential damage caused by high winds often associated with high-intensity storms. The research team was not able to find any research or studies that had attempted to forecast high wind events associated with more intense storms. Maintenance personnel at MARTA also did not have any memory of high winds causing significant damage to MARTA assets.

It will also be important for MARTA to consider how wider variations or fluctuations in temperature, as well as possible droughts, can affect its operations and assets.

The implications of this climate change assessment is that those assets most vulnerable to flooding (at lower elevations near streams or creeks, or that depend on well-maintained drainage systems to remove runoff from the facility) and those whose performance can be affected by longer exposures to higher temperatures, as well as a wider variation in temperatures (signal and communications equipment and perhaps tracks and pavements), are those in most need of monitoring. This monitoring could entail actual condition monitoring of individual assets, or keeping track of maintenance records associated with certain types of assets (and introducing different design or maintenance strategies once a certain threshold level is reached). MARTA will also need to consider the implications of droughts and high winds on agency operations and assets.

Assessing and Addressing Climate-Related Risks through Transit Asset Management at MARTA

The MARTA System

The MARTA rail system began operating in 1979 and provides transit service to the city of Atlanta, as well as to Fulton and DeKalb counties. The agency operates 132 bus routes, covering approximately 1,000 route miles with 621 buses. The agency also operates approximately 175 paratransit vehicles and 450 non-revenue vehicles. MARTA's system includes 4 lines serving 38 stations. It also includes approximately 48 miles of track and operates with 318 rail vehicles. Annual ridership is more than 105 million trips (approximately half a million per day) [2]. Figure 4-1 shows a map of MARTA's rail system.

MARTA's system is considered a maturing one in the sense that many of its assets, particularly on the rail system, are getting to the point when they will require overhaul or replacement [2]. The agency, therefore, has an opportunity to address climate changes and hazards systematically and system-wide as different elements and portions of the system get overhauled or replaced. MARTA's definition of SGR emphasizes maintaining assets in a functioning condition over eliminating the backlog of investment needs or replacing assets based solely upon their age. By this definition, approximately 80 to 90 percent of MARTA's assets were estimated to be in a state of good repair in 2010. However, MARTA expects maintaining SGR to be a continuing challenge in the future [2]. This implies that climate change considerations will likely occur within the context of SGR decision-making, making the agency's asset management program an appropriate platform that can be used to adapt MARTA's services and system to anticipated climate changes. It appears, therefore, that asset management platforms will be highly useful decision-making systems in which to address climate change issues balancing SGR needs with the risks of climate hazards and the need for system resiliency.

Figure 4-1
MARTA
rail system map



Overview of MARTA's Transit Asset Management Program

History of Development

Since the mid-1970s, MARTA has been involved in construction and expansion of the transit system. A combined bus and rail service was launched in 1979 with assistance from FTA. In the 1990s, MARTA implemented a maintenance management information system (MMIS) platform responding to the need to accurately monitor the condition of assets and prioritize them for improvement. The MMIS provided asset data access to operations and maintenance decision makers, resulting in more cost-efficient decisions and creating the platform for MARTA's SGR program. In 2006, MARTA leadership saw the need to better use asset management data in developing long-term capital planning needs prompting

the agency to re-evaluate their asset management program (AMP), including asset breakdown structure, priority and condition codes, and replacement values. MARTA initiated a business transformation project with the goal of linking financial, MMIS and resource allocation systems together in a single Enterprise Asset Management (EAM) system that would enable the use of asset management data in the development of long-term capital planning needs. The EAM (AssetWorks FASuite system) integrated asset information at MARTA on a single platform, a tool that could be used for agency-wide asset management programming with implementation of the right processes and support tools across the agency. In 2009, MARTA joined FTA's SGR Workgroup and attended the inaugural SGR Roundtable, and followed up with accelerated efforts to modernize the existing asset management program, based on a full understanding of the extent of the National asset backlog issue [7].

In 2010, MARTA initiated an agency-wide condition assessment with an aggressive approach to improving, cataloging and prioritizing asset data. This effort provided the basis to implement the following initiatives [7]:

- Identification of a project management team to oversee execution of MARTA's Asset Management Plan.
- Introduction of periodic assessments driven by condition and operational priority as well as useful life.
- Update of the 30-year capital needs forecast including the backlog, using lifecycle data, condition, and priority codes.
- Initiated the development of a new capital planning module in partnership with agency's enterprise asset management partner AssetWorks/Trapeze. This module will develop projects directly from the asset database.
- Initiated implementation of Expert Choice decision-making software to prioritize projects for portfolio optimization. This tool selects the best value projects when the capital budget is constrained.
- Initiated re-engineering of project delivery and controls to increase the success of delivering capital improvement program (CIP) on time and within budget.

Successful implementation and integration of these initiatives is expected to provide the foundation and tools for an asset management program that delivers a safe, high-performance and sustainable system.

Structure, Functions and Ongoing Improvements of MARTA's Asset Management System

MARTA's TAM program is composed of two primary systems that are linked by the information they provide to one another. MARTA uses EAM system software, which is the central platform for all the asset management data at MARTA. It includes an inventory of physical assets (such as track, signals, and

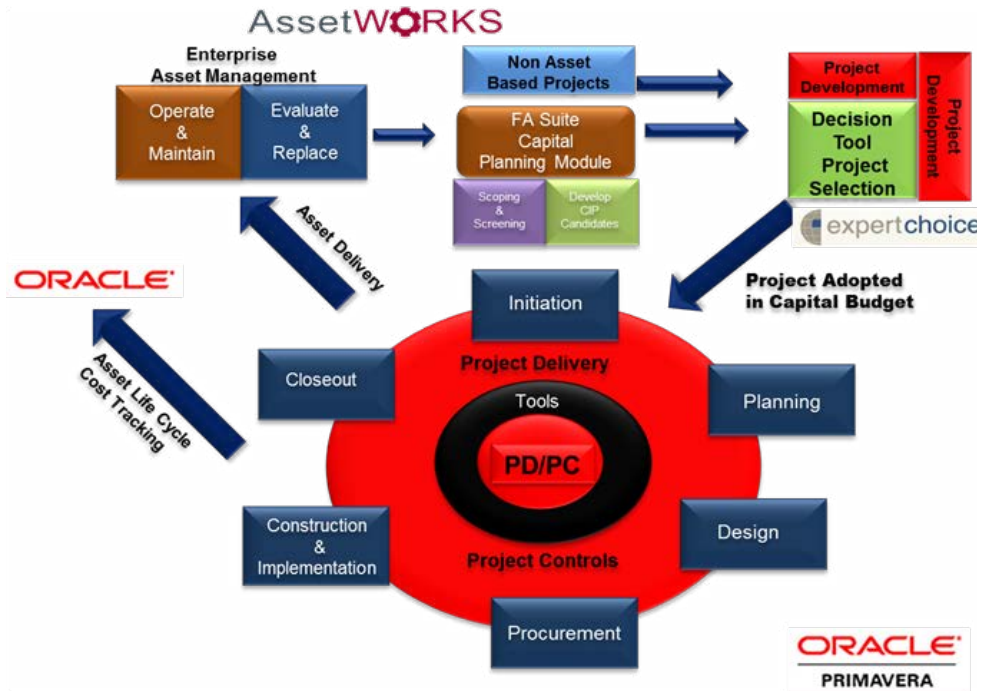
vehicles) and their actual condition (whether known or unknown). The system stores basic inventory information (such as ID, status, mileage, and location) for all of MARTA's physical assets, as well as condition assessment data. The EAM system tracks the asset (and all of its subcomponents) over its lifecycle—from procurement to salvage—since it is designed to create, process, and close maintenance work orders for MARTA's assets. While several systems consider only the age of an asset in project prioritization for repair or replacement, MARTA also factors in asset condition and criticality (e.g., life criticality, safety criticality, and operation criticality).

To ensure that the asset data are current, MARTA periodically conducts condition assessments. MARTA conducted the first condition assessment of its assets in 2000 and is currently completing another condition assessment. Because of the high cost and time that would be needed to inspect and determine the condition of every asset in the MARTA system (53,000+ total), MARTA decided to adopt a sampling approach to determine the condition of its assets. A statistically-significant sample size was determined for each asset category and assets within the category were inspected at random and assigned a condition rating ranging from 1 (failed) to 5 (excellent), based on the FTA's guidelines for condition ratings. In addition, a minimum of 30 assets were inspected for each asset category. Currently, the EAM is able to analyze and prioritize assets only within a single asset group (e.g., buses); however, this issue is expected to be corrected within the next year through implementation of a new capital planning module.

The second system within MARTA's TAM program addresses CIP. This system uses information generated by the EAM system to develop a list of priority projects to be completed over the next several years based on the agency's most critical needs and priorities. This software-based decision tool (developed by Expert Choice) generates an optimal portfolio of projects to implement over the time frame of the CIP based on agency criteria, funding constraints, and agency needs. While the current EAM system can prioritize assets only within a single asset group, the new Capital Planning Module will be able to prioritize assets across multiple asset groups. Currently, candidate CIP projects are created and developed by MARTA's individual departments, through project sponsors and champions, and then further culled by the CIP's Project Delivery/Project Controls process. The new Capital Planning Module will allow the EAM to automatically generate portfolios of projects from the data stored within the system for consideration in the Capital Improvement Program.

Figure 4-2 depicts MARTA's Asset Management Program.

Figure 4-2
 MARTA's asset management program



Opportunities to Incorporate Climate Change Considerations

MARTA's asset management system offers the possibility of determining a climate vulnerability index for different assets in the system based on their relative vulnerability to the climate hazards discussed in Section 3. This vulnerability is a function of how susceptible the asset is to high temperatures and heat waves, wide variations in temperatures, high-intensity precipitation, droughts and high-wind events; as well as the relative impact of associated hazard scenarios to MARTA services. Such an index may be considered alongside the condition (i.e., SGR) data in the asset management system. Thus, project prioritization can be done considering SFT and climate vulnerability factors simultaneously.

Integrating Climate Adaptation into Decision-Making: Mapping Adaptation Strategies and Costs to Organizational Units

Matrix of Adaptation Strategies, Order-of-Magnitude Costs, and Mapping to Organizational Units

Adapting to climate change involves proactive measures to strengthen or harden infrastructure assets and systems and improve resilience. Several strategies may be considered to adapt various assets and systems to the climate hazards identified for the region. The matrix (Table 5-1) is an inventory of possible adaptation strategies for addressing climate change. The strategies have been mapped to appropriate units within the agency. Table 5-1 outlines adaptation strategies for MARTA based on the identified climate hazards in the MARTA service area and Atlanta metro region. These are categorized by key functional units in the organization: 1) bus maintenance and operations; 2) rail vehicle maintenance and operations; 3) track and structures; 4) civil engineering design; 5) capital facilities, and 6) architecture. A general category is also included to capture cross- and external agency actions. The adaptation strategies are also categorized according to whether they can be readily implemented in the short term or may need a longer time frame for implementation. Estimated costs are included where available. Decisions on implementing adaptation strategies within an asset management system will be made by evaluating the benefit, costs, risks and tradeoffs of candidate improvement actions to maintain the system in a state of good repair as well as harden the system against extreme weather events. Adaptation should be viewed as a process to be revisited periodically as climate changes continue and scientific capabilities for forecasting climate continue to be refined.

Table 5-1 Initial Adaptation Strategies for MARTA

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Bus Maintenance & Operations	Short Term	<p>Establish explicit policies for conducting more frequent inspections of air conditioning systems and CNG buses during summer months and establishing temperature thresholds for increased inspections during other months</p> <p>Evaluate existing policies on worker safety during hot days and update/clarify as necessary (thresholds)</p> <p>Educate customers on ways to stay cool when waiting at a bus stop [Already done \$0]</p>	<p>Identify all flood prone areas on all bus routes [\$50K to study]</p> <p>Ensure all bus storage facilities are above existing floodplains and not in flash flood prone areas. If not, identify temporary storage locations if flood conditions are expected [\$0] Establish a bus rerouting procedure for flood prone areas and a communication plan for affected customers [\$50K]</p> <p>Establish a combined emergency shut down and facility restart plan for any bus maintenance facility in a flood prone area and practice the plan with facility employees [\$50K]</p>	Establish modified bus washing plans for varying degrees of drought	<p>Establish thresholds for increased inspection of bus cooling systems for both extreme hot and cold days [Already done \$0]</p> <p>Examine potential impacts of wider temperature ranges on bus tire pressures [Already done (Maintenance function) \$0]</p>	Establish thresholds for alternate routing or suspended service in areas vulnerable to high winds

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Bus Maintenance & Operations	Long Term	Update design standard for new buses to have heat resistant materials where feasible [Ongoing by vendor \$0 to MARTA]	Develop an alternative route schedule/ plan for all flood prone areas [\$200K] Communicate plan to customers [Less than or equal to \$50K]	Replace all bus washing equipment with more efficient systems (low flow heads and water reclamation) [\$1.4M each]	Incorporate materials that better withstand greater temperature ranges [\$25-50K]	Harden bus storage facilities against damage from falling vegetation [Normal landscape maintenance: \$5K/year]
		Update to more efficient and durable engine cooling systems (especially for CNG buses), and more durable air conditioning systems [\$25 50K per bus] Retrofit or redesign maintenance facilities and install fans to utilize natural air flow to cool facilities during summer months where air conditioning is unfeasible	Relocate or harden maintenance facilities against flooding [\$60M for new facility \$3 – 10M to protect existing facilities]			
Rail Vehicle Maintenance & Operations	Short Term	Conduct more frequent inspections of air conditioning and electrical systems during summer months and establish thresholds for increased inspections during other months [Already done \$0] Evaluate existing policies on worker safety during hot days and update/clarify as necessary (thresholds) [Already done \$0]	Establish a combined emergency shut down and facility restart plan for any rail maintenance facility in a flood prone area and practice the plan with facility employees [\$50k]	Establish modified railcar washing plans for varying degrees of drought	Identify materials and components that are most impacted by wider temperature ranges [By vendor \$0 to Authority]	Establish thresholds for slow orders or suspended service on elevated track structures and stations

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Rail Vehicle Maintenance & Operations	Long Term	<p>Update design standard for new railcars to have heat resistant materials where feasible, increased ventilation for electrical components, and more durable air conditioning systems [By vendor \$0 to Authority]</p> <p>Upgrade air conditioning on existing railcars with systems that are designed for longer operating cycles [\$60/HVAC unit = \$20M for full fleet of 318 cars]</p>	Relocate or harden maintenance facilities against flooding [\$3–10M for project]	<p>Replace all railcar washing equipment with more efficient systems (low flow heads and water reclamation) [\$1.4M each]</p> <p>Investigate new paints or coverings that could be applied to reduce the frequency of washing [Already done \$0 cost]</p>	Incorporate materials that better withstand greater temperature ranges	
Track & Structures	Short Term	<p>Develop an explicit policy that establishes thresholds for conducting more frequent inspections during hot days or heat waves [Done normally \$2K per day]</p> <p>Unify and re-evaluate policies regarding inspecting, maintaining, and replacing rail and track elements during extreme weather conditions</p>	Conduct more frequent inspection of drains and pipes located near tunnel entrances and on aerial structures to check for clogging [Heavy rain day only \$2K/day, \$0 otherwise]	<p>Identify and remove vegetation that may pose a fire hazard during drought conditions in MARTA's ROW [\$10K]</p> <p>Develop a plan with stakeholders located next to ROW for identifying and removing hazardous vegetation during drought conditions [\$10K]</p>	Identify track areas that are vulnerable to large temperature ranges and fluctuations [Already done \$0]	<p>Identify and remove vegetation within MARTA's ROW that may pose a falling or debris hazard Develop a plan with stakeholders located next to ROW for identifying and removing hazardous vegetation [\$10K]</p>

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Track & Structures	Long Term	Replace track elements and rail with more heat resistant materials and expansion joints [Already have expansion joints \$0 to Authority]	Increase drainage capacity near tunnel entrances and on aerial structures [\$500K/location]	Establish a process for regularly identifying and removing hazardous vegetation within and near the ROW [\$2K/day]	Install systems (e.g. expansion joints) that allow rail to expand and contract without compromising system speed or rail integrity [Already done \$0 to Authority]	Establish a process for regularly identifying and removing hazardous vegetation within and near the ROW Retrofit King Memorial station to withstand higher wind speeds [\$500K/station]
Civil Engineering/ Design	Short Term	Continue to monitor how extreme heat and heat waves affect facilities, materials, and assets [\$250K]	Coordinate with future developers to reduce water runoff into MARTA's ROW Establish policies and procedures for regularly inspecting and clearing clogged drains and pipes Be aware of pending updates to FEMA floodplain maps	Examine if subsurface conditions change in certain areas during prolonged drought conditions [\$250K]	Identify and monitor structures and materials vulnerable to large temperature fluctuations [\$250K In progress]	
Civil Engineering/ Design	Long Term	Update design standards as necessary to incorporate heat resistant materials where possible and feasible [Already done \$0 to Authority]	Incorporate higher flood design standards for facilities, pipes, and drains [\$100K] Incorporate low impact developments (rain gardens, bioswales, etc.) into the design of new facilities to reduce runoff [Already done \$0 to Authority]	Incorporate water saving mechanisms (e.g. low flow toilets) and grey water usage into design standards [\$5K/unit] Modify design standards for subsurface structures	Incorporate materials that can withstand a wider range of temperatures in design standards	Modify design standards to account for greater wind velocities [Already done \$0]

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Capital Facilities	Short Term	<p>Coordinate all heat related adaptation efforts from other departments [\$100K]</p> <p>Conduct detailed analysis of the effect of heat waves on major capital assets [\$100K]</p>	<p>Identify areas along MARTA's ROW with steep slopes and strategies for preventing mudslides during heavy precipitation events [Already done \$0 to Authority]</p> <p>Harden most vulnerable capital facilities against flooding [\$3–10M]</p>	In relevant areas (e.g. bathrooms), post information on how to conserve water	<p>Identify energy and water use metrics [Already done \$0 to Authority]</p> <p>Measure energy consumption [Already done \$0 to Authority]</p> <p>Measure water usage [\$5K]</p>	Prepare an alternative communication plan and distribute back up communication equipment to most critical staff and operators [Already done]
Capital Facilities	Long Term	<p>Replace major capital facilities with new designs that incorporate heat resistant materials [Already done \$0 to Authority]</p>	<p>Increase pumping capacity at underground rail stations Implement strategies for preventing mudslides on steep slopes</p> <p>Incorporate future floodplains when siting new major capital facilities [Already done \$0]</p> <p>Evaluate feasibility of providing shelters at bus stops with no shelter [\$15K/shelter]</p>	<p>Mandate water saving/reduction plans for new/rehabilitated facilities [\$5K/facility]</p> <p>Install water efficient faucets, water fountains, and cleaning apparatuses</p>	<p>Retrofit existing buildings to meeting “green” building design standards; seek to certify new buildings to LEED or similar standards [10–15% to capital cost]</p>	<p>Install back up communications systems that can be activated if primary systems fail [Already done]</p>

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
Architecture	Short Term	<p>Conduct an assessment of available shade at rail stations and develop a plan for at most vulnerable stops first [\$550K per rail station]</p> <p>Evaluate design methods for improving natural cooling in rail stations during hot days</p>	<p>Develop code and implement a coordination effort with local communities and governments to reduce runoff from existing and planned future developments</p> <p>Develop a roof replacement prioritization plan for all rail station roofs that have no pitch and/or have exceeded their expected useful life [\$500K]</p>	Better design to protect newly-installed vegetation from customer abuse	Develop a station floor replacement prioritization plan Identify new materials and installation techniques that are more resistant to freeze thaw cycles	Identify potential landscape designs (natural or manmade) that can reduce or better withstand greater wind velocities
Architecture	Long Term	<p>Employ methods for improving natural cooling in stations</p> <p>If natural cooling methods are not feasible or possible, enclose rail stations and install air conditioning [\$1M/station for air conditioning installation]</p>	<p>Incorporate low impact developments (rain gardens, bioswales, etc.) into station design and areas leading up to bus stops [Already done]</p> <p>Replace original roofs with more durable, weather resistant materials and a pitch to allow water to drain properly [\$500K]</p> <p>Roof replacements should include installation of low impact developments to capture and filter rainwater runoff [\$200K]</p>	Utilize rainwater captured from new roofs to water vegetation near stations [\$150K/station]	Replace most exposed station platforms with more durable, weather resistant materials [\$1M/station platform]	Incorporate aesthetic elements that also block or reduce wind velocities [Done]

Dept.	Time Period	Heat Waves	More Intense Precipitation During Storms ¹	Droughts	Wider Temperature Variations	More Frequent High Wind Events ²
General/Miscellaneous		<ul style="list-style-type: none"> • Adopt an agency wide policy on climate change and climate adaptation and mitigation. • Conduct climate vulnerability and risk assessment for assets and operations. • Develop and implement a climate change adaptation and mitigation plan. • Utilize existing agency processes and standard operating procedures to implement adaptation/mitigation strategies [\$200K (150K Capital plus \$50K annual operating)]. • Install sufficient generator capacity to entirely power bus maintenance facilities and their equipment during power outages [Done \$500K/facility] • Review and update standard operating procedures for extreme weather conditions to incorporate emergency evacuation and restart plans for maintenance facilities and alternative communication plan [Done \$0]. • Develop a system accessibility plan which should establish what level of service will be provided during or after extreme weather events (ice storm, floods, etc.) as well as how access to that service will be maintained (e.g. snow/ice removal) [\$50K]. • Coordinate with local weather services to identify extreme weather events within the service area in real time [Done]. • Allow system users (passengers) to crowd source updates via social media (like Twitter) (e.g. flooded routes, broken A/C in train cars and buses) to key agency personnel [Done]. 				

¹ Can result in flooding.

² From strong storms or tornadoes.

Source: Developed by M. Crane, with T. Wall, J. P. O’Har, A. Amekudzi, S. Thomas, and D. Springstead.

REFERENCES

1. American Association of State Highway and Transportation Officials (AASHTO). 2011. AASHTO transportation asset management guide – A focus on implementation.
2. Federal Transit Administration, U.S. Department of Transportation. 2010. Transit asset management practices – A national and international review. June.
3. Public Law 112-141, 112 Congress, *Moving Ahead for Progress in the 21st Century*. Section 20019. Transit Asset Management. July 6, 2011.
4. Federal Transit Administration, U.S. Department of Transportation. 2012. Asset management guide. October, FTA Report No. 0027.
5. United Nations Environment Program (UNEP). 2013. Climate change adaptation. Accessed at <http://www.unep.org/climatechange/adaptation/KnowledgeandPolicy/tabid/29577/Default.aspx>.
6. Federal Transit Administration, U.S. Department of Transportation. 2009. Rail modernization study. Report to Congress, April.
7. Metropolitan Atlanta Rapid Transit Authority. 2012. MARTA's state of good repair asset management program. June.
8. Tamvakis, P., and X. Yiannis. 2012. Resilience in transportation systems. Transport research arena – Europe 2012. *Proceedings—Social and Behavioral Sciences* 48: 3441-3450.
9. Dekker, S., Hollnagel, E., Woods, D., and R. Cook. Resilience engineering: New directions for measuring safety in complex systems, final report. Sweden: Lund University, School of Aviation.
10. Federal Transit Administration, U.S. Department of Transportation. 2011. *Flooded Bus Barns and Buckled Rails*. August, FTA Report No. 0001.



U.S. Department of Transportation
Federal Transit Administration

East Building
1200 New Jersey Avenue, SE
Washington, DC 20590
<http://www.fta.dot.gov/research>