Climate Vulnerability and Adaptation Report for Chattanooga

2022

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EcoAdapt™

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Introduction

The effects of climate change are already being experienced in Chattanooga and will continue for decades to come. These changes include higher average temperatures and more extreme heat, changes in precipitation intensity and seasonal distribution and increased risk of flooding, more frequent and severe droughts, and more frequent wildfires and a longer fire season. Climate-related impacts, coupled with pre-existing challenges such as lack of affordable housing, demographic shifts, water pollution, habitat loss and fragmentation, and aging infrastructure have significant implications for the people, infrastructure, and environment of Chattanooga.

The purpose of this report is to improve understanding about local climate change impacts and vulnerabilities and present adaptation responses that can help reduce community vulnerability and/or increase resilience. The report synthesizes the results of a 3-day virtual workshop held in October 2022. This workshop brought together 26 stakeholders from across Chattanooga to evaluate community vulnerability and develop adaptation strategies for three focus areas of importance to the community: (1) housing, (2) transportation, and (3) natural resources.

The subsequent sections in this report are described below:

- **Project Methods and Workshop Activities** – Provides an overview of the climate adaptation planning process, workshop series, and selection of pre-existing conditions and climate stressors.
- **Overview of Climate Projections and Impacts** – Presents a summary of current and projected climate changes for the community.
- **Vulnerability Assessment and Adaptation Planning Results** – Summarizes vulnerability and adaptation information for each of the three focus areas.
- **Conclusions** – Highlights common concerns, impacts, and adaptation strategies across the different focus areas.

Project Methods and Workshop Activities

Climate Adaptation Planning Overview

Climate change adaptation refers to how we prepare for, respond to, and recover from changes we are already experiencing and/or are expected to experience. *Adaptation*, which focuses on managing the impacts of climate change, can be distinguished from *mitigation*, which refers to efforts intended to decrease the potential for climate change itself (e.g., by reducing greenhouse gas emissions or enhancing carbon sequestration). The adaptation planning process (Figure 1) intentionally integrates the consideration of climate change into plans, programs, projects, and operations and is meant to be iterative.

While there are many different climate adaptation planning frameworks, they generally consist of the same steps: (1) project scoping, (2) assess vulnerability, (3) identify adaptation strategies, (4) implement those strategies, and (5) monitor, evaluate, and adjust strategies, as needed.

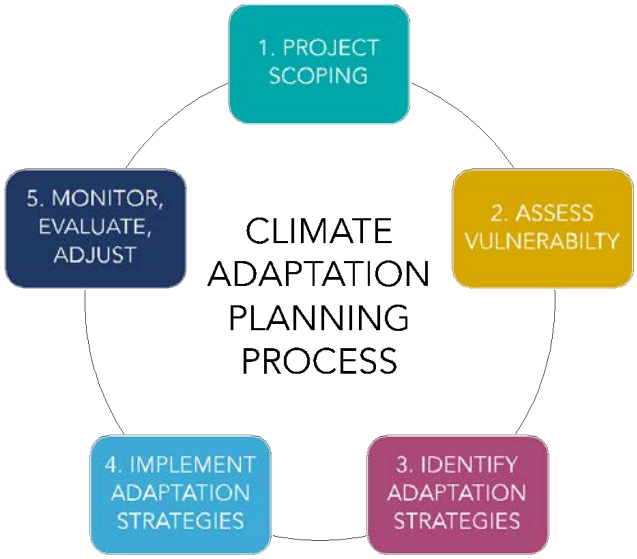

Figure 1. Steps in a Basic Climate Adaptation Planning Process.

These steps are described below:

1. **Project scoping**. This step includes identifying goals and desired outcomes of the process, establishing the geographic boundaries and timeframe of interest (i.e., near-term= 0–20 years; mid-term= 25–50 years; long-term= 50+ years), identifying and engaging with key stakeholders and partners, and identifying key climate stressors and pre-existing conditions (i.e., stressors that already impact a

community). Completion of this step is critical to provide the foundation for a clear and efficient adaptation planning process.

2. **Assess Vulnerability**. Vulnerability assessments improve understanding of how climate change is likely to impact a community and its ability to respond to those impacts. Vulnerability assessments include consideration of the likelihood of exposure to climate change, the consequence of that exposure, and the community's capacity to adapt to those impacts. These assessments include consideration of the following three components of vulnerability:

    - **Likelihood** is the degree to which a community is exposed to significant changes in climate and considers both the anticipated direction and magnitude of change.
    - **Consequence** is the degree to which a community is affected by exposure to a changing climate and considers both the anticipated impacts of climate stressors as well as the impacts of pre-existing conditions.
    - **Adaptive capacity** is the ability to adjust to climate change to minimize potential damages, take advantage of opportunities, or cope with consequences.

Likelihood and consequence together give an estimation of risk that, when combined with adaptive capacity, provides an overall picture of vulnerability (Figure 2). It is important to evaluate all three components—likelihood, consequence, and adaptive capacity—to gain a holistic perspective of the factors that are driving vulnerability.

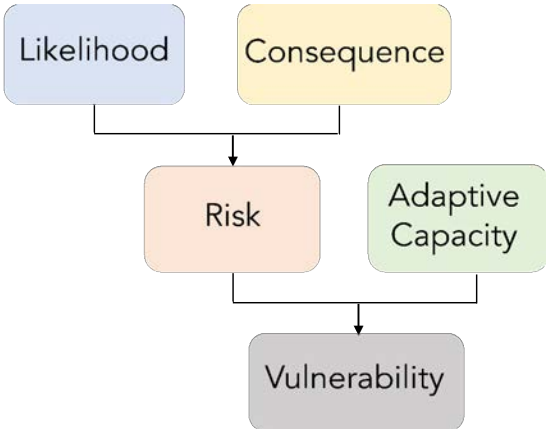

Figure 2. Components of Vulnerability.

The vulnerability assessment step of the adaptation planning process includes evaluating the impacts of climate change on a community; characterizing the community's ability to minimize or cope with impacts; assigning likelihood, consequence, and adaptive capacity rankings; and summarizing overall vulnerability based on rankings, impacts, and adaptive capacity information. The resulting level of vulnerability is assessed using risk matrices that incorporate these components (Figure 3).

RISK CALCULATOR MATRIX

Likelihood	Consequence			
	Negligible	Moderate	Major	Catastrophic
Rare	Low	Low	Low	Low
Unlikely	Low	Moderate	Moderate	High
Likely	Low	Moderate	High	Extreme
Almost Certain	Low	High	Extreme	Extreme

VULNERABILITY CALCULATOR MATRIX

Risk	Adaptive Capacity		
	Low	Moderate	High
Low	Low	Low	Low
Moderate	Moderate	Moderate	Low
High	High	Moderate	Moderate
Extreme	High	High	Moderate

Figure 3. Matrices for assessing level of risk and vulnerability.

3. **Identify Adaptation Strategies**. Adaptation strategies aim to reduce the negative effects or take advantage of the opportunities provided by climate change. The goal of this step is to identify adaptation strategies that reduce risk (limit exposure or minimize consequence) and/or enhance resilience (increase adaptive capacity). Understanding what drives vulnerability to climate change (likelihood, consequence, adaptive capacity, or some combination of these) provides a good starting point for identifying possible adaptation strategies. General types of adaptation strategies that may be considered include programmatic; capital improvements and infrastructure; coordination and/or collaboration; knowledge and evaluation; and plans, regulations, and policies. To help decide which actions to prioritize for implementation, it can be helpful to articulate co-benefits (e.g., greenhouse gas reduction, public health improvement, water quality improvement, etc.) and conflicts or challenges (e.g., unintended consequences on people or community assets).

4. **Implement Adaptation Strategies**. When a list of adaptation strategies has been generated and prioritized, they must be put into action. Developing an

adaptation implementation plan for each prioritized strategy helps communities articulate how and when (e.g., immediately or within the next 5 years) the strategy should be implemented, leads and partners responsible for implementation, existing resources and those that are still needed, and potential barriers to implementation.

5. **Monitor, Evaluate, and Adjust**. Climate change adaptation planning should be an iterative process, and monitoring and evaluation are essential components that allow communities to make progress while also adjusting actions based on project outcomes and new information. For instance, post-implementation monitoring of adaptation strategies helps to determine whether the strategies are having their intended effect and when or where adjustments might be needed. Developing a monitoring and evaluation plan is critical to minimize wasted time, money, and effort. These plans should include identification of desired outcomes, parameters to monitor and the method to do so, thresholds that may signal desired outcomes are not being met, and possible alternative strategies to pursue if these thresholds are crossed.

Tools Used in the Workshop

Climate Change Adaptation Certification Tool

The Climate Change Adaptation Certification Tool (CCAC)[1] is intended for use during regulatory or procedural review processes being carried out as part of routine community functions. The CCAC can be applied to decisions about any project or proposal that will involve the use of public funds, has a life cycle of greater than 5 years, and can impact public good (e.g., fiscal expenditures, capital planning, permitting, infrastructure design, and siting). Applying the CCAC to these decisions allows explicit evaluation of future conditions on project function and longevity, increases understanding of the long-term sustainability of a project at the funding or permitting phase and considers how to reduce community risk that could arise from actions that become a liability under future conditions. The CCAC process includes three steps:

1. Identification of climate change risk factors
2. Evaluation of climate impact on a project
3. Determination of project review

[1] http://ecoadapt.org/data/documents/EcoAdaptCCAC_2022_Chattanooga.pdf

Rapid Vulnerability and Adaptation Tool

The Rapid Vulnerability and Adaptation Tool (RVAT)[2] for Climate-Informed Community Planning was developed to make climate adaptation planning a simple, direct, and feasible process for communities. The purpose of the tool is to improve understanding of community vulnerability to climate impacts and to develop implementable solutions that reduce vulnerability and/or increase resilience. The RVAT is designed to cover the major steps of a basic climate adaptation planning process, which include the following:

1. Project scoping
2. Vulnerability assessment
3. Adaptation strategy development
4. Adaptation implementation

Workshop Series Overview

The Chattanooga Climate Change Adaptation Workshop series[3] was held virtually on October 3, 4, and 6, 2022, from 1 pm – 5pm each day. The first day of the workshop focused on discussing climate impacts; the second day focused on assessing vulnerability; and the third day focused on developing adaptation strategies. Workshop activities for each day are discussed in more detail below.

Climate Adaptation Workshop Activities: Day 1

The first day focused on orienting participants to the workshop series, introducing climate adaptation planning and the steps involved, identifying and prioritizing pre-existing conditions (i.e., stressors that currently impact the community), presenting climate change projections and discussing impacts, introducing and completing the first step of the CCAC, and completing the first step of the RVAT (project scoping, including prioritizing pre-existing conditions and climate stressors).

Workshop activities were divided between presentations, large group discussions, and breakout group activities. Workshop participants were divided into breakout groups to address three focus areas:

- Group 1 – Housing
- Group 2 – Transportation
- Group 3 – Natural Resources

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[2] http://ecoadapt.org/data/documents/EcoAdaptRVAT_2022_Chattanooga.pdf

[3] The workshop support page (http://ecoadapt.org/workshops/chatt-oct2022-workshop) includes links to presentation slides and all other workshop materials.

Workshop participants, including affiliations and breakout group assignments, can be found in Appendix A.

Project Scoping: Identifying Pre-Existing Conditions and Climate Stressors

As part of the first step of the RVAT (project scoping), workshop participants were asked to identify pre-existing conditions for Chattanooga (i.e., stressors that already impact the community). Participants collectively identified more than 25 pre-existing conditions that, through discussion and ranking in each breakout group, were narrowed down to top priority conditions (bolded items represent top three or four conditions selected by the group):

- Group 1, Housing – **Low quality and energy-inefficient existing affordable housing; aging and inadequate utility infrastructure;** lack of affordable, safe housing; pre-existing gridded neighborhood infrastructure near downtown; **rapid population growth and pressure on natural resources;** contamination and brownfields; steep slopes and siting challenges; loss of habitat for new housing
- Group 2, Transportation – **Poorly planned development patterns regarding transportation options**; natural area impacts by transit corridors; **challenges in promoting alternative transportation options and incentives (electric vehicles, etc.)**; **poor condition of infrastructure and roadway congestion**; **lack of multi-modal options and geographic limits to routing options;** population migration; transit expansion goals and first and last mile issues; airport capacity increases versus greenhouse gas reduction goals
- Group 3, Natural Resources: **Unequal access to and investments in natural resources and recreation;** inadequate urban tree canopy; **water pollution** (including microplastics and bacteria); brownfields and contaminated properties; **habitat loss and fragmentation driven by factors including population growth and invasive species**; slope instability; development of steep slopes; aging infrastructure, including combined sewer overflow issues; and loss of floodplains, wetlands and riparian corridors due to development

Major climate stressors for Chattanooga were identified by workshop facilitators (Appendix B) and included extremes and seasonal shifts in precipitation and flooding, increasing and extreme temperatures, increasing wildfire risks, and drought.

Climate Adaptation Workshop Activities: Day 2

On Day 2, workshop participants used the pre-existing conditions and climate stressors identified during the first day of the workshop as the basis for initiating the second step of the RVAT (vulnerability assessment).

Conducting the Vulnerability Assessment

Each breakout group explored the intersection of these conditions and climate stressors to identify the impacts of greatest concern for their focus area. For each of these impacts, the groups assessed the primary components of vulnerability:

- *Likelihood* of the impact occurring
- C*onsequence* to the community were the impact to occur
- The consequent *risk* resulting from the product of likelihood and consequence
- *Adaptive capacity* of the community in terms of the staff and resources that the relevant jurisdictional and/or community groups have available to address the impact

These rankings were then used to determine risk (resulting from the intersection of likelihood and consequence) and overall vulnerability for that impact, based on matrices provided within the RVAT worksheets. The results of this vulnerability assessment formed the foundation for the adaptation solutions work during Day 3 of the workshop.

On Day 2, workshop participants were also introduced to a network mapping tool (https://network-mapping-41fb1.web.app/). This tool, developed by Virginia Tech staff based on registrations and pre-workshop planning, shows participants the existing relationships among local government departments/agencies and/or community organizations and how each links to different focus areas. The tool is designed to help participants think about the connections and partnerships that can support Chattanooga in implementing adaptation solutions developed in the workshop as well as moving forward on community collaboration for climate change adaptation.

Climate Adaptation Workshop Activities: Day 3

On Day 3, the breakout groups focused primarily on identifying adaptation strategies that would reduce impacts of greatest concern for each focus area and then developing implementation plans for priority strategies (the third and fourth steps of the RVAT, respectively). At the end of these breakout sessions, the group reconvened as a whole to share selected adaptation solutions from each group, including whether

individuals or organizations had been identified for lead or partnering roles in solution implementation.

Overview of Climate Projections and Impacts

The following summaries provided foundational information for the workshops about current and projected future climate changes. A table of observed and projected climatic changes can be found in Appendix B.[4]

Air Temperature and Extreme Heat

By 2050, average daily minimum temperatures (minimum daily temperatures averaged across the whole year) in Chattanooga are projected to increase by 3.9°F above the historical average of 47.5°F, and average daily maximum temperatures are projected to increase by 4.3°F above the historical average of 70°F. By 2100, minimum and maximum temperatures are likely to have increased by 8.9°F and 9.5°F, respectively, above historical averages.

Extreme heat events are also likely to increase significantly. The number of days with maximum temperatures over 95°F are likely to increase from the historical average of 6.1 days per year to 34.8 days per year by 2050 and to just over 84 days per year by 2100 (representing a 470% and 1,280% increase, respectively).

Precipitation and Drought

Changes in annual precipitation in Chattanooga are expected to be relatively modest by mid-century, with model projections suggesting increases of 5.4% from the historical average of 56.9 inches per year to 60 inches per year. By 2100, annual precipitation is projected to have increased by 8.8%, to 61.9 inches per year. Seasonal precipitation shifts are expected in terms of small increases expected in Spring and Fall precipitation (7% and 6%, respectively) by 2100, with little to no change in winter or summer rainfall.[5]

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[4] Projections for air temperature, extreme heat, and annual precipitation were obtained from the U.S. Climate Resilience Toolkit Climate Explorer (https://crt-climate-explorer.nemac.org), generated using the high-emissions scenario for 2050/mid-century (average of 2035–2064) and 2100/late-century (average of 2070–2099) time periods compared to average conditions between 1961–1990.

[5] J.R. Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey (https://doi.org/10.5066/F7W9575T), county-scale projections generated using the high-emissions (RCP 8.5) scenario for the late-century (average of 2075–2099) time periods compared to recent conditions (average of 1981–2010).

Extreme Precipitation and Flooding

Extreme precipitation, which is strongly associated with flooding, is likely to increase in terms of both frequency and amount. The number of days each year when at least 2 inches of rain falls in 24 hours is expected to increase slightly, from 2.1 days to 2.3 days (+9.5%) by 2050, and then to 2.8 days (+33%) by 2100. An increase is also projected in the amount of rain falling in a given extreme precipitation event, with rainfall totals within a 20-year storm event expected to increase 12% by 2050 and 21% by 2100.[6] Flood frequency and severity, and the area vulnerable to flooding, is expected to increase over the coming century as well[7,8]. The Chattanooga area is also expected to experience an increase in the frequency and severity of severe thunderstorms and tornadoes[9].

Drought

The Chattanooga area is likely to see increases in drought frequency and severity due to longer periods without rain and warmer temperatures, which increase evaporation and plant transpiration and results in less water remaining in soil.[10,11]

Wildfire

Chattanooga is likely to face increased potential for wildfire due to drier conditions.[10,11] Over the next 50 years, the length of the fire season is expected to double, from 1 month to 2 months.[10]

Summary of Potential Impacts

Potential impacts of the projected climate changes described above are summarized below. (The specific intersections of these impacts with climate and pre-existing conditions discussed by workshop participants as part of the vulnerability assessment are described in subsequent sections of this report).

Likely impacts of projected climate changes on **housing** may include the following:

- More expensive electric bills from increased need for cooling homes
- More heat stroke, illness, and death from extreme heat

[6] U.S. Climate Resilience Toolkit Climate Explorer, op.cit.

[7] P. D. Bates et al., Water Resources Research, 57 (2021). https://doi.org/10.1029/2020WR028673

[8] O. E. J. Wing et al., Nat. Clim. Chang. 12, 156–162 (2022).

[9] N. S. Diffenbaugh, M. Scherer, R. J. Trapp, PNAS. 110, 16361–16366 (2013).

[10] Y. Liu, S. L. Goodrick, J. A. Stanturf, Forest Ecology and Management. 294, 120–135 (2013).

[11] R. J. Mitchell et al., Forest Ecology and Management. 327, 316–326 (2014).

- Increased pressure on water and power plant capacities associated with extreme heat and wildfire impacts
- Increased wear and tear on housing
- Accelerated disparities in heat island effects from higher temperatures in lower-income neighborhoods
- Increased housing damage and displacement of people by storms and flooding
- Potential for loss of affordable housing and displacement of people if disasters destroy the affordable housing inventory and these are replaced by more expensive housing
- Reduced food security
- Air quality issues for residents due to wildfires

Likely impacts of projected climate changes on **transportation** may include the following:

- Impacts of extreme heat on the rail transport system and roadway surfaces
- Increased energy use for cooling needs
- Drought impacts on river-based freight
- Flooding impacts on low-lying neighborhoods, tunnels, and older streets and bridges
- Increasing landslides and sinkholes from extreme precipitation events and impacts on infrastructure and rerouting
- Flooding in manufacturing centers

Likely impacts of projected climate changes on **natural resources** may include the following:

- Impacts of extreme heat and extreme weather on vegetation and wildlife, leading to mortality and displacement of species, with serious consequences for already threatened or endangered species
- Increased variability and lowered predictability of weather for agricultural systems
- Exacerbation of inequitable distribution of urban tree canopy cover through loss to extreme heat and storm events
- Increases in invasive species that may be more likely to persist under extreme heat and weather conditions than their native counterparts
- Shifts in vegetation and wildlife communities due to changing climate conditions
- Reductions of soil capacity due to drought and consequences for increased flooding

- Reduced availability of water to wildlife and people
- Increased risk of wildfire impacts due to drought and shifts in precipitation

Vulnerability Assessment and Adaptation Strategies

The following sections summarize the vulnerability and adaptation information for each of the three focus areas addressed in this workshop series: Housing, Transportation, and Natural Resources. The information presented is based on the discussions and input of workshop participants during breakout group activities.

Housing

This group focused on the goal of providing access to high quality, energy efficient, affordable housing to Chattanooga residents, while recognizing current racial and socioeconomic disparities in housing availability and the expected impacts of climate change on housing availability and performance. The time frame considered for this assessment was 30 years (to approximately 2050).

VULNERABILITY ASSESSMENT

Summary of observed and/or anticipated effects of pre-existing conditions and climate stressors

Pre-existing Conditions

Rapid population growth; low quality, energy-inefficient, and limited existing affordable housing; and **aging and inadequate utility infrastructure** were identified by participants as primary pre-existing conditions that impact housing.

Rapid population growth increases demand for affordable housing that is already limited and can increase rates of homelessness. Building more housing and services to meet population growth can increase clearing of forested lands and displace vulnerable community members. Rapid population growth and densification can also lead to increased disease transmission and increases in other health conditions.

Low quality, energy-inefficient, and **limited existing affordable housing** means the housing stock is more expensive and less affordable because of added heating and cooling costs. Poor housing conditions increase chronic health issues such as asthma, heat stroke, and mold-related illnesses; increases pest issues; can create conditions for increases in impacts to public safety; and can create higher rates of eviction and transience. Market drivers for building less affordable housing creates a potential for gentrification and displacement.

Aging and inadequate utility infrastructure can lead to service interruptions due to repairs, delays in creating new hookups, and even displacement when utilities fail on a large scale. Events like combined and sanitary sewer system overflows are more likely with aging infrastructure. As the cost of maintaining utilities aren't currently captured in property tax rates, the costs are disproportionately born by people who are dealing with the oldest infrastructure. There are current issues with lead within existing pipes and building fixtures that are particularly difficult to address behind the meter. Utility line placement can be a barrier to tree canopy cover. The lack of net metering is a barrier to implementing distributed solar systems. There is a lack of backup or redundancy of water supplies that can create problems during water main breaks.

Climate Stressors

Extreme heat; extreme precipitation, including storms and flooding; and **drought and wildfire** were identified by group participants as the climate stressors that have the most significant impacts on housing in Chattanooga.

Extreme heat is likely to cause a rise in cooling and electric bills; increase heat stroke and heat-related illness; increased pressure on water plant and power plant capacities; increase wear-and-tear on housing, particularly lower-quality housing; and accelerate disparities in terms of heat island effects in lower income neighborhoods.

Extreme precipitation, including storms and flooding, is likely to increase property damage and displacement, lead to loss of affordable housing if such housing is destroyed and replaced by more expensive homes, increase wear and tear on housing, and cause changes in the floodplain.

Drought and wildfire are likely to increase pressure on water plant capacity due to additional drought response and fire suppression, reduce food security, cause damage to or loss of housing stock from wildfire that could contribute to loss of affordable housing if it is replaced with more expensive housing, and create air quality issues.

Combined Impacts of Pre-existing Conditions and Climate Stressors

Climate change is likely to exacerbate the impacts of or be exacerbated by these pre-existing conditions. Participants identified several ways in which climate stressors and pre-existing conditions can intersect to affect connected communities:

Increasing frequency and duration of extreme heat is likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including:

- Loss of tree canopy further exacerbates heat island effects.
- An increasing population housed in poor-performing housing and unhoused people are exposed to increased exposure to heat, leading to a rise in heatstroke and heat-related illnesses.
- More expensive heating and cooling bills further reduces housing affordability.
- Population increases intersecting with additional cooling needs exacerbates increased demand on utilities, including water and power.
- Water quality issues, already a problem due to aging infrastructure, are further exacerbated by rising temperatures.

Extreme precipitation, storms, and flooding are likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including:

- Loss of tree canopy exacerbates runoff and flooding, erosion issues, particularly in communities that already have lower tree canopy cover.
- Extreme weather exacerbates homelessness following displacement and climate migration, and exposes homeless populations to greater health risks, including poor air quality.
- Development to create more housing to supply an increasing population could lead to loss of wetlands that help reduce stormwater and flooding impacts.
- Poor quality of housing exacerbates health risks and risks of displacement associated with storms and flooding.
- Extreme weather accelerates the deterioration of housing that already is underperforming.
- Extreme weather exacerbates extant issue with health that are tied to water-borne illnesses and mold.
- Extreme precipitation and flooding exacerbate extant issues with aging infrastructure, including combined sewer and sanitary sewer overflows.
- Extreme weather exacerbates issues with power supply and increases the potential for outages.
- Demands increase on already burdened energy systems and infrastructure to treat very large amounts of water resulting from extreme precipitation events.

Drought and wildfire are likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including:

- Increased population growth means that more homes may be built in areas that are at higher wildfire risk.
- Drought and wildfire impact agricultural systems, affecting food security, especially with a growing population.
- Drought and wildfire can exacerbate climate migration and homelessness following displacement and exposes homeless populations to greater risks, such as air quality issues.
- Poor-performing homes exacerbate health risks associated with drought and wildfire, including air quality issues.
- Lack of specific wildfire provisions in zoning and building codes may result in increased wildfire risk.
- There is a potential of loss of affordable housing if wildfires destroy low-quality housing and it is replaced by more expensive homes, leading to gentrification and displacement.
- There is an increased potential for aging utility infrastructure to start wildfires during high-risk days, possibly necessitating rolling blackouts.
- These climate impacts place increasing pressure on water plant capacity due to increases in demand, including fire suppression.

Overall vulnerability

Participants selected five impacts of greatest concern for housing in Chattanooga and assessed vulnerability (see Figures 2 and 3 for the vulnerability assessment process) for each of these impacts, as described below. Table 1 presents the assessment ranking results.

The potential for loss of affordable housing and displacement of vulnerable populations if disasters destroy existing housing and it is replaced by more expensive homes; the loss of tree canopy cover exacerbating heat island effects and flooding; and **exacerbation of health risks associated with increased heat, storms, and wildfires because of poor quality housing** were all ranked by breakout group participants as having **high vulnerability** due to extreme risk and low-to-moderate adaptive capacity to respond to the impact. **Increased homelessness following displacement and climate migration, with higher health risks in these exposed populations** received a **moderate vulnerability** ranking because, while risk was seen as extreme, adaptive capacity of the community was viewed as high to address this problem. **Increased pressure of climate change on utility capacity** was ranked as having **high vulnerability** for the sewer utility[12]

[12] Sewer utility staff weren't available for the workshop to provide insight into adaptive capacity; additional information was provided post-workshop illustrating several ways in which the City is working

but **low vulnerability** for water, electricity, and gas, primarily because the adaptive capacity for sewer was seen as low, while for the other utilities, adaptive capacity was considered high, and because the consequences for sewer were seen as catastrophic but limited for the other utilities.

Table 1. Vulnerability Assessment Ranking Results for Impacts of Greatest Concern for Housing

Effects/Impacts of Greatest Concern	Likelihood	Consequence	Risk	Adaptive Capacity	Vulnerability
Potential for loss of affordable housing if natural disasters destroy existing housing and it is replaced by more expensive homes by the Federal Emergency Management Agency (FEMA).	Almost Certain	Catastrophic	Extreme	Low	High
Loss of tree canopy exacerbates heat island effects and runoff/flooding.	Almost Certain	Major	Extreme	Moderate	High
Increased homelessness following displacement and climate migration and increased health risk exposure for homeless populations.	Almost Certain	Major	Extreme	High	Moderate
Poor quality of housing exacerbates health risks associated with extreme heat, flooding, and wildfire.	Almost Certain	Major	Extreme	Low	High
Increased pressure of climate change on utility capacity.	Almost certain	Water, Electric, Gas- Negligible; Sewer- Catastrophic	Water, Electric Gas- Low; Sewer- Extreme	Water, Electric, Gas – High; Sewer – Low[12]	Low for Water, Electric, Gas; High for Sewer

on increasing adaptive capacity to retain, direct and treat both separate and combined sewer influent, resulting in significant reduction in sanitary sewer overflows, including a recent $186 million low-interest loan from USEPA to support energy efficiency and operational resilience. For more information on these efforts visit https://clearchattanooga.com.

PROPOSED ADAPTATION STRATEGIES AND IMPLEMENTATION PLANS

Adaptation strategies for effects of greatest concern

Participants identified several possible adaptation strategies for each of the effects of greatest concern selected for housing (see Table 2). Time limitations meant that not all co-benefits and unintended consequences were identified by the breakout group for every effect of concern.

Table 2. Identified Effects of Greatest Concern and Possible Adaptation Strategies for Housing

Effects of Greatest Concern	Adaptation Strategies to Reduce Vulnerabilities
Potential for loss of affordable housing if natural disasters destroy existing housing and it is replaced by more expensive homes by FEMA	• Improve the quality of existing affordable housing stock to reduce likelihood it is damaged by climate change impacts. • Increase the availability/amount of resilient affordable housing to reduce the likelihood that a large proportion will be lost in a single event and ensure that it is sited in areas that don't place it at higher risk**. • Increase options to ensure affordable housing remains affordable in perpetuity (e.g., community land trusts, cooperatives, deed restrictions, home ownership programs to help renters become owners). • Increase density within vacant spaces turned into affordable housing. *Co-benefits:* Public health is improved, equity increased, transportation improvements (could support public transit systems).
Loss of tree canopy exacerbates heat island effects and runoff/flooding	• Create a vegetation master plan to inform where/how to address this issue and how to pay for it, as well as which species should be planted and where to ensure survival under future climate conditions**. • Create grants that support tree planting on private property, particularly in targeted areas. • Ensure that planted trees are well-maintained to maximize survival and safety during storms. • Develop a city or county nursery to create a supply of trees. *Co-benefits:* Improvements in public health, water quality, biodiversity, increased property values, improved quality of life *Unintended Consequences:* Increases maintenance required from property owners and to ensure safety in storms.
Increased homelessness following displacement and climate migration and increased health risk exposure for homeless populations	• Increase the availability/amount of resilient affordable housing to reduce the likelihood that a large proportion will be lost in a single event, ensuring that it is sited in areas that don't place it at higher risk.

	● Increase density within vacant spaces turned into resilient affordable housing. ● Open a cooling center for city residents and/or expand hours at shelter (currently only open in the winter). ● Improve the shelter system, the number of shelters, quality of shelter system, and accessibility of shelters. ● Expand programs to help homeless residents get back on their feet (e.g., transitional housing, workforce development, mental health/substance abuse resources, shelter systems). *** *Co-benefits:* Improvements in public health, equity improvements, economic benefits to both individuals and community, transportation (shelter accessibility), crime reduction
Poor quality of housing exacerbates health risks associated with extreme heat, flooding, and wildfire	● Improve the quality of existing affordable housing stock (e.g., create an incentive program for landlords to improve housing, particularly in low-income neighborhoods). ** ● Expand existing programs – weatherization assistance, workforce development focused on weatherization, EPB energy efficiency program, Habitat, Housing Authority programs. ● Launch Pay As You Save (PAYS) model (plan already prepared by EPB). ● Create a resource hub for residents to access information and programs. ● Establish an energy-efficiency standard for rental housing to increase affordability and/or require the disclosure of average daily energy costs. ● Create a Civilian Climate Corps/works program to improve homes. *Unintended consequences:* New standards could increase rents.
Increased pressure of climate change on utility capacity	● Stop adopting new miles of infrastructure and infrastructure that the City can't afford to maintain with sufficient incremental property tax (currently based on value of home rather than cost of serving the home). ** ● Build more sewer treatment plants to build redundancy into the system through multiple plants. ● Expand green infrastructure to reduce volume of stormwater entering the system (e.g., use existing parks to store floodwater). ● Increase water efficiency to reduce volume of water entering the system. ● Create a Civilian Climate Corps/works program to expand green infrastructure. ● Evaluate and upgrade stormwater regulations. ● Green bond to reduce runoff from existing impervious surfaces.

	Unintended Consequences: Reducing supply of new housing can increase cost of existing housing.

Starred (**) adaptations were those carried forward to discuss for implementation.
***this adaptation regarding services for unhoused populations was identified as a high priority by participants but was not able to be discussed in further detail due to time limitations.

Implementation Plans for Priority Strategies

The housing group participants selected four priority adaptation strategies and developed implementation plans for each:

1. Increase the availability/amount of resilient affordable housing to reduce the likelihood that a large proportion will be lost in a single event and ensure that it is sited in areas that don't place it at higher risk.

   ***How and when to implement*:** Implement now. Consider FEMA flood map and data on publicly owned lands, vacant lots, and access to schools, jobs, transit, and groceries. Create a ranking system to identify parcel priority for affordable housing (e.g., TPL map for Healthy Connected Chattanooga). Fund projects that have already been identified as high priorities but haven't yet been implemented. Increase collaboration among organizations.

   ***Leads and partners*:**

   Leads: City of Chattanooga (check with new Chief Housing Officer)

   Partners: Housing Authority, Chattanooga Neighborhood Enterprise (CNE), Habitat for Humanity, TN Housing Development Authority (THDA), U.S. Department of Housing and Urban Development (HUD), Chattanooga Design Studio, GreenSpaces

   ***Resources and barriers*:** Funding, people power, parcel-scale map of future flood risk to overlay with resource access and other layers is needed. Land acquisition is needed. Barriers including timing (can be very slow-moving), zoning codes, and NIMBYism.

   ***Efficacy*:** Medium (noted impossible to replace unit for unit what could be lost in a major event).

   ***Feasibility*:** High

2. Create a vegetation master plan to inform where/how to address loss of/inadequate tree canopy and how to pay for it, as well as which species should be planted and where to ensure survival under future climate conditions.

   ***How to implement*:** A county-wide vegetation master plan based on a high-resolution landcover map is currently underway with fundraising. This will be a

complete county-wide vegetation master plan, thus ensuring that heat island effects, water quality and stormwater benefits, and biodiversity benefits are all included.

***Leads and partners*:**

Lead: City forester

Partners: City stormwater, Parks & Rec, GreenSpaces, UT Chattanooga, EPB (tree trimming plans), Southeast Conservation Corps, TPL

***Resources and barriers*:** Funding needed (expecting Inflation Reduction Act funding coming for urban forestry); nursery needed to supply trees for planting; maintenance plans needed; 811 (call before you dig) an extant resource

***Efficacy*:** High

***Feasibility*:** High

3. Improve the quality of existing affordable housing stock (e.g., create an incentive program for landlords to improve housing, particularly in low-income neighborhoods).

***How to implement*:** Enhance existing programs that focus on improving existing housing stock (e.g., weatherization, energy efficiency). Establish an energy-efficiency standard for rental housing to increase affordability. Identify/create forgivable loans and a revolving loan fund. Consider free or low-cost financing for improvements if an owner agrees to keep the unit affordable for a certain length of time. Standardize the payment in lieu of taxes (PILOT) program so that people other than large developers can use it. Consider approaches including tax increment financing, ROUND UP program (electric/communications bills are rounded up to the nearest dollar to be used to fund programs for energy efficiency, solar, and the like).

***Leads and partners*:**

Lead: Not identified.

Partners: EPB, City of Chattanooga, Housing Authority, CNE, Habitat, TN Housing Development Authority, HUD, Chattanooga Design Studio, GreenSpaces, United Way (for volunteers)

***Resources and barriers*:** Not identified

***Efficacy*:** Not identified

***Feasibility*:** Not identified

4. Stop adopting new miles of infrastructure and infrastructure that the City can't afford to maintain with sufficient incremental property tax (currently based on value of home rather than cost of serving the home).

***How to implement*:** Analyze and improve the process by which development plans are approved. Make public the number of roads and new utilities being added every month (as part of public record)—this would make clear that this approach is economically unsustainable. Increase property taxes or sewer/stormwater fees based on factors such as cost of service and density.

***Leads and partners*:**

Leads: Regional Planning Agency

Partners: All levels of jurisdiction (local, county, state), utilities, developers, U.S. Environmental Protection Agency, Department of Justice, Urban 3

***Resources and barriers*:** Political will and current systems and state law are all barriers. The consent decree Hamilton County is about to enter into will need to address this.

***Efficacy*:** High

***Feasibility*:** Low

Transportation

The transportation group focused on the full range of transportation modalities that contribute to health, livability, and connectivity to community resources, be they employment, healthcare, food, community or green spaces. The time frame considered for this assessment was 10 to 30 years, with planning starting now.

VULNERABILITY ASSESSMENT

Summary of observed and/or anticipated effects of pre-existing conditions and climate stressors

Pre-existing Conditions

Lack of development planning and aging and inadequate infrastructure, freight mobility issues, and **lack of alternative (non-motorized and public) transit** were identified by group participants as the primary pre-existing conditions that have the most significant impacts on transportation.

Lack of development planning and aging and inadequate infrastructure interferes with transportation because past and current trends of low-density, dispersed, and isolated development have created roadway bottlenecks and other challenges; infrastructure is currently in poor condition, predisposing it to higher risk of disrepair and failure.

Freight mobility issues are a major concern for transportation, as the City and region has one of the top 10 highest freight pass-throughs by truck, rail, and river-based freight, which challenges capacity and management.

Lack of alternative transit is a significant challenge in the transportation sector; options for public and non-motorized transit are currently very limited (though participants noted that Chattanooga Area Regional Transportation Authority (CARTA) could not be present at the workshop, which could have been useful for this discussion).

Climate Stressors

Increasing temperatures, shifts in precipitation timing and amount, and **extreme precipitation and flooding** were identified by participants as the primary climate stressors that impact water resources.

Increasing temperatures are likely to have impacts on the rail transport system and roadway surfaces and increase energy use for cooling.

Precipitation shifts are likely to particularly impact river-based freight, particularly during prolonged drought conditions.

Extreme precipitation and flooding are likely to cause impacts to older streets, bridges, low-lying neighborhoods, and tunnels, as well as to river-based freight and manufacturing centers; and flooding, landslides and sinkholes are likely to impact roadways, especially evacuation routes and emergency personnel/vehicle access, and may require long-term, significant re-routing.

Combined Impacts of Pre-existing Conditions and Climate Stressors

Climate change is likely to exacerbate the impacts of or be exacerbated by all three pre-existing conditions. Breakout group participants identified the following challenges:

Increasing temperature is likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including the following:

- Additional impacts will add to current issues with rail freight mobility.
- Increasing energy demand may compete with developing electric vehicle (EV) - based freight transport needs.
- Limited public transit is made less preferable by unpleasant/risky outdoor conditions in extreme heat.
- Increasing energy demands for air conditioning with extreme heat may create additional barriers to growth of electric transit and EV charging.
- Transportation to schools is already inefficient and easily disrupted and could be even more disrupted by extreme heat events.

Precipitation shifts and **extreme precipitation/flooding** is likely to intersect with pre-existing conditions to exacerbate impacts in ways listed below:

- Shifts in seasonal precipitation and extreme precipitation are both likely to exacerbate current issues with river-based freight mobility.
- Aging and inadequate infrastructure and historic planning may intersect with extreme precipitation to create even greater roadway flooding, slide, and sinkhole issues.
- Aging and inadequate infrastructure and poorly planned roadway routing may create serious bottlenecks and rerouting issues during flood events.

- Flooding and road damage may particularly exacerbate transportation to schools.
- Flooding and extreme precipitation events may further impact freight truck routing and transit time problems.

Overall vulnerability

Participants selected five impacts of greatest concern for transportation in Chattanooga and assessed vulnerability for each of these impacts (see Table 3), as described below.

Flooded neighborhoods, stranding residents and at-risk populations was evaluated as having **moderate vulnerability** due to high risk and moderate to high adaptive capacity. **Roadway bottlenecks and rerouting due to flooding, slides, and sinkholes; freight re-routing and impacts on river, rail, and roadway freight movement,** and **impacts on emergency personnel/vehicle access** were all ranked by breakout group participants as having **high vulnerability** due to extreme risk and moderate adaptive capacity. **Challenges to increasing use of alternative transit in extreme weather** was acknowledged as an impact of concern, but there was not time to develop the vulnerability assessment for this specific impact.

Table 3. Vulnerability Assessment Ranking Results for Effects/Impacts of Greatest Concern for Transportation

Effects/Impacts of Greatest Concern	Likelihood	Consequence	Risk	Adaptive Capacity	Vulnerability
Roadway bottlenecks; rerouting due to floods, slides, and sinkholes; impacts on transit and mobility.	Almost Certain	Major	Extreme	Moderate	High
Flooded neighborhoods strand residents and at-risk populations.	Almost Certain	Moderate	High	Moderate/ High	Moderate
Freight re-routing and consequent impacts on river, rail, and roadway-based freight movement .	Almost Certain	Major	Extreme	Moderate	High
Reductions in evacuation route options and access issues for emergency personnel and vehicles.	Almost Certain	Major/ Catastrophic	Extreme	Moderate	High

PROPOSED ADAPTATION STRATEGIES AND IMPLEMENTATION PLANS

Adaptation strategies for effects of greatest concern

Breakout group participants identified several possible adaptation strategies for transportation. The following table summarizes adaptation strategies in response to effects of greatest concern that were explored by breakout group participants (Table 4). Time limitations meant that not every effect of concern and not all co-benefits and unintended consequences were identified by the breakout group.

Table 4. Identified Effects of Greatest Concern and Possible Adaptation Strategies for Transportation

Effects of Greatest Concern	Adaptation Strategies to Reduce Vulnerabilities
Roadway bottlenecks; rerouting due to floods, slides, and sinkholes; impacts on transit and mobility	• Adopt "15-minute" city planning approaches; community hubs can reduce vehicle miles traveled (VMT), especially when extreme event-caused bottlenecks exist. • Leverage and expand intra-community-to-region transportation framework strategies and be more creative and sophisticated with transportation planning. • Improve resilience of EV charging network. • Improve existing roadway resilience by accelerating road maintenance (need to address lack of available repair service companies). *Co-benefits:* Can prioritize U.S./regional sourcing of energy, technology, and goods; increases overall readiness for emergency response.
Flooded neighborhoods strand residents, at-risk populations	• 15-minute city planning approaches—community hubs that include basic services and reduce travel needs during emergencies.** • Create resilience hubs, community safety networks and social networks.** • Create community safety networks and social networks. • Adjust allocation of existing emergency services to reflect need; expect more frequent emergency events (police, fire, etc.).** • Learn from past emergency events. • Identify low-lying neighborhoods and plan for relocation. *Co-benefits:* Resilience hubs can contain multiple resources to support community health and safety.
Freight rerouting and consequent impacts on river, rail, and roadway-based freight movement	• Prioritize goods transport and reduce people transport across larger distances as possible (stay within hubs, 15-minute city planning). • Strategically expand rail and river freight transport to reduce roadway use.

	• Leverage and expand community-to-region transportation framework strategies. • Reduce dependence on external fuel sources by electrifying transport. • Improve resilience of EV charging network.
Evacuation route options and access issues for emergency personnel and vehicles	• Airport as emergency response base, assess vulnerability/resilience based on future climate and flood modeling (known flooding issues on some access roads). • Boat-based evacuation may need to be developed. • Shuttle/bus/helicopter-based people movement during emergencies; plan and prepare for faster response (update county hazard mitigation and response plans).** • Include resilience hubs in community hub planning.**
Challenges to increasing use of alternative transit due to extreme weather	• 15-minute city planning approaches, community hubs can help reduce VMT.** • Shift development so density exists to support transit corridors and efficient public transit.** • Leverage and expand intra-community-to-region transportation framework strategies (planning sophistication).

**Starred adaptations were carried forward to discuss for implementation

Implementation plans for priority strategies

Participants discussed three of their highest priority adaptation strategies for transportation.

1. 15-minute city planning approaches, community hubs can reduce VMT, especially when bottlenecks exist. Leverage and expand intra-community-to-region transportation framework strategies.

   ***How to implement*:** Begin planning and outreach now. Understand and identify community hub basic needs for vulnerable neighborhoods, including utilities, school, employment, food, and retail. Identify location opportunities and needs. Incorporate education, outreach, collaboration, and community input. Adjust zoning standards and land use planning. Identify and engage financial tools including tax incentives and increment financing. Leverage regional transit planning, leverage new development.

   ***Leads and partners*:**

   Leads: Dan Reuter, city planner

   Partners: Form cross-organization/agency Climate & Resilience Council; Transportation Planning Office; Mayor/City Council

***Resources and barriers*:** All of the following were identified as existing resources: Climate Action Plan (CAP); zoning and code review process in progress; transportation planning processes; Climate and Resilience Committee

***Efficacy*:** Not identified

***Feasibility*:** Not identified

2. Increase overall readiness of emergency response, resilience of evacuation routes and responses (including airport), and resilience hubs.

   ***How to implement*:** Update hazard mitigation and response plan. Include planning department, CAP team, and Community Resilience Report input. Include relevant climate change risk information.

   Lead: County Emergency Services

   Partners: Tap into partners and stakeholders that already exist for current review and update process.

   ***Resources and barriers*:** Planning, processes, and stakeholder groups exist. Barriers include limited staff capacity and funding; may require grant-based funding.

   ***Efficacy*:** High

   ***Feasibility*:** Moderate

3. Shift development so density exists to support transport corridors.

   ***How to implement*:** Integrate with 15-minute city planning action. Leverage current transit planning efforts.

   ***Leads and partners*:**

   Leads: Not identified

   Partners: Not identified

   ***Resources and barriers*:** Not identified

   ***Efficacy*:** Not identified

   ***Feasibility*:** Not identified

Natural Resources

The natural resources group identified a goal to cooperatively plan for the conservation of and equitable access to natural resources and biodiversity in the face of a changing climate to ensure these systems remain resilient. The timeframe for this discussion was considered to be highly variable, from near to very long (100 years or more) term, depending on the topic, acknowledging that ecological processes can often be far longer than typical planning time frames.

VULNERABILITY ASSESSMENT

Summary of observed and/or anticipated effects of climate stressors and pre-existing conditions

Pre-existing Conditions

Unequal access to and investments in natural resources and recreation; habitat loss and fragmentation driven by factors including human population growth and invasive species; and **water pollution, including microplastics, bacteria, and other contaminants** were identified by group participants as the primary pre-existing conditions stressors that have the most significant impacts on natural resources.

Unequal access to and investments in natural resources and recreation is likely to impact natural resources by impacting awareness and education for future generations, including underserved communities; impacts on community health, particularly in underserved communities; and exacerbating the socioeconomic divide. These trends demand action to invest in underinvested areas and makes it essential that Chattanooga is more intentional about prioritizing neighborhoods that aren't being heard and aren't convinced what they say matters.

Habitat loss and fragmentation driven by factors including human population growth and invasive species decreases biodiversity; impacts wildlife migration patterns; increases the cost of restoration and management, particularly resulting from invasive species; has implications for human health, including emerging diseases and vectors; reduces the quality of recreation experiences; and reduces carbon sinks and increases greenhouse gas emissions.

Water pollution reduces the quality of and increases the treatment costs of drinking water; can impact biodiversity, food webs, and the reproduction and health of wildlife; increases human health impacts from exposure to and bioaccumulation of

contaminants; and reduces recreation opportunities if polluted waters are closed to access or avoided.

Climate Stressors

Extreme heat events, drought, and **extreme weather, including increased precipitation and flooding** were identified by participants as the primary climate stressors that impact natural resources.

Extreme heat events are likely to have impacts on natural resources, including impacting the health and persistence of native vegetation and wildlife; public health impacts, particularly communities with greater heat island effects and those who do not have access to cooling effects of tree canopy coverage; stresses on agricultural crops; and reduced success of endangered species protection and recovery for sensitive species.

Drought is likely to stress vegetation, crops, and wildlife; increase wildfire risk; increase flooding risk by reducing soil capacity; and make water less available and more expensive.

Extreme weather can displace and destroy native vegetation and wildlife; impact water quality, including increases in turbidity; increase erosion; increase variability and reduce predictability of agriculture; and reduce ecosystem resiliency.

Combined Impacts of Pre-existing Conditions and Climate Stressors

Climate change is likely to exacerbate the impacts of or be exacerbated by all three pre-existing conditions. Breakout group participants identified the following challenges:

Extreme heat and **drought** are likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including:

- Exacerbating unequal access to and investment in resources and recreation by reducing access to natural areas, cultural tourism, and recreation even more dramatically, which can lead to reduced visitation, reduced economic activities, and cultural and heritage loss.
- Contributing to loss of tree canopy and exacerbation of heat island effects in vulnerable communities already exposed to disproportionate impacts, leading to exacerbation of stress and chronic health issues.

- Extreme heat and drought can intersect with fragmented and stressed habitats to further exacerbate wetland loss and move the needle backwards on species recovery.
- Habitat fragmentation and loss can be compounded by extreme heat and drought by leading to even greater losses of agricultural lands as they become less productive and are converted for development.
- Extreme heat and drought can exacerbate water pollution issues by making it more likely that pesticides and fertilizers used to combat invasive species, pathogens, and reductions in agricultural productivity are likely to run off into surface water bodies.
- Water pollution can intersect with extreme heat and drought by exacerbating issues with bacteria, stressing and shrinking aquatic ecosystems, and reducing public recreation opportunities even further.

Extreme weather events, including increased precipitation and *flooding* is likely to intersect with pre-existing conditions to exacerbate impacts in several ways, including:

- Extreme weather and its impacts on hydrologic variability can intersect with ecosystems already stressed by fragmentation and development, exacerbating issues including erosion, and increase wildlife impacts (particularly impacts on waterfowl and other birds tied to aquatic habitats).
- Extreme weather can intersect with water pollution by overwhelming wastewater treatment plants (WWTPs), making combined sewer overflows more likely, and overwhelming stormwater controls, contributing to reduced water quality and human health and ecological impacts.
- Extreme weather can contribute to loss of tree canopy and, consequently, exacerbation of heat island effects in vulnerable communities already exposed to disproportionate impacts, leading to exacerbation of stress and chronic health issues.

Overall vulnerability

Impacts on WWTPs and stormwater controls; loss of tree canopy and exacerbation of heat island effects; effects of erosion on habitats and ecosystems; and **biodiversity impacts from extreme heat and drought** were ranked by breakout group participants as impacts to which the community has **high vulnerability** due to extreme risk and low to moderate adaptive capacity. **Increased use of pesticides and fertilizers and impacts on water quality and food supply** was identified as an impact to which the community has **moderate to high vulnerability** due to high to extreme risk and low to high

adaptive capacity (there is community effort, but also public resistance to making change). **Inequitable reductions in visitation to natural resource and conservation areas and reduced recreation, cultural tourism, and economic opportunity** was described as having **moderate vulnerability** due to extreme risk but high adaptive capacity. Table 5 summarizes this vulnerability assessment.

Table 5. Vulnerability Assessment Ranking Results for Effects/Impacts of Greatest Concern for Natural Resources

Effects/Impacts of Greatest Concern	Likelihood	Consequence	Risk	Adaptive Capacity	Vulnerability
Impacts on WWTPs, green infrastructure, stormwater controls, and impacts on rivers and wetlands.	Almost Certain/ Already Happening	Major	Extreme	Moderate	High
Increased use of pesticides and fertilizers to control pests and address agricultural changes, and consequent issues with runoff and water quality and affordability.	Almost Certain	Moderate to Catastrophic (variable)	High to Extreme	Low to Moderate (there is community effort, but also public resistance)	Moderate to High
Reduced visitation to natural resource and conservation areas, reduced recreation opportunities, navigation, cultural tourism, and economic opportunities, disproportionately borne by vulnerable communities.	Almost Certain	Major	Extreme	High	Moderate
Further loss of tree canopy and exacerbation of heat islands and impacts to stress and chronic health conditions, particularly for vulnerable populations.	Almost Certain	Catastrophic	Extreme	Moderate	High
Biodiversity impacts of extreme temperatures and drought and reduction in species recovery, increase in endangered species.	Almost Certain	Catastrophic	Extreme	Low	High

Impacts of erosion on habitats and ecosystems.	Almost Certain	Catastrophic	Extreme	Moderate	High

PROPOSED ADAPTATION STRATEGIES

Adaptation strategies for effects of greatest concern

Breakout group participants identified several possible adaptation strategies for natural resources. Table 6 summarizes adaptation strategies in response to effects of greatest concern that were explored by the group participants.

Table 6. Identified Effects of Greatest Concern and Possible Adaptation Strategies for Natural Resources

Effects of Greatest Concern	Adaptation Strategies to Reduce Vulnerabilities
Impacts on WWTPs, green infrastructure, stormwater controls, and impacts on rivers and wetlands	• Rain-smart yards: reimbursing rain garden investment and incentives through reducing costs via a stormwater fee. • Rain barrel distribution by City of Chattanooga. • Septic outreach and education for proper maintenance (there is no capacity for more sewering, so proper maintenance is very important). Are there grant opportunities and ways to incentivize upgrades for private systems? • The community needs an additional WWTP—the current plant is over capacity. • Look at zoning rules for certain size developments and their impacts on sewer/septic. • Create incentives for green infrastructure. • If the current combined sewer system could be retrofitted and Lookout and Signal Mountain could be added as service areas, water quality could be significantly improved. *Potential challenges/unintended consequences:* Disproportionate impacts on renters who may not invest in these technologies; increasing sewering capacity could have impacts on development patterns.
Increased use of pesticides and fertilizers to control pests and address agricultural changes, and consequent issues with runoff and water quality and affordability	• Education, especially targeted towards youth, to teach people how to actively control invasives, in order to grow talent and expertise and expand capacity. • Educating the public about the many benefits of removing invasive species.

	• Outreach to nurseries to stop selling invasive species and to not sell plants treated with harmful pesticides, such as neonicotinoids.** • Take a regulatory approach: add species to the banned species list (e.g.., Pittman Center has an invasive species ordinance that includes prohibited species).** • Research and test non-chemical invasive plant removal methods. • Share best practices among organizations for controlling invasives. • Goats and more goats! The City is currently using goats, and they are particularly good for fast-growing species like kudzu. *Co-benefits:* Cleans up lines of sight and promotes public safety (reduces areas that are not visible and can hide illegal activity); water conservation potential; job creation, economic opportunities (e.g., the Nashville Chew Crew, nashvillechewcrew.org). *Potential challenges/unintended consequences:* Removal of invasives could lead to planting of monocultures to get the plants back in the ground quickly, thus reducing biodiversity; if significant soil disturbance results, that can increase invasiveness and erosion; goats are non-selective feeders and do create waste.
Reduced visitation to natural resource and conservation areas, reduced recreation opportunities, navigation, cultural tourism, and economic opportunities, disproportionately borne by vulnerable communities	• Educate people how to visit safely with individual adaptation, such as visiting earlier and later in the day, wearing appropriate clothing, bringing water (e.g., Grand Canyon has rangers for distributing water; noted that Miami just appointed a Heat Officer to create a comprehensive plan for addressing heat-related issues for the community). • Reduced entry fees on days that are hotter? • Plant more trees so we have more shade available to people—riverfront area is a great example. • Make refillable bottle stations available. • Increase access to water recreation and be intentional about better services for underserved communities: more put ins for paddling, more beach access, more programming that provides access.** • Add capacity and education about bicycling. *Co-benefits:* Refillable bottles reduce plastic waste; increase in sense of ownership and stewardship that comes with greater access to recreation and enjoyment of natural resources. *Unintended consequences:* Additional disturbances to wildlife during what is already stressful conditions; increased public safety costs.

Further loss of tree canopy and exacerbation of heat islands and impacts to stress and chronic health conditions, particularly for vulnerable populations	• Provide free trees through the city; add small trees and shrubs that may be less vulnerable to climate impacts and pose less risk of falling. • Create an urban tree canopy plan for the city based on the urban tree canopy study data already generated. Look at the inequity data from the survey, specifically parks and their locations relative to underserved communities. • Urban Century Institute can provide training for tree planting for youth, who can then plant trees on private property to expand benefits.** • Create an agency policy to calculate not only costs but also savings from the co-benefits of trees as part of a budget review. • Tennessee Tree Day exchange: Reflection Riding Nature Center and Arboretum is already a pick-up location for this state event. • Evaluate when trees become a conflict for individual solar installation and consider community solar solutions; particularly consider higher downtown roofs that will not be blocked by trees. • Review and update City tree ordinance and tree-related policies. • Build in biodiversity so disease doesn't wipe out large sections of trees, selective breeding for resistant strains. Increase investment in both research and planting. *Co-benefits:* Gains in community capacity and community pride; energy savings; rainfall interception; reduce air conditioning needs; carbon sequestration; increase in property values (maybe?); lower crime rates (maybe?) *Unintended consequences:* Can increase disparity of investment if those who participate already have advantages; line of site and light can be concerns, particularly for high-crime areas (don't block streetlights); decreased perception of public safety, driving safety; can interfere with solar arrays; needs to be kept in mind that grassland ecosystems are also important, and we should not plant trees in places in which we would lose these systems.
Biodiversity impacts of extreme temperatures and drought and reduction in species recovery, increase in endangered species	• Work upstream of endangered species rescue and rehabilitation; use the Early Detection and Rapid Response framework from the invasives realm. • Protect wetlands, especially vernal pools, so that water is a resource for species when it is limited in availability and increases competition and spread of disease; also need to ensure access. • Implement ecosystem restoration projects, e.g., dam removal to promote species recovery, reduce fragmentation. • Get information from Tennessee river network. • Protect and connect refugia under climate change (a good example from Thrive:

	https://storymaps.arcgis.com/stories/1320f4a2452e412f987931976249632c). ● Conduct controlled burns to promote fire-adapted native species and promote healthy forests. This practice also controls many invasive species and reduces wildfire risk, but can be a communication challenge, phrase in terms of "fuel reduction." ● Community science: get the public involved in inventories and bio-blitzes (e.g., Reflection Riding's privet control observations, umbrella project through Thrive: https://www.inaturalist.org/projects/thrive-regionalpartnership-biodiversity-project.) ** *Co-benefits:* Prescribed burning can improve air quality in the longer term if you are achieving healthy forests; engaging in community science grows capacity, gets people invested in resources. *Unintended consequences:* Short-term air quality issues and potential public safety and risk issues with prescribed burning.
Impacts of erosion on habitats and ecosystems	● Get watershed management plans in place to address 303(d) list—these plans are currently about halfway through development and helps open up federal funding (Chattanooga has a grant for this). ** ● Outreach and education to property owners on erosion—increase education on how to get attention on an issue. ● Update needed for Chickamauga Creek watershed, which has sediment, scouring, and erosion issues that are all linked to upstream management practices—also needs more coordination across state lines. ● Increase inspector funding for stormwater controls; there is currently insufficient capacity. ● Look to USFS model of road inventories to assess primary contributions of sediment and prioritize addressing worst sources. ● Widen and improve quality of riparian zones to reduce erosion; increase buffer zone requirements and stricter codes on development on steep slopes, and actually enforce them. ● Provide incentives for green infrastructure. *Co-benefits:* Reduces road closures and reduces agency costs. *Unintended consequences:* These efforts can slow development, increase housing costs and costs of living; reduce the influx of new people, which has both pros and cons; reducing erosion could lead to hardening or armoring of banks and cumulative impacts of those actions.

**Starred adaptations were those carried forward to discuss for implementation.

Implementation plans for priority strategies

Breakout group participants discussed five of their highest priority adaptation strategies for natural resources.

1. Reduce the sale and spread of invasive species, using both outreach/education, by reaching out to nurseries to stop selling invasive plants and those treated with harmful pesticides and by using regulatory approaches such as adding to prohibited species list.

   ***How to implement*:** Investigate outreach targets, such as nursery trade associations. Create a pamphlet with a list of best practices, climate smart plants, and prohibited/invasive plants; question whether nurseries would be willing to share this or other educational signage with their customers. Educate customers about native and non-native species, while keeping in mind that these definitions may shift with climate change. Promote an inclusive business model that is focused on native and climate-smart plants. In the longer term, seek opportunities for state legislation—the Tennessee Invasive Plant Council has a list of regulated plants, so that a regulation could be pointed towards this list; Pittman Center has an invasive ordinance that could be used as an example.

   ***Leads and partners*:**

   Leads: Reflection Riding

   Partners: Local chapter of The Wild Ones (potential lead?); Tennessee Landscape and Nursery Association; Master Gardeners Program; Department of Agriculture; University of Tennessee (UT) Extension: Smart Yards; UT Chattanooga students who could be trained for this work

   ***Resources and barriers*:** Smart Yards is a current resource, find ways to increase subscriptions; extant UT Chattanooga collaboration funded by Benwood Foundation; staffing and funding are both barriers and resources (e.g., Reflection Riding already commits about 15% of its budget to this issue)

   ***Efficacy*:** Medium (because it is a slow process to change minds and build capacity)

   ***Feasibility*:** High

2. Increase access to water recreation and be intentional about better services for underserved communities, including more put ins for paddling, more beach access, and more programming that provides access.

   ***How to implement*:** Create geographic hubs of water center programming, especially in communities that currently lack access (this has come up in parks master planning); increase beach accessibility and establish new beach areas and

paddling put ins; include access to public water use when the Tennessee Department of Transportation (TDOT) is undertaking infrastructure projects; expand camp and paddle projects such as Blueways.

***Leads and partners*:**

Leads: Outdoor Chattanooga

Partners: Trust for Public Lands, TV Canoe Club, Tennessee Valley Authority, National Park Service, TDOT (posting prohibiting access needs to be addressed), Chattanooga Audubon Society,

Camp and Paddle Project, South Chickamauga Creek Watershed alliance, North Chickamauga, My Waterways

***Resources and barriers*:** All listed partners are resources; City Land Acquisition funding is available for acquiring put-ins. Barriers include private property owners, staff and funding limitations, and the perception and reality of public safety due to contamination and flooding issues.

***Efficacy*:** High (easy to measure use rates)

***Feasibility*:** High

3. Increasing capacity and desire for planting more climate-ready trees, including providing training for tree planting for youth, so they can plant trees on private property to extend placement.

***How to implement*:** Hold educational workshops/trainings to get citizens from the neighborhood learn how to plant trees (intersect with data-driven understanding of where we should be planting) and an extant program: Take Root (though participants were unsure of current status, current activity needs confirmation); create a tree ordinance that has teeth and can incentivize protecting and planting of trees. (Participants noted that EPB, the City, and Reflection Riding launched a re-imagined Free Tree program at the end of October, as an example. Trees Atlanta and Root Nashville were mentioned as models to look at for more examples.)

Lead: Urban Century Institute

Partners: Neighborhood groups, Interfaith Power and Light as liaison to church groups, EPB, City, Reflection Riding, City Forester, GreenSpaces Build It Green program.

***Resources and barriers*:** Funds to pay for planning does exist through the Urban Century Institute, and more sources could be identified; staff capacity is a barrier,

e.g., the City Forester is only one person; political barrier of developer community that may be in opposition; lack of knowledge of how to correctly plant trees is also a barrier.

***Efficacy*:** High

***Feasibility*:** High

4. Getting the public involved in community science, including inventories, bio blitzes (e.g., privet project at Reflection Riding, umbrella project through Thrive).

***How to implement*:** Integrate community science into the middle school science curriculum in county school districts. This work sets a baseline to monitor change over time. Ensure that in developing programs, we are incorporating early detection- rapid response (EDRR) possibilities and making observations of noticeable changes/climate-related changes. An extant project monitors heat island effect—could we expand its reach by tying data collection to a bike share program that collects during bike use?

Lead: Reflection Riding, TN Aquarium

Partners: Bike Share Chattanooga for adding sensors to track urban heat data; informal Chattanooga educators (zoo, arboretum).

***Resources and barriers*:** National Science Fund funding for informal educators.

***Efficacy*:** Unknown

***Feasibility*:** High

5. Get watershed management plans completed to address 303(d) list and include planning for climate impacts.

***How to implement*:** There is a need to first understand where the existing plans are in the development process and understand where the gaps exist. Need to identify individuals or an institution to evaluate whether the existing plans address climate issues. Conduct education and outreach around water quality impairment and bring a broader awareness of the issues. There is an existing urban water scorecard—could this possibly incorporate climate vulnerabilities and climate readiness? Such a scorecard could build political capital. Examples suggested by participants include TN urban waters report: https://users.tnurbanwaters.org and an example from Chesapeake Bay: https://ecoreportcard.org.

Lead: Waterways, Thrive, TN Department of Environment and Conservation

Partners: TN Tech, TN American Water, Southeast TN Development District, Limestone Valley Resource Conservation District, City of Chattanooga Water Quality Program, TN Aquarium, TN Basin Network as an example

***Resources and barriers*:** The Natural Resources Conservation Service has available grant funding; TN Water Resources Research Center at UT Knoxville has lots of information; TN Aquarium identified as having $10 million for improving water quality and farming. Barriers include a lack of public education and awareness and lack of political capital for addressing the issue.

***Efficacy*:** Moderate (it is a big task!)

***Feasibility*:** Low

Conclusions

This workshop and the resulting report aimed to improve the understanding of how housing, transportation, and natural resources are vulnerable to changing climate conditions in Chattanooga. This report summarizes possible adaptation strategies that were identified and discussed by the breakout groups as well as adaptation implementation plans designed to minimize vulnerabilities and/or increase resilience of the focus areas.

Similarities were found across focus areas in terms of pre-existing conditions and climate stressors, and the combined impacts of these effects emerged across focus areas, including the following:

- *Pre-existing conditions* – Population growth and resulting pressures on infrastructure and resources; aging and inadequacy of infrastructure and buildings, including roads, wastewater treatment, and affordable housing; and inequity of access to resources and services, were among themes discussed in multiple focus areas.
- *Climate stressors* – Extreme weather, including extreme precipitation and flooding, increasing temperatures, and drought and wildfire risk were all identified as major climate impacts for discussion by all three groups.

Combined impacts of pre-existing conditions and climate stressors listed above were also identified across breakout groups as impacts of greatest concern, including the following:

- Loss of tree canopy due to multiple climate impacts is exacerbating heat island effects and is disproportionately impacting communities that are already vulnerable and less resilient to these impacts.
- Increasing population growth is intersecting with climate changes, including extreme heat and extreme weather, to create additional issues of loss and inadequate capacity of affordable housing, contributing to increased homelessness, increased pressure on transportation systems, increasing pressure on the provision of safe recreation and natural resources, and increasing migration from areas farther south that may be even more impacted by climate change.
- Inadequacies in infrastructure, including roadways, freight mobility, wastewater treatment, provisioning of drinking water and other utilities, and non-motorized

and electrified transportation are exacerbated by all the climate change stressors discussed.

The similarities in impacts of greatest concern also resulted in overlapping and intersecting adaptation strategies, such as:

- Private-public partnerships to bring more resources to bear to a wide variety of adaptation solutions, including water quality improvement; increased tree canopy cover, particularly in communities lacking these resources; increased availability of high-quality affordable housing; development of resilience hubs and emergency response resources; community science efforts; and improved coordination and management of transportation infrastructure.
- Public education and outreach to increase public awareness and support for adaptation efforts and to build capacity for adaptation actions (e.g., education on climate-smart and drought-resistant trees and tree planting skill development for youth and other community members; working with nurseries to reduce the sale of invasive plants and plants treated with pesticides; building capacity via job training and programs like Civilian Climate Corps to build sustainable, affordable housing).
- Leveraging existing resources to support adaptation (e.g., significant community research and advocacy for EV adoption, Inflation Reduction Act funding that will be coming for clean energy and urban forestry efforts, and an already extant and robust outdoor and ecotourism community).
- Updating codes and zoning to better address risks and capacity of sectors, including wastewater treatment, housing energy efficiency standards, urban tree canopy management, regional transportation planning, and watershed management plans.

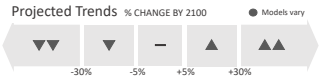
This report can be used as a reference for decision-makers in Chattanooga as they plan for and commit resources to create a more sustainable and resilient community. The adaptation strategies that participants have identified during this workshop can advance resiliency and may present opportunities to leverage resources across multiple focus areas. Because climate adaptation is an iterative process and new research and modeling on projected climate changes and impacts are regularly released, it is important to revisit and/or revise the vulnerability assessments and adaptation strategies on a regular basis (e.g., every 5 to 10 years), as well as when additional topics of concern become priorities.

Appendix A. Workshop Participants and Breakout Group Assignments

Participant Name	Affiliation	Breakout Group
Abigayle Dylag	TN American Water Company - Analyst	Housing
Anna Mathis	City of Chattanooga- Natural Resources	Natural Resources
Bruz Clark	Lyndhurst Foundation - President	Transportation
Dan Reuter	City of Chattanooga – RPA Planning	Housing
Dr. Dawn Ford	UT Chattanooga - Professor	Housing
Elizabeth Hammitt	EPB - Director	Housing
Eric Myers	Chattanooga Design Studio – Executive Director	Housing
Erik Schmidt	City of Chattanooga – Director of Sustainability	Transportation
Holly Odell	Lookout Mountain Conservancy – Community Engagement Coordinator	Natural Resources
Jack McAfee	Chattanooga Metropolitan Airport Authority – VP Operations	Transportation
Jed Henderson	Chattanooga Housing Authority- Operations Analyst	Housing
John Bilderback	Thrive Regional Partnership – Program Director, Natural Treasures	Natural Resources
Julia Poland	National Park Service – Acting Chief of Resource Management	Natural Resources
Mark McKnight	Reflection Riding Arboretum and Nature Center – President	Natural Resources
Matthew Taylor	Tennessee Department of Environment and Conservation – Deputy Director	Natural Resources
Meghan Ploch	TN Department of Environment and Conservation- Director of External Affairs	Natural Resources
Melissa Taylor	Chattanooga Department of Planning – Director of Long-range planning	Transportation
Michael Walton	GreenSpaces – Executive Director	Housing

Noel Durant	Trust for Public Land- State Director	Natural Resources
Rick Huffines	Tennessee River Gorge Trust – Executive Director	Natural Resources
Sandra Gober	City of Chattanooga – Manager	Housing
Sandy Kurtz	Urban Century Institute – Educator	Natural Resources
Savannah Robertson	East Tennessee Clean Fuels – Drive Electric TN Coordinator	Transportation
Shannon Milsap	Thrive Regional Partnership	Transportation
Simon Key	EPB	Housing

Appendix B. Climate Changes and Impacts Table for Chattanooga



CLIMATE CHANGES	METRIC	TREND	OBSERVED/PROJECTED CHANGES
Air temperature	Minimum temperature AVG DAILY MIN TEMP (°F)	▲	51.4°F (+3.9°F) by 2050 and 56.4°F (+8.9°F) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 47.5°F FROM 1961–1990
	Maximum temperature AVG DAILY MAX TEMP (°F)	▲	74.3°F (+4.3°F) by 2050 and 79.5°F (+9.5°F) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 70.0°F FROM 1961–1990
	Frost days DAYS WITH MIN TEMP < 32°F	▼▼	59.1 days (–21%) by 2050 and 39.2 days (–48%) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 75.1 DAYS FROM 1961–1990
Extreme heat	Days over 95°F # OF DAYS WITH MAX TEMPS >95°F	▲▲	34.8 days (+470%) by 2050 and 84.3 days (+1,281%) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 6.1 DAYS PER YEAR FROM 1961–1990
Precipitation	Annual precipitation AVG INCHES PER YEAR	▲	60.0 in (+5.4%) by 2050 and 61.9 in (+8.8%) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 56.9 INCHES PER YEAR FROM 1961–1990
	Seasonality	▲▼	Slight increase in spring (+7%) and fall (+6%) precipitation, with little to no change in winter or summer rainfall[2]
Extreme precipitation	Frequency # OF DAYS WITH 2" RAIN IN 24 HOURS	▲	2.3 days (+9.5%) by 2050 and 2.8 days (+33.3%) by 2100[1] COMPARED TO HISTORICAL AVERAGE OF 2.1 DAYS PER YEAR FROM 1961–1990
	Amount 20-YEAR RETURN PERIOD TOTAL	▲	+12% increase in precipitation amount during 20-year events projected by 2050 and 21% by 2100[3]
Storms & flooding	Frequency & severity	▲▲	Likely increase in occurrence of severe thunderstorms, including tornadoes[4] Increases in flood frequency, severity, and area vulnerable to flooding[5,6]
Drought	Frequency & severity	▲	Likely increases in drought frequency and severity due to longer periods without rain and increased temperatures that enhance evapotranspiration[7,8]
Wildfire	Fire potential	▲	Increased fire potential in the summer and fall due to drier conditions[7,8]
	Season length TIME W/ HIGH OR EXTREME FIRE POTENTIAL	▲	Increased length of the fire season from 1 month to 2 months by 2070[7]

[1] U.S. Climate Resilience Toolkit Climate Explorer (https://crt-climate-explorer.nemac.org), county-scale projections generated using the high-emissions (RCP 8.5) scenario for the average of 2040–2049 and 2090–2099 time periods compared to historical conditions (average of 1961–1990).
[2] J.R. Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey (https://doi.org/10.5066/F7W9575T), county-scale projections generated using the high-emissions (RCP 8.5) scenario for late-century (average of 2075–2099) time periods compared to recent conditions (average of 1981–2010).
[3] D. R. Easterling et al., in Climate Science Special Report: Fourth National Climate Assessment, Volume I, D. J. Wuebbles et al., Eds. (U.S. Global Change Research Program, Washington, DC, 2017; https://science2017.globalchange.gov/chapter/7/), pp. 207–230.
[4] N. S. Diffenbaugh, M. Scherer, R. J. Trapp, PNAS. 110, 16361–16366 (2013).
[5] P. D. Bates et al., Water Resources Research, 57, e2020WR028673 (2021).
[6] O. E. J. Wing et al., Nat. Clim. Chang. 12, 156–162 (2022).
[7] Y. Liu, S. L. Goodrick, J. A. Stanturf, *Forest Ecology and Management*. 294, 120–135 (2013).
[8] R. J. Mitchell *et al.*, *Forest Ecology and Management*. 327, 316–326 (2014).