Triangle Regional Resilience Partnership
Resilience Assessment

TECHNICAL REPORT

PREPARED FOR THE

TRIANGLE J
COUNCIL OF GOVERNMENTS

OCTOBER 2018

Cover photo sources, clockwise from top:
Town of Cary
Town of Chapel Hill
David Hunt, Orange County
City of Durham
Higgins Spooner, "Downtown Raleigh NC at night" (2018)

Disclaimer

This assessment is an ongoing process; all information contained in this final report is subject to change. The assessment is based on best available information for specific threats and assets at the time the analysis was conducted. Quantitative results presented herein are preliminary and are based on data with inherent uncertainties and generalized assumptions; site-specific evaluations of vulnerability and risk are beyond the scope of this assessment and should be reserved for a detailed evaluation of specific adaptation measures. Values should be interpreted as indicators of relative risk among different areas within the region.

The authors of this report do not offer engineering or safety advice; this report is for informational purposes only and is not meant as a substitute for professional engineering or safety advice. Maps and analysis products contained in this report are for graphical purposes only and do not represent a legal survey. While every effort has been made to ensure that these data are accurate and reliable, the authors do not assume liability for damages caused by any errors or omissions in the data. Users of maps and other analysis products are solely responsible for interpretations and inferences made from these products.

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Acknowledgments

The Triangle Regional Resilience Partnership (TRRP) is a cooperative initiative among Durham County, Orange County, the Town of Cary, the Town of Chapel Hill, the City of Durham, and the City of Raleigh, with administration assistance from the Triangle J Council of Governments (TJCOG). TJCOG administered the project and provided logistical support. UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) provided facilitation, analysis, and technical communication.

The TRRP is grateful for the support of the participants who served on the project's Steering Committee and Core Team, attended meetings, and otherwise contributed to the assessment's development.

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Executive Summary

Resilience is about planning and investing today for a better future.

The Triangle region of North Carolina, like other communities across the United States, faces increasingly severe impacts from weather- and climate-related threats—threats that are expected to become even more frequent and severe in the future. The region is simultaneously dealing with stressors unrelated to climate, such as rapid population growth, continued development, and shifts in economic and demographic trends.

To better prepare for and adapt to these changing realities, the Triangle Regional Resilience Partnership (the TRRP)—in partnership with UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) and the Triangle J Council of Governments—performed a quantified assessment to help regional decision makers understand which assets are most vulnerable to specific threats and provide guidance on potential solutions. This regional assessment provides an initial framework to inform more detailed local plans and investments.

How is the Triangle Region Changing?

The region is experiencing certain trends, primarily:

- Increasing extreme precipitation events that lead to more frequent local flooding
- Increasing temperatures and temperature variability
- Increasing frequency and duration of drought conditions
- Robust population growth leading to an increasing demand for resources and services and increasing social vulnerability

The purpose of the assessment was to examine these and other trends to see how these changes impact our valued assets—such as human health, infrastructure, and agriculture.

How Do These Changes Impact the Triangle Region?

The assessment explores how and where our assets—people, property, services, and infrastructure—are impacted by these changes. There is a trend toward increasing **vulnerability and risk** in these key areas:

- ### Impacts of Flooding on Properties and Road Access

  With an expectation of increased precipitation and continued development comes the reality of increased localized flooding.

  A major or widespread flooding event in the region could result in more than 30,000 properties becoming partially or fully inaccessible to residents and emergency vehicles due to either inundated or damaged roads.

- ### Impacts of Minor Flooding on All Assets

  The threat of minor flooding—flooding events that cause stress to stormwater systems, regardless of the size—arises from extreme or heavy precipitation that could result in runoff and erosion and impacts to surface water quality.

- ### Impacts of Water Shortage on Water Supply

  Changes in the amount and intensity of rainfall can and will affect the quality and quantity of regional water supplies.

- ### Impacts of Extreme Heat on Residents

  Extreme heat can cause negative health impacts, which causes concern for the region's socially vulnerable populations.

- ### Impacts of Wildfire on Residential Properties

  Development in the region has led to many homes being located in the wildland-urban interface, raising their vulnerability and risk to wildfire.

> Socially vulnerable populations in the Triangle region may be disproportionately affected by stressors and impacts.

How Can We Use the Assessment?

The assessment should be considered a starting point—one that focuses on regional solutions and begins the process of building community preparedness. Local governments should use the assessment as a guide for more detailed local planning to promote a more equitable and resilient future. The assessment empowers the region and its people to integrate long-term data analysis into current decision-making processes so that they can make decisions with confidence and take action to build a resilient, climate-ready place to live, work, and thrive.

Using results from the assessment, the TRRP partners developed a number of **options and strategies** to help guide the region as it responds to climate and non-climate stressors while providing an improved quality of life and supporting regional vitality and livability.

The Triangle Regional Resilience Partnership

The TRRP is a cooperative partnership among the Town of Cary, the Town of Chapel Hill, the City of Durham, the City of Raleigh, Durham County, and Orange County. The Steering Committee is composed of the partners' Sustainability Managers, Sustainability Directors, and Resilience Officers. The Triangle J Council of Governments provides administrative assistance.

Community Resilience

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

Many local governments are recognizing the need to build community resilience as they experience (1) rapid growth, and (2) more frequent and/or severe extreme weather events.

> The goal of resilience is more than simply "bouncing back" after an event—the idea is to "bounce forward" to a place where the community will be better able to withstand a future event.

The Resilience Assessment Process

The Triangle Regional Resilience Assessment used a quantified process to identify and respond to both climate threats and non-climate stressors in the region. Using the "Steps to Resilience" framework from the U.S. Climate Resilience Toolkit[1] and guided by NEMAC, the TRRP partners determined key assets in each community, assessed the vulnerability and risks that these assets face, and developed potential strategies to address those vulnerabilities and risks to improve the region's overall resilience.

GIS-based analyses were performed and mapped at the census tract level to assess regional-scale impacts. Not all areas within a census tract will have uniform vulnerability, and localized impacts may vary within any given census tract.

Interactions between climate and non-climate stressors are complex, and the decisions being made are related to growth/ sustainability and to climate. For example, the amount of precipitation that falls (or the lack thereof) is not a threat in and of itself. Extreme precipitation, however, is a climate stressor if enough of it falls in a short time frame and/or in combination with a high level of impervious surface—leading to the threat of flooding. Changing conditions can affect both climate and non-climate stressors, resulting in increased threats and hazards to key community assets.

1 toolkit.climate.gov

The Triangle Region

Shared values and assets are vital to the way of life in this part of North Carolina and contribute to the regional culture of TRRP cities, towns, and counties. Key regional values and assets include:

- A strong, diversified economy;
- A highly educated populace, with excellent higher education institutions;
- Plentiful parks and open space;
- A regional culture of connectivity;
- Resurgent downtown spaces;
- Transit solutions to connect hubs and develop walkable neighborhoods;
- A sustainable environment;
- An abundant surface water supply (in normal conditions);
- A robust tree canopy; and
- Historic and cultural destinations that support quality of life (e.g., culture, entertainment, and dining).

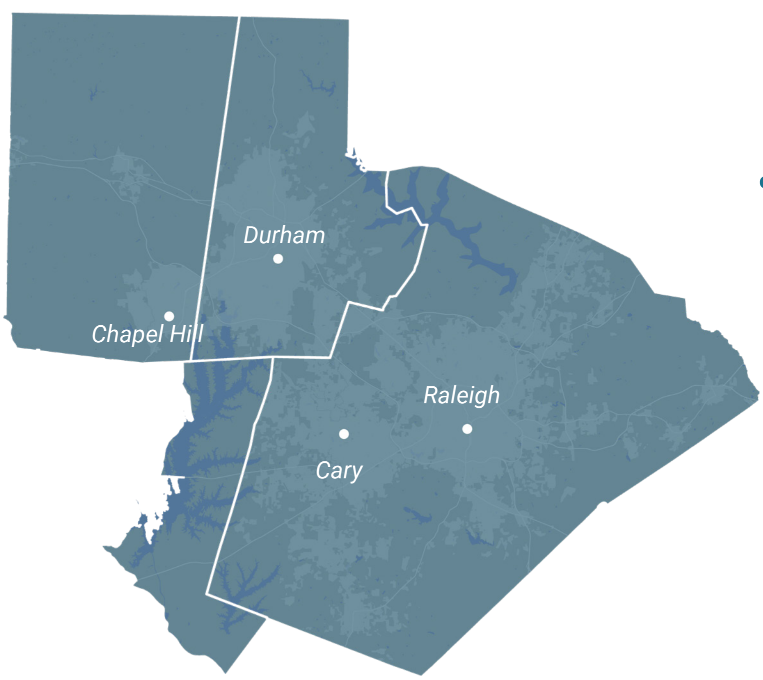
Each community has its own set of values. The assessment does not attempt to reflect each community's values, but rather to show regional variability in order to facilitate regional coordination and collaboration to enhance resilience. Each partner needs to define its own acceptable risk level and make plans to address the risks that affect its community.

• Water

The region boasts a plentiful supply of surface water, but may not have adequate water supply during periods of drought.

• Transportation

The region is a transportation node for the Southeastern U.S., supporting regional as well as local mobility.



• Energy

Increased growth and subsequent demand may stress local energy supplies, which would have an impact on the local economy and quality of life. Higher prices and/or a limited fuel supply would make a car-dominated and air-conditioning-dependent economy vulnerable.

• Food

The region's proximity to the state's largest agricultural area is beneficial for food sustainability and resilience.

• Land Use Patterns

Human changes to urban and rural landscapes that are not adaptive to anticipated risks could exacerbate regional impacts, such as from flooding and wildfire.

Social Vulnerability

Socially vulnerable populations may experience more severe impacts on their health and access to services from extreme weather events.

Climate Stressors

The assessment identifies several climate stressors, primarily:

Increasing extreme precipitation events that lead to more frequent local flooding

Increasing temperatures and temperature variability

Increased frequency and duration of drought conditions

Non-Climate Stressors

Robust population growth leading to an increased demand for resources and services and increasing social vulnerability

The Triangle region has a reputation for a good quality of life, affordable housing, and excellent opportunity for high-paying jobs. This has led to robust population growth: from 1970 to 2016, the Triangle Region's population grew **over 250%**—compared to a national average of **less than 60%**—and growth is projected to continue at this rate.

The desire for newer houses in the suburbs resulted in sprawl, leading to:

- An increased demand for resources and services: water, energy, roads, schools, emergency services.
- Higher than normal average wages and median home prices do not translate across all sectors, leading to greater disparity and increased social vulnerability for some populations.

Vulnerability and Risk

The assessment, based on the national standard risk framework, shows how the people, places, and assets of the Triangle region are affected by climate threats and non-climate stressors.

When considering the vulnerability and risk to people, the assessment focuses on socially vulnerable populations. Impacts to property and infrastructure were considered when focusing on the transportation, water, natural areas, health, and public services sectors.

The results of the analysis show a concerning trend toward increased vulnerability and risk for some assets and threats in the Triangle region.

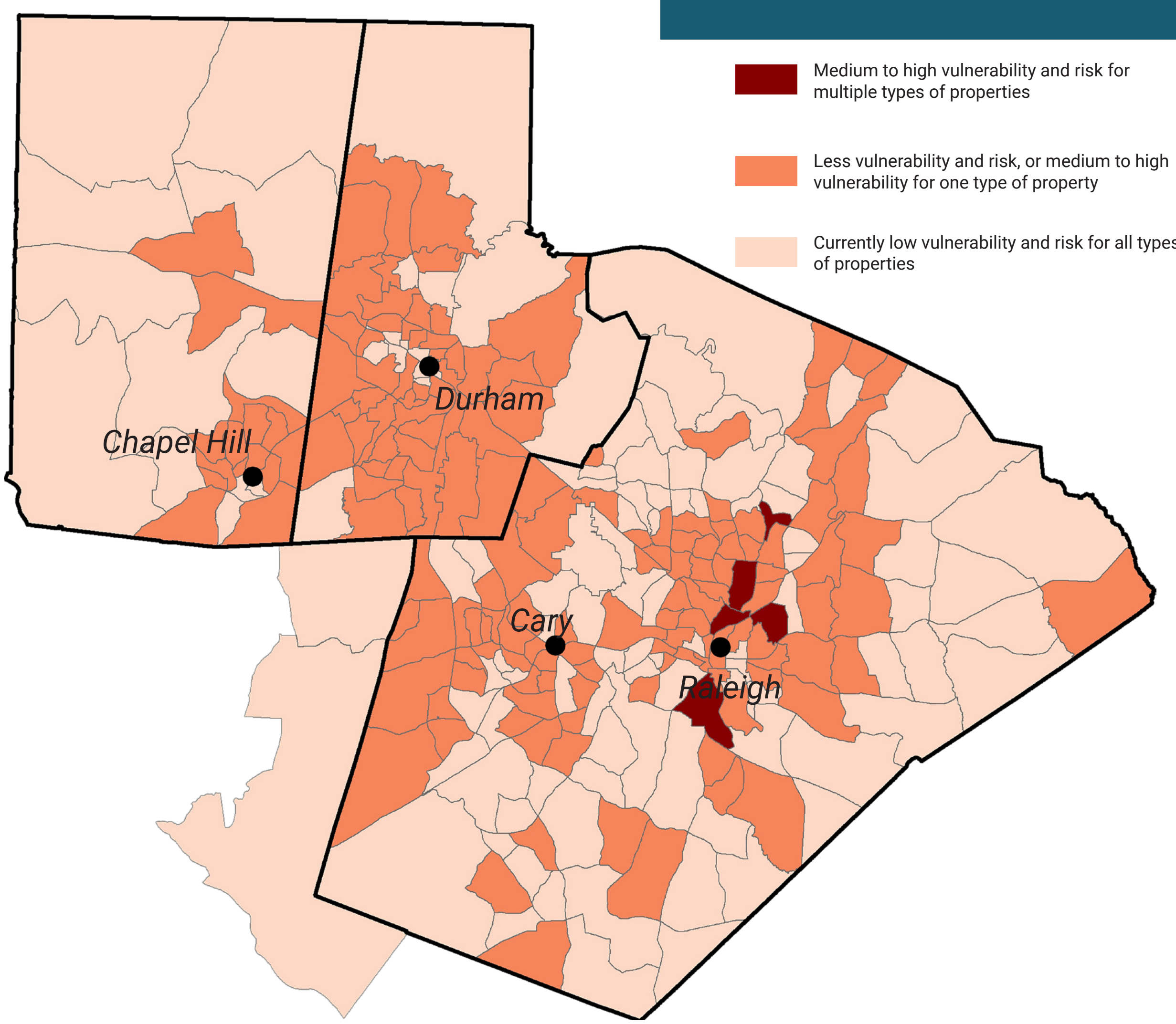
Results from the vulnerability and risk analysis performed as part of the assessment are found below and on the following pages. The analysis results are presented in "asset-threat pairs"—that is, examining the impact of one threat on one asset type—and are aggregated to and displayed at the census tract level. The asset-threat pairs included here are some that posed significant vulnerability and risk and were of high concern to the TRRP partners. They also show the range of regional issues and opportunities included in the assessment.

Please refer to the Technical Report for a full list of analyzed asset-threat pairs, the results of the analysis, and the vulnerability and risk rulesets and criteria used for all asset-threat pairs.

Properties and Flooding

With an expectation of more frequent and intense precipitation events and continued population growth and urbanization comes the reality of increased localized flooding that can affect commercial, industrial, and residential properties.

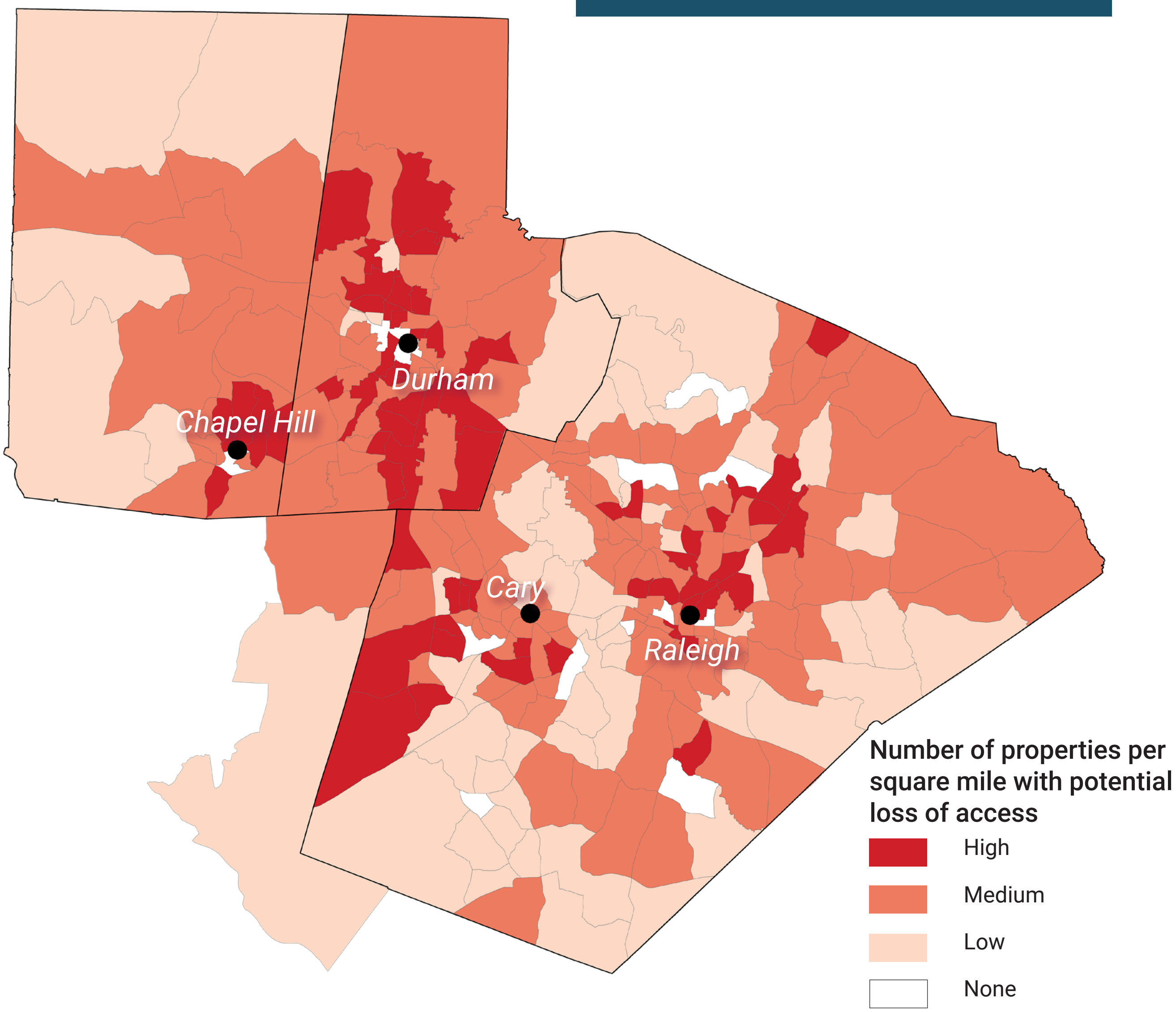
The assessment shows that a large number of commercial, industrial, and residential properties in the region face significant vulnerability and risk due to flooding.

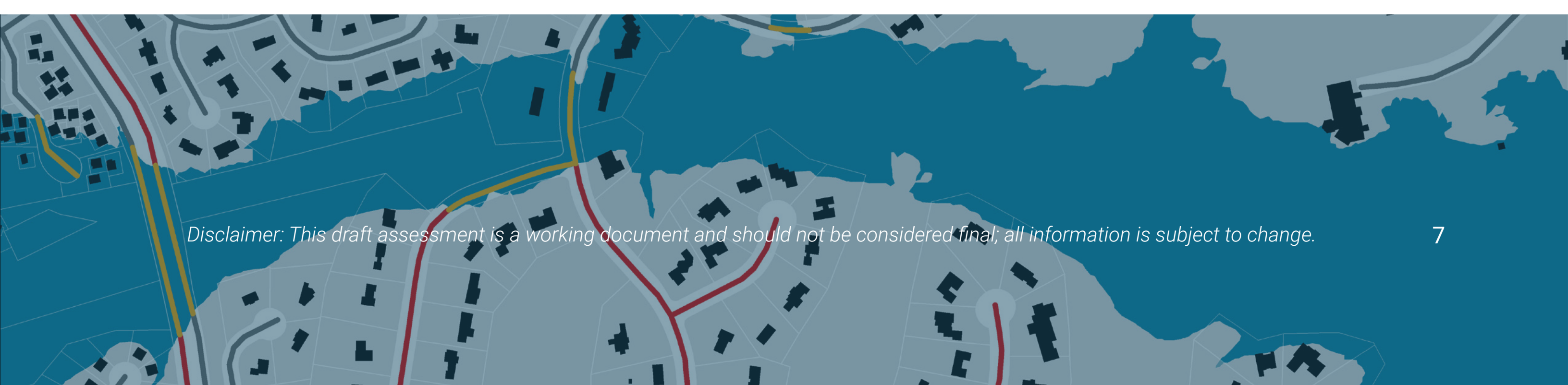


Road Access and Flooding

Beyond day-to-day transportation needs, roads provide vitally important access for safety and emergency services. Many of these are in areas with a single access point. Red areas on the map have the highest estimated number of properties with the potential for loss of access during a flood event.

Depending on the circumstances, a flooding event in the region could result in more than 30,000 properties becoming inaccessible to residents and emergency vehicles due to either inundated or damaged roads.



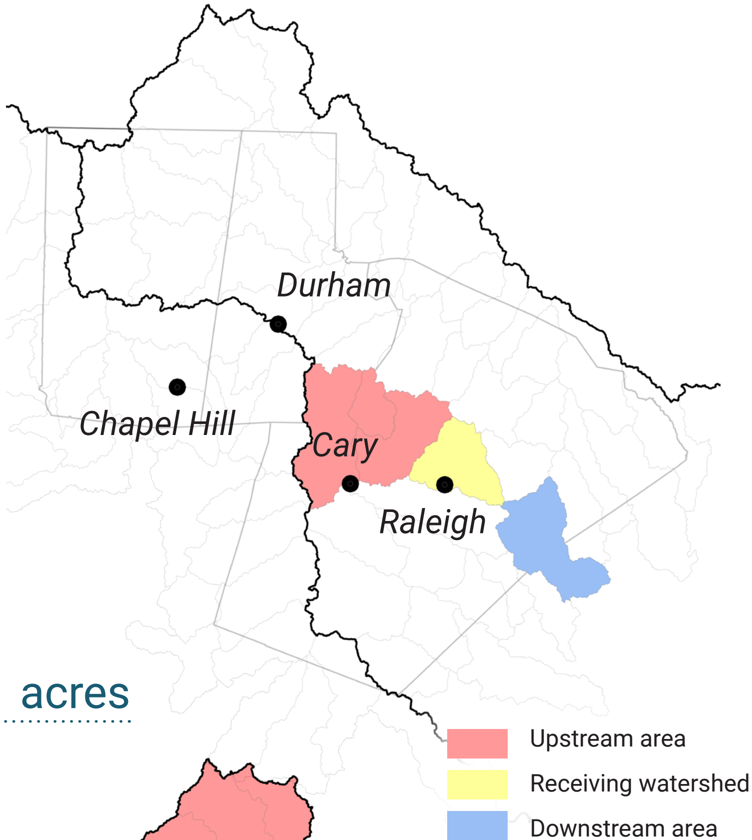


Disclaimer: This draft assessment is a working document and should not be considered final; all information is subject to change.

All Assets and Minor Flooding

Minor flooding events are usually less severe than major flooding, but can still cause significant impacts. Minor flooding is heavily influenced by the amount of developed land cover and impervious surfaces that contribute to runoff.

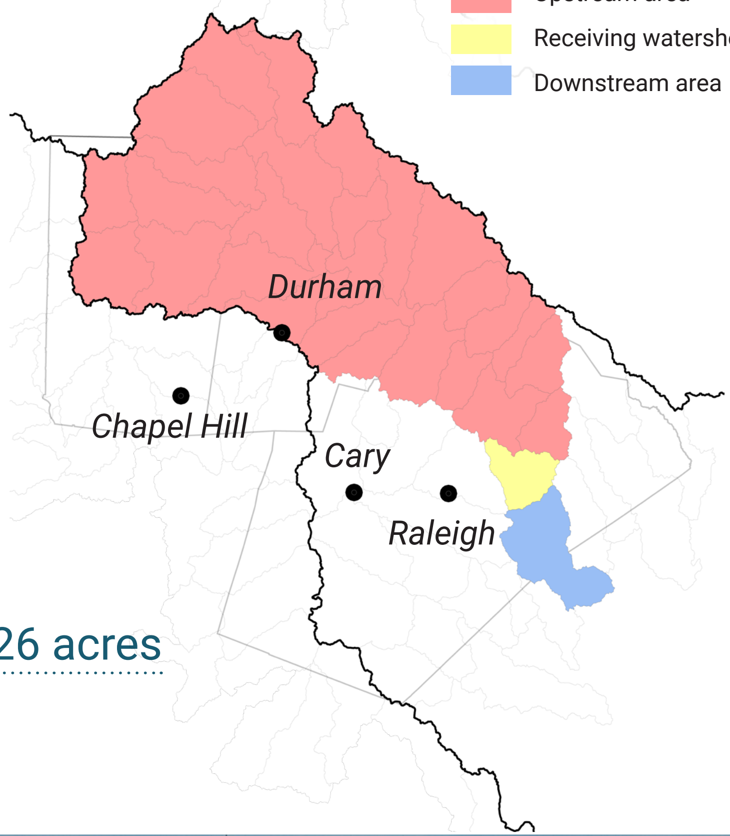
The problems related to minor flooding are regional because of the connectivity of shared watersheds in the region. Compare how east Raleigh/Knightdale and northeast/central Raleigh may be impacted differently due to amount of developed land cover and the size (area) of the watersheds upstream.



NORTHEAST/CENTRAL RALEIGH

Total Upstream Area | 92,971 acres

Total Upstream Developed Land Cover | 35%

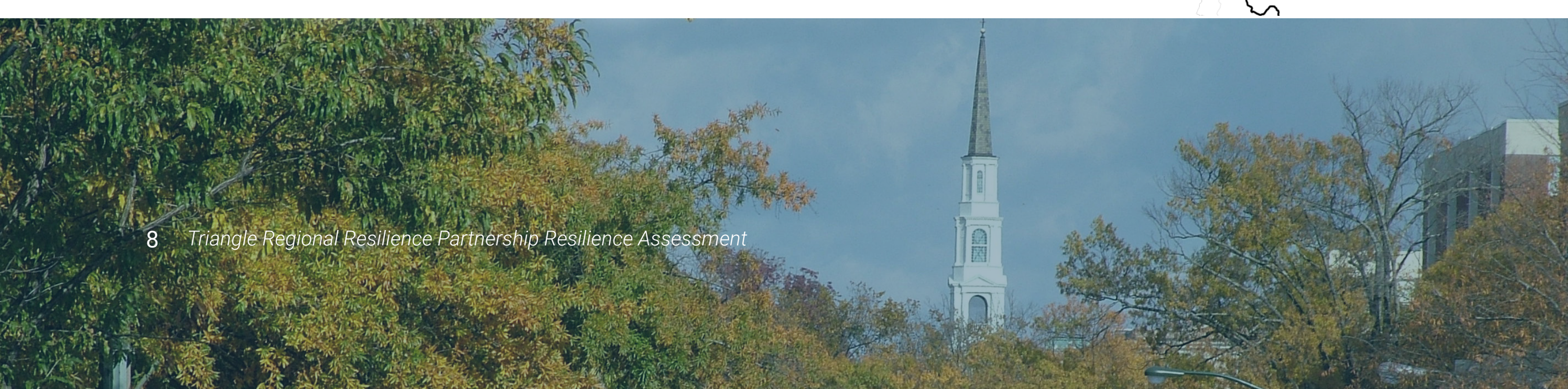


> The threat of minor flooding arises from extreme or heavy precipitation that results in runoff and erosion.

EAST RALEIGH/KNIGHTDALE

Total Upstream Area | 479,926 acres

Total Upstream Developed Land Cover | 7%



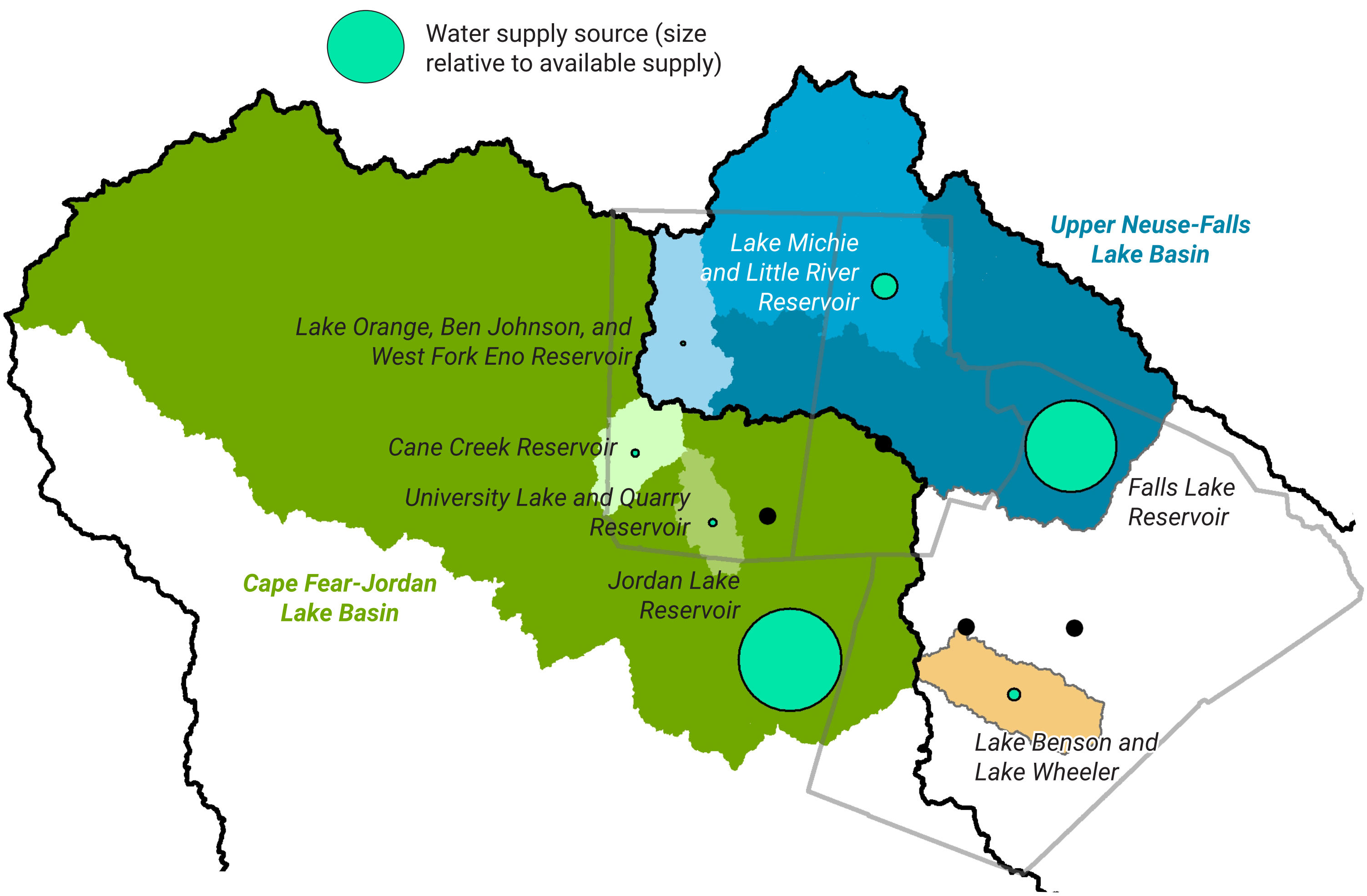
Water Supply and Water Shortage

Non-climate factors—such as increased demand and aging infrastructure—compound climate-related issues, threatening the region's supply of clean, safe water and reliable wastewater services.

As climate and non-climate stressors change, optimizing the use of supplies from different sources while meeting water-quality standards may present new challenges, even for veteran water managers.

The region has a strong history of partnership on water resource issues, such as the Jordan Lake Partnership and other continued efforts. The infrastructure investments and water sharing agreements established through these partnerships will help the region cope with water shortages; continuing the partnerships will help the region become adaptive to meeting water supply needs in the future.

> Changes in the frequency and severity of drought can and will affect the quality and quantity of regional water supplies.

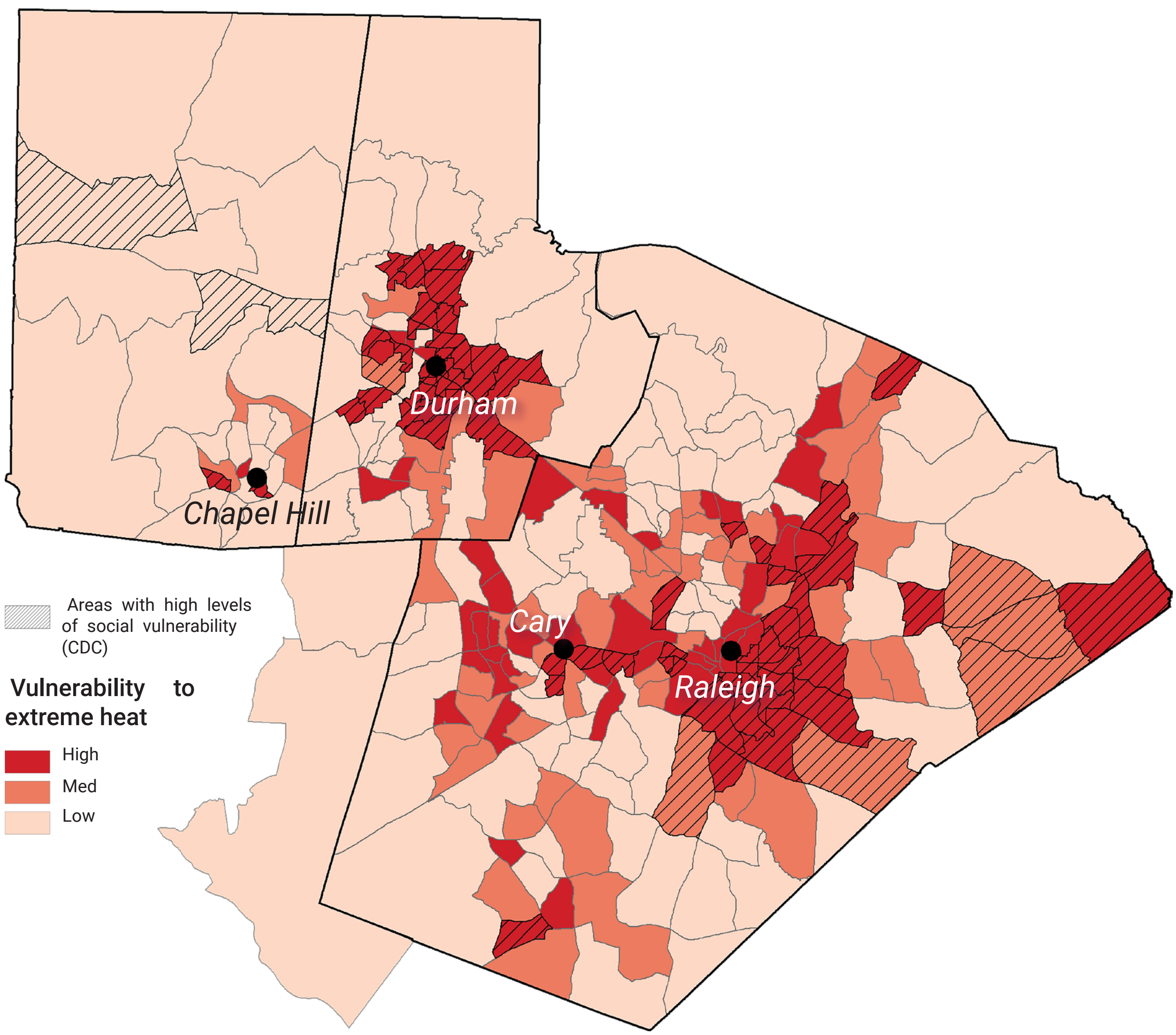


Residents and Extreme Heat

> Extreme heat can cause negative health impacts, which causes concern for the region's socially vulnerable populations.

The Triangle region has a history of extreme heat events, and their number is expected to increase. For example, from 2005 to 2012 the City of Raleigh experienced a higher than normal number of days over 92°F, particularly in 2010—with 48, the most on record.

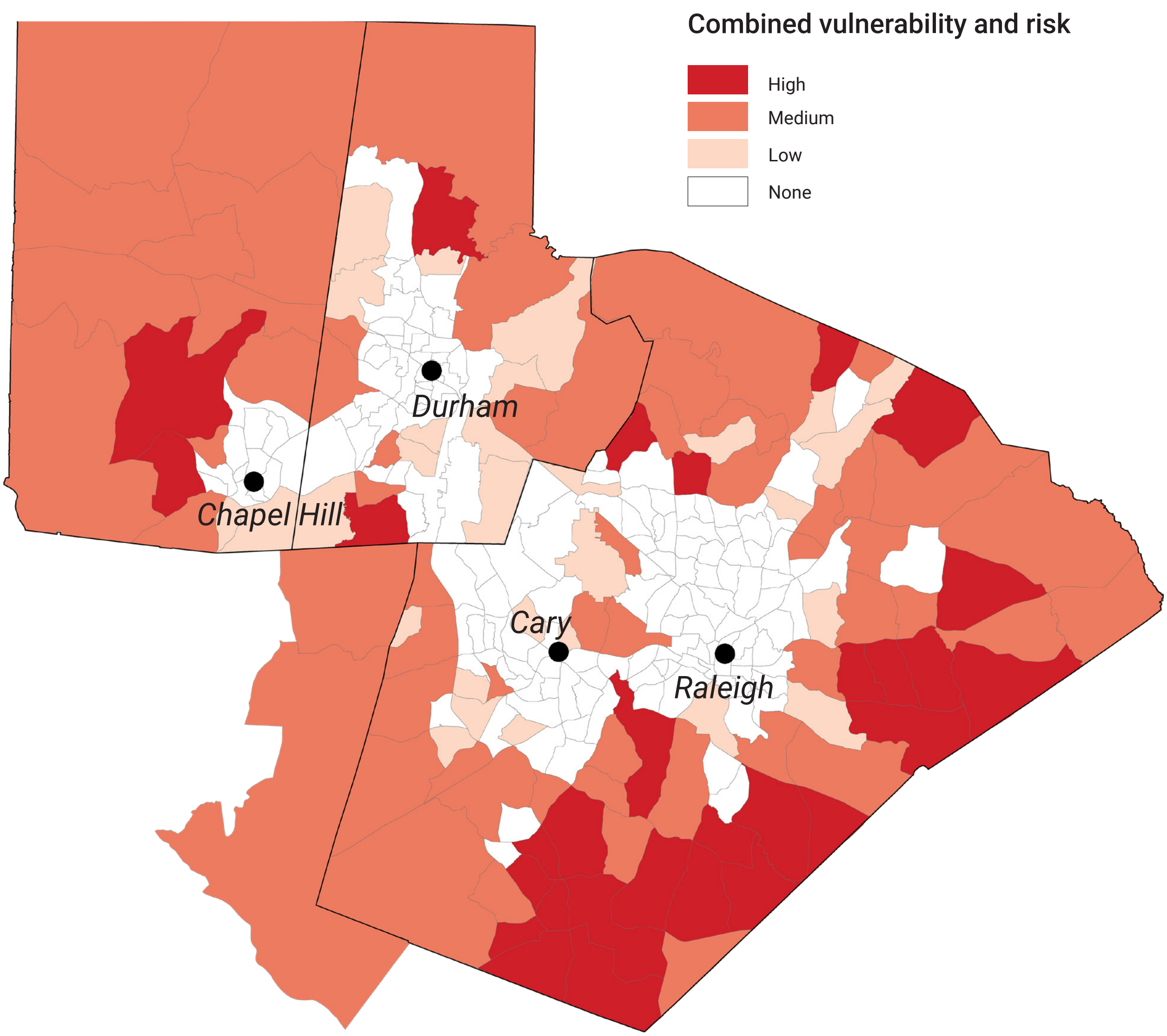
The assessment considers socially vulnerable populations (using the CDC's Social Vulnerability Index, or SVI) who live in proximity to developed land cover. The SVI includes families living below the poverty line, households with disabilities and members who are age 65 and older, and households who have limited English language proficiency, among other metrics. Socially vulnerable populations in areas with a high percentage of developed land cover and low tree canopy are most vulnerable to negative health effects related to heat stress and due to the urban heat island effect.



Residential Properties and Wildfire

Increasing temperatures and drought conditions will contribute to increased wildfire frequency, intensity, and size. In the Triangle region, most of the properties with relatively high wildfire vulnerability and risk are residential.

Over 23,000 residential properties are located in the wildland-urban interface and are outside an eight-minute drive time from their local fire station.



This is not an exhaustive list of the asset-threat pairs analyzed in the assessment. To learn more about impacts to other key assets—such as transportation networks, energy supplies, and food infrastructure—please refer to the Technical Report.

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Strategies to Build Resilience

The assessment is a snapshot in time identifying regional assets that may face increasing vulnerability and risk. If we do nothing, we can expect a future that includes dealing with the consequences of that vulnerability and risk.

As a part of this effort, the partners developed options and strategies that may help guide the region as it responds to both climate threats and non-climate stressors, provide an improved quality of life, and support each community's vitality and livability.

These strategies address the most vulnerable and at-risk assets and the key threats and stressors. Each strategy also addresses vulnerability and risk by either (1) reducing exposure—removing assets from harm's way, (2) increasing adaptive capacity—increasing the asset's ability to cope with impacts, or (3) supporting response and recovery.

They are regional strategies and illustrate the best use of joint planning, action, and communication efforts.

The strategies were evaluated using criteria developed based on lessons learned from other jurisdictions, both here in the U.S. and across the globe, and on principles considered by the TRRP partners to be important to the Triangle region.

EVALUATION CRITERIA

what	Ability to increase regional resilience	Provides co-benefits	Socially responsible	Ability to implement
why	To ensure that vulnerability and risks are addressed at a regional scale	To ensure that options and strategies address multiple problems	To promote fairness, equity, and social responsibility	To determine the feasibility for implementation

The resilience options and strategies will prepare the Triangle region for our changing realities.

The following potential strategies are organized into themes that represent topics of key concern for the region, based on the assessment. Some of these strategies also build on a broad set of efforts that are already underway.

PRIORITIZED OPTIONS AND STRATEGIES

- ### Building greater community capacity
  - Develop a regional outreach and communication plan for all threats
  - Create a communication plan for socially vulnerable populations
  - Determine the use of distributed energy resources to provide backup power to critical facilities
  - Transition public fleets to be less dependent on fossil fuels
  - Establish regional coordination of fire station locations to reduce response time in key areas
- ### Addressing flooding
  - Establish regional evaluation of flooding potential
  - Conduct regional mapping assessment of stormwater conveyances
  - Implement a stream monitoring system that alerts emergency management about rising water levels
  - Create and implement green stormwater infrastructure programs and fee credit programs for stormwater retention
  - Create green infrastructure incentives and/or policies for redevelopment and new development
  - Develop cross-boundary watershed solutions through comprehensive regional collaboration
- ### Addressing extreme heat
  - Establish regional "resilience centers" in partnership with faith-based and other community organizations
  - Establish design standards to reduce heat absorption from roofs
  - Increase the regional tree canopy coverage by implementing urban forestry programs
- ### Addressing water shortage
  - Utilize regional water supply planning for long-term demands
  - Enhance capacity of regional water system interconnects

Going forward, the TRRP will continue to assess the impacts of climate and non-climate stressors, explore regional collaborative approaches to address these impacts, and identify and supplement local actions.

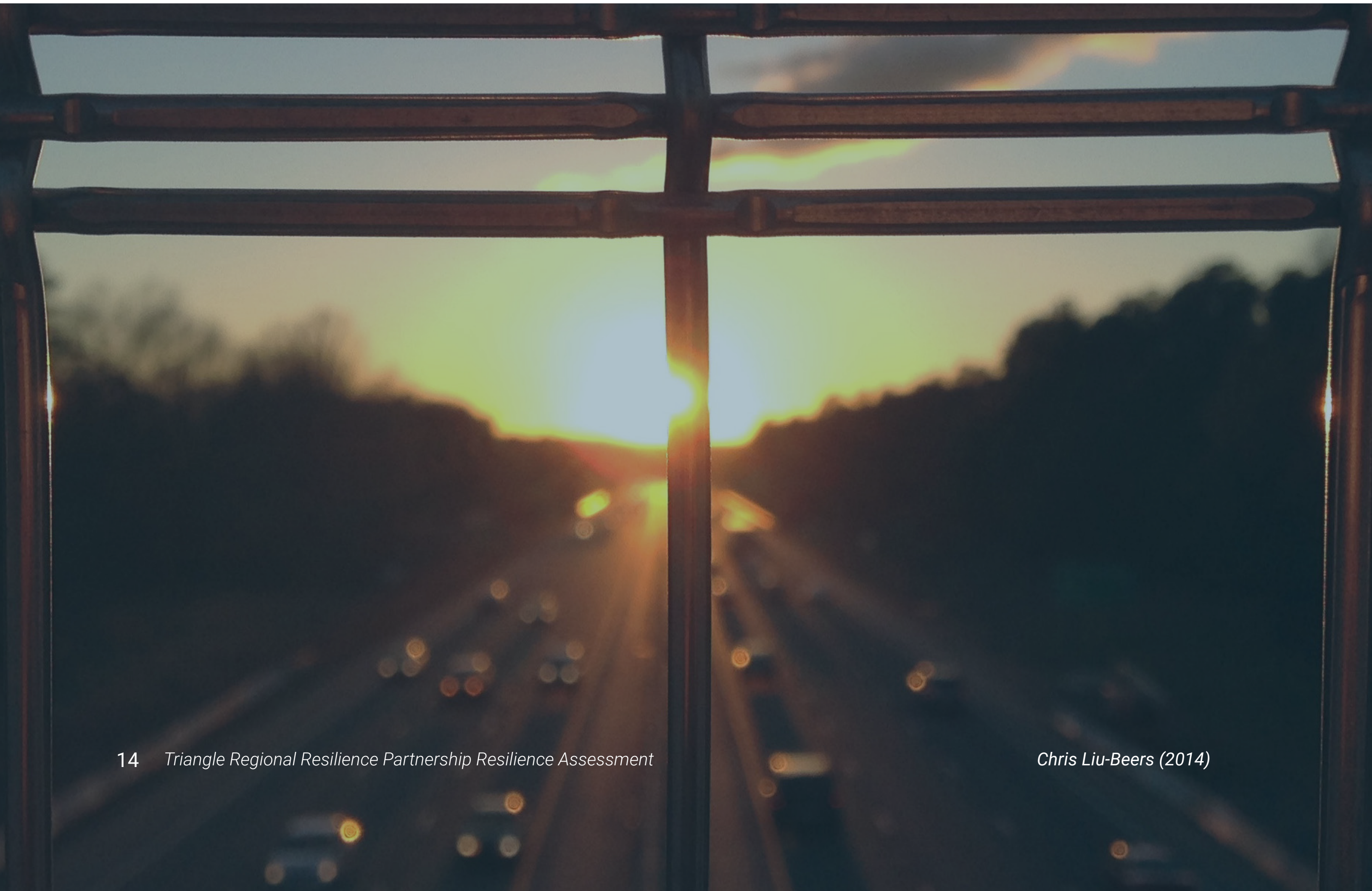
Taking Action

How do we use the assessment to plan for action and build resilience?

The assessment identifies potential options and strategies that may be approached at the regional scale to enhance resilience and provides the basis to inform more detailed local plans and investments. These strategies represent a starting point for planning and implementing local actions to increase resilience.

The assessment itself can be used and integrated into each community's existing hazard mitigation, comprehensive, and emergency management plans to further current local actions.

Individual cities, towns, and counties can also use the assessment to generate and prioritize their own options and strategies to increase resilience at the local level, incorporating the input of all interested stakeholders.



Chris Liu-Beers (2014)

Introduction

Communities across the United States face impacts from more frequent weather and climate-related threats. Since 1980, there have been more than 200 weather- and climate-related disaster events in the United States that have exceeded $1 billion in damages. According to the third National Climate Assessment, the frequency of extreme weather events is increasing, and they are expected to become even more frequent and severe in the future.

To further exacerbate these climate-related impacts, certain regions of the country are facing increased stressors not related to climate—such as population growth, development, and economic and demographic shifts. To better address impacts related to these events and shifting realities, communities are incorporating resilience and adaptation into their municipal planning. Resilience planning considers ways that communities can prepare for climate- and non-climate-related impacts to protect people and community assets and best deliver key services.

To become better prepared as it faces both existing hazards and a changing environment, the Triangle region—including Durham County, Orange County, the Town of Cary, the Town of Chapel Hill, the City of Durham, and the City of Raleigh—formed the Triangle Regional Resilience Partnership (TRRP) to consider threats and hazards with a goal of becoming more resilient to them, and to integrate the results into a regional perspective for future planning purposes.

To this end, these jurisdictions partnered with UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) and the Triangle J Council of Governments (TJCOG) to lead a series of workshops and activities aligned with the "Steps to Resilience" outlined in the U.S. Climate Resilience Toolkit.[1] This phased approach provides communities, municipalities, and organizations with a blueprint for climate resilience planning.

The following project goals were used to guide the TRRP throughout the process:

- Identify relevant climate and non-climate stressors and related hazards and threats and quantify the impact on regional assets;
- Perform a detailed vulnerability and risk assessment based on the national standard risk framework in order to understand the comparative magnitude of impacts;
- Develop options and strategies to address the most critical issues and build resilience;
- Prioritize and list the options that should be implemented to effectively build resilience; and
- Identify key resources and stakeholders to implement the prioritized strategies.

1 toolkit.climate.gov

Project Team

A project team was assembled in June 2017, dubbed the Triangle Region Resilience Partnership (TRRP). The TRRP includes a Steering Committee that represent the six jurisdictions in the region and serves as coordinating staff for the entire process. The Steering Committee was responsible for logistical coordination, information gathering, and participation in planning. A Core Team was also assembled to participate in each of the workshops and provide input to the TRPP. A team from UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) provided facilitation of the assessment process, as well as technical support and scientific analysis. Project team participants are listed below.

PROJECT TEAM: STEERING COMMITTEE

Emily Barrett	Sustainability Manager	Town of Cary
John Richardson	Community Resilience Officer	Town of Chapel Hill
Amanda Drake	Sustainability Specialist	Durham City-County
Tobin Freid	Sustainability Manager	Durham City-County
Megan Anderson	Sustainability Manager	City of Raleigh
Cindy Holmes	Assistant Sustainability Manager	City of Raleigh
Brennan Bouma	Sustainability Coordinator	Orange County
Kirby Saunders	Emergency Management Coordinator	Orange County
Andrea Eilers	Program Manager	Triangle J Council of Governments
Jen Schmitz	Principal Planner	Triangle J Council of Governments

PROJECT TEAM: CORE TEAM

Jeff Adkins	Water Resources Manager	Town of Cary
Emily Barrett	Sustainability Manager	Town of Cary
Leith Britt	IT Platform Developer	Town of Cary
Loren Cone	Assistant Fire Chief	Town of Cary
Shuchi Gupta	Sustainability Analyst	Town of Cary
Will Hartye	Long Range Planner	Town of Cary
Todd Milam	Facilities Planner	Town of Cary
Jan Patterson	Senior Project Manager, Stormwater	Town of Cary
Dave Almond	GIS Analyst	Town of Chapel Hill
Vence Harris	Community Emergency Coordinator	Town of Chapel Hill
Chris Jensen	Senior Engineer	Town of Chapel Hill

Name	Title	Affiliation
John Richardson	Community Resilience Officer	Town of Chapel Hill
Amanda Drake	Sustainability Specialist	Durham City-County
Tobin Freid	Sustainability Manager	Durham City-County
Tasha Johnson	Assistant Director of Public Works	City of Durham
Sydney Miller	Water Resources Planning Manager	City of Durham
Felix Nwoko	Transportation Planning Manager	City of Durham
Leslie O'Connor	Emergency Management Division Chief	Durham City-County
Laura Woods	Senior Planner	Durham City-County
Megan Anderson	Sustainability Manager	City of Raleigh
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Dr. Jarrett Clinton	Public Health	City of Raleigh
Chris Frelke	Parks, Recreation and Cultural Resources Director	City of Raleigh
McKenzie Gentry	Stormwater Manager	City of Raleigh
Nicole Goddard	Sustainability Analyst	City of Raleigh
Cindy Holmes	Assistant Sustainability Manager	City of Raleigh
Kelly Lindsey	Emergency Management Coordinator	City of Raleigh
Valerie Malloy	Director of Community Development	City of Raleigh
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Janice Tyler	Department on Aging Director	Orange County

PROJECT TEAM: UNC ASHEVILLE'S NATIONAL ENVIRONMENTAL MODELING AND ANALYSIS CENTER (NEMAC)

Name	Title
Jim Fox	Director
Karin Rogers	Director of Operations
Matt Hutchins	Environmental Change Project Lead
Nina Hall	Lead Science Editor
Caroline Dougherty	Principal Designer
Dave Michelson	Applied Research Software Designer

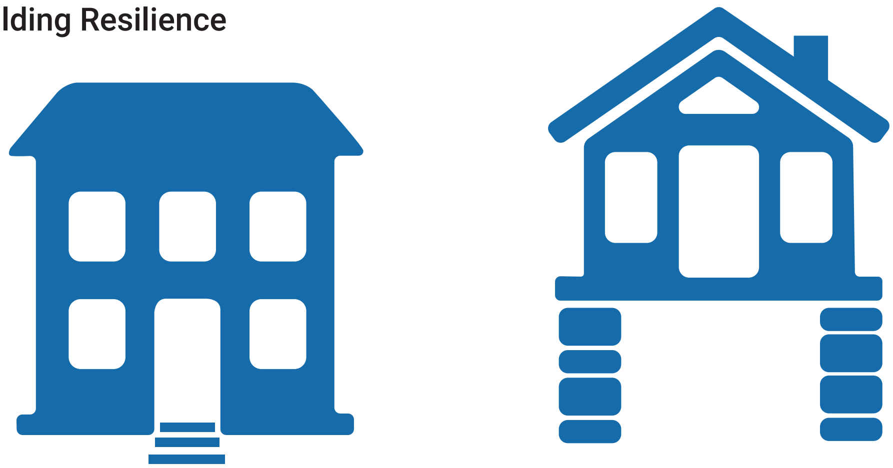
Name	Title
Ian Johnson	Geospatial and Science Communications Associate
Kim Rhodes	Geospatial Associate
Rachel Massa	Community Resilience Intern
Rachel Dunn	Community Narrative Writing Intern

What is Community Resilience?

Resilience is defined as the capacity of a community, business, or natural system to prevent, withstand, respond to, and recover from a disruption.[1],[2] With increasing population, development, and extreme weather events, many local governments in the Southeast and nationwide are recognizing the need to build community resilience (Figure 1).

The goal of resilience should be seen as more than simply "bouncing back" after an event. Instead, the idea is to "bounce forward" to a condition that puts a community in a better place than it was to better withstand a future event. Defining "normal"—a baseline point for resilience—can be difficult and will look different for each jurisdiction and community.

Figure 1. Building Resilience



Resilience focuses on reducing vulnerability and risk. As an example, elevating a structure can build resilience to flood inundation. (Figure source: UNC Asheville's NEMAC.)

The purpose of this assessment is to help the communities in the region identify where they might be most vulnerable and at risk, and allow the TRRP members to strategically identify which options and solutions are most likely to help build resilience.

Many local governments already focus on climate mitigation (reducing greenhouse gas emissions) through "green" initiatives, such as energy conservation. There is an increasing realization by local government, however, of the need to focus on climate resilience and adaptation, with the expectation that some degree of future change is unavoidable. Climate adaptation refers to the efforts taken to cope with and withstand the impacts associated with existing climate-related hazard events or events attributed to climate change.

Building resilience involves considering responses to (1) current climate variability or past hazard events, (2) recently observed changing trends in climate threats and non-climate stressors, and (3) future projected or expected changes in climate threats and non-climate stressors. Adapting to current climate variability makes sense, and can be synergistic with existing and future development priorities—although there could also be conflicts where development might exacerbate climate or non-climate stressors. Such adaptation can also increase resilience to long-term climate change.[3]

Long-term climate change may also require forward-looking investment and planning responses that go beyond short-term responses. For instance, in some cases it could be more cost-effective to implement adaptation measures early on (particularly for infrastructure with long economic life), or current activities might need to be limited if they will irreversibly constrain future adaptation to the impacts of climate change.[3]

Efforts to increase resilience to climate and non-climate impacts are built on the foundation of understanding, and reducing, vulnerability. Vulnerability is a ubiquitous term often used to describe susceptibility to harm. In the context of building climate resilience, a vulnerability assessment is a structured process that identifies ways in which an organization or community is susceptible to harm from existing or potential threats.

Vulnerability assessments tend to have three main components—exposure, potential impact, and adaptive capacity—where both physical and socioeconomic dimensions are considered. An additional key concept used in a resilience assessment is the understanding of risk and risk scoping. Risk involves the likelihood and consequence of a climate threat.

Together, the concepts of vulnerability and risk within a resilience framework can serve to inform the development of strategies to reduce the vulnerability or risk. By taking an integrated viewpoint of these concepts, efforts can focus on building resilience for the assets that are most susceptible and most likely to be impacted. This approach also complements risk-hazard mitigation activities and management practices.

Another important aspect of a resilience assessment is to recognize the iterative nature of the process. Once strategies are implemented, it is necessary to monitor their effectiveness and to regularly reassess vulnerability and risk, and to identify new actions or strategies to continue building resilience as conditions change.

Please consult Appendix A for a glossary containing full definitions and use examples of the terminology used throughout this report.

The TRRP Region

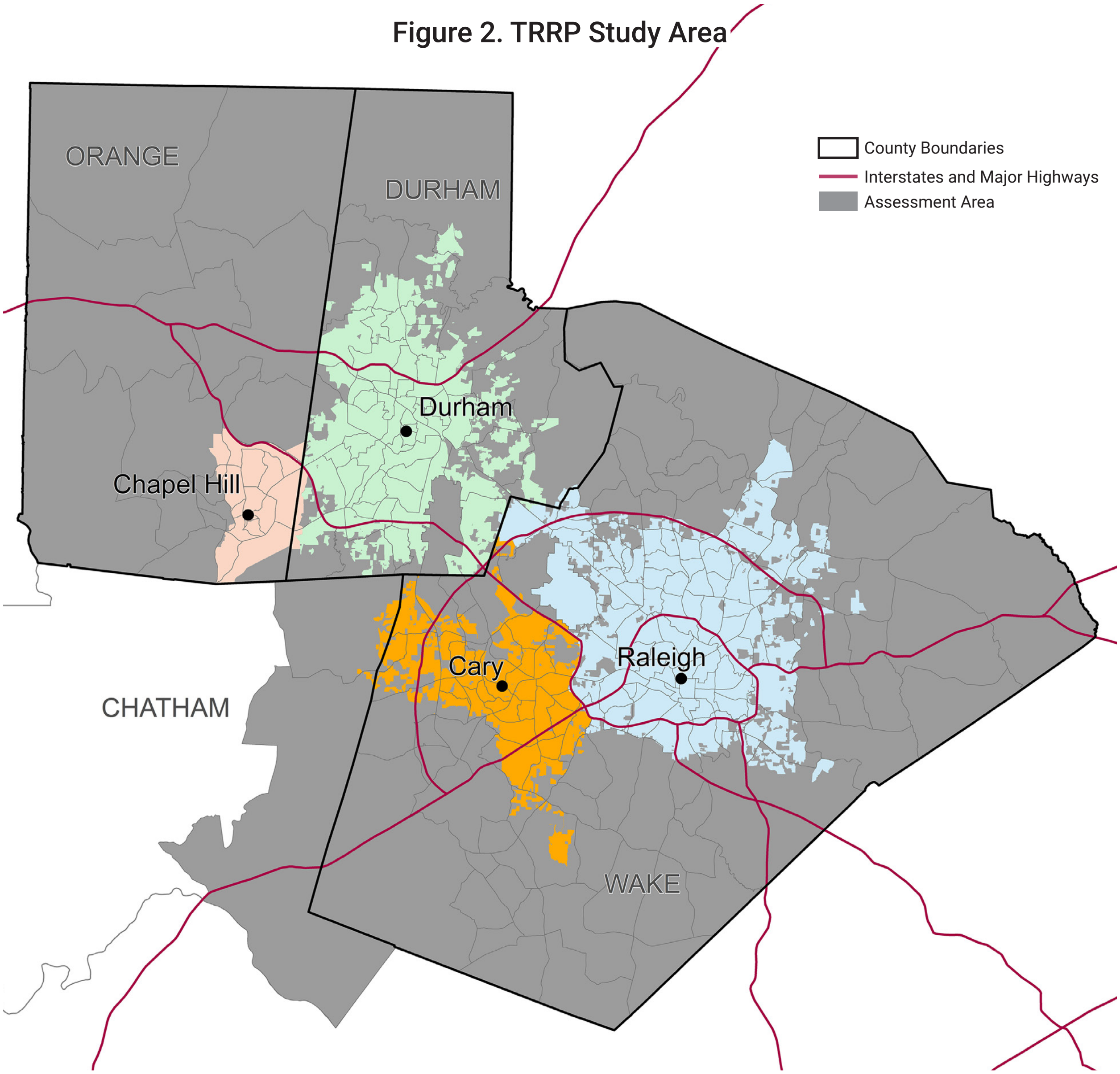
The Triangle region is the economic, governmental, and educational center of the State of North Carolina. Its centrality makes resilience important not only for local jurisdictions, but also for the stability and vibrancy of the entire state.

Located in North Carolina's central Piedmont, in the geographic foothills between the mountains and the coastal plain, the region houses North Carolina state government, several major public and private research universities, state museums, an international airport, major medical centers, and Research Triangle Park—the country's largest research park. Urban areas are buffered by farms and rural areas outside of city centers.

For purposes of the assessment, the study area includes the census tracts containing all of the participating jurisdictions (the Town of Cary, the Town of Chapel Hill, the City of Durham, the City of Raleigh, Durham County, and Orange County) as well as other, non-participating jurisdictions. Thus, the study area includes the entirety of Orange, Durham, and Wake Counties and, because the Town of Cary crosses into a neighboring census tract, a portion of Chatham County. In total, the study area comprises about 1,688 square miles, and as of 2015 had an estimated population of approximately 1.41 million people.[4]

GIS-based analyses were performed and mapped at the census tract level to assess regional-scale impacts. Not all areas within a census tract will have uniform vulnerability, and localized impacts may vary within any given census tract.

Figure 2. TRRP Study Area



From a review of comprehensive plans from throughout the Triangle region, a handful of shared values and assets have emerged as regionally important, consistent, and vital to the way of life in this part of North Carolina. These assets contribute to the regional culture of TRRP cities, towns, and counties, and in turn are highly valued in the resilience assessment. They include, in no particular order:

- A strong, diversified economy;
- A highly educated populace, with excellent higher education institutions;
- Plentiful parks and open space;
- A regional culture of connectivity;
- Resurgent downtown spaces;
- Transit solutions to connect hubs and develop walkable neighborhoods;
- A sustainable environment;
- An abundant surface water supply (in normal conditions);
- A robust tree canopy; and
- Historic and cultural destinations that support quality of life (e.g., culture, entertainment, and dining).

Overview of the "Steps to Resilience"

The U.S. Climate Resilience Toolkit[1] provides an iterative, five-step process for communities to follow when planning for climate resilience. This framework—known as the Steps to Resilience—is used as the foundation of the resilience assessment for the TRRP. The framework integrates the components of climate resilience that can be used in existing jurisdictional planning processes at the local and regional level, and can be used to understand the characteristics of vulnerability and risk in a community, inform policy, and evaluate the effectiveness of strategies that are implemented. These steps are outlined in Figure 3.

Step One: Explore Hazards (Threats). Research and explore regional climate and weather events, trends, and projections to understand how assets (people, infrastructure, services, or resources) may be threatened. This is followed by identifying stressors—both climate and non-climate—that cause or contribute to a threat or hazard event.

Step Two: Assess Vulnerability and Risks. Conduct a vulnerability assessment. The purpose of this step is to understand how a community's assets are likely to be impacted by the threats identified during Step One. This assessment then becomes the foundation for developing options to build resilience in Step Three.

Vulnerability is the susceptibility of societal assets to be impacted by both physical and social factors. To define vulnerability, the assessment examines both potential impact and adaptive capacity. This can be thought of simply as *vulnerability = potential impact – adaptive capacity*.[1,2,5]

> ***Potential impact*** includes evaluating sensitivity, or the degree to which exposed assets are potentially affected.
>
> ***Adaptive capacity*** is the ability to cope with identified impacts with minimal disruption or cost.

Vulnerability is determined by considering both the potential impact and the adaptive capacity, with the most vulnerable having the highest potential impact and the lowest adaptive capacity.

For areas with high vulnerability, it is then necessary to scope the level of risk. Risk depends on both the probability of an event happening and the consequence of that event—that is, what is the chance of a loss?

It is important to note that the scoping of risk at this stage is not the same as undertaking a detailed risk assessment, which can be a time- and cost-intensive process. Instead, risk scoping is an initial broad quantification of risk that can be used to compare general probabilities and consequences of certain threats occurring.

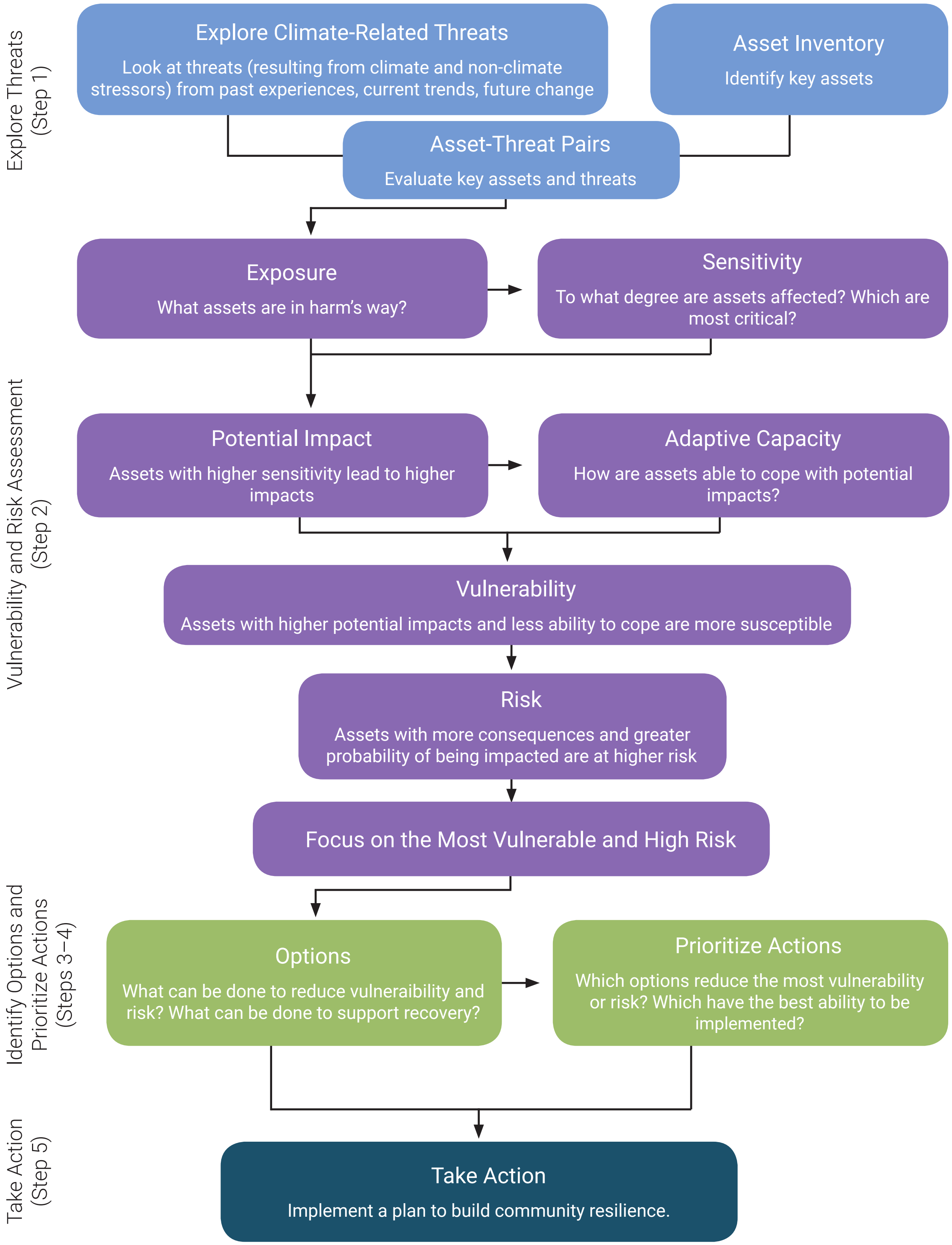
Step Three: Investigate Options. Identify options for resilience. The ultimate goal this step is to have actionable options to build resilience for the assets that are most vulnerable and at-risk. To be actionable, an option should have the potential of building resilience by (1) reducing exposure (removing assets from harm's way), (2) increasing adaptive capacity (increasing the asset's ability to cope with impacts), or (3) supporting response and recovery.

Step Four: Prioritize Actions. Prioritize the options. Prioritization is a two-part process, the first of which involves looking at the actions that will have the most impact. The second part of the prioritization process is to determine criteria on which to rank the options.

Step Five: Take Action. Implement the plan to build community resilience. This step can take years to fully implement, and it is critical for the community to monitor results as time passes—some of the assumptions made during the original analysis may have been faulty, or on-the-ground implementation may not have been completed. This is to be expected, and the community should be open to modifying its approach as needed.

1 toolkit.climate.gov

Figure 3. Steps to Resilience and Supporting Components



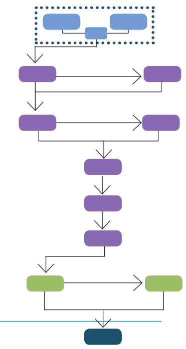
Disclaimer: This draft assessment is a working document and should not be considered final; all information is subject to change.

Acting Today for a More Resilient Future

After the inception of this project, impacts from extreme weather events were felt throughout the United States, particularly keenly by more vulnerable populations. Many communities are still recovering, for example, from the historic flooding in eastern North Carolina after Hurricane Matthew in 2016, in Houston after Hurricane Harvey in 2017, and in North Carolina counties neighboring the Triangle region after Hurricane Florence in 2018. As these communities continue to recover, we see and recognize the importance of preparing for future challenges now, and to focus on how this resilience assessment can be utilized by taking preparatory action.

This assessment should be considered a starting point—one that focuses on regional solutions and begins the process of building community preparedness. Local governments should use this assessment as a guide for more detailed local planning to lead to a more equitable and resilient future.

This assessment empowers the region and its people to integrate long-term data analysis into current decision-making processes so that they can make decisions with confidence and take action to build a resilient, climate-ready place to live, work, and thrive.

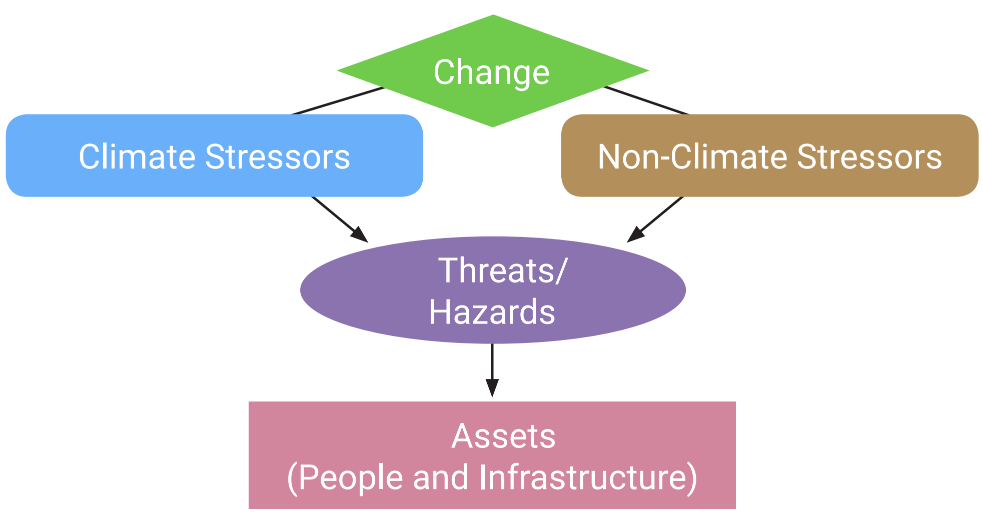


Step One | Explore Threats and Assets

Impacts related to climate threats must be evaluated and measured in a structured way so that communities can understand those impacts to make informed decisions. A conceptual model is one technique that can be used to explore the causal relationships between stressors, threats, and assets that are potentially affected.

The conceptual model framework shown in Figure 4 illustrates the relationships between climate and non-climate stressors, threats and hazards, and assets that may be affected. The arrows in the model reflect the causal influences between these different components. This type of model can also be used to reveal strategies or actions (not shown) that have the potential to reduce vulnerability and build resilience.

Figure 4. Conceptual Model Framework



As shown in the framework, climate threats and hazards are the result of the interaction between climate and non-climate stressors. For example, the amount of precipitation (or lack thereof) in and of itself is not a threat. However, extreme precipitation is a climate stressor if enough precipitation falls in a given time, or in combination with a substantial amount of impervious surface, that can lead to the threat of flooding. Likewise, the lack of precipitation (i.e., drought) is a climate stressor that can lead to the threat of water shortage. Note also that threats and hazard events occur only where assets are potentially negatively affected. If an asset is potentially affected negatively by a threat—if the asset is in harm's way—then it is considered exposed to that threat.

Table 1 shows each climate threat considered for the Triangle region, along with its associated climate and non-climate stressors. Expected future change to stressors that have an influence on climate threats is noted in the last column. All stressors and threats are discussed in more detail in the pages that follow.

TABLE 1. CLIMATE THREATS CONSIDERED FOR THE TRIANGLE REGION

Climate Threat	Climate Stressor	Non-Climate Stressor	Expected Change
Air Pollution	Temperature variability	Socioeconomic vulnerability, sources of air pollutants and emissions	• Potential for increased number of extreme heat days
Change in Growing Season	Temperature variability		• Potential for increased number of extreme heat days • Potential for more mild winters • Reductions in the number of cold days • Increased delays in winter freezing • Earlier spring thaws
Disease	Temperature variability, precipitation variability	Forest cover and impervious surfaces	• Potential for increased number of extreme heat days • Increased development and more impervious surfaces
Extreme Cold	Temperature variability	Socioeconomic vulnerability	• Decreased frequency of cold waves • Increased population and energy use/demand

Climate Threat	Climate Stressor	Non-Climate Stressor	Expected Change
Extreme Heat	Temperature variability	Socioeconomic vulnerability, impervious surfaces and land cover	• Potential for increased number of extreme heat days • Increased development and more impervious surfaces
Flooding	Heavy precipitation, tropical storms	Impervious surfaces, aging/undersized infrastructure	• Increased frequency and severity of extreme precipitation • Increased development and more impervious surfaces
Minor Flooding, Runoff, and Erosion	Heavy precipitation, tropical storms	Impervious surfaces, aging/undersized infrastructure	• Increased frequency and severity of heavy precipitation • Increased development and more impervious surfaces
Snow/Ice Event	Temperature variability, heavy precipitation	Number of vehicles using the roadways	• Potential for more mild winters • Reductions in the number of cold days • Increased delays in winter freezing • Earlier spring thaws
Supply Chain Interruption	Heavy precipitation, tropical storms	Supply use/demand	• Potential for increased frequency of tropical storms • Increased population and energy use/demand
Water Shortage	Drought	Water use/demand	• Increased frequency and severity of drought • Increased population and water use/demand
Wildfire	Temperature variability, drought	Fuels and vegetation, human-caused ignitions	• Increased frequency and severity of drought
Wind	Microbursts, tropical storms, tornadoes		• Increase in the frequency of conditions favorable for severe thunderstorms

Climate Stressors

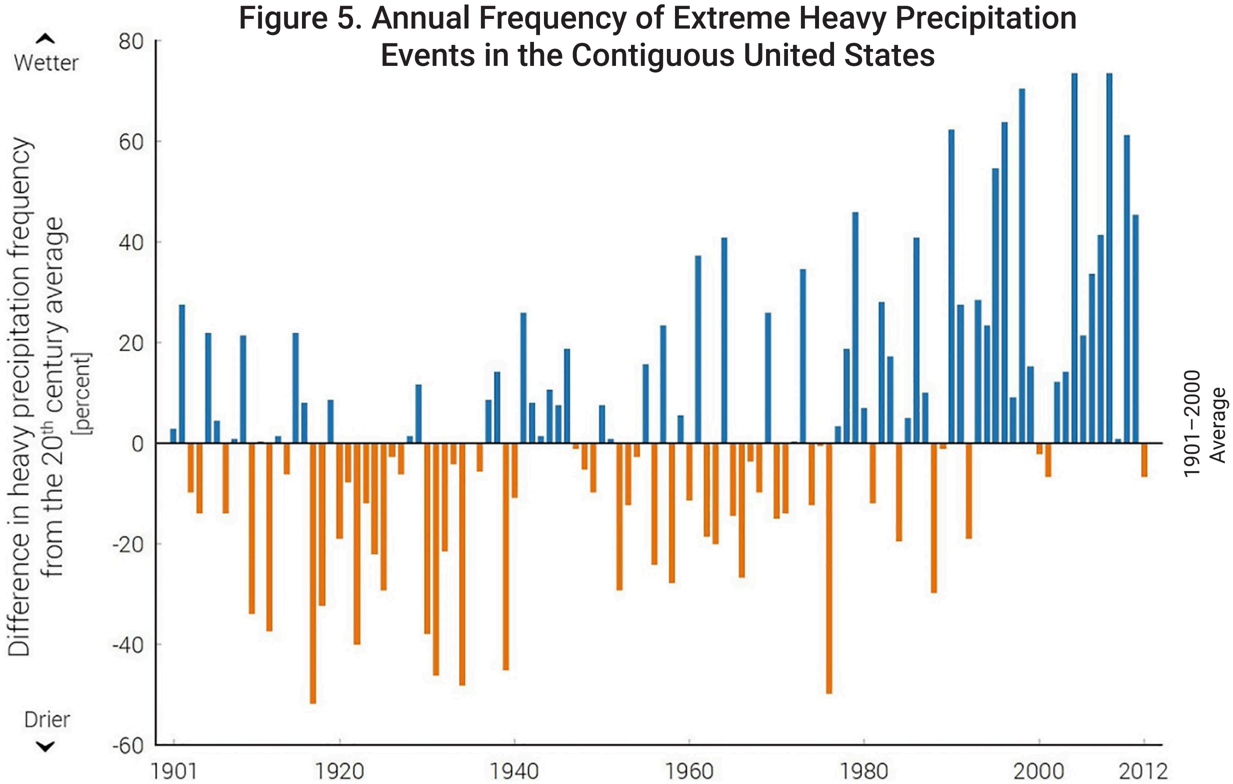
Conditions that exacerbate hazards and promote damage are called stressors, and they come from both the climate and non-climate realms. Climate stressors include events such as consecutive days of temperature and precipitation variability. Non-climate stressors (discussed more fully in the next section), include things such as changes in land cover.

Precipitation Variability

Extreme Precipitation

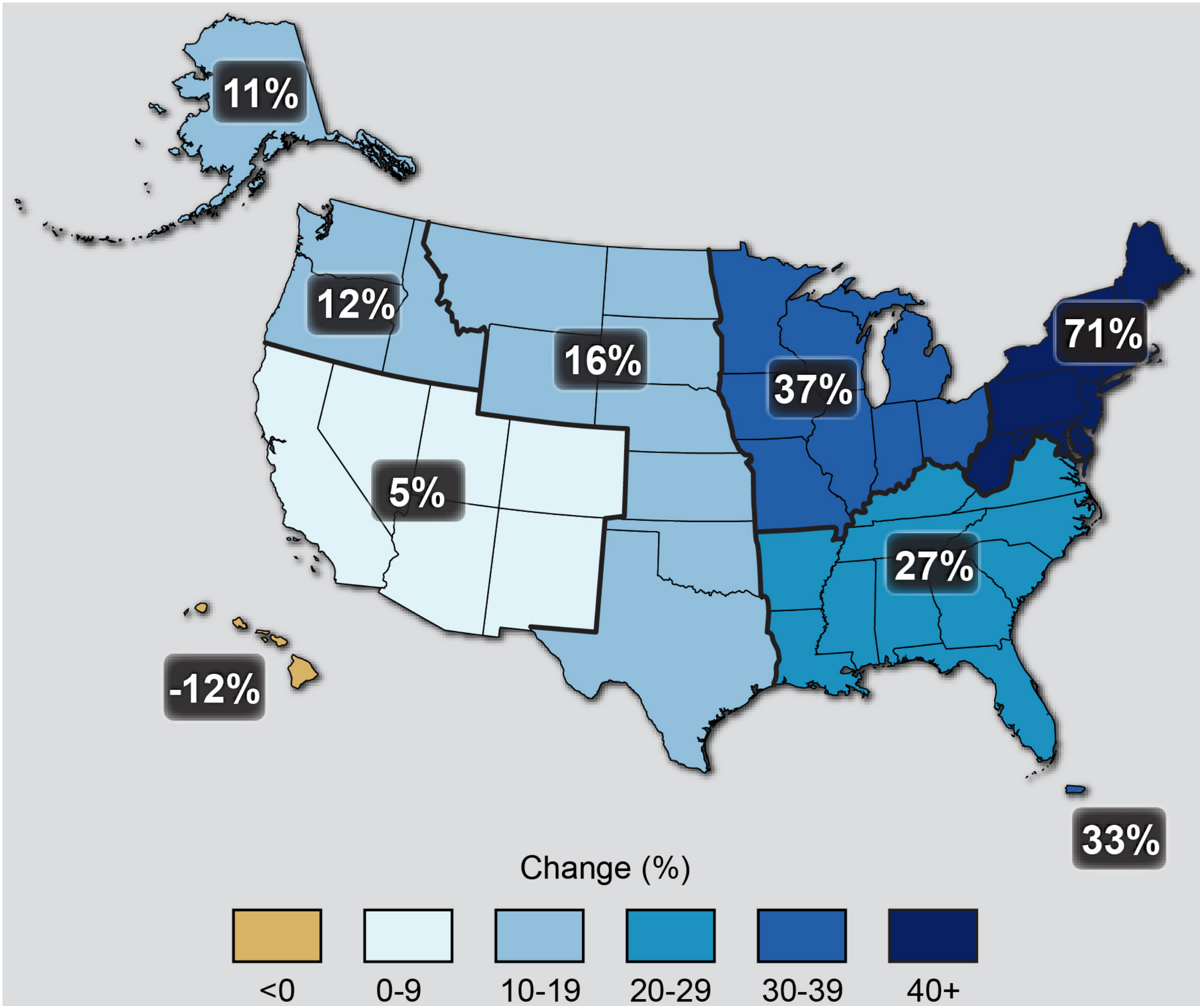
Overall, trends in precipitation are changing not only in the Southeast but nationwide, and contribute to climate threats such as flooding. The frequency of extreme heavy precipitation events (once in a five-year period) in the contiguous United States is increasing compared to the twentieth-century average (Figure 5). According to the Third National Climate Assessment, from 1958 to 2012 the Southeast region experienced a 27 percent increase in the heaviest one percent of precipitation events (Figure 6).[1] The Climate Science Special Report, Volume 1 of the Fourth National Climate Assessment published in 2017, revisited this analysis and found no change in this regional trend.[6] These national and regional trends show the importance of considering how extreme precipitation events impact communities.

Figure 5. Annual Frequency of Extreme Heavy Precipitation Events in the Contiguous United States



Difference in heavy precipitation frequencies from the twentieth-century average for the contiguous United States from 1901 to 2012. Extreme heavy precipitation events are defined as a two-day precipitation total that is exceeded on average only once in a five-year period, also known as a one-in-five-year event. (Figure source: [1], NOAA NCDC/CICS-NC.)

Figure 6. Observed Change in Very Heavy Precipitation

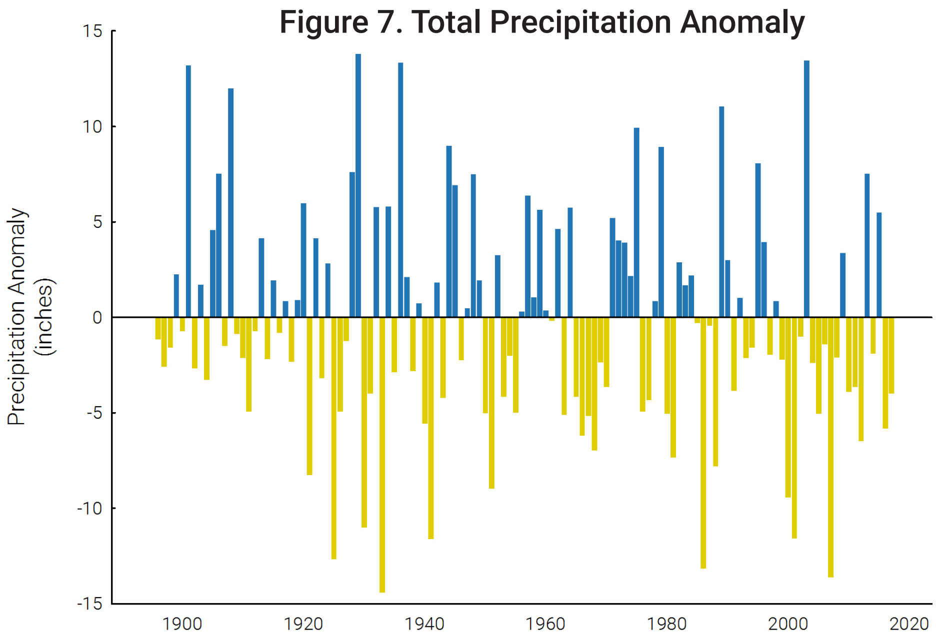


Pecentage increases in the amount of precipitation falling in very heavy events (defined as the heaviest one percent of all daily events) from 1958 to 2012 for each region of the continental United States. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. (Figure source: [1], updated from Karl et al. 2009.)

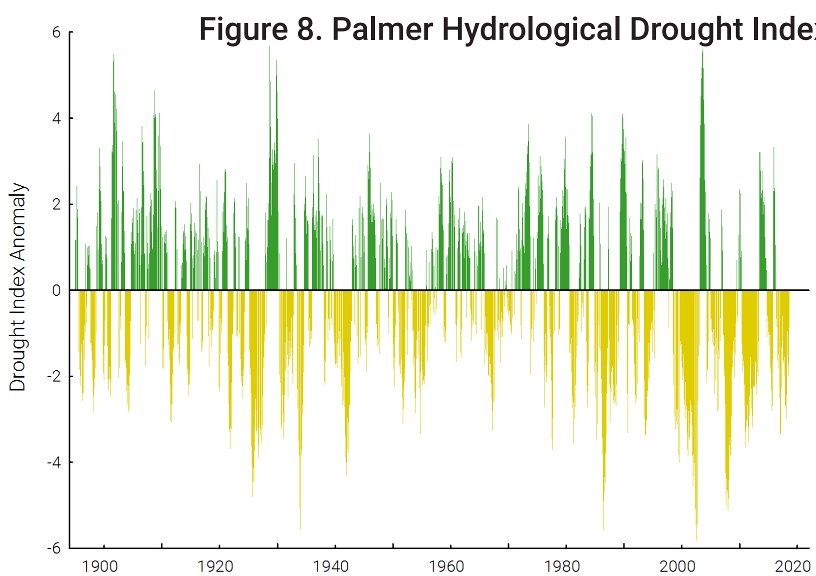
Drought

For central North Carolina, we must also consider the lack of precipitation—drought. Figure 7 shows total annual precipitation anomalies for North Carolina's Central Piedmont Climate Division: since 2000, there have been 14 years of precipitation deficits.

The result is that the Triangle region may experience considerable changes in the frequency and intensity of precipitation events. The trend shows longer and more intense periods of drought interspersed with more intense precipitation events (Figure 8).



Total annual precipitation anomalies for the Central Piedmont Climate Division of North Carolina over the past century. (Figure source: UNC Asheville's NEMAC, October 2018. Data source: NOAA National Centers for Environmental information, Climate at a Glance Divisional Time Series data.)

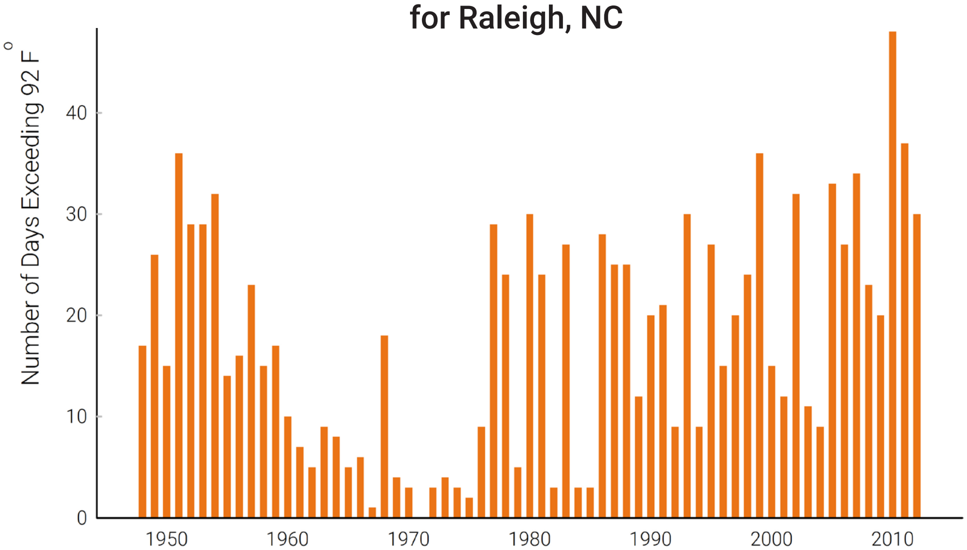


Trends in periods of drought for the Central Piedmont Region of North Carolina from 1895 to mid-2018. The Index uses 0 as normal; yellow bars indicate periods of drought, while green bars indicate wetter periods. The horizontal axis represents time (in years), so wider expanses of yellow indicate longer periods of drought. (Figure source: UNCA's NEMAC; Data source: [1], NOAA National Centers for Environmental information, Climate at a Glance Divisional Time Series data. October 2018.)

Temperature Variability

Another regional climate stressor is temperature variability. The Triangle region has a history of extreme heat events. In Raleigh, for instance, the number of days per year exceeding 92°F (the city's 85th percentile threshold) is increasing with time. From 1948 to 2012, Raleigh had an average of 18 days per year over 92°F. During the period 2005–2012, however, the city experienced a higher than average number of days over 92°F, particularly in 2010—with 48, the most on record (Figure 9).

Figure 9. Maximum Apparent Temperature Exceeding 92˚F for Raleigh, NC

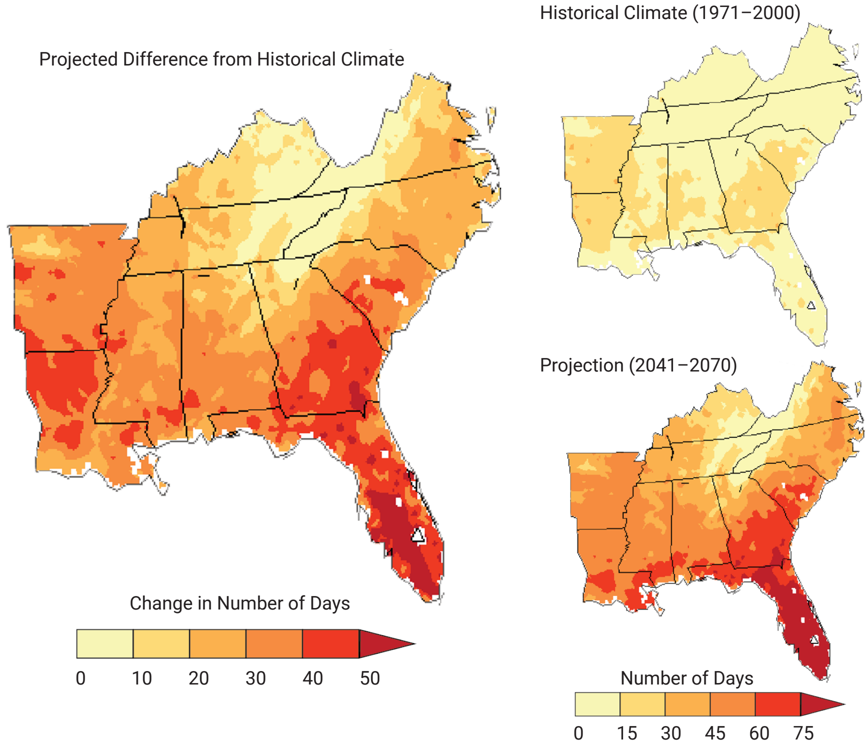


Number of days exceeding 92°F per year for Raleigh from 1948 to 2012. (Figure source: UNC Asheville's NEMAC. Data source: [1], NOAA NCDC/CICS-NC.)

Figure 10 shows the projected increase in the number of days over 95°F for the southeastern United States, as compared to the 1971–2000 historic trend.

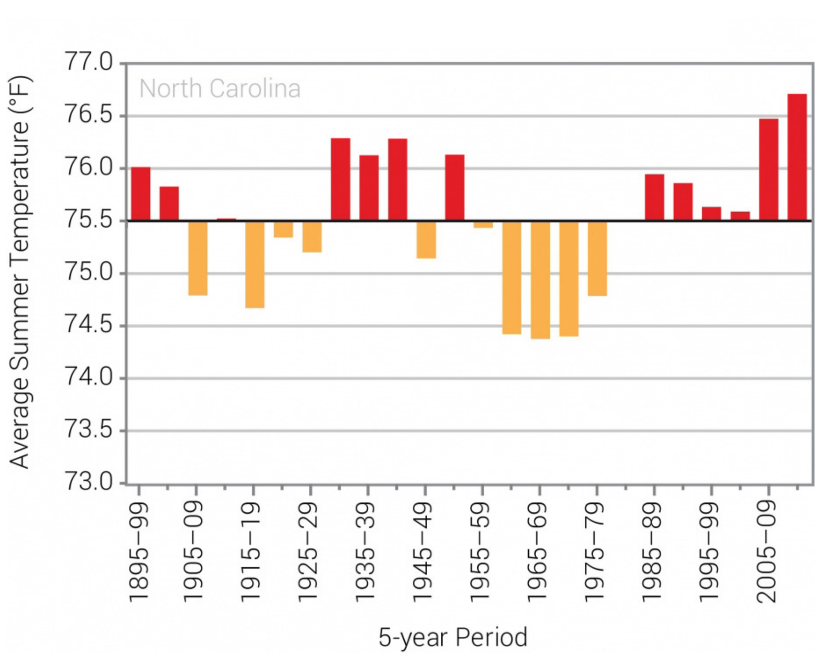
Increasing temperatures and extreme heat events increase energy consumption due to greater use of air conditioning in homes, businesses, and institutional settings, particularly in the summer months.[7] North Carolina has seen an increase in summer temperatures since the 1980s (Figure 11). In the Piedmont region, the number of "cooling degree days" is expected to increase over the next century, relative to the 1970–2010 average, as shown in Figure 12. The number of cooling degree days per year can be used as a proxy for the amount of energy people use to cool buildings. Degree days are calculated using the number of degrees by which the average daily temperature is higher than 65°F. For example, one day with an average temperature of 90°F equals 25 cooling degree days—the same as 25 days with an average temperature of 66°F.

Figure 10. Projected Change in Number of Days Over 95˚F and Projected Difference from Historical Climate



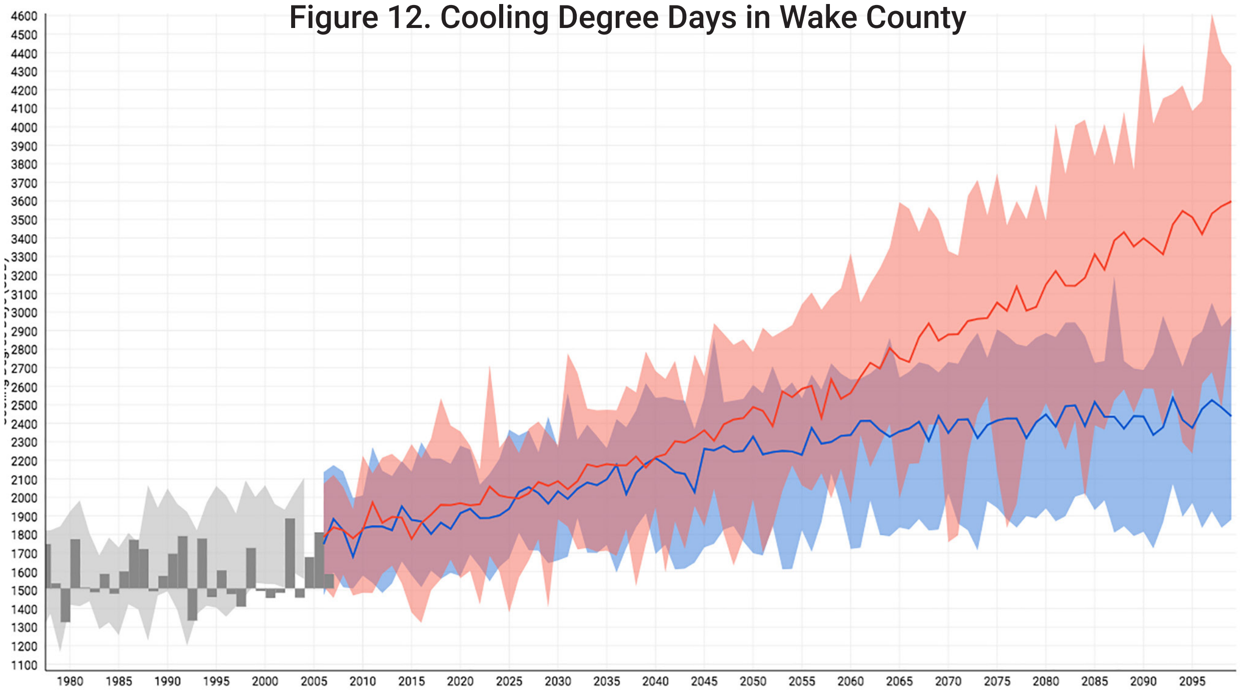
Projected average number of days per year with maximum temperatures above 95°F in the Southeast region for 2041–2070 compared to 1971–2000, assuming emissions continue to grow. The projected average increase in over-95°F days may range from 10 to 30 for most of the Piedmont region of North Carolina. (Figure source: [1], NOAA NCDC/CICS-NC.)

Figure 11. Observed Summer Temperature



Observed summer temperatures across North Carolina for 1895–2014, averaged over five-year periods. The 1930s and 1950s were some of the warmest periods in North Carolina's history, while the 1960s–70s were a cool period for the state. Over the past two decades, summer temperatures have once again increased. The dark horizontal line on the graph is the long-term average (1895–2014) of 75.5°F (summer). Figure and data source: CICS-NC/NOAA NCEI.

Figure 12. Cooling Degree Days in Wake County



The graph shows the observed and projected number of cooling degree days in Wake County from 1980 through 2095, under higher emissions (red) and lower emissions (blue) scenarios. (Figure source: U.S. Climate Resilience Toolkit, Climate Explorer.)

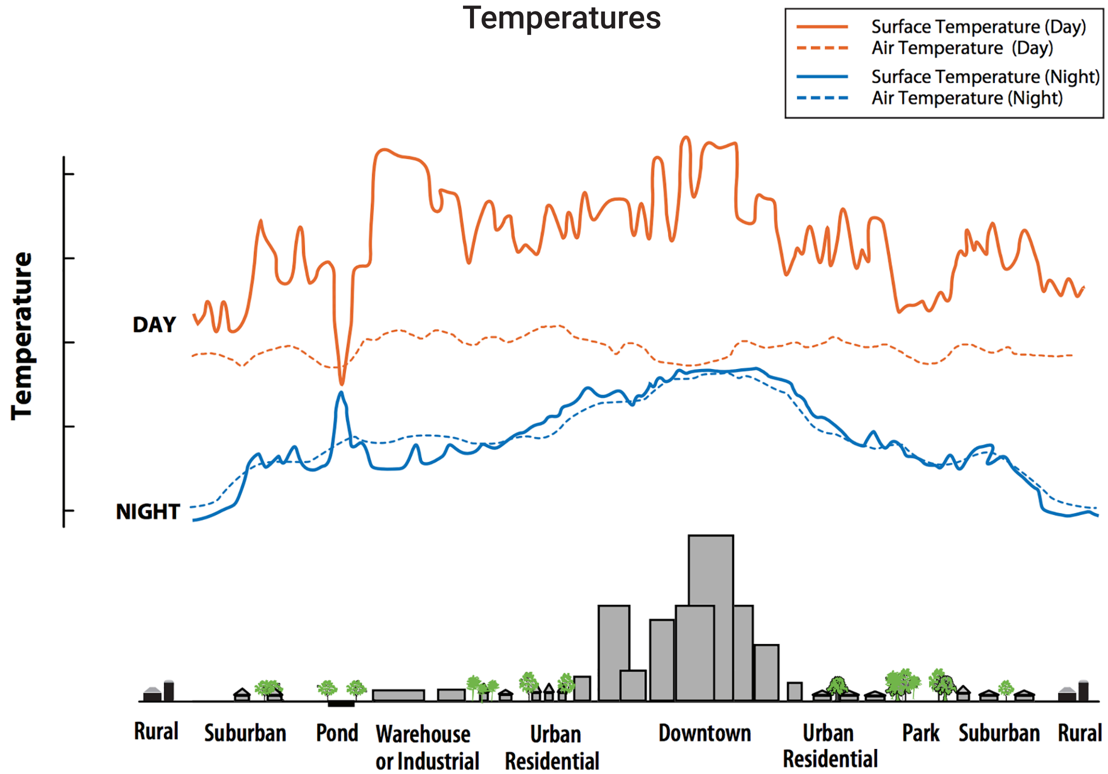
The data indicate that over the last several decades heat waves are generally increasing, while cold waves are decreasing. At the same time, recent "polar vortex" cold events in the central and southern U.S. are proving to be challenging in many sectors, including infrastructure and health care.[8] The National Weather Service defines a cold wave (or, in some regions, a cold snap) as a phenomenon distinguished by a rapid fall in temperature within a 24-hour period. The criterion depends on the rate at which the temperature falls and the minimum to which it falls, as well as the geographic region of the country where it occurs. Cold waves affect much larger geographic areas than blizzards, ice storms, and other winter hazards.[8]

Both climate and non-climate stressors have the potential to change in the future and increase risk for the Triangle region. However, in some cases, changes to non-climate stressors can have the same or greater influence on climate hazards than do changes to climate stressors.

Non-Climate Stressors

Non-climate stressors are factors or conditions that contribute to the occurrence of a threat. For example, impervious surfaces are considered a non-climate stressor, as they are known to contribute to increased runoff, erosion, and flooding in urban areas and also to the urban heat island effect (described in Figure 13). Other non-climate stressors for the Triangle region are related to population growth and demand for resources, such as water, energy, roads, schools, and emergency services. Higher than normal average wages and regional median home prices do not translate across all sectors, leading to greater disparity and increased social vulnerability for some populations.

Figure 13. Variations of Surface and Atmospheric Temperatures



Surface and atmospheric temperatures vary over different land use areas, leading to what's known as the "urban heat island effect." Surface temperatures vary more than air temperatures during the day, but they both are fairly similar at night. The dip and spike in surface temperatures over the pond show how water maintains a fairly constant temperature day and night, due to its high heat capacity. Note that the temperatures displayed do not represent absolute temperature values or any one particular measured heat island. Temperatures will fluctuate based on factors such as seasons, weather conditions, sun intensity, and ground cover. Figure source: U.S. EPA (2008), modified from Voogt (2000).

During Step One, the TRRP identified key non-climate stressors facing the Triangle region. Some of these challenges are also mentioned in the region's comprehensive plans and other jurisdictional planning efforts. They include:

- Affordable housing;
- Aging population;
- Water supply and demand;
- Population and demographic shifts;
- Growth and development;
- Unemployment;
- Aging infrastructure (e.g., transportation, wastewater systems, food infrastructure, etc.);

- Social vulnerabilities; and
- Access to health care.

To evaluate the impact of primary non-climate stressors for the region, how these stressors may be changing over time, and how these stressors interact with threats, the TRRP determined which to include in this assessment based on available and usable information.

Below is an overview of trends involving non-climate stressors throughout the southeastern United States that can have implications for the Triangle region. They are grouped into the following categories:

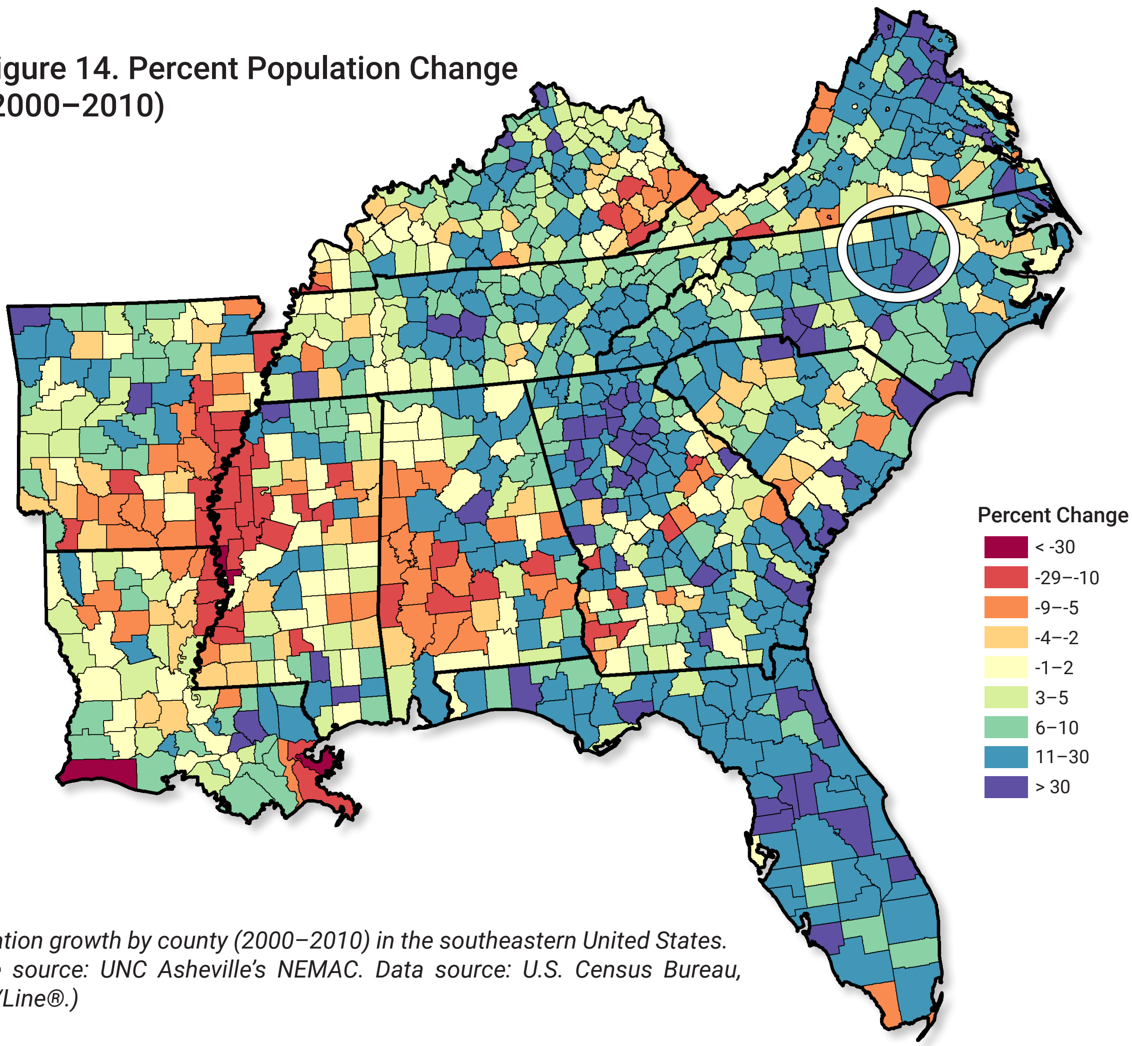
- Population and demographics;
- Built environment;
- Economics; and
- Natural.

Population and Demographics

Certain areas of the country have experienced increased population growth over the past 50 years, and the demographics of these areas are also changing. Demographic trends can often be explained by metrics related to growth and urban areas, median age, level of education, and other similar datasets.

Figure 14 shows recent population change. The counties shaded in dark blue and purple experienced a high amount of population growth between 2000 and 2010. This is particularly apparent in many of the metropolitan areas—Atlanta and its environs, the Triangle region, and through most of the central Piedmont region of North Carolina.

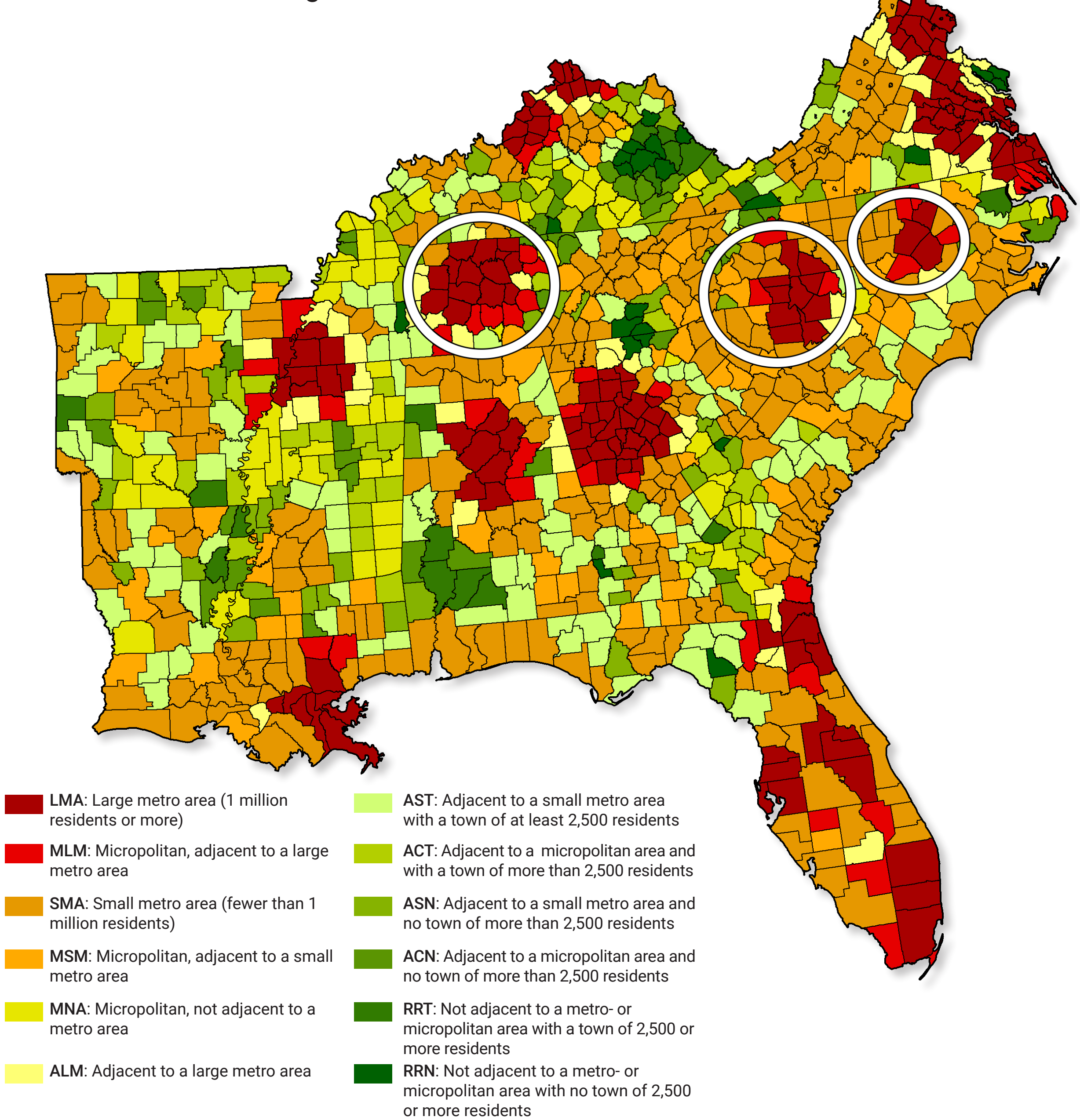
Figure 14. Percent Population Change (2000–2010)



Population growth by county (2000–2010) in the southeastern United States. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau, TIGER/Line®.)

Another trend is the impact of population centers on neighboring counties, or "urban influence," that indicates economic opportunities among counties. Figure 15 shows that all counties in the Triangle are within metro areas and, taken together, the two metro areas for Raleigh and Durham-Chapel Hill are comparable in size and population to other large metro areas in the Southeast, such as Charlotte and Nashville.

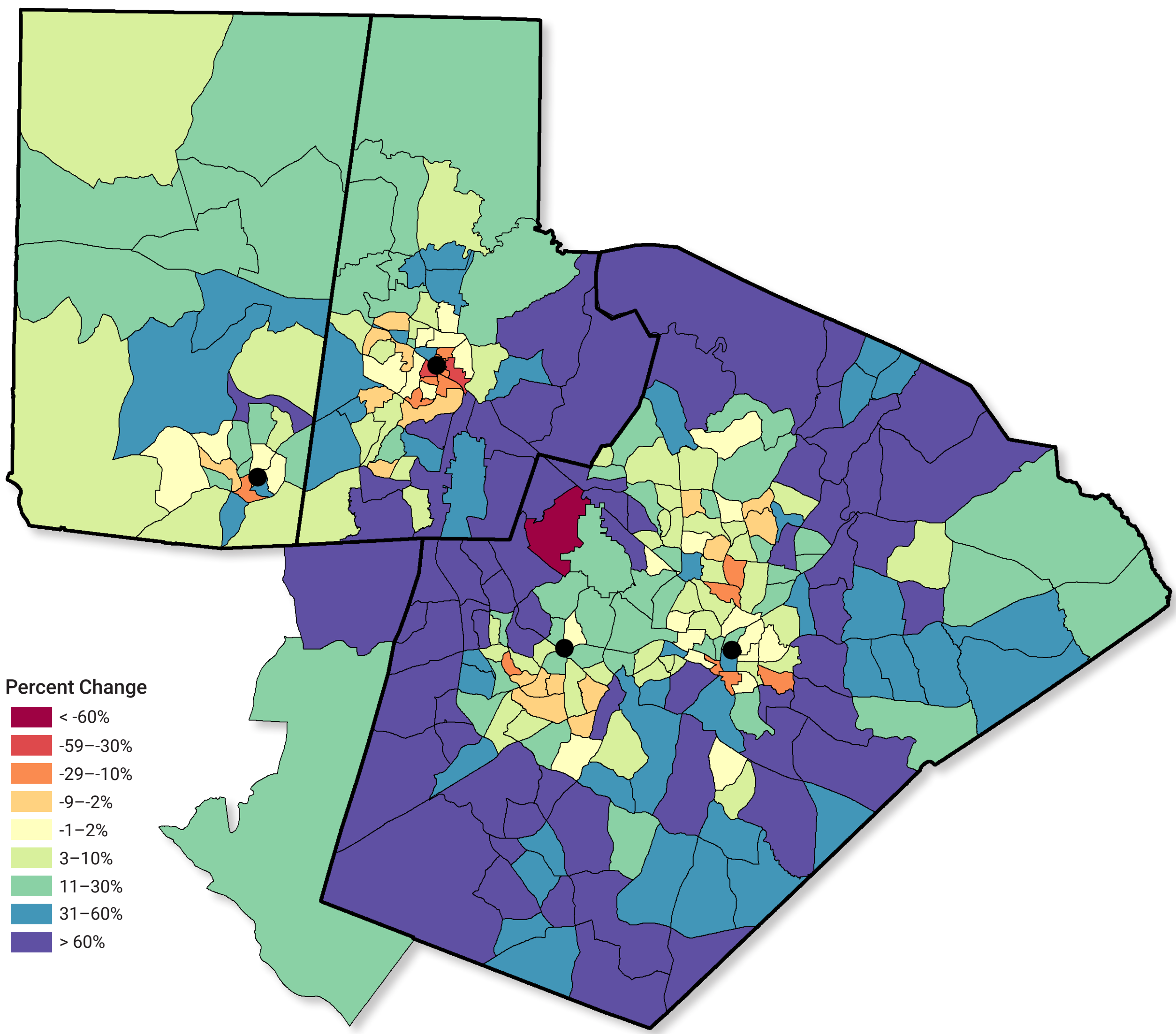
Figure 15. Urban Influence in the Southeast



Urban influence in the Southeast by county (2013). (Figure source: UNC Asheville's NEMAC. Data source: USDA ERS.)

If we look more closely at the Triangle region and its apparent trend in population and growth, it's clear that much of the recent growth and development (2000–2010) has occurred outside of the city centers and more in the suburban areas of the region (Figure 16). As population increases in an area, it is often accompanied by an increase in development, which often exposes valuable assets to new threats, such as minor flooding, runoff and erosion. Furthermore, transportation and commuting factors are a large part of the Triangle's development picture, and recent growth within the Triangle counties can contribute to longer commute times.

Figure 16. Regional Percent Population Change (2000–2010)

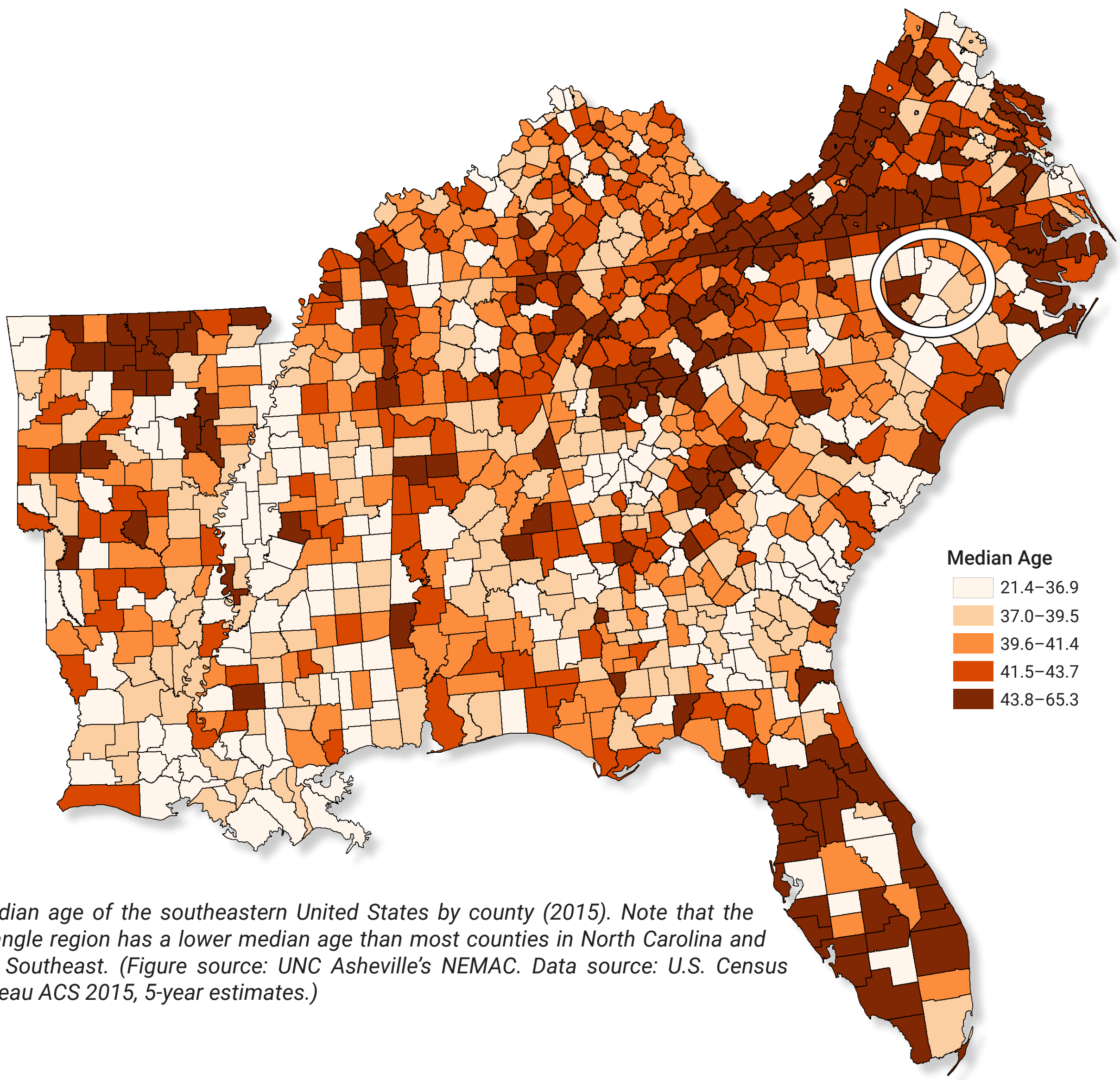


Regional population change 2000–2010 by census tract. (Figure source: UNC Asheville's NEMAC. Data source U.S. Census Bureau, TIGER/Line®.)

Median age is also a telling statistic for this region. Unlike other areas of the Southeast that have a large proportion of older populations (such as western North Carolina and Florida), the Triangle region has a lower median age than most counties in North Carolina, or indeed in the entire Southeast. There are undoubtedly multiple factors contributing to this trend, and it is worthwhile to look at both the low median age (Figure 17) and educational level (Figure 18).

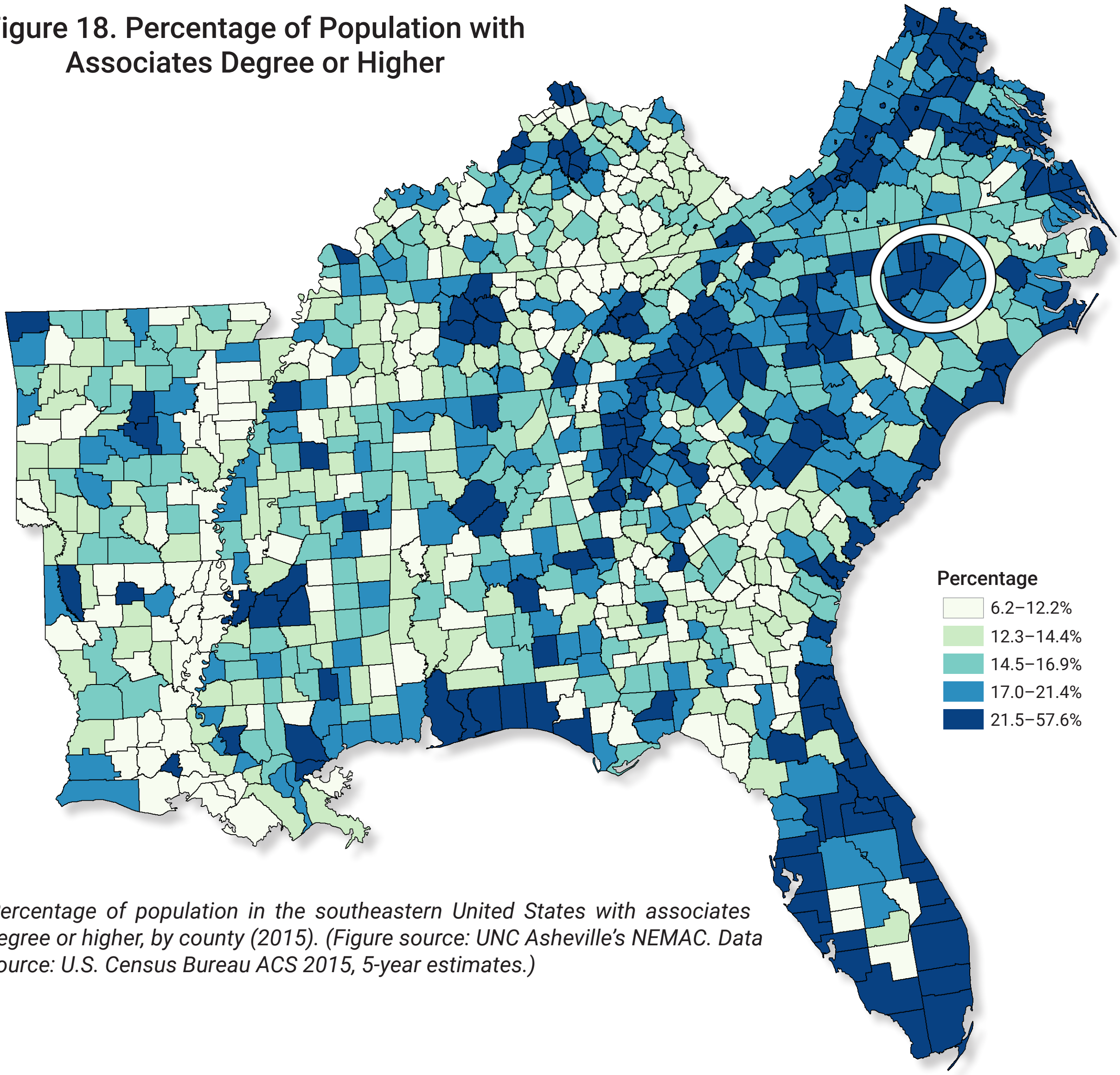
Here, it is important to note the difference between urban and rural areas of North Carolina. Some of the more urban areas tend to have populations with lower median age (lighter red/orange colors) and higher educational levels (darker blue colors), which clearly demonstrates how universities, the state capital, and technology employers are utilizing young professionals in the Triangle region.

Figure 17. Median Age of the Southeastern United States



Median age of the southeastern United States by county (2015). Note that the Triangle region has a lower median age than most counties in North Carolina and the Southeast. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau ACS 2015, 5-year estimates.)

Figure 18. Percentage of Population with Associates Degree or Higher



Percentage of population in the southeastern United States with associates degree or higher, by county (2015). (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau ACS 2015, 5-year estimates.)

The Triangle region has a high percentage of highly educated people. This fact, coupled with its large population size and growth, indicates that younger, more educated people are driving the region's growth.

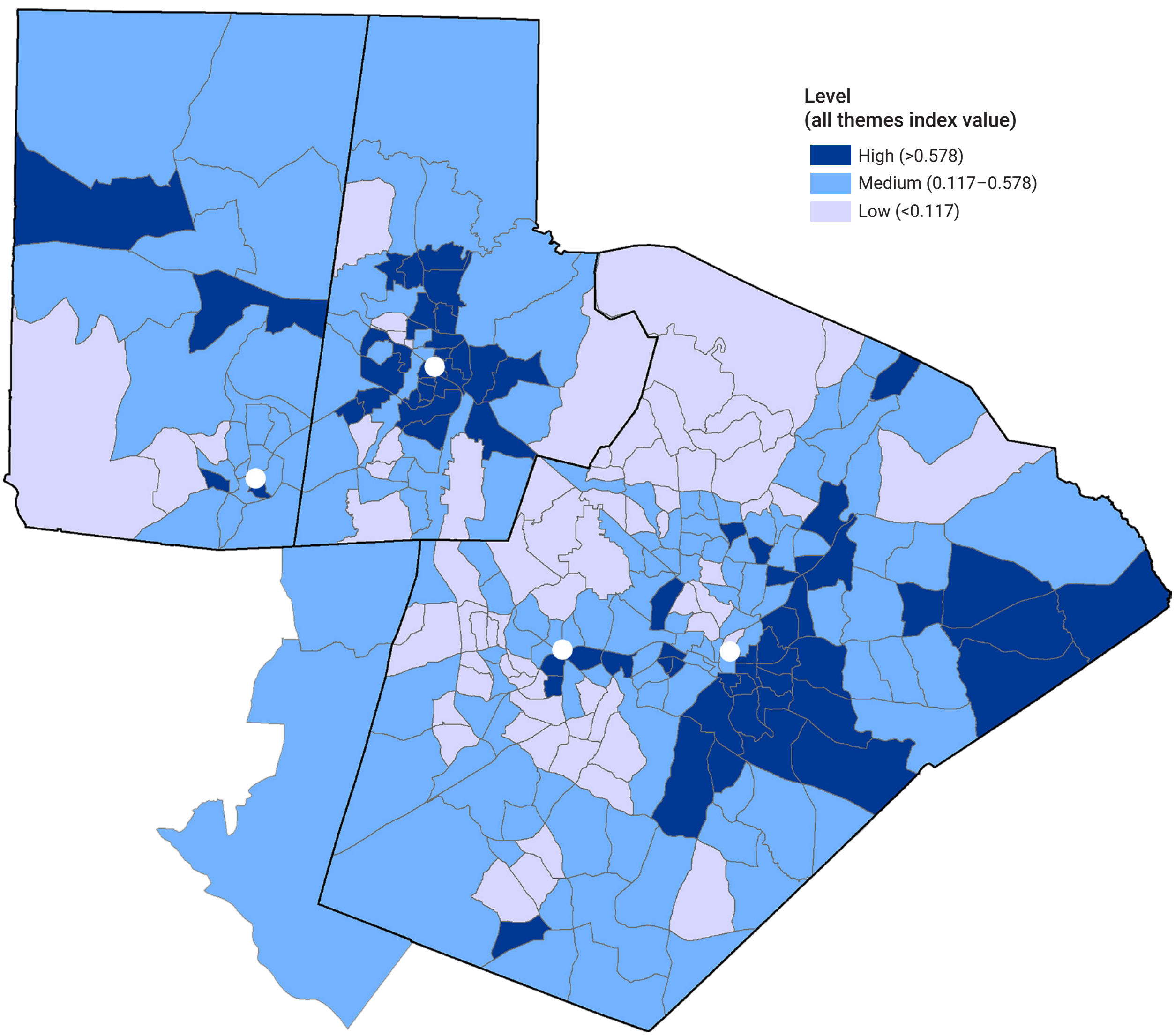
Social Vulnerability

Social vulnerability is a term describing how resilient a community is when confronted by external stresses on human health. These stresses can range from natural or human-caused disasters to disease outbreaks.

The Social Vulnerability Index (SVI) was created by the U.S. Census Bureau to help identify communities that may need support in preparing for hazards or recovering from disasters. The SVI uses U.S. Census Bureau data to determine the social vulnerability of every census tract and ranks each tract on 14 social factors—including poverty, lack of vehicle access, and crowded housing—and groups them into four related themes. Each tract receives a separate ranking for each of the four themes, as well as an overall ranking. These themes include socioeconomic status, household composition, race/ethnicity/ language, and housing/transportation.

The SVI was widely used throughout this assessment to help define sensitivity of certain populations to climate-related threats and can be found as a "hatched" overlay on the assessment maps.

Figure 19. CDC Social Vulnerability Index

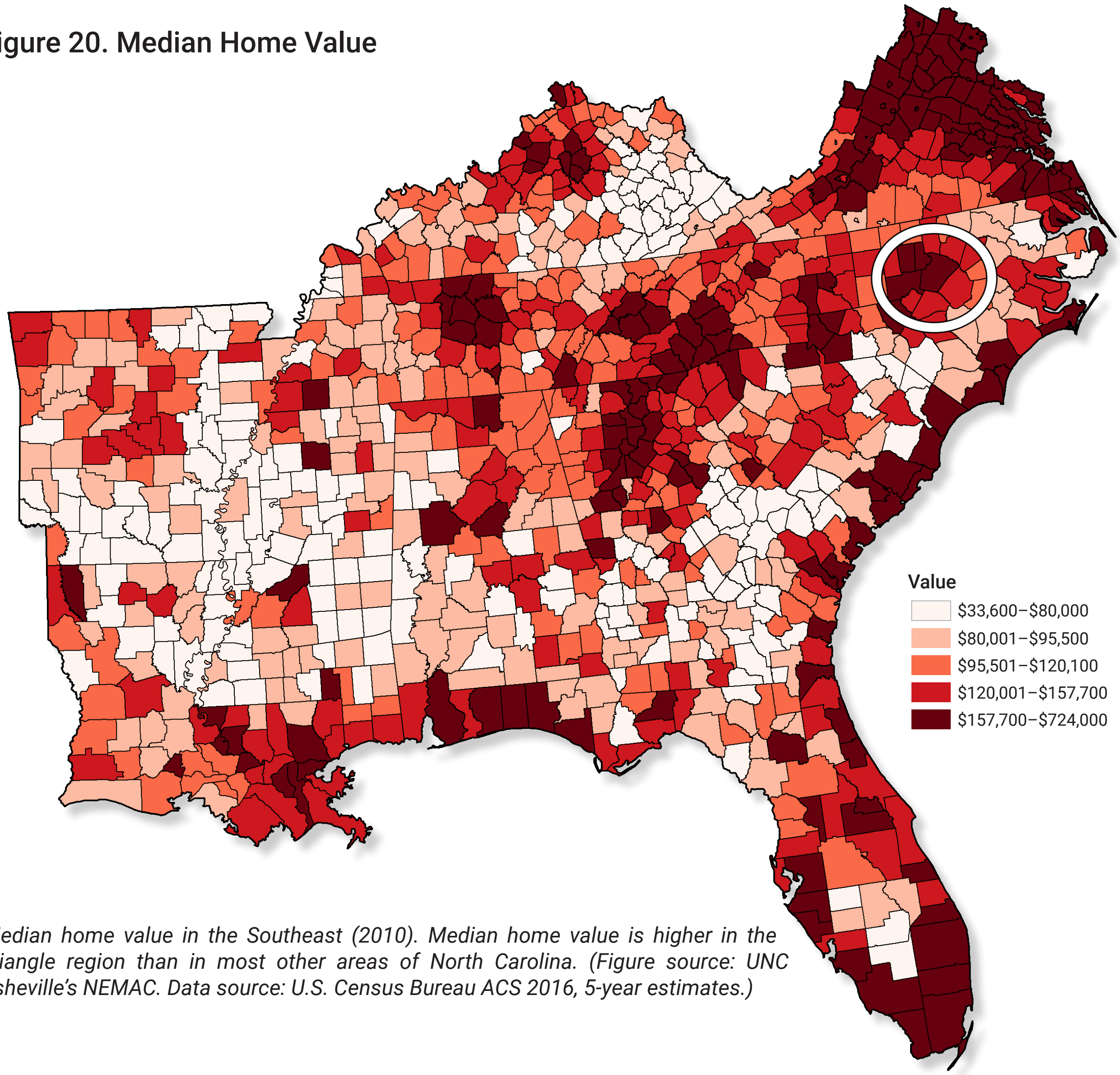


Social vulnerability in the Triangle region, as determined using the Centers for Disease Control and Prevention's Social Vulnerability Index. (Figure source: UNC Asheville's NEMAC. Data source: CDC.)

Built Environment

Similar to population growth and demographics, the Triangle region's development and built environment has a unique story. The region has among the highest median home values in North Carolina, and indeed in the entire Southeast. This may be a favorable outcome for individual homeowners, but may also negatively impact affordable housing and entry-level housing values.

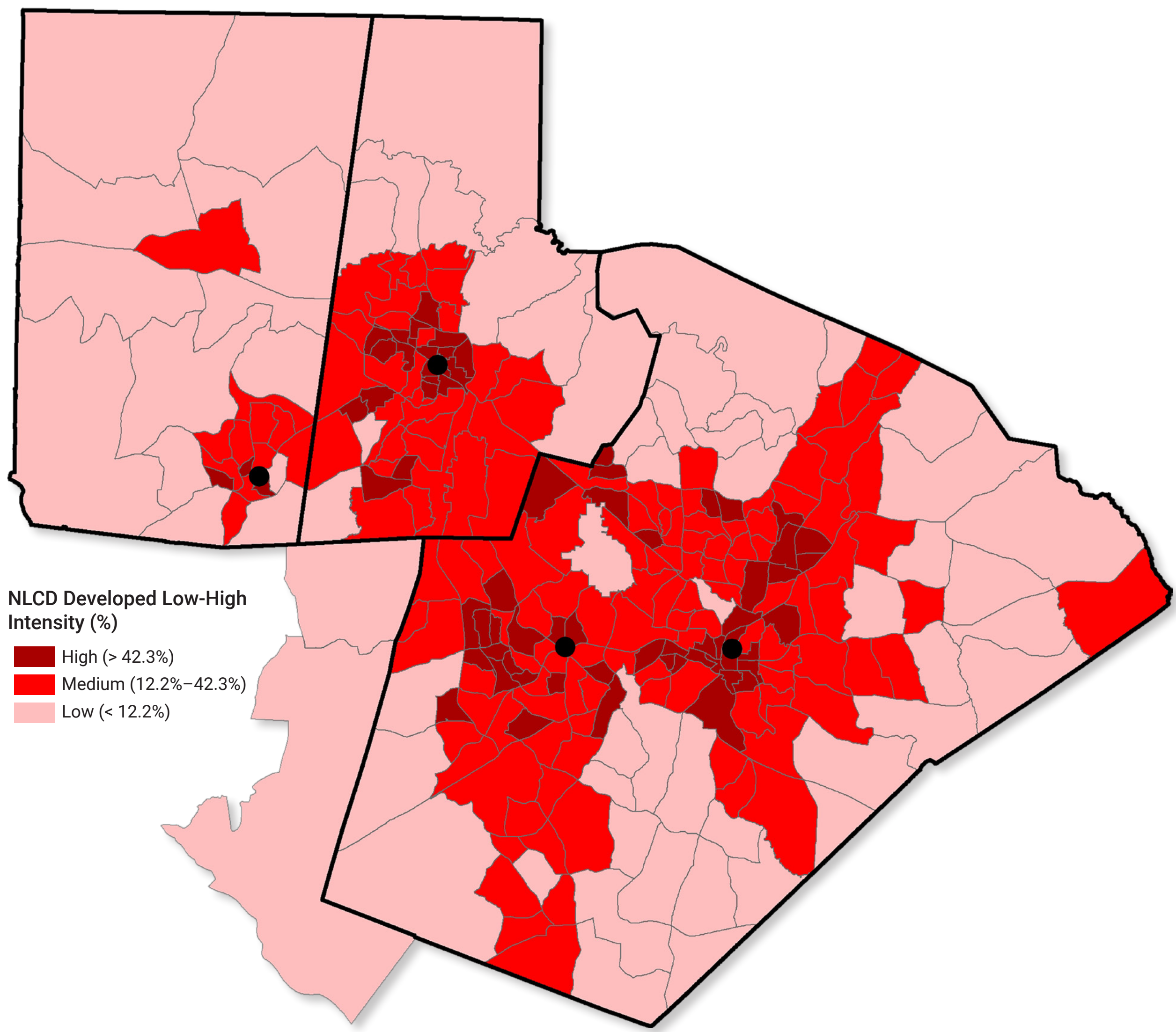
Figure 20. Median Home Value



Median home value in the Southeast (2010). Median home value is higher in the Triangle region than in most other areas of North Carolina. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau ACS 2016, 5-year estimates.)

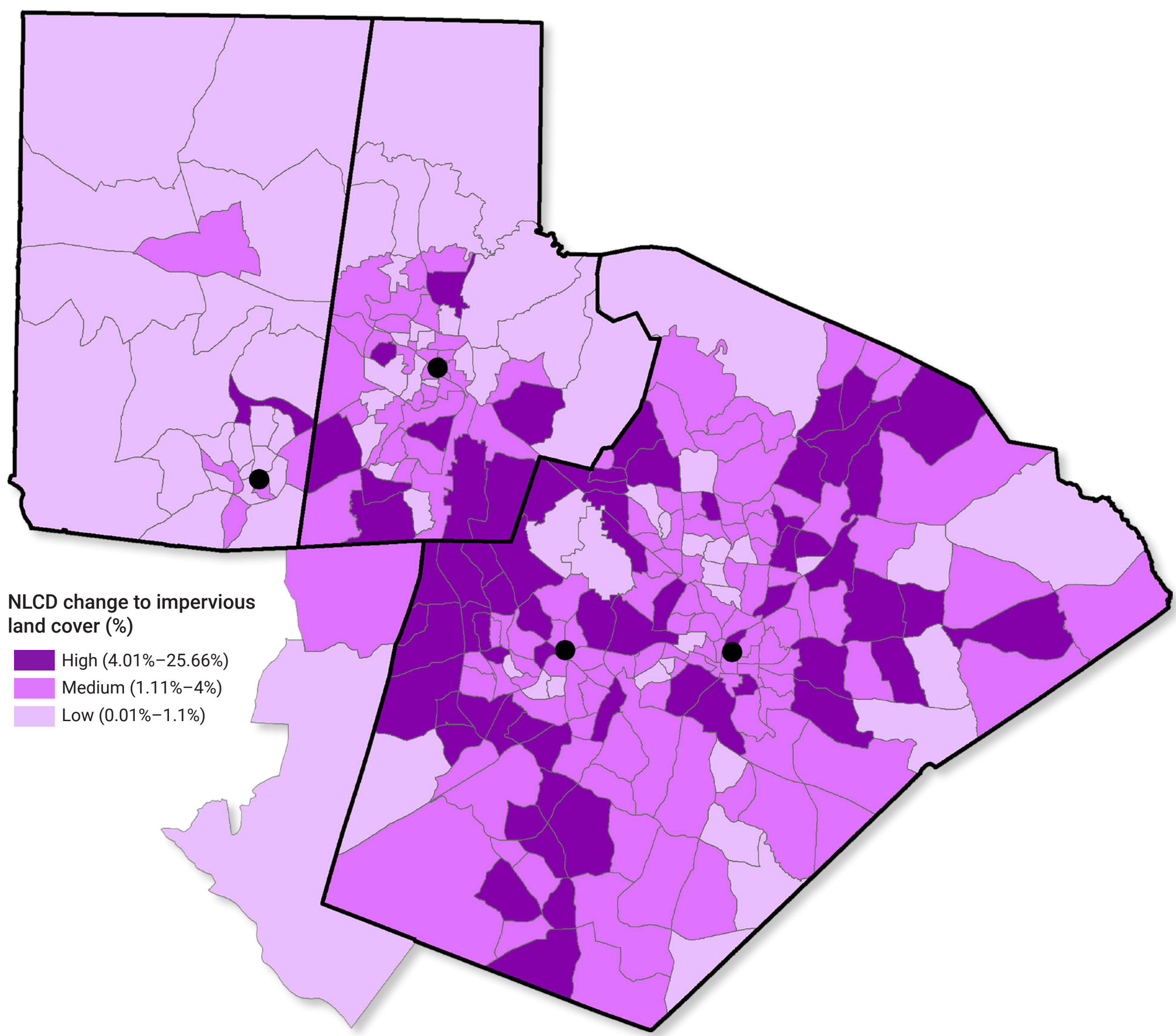
Land cover also plays an important role in shaping how communities and landscapes experience threats and cope with their impacts (Figure 21). For example, patterns of development and impervious surfaces are important for understanding how they contribute to stormwater runoff and flooding. Likewise, natural and forested areas can help to mitigate flooding and the urban heat island effect. Patterns of development vary across the Triangle region, with some areas experiencing a rapid increase in development over the past two decades (Figure 22). How the region continues to develop will have a significant impact on how it is able to cope with future change.

Figure 21. Developed (Impervious) Land Cover



Developed (impervious) land cover in the project area, by census tract. The dark red "high" areas on the map are census tracts in the highest quartile (top 25th percent) for amount of developed land cover (more than 42.3 percent developed). (Figure source: UNC Asheville's NEMAC. Data source: National Land Cover Database 2011, 2014 edition.)

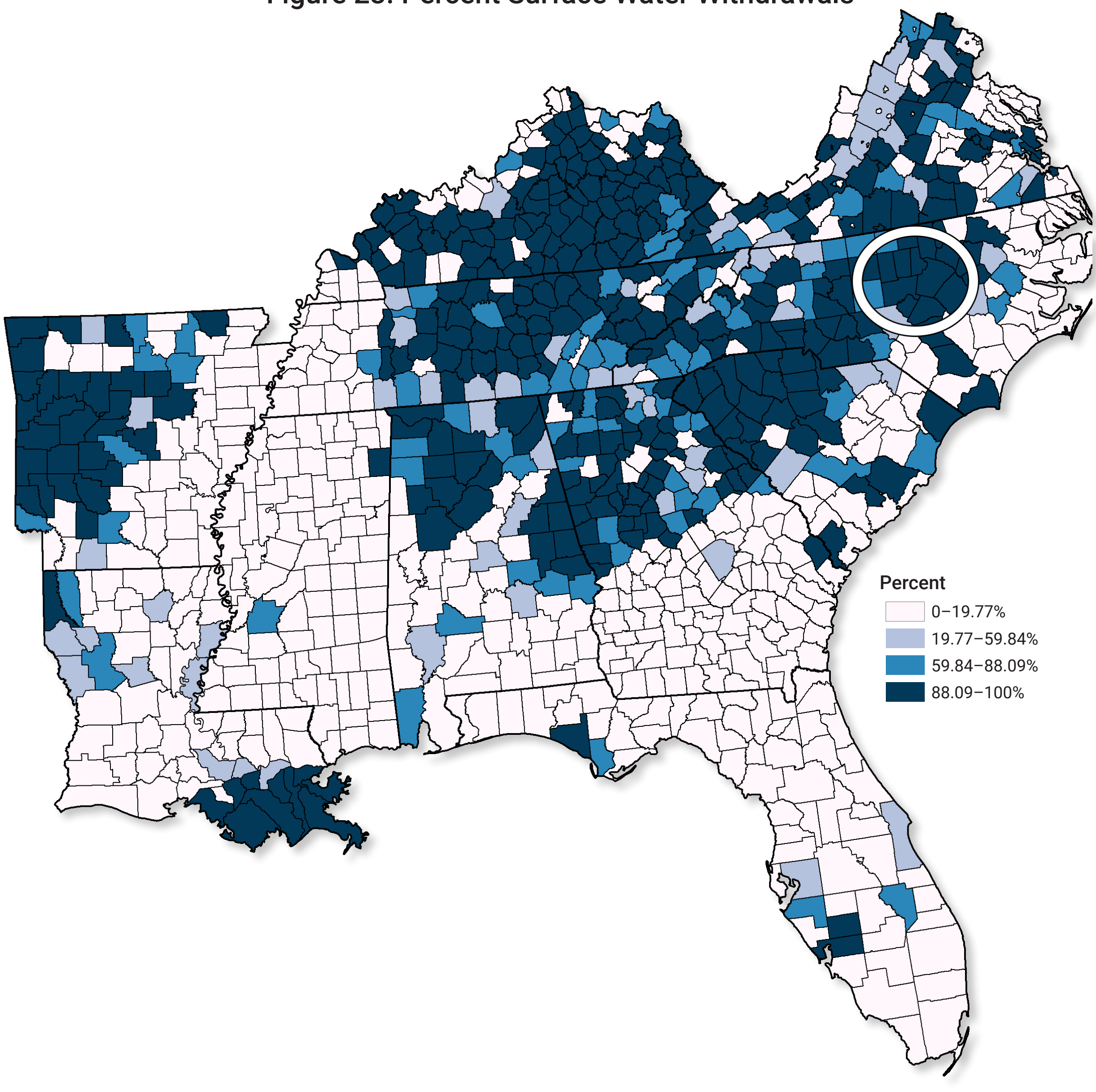
Figure 22. Change to Developed (Impervious) Land Cover



Change to impervious land cover in the project area, by census tract, 2006–2011. The dark purple "high" areas on the map are census tracts in the highest quartile (top 25th percent) for amount of recent change to developed/impervious land cover (between 4.01 and 25.66 percent area change). (Figure source: UNC Asheville's NEMAC. Data source: National Land Cover Database 2011, 2014 edition.)

Water use is another indicator of the built environment and the role it plays as a non-climate stressor. Figure 23 shows the region's surface water use. Similar to many parts of the Southeast, the darker shading clearly demonstrates the Triangle region's reliance on surface water (more than 88 percent). The Triangle counties and jurisdictions lie within the headwaters of two watersheds—the Upper Cape Fear and Upper Neuse—and must carefully manage their surface water supply during times of drought.

Figure 23. Percent Surface Water Withdrawals



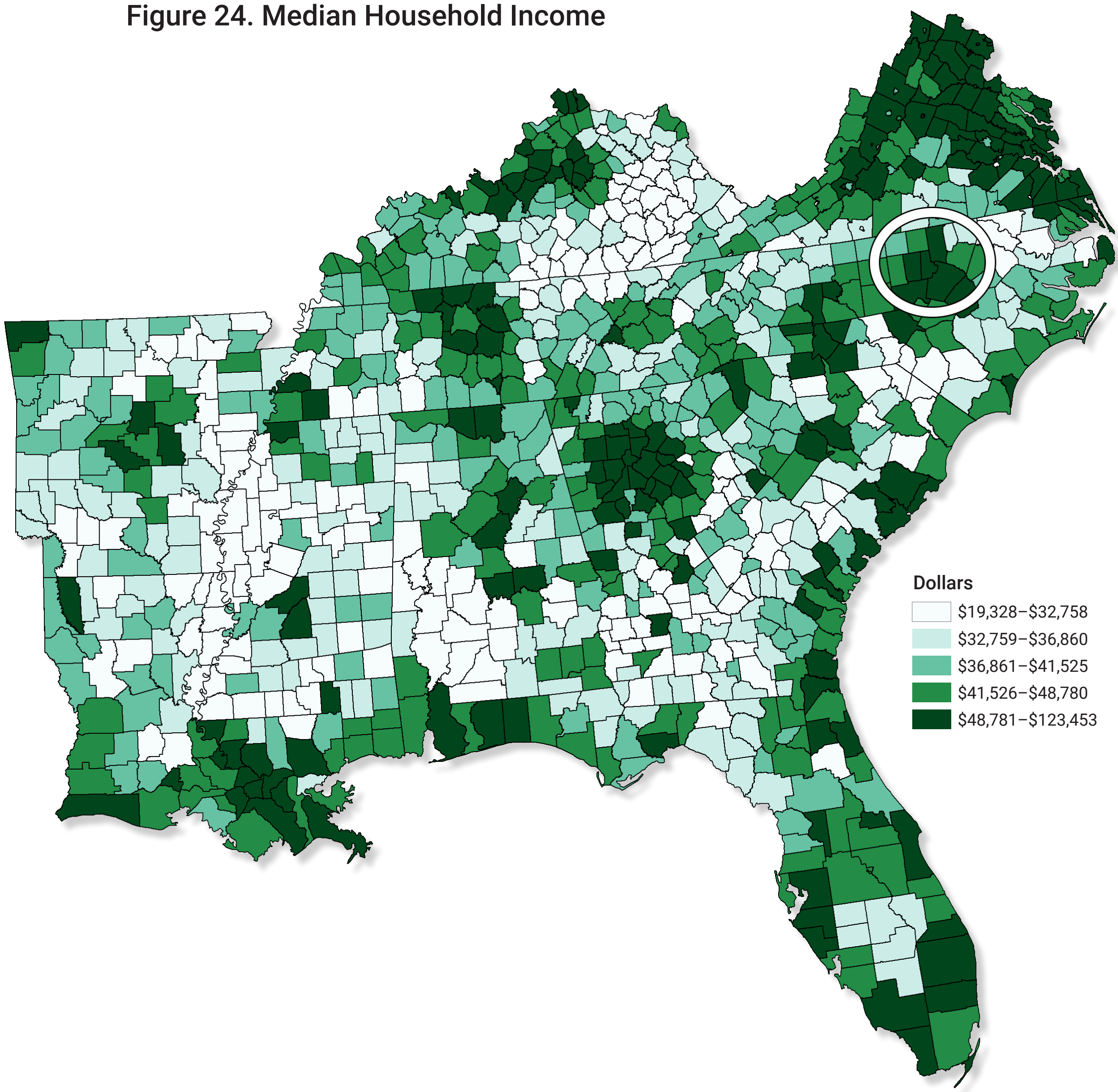
Percent surface water withdrawals in the southeastern United States, by county (2010). (Figure source: UNC Asheville's NEMAC. Data source: U.S. Geological Survey.)

Economics

Economics can also explain various trends related to non-climate stressors in the Triangle region. This category showcases information specifically related to income levels of the region's various populations and can relate to the region's overall resilience when facing both climate and non-climate threats and stressors.

Median income, as seen in Figure 24, tends to be higher in the urban areas of the Southeast, including the Triangle region. Oftentimes, this metric can be seen as a resilience "positive" because it may indicate that individual stakeholders have more personal resources to apply to resilience-building measures.

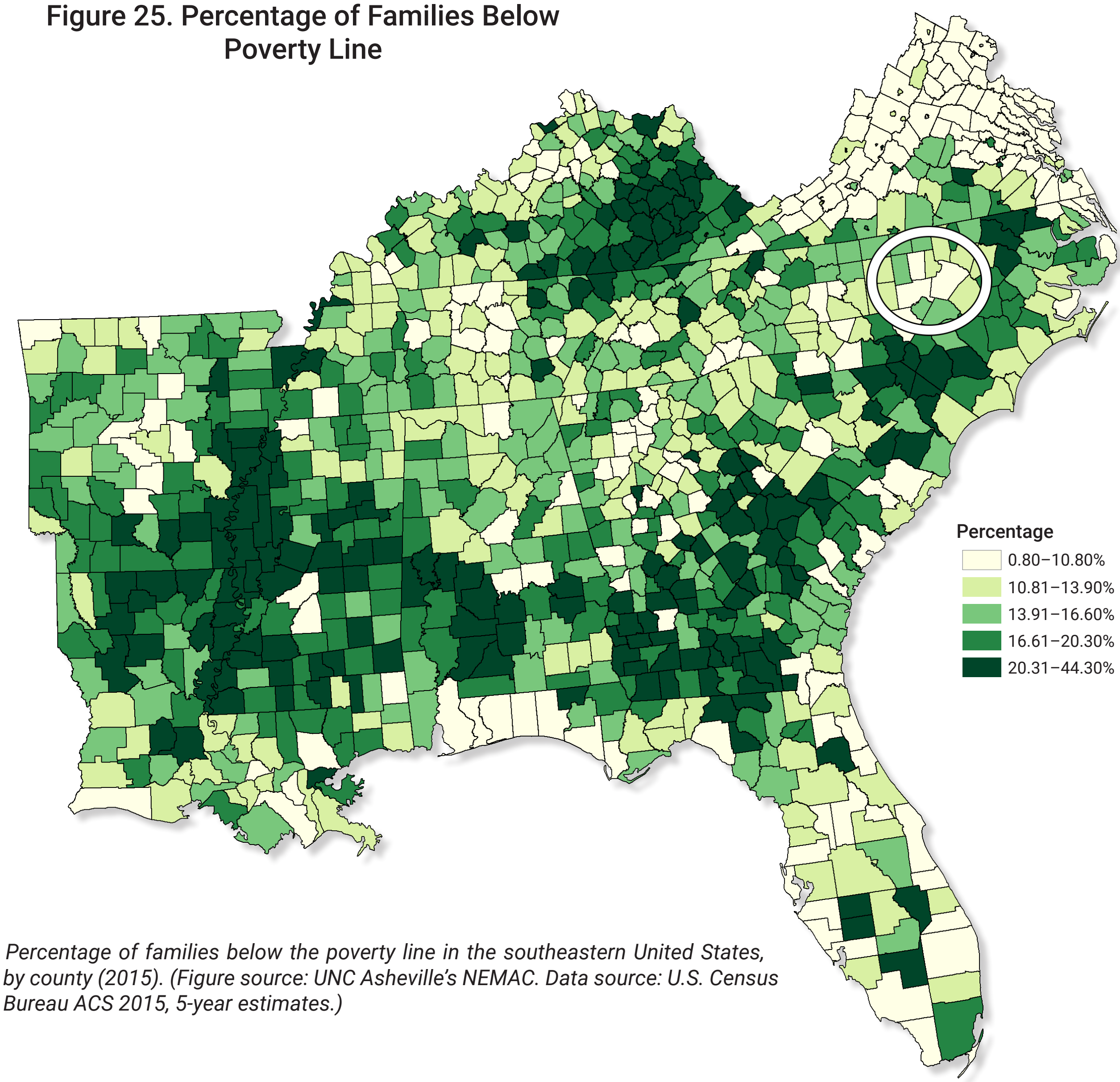
Figure 24. Median Household Income



Median household income in the southeastern United States, by county (2015). Urban centers, including the Triangle region, display higher median incomes (darker green shading). (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau ACS 2015, 5-year estimates.)

Another important metric and trend to note is the number of families with incomes below the poverty line, as calculated by the U.S. Census Bureau.[9] Despite its higher median income, the Triangle region has a large number of families living below the poverty line. County-level poverty rates in the Triangle region, however, are not as high as many other areas in the Southeast (Figure 25).

Figure 25. Percentage of Families Below Poverty Line



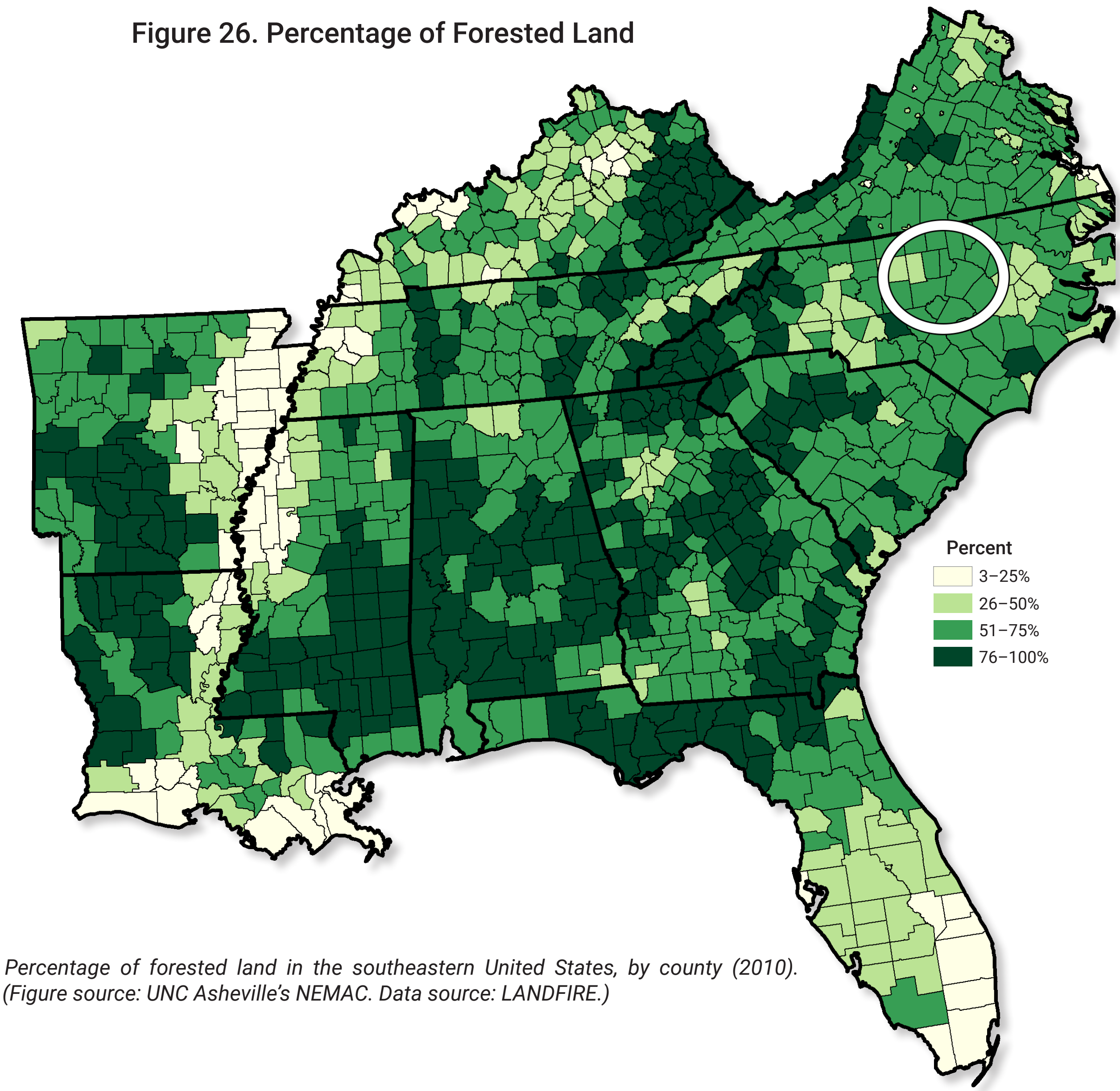
Percentage of families below the poverty line in the southeastern United States, by county (2015). (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau ACS 2015, 5-year estimates.)

Natural

Development in the region has led to many homes being located in the wildland-urban interface (WUI). As a result, one of the region's primary non-climate stressors related to the threat of wildfire is the management of fuels and vegetation. Lack of active fuel management can contribute to a decline in fire-resilient ecosystems, an increase in wildfire burn severity, and increased risk of destructive wildfires that damage landscapes and threaten people and communities.

Despite the urban nature of the Triangle, the map shows that it is still in the second highest quantile for forested regions in the nation (51 to 75 percent), making it an area of concern for exposure to wildfire. Most residents in the Triangle region value having these forested areas in their neighborhoods. While this adds to quality of life, it does raise the danger of available fuels that might lead to wildfire.

Figure 26. Percentage of Forested Land



Percentage of forested land in the southeastern United States, by county (2010). (Figure source: UNC Asheville's NEMAC. Data source: LANDFIRE.)

Climate-Related Threats

According to the NOAA Storm Events Database, between 1996 and 2016 the Triangle region—Durham, Orange, and Wake Counties—experienced over 1,400 climatic and extreme weather events that resulted in over $219 million in damages. It is important to note that these are broad estimates, and actual damages may be higher.[10]

In an initial review of comprehensive and hazard mitigation plans, jurisdictions in the region have acknowledged that they are facing shared climate-related threats and hazards. Some of these include, in no particular order:

- Flooding due to an increase in heavy precipitation events and increased development;
- Heavy precipitation and storm-related events;
- Water shortages due to drought;
- Wildfire;
- Temperature variability (e.g., extreme heat events); and
- Wind events.

Most of the threats and hazards selected for this assessment are existing hazard events that have impacted the community in the past. What should be noted is that they have the potential to change in frequency or severity in a changing climate.

Threats addressed in the resilience assessment were captured based on the project team's institutional knowledge of past events, the NOAA National Centers for Environmental Information Storm Events Database,[10] and regional climate trends and projections from the second and third National Climate Assessments.[11,1] Additional resources used to explore climate threats for the Triangle region include:

- Information from the second and third National Climate Assessments was used as a basis for understanding some of the causal relationships between stressors (climate and non-climate) and the threats that the community is facing.[11,1]
- A database created through an initiative by the North Carolina Interagency Leadership Team in 2010 provided information on stressors, impacts, and resources affected.[12]

Air Pollution

Climate variability and change have modified weather patterns, which have in turn influenced the levels and location of outdoor air pollutants such as ground-level ozone (also known as smog) and small particulate matter that can reach the deepest parts of the lung. Ground-level ozone and particulate matter are associated with many health problems, such as diminished lung function, more frequent hospital admissions and emergency department visits for asthma, and increases in premature deaths.[13]

Additionally, warmer and drier conditions associated with climate change can increase the range and severity of wildfires. Wildfire smoke contains particulate matter, carbon monoxide, and other harmful emissions that significantly reduce air quality both locally and in areas downwind of fires. Smoke from wildfires hundreds of miles away can affect people's health. Smoke exposure can cause respiratory and cardiovascular complications that lead to more emergency department visits, hospitalizations, and use of medication to treat asthma, bronchitis, chest pain, and other ailments. Climate change is projected to increase the number and severity of naturally occurring wildfires in parts of the United States, resulting in additional adverse health outcomes.[13]

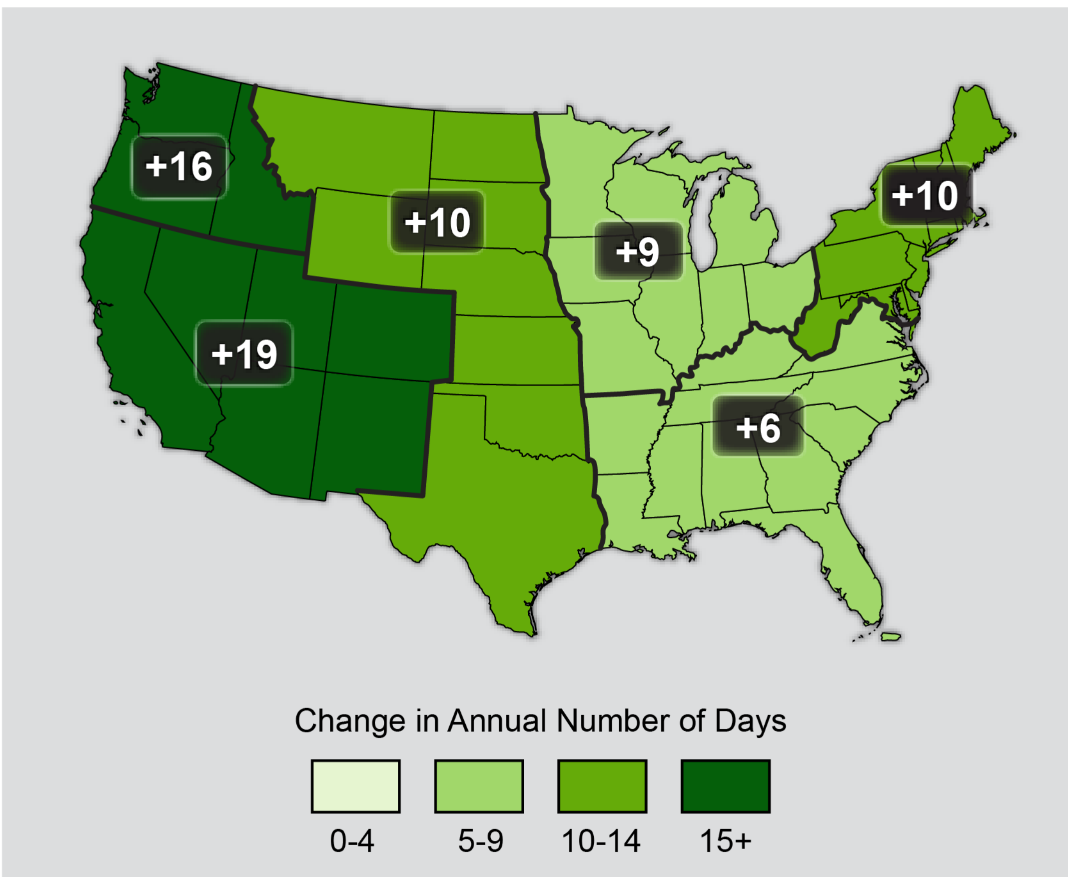
Climate change can also lead to higher pollen counts and longer pollen seasons. Higher pollen concentrations and longer pollen seasons can increase allergic sensitivity and asthma episodes in some people. Simultaneous exposure to air pollution can worsen allergic response.[13]

Decreased outdoor air quality and increased airborne allergens also affect indoor air quality. Whether outdoors or indoors, poor air quality can negatively affect the human respiratory and cardiovascular systems.[13]

Change in Growing Season

The length of the frost-free season (and the corresponding growing season) has been increasing nationally since the 1980s, affecting ecosystems and agriculture, and is projected to continue to lengthen. A longer growing season provides a longer period for plant growth and productivity, and can increase the growth of beneficial plants (such as crops and forests) as well as undesirable ones (such as ragweed).[14] Longer growing seasons could therefore provide opportunities for greater timber and agricultural production. Projected warmer and drier summers could, however, offset the potential economic benefits through an increase in demand for crop irrigation.[15]

Figure 27. Observed Increase in Frost-Free Season Length



The frost-free season length, defined as the period between the last occurrence of 32°F in the spring and the first occurrence of 32°F in the fall, has increased in each U.S. region during 1991–2012 relative to 1901–1960. Increases in frost-free season length correspond to similar increases in growing season length. (Figure source: [1], NOAA NCDC/CICS-NC.)

Some perennial specialty crops—including some vegetables and fruit and nut trees—have a winter chilling requirement; yields decline if the chilling requirement is not completely satisfied because flower emergence and viability is low. Warmer winters can also lead to early bud burst or bloom of some perennial plants, resulting in frost damage when cold conditions occur in late spring.[16]

The threat of a changing growing season includes potential changes in the number of frost-free days, the number of hot nights, and increased temperature extremes. This threat has a primary impact on agriculture.

Disease

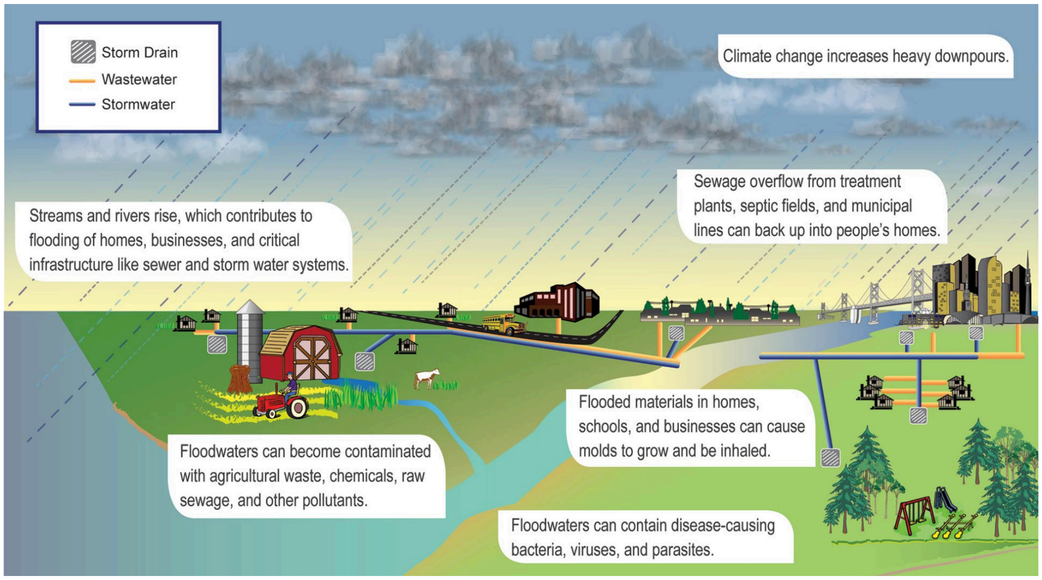
Variations in air and water temperature, precipitation patterns, extreme rainfall events, and seasonality can create conditions that are more or less favorable for the spread of vector-borne diseases (diseases carried by vectors, such as ticks and mosquitoes). As the climate changes, vector populations may increase, survive over longer periods during the year, and/or expand into new areas when ambient temperatures rise. Vector-borne infectious diseases include Lyme disease, dengue fever, West Nile virus infection, chikungunya, Rocky Mountain spotted fever, plague, and tularemia. These diseases are major public health concerns.[17]

Climate change can also exacerbate food and water safety risks in a number of ways. For instance, illnesses from pathogens such as Salmonella and Campylobacter are generally more common when temperatures are higher. Climate extremes, especially heavy precipitation and flooding, are also key drivers of food contamination and foodborne disease. Such extremes can change the level of exposure to specific contaminants and chemical residues for crops and livestock.[18]

Exposure to pathogens and toxins occur through drinking, inhaling, or other direct contact with contaminated drinking or recreational water and through consumption of contaminated food, including fish and shellfish. Climate change impacts—including increasing temperatures, precipitation and related runoff, hurricanes, and storm surge—affect the growth, survival, spread, and virulence or toxicity of agents (causes) of water- and food-related illness.[18]

For purposes of this assessment, disease includes the threat of illnesses from water or vector-borne diseases, such as those carried or spread by mosquitoes.

Figure 28. Heavy Downpours are Increasing Exposure to Disease



Heavy downpours, which are increasing in the United States, have contributed to increases in heavy flood events. The figure illustrates how people can become exposed to waterborne diseases. Human exposures to waterborne diseases can occur via drinking water as well as recreational waters. Figure source: NOAA NCEI/CICS-NC.

Extreme Cold

While the frequency of cold waves has been decreasing over the past few decades, they still occur and can have significant impact. A cold wave can cause poorly insulated water supply pipes and mains to freeze. It may impact building water supply piping, if not buried deeply enough underground. In addition, regions of the U.S. that experience limited cold weather have come to rely on electric heating for residential buildings; hence, when temperatures plunge, electrical demand peaks or exceeds grid capacity, resulting in rolling blackouts.[8]

Cold waves accompanied by precipitation often produce ice storms, resulting in massive transportation disruptions, electrical grid interruptions, and increased emergency service activities as auto accidents and slip-and-fall injuries peak (see also the Snow/Ice Event discussion below). Cold waves have greater effects on the poor and older adults, as these populations are less likely to have the financial resources to adequately heat their homes or manage snow removal, and are more vulnerable to injury. The National Weather Service refers to winter storms as the "Deceptive Killers" because most deaths are indirectly related to the storm. Instead, people die in traffic accidents on icy roads and of hypothermia from prolonged exposure to cold.[8]

For purposes of this assessment, sensitive populations—families with incomes below the poverty line and households with members over 65 years of age—were determined as being more sensitive to cold events.

Extreme Heat

Extreme heat events are periods of excessively hot and/or humid weather that can last for multiple days. For more information, refer also to the discussion of temperature variability in the Climate Stressors section of this report.

For purposes of this assessment, sensitive populations—families below the poverty line and households with members over 65 years of age—were determined as being more sensitive to heat events.

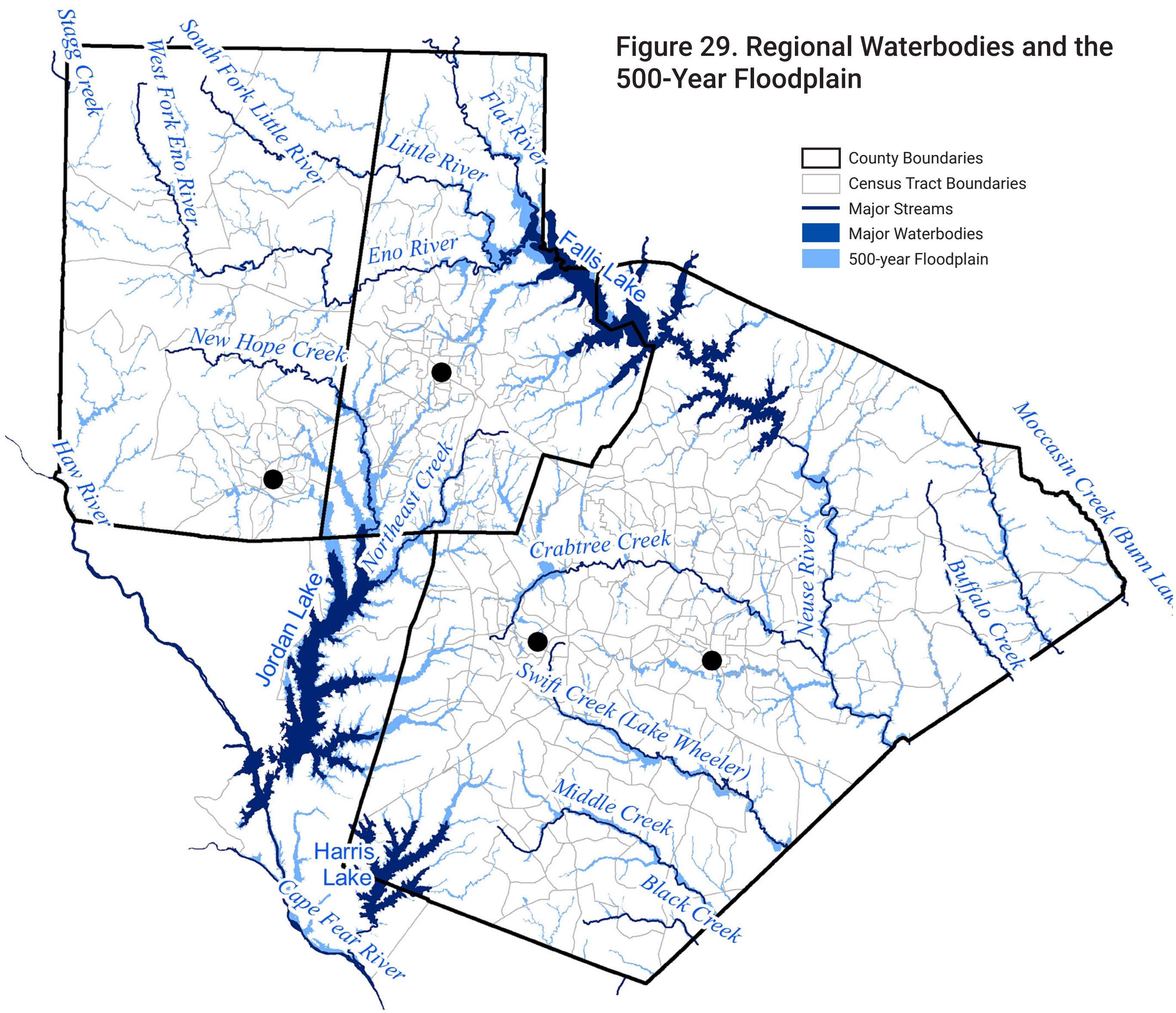
Flooding

Precipitation trends are changing both nationally and in the Southeast, and contribute to climate threats such as flooding. For more information, refer also to the discussion of extreme precipitation in the Climate Stressors section of this report.

For purposes of this assessment, the threat of flooding was defined by the flood hazard areas as determined by the North Carolina Floodplain Mapping Program (NCFMP)[19]; assets within any of these flood hazard zones were determined as being exposed to flooding. The different flood hazard zones were also used to determine different levels of risk: floodway (high), 100-year floodplain (medium), and 500-year floodplain (low).

A 100-year flood event has a one-percent chance of occurring every year, while a 500-year flood event has a 0.2-percent chance of occurring in any given year.

Figure 29. Regional Waterbodies and the 500-Year Floodplain



Major streams, waterbodies, and the 500-year floodplain extent for the Triangle region. (Figure source: UNC Asheville's NEMAC. Data source: North Carolina Floodplain Mapping Program.)

Minor Flooding, Runoff, and Erosion

The threat of minor flooding (urban flooding), runoff, and erosion includes events caused by extreme or heavy precipitation that results in minor flooding or erosion from runoff.[1] NOAA defines minor flooding as events that overwhelm stormwater infrastructure and result in inconveniences, such as road closures and damage to infrastructure.[20]

Minor flooding is often associated with coastal tidal flooding, but this assessment uses the minor flooding terminology to describe the minor flooding, runoff, and erosion that can occur after heavy precipitation in non-coastal areas. These events are usually less severe than major flooding, but can still cause significant impacts.

The Triangle has experienced more minor flooding and erosion-related issues in recent years after heavy precipitation events. This threat is also greatly influenced by the amount of development and impervious surfaces that contribute to runoff.

Snow/Ice Event

For the entire Northern Hemisphere, there is evidence of an increase in both storm frequency and intensity during the cold season since 1950, with storm tracks having shifted slightly towards the poles. Extremely heavy snowstorms increased in number during the last century in northern and eastern parts of the United States, but have been less frequent since 2000.[14] In the future, parts of the Southeast may expect milder winters, reductions in the number of cold days, delays in winter freezing, and earlier spring thaws, which may impact various public services and assets.[21]

As noted under Extreme Cold, cold waves accompanied by precipitation often produce ice storms, resulting in massive transportation disruptions, electrical grid interruptions, and increased emergency service activities as auto accidents and slip-and-fall injuries peak. The impact of ice and snow on the supply chain, power, and access to facilities may affect the function of facilities used to carry out public services.[8] Loss of power and transportation issues during ice and snow events may also limit access to medical help.

For this assessment, snow and ice events include extreme events that cause significant damage to property and infrastructure or that cause critical interruptions to transportation and power systems.

Supply Chain Interruption

Supply chains are the sequences of processes involved in the production and distribution of goods and services. In today's economy, many supply chains are complex national and international networks that rely on roads, rails, waterways, air routes, and pipelines to gather raw materials and deliver goods and services to the customers who use them.[22] Multiple stressors and threats can result in supply chain interruptions, including tropical storm impacts to the Gulf of Mexico and South Atlantic coastal areas, with related flooding events that can interrupt transportation.

For purposes of this assessment, supply chain threats were defined by events that can interrupt petroleum and natural gas pipelines, as well as road, highway, and rail infrastructure leading into the Triangle region.

Water Shortage

The threat of water shortage is due to drought, or the lack of precipitation. For more information, refer to the discussion of drought in the Climate Stressors section of this report.

The Triangle region lies within the headwaters of two watersheds and relies heavily on surface water, but it cannot necessarily do so during times of drought. Groundwater can augment supplies and minimize drought impacts; however, the complex geology of the Piedmont region results in groundwater variability and means that groundwater flow and potential resources in this region of North Carolina are not well understood.[23]

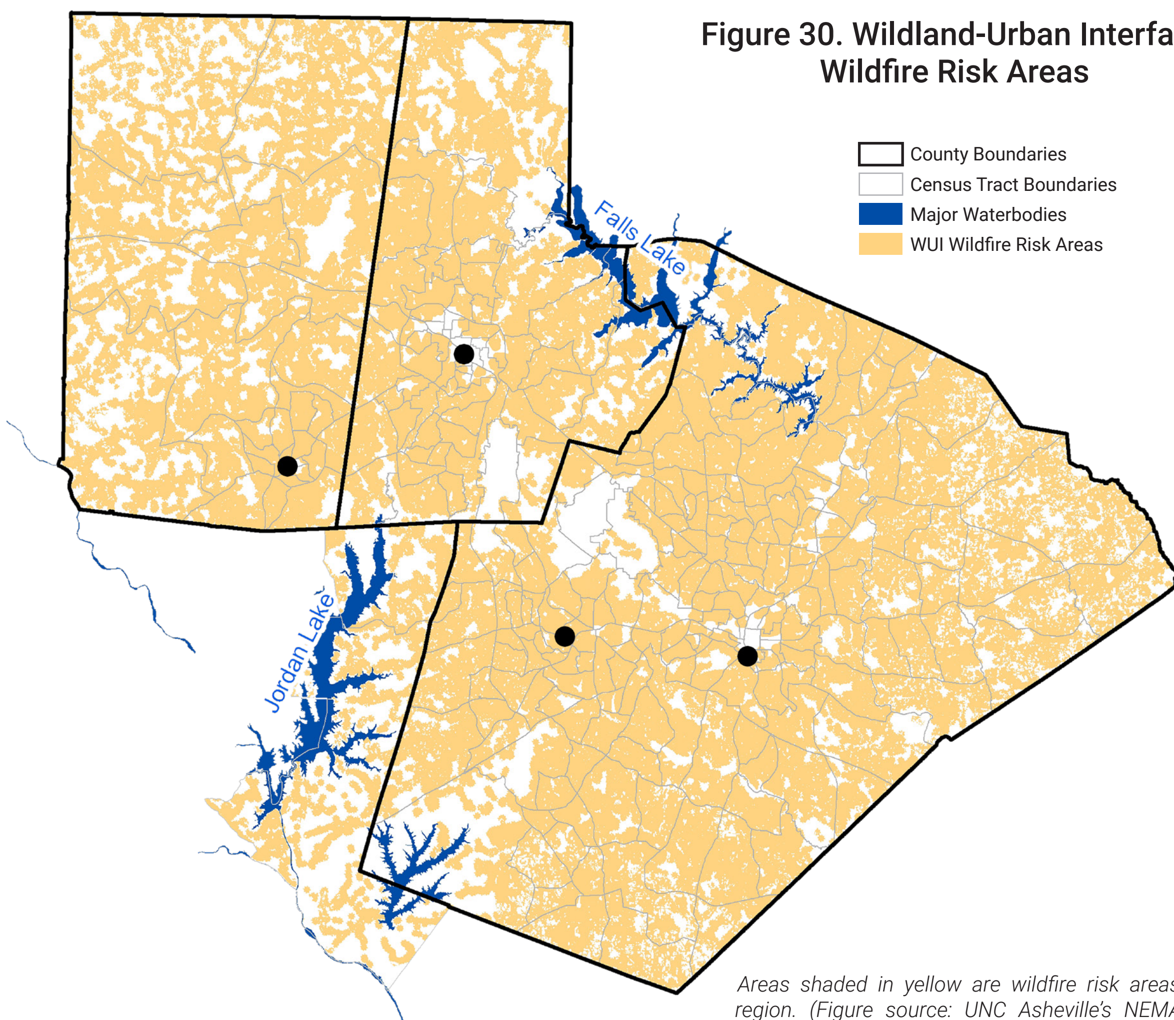
Wildfire

Wildfire is a natural disturbance that provides benefits to ecosystems and natural systems, but it can become a threat when it negatively impacts communities and the assets we value. Drought conditions can lead to a greater chance of wildfire. For purposes of this assessment, the threat of wildfire was defined by wildland-urban interface (WUI) risk areas as defined by the Southern Group of State Foresters.[24]

As water shortage is not confined to specific areas, all areas within the region were determined to be exposed and potentially affected. Instead of using hazard areas, exposure to the threat of water shortage was evaluated by considering the assets that use or rely on the supply and availability of water.

The southeastern U.S. leads the nation in number of wildfires, averaging 45,000 fires per year. Increasing temperatures contribute to increased fire frequency, intensity, and size. Expanding population and associated land-use fragmentation can limit the application of prescribed burning, a useful adaptive strategy, particularly in the Southeast.[25]

Figure 30. Wildland-Urban Interface Wildfire Risk Areas



Areas shaded in yellow are wildfire risk areas for the region. (Figure source: UNC Asheville's NEMAC. Data source: Southern Group of State Foresters, Southern Wildfire Risk Assessment WUI Risk Index, 2015.)

Wind

Climate change increases the risk, frequency, and intensity of extreme events that can bring high wind speeds, including tropical storms, tornadoes, and strong thunderstorms (microbursts). In fact, tornadoes and other severe thunderstorm phenomena frequently cause as much annual property damage in the U.S. as do hurricanes, and often cause more deaths. Recent research has yielded insights into the connections between global warming and the factors that cause tornadoes and severe thunderstorms, such as atmospheric instability and increases in wind speed with altitude. Although these relationships are still being explored, a recent study suggests a projected increase in the frequency of conditions favorable for severe thunderstorms.[14]

North Carolina has been affected by extreme wind events over the past 75 years, including tornadoes, tropical storms, hurricane-force winds, and large hail events. As shown in Tables 2 through 5, these events have produced light to severe damage.

Wind events can damage property and infrastructure and can cause temporary interruptions to transportation and power systems (Figure 31).

Figure 31. Wind Damage in Orange County

Tree limbs down on a house and pickup truck in Orange County, NC, after a storm. (Image credit: David Hunt, Orange County, North Carolina, taken 05/29/2010. Used with permission.)

TABLE 2. TORNADO OCCURRENCES AND MAGNITUDES SINCE 1950 (NORTH CAROLINA)

F-Scale	Damage	# of Occurrences
F-0	65–85 mph, light damage	61
F-1	86–110 mph, moderate damage	57
F-2	111–135 mph, considerable damage	29
F-3	136–165 mph, severe damage	6
F-4	166–200 mph, devastating damage	1
F-5	Over 200 mph, incredible damage	0

TABLE 3. RECORDED WIND EVENTS AND MAGNITUDES SINCE 1955 (NORTH CAROLINA)

Beaufort Wind Scale	Wind (knots)	Damage Description	# of Occurrences
10	48–55	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"	1,686
11	56–63	Violent storm	81
12	64+	Hurricane-force	29

TABLE 4. RECORDED TROPICAL STORM EVENTS FROM 1955–2015 (WITHIN A 50 MILE RADIUS OF MORRISVILLE, NC)

Saffir-Simpson Scale	Wind Speed (mph)	# of Occurrences
Tropical Depression	0–38	10
Tropical Storm	39–73	3
Category 1 Hurricane	74–95	1

TABLE 5. HAIL EVENTS AND SIZE SINCE 1955 (NORTH CAROLINA)

Size (inches)	# of Occurrences
0.75	481
0.76–0.88	187
0.89–1	382
1.01–1.5	87
1.51–4	241

Storm Events Database. National Ocean and Atmospheric Administration, National Centers for Environmental Information. Last modified May 2018. https://www.ncdc.noaa.gov/stormevents/

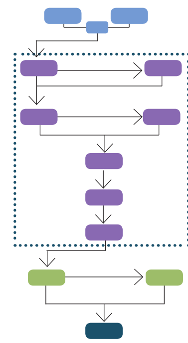
Assets

In this resilience assessment process, assets were identified by exploring the project team's institutional knowledge of shared types of assets, as well as local comprehensive and hazard mitigation plans. From this combined effort, Table 6 lists asset categories (broad) and the assets that define them (more specific) used as the TRRP moved into Step Two of the resilience assessment.

TABLE 6. TRIANGLE REGION ASSETS

Asset category	Short description
Natural	
Agriculture	Includes agricultural properties.
Natural Areas	Includes existing natural areas of conservation value defined using North Carolina's Biodiversity/Wildlife Habitat Assessment,[26] which prioritizes aquatic and terrestrial habitat, landscape function, and connectivity. This asset does not include areas of low habitat quality that may have potential for land restoration.
Properties	
Commercial Properties	Includes non-residential properties that serve businesses and organizations. They also typically support commerce, jobs, and tourism.
Cultural and Historic Resources	Includes buildings or properties that are cultural, religious, or historic resources.
Industrial Properties	Includes small businesses, factories, and companies that manufacture goods or materials. They are significant locations for local employment and often include distribution centers, which distribute goods to stores or directly to customers. Industrial properties and companies also serve as important sites of raw materials, such as gravel and concrete, and support the local construction sector.
Residential Properties	Includes all single-family residences, multiple-family residences, low-income housing, group homes, apartments, manufactured houses, and mobile home parks.
Public Services and Health	
Emergency Services	Includes fire and police stations and other facilities that aid in emergency response.
Energy and Utilities	Includes buildings or infrastructure for the generation or
Food Infrastructure	Includes food processing/distribution centers and locations where people access food (including grocery stores, SNAP businesses, food pantries, and restaurants).
Hospitals and Medical Facilities	Includes major regional hospitals and local clinics that provide access to medical care.

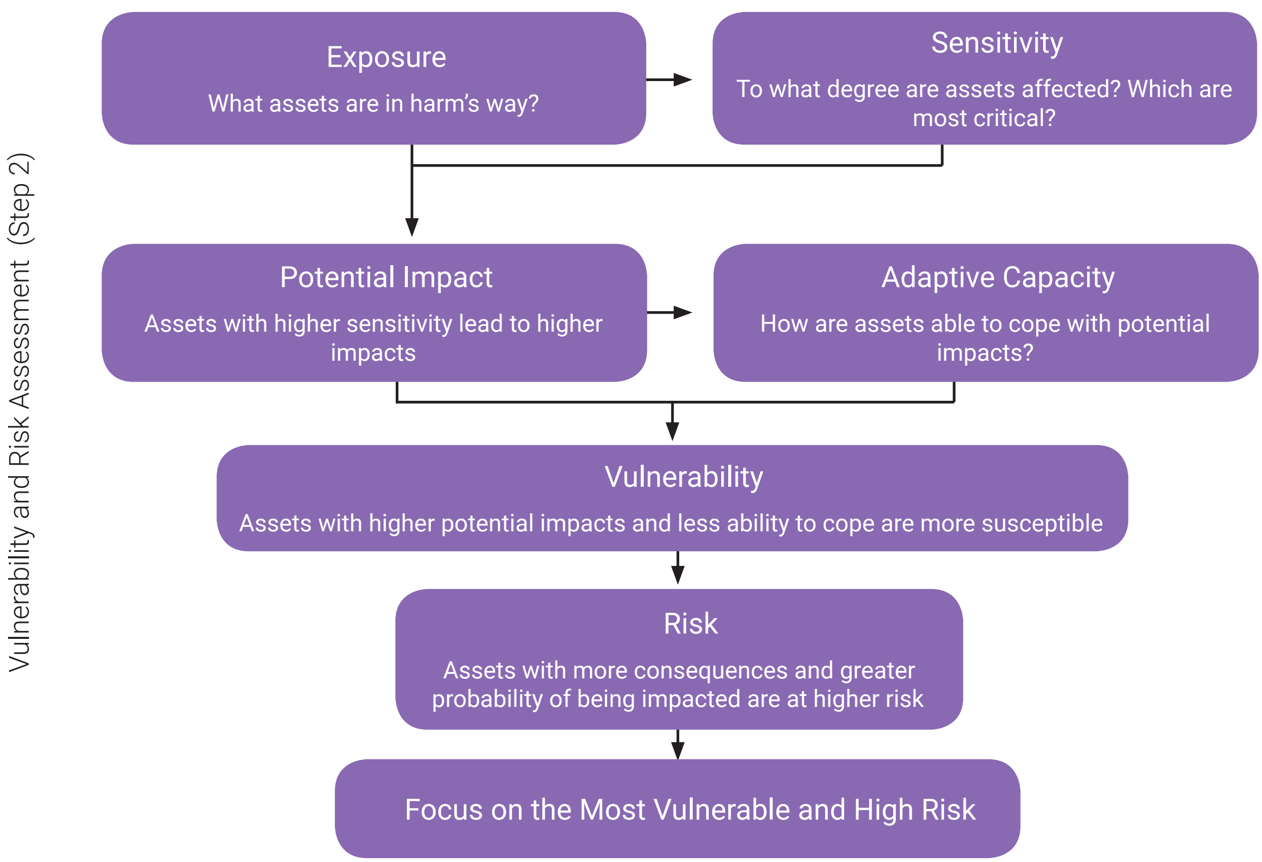
Asset category	Short description
Jurisdictional- and State-Owned Properties	Includes any universities or state-owned properties that support the operation of jurisdictional and state operations or governance and public and private schools (primary, middle, and high schools and colleges/universities).
Parks and Greenways	Includes all parks and community centers.
People and Human Health	Includes all people within the study area, including sensitive populations.
Transportation	
Airport	Includes the Raleigh-Durham International Airport.
Railways	Includes all rail lines.
Roads	Includes major and minor roads, bridges, and the service they provide for mobility and access for emergency services.
Water	
Stormwater Infrastructure	Includes pipes, culverts, and channels (natural and man-made).
Wastewater	Includes sewer lines, wastewater treatment plants.
Water Distribution	Includes dams, water lines, tanks, and treatment plants.
Water Supply	Includes major regional water supply sources, including reservoirs, lakes, and river intakes.



Step Two | Assess Vulnerability & Risks

Assessment Approach

The purpose of Step Two is to understand how a community's assets are likely to be impacted by the climate threats indentified during Step One. This assessment then becomes the foundation for developing option to build resilience in Step Three.



The assessment approach begins with the following steps: (1) asset data normalization and categorization; (2) spatial relation of individual assets to each threat layer to determine exposure; (3) application of criteria for exposed assets to assess vulnerability and risk; and (4) aggregation of most vulnerable and at-risk assets to census tracts.

Asset Data Normalization and Categorization

As the data for asset types differs, it must first be normalized into a general shape by removing superfluous fields and ensuring that the spatial data is complete, and then categorized according to the asset's use. For this assessment, parcel data for property-based assets were categorized according to the parcel use codes attached to each parcel record. Other asset types did not require additional categorization.

Determine Exposure

For each asset-threat pair, we performed a spatial intersection of the asset with the threat.

- For assets of Property Parcels and Structure types, if any part of the threat extent fell within the extent of a given parcel, it was marked as exposed. Only the intersection of parcels to the threat data was considered; structures were not considered for properties in the exposure assessment.
- For assets of Linear Feature type, if any part of a line segment of the feature intersected with the threat extent, that line segment was marked as exposed. Note that this may cause an overestimation of length exposed to the threat.
- For assets of Structure type, if any part of that structure intersected with the threat extent, that structure was marked as exposed.

Asset-Threat Pairs

Exposure is the presence of assets in relation to a threat—assets that are in harm's way. This exposure determination was made based on the spatial intersection of the asset with the threat as described above, as well as the team's institutional knowledge and past historical events. Each unique combination of an asset and the threats to which it is exposed is referred to as an "asset-threat pair." The identified asset-threat pairs included in this assessment are listed in Table 7.

TABLE 7. ASSET-THREAT PAIRS

	Air Pollution	Change in Growing Season	Disease	Extreme Cold	Extreme Heat	Flooding	Minor Flooding, Runoff, and Erosion	Snow/Ice Event	Supply Chain Interruption	Water Shortage	Wildfire	Wind
Natural												
Agriculture		•				•	•			•		
Natural Areas							•			•		
Properties												
Commercial Properties						•	•			•	•	
Cultural and Historic Resources						•	•			•		

	Air Pollution	Change in Growing Season	Disease	Extreme Cold	Extreme Heat	Flooding	Minor Flooding, Runoff, and Erosion	Snow/Ice Event	Supply Chain Interruption	Water Shortage	Wildifre	Wind
Industrial Properties						•	•			•	•	
Residential Properties						•	•			•	•	•
Public Services and Health												
Emergency Services				•	•	•	•	•		•	•	•
Energy and Utilities				•	•	•	•	•	•	•	•	•
Food Infrastructure				•	•	•	•	•	•	•		•
Hospitals and Medical Facilities	•		•	•	•	•	•	•	•	•		•
Jurisdictional- and State-Owned Properties				•	•	•	•	•				•
Parks and Greenways						•	•					
People and Human Health	•		•	•	•		•	•		•		
Transportation												
Airport						•	•	•				•
Railways						•	•	•				•
Roads					•	•	•	•			•	•
Water												
Dams						•	•					
Stormwater Infrastructure						•	•					
Wastewater Infrastructure						•	•					
Water Infrastructure						•	•					
Water Supply						•	•			•		

Assessment of Vulnerability and Risk

The purpose of assessing assets and threats is to provide a foundation of information for building resilience. Different types of assessments were conducted based on available information and resources, but also based on the level of detail needed for identifying resilience-building options. These resulted in spatially distinct assessments and non-spatially distinct assessments.

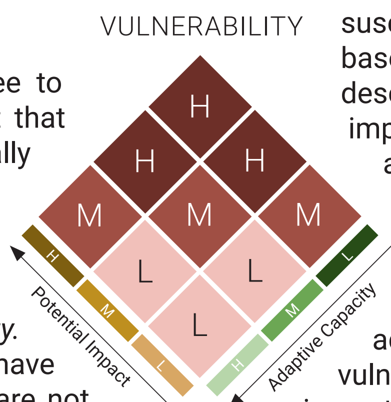
Spatially Distinct Assessments

The team applied a vulnerability and risk assessment framework to each asset-threat pair that resulted in levels of vulnerability and risk that are relative to each asset-threat assessment, although similar criteria were often applied across assessments. The assessment framework used multi-criteria decision analysis as well as spatial analysis in a data-driven pipeline.[27] This involved developing criteria, or rules, that were used to assign to assets specific ordinal classifications of high, medium, and low for each of the variables described below. The classifications were then combined using a matrix approach to determine levels of vulnerability, risk, and combined vulnerability and risk.[28]

Potential Impact

Potential impact is the degree to which an exposed asset (asset that is in harm's way) is potentially negatively affected by a climate-related threat. The level at which an exposed asset is negatively affected is also referred to as the asset's *sensitivity*. Assets that are not exposed have no potential impact; thus, they are not vulnerable, or at risk. Exposed assets were evaluated for levels of sensitivity, which were used in determining levels of potential impact.

Factors used to determine levels of potential impact were based on the asset's characteristics or on the level of impact due to service loss if the asset were to be affected.[29]



For example, a property with a building structure in a flood hazard area has a higher potential impact than does a property that does not have a building in a flood hazard area.

Adaptive Capacity

Adaptive capacity considers how an asset is able to cope with a threat event or impact. An asset with adaptive capacity is able to withstand an impact with minimal disruption or loss. Measures of adaptive capacity can include physical elements, conditions, or designs in place that help an asset absorb an impact. Exposed assets were evaluated for indicators of adaptive capacity and classified accordingly.

For example, a commercial building that has flood-proofed its foundation and raised its ground floor above flood levels has more adaptive capacity than a commercial building that has not done so. As another example, a park with facilities designed to withstand flood waters without damaging its infrastructure has adaptive capacity.

Vulnerability

Vulnerability describes the susceptibility of exposed assets based on the two core concepts described above: (1) potential impact—the degree to which an asset is affected; and (2) adaptive capacity—the ability the asset has to cope with a potential impact. Assets with low potential impact and high adaptive capacity are the least vulnerable. Assets with high potential impact and low adaptive capacity are the most vulnerable. For example, a business-related structure in the flood hazard zone has a "high" level of potential impact and, if it was built before 1979, it is classified as having "low" adaptive capacity. Together, they result in a "high" vulnerability classification.

Risk Probability

Probabilities were determined for each threat using annualized likelihoods of threat occurrence or relative levels based on known risk factors. For example, for flooding, the floodway, 100-year, and 500-year flood hazard zones were used to evaluate different probabilities of flooding for each asset.

Risk Consequence

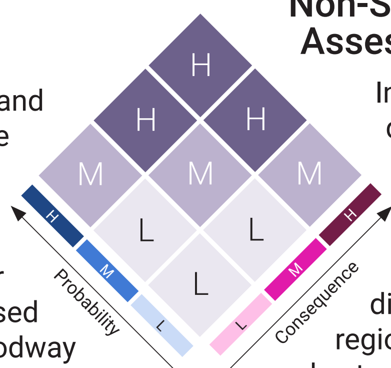
Risk consequence refers to negative outcomes or critical thresholds that indicate varying levels of significance if a threat were to occur. For example, assets with affected structures or a higher monetary value may have a greater negative consequence than assets with no affected structures or that have a lower monetary value.

Risk

Just as potential impact and adaptive capacity combine to determine vulnerability, risk probability and risk consequence combine to give us an assessment of risk. For example, a parcel with an exposed high-value building in the floodway would have a high risk classification, while a parcel in the 100-year flood hazard zone without an exposed building would have a low risk classification.

It is important to note that this step is referred to as risk scoping, as no loss estimates were quantified.

RISK

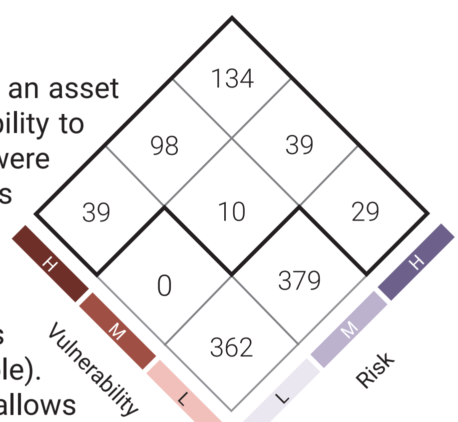


Combined Vulnerability and Risk

Vulnerability considers how an asset might be impacted and its ability to cope if a given threat event were to occur, and risk considers the probability of the threat occurring and the general consequence of the threat (without considering factors that make it susceptible). Combining these concepts allows decision makers to evaluate which assets are most susceptible and most likely to be impacted, and also to consider options according to different levels of risk threshold.

The matrix shown here features the combination of vulnerability and risk for Commercial Property and Flooding. High-vulnerability and high-risk parcels are in the top-most cell. Those that have low vulnerability and low risk are in the bottom-most cell. The cells with high or medium combined vulnerability and risk are included within a darker border outline. Note that most parcel-based assessments do not have criteria that result in a low vulnerability and high risk classification, so the right-most cell will often be zero.

COMBINED VULNERABILITY AND RISK



Non-Spatially Distinct Assessments

In addition to these spatially distinct assessments, there are a series of non-spatially distinct assessments that are addressed in narrative form. These threats are not spatially distinct either (a) because the entire region is effectively exposed, or (b) due to a lack of available modeled threat or corresponding asset data. Despite the lack of spatial distinction, many of these are major threats to the Triangle region and should be considered with weight similar to that given to the spatially distinct threats. These threats include:

- Air Pollution
- Change in Growing Season
- Disease
- Extreme Cold
- Minor Flooding, Runoff and Erosion
- Snow/Ice Event
- Supply Chain Interruption
- Water Shortage
- Wind

Disclaimer: This draft assessment is a working document and should not be considered final; all information is subject to change.

Aggregation to Census Tracts

The U.S. Census Bureau defines census tracts ("tracts") as small, relatively permanent statistical subdivisions of a county or equivalent entity with a primary purpose of providing a stable set of geographic units for the presentation of statistical data.[30] A census tract generally has a population size between 1,200 and 8,000 people, with an optimum size of 4,000 people. Census tracts were used to summarize the assessment results. Using census tracts as a common spatial unit for aggregation allows for comparison with socioeconomic variables published by the U.S. Census Bureau, and also allows comparison across asset categories for a given threat and across threats for a given asset.

Assets with medium to high combined vulnerability and risk were identified in order to focus on those assets with the greatest amount of vulnerability and risk. This is illustrated in the Combined Vulnerability and Risk matrix on the previous page: the categories within the solid black outline are those with medium to high combined vulnerability and risk. Assets that fell within these medium to high categories were then mapped at the census tract level.

Census tracts were then classified, based on the number of quantified assets located within them, into levels of high, medium, and low. Census tracts in the upper quartile were classified as high, tracts in the interquartile (between lower and upper quartiles) were classified as medium, and tracts in the lower quartile were classified as low.

The assessment maps found on the following pages thus display only individual assets with medium to high combined vulnerability and risk.

Vulnerability and Risk Summary

Building upon the exposure assessment, combined vulnerability and risk is presented on the following pages across the collection of assets and threats, and begins to highlight the most pressing issues for the Triangle region.

Table 8 lists results for the spatially distinct assessments, presenting the total number of assets, the exposure results (count and proportion), and the results for high and medium levels of combined vulnerability and risk (count and proportion) in the applicable asset category. Each entry also specifies which type of assessment was completed. Due to their nature, non-spatially distinct assessments are not included in the table.

TABLE 8. VULNERABILITY AND RISK SUMMARY

Asset	Threat	Type	Total	Exposed (count)	Exposed (%)	Medium-High V&R (count)	Medium-High V&R (%)
Natural							
Agriculture	Flooding	Vulnerability & Risk	5,412	1,438	26.6%	26	0.5%
Properties							
Commercial Property	Flooding	Vulnerability & Risk	12,022	1,086	9%	349	2.9%
Commercial Property	Wildfire	Vulnerability & Risk	12,022	9,770	81.3%	138	1.1%

Asset	Threat	Type	Total	Exposed (count)	Exposed (%)	Medium-High V&R (count)	Medium-High V&R (%)
Cultural and Historic Resources	Flooding	Vulnerability & Risk	2,588	94	3.6%	15	0.6%
Industrial Property	Flooding	Vulnerability & Risk	2,294	295	12.9%	72	3.1%
Industrial Property	Wildfire	Vulnerability & Risk	2,294	1,918	83.6%	37	1.6%
Residential Property	Flooding	Vulnerability & Risk	349,475	14,339	4.1%	3,227	0.9%
Residential Property	Wildfire	Vulnerability & Risk	349,475	335,496	96.0%	23,285	6.7%
Public Services and Health							
Energy and Utilities	Flooding	Vulnerability & Risk	565	129	22.8%	22	3.9%
Food Infrastructure	Flooding	Vulnerability & Risk	1,032	69	6.7%	27	2.6%
Jurisdictional and State-Owned Property	Flooding	Vulnerability & Risk	23,130	3,126	13.5%	369	1.6%
Parks and Greenways	Flooding	Vulnerability & Risk	209	59	28.2%	12	6.7%
Transportation							
Railways	Flooding	Exposure	237 (linear miles)	9	3.7%	N/A	
Roads	Flooding	Potential Impact/ Vulnerability	3,280 (linear miles)	158	4.8%	N/A	
Road Access—Non-residential	Flooding	Potential Impact/ Vulnerability	92,604	10,400	11%	N/A	
Road Access—Residential	Flooding	Potential Impact/ Vulnerability	349,475	20,000	6%	N/A	

Asset	Threat	Type	Total	Exposed (count)	Exposed (%)	Medium-High V&R (count)	Medium-High V&R (%)
Water							
Wastewater Facilities	Flooding	Exposure	209	45	21.5%	N/A	
Water Distribution Lines	Flooding	Exposure	15,077,474 (linear feet)	2,856	0.02%	N/A	
Water Distribution Facilities	Flooding	Exposure	92	7	7.6%	N/A	
Dams	Flooding	Vulnerability & Risk	605	605	100.0%	268	44.3%

Three asset-threat pairs initially identified for the assessment had either low regional exposure or low regional vulnerability and risk and discussions are therefore not included in the pages that follow. These asset-threat pairs include:

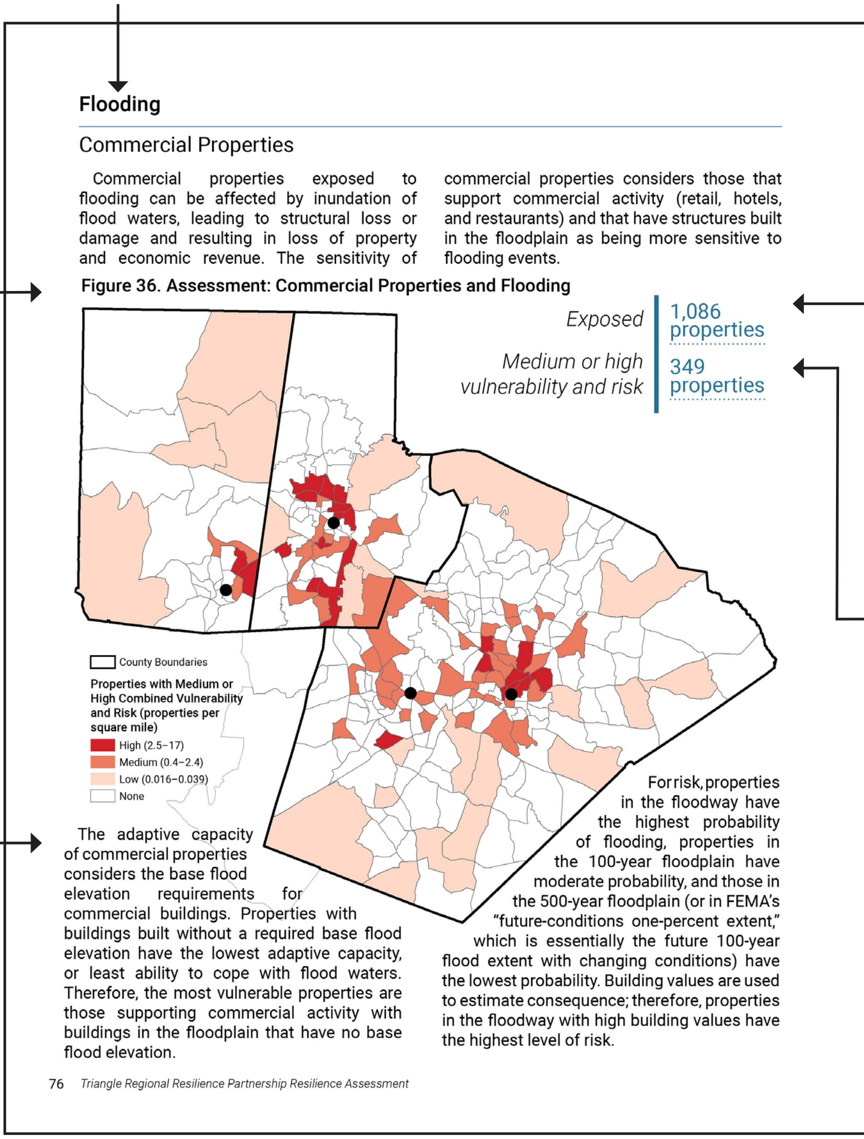
- Cultural and Historic Resources/Flooding
- Emergency Services/Flooding
- Hospitals and Medical Facilities/Flooding

How to Read the Assessments

The results of all asset-pair assessments are presented on the following pages, grouped by asset category in alphabetical order. Non-spatially distinct and spatially distinct assessments are interspersed to conform to the asset category structure; thus, some pages may have space that was intentionally left blank due to layout requirements.

The guide below points out the key features of the spatially distinct asset-threat pairs.

Asset-Threat Pair


Flooding

Commercial Properties

Commercial properties exposed to flooding can be affected by inundation of flood waters, leading to structural loss or damage and resulting in loss of property and economic revenue. The sensitivity of commercial properties considers those that support commercial activity (retail, hotels, and restaurants) and that have structures built in the floodplain as being more sensitive to flooding events.

Figure 36. Assessment: Commercial Properties and Flooding

Exposed 1,086 properties

Medium or high vulnerability and risk 349 properties

The adaptive capacity of commercial properties considers the base flood elevation requirements for commercial buildings. Properties with buildings built without a required base flood elevation have the lowest adaptive capacity, or least ability to cope with flood waters. Therefore, the most vulnerable properties are those supporting commercial activity with buildings in the floodplain that have no base flood elevation.

For risk, properties in the floodway have the highest probability of flooding, properties in the 100-year floodplain have moderate probability, and those in the 500-year floodplain (or in FEMA's "future-conditions one-percent extent," which is essentially the future 100-year flood extent with changing conditions) have the lowest probability. Building values are used to estimate consequence; therefore, properties in the floodway with high building values have the highest level of risk.

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Exposure

Number of assets region-wide in harm's way of the threat.

Count of assets most affected

Number of assets region-wide with medium or high combined vulnerability and risk.

Assets potentially most affected in each census tract

The high and medium vulnerability and risk parcels are aggregated within each census block group to identify the most vulnerable neighborhoods in the assessment area.

Note that the legend ranges are per census tract, which will vary from the "medium or high vulnerability and risk" total.

Assessment Criteria

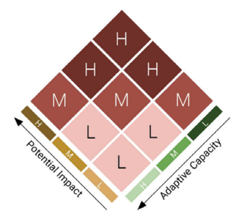
Rules used to assess levels of potential impact, adaptive capacity, risk probability, and risk consequence.

Vulnerability and Risk Matrices

Rules used to assess levels of potential impact, adaptive capacity, risk probability, and risk consequence.

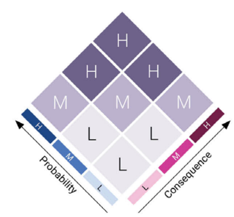
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain and business-related	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium	Structure in floodplain and warehouse or storage	Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



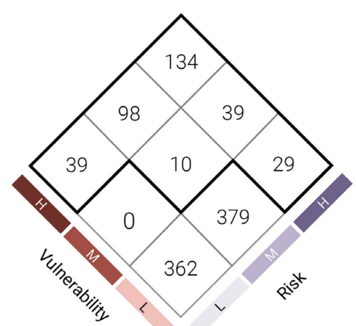
Risk

	Probability of Threat Event	Consequence of Threat Event
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



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Matrix Showing Selection of Medium to High Combined Vulnerability and Risk

Matrix showing how concepts are combined to produce levels of combined vulnerability and risk. Also, the number of assets that fall into each category and the total number in medium to high.

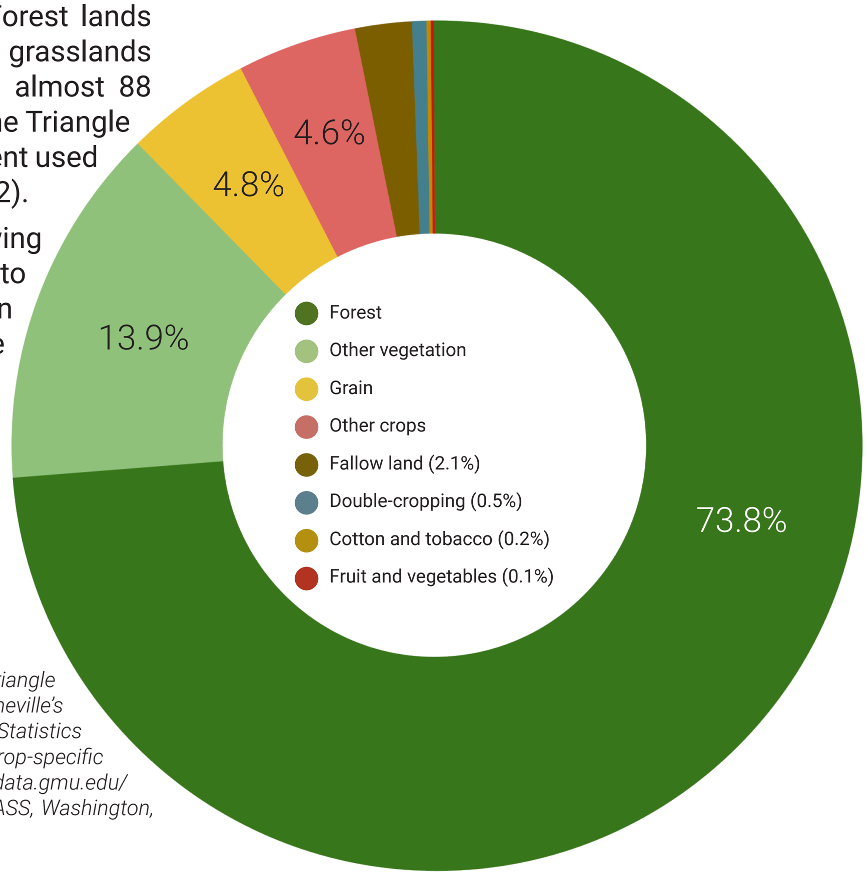
Note that the bold outline around the high and medium totals correspond to the map.

Agriculture

This asset includes properties identified as agricultural and includes cropland, horticultural land, and timber/forestry lands. Forest lands and other vegetation (including grasslands and wetlands) together compose almost 88 percent of this asset category in the Triangle region, with the remaining 12 percent used for grain and other crops (Figure 32).

The impact of longer growing seasons may be beneficial to agricultural and timber production in the region for the foreseeable future, with the exception of specific crop types or natural systems that may be sensitive to longer growing seasons or fewer frost-free days.

Figure 32. Regional Agricultural Lands



Breakdown of forest and crop lands in the Triangle region, by percentage. Figure source: UNC Asheville's NEMAC. Data source: USDA National Agricultural Statistics Service Cropland Data Layer. 2017. Published crop-specific data layer [Online]. Available at https://nassgeodata.gmu.edu/CropScape/ (accessed February 2018). USDA-NASS, Washington, DC.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Agricultural land that has a high economic value and/or has crops and livestock that are sensitive to cold, frost, changes in air temperature, and amount of rainfall	Property owner participates in incentive programs for crop diversification and/or produces more than one crop per farm
Medium		Property owner has limited participation in incentive program for crop diversification and/or produces few crops per farm
Low	Agricultural land that has a low economic value and/or does not have crops and livestock that are sensitive to cold, frost, changes in air temperature, and amount of rainfall	Incentive program for crop diversification is unavailable and/or a single crop is produced per farm

Flooding

Agriculture

This asset includes properties identified as agricultural and includes cropland, horticultural land, and timber/forestry lands. This assessment considers the structures and facilities within agricultural properties, so it does not account for potential damages directly to crops or production on these lands. Properties with facilities in flood-prone areas are more vulnerable.

Exposed — 1,438 properties

Medium or high vulnerability and risk — 26 properties

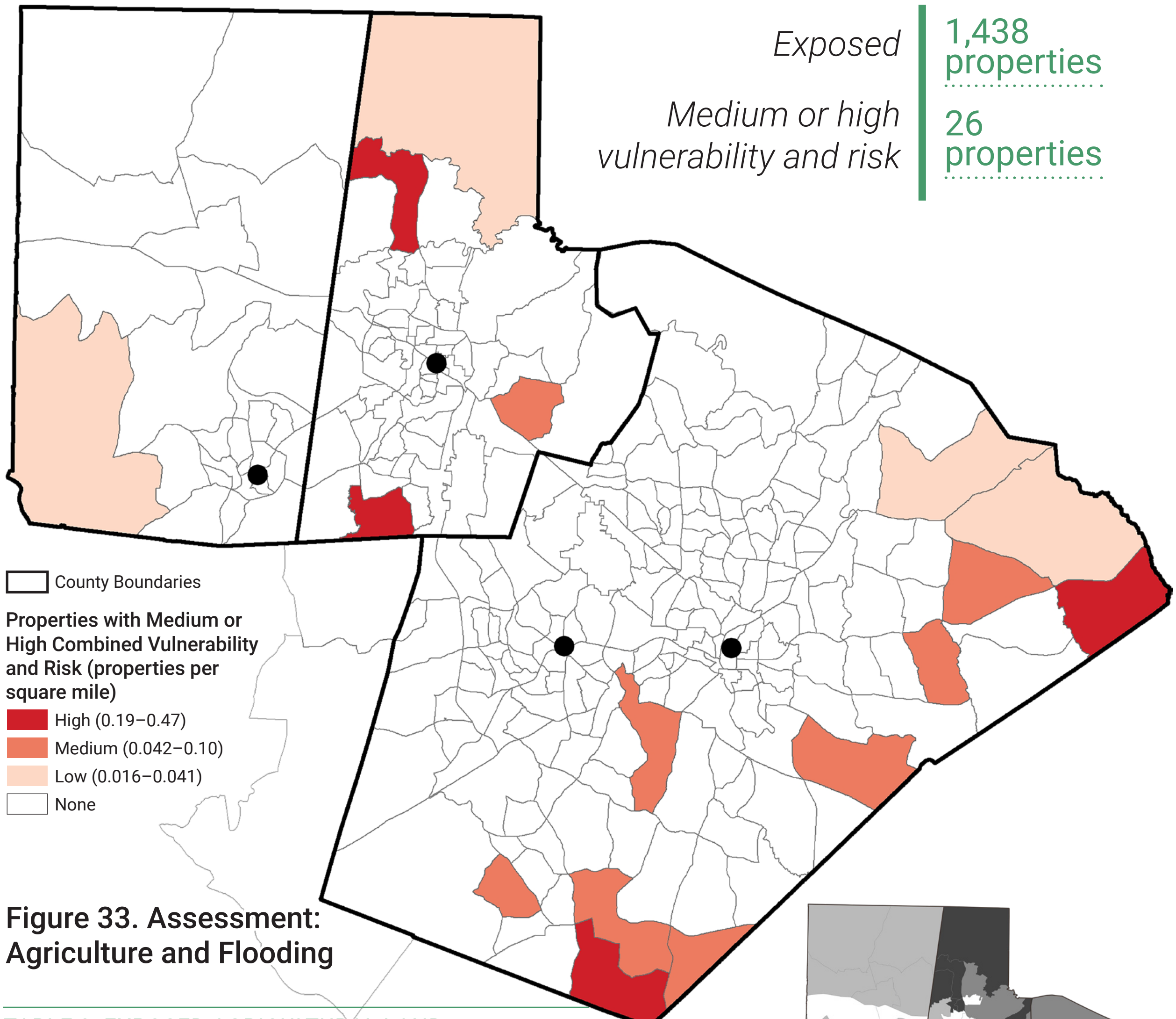


Figure 33. Assessment: Agriculture and Flooding

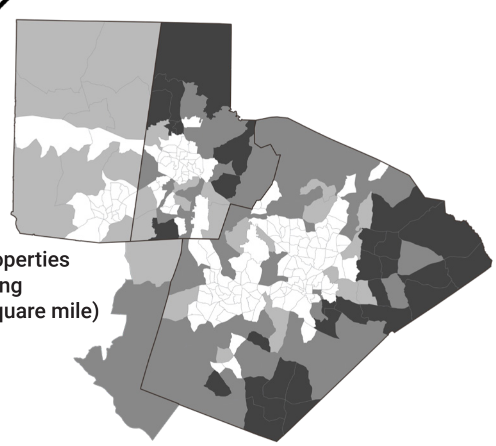
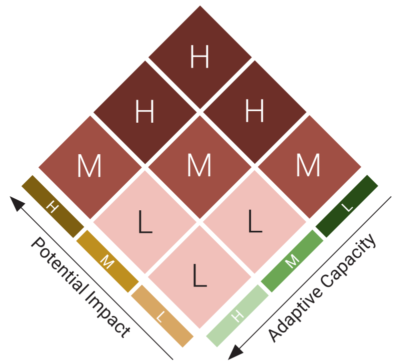


TABLE 9. EXPOSED AGRICULTURAL LAND

Agriculture type	Total Properties	Exposed
Forestry	1,456	499
Horticulture	134	20
Other agriculture	3,822	919

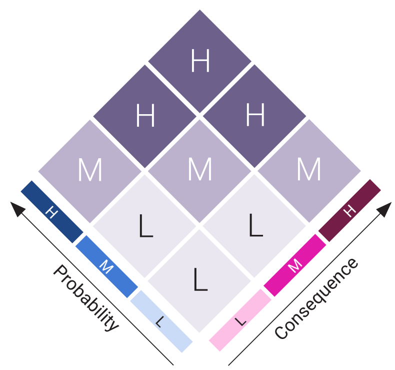
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



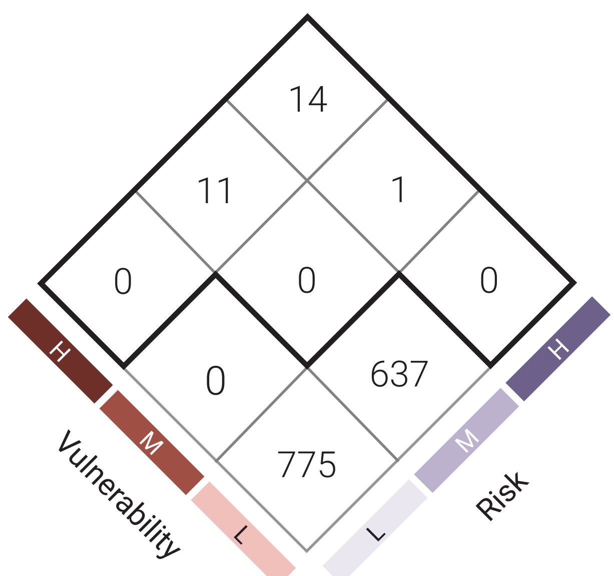
Risk

	Probability of Threat Event	Consequence of Threat Event
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



Water Shortage

Agriculture

Expanded irrigation is often suggested as one way to cope with water shortages.[31] Table 10 shows, for the region by county and for the state, irrigation information from the most recent Census of Agriculture.

TABLE 10. IRRIGATION IN THE TRIANGLE REGION, BY COUNTY, AND IN THE STATE OF NORTH CAROLINA

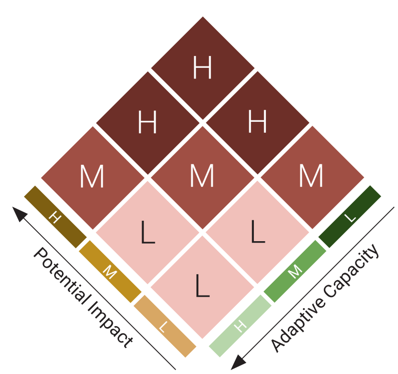
	Orange	Durham	Wake	Triangle Region	North Carolina
Total Farms, 2007	112	50	168	330	5,788
Total Farms, 2012	128	38	152	318	4,699
Acres of Land in Irrigated Farms, 2007	8,049	5,581	33,555	47,185	1,706,053
Acres of Land in Irrigated Farms, 2012	9,093	6,804	25,191	41,088	1,420,621
Acres of Irrigated Land, 2007	763	284	3,764	4,811	232,075
Acres of Irrigated Land, 2012	789	282	3,206	4,277	174,526

"Irrigated land" includes all land watered by any artificial or controlled means, such as sprinklers, flooding, furrows or ditches, subirrigation, and spreader dikes. Included are supplemental, partial, and preplant irrigation. Each acre was counted only once regardless of the number of times it was irrigated or harvested. If an operation reported less than one acre irrigated, the irrigated land for the operation was rounded to one acre. Livestock lagoon wastewater distributed by sprinkler or flood systems was also included. (Data Source: U.S. Department of Agriculture, 2012 Census of Agriculture, United States Summary and State Data.)

Some ecosystems—such as forests, dry land farms, and rangelands—rely solely upon rainfall, having no other water supply. These areas may be especially affected during periods of reduced precipitation.[31]

Vulnerability

	Potential Impact	Adaptive Capacity
High	Agricultural land using a crop type that is a high water user and having a large number of animals	Agricultural land that has drought-tolerant alternatives; agricultural land with alternative water supplies; permaculture
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	Agricultural land that is a low water user	Agricultural land that practices monoculture; agricultural land without alternative water supplies



Water Shortage

Natural Areas

In natural forested areas, water shortages can lead to greater susceptibility to insect infestations and disease outbreaks. When riparian areas are affected, it limits their ability to improve water quality, regulate stream flows, and provide flood control.

For this assessment, the North Carolina Natural Heritage Program's (NHP) biodiversity and habitat assessment[26] was used to consider natural lands with conservation value. In addition, the NHP's Managed Areas dataset was used to consider the management status (GAP status) of these natural conservation lands. This status is associated with the type of protection and the mandated management plan, some of which manage for natural disturbance events (including drought).

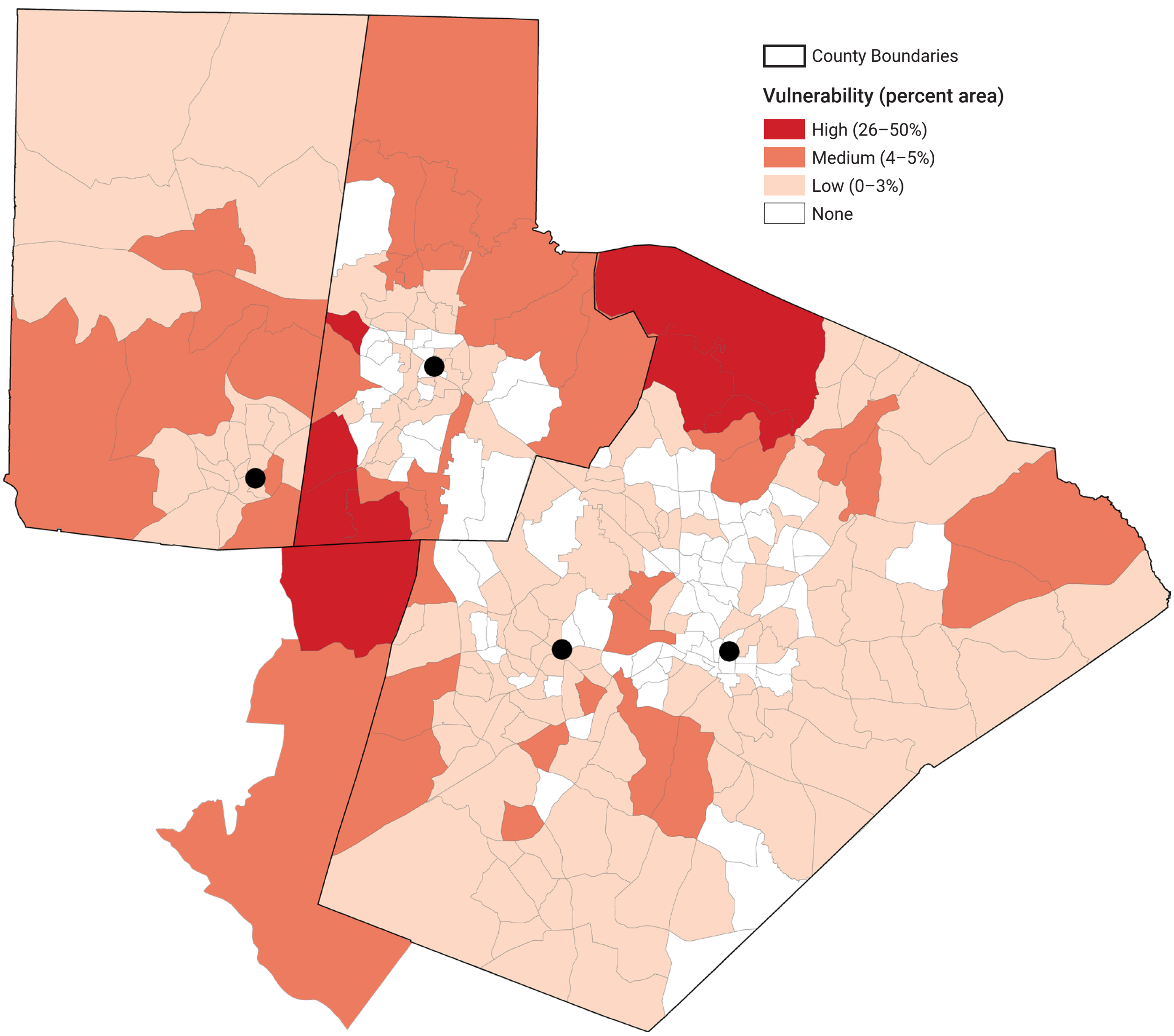


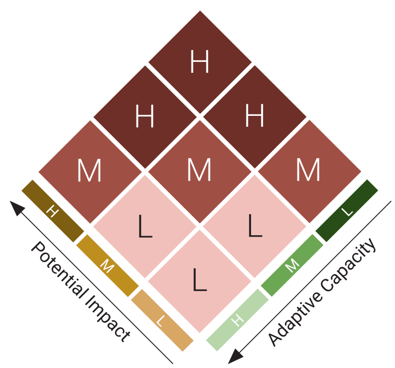
Figure 34. Assessment: Natural Areas and Water Shortage

For the Triangle region, the most vulnerable natural areas were considered to be those that are unmanaged (based on GAP status) but that have high conservation value. Most large blocks of natural land with high conservation value are in the areas surrounding Lake Jordan and Falls Lake, with the exception of a few city/state parks and several other areas with high conservation value.

The more urbanized areas within town or city limits are ranked medium or low in terms of their percentage of total natural area; however, most of the existing natural areas within these urbanized settings are associated with riparian stream buffers—important for regulating stream flows and for maintaining water quality. Therefore, the percent area (as shown on the assessment map) should not discount the important value of natural areas in the urbanized parts of the region.

Vulnerability

	Potential Impact	Adaptive Capacity
High	High conservation value (7–10) (based on NCDEQ's Biodiversity/Wildlife Habitat Assessment conservation values)	Area managed for disturbance and biodiversity (GAP status 1 or 2) (based on GAP management status)
Medium	Moderate conservation value (2–6) (based on NCDEQ's Biodiversity/Wildlife Habitat Assessment conservation values)	Area managed for multiple uses, but not for biodiversity or habitat (GAP status 3) (based on GAP management status)
Low	Low conservation value (1) (based on NCDEQ's Biodiversity/Wildlife Habitat Assessment conservation values)	No known management



PROPERTIES

Flooding

All Properties

The types of properties in this asset category include commercial, industrial, and residential. All properties were assessed for vulnerability and risk using comparable rulesets across the region.

Vulnerability considers how certain property uses/types are more sensitive than others and how buildings on these properties are able to cope and withstand flooding events. Varying levels of risk were also considered based on the consequence and probability of a flood event.

Figure 35 provides an overview of vulnerability and risk for all properties in the region.

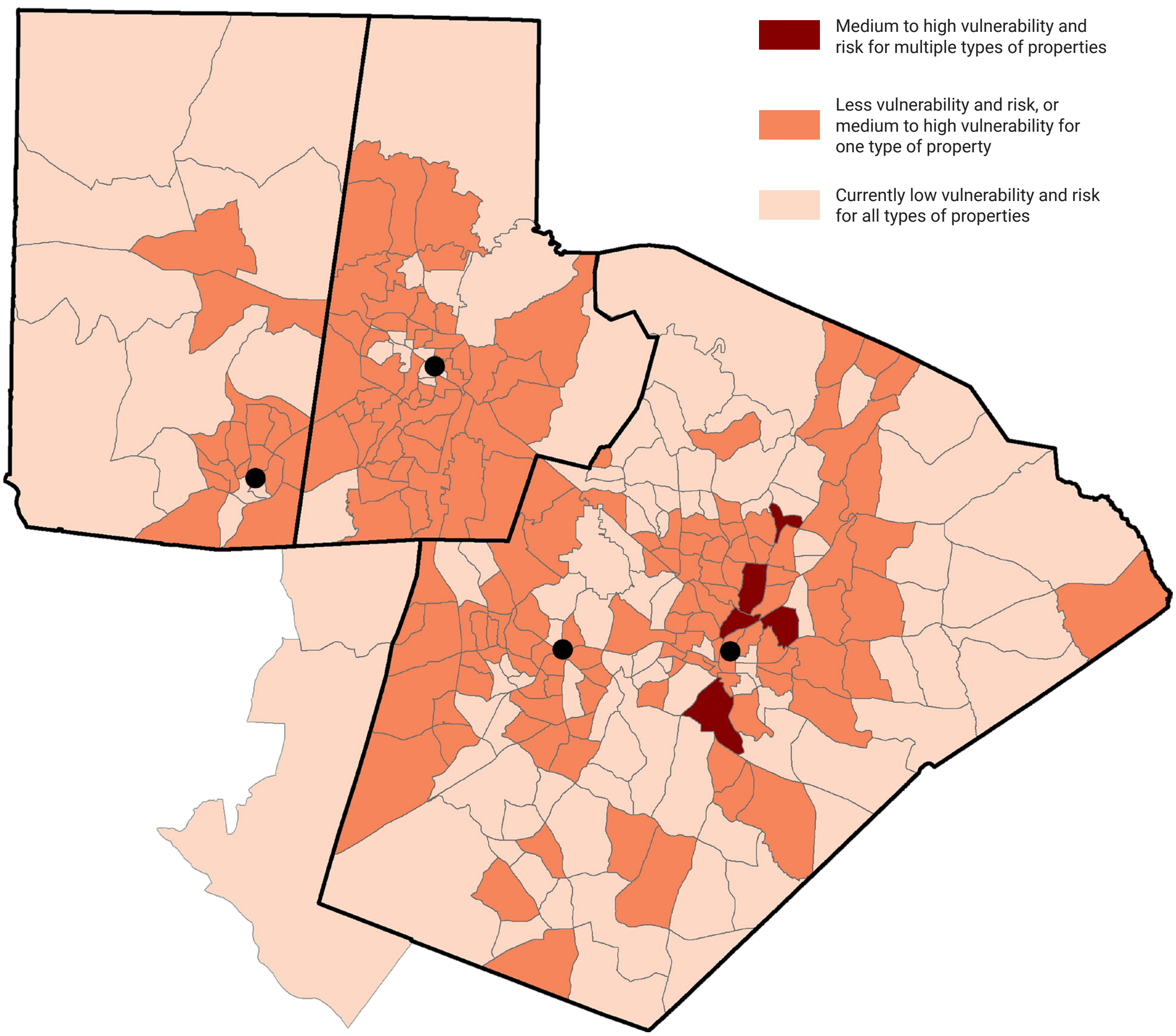


Figure 35. Assessment: All Properties and Flooding

Flooding

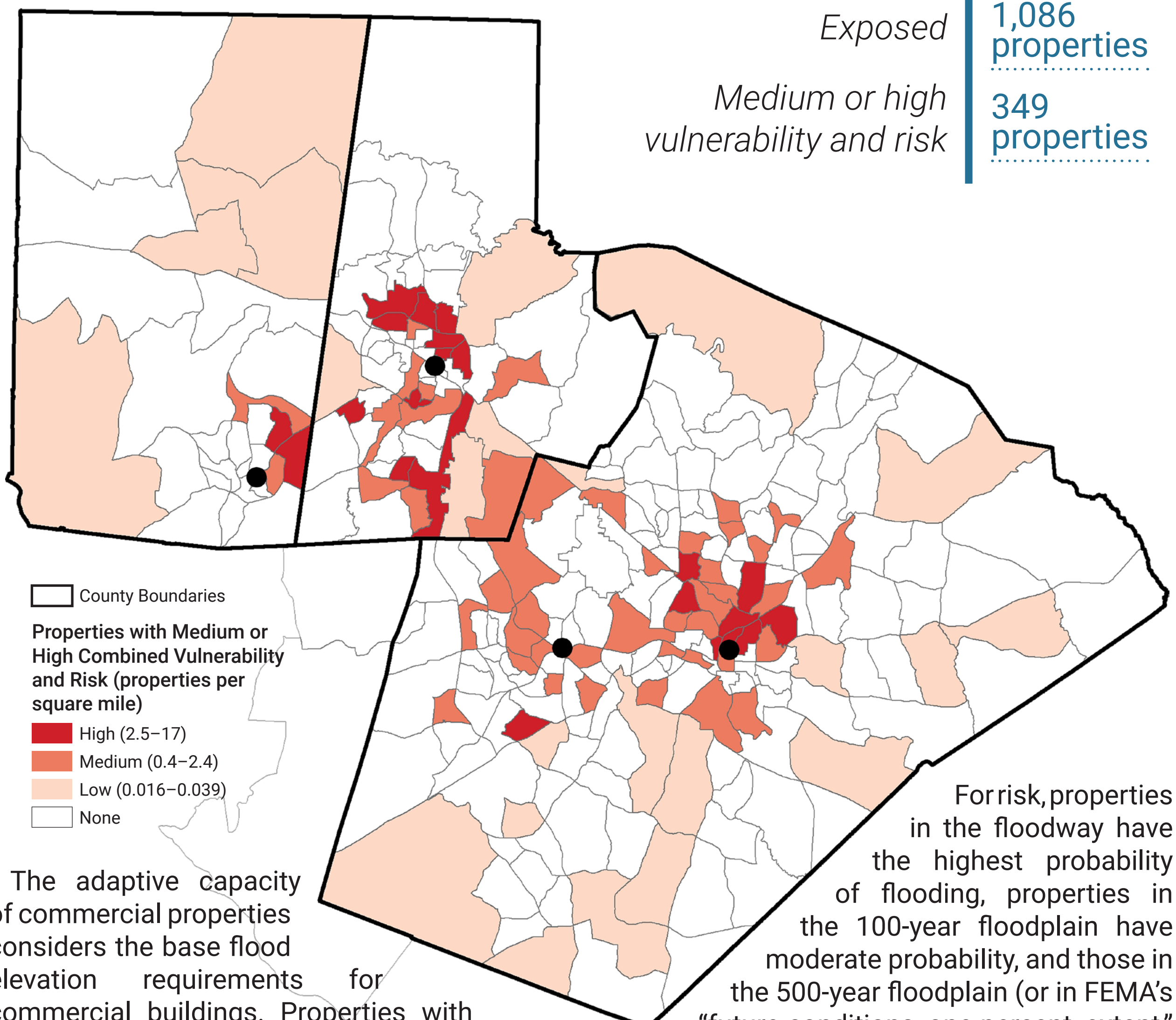
Commercial Properties

Commercial properties exposed to flooding can be affected by inundation of flood waters, leading to structural loss or damage and resulting in loss of property and economic revenue. The sensitivity of commercial properties considers those that support commercial activity (retail, hotels, and restaurants) and that have structures built in the floodplain as being more sensitive to flooding events.

Figure 36. Assessment: Commercial Properties and Flooding

Exposed 1,086 properties

Medium or high vulnerability and risk 349 properties



The adaptive capacity of commercial properties considers the base flood elevation requirements for commercial buildings. Properties with buildings built without a required base flood elevation have the lowest adaptive capacity, or least ability to cope with flood waters. Therefore, the most vulnerable properties are those supporting commercial activity with buildings in the floodplain that have no base flood elevation.

For risk, properties in the floodway have the highest probability of flooding, properties in the 100-year floodplain have moderate probability, and those in the 500-year floodplain (or in FEMA's "future-conditions one-percent extent," which is essentially the future 100-year flood extent with changing conditions) have the lowest probability. Building values are used to estimate consequence; therefore, properties in the floodway with high building values have the highest level of risk.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain and business-related	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
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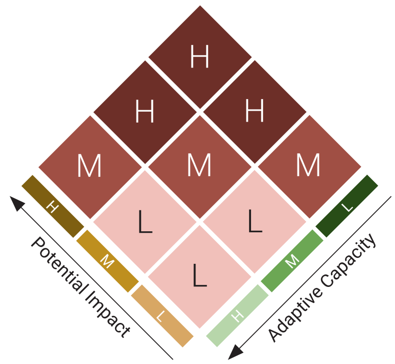
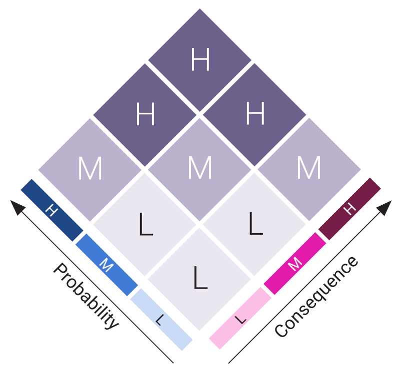


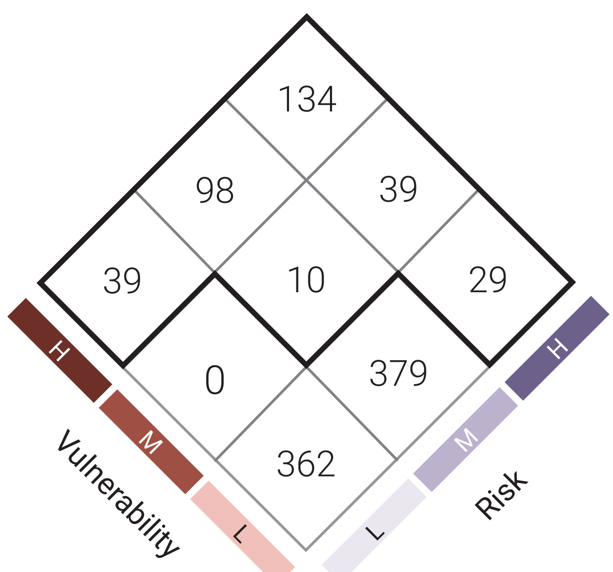
Risk

	Probability of Threat Event	Consequence of Threat Event
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



Flooding

Industrial Properties

Industrial properties include small businesses, factories, and companies that manufacture goods or materials. They are significant locations for local employment and often include distribution centers. Properties with structures in the floodway and 100-year floodplain have a higher risk than those in the 500-year floodplain.

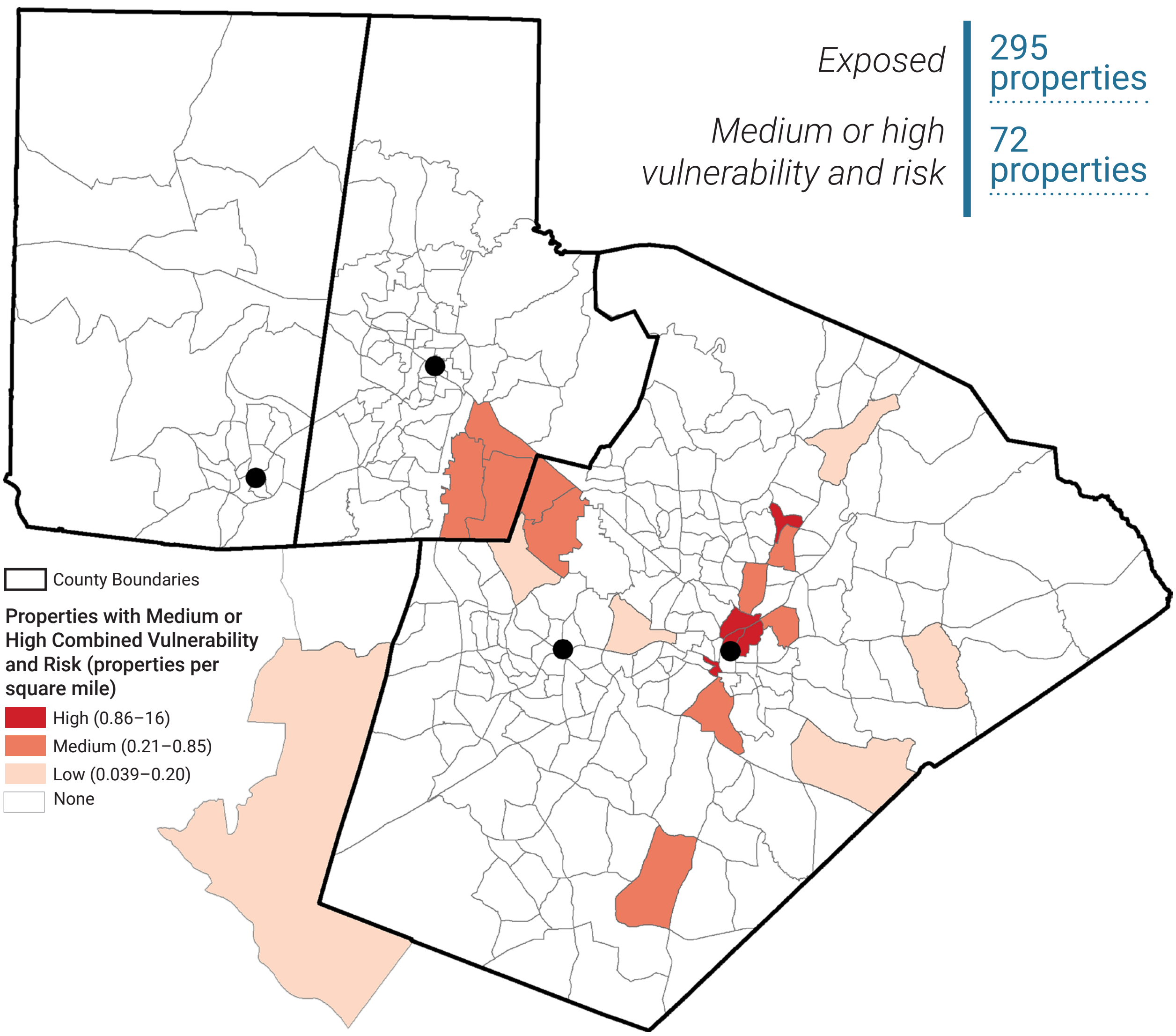
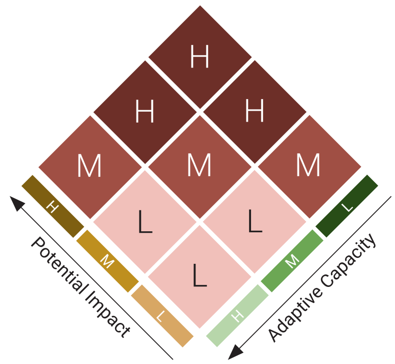


Figure 37. Assessment: Industrial Properties and Flooding

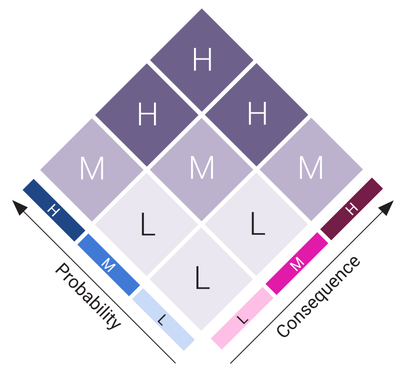
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



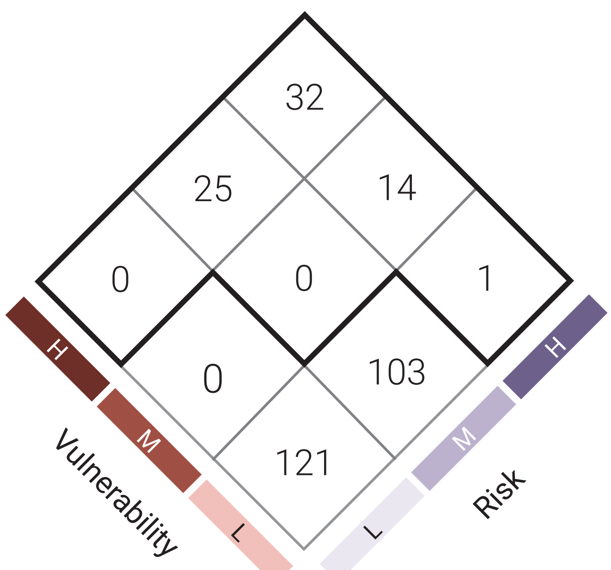
Risk

	Probability of Threat Event	Consequence of Threat Event
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



Flooding

Residential Properties

The sensitivity of residential properties considers different types of properties. Multi-family residential properties (apartments, low-income housing, nursing and retirement homes, group homes, and mobile home parks) are considered as being more sensitive than single-family residential properties to flooding events. Properties that have structures built within flood-prone areas are also considered more sensitive. Properties with buildings built without a required base flood elevation have the lowest adaptive capacity, or least ability to cope with flood waters. Therefore, the most vulnerable properties are those that are multi-family residential with buildings in flood-prone areas that have no base flood elevation.

Properties in the floodway have the highest probability of flooding, while properties in the 100-year floodplain have moderate probability and those in the 500-year floodplain (or in FEMA's future-conditions one-percent extent) have the lowest probability. Building values are used to estimate consequence; therefore, properties in the floodway with high building values have the highest level of risk.

Exposed — 14,339 properties

Medium or high vulnerability and risk — 3,227 properties

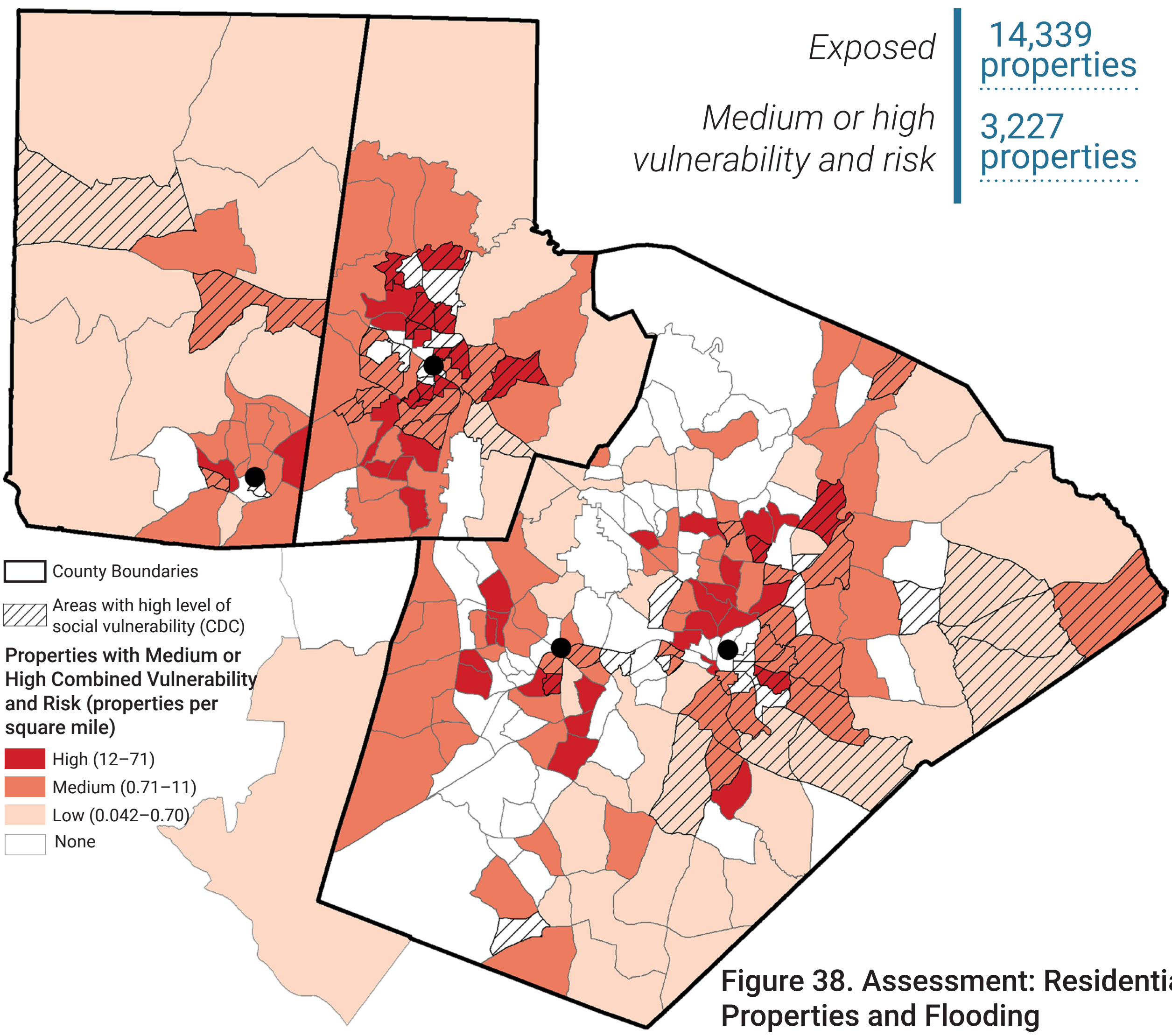
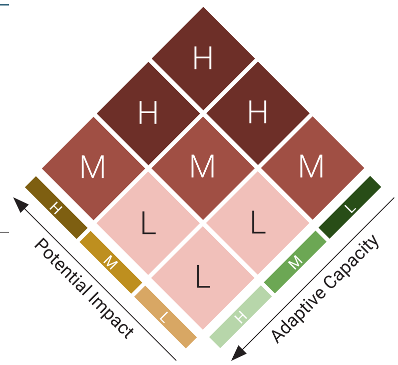


Figure 38. Assessment: Residential Properties and Flooding

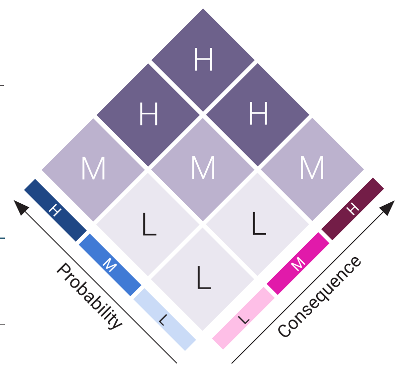
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain and multifamily residence, apartment, manufactured house, group home, nursing home, retirement home, or mobile home park	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium	Structure in floodplain and single residence	Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



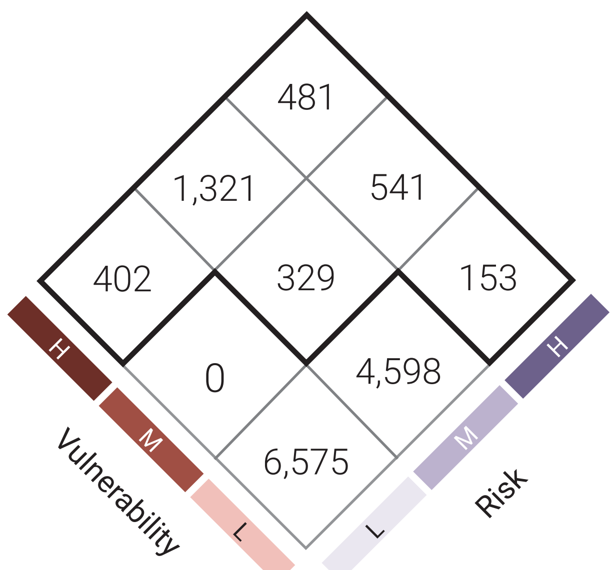
Risk

	Probability of Threat Event	Consequence of Threat Event
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



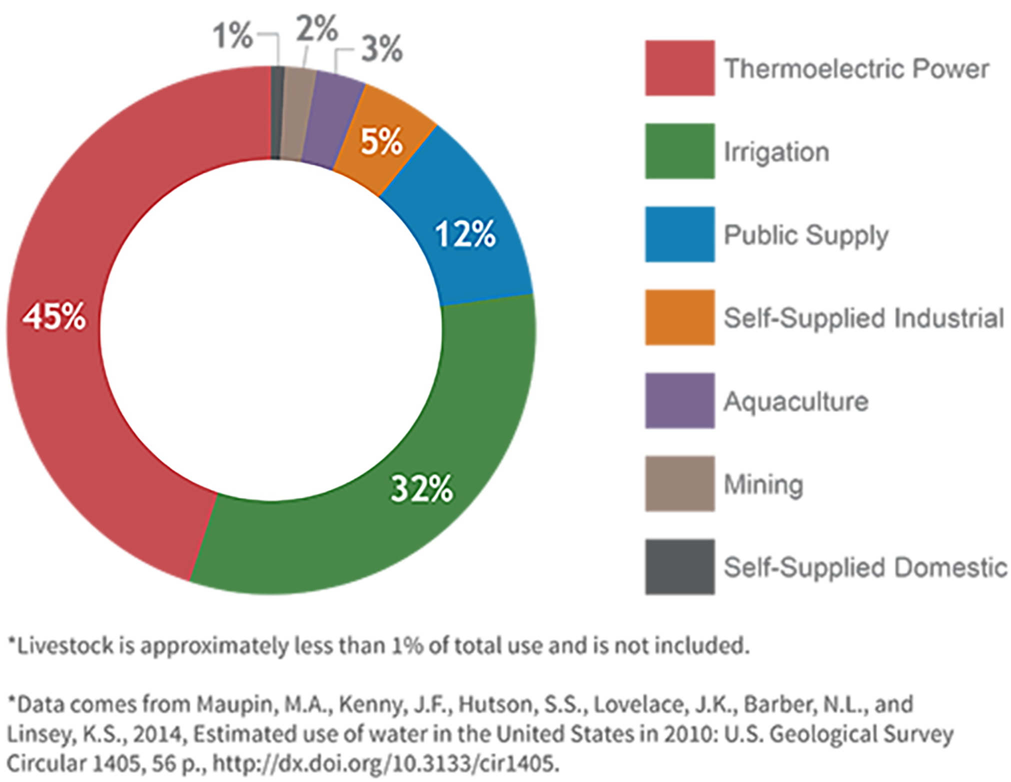
Water Shortage

All Properties

Water shortage can disrupt the supply of water to properties, which can be necessary for operations or the health and safety of the property's users.[32] In addition to direct impact of water supply disruption, an ongoing water shortage can increase the risk of soil erosion, increase vulnerability to fire, and affect building materials that are sensitive to humidity.[33]

At the national scale, the commercial and institutional sector is the second largest consumer of publicly supplied water, accounting for 17 percent of the withdrawals from public water supplies. This includes properties such as hotels, restaurants, office buildings, schools, hospitals, laboratories, and government and military institutions. Each facility type has different water use patterns depending on its function. Figure 39 shows how water is used, nationally, in different commercial and institutional facilities.[34]

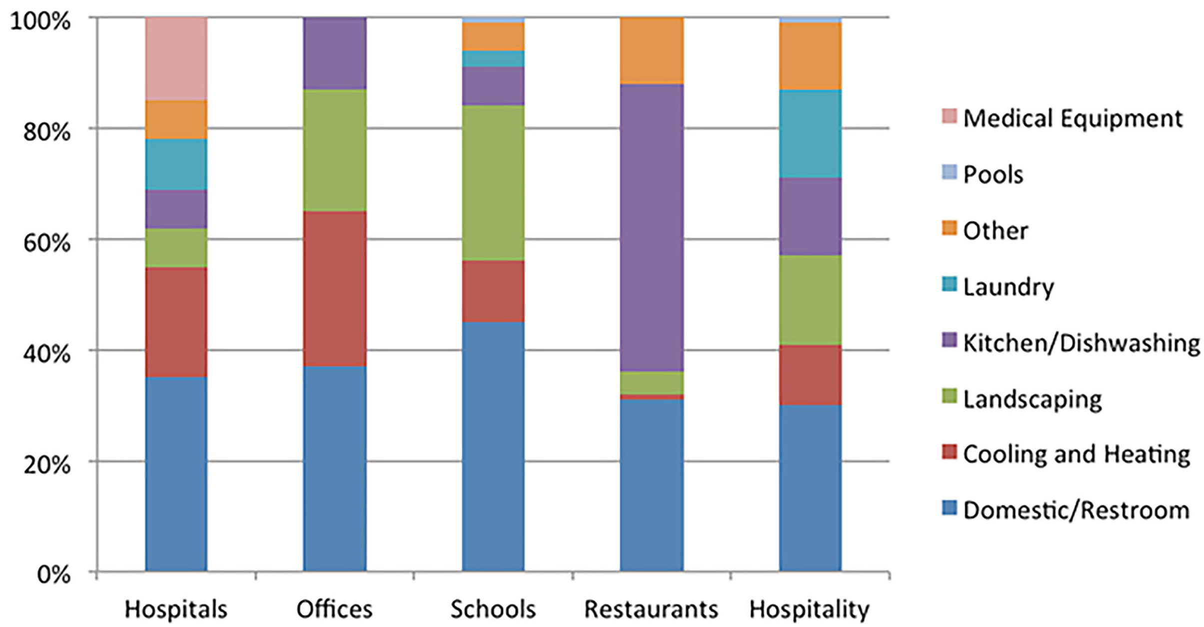
Figure 39. U.S. Freshwater Withdrawals



National freshwater withdrawals by sector (2010). (Figure source: U.S. Environmental Protection Agency, "WaterSense: How We Use Water.")

Specific sector-based water usage data for the Triangle region is not currently available, although it may be of some interest to the TRRP. It's important to note that thermoelectric power is the largest source of freshwater withdrawals nationally, followed by irrigation (Figure 40).

Figure 40. End Uses of Water



End uses of water in various types of commercial and institutional facilities. (Figure source: U.S. Environmental Protection Agency, "WaterSense: Commercial Buildings: Types of Facilities.")]

The Triangle region has undergone significant changes in the way it uses water, reflecting a national trend toward more efficient water use.[35] While the U.S. population has continued to increase, water usage efficiency on a national scale has improved considerably over the last 30 years. Those national trends are mirrored in North Carolina through the mid-2000s. For instance, a 2012 report from the North Carolina Division of Water Resources indicates that not only had total use per connection (all customer types) decreased, but that residential use per connection had declined considerably and was continuing to decline gradually.[35]

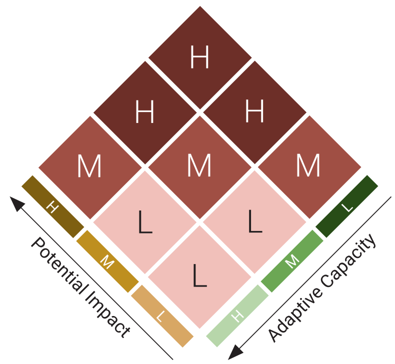
Recent trends have accelerated increases in water efficiency in North Carolina and, more specifically, in the Triangle region. The response of water utilities to the drought of 2007–2008, in the form of public communication and education, policy development, rate changes, and investments in infrastructure and programs, drove effective changes in water use that have continued even after the drought ended.[35]

Water Shortage

Commercial Properties

Vulnerability

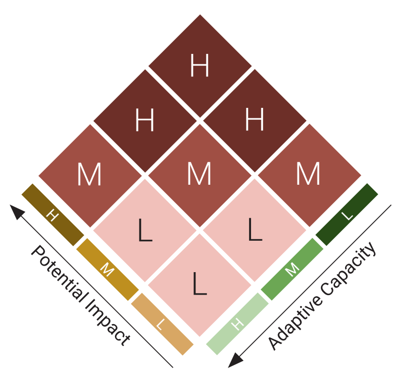
	Potential Impact	Adaptive Capacity
High		Properties where industries can change their process or shift production elsewhere during the shortage; properties where cooling water is used for comfort; properties where the industry has a continuity of operations plan (COOP) and it is exercised
Medium		Properties that have a COOP but it is not exercised
Low		Properties that can't change product lines or shift production; properties where cooling water is essential to operation; properties where industry doesn't have a COOP



Cultural and Historic Properties

Vulnerability

	Potential Impact	Adaptive Capacity
High	Properties that require water to maintain or function (e.g., botanical garden, park, fountain, arboretum)	Properties that have an alternative water supply; properties that use drought-tolerant species
Medium		
Low	Properties where water is not essential to function	Properties that do not have an alternative water supply; properties that do not use drought-tolerant species

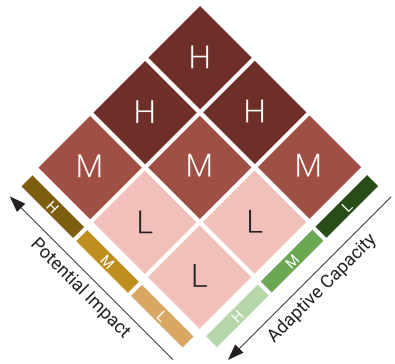


Water Shortage

Industrial Properties

Vulnerability

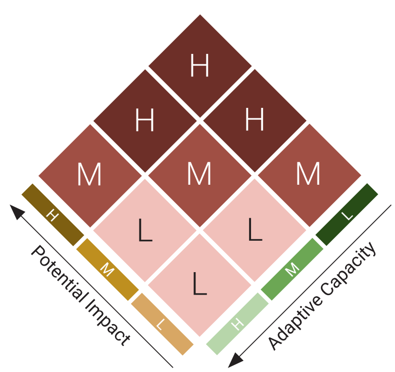
	Potential Impact	Adaptive Capacity
High		Properties where industries can change their process or shift production elsewhere during the shortage; properties where cooling water is used for comfort; properties where the industry has and exercises continuity of operations plans (COOP) and industry plans
Medium		Properties where the industry has COOP but it isn't exercised
Low		Properties where industry can't change product lines or shift production; properties where cooling water is essential to operations; properties where the industry does not have COOP



Residential Properties

Vulnerability

	Potential Impact	Adaptive Capacity
High	Properties with a high population; properties with a population of primarily older or very young people; properties with a large household size	Properties with residents with no accessibility needs
Medium		
Low	Properties with a low population; properties with few older or very young people; properties with a small household size	Properties with residents having accessibility needs



Wildfire

All Properties

Vulnerability and risk for residential properties is the highest where properties are within the wildland-urban interface (WUI). The WUI is where people and structures are in proximity or adjacent to fuels and burnable vegetation.

The WUI Risk Index from the Southern Group of State Foresters was used to estimate vulnerability of properties to wildfire, which incorporates WUI areas, fire intensity, and the presence of people and structures. In addition, drive times from fire stations were calculated and used as an adaptive capacity measure for initial response in a wildfire event.

The most vulnerable areas in the region have the highest number of properties within high WUI risk areas that are outside an eight-minute drive time from a fire station.

Figure 41 provides an overview of vulnerability and risk for all properties in the region.

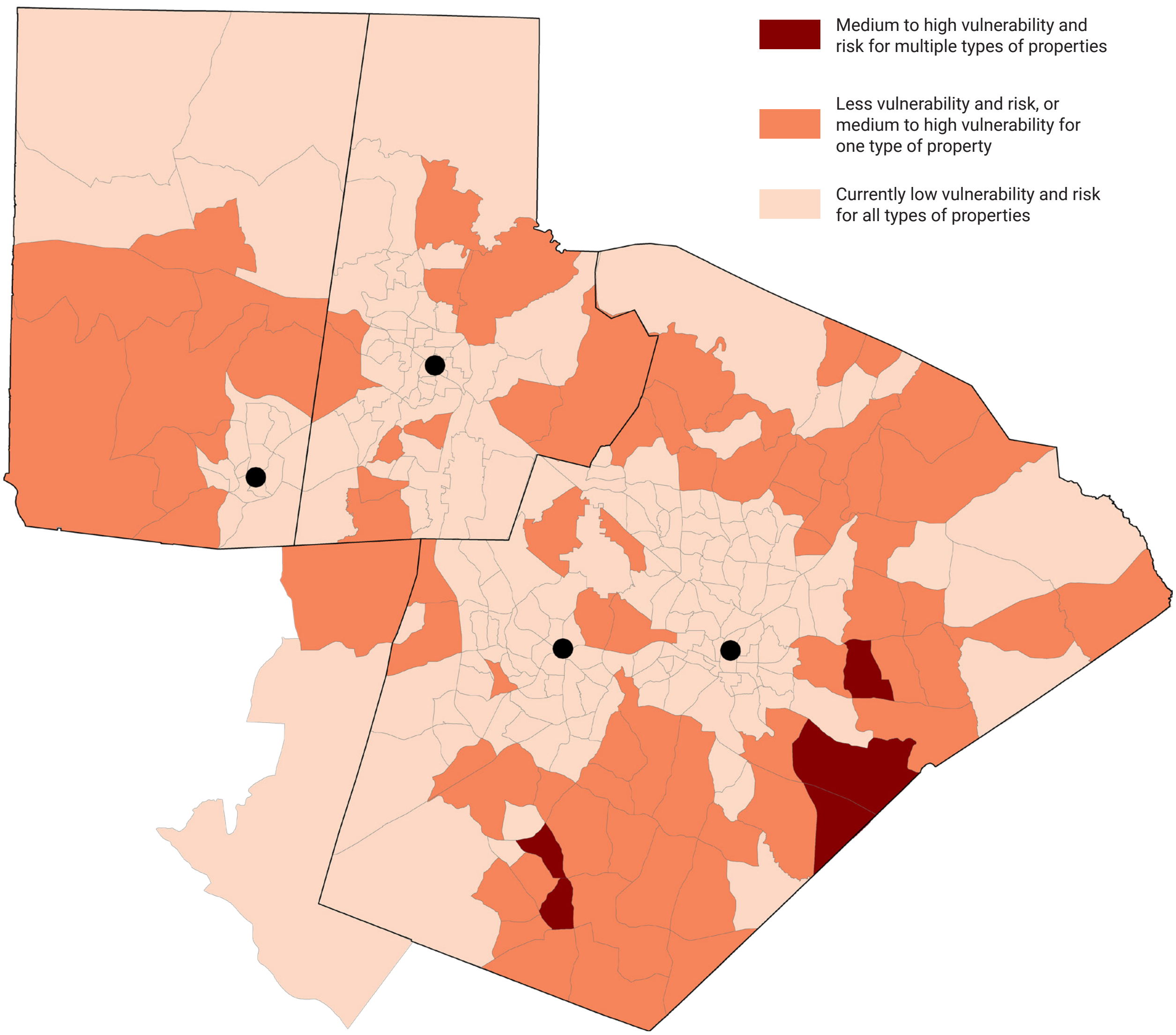


Figure 41. Assessment: All Properties and Wildfire

Wildfire

Commercial Properties

Commercial properties include retail businesses, hotels, restaurants, and offices. In addition to providing commerce, they are locations for local employment. Properties in high WUI risk areas outside an eight-minute drive time from a fire station have the highest vulnerability and risk.

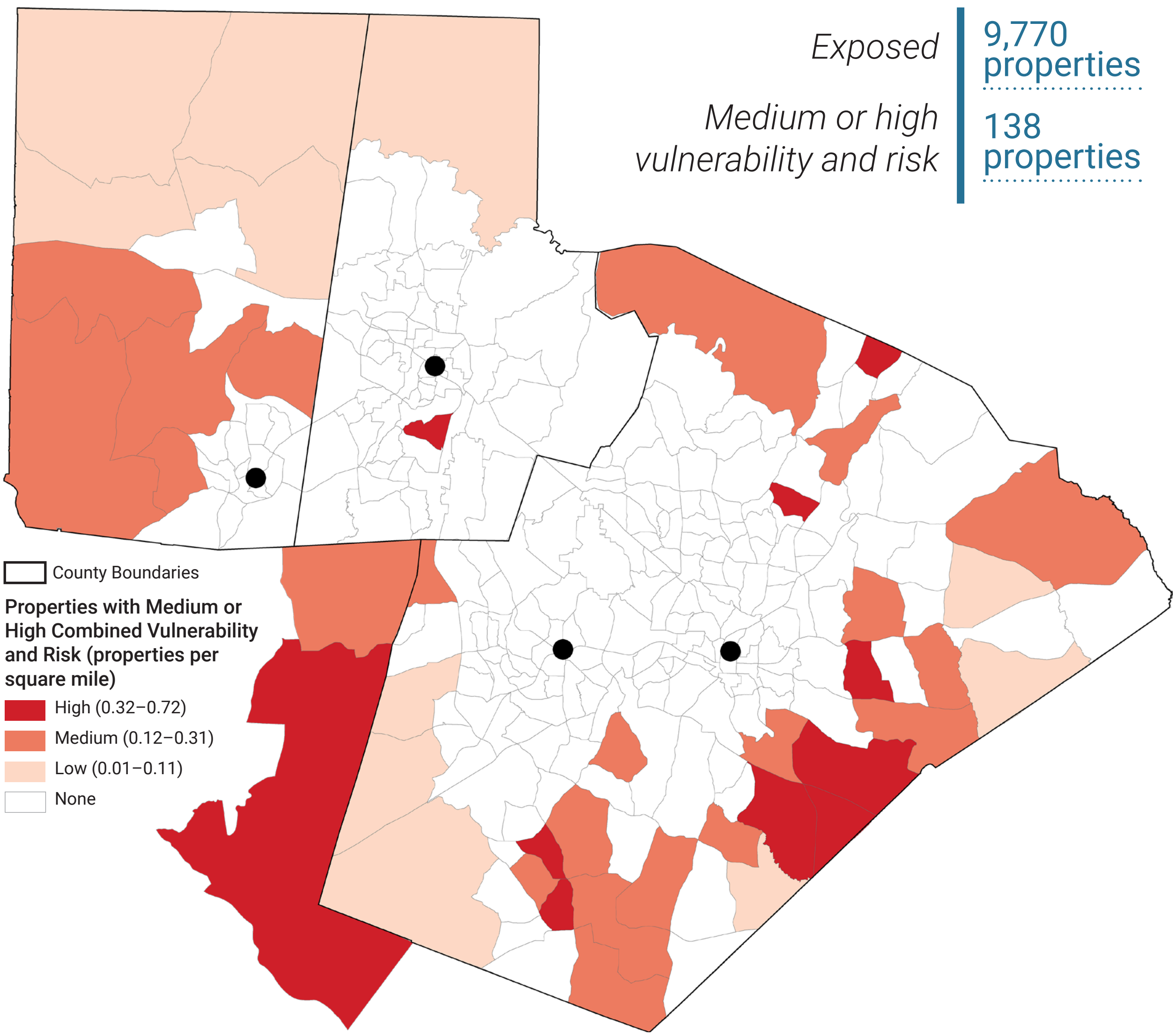
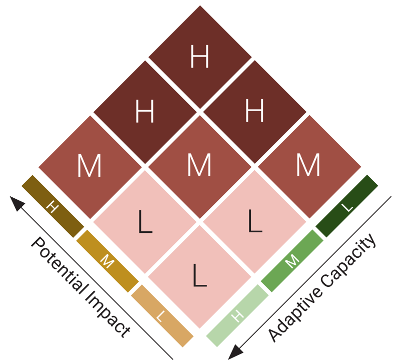


Figure 42. Assessment: Commercial Properties and Wildfire

Vulnerability

	Potential Impact	Adaptive Capacity
High	Property in WUI risk area and business related	Property within eight-minute Fire/Emergency Medical Services (EMS) drive time
Medium		
Low	Property in WUI risk area and not business related	Property outside of eight-minute Fire/EMS drive time

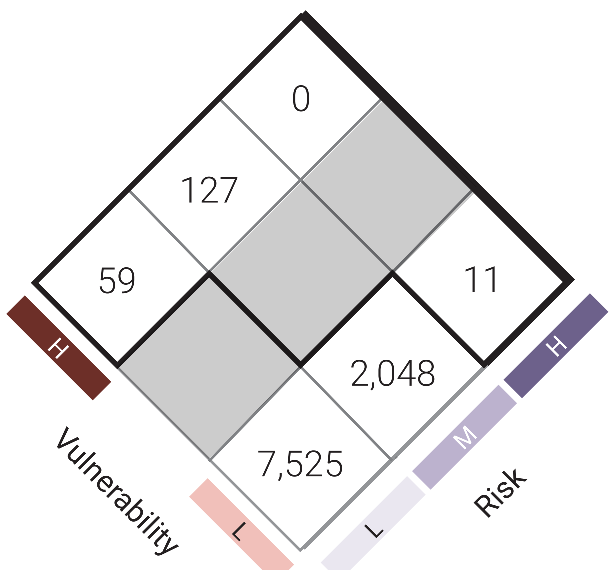


Risk

	Probability and Consequence of Threat Event
High	In high WUI risk area (WUI risk value -9)
Medium	In moderate WUI risk area (WUI risk value -6 to -8)
Low	In low WUI risk area (WUI risk value -1 to -5)

Combined Vulnerability and Risk

(Number of parcels)



Wildfire

Industrial Properties

Industrial properties include small businesses, factories, and companies that manufacture goods or materials. They are significant locations for local employment and often include distribution centers. Properties in high WUI risk areas outside an eight-minute drive time from a fire station have the highest vulnerability and risk.

Exposed — 1,918 properties

Medium or high vulnerability and risk — 37 properties

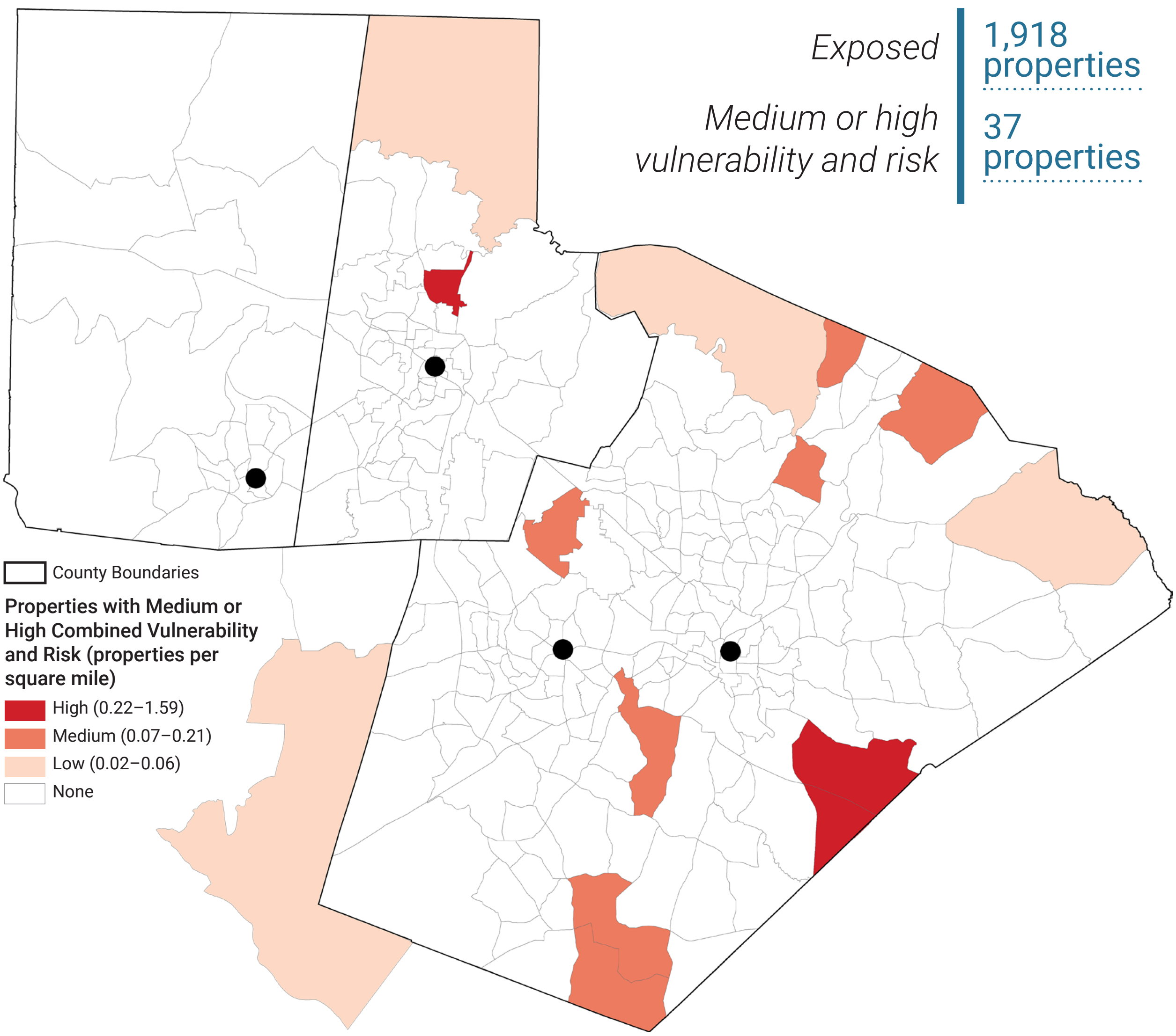
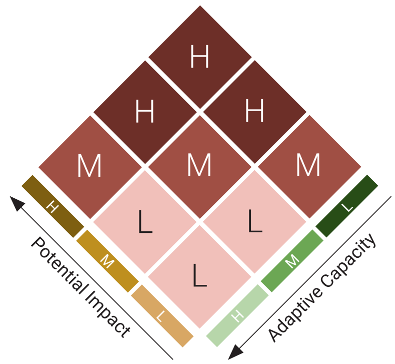


Figure 43. Assessment: Industrial Properties and Wildfire

Vulnerability

	Potential Impact	Adaptive Capacity
High	Property in WUI risk area	Property within eight-minute Fire/EMS drive time
Medium		
Low	Property in WUI risk area	Property outside of eight-minute Fire/EMS drive time

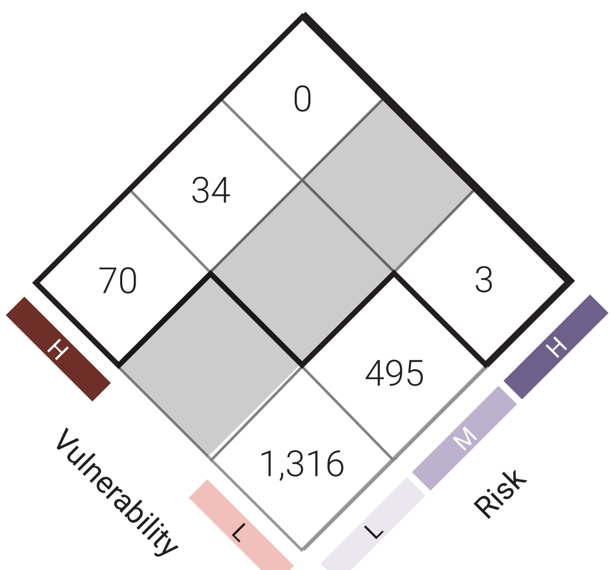


Risk

	Probability and Consequence of Threat Event
High	In high WUI risk area (WUI risk value -9)
Medium	In moderate WUI risk area (WUI risk value -6 to -8)
Low	In low WUI risk area (WUI risk value -1 to -5)

Combined Vulnerability and Risk

(Number of parcels)



Wildfire

Residential Properties

Residential properties include multi-family residences such as apartments, single-family residences, and nursing and retirement homes. In the Triangle region, most of the properties with relatively high wildfire risk are residential (over 90 percent). Properties within high WUI risk areas outside an eight-minute drive time from a fire station have the highest vulnerability and risk.

Exposed — 335,496 properties

Medium or high vulnerability and risk — 23,285 properties

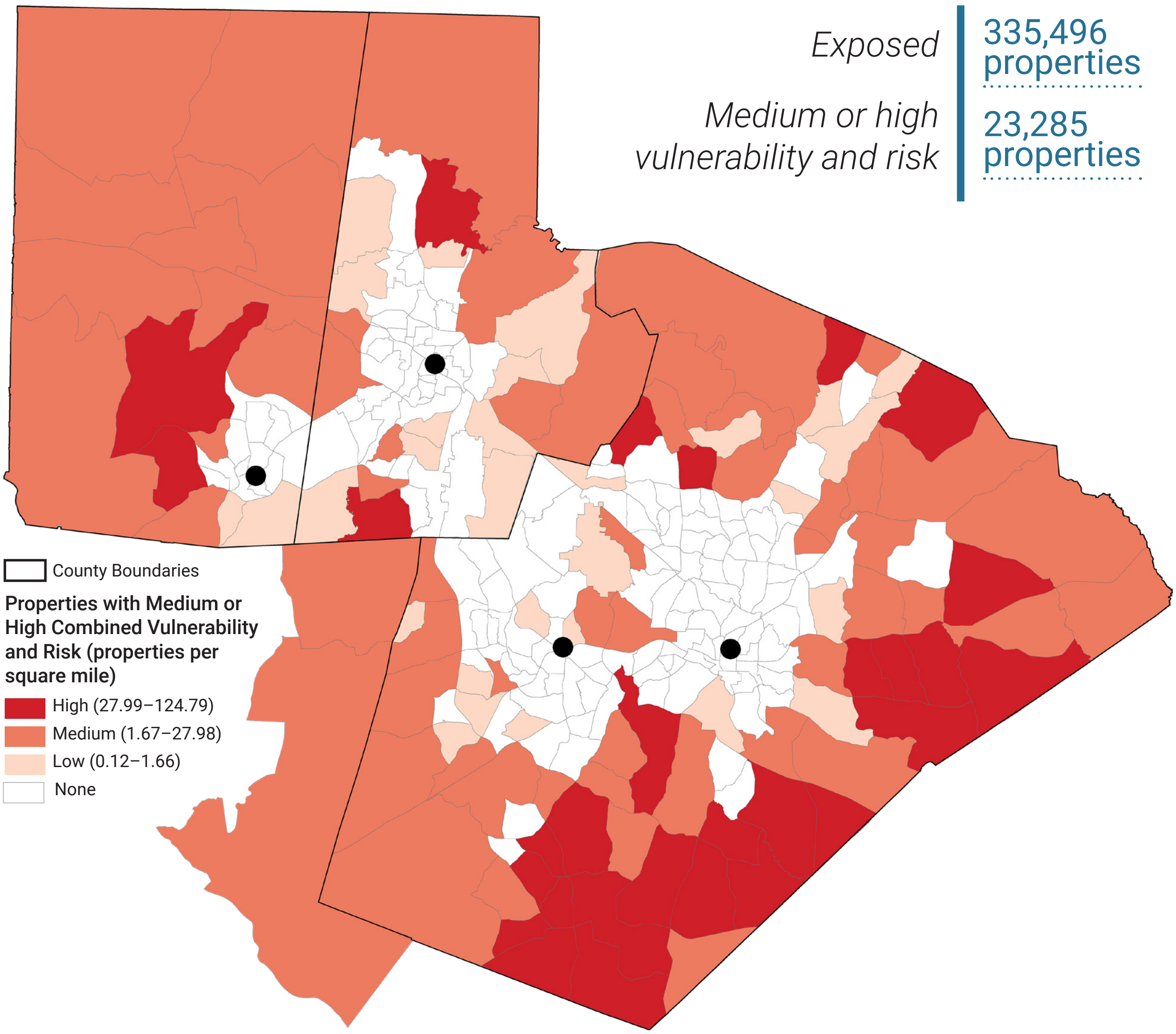
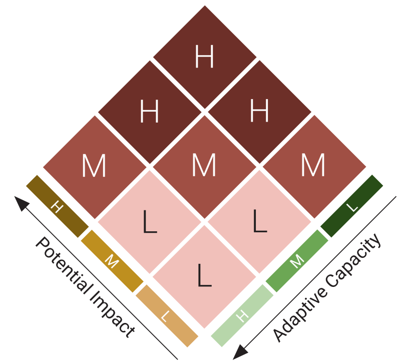


Figure 44. Assessment: Residential Properties and Wildfire

Vulnerability

	Potential Impact	Adaptive Capacity
High	Property in WUI risk area and multifamily residence, group home, retirement home, or nursing home	Property within eight-minute Fire/ EMS drive time
Medium		
Low	Property in WUI risk area and single residence	Property outside of eight-minute Fire/ EMS drive time

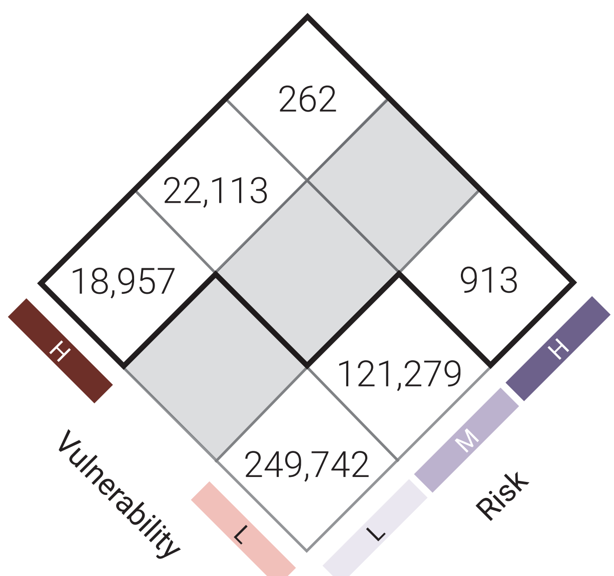


Risk

	Probability and Consequence of Threat Event
High	In high WUI risk area (WUI risk value -9)
Medium	In moderate WUI risk area (WUI risk value -6 to -8)
Low	In low WUI risk area (WUI risk value -1 to -5)

Combined Vulnerability and Risk

(Number of parcels)



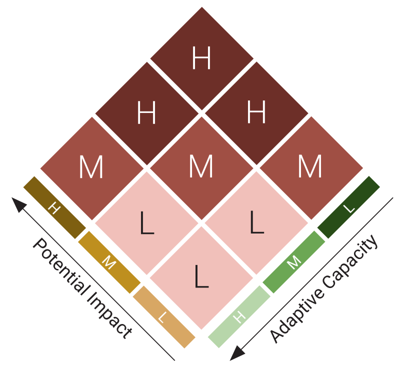
Wind

Residential Properties

Buildings can be impacted by direct gusts, by persistent wind, and by windblown rain or debris such as that from trees. All properties have the potential for wind exposure during a high wind event, but their vulnerability for wind damage may depend on proximity to dense tree cover, age and height of structure, and compliance with building codes.

Vulnerability

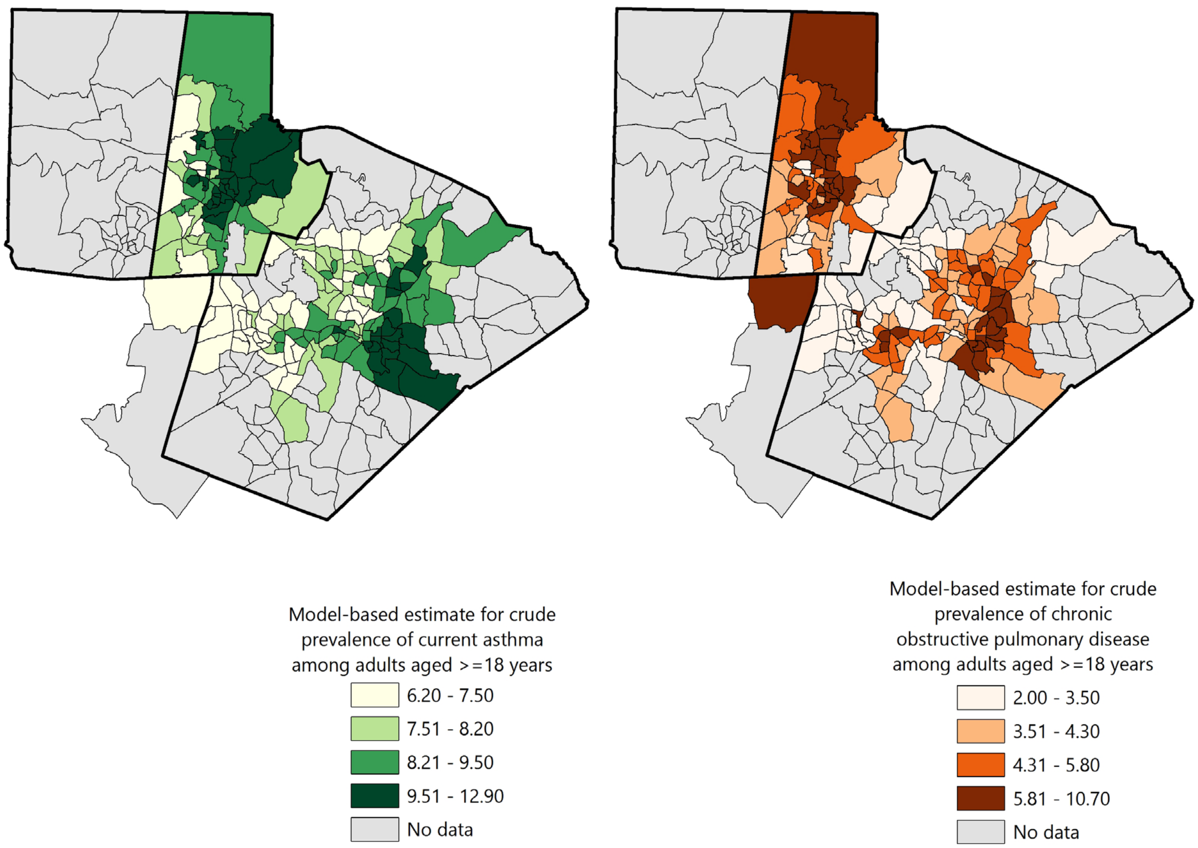
	Potential Impact	Adaptive Capacity
High	Dense tree cover; high structures; structures built in years with building codes that do not ensure proper wind resistance	Buildings constructed to code with wind criteria, following minimal distance of large trees from residence
Medium		
Low	Minimal tree cover; low structures; structures built in years with building codes that ensure proper wind resistance	Buildings not constructed to code with wind criteria, not following minimal distance of large trees from residence



Hospitals and Medical Facilities, People and Human Health

The maps in Figure 45 show model-based estimates for the prevalence of adults with asthma and chronic obstructive pulmonary disease (COPD) in the Triangle region.

Figure 45. Model-Based Estimates for Regional Prevalence of Asthma and COPD

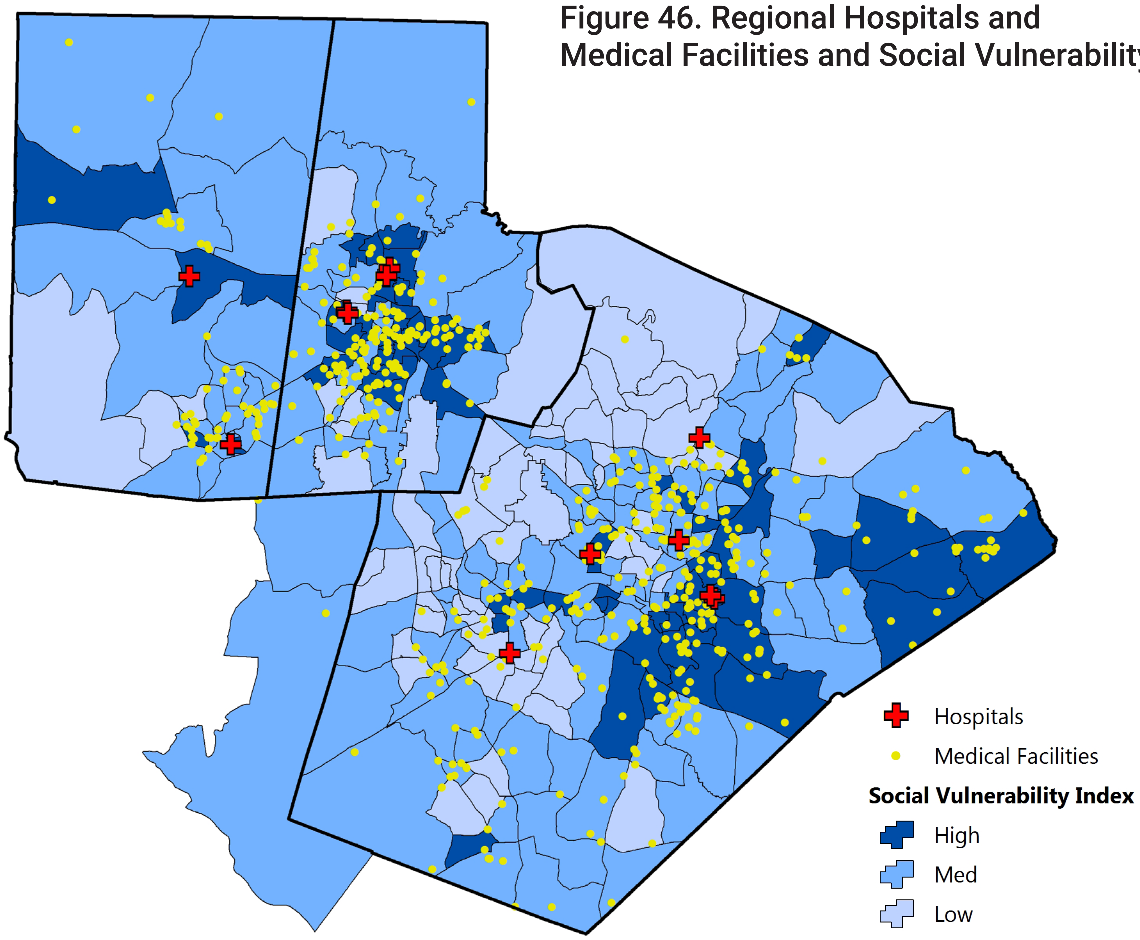


Model-based estimates for crude prevalence of current asthma and COPD among adults in the Triangle region. (Figure source: UNC Asheville's NEMAC. Data source: CDC, 500 Cities 2017.)

A variety of factors can increase a person's or population's vulnerability to climate change-related health impacts, include age, underlying physical and mental conditions, socioeconomic status, communities of color, and geographic location.[36] Throughout this assessment, the CDC's Social Vulnerability Index was used to identify populations that might have special needs in the event of a public health emergency. Figure 46 shows the SVI for the Triangle region as well as the location of regional hospitals and medical facilities. Factors used to determine the SVI include socioeconomic status, household composition and disability, minority status and language, and housing and transportation considerations.[37]

Note that geographic proximity is only one of several barriers to medical care for vulnerable populations. Barriers include, among others, cost, transportation, social access, and communication.

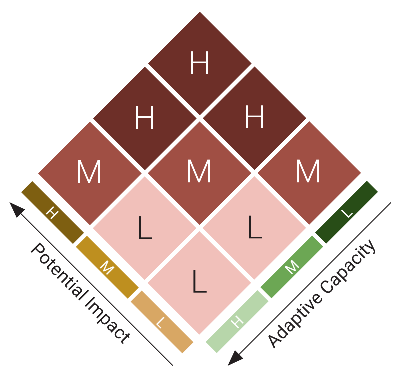
Figure 46. Regional Hospitals and Medical Facilities and Social Vulnerability



Locations of regional hospitals and medical facilities over social vulnerability, as determined using the Centers for Disease Control and Prevention's Social Vulnerability Index. (Figure source: UNC Asheville's NEMAC. Data source: CDC.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	Facilities that serve a high population of people with asthma, heart disease, or other sensitivity to air pollution; facilities closer to point source pollution (including wildfires)	Facilities with adequate space, equipment, and trained staff to handle an influx of people affected by air pollution
Medium		
Low	Facilities that do not serve a high population of people with asthma, heart disease, or other sensitivity to air pollution; facilities that are not close to point source pollution	Facilities without adequate space, equipment, or trained staff to handle an influx of people affected by air pollution



Disease

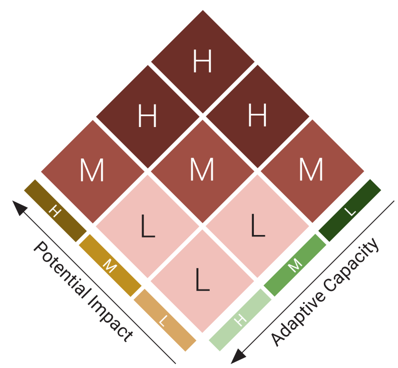
Hospitals and Medical Facilities, People and Human Health

According to the North Carolina Department of Public Health, between 2008 and 2012 Wake County had the highest number of confirmed and probable Lyme disease occurrences in North Carolina (more than 34), followed by Orange and Durham Counties (between 7 and 33).[38]

For mosquito-borne illnesses, between 2003 and 2012 the two types of confirmed and probable illnesses in the Triangle region included La Crosse Encephalitis and West Nile virus.[39] See also the discussion and Figure 46 relating to vulnerable populations in the Air Pollution discussion.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Facilities that serve sensitive populations, care for babies and pregnant women, or offer a birthing center	Facilities with equipment and trained staff to handle cases of vector-borne and water-related illnesses
Medium		
Low	Facilities that serve affluent parts of the region	Facilities without equipment and trained staff to handle cases of vector-borne and water-related illnesses



Extreme Cold

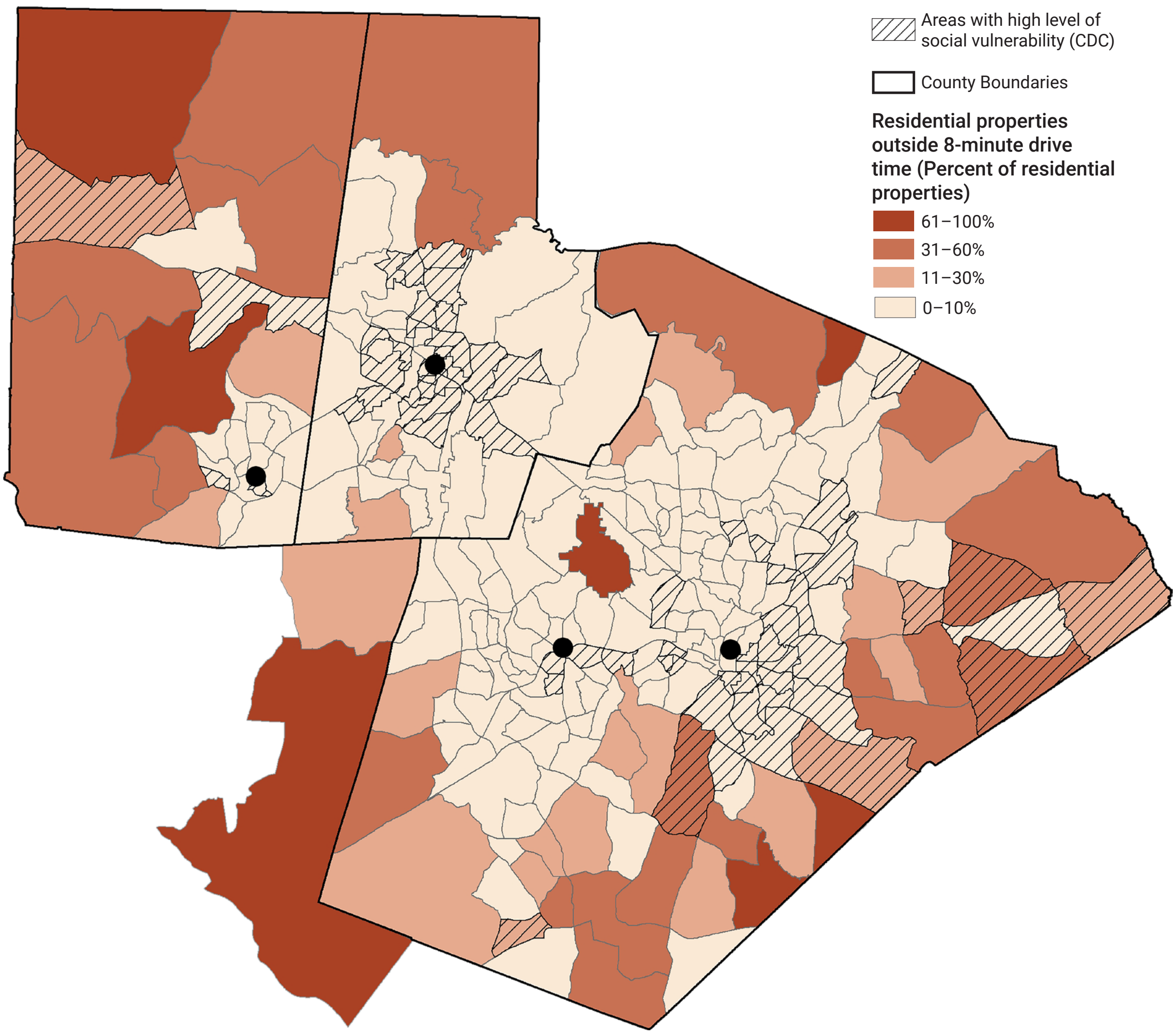
Emergency Services

Critical infrastructure related to emergency services, including 9-1-1 dispatch centers, police, fire, emergency medical service (EMS), and emergency operations centers rely on communications systems and electrical power. Emergency response delays are usually expected only if significant disruptions occur to transportation, electrical power, and communications systems.[40]

Figure 47 shows the percentage of residential properties located in areas outside an eight-minute drive time from any emergency medical service location or fire station. These properties are relatively isolated, often in rural areas or in areas with more limited access. During a winter storm event with extreme cold, emergency response to properties in these locations would likely be more difficult and have slower response times.

Dark red areas on the map indicate census tracts where more than 60 percent of the properties are beyond an eight-minute drive time; medium red areas indicate census tracts where between 30 and 60 percent of residential properties are beyond the eight-minute drive time. Note that some of these areas, mostly in Wake County, also have high social vulnerability according to the CDC Social Vulnerability Index.

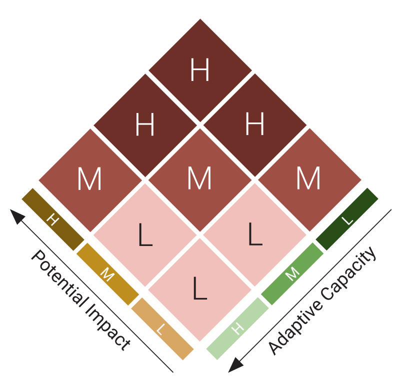
Figure 47. Residential Properties Outside Eight-Minute Drive Time



Percentage of residential properties that are outside an eight-minute drive time from any emergency medical service location or fire station. These properties are relatively isolated, often in rural areas or in areas with more limited access. (Figure source: UNC Asheville's NEMAC. Data source: Multiple county parcel dataset (Orange, Durham, Wake, Chatham), USGS National Structures Dataset, Open Street Map.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities with a reflective roof type and material • Serving highly sensitive populations and areas without air conditioning • Services that involve a long shift on the line	• Facilities with full power redundancy • Facilities where good auxiliary heating sources are deployable • High-performing and highly efficient buildings • Regular fit-for-duty program or assessments for emergency responders • Shorter work shifts and altered work assignments for non-critical outdoor duties • Adaptive uniforms and uniform policy, including weather-appropriate bullet-proof vests • Community facilities to help with heating • Shore parking • Conditioned bays for EMS
Medium		• Facilities with partial power redundancy • Shorter work shifts for outdoor duties
Low	• Facilities with an absorptive roof type • Serving populations with low sensitivity and access to heating • Services that do not involve long shifts	• Facilities with no power redundancy • No auxiliary heating sources available • Low-performing or inefficient building • No regular fit-for-duty program or assessments for emergency responders • Non-adaptive work schedules for outdoor duties • No adaptive uniforms or uniform policy in place



Extreme Cold

Energy and Utilities

During severe winter weather, wind, cold, snow, and ice can damage energy sector assets. Severe winter storms usually cause extensive electric power outages due to distribution system damage from ice and snow. The amount of damage and the number of repair crews that can be brought to the area have a direct result on electric power restoration. Areas that experience large amounts of snowfall and ice accumulation may experience longer restoration delays due to limited access to repair equipment.[40] Refer also to the Snow/Ice Event discussion.

Severe cold can change the properties of oil. When temperatures drop, solids (such as paraffin wax) begin to form and separate from the oil and then crystalize and become visible; this is called the cloud point. Certain oils must be maintained at temperatures above the cloud point to prevent clogging of filters. As temperatures drop lower, the fuel continues to thicken or gel until it stops flowing. To help prevent clouding and gelling, heating oil is refined so its low temperature properties are optimal for the location and the time of year where it is being used. During severe cold weather, fuel blending and additives are commonly used to prevent the oil from reaching its cloud point and to keep it flowing. Measures to prevent clouding and gelling include storing fuel oil indoors and insulating storage tanks and pipes.[40]

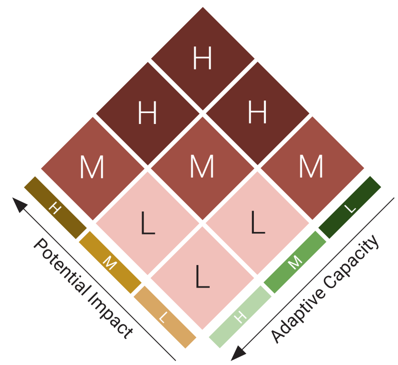
Natural gas pipelines do not freeze; however, if there is a significant amount of water in the pipeline, it may freeze and cause problems. Water can also enter the propane distribution system at a variety of points, and in cold weather this water may freeze and potentially damage or impair the operation of pipes, valves, pumps and appliances. At the consumer end, liquid propane is converted into gas for use in propane-fueled heating and appliances by being released from its storage tank at temperatures above -44°F. Extreme cold (i.e., below -44°F) can cause the propane in these tanks to remain in its liquid state and potentially freeze.[40]

If a storm causes electric power outages that directs offsite power to nuclear power plants, affected plants would likely implement relevant regulations and licensing conditions and go into controlled shutdown, as appropriate.[40]

Localized communications outages may occur due to wind and ice damage to pole-mounted communications systems or cellular towers. Communications facilities have varying levels of backup power capabilities to ensure resilience to power failures; widespread communications network failure is unlikely. Communications systems are important to response and recovery efforts following a winter storm, and repairs can be expected to proceed quickly once the storm abates and transportation routes are cleared of snow. Wireless telecommunications switching centers can be expected to continue operation in the absence of an extended power outage.[40]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities with a reflective roof type • Facilities built in a year in which building codes do not ensure sufficient insulation or HVAC capacity	• Facilities with high-performing and highly efficient buildings • Good redundancy in communication methods or pathways • Good auxiliary heating sources available to be deployed • Full power redundancy
Medium		Facilities with partial power redundancy
Low	• Facilities with an absorptive roof type • Facilities built in a year in which building codes ensure sufficient insulation or HVAC capacity	• Facilities with low-performing or inefficient buildings • No redundancy in communication methods or pathways • No auxiliary heating sources available • No power redundancy



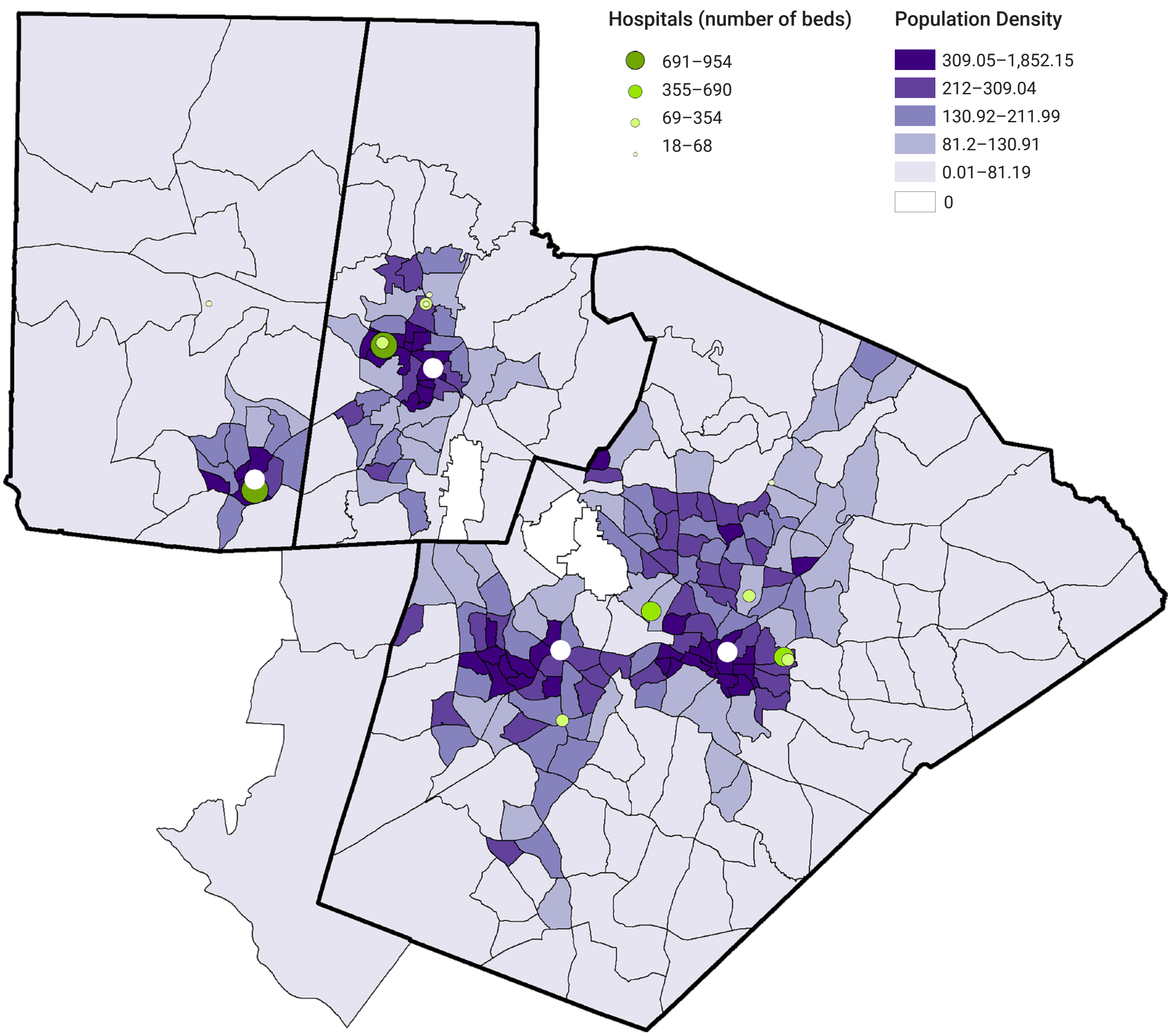
Extreme Cold

Hospitals and Medical Facilities

Hospitals and other healthcare facilities can potentially be impacted by winter storms and cold waves. Short delays to emergency response may occur because of transportation and electrical power impacts.[40]

The availability and location of hospital resources can complicate emergency response services during cold snaps, particularly when snow and ice develops. Figure 48 shows the locations of hospitals in the Triangle region and the corresponding number of available beds (larger green points indicate more beds) over the region's population density. Notice that areas near Cary have a high population density and a low number of nearby hospital beds.

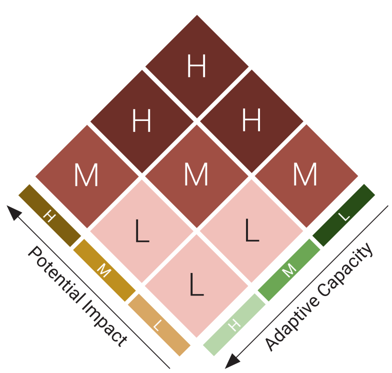
Figure 48. Location of Regional Hospitals and Surrounding Population Density



Location of regional hospitals (with associated numbers of beds for each) and surrounding population density by census tract. (Figure source: UNC Asheville's NEMAC. Data source: USGS National Structures Dataset 2017, U.S. Census Bureau 2010, American Hospital Directory.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities in which critical building systems are not shielded • Facilities with roof type and materials that are reflective • Facilities built at a time during which building codes did not ensure sufficient levels of insulation and HVAC capacity • Facilities that serve sensitive or large populations	• Facilities with full power redundancy • Good auxiliary heating sources available to be deployed • High-performing and highly efficient buildings • Accredited by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) or similar accreditation • Facilities having a state license
Medium		• Facilities with partial power redundancy • Facilities having only a state license without additional accreditation • Center for Medicaid/Medicare system
Low	• Facilities in which critical building systems are well-protected or inside • Facilities with roof type and materials that are absorptive • Facilities built at a time during which building codes ensure sufficient levels of insulation and HVAC capacity • Facilities that serve populations that are small or not sensitive	• Facilities with no power redundancy • No auxiliary heating sources available • Low-performing or inefficient building • No license



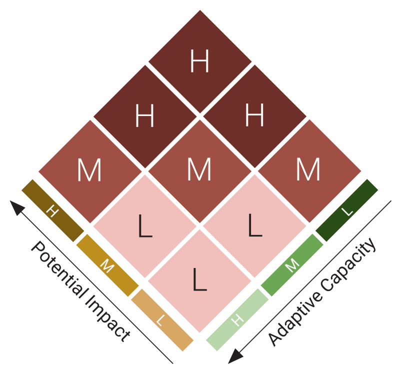
Extreme Cold

People and Human Health

Winter storms can be accompanied by freezing winds and frigid temperatures that can cause frostbite and hypothermia. Individuals that lack proper clothing and shelter (for example, the homeless) are more at risk of injuries from direct exposure to weather conditions associated with winter storms and cold waves. Low-income populations have increased exposure risk to severe winter weather conditions because they are more likely to live in low-quality, poorly insulated housing; may be unable to afford sufficient domestic heating; or may need to make tradeoffs between food and heating expenditures.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Highly sensitive populations	Properties closer to shelters, underground utilities
Medium		
Low	Presence of heat pumps	Properties with pipes that can freeze



Extreme Cold

Buildings and Facilities

Emergency Services, Food Infrastructure, Hospitals and Medical Facilities, Jurisdictional- and State-Owned Properties

Often, buildings associated with the provision of public services—for example, police and fire stations, universities and schools, grocery stores, food distribution centers, and federal, state, and local government offices—were not built to withstand the impending range of climate conditions. Mechanical systems may therefore not be sufficient to heat facilities, and power outages may cause indoor temperatures to plummet rapidly to uninhabitable levels.[41]

Additional factors to be considered when examining impacts of extreme cold on buildings and facilities:

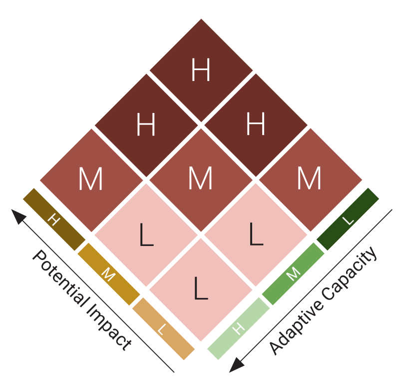
- Facility HVAC units that fail in extreme weather will not be able to regulate moisture, resulting in mold issues if the interruption is long-term.
- Computer equipment will be damaged if internal temperatures are too high or too low for long time periods. The recommended temperature range for data center environments is 64.4°–80.6°F; the allowable temperature range for powered-off equipment is 41°–113°F.[42]
- Based on energy use intensity and benchmark data, a highly efficient building is easier to operate with auxiliary power and temperature control systems.

Buildings and Facilities | Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities with reflective roof type and material on buildings such as shelters, dorm, servers, some labs, critical services, and jails • Facilities built in a year for which building codes do not ensure sufficient levels of insulation and HVAC capacity	• Facilities with full power redundancy • Good auxiliary cooling sources deployable • High-performing/highly efficient building
Medium		Facilities with partial power redundancy
Low	• Facilities with absorptive roof type and material on buildings • Facilities built in a year for which building codes ensure sufficient levels of insulation and HVAC capacity	• Facilities with no power redundancy • No auxiliary cooling sources available • Low-performing/inefficient building

Food Infrastructure | Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities having a reflective roofing type • Facilities built in a year in which building codes do not ensure sufficient levels of insulation and HVAC capacity	• Facilities with full power redundancy • Good auxiliary heating sources that are deployable • High-performing and highly efficient buildings.
Medium		Facilities with partial power redundancy
Low	• Facilities with absorptive roof type and material on buildings • Facilities built in a year for which building codes ensure sufficient levels of insulation and HVAC capacity	• Facilities with no power redundancy • No auxiliary cooling sources available • Low-performing/inefficient building



Extreme Heat

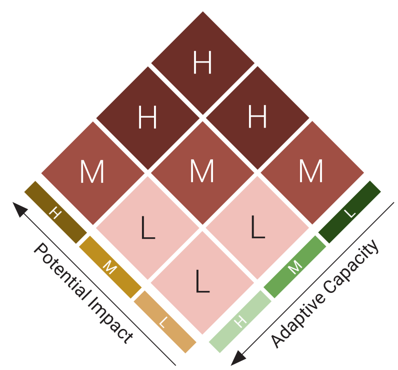
Emergency Services

Police officers, firefighters, paramedics, and the many others who protect people during heat waves need information to understand how to find and help those who are most vulnerable, while ensuring they are protected themselves. Before an extreme heat event, emergency responders should prepare themselves to tend to members of vulnerable populations.[43]

Socially vulnerable populations in areas with a high percentage of developed land and a low tree canopy are most vulnerable to the negative health effects of heat stress, including effects of the urban heat island effect. See People and Human Health for a further discussion of extreme heat and vulnerable populations.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities with an absorptive roof type and material • Serving highly sensitive populations and areas without air conditioning • Services that involve a long shift on the line	• Facilities with full power redundancy • Good auxiliary cooling sources deployable • High-performing and highly efficient buildings • Regular fit-for-duty program or assessments for emergency responders • Shorter work shifts and altered work assignments for non-critical outdoor duties • Adaptive uniforms and uniform policy, including weather-appropriate bullet-proof vests • Community facilities to help with cooling • Shore parking • Conditioned bays for EMS
Medium		• Facilities with partial power redundancy • Shorter work shifts for outdoor duties
Low	• Facilities with a reflective roof type • Serving populations with low sensitivity and access to air conditioning • Services that do not involve long shifts	• Facilities with no power redundancy • No auxiliary cooling sources available • Low-performing or inefficient building • No regular fit-for-duty program or assessments for emergency responders • Non-adaptive work schedules for outdoor duties • No adaptive uniforms or uniform policy in place



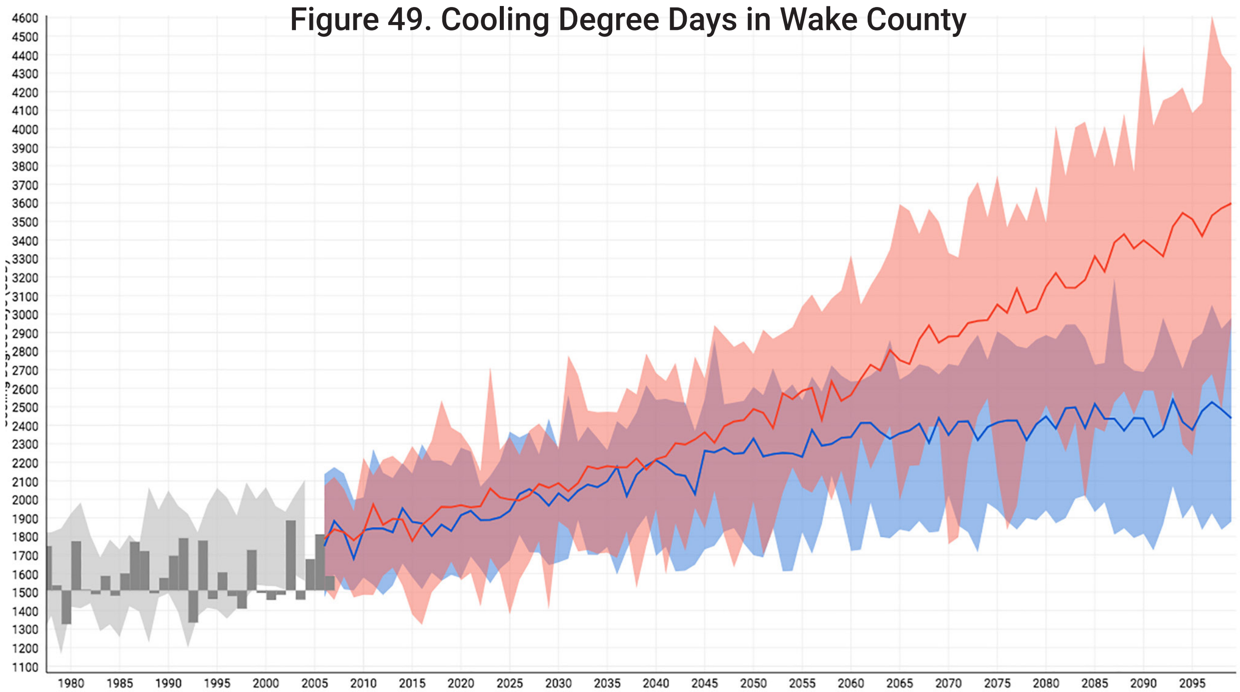
Extreme Heat

Energy and Utilities

Extreme heat events increase energy consumption due to greater use of air conditioning in homes, businesses, and institutional settings; increased demand can also affect energy-generating facilities, increasing the frequency of blackouts and brownouts.[7] Physical damage to energy and communications infrastructure and related critical equipment can also lead to failure of dependent systems, such as water and transportation.[44]

In the Piedmont region, the number of "cooling degree days" is expected to increase over the next century, relative to the 1970–2010 average. The number of cooling degree days per year can be used as a proxy for the amount of energy people use to cool buildings. Degree days are calculated using the number of degrees by which the average daily temperature is higher than 65°F. For example, one day with an average temperature of 90°F equals 25 cooling degree days—the same as 25 days with an average temperature of 66°F. Utility companies use cooling degree days to estimate the annual amount of energy people will use to cool buildings.[45] Figure 49 shows the observed and projected number of cooling degree days in Wake County from 1980 through 2095.

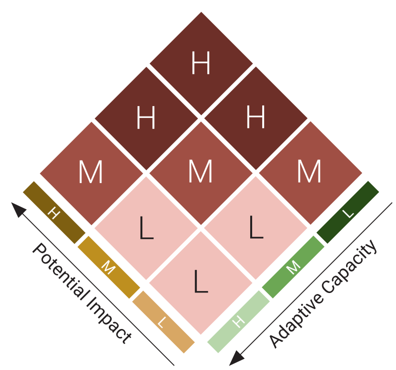
Figure 49. Cooling Degree Days in Wake County



Observed and projected number of cooling degree days in Wake County from 1980 through 2095, under higher emissions (red) and lower emissions (blue) scenarios. (Figure source: U.S. Climate Resilience Toolkit, Climate Explorer.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Infrastructure built at a time at which building codes did not ensure sufficient levels of insulation and HVAC capacity • Infrastructure with absorptive roof types and material • Utilities that are above ground • Utilities that are reliant on ambient water temperatures	• Infrastructure with full power redundancy • Good auxiliary cooling sources deployable • Good redundancy in communication methods or pathways • High-performing or highly efficient buildings • Having the ability to communicate and de-load management • Underground utilities
Medium		Infrastructure with partial power redundancy
Low	• Infrastructure built after a certain year, such that building codes ensure sufficient levels of insulation and HVAC capacity • Infrastructure with reflective roof type and material	• Infrastructure with no power redundancy • No auxiliary cooling sources available • No redundancy in communication methods or pathways • Low-performing or inefficient buildings



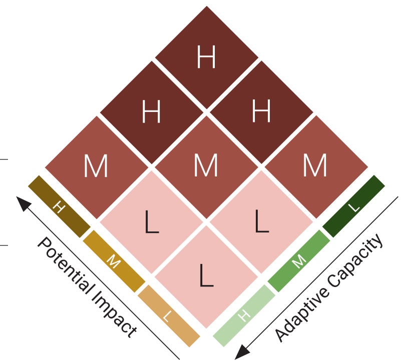
Extreme Heat

Food Infrastructure

Proper food storage during processing, packaging, and transport is important for delivering safe, quality food. Warmer temperatures and shifts in humidity associated with electrical blackouts and brownouts due to extreme heat events could increase the risk of food poisoning and food spoilage.[46]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Absorptive roof type and material	• Full power redundancy • Good auxiliary cooling sources are deployable • High-performing/ highly efficient building
Medium		Partial power redundancy
Low	• Roof type and material is reflective • Year facility built—different codes mean different levels of insulation and HVAC capacity, unsure of when the dividing lines should be	• No power redundancy • No auxiliary cooling sources available • Low-performing/ inefficient building



Extreme Heat

Hospitals and Medical Facilities

During heat waves, health care service volumes can surge as residents present to emergency departments, urgent care centers, and physician practices. If area energy infrastructure is over-stressed, rolling electrical blackouts often accompany extended heat waves, which can compromise health care delivery.[8] Also consider the map (Figure 48) in the Extreme Cold discussion, which displays the distribution of regional hospitals and the population density of the areas they service.

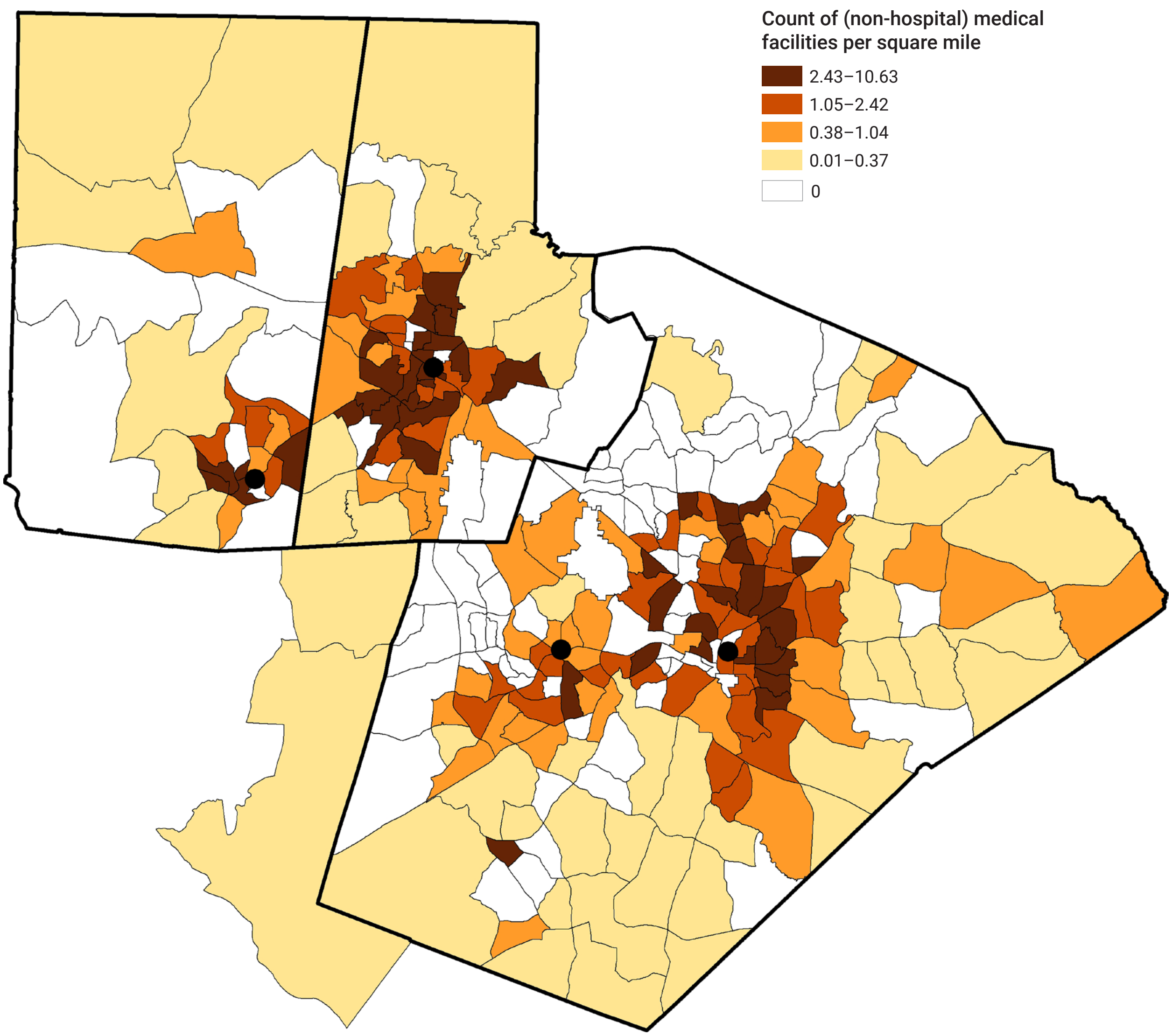
Urban hospitals, as large electricity consumers, are often asked to shift to emergency power generation in order to free grid resources during peak demand periods.[8] Many hospitals do not have their cooling systems on their emergency power generation systems; when blackouts occur, hospitals are required to continue to operate their basic ventilation systems but may lose portions of their space cooling systems. For the most part, hospitals are sealed buildings (i.e., they do not incorporate operable windows due to infection control and pressurization requirements).[8]

In recent years, many hospitals have improved their resilience to heat waves by voluntarily increasing their emergency power capability above minimum regulatory requirements to include mechanical cooling. In Florida, for example, hospitals are required to have an external generator connection that allows additional generator capacity to supplement the facility-level infrastructure. New hospitals must have their cooling on emergency power due to concerns about high humidity and mold/mildew impacts on indoor environments during extended power outages.[8]

Nursing homes and assisted living facilities are often not equipped to provide emergency cooling when grid power is lost. While many of these buildings include operable windows, concerns about patient safety have limited the extent of window operability, and high-humidity climates present a range of challenges. Certainly, however, operable windows (and engineered natural ventilation systems) are a key element of passive survivability during extended heat waves in non-acute residential health care settings in many parts of the United States. Ambulatory facilities vary widely in their emergency power provisions and capabilities.[8]

In North Carolina, a special set of building codes applies to medical facilities. However, in some instances (such as unlicensed retirement homes not classified as nursing homes) facilities are not required to adhere to such codes or make important investments in the resilience of their buildings. Figure 50 shows the number of non-hospital medical facilities per square mile in the Triangle region.

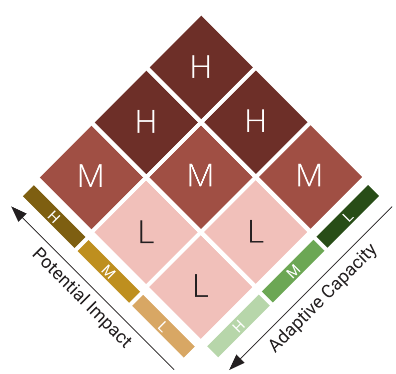
Figure 50. Number of Regional Non-Hospital Medical Facilities



Number of regional non-hospital medical facilities per square mile by census tract. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Census Bureau, NC OneMap GeoSpatial Portal Medical Facilities 2003.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities in which critical building systems are not shielded • Roof type and materials that are absorptive • Facilities built at a time during which building codes did not ensure sufficient levels of insulation and HVAC capacity • Facilities that serve sensitive or large populations	• Facilities with full power redundancy • Good auxiliary cooling sources available to be deployed • High-performing and highly efficient buildings • Accredited by the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) or similar accreditation • Facilities having a state license
Medium		• Facilities with partial power redundancy • Facilities having only a state license without additional accreditation • Center for Medicaid/Medicare system
Low	• Facilities in which critical building systems are well-protected or inside • Roof type and materials that are reflective • Facilities built at a time during which building codes ensure sufficient levels of insulation and HVAC capacity • Facilities that serve populations that are small or not sensitive	• Facilities with no power redundancy • No auxiliary cooling sources available • Low-performing or inefficient building • No license



Extreme Heat

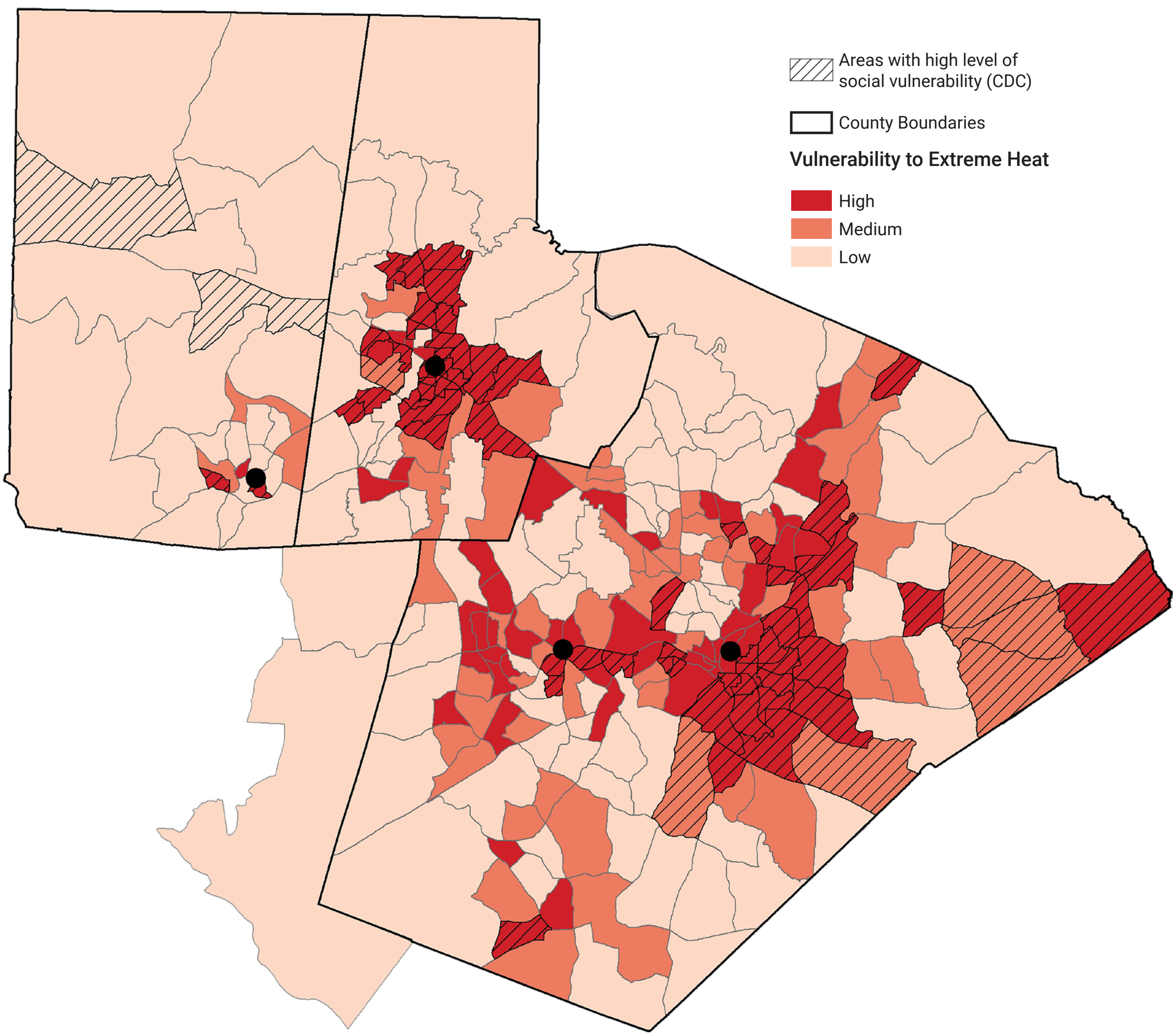
People and Human Health

The vulnerability of people and human health to extreme heat considers socially vulnerable populations using the CDC's Social Vulnerability Index—which includes metrics such as families living below the poverty line, households with disabilities and members 65 years of age and older, limited English language, and others—that live in proximity to developed land cover.

Areas with the highest sensitivity have a relatively high social vulnerability and high developed land cover. The amount of tree canopy was used as a measure of adaptive capacity to an extreme heat event.

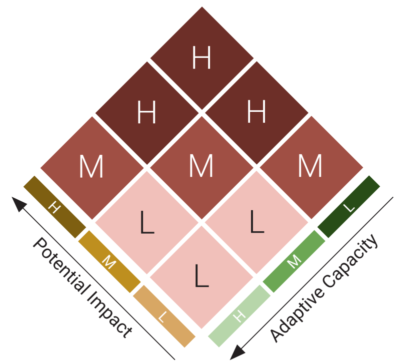
Socially vulnerable populations in areas with a high percentage of developed land cover and low tree canopy are most vulnerable to negative health effects related to heat stress and due to the urban heat island effect.

Figure 51. Vulnerability to Extreme Heat



Vulnerability

	Potential Impact	Adaptive Capacity
High	Highest number of sensitive populations and high percentage of developed land cover (>85%)	High amount of tree canopy coverage (>62.2%)
Medium	Lower number of sensitive populations or lower percentage of developed land cover (62.5-85%)	Moderate amount of tree canopy coverage
Low	Lower number of sensitive populations and low percentage of developed land cover (<62.5%)	Low amount of tree canopy coverage



Extreme Heat

Buildings and Facilities

Emergency Services, Jurisdictional- and State-Owned Properties

Often, buildings associated with the provision of public services—for example, police and fire stations, universities and schools, grocery stores, food distribution centers, and federal, state, and local government offices—were not built to withstand the impending range of climate conditions. Mechanical systems may therefore not be sufficient to cool facilities, and power outages may cause indoor temperatures to rise rapidly to uninhabitable levels.[41] Also consider additional factors for buildings and facilities discussed under Extreme Cold.

Vulnerability

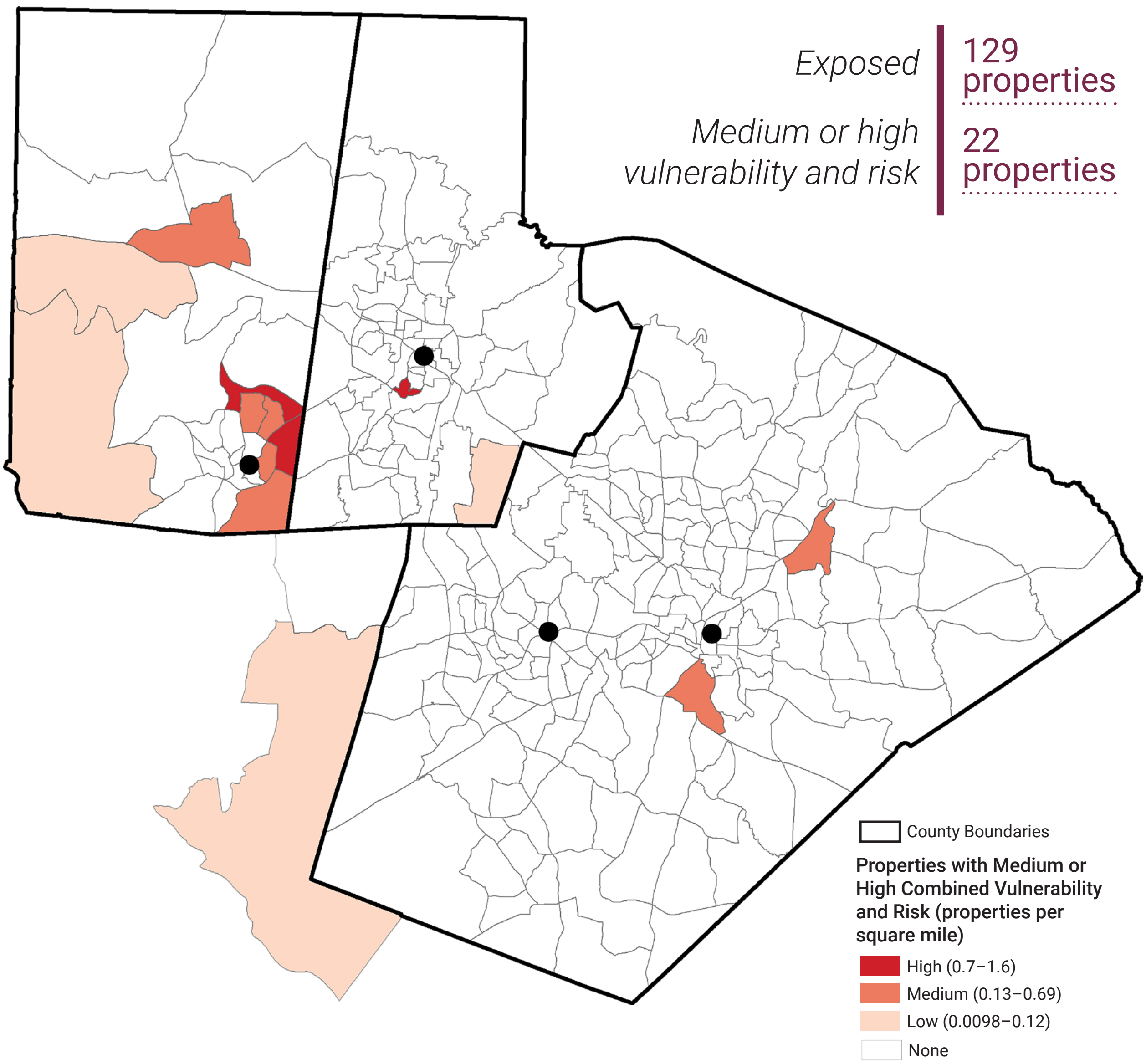
	Potential Impact	Adaptive Capacity
High	• Facilities with absorptive roof type and material on buildings such as shelters, dorm, servers, some labs, critical services, and jails • Facilities built in a year for which building codes do not ensure sufficient levels of insulation and HVAC capacity	• Facilities with full power redundancy • Good auxiliary cooling sources deployable • High-performing/highly efficient building
Medium		Facilities with partial power redundancy
Low	• Facilities with reflective roof type and material on buildings • Facilities built in a year for which building codes ensure sufficient levels of insulation and HVAC capacity	• Facilities with no power redundancy • No auxiliary cooling sources available • Low-performing/inefficient building

Flooding

Energy and Utilities

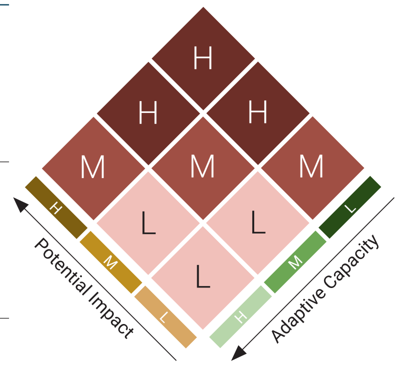
This asset includes properties with buildings or infrastructure used for generation or distribution of energy. Other assets in this group include communications and other utilities.

Figure 52. Assessment: Energy/Utilities and Flooding



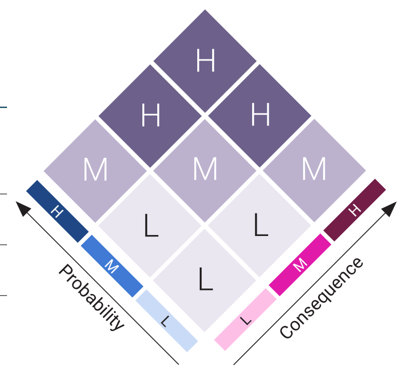
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



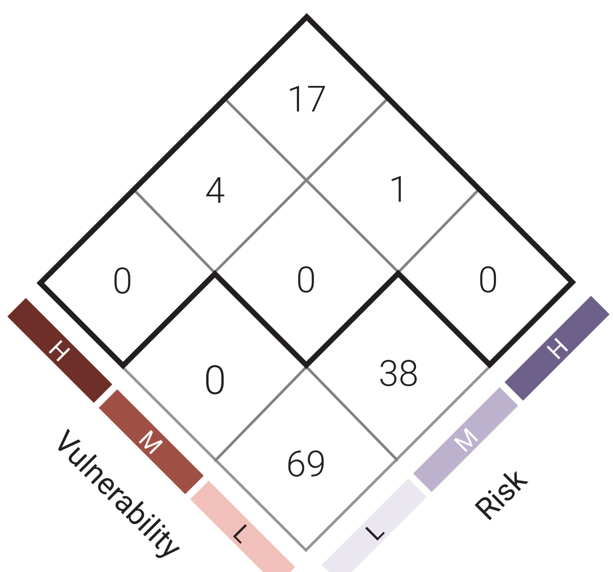
Risk

	Probability	Consequence
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



Flooding

Food Infrastructure

Figure 53 considers where Supplemental Nutrition Assistance Program (SNAP) retailers are vulnerable and at risk to flooding, as well as areas within the region with relatively high SNAP participation.

In some cases, the number of SNAP retailers that are vulnerable and at risk is a high percentage of all SNAP retailers located in a particular area. The darkest red areas on the map are those where between 50 and 100 percent of SNAP retailers are highly vulnerable and at risk.

Figure 53. Assessment: Food Infrastructure and Flooding

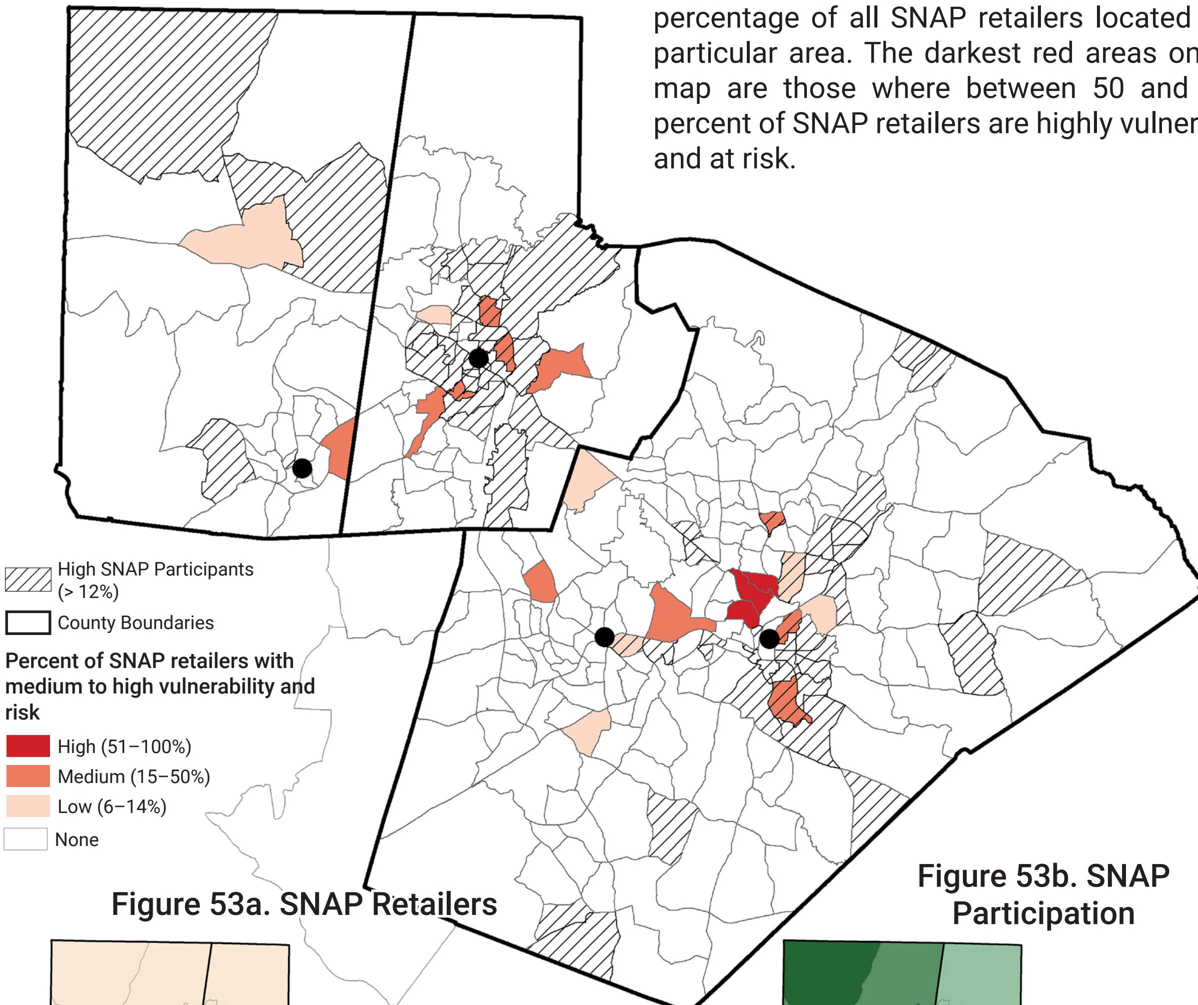


Figure 53a. SNAP Retailers

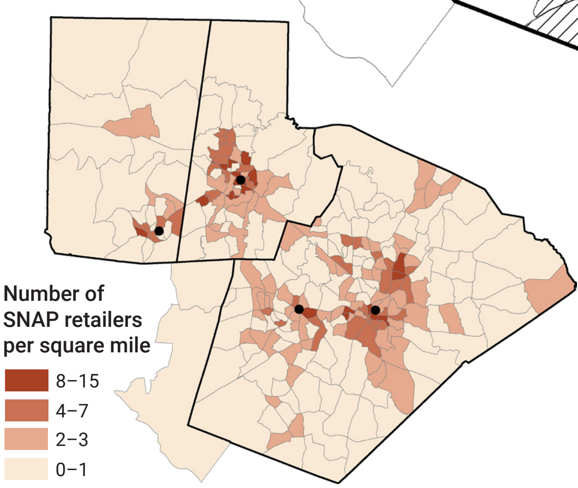
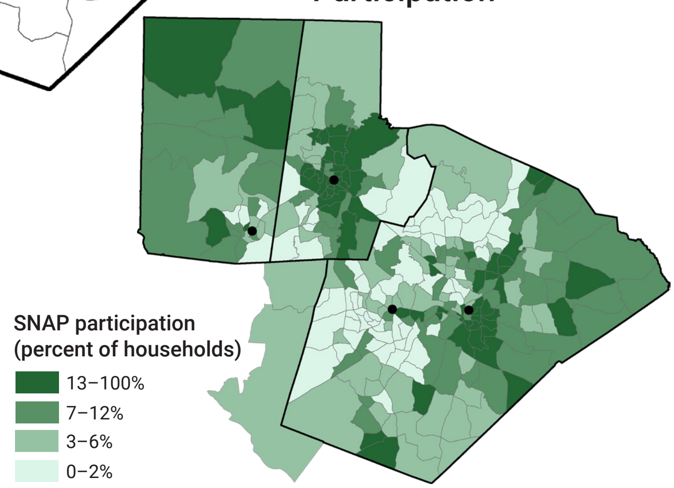


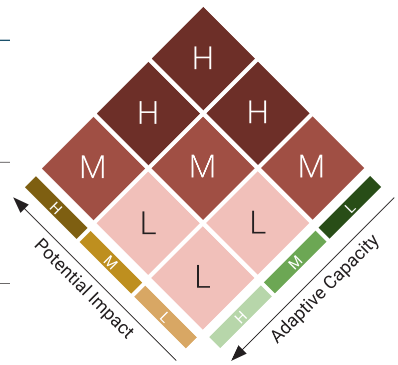
Figure 53b. SNAP Participation



There are also several areas with a moderate percentage (15–50 percent) of vulnerable and at-risk SNAP retailers that are also areas with high levels of SNAP participation. These areas include Southeast Raleigh and within the City of Durham. Areas with a lower percentage of vulnerability and risk and that have high SNAP participation include Northeast and West Raleigh.

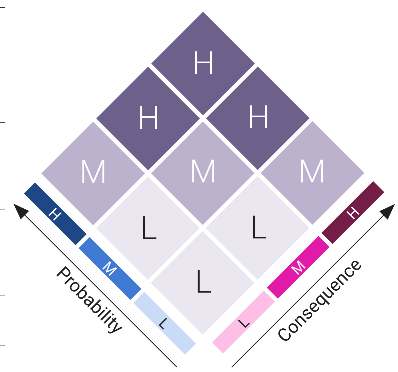
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	No structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



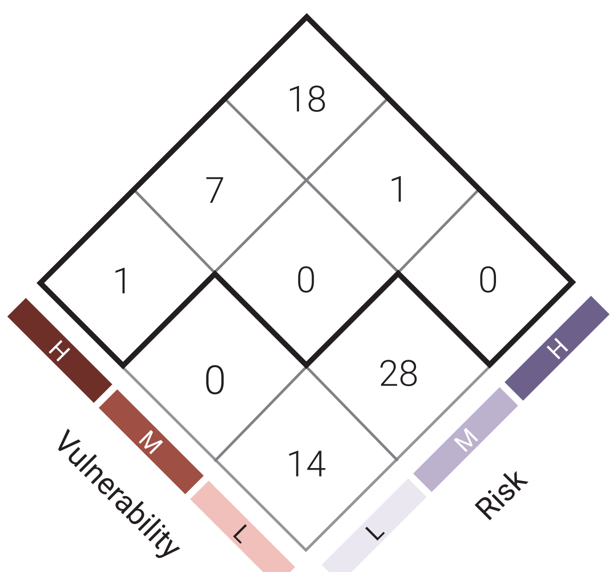
Risk

	Probability	Consequence
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)

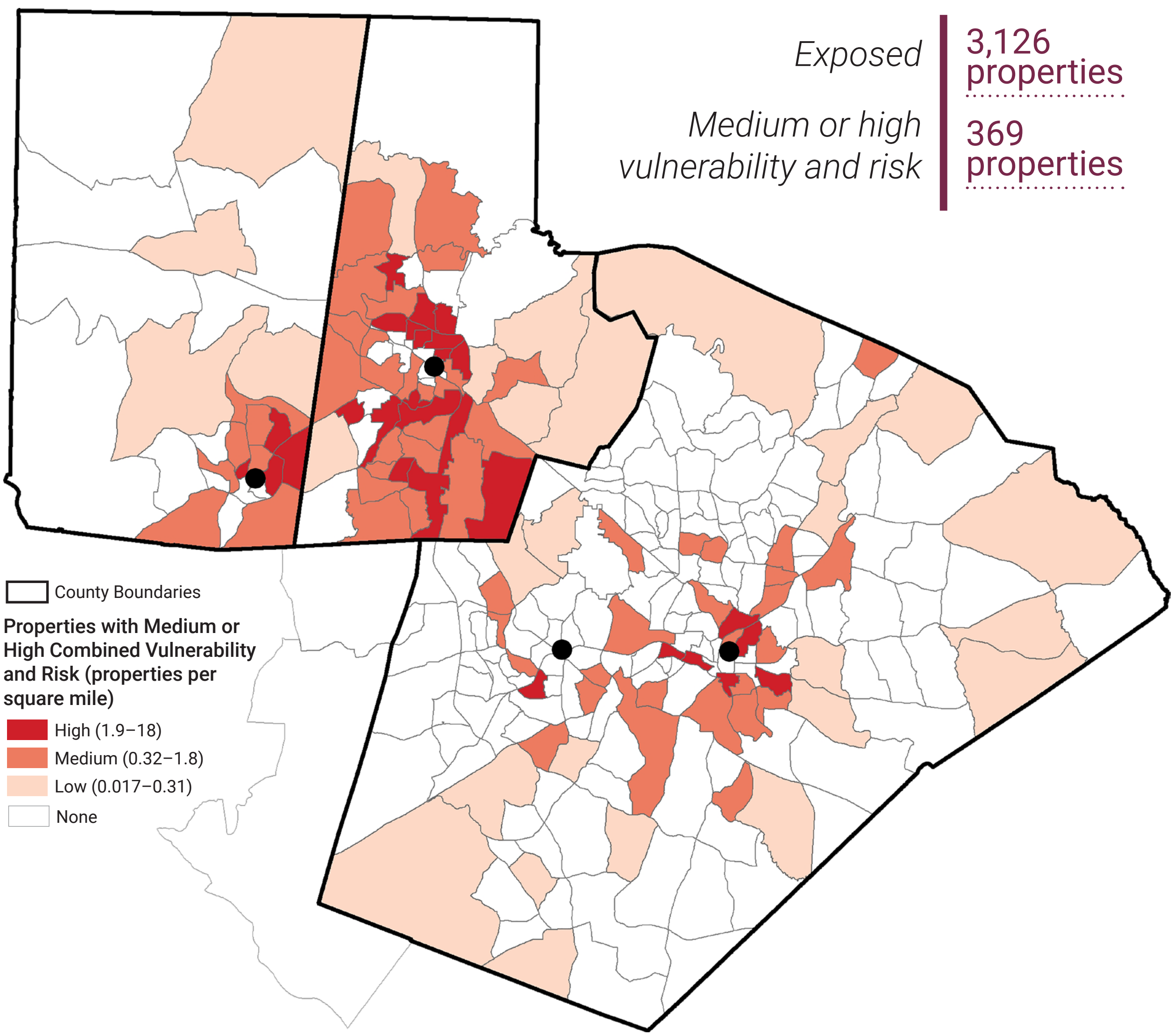


Flooding

Jurisdictional- and State-Owned Properties

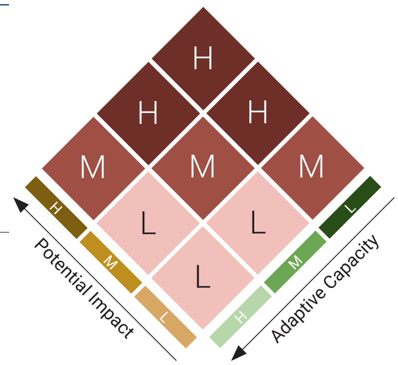
This asset includes all jurisdictional- and state-owned properties except for those associated with parks and recreation and energy/utilities. This includes schools, libraries, and other county/city/town-owned properties as well as colleges and universities, military, correctional, and other state-owned properties.

Figure 54. Assessment: Jurisdictional-/State-Owned Properties and Flooding



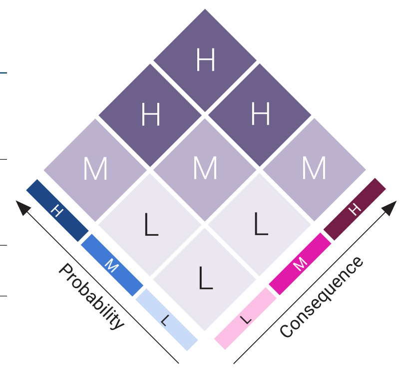
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structures including dorms, shelters, schools, anything with high population, medical facilities, correctional facilities in floodplain	Structure is built out of floodplain or building elevation 2 feet above base flood elevation
Medium		Structure in floodplain building elevation at or 1 foot above base flood elevation
Low	Properties with warehouses and properties with no structure in floodplain (land only)	Structure in floodplain built before floodplain development ordinance



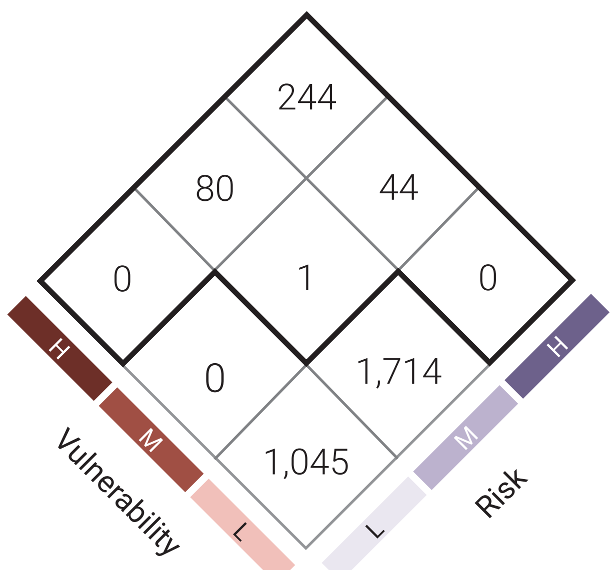
Risk

	Probability	Consequence
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



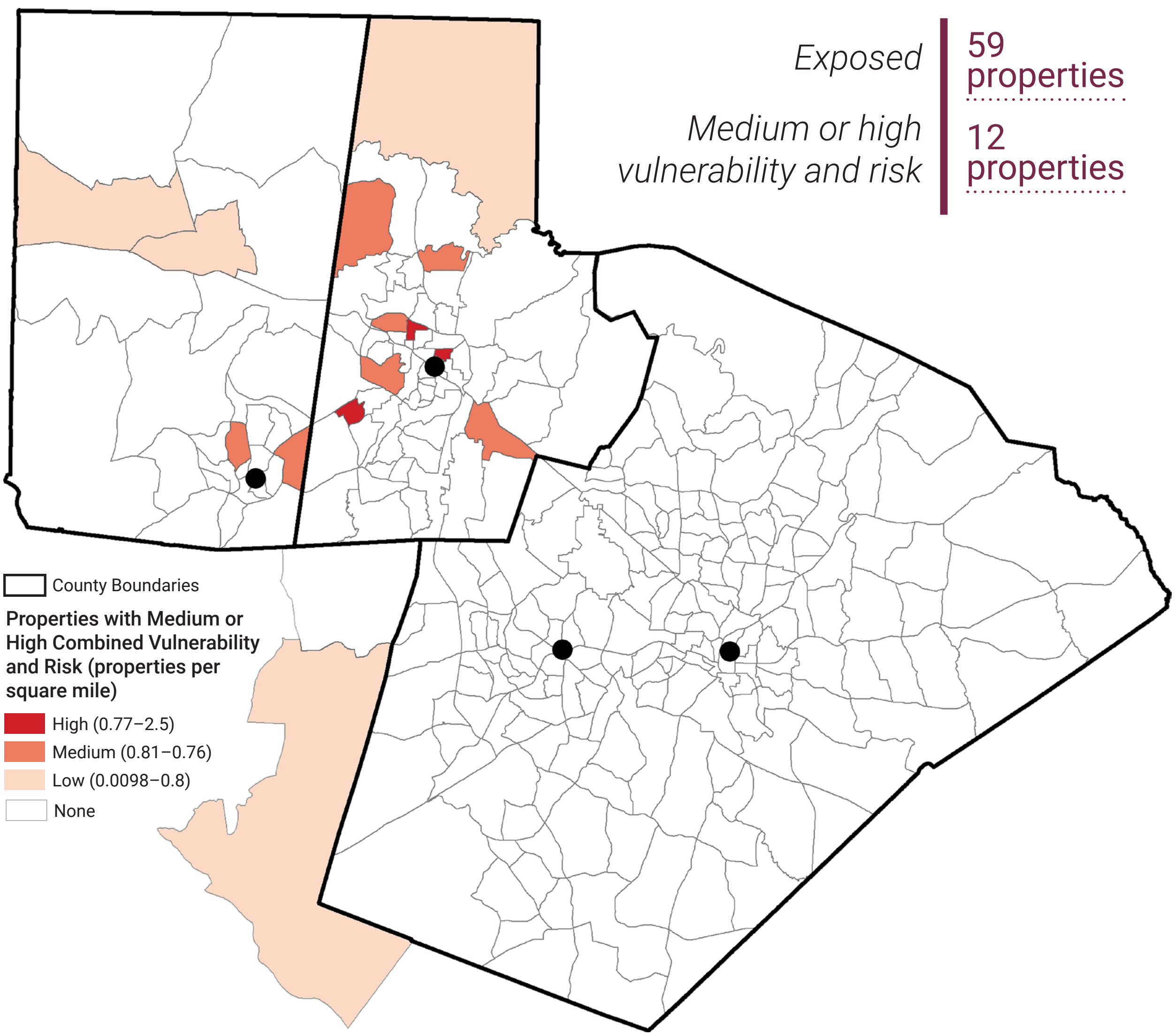
Flooding

Parks and Greenways

Parks and greenway assets include all regional parks, greenways, and community centers. Parks were evaluated based on their type of use and the expected cost and service interruption in a flooding event. Parks that serve as special facilities, such as for emergency service or community centers, and that have structures in the floodplain have the highest vulnerability. Parks with structures in the floodway or 100-year floodplain have higher risk.

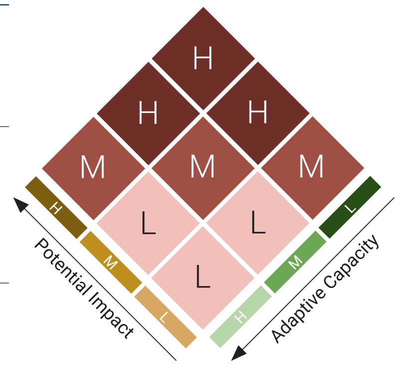
Many parks are in the floodplain and are therefore inherently exposed to flooding. However, parks with high vulnerability and risk have structures or infrastructure that have the potential to be impacted by flooding events.

Figure 55. Assessment: Parks/Greenways and Flooding



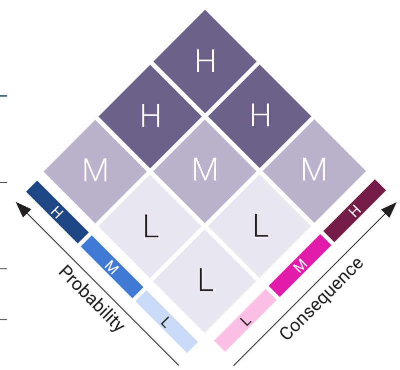
Vulnerability

	Potential Impact	Adaptive Capacity
High	Structure in floodplain and serves as a special facility or community center	High cost and service interruption
Medium	Special facility or community center with no structure in floodplain (land only)	Moderate cost and service interruption
Low	Not a special facility or community center and no structure in floodplain (land only), i.e. playgrounds	Low cost and service interruption



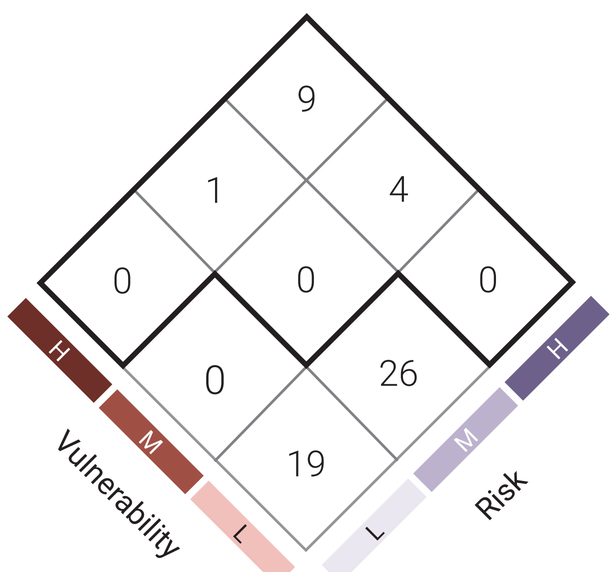
Risk

	Probability	Consequence
High	In floodway	Structure exposed and above median value
Medium	In 100-year floodplain	Structure exposed and below median value
Low	In 500-year floodplain	No structure exposed



Combined Vulnerability and Risk

(Number of parcels)



Snow/Ice Event

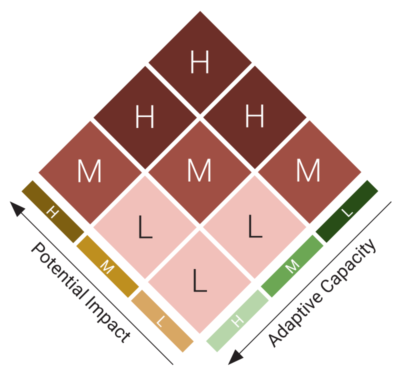
Emergency Services

Responders must deal with emergencies that arise during such events while also mitigating the risk of secondary emergencies—those that might be caused by the interruption of services from complications caused by the initial emergency. The reliance of many of these services on power and communications makes continuance of operations more difficult in extreme weather events.

For a discussion of residential properties located in areas outside an eight-minute drive time from any emergency medical service location or fire station that might be particularly adversely impacted in snow/ice events, please refer to the Extreme Cold discussion and Figure 47.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities serving a large area and/or large population • Facilities that experience widespread or multiple events	• Facilities that have adequate types and amounts of equipment • Facilities with redundancy in equipment and personnel • Facilities with backup generators
Medium		
Low	• Facilities serving a small area and/or a small population • Facilities that do not receive widespread or multiple events	• Facilities that have inadequate types and amounts of equipment • Facilities with no redundancy in equipment and personnel • Facilities without backup generators



Snow/Ice Event

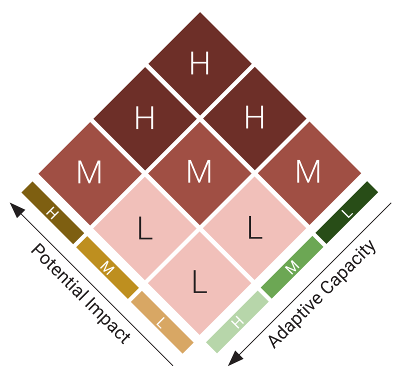
Energy and Utilities

During severe winter weather, wind, cold, snow, and ice can damage energy sector assets. Severe winter storms can cause extensive electric power outages due to distribution system damage from ice and snow. The amount of damage and the number of repair crews that can be brought to the area have a direct result on electric power restoration. Areas that experience large amounts of snowfall and ice accumulation may experience longer restoration delays due to limited access to repair equipment.[40]

Localized communications outages may occur due to wind and ice damage to pole-mounted communications systems or cellular towers. Communications facilities typically have varying levels of backup power capabilities to ensure resilience to power failures. Communications systems are important to response and recovery efforts following a winter storm, and repairs can be expected to proceed quickly once the storm abates and transportation routes are cleared of snow. Wireless telecommunications switching centers can be expected to continue operation in the absence of an extended power outage.[40]

Vulnerability

	Potential Impact	Adaptive Capacity
High	Facilities and infrastructure that serve vulnerable populations, highly populated areas, critical infrastructure, or future light rail systems	• Facilities and infrastructure that are around trimmed, healthy trees • Facilities that receive high response times • Facilities that use underground lines • Facilities that have back-up energy available
Medium		
Low	Facilities and infrastructure at risk due to trees along road that can accumulate ice and snow	• Facilities and infrastructure that are around untrimmed, unhealthy trees • Facilities that do not receive high response times • Facilities that use above-ground lines • Facilities that do not have back-up energy available



Snow/Ice Event

Food Infrastructure

Rising global temperatures and the subsequent changes in weather patterns and extreme climate events have consequences for contamination, spoilage, and the disruption of food distribution.[47] Many of these impacts are thought to be related to rising temperatures and humidity; however, snow and ice events are expected to also impact supply chain, power supply, and access to food locations and distribution centers.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities that serve a large population • Few access points • Located a distance from other food distribution points and from sources of food	• Facilities that have backup generators/power • Large storage capacity • Ability for staff to get to the store • Redundancy in payment acceptance • Plans to receive additional deliveries prior to an event • Contracts for parking and sidewalk clearing
Medium		
Low	• Facilities that serve a small population • Multiple access points • Located not a far distance from other food distribution points and sources of food	• Facilities that do not have backup generators/power • Small storage capacity • No ability for staff to get to the store • No redundancy in payment acceptance • No plan to receive additional deliveries prior to the event • No contracts for parking and sidewalk clearing

Snow/Ice Event

Hospitals and Medical Facilities

The availability and location of hospital resources can complicate emergency response services during snow and ice events. Refer also to the map of hospital locations and regional population density in the Extreme Cold discussion (Figure 48).

Vulnerability

	Potential Impact	Adaptive Capacity
High	Properties used as shelters, for emergency coordination, or that house and feed people (e.g., dorms)	• Properties on which the buildings have a backup power source • Multiple access points • Contracts for parking and sidewalk clearing • On-site storage of food and equipment • Buildings that are generally in good condition
Medium		
Low	Properties not used as shelters or for emergency coordination, and which do not house and feed people, but that do house a clinic	• Properties with buildings that do not have backup power • Limited access points • No contracts for parking and sidewalk clearing • No on-site storage of food and equipment • Buildings in poor condition

Snow/Ice Event

Jurisdictional- and State-Owned Properties

It is anticipated that various services provided by jurisdictional facilities will also be impacted by snow and ice events. These likely are related to supply chain, power, and access to physical facilities, which will affect these properties' ability to carry out public services. Refer also the Extreme Cold discussion for factors to be considered when examining impacts of prolonged cold and snow and/or ice on buildings and facilities.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Properties used as shelters, for emergency coordination, or that house and feed people (e.g., dorms)	• Properties on which the buildings have a backup power source • Multiple access points • Contracts for parking and sidewalk clearing • On-site storage of food and equipment • Buildings that are generally in good condition
Medium		
Low	Properties not used as shelters or for emergency coordination, and which do not house and feed people, but that do house a clinic	• Properties with buildings that do not have backup power • Limited access points • No contracts for parking and sidewalk clearing • No on-site storage of food and equipment • Buildings in poor condition

Snow/Ice Event

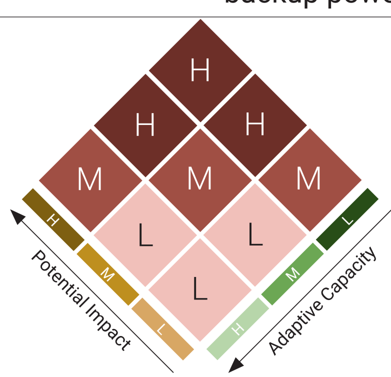
People and Human Health

Winter storms can be accompanied by freezing winds and frigid temperatures that can cause frostbite and hypothermia. Individuals that lack proper clothing and shelter (for example, the homeless) are more at risk of injuries from direct exposure to weather conditions associated with winter storms and severe thunderstorms. Low-income populations have increased exposure risk to severe winter weather conditions because they are more likely to live in low-quality, poorly insulated housing; be unable to afford sufficient domestic heating; or need to make tradeoffs between food and heating expenditures.

Freezing rain, snow, and ice have been linked to increased injuries associated with falling, as well as motor vehicle deaths and injuries due to treacherous road conditions and impaired driving visibility.[48]

Vulnerability

	Potential Impact	Adaptive Capacity
High	Populations that are highly sensitive, including: • Rural • Homeless • Language barriers • Medical conditions, such as dialysis patients • Elderly • Low technological capacity • Reliant on public transportation, but not on major routes	• Populations that have good transportation • Populations that are close to shelters, food, backup power, and public transit routes
Medium		
Low	Populations that are not sensitive	• Rural populations • Populations that do not have good transportation or access to shelters, food, backup power, or public transit routes



Supply Chain Interruption

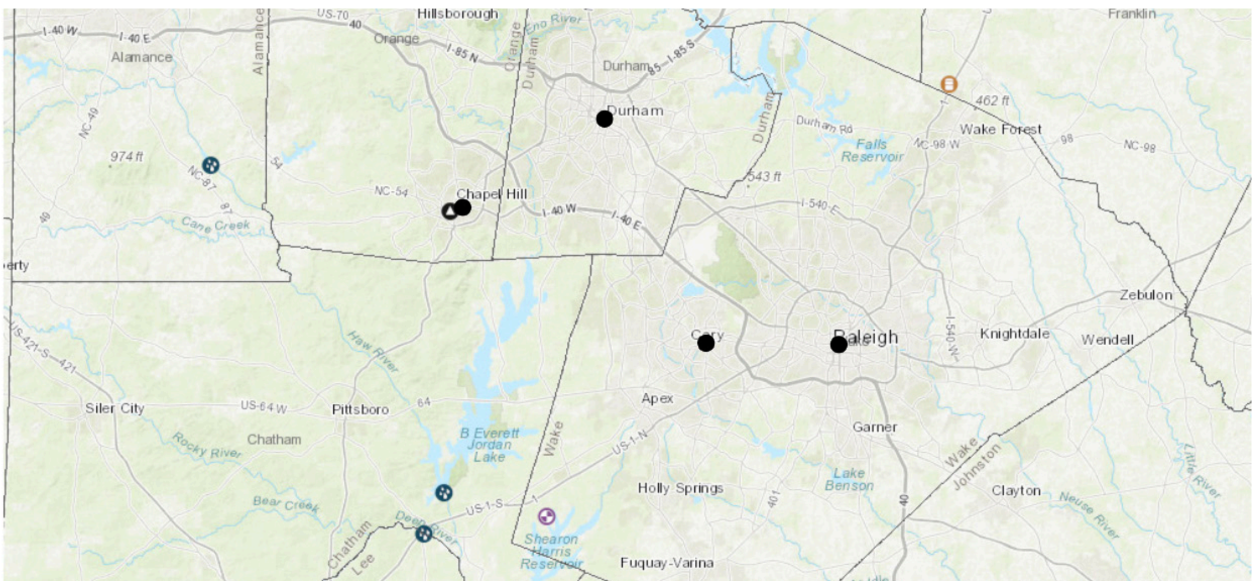
Energy and Utilities

Much of the regional energy infrastructure is vulnerable to extreme weather events. Because so many components of U.S. energy supplies—like coal, oil, and electricity—move from one area to another, extreme weather events affecting energy infrastructure in one place can lead to supply consequences elsewhere.[49] For the Triangle, this analysis must include both energy supply and energy distribution.

Figure 56 shows the location of the major power-generating facilities in the region. These include:

- The Duke Energy Shearon Harris Nuclear Power Plant (928 MW)
- UNC Chapel Hill Cogeneration Facility (coal) (32 MW)
- Small hydro power plants (10 MW)

Figure 56. Major Regional Power-Generating Facilities

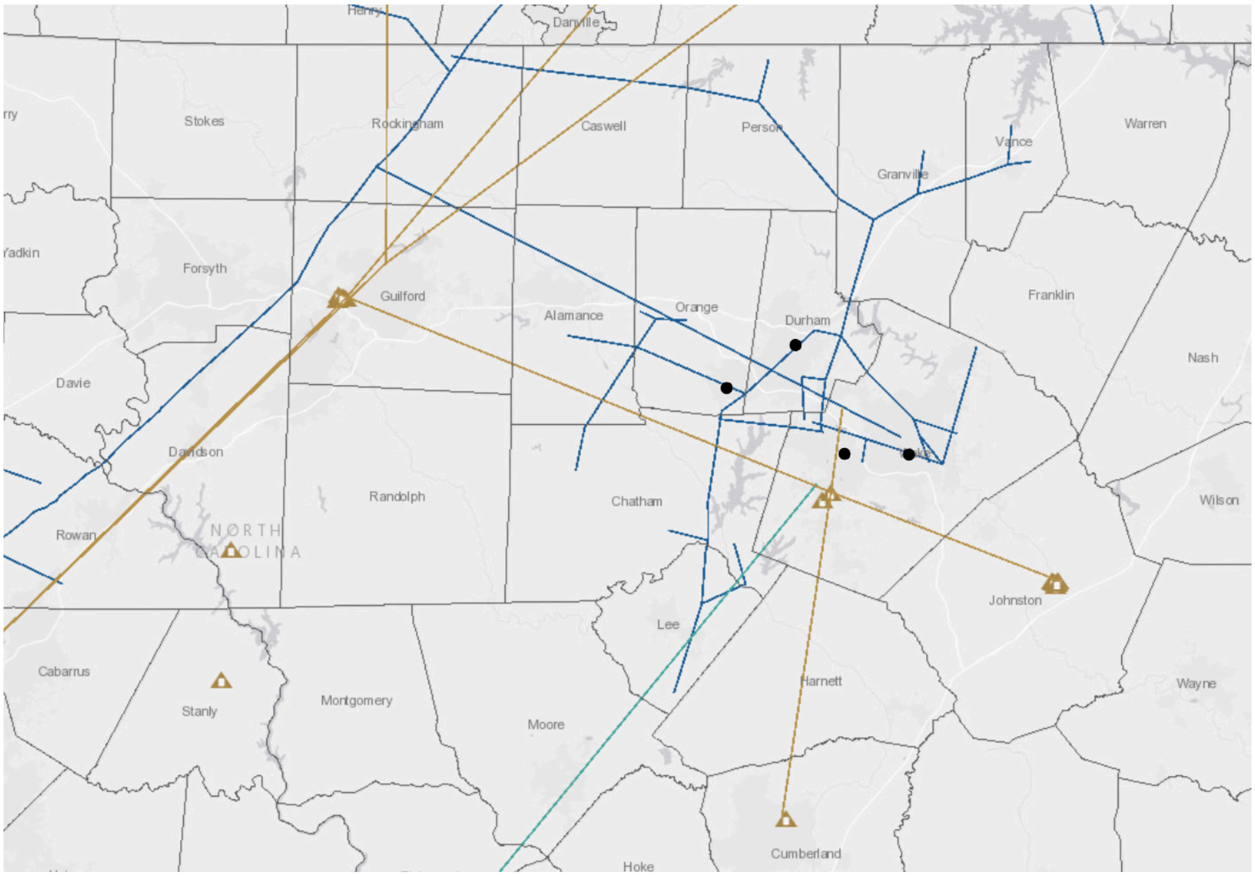


Major regional power-generating facilities. (Figure source: U.S. Energy Information Agency.)

The Harris nuclear plant provides the majority of the region's electricity. Nuclear fuel can be stockpiled; therefore, a supply chain interruption due to first-order energy supply is not an issue. However, the plant relies on Harris Lake for cooling. A projected increase in the number of cooling degree days coupled with projected warming temperatures—or decreased lake water volume as a result of drought—may result in Harris Lake not being able to provide sufficient water for cooling at some time in the future. In such a case, the plant may not be able to supply sufficient electricity for the region during periods of peak demand.

The Triangle region relies heavily on hydrocarbons, primarily for transportation and home heating. North Carolina does not have oil or natural gas fields; these products are imported via pipelines. Figure 57 shows the locations of the major hydrocarbon pipelines.

Figure 57. Major Regional Hydrocarbon Pipelines



Major regional hydrocarbon pipelines. (Figure source: U.S. Energy Information Agency.)

The Colonial Pipeline (in gold) is the major petroleum liquids line that runs from Gulf Coast refineries to the southeastern United States. The Triangle Region is on a trunk line extension, with a distribution terminal (gold triangle) located in south Wake County.

Over the past 10 years there have been several distribution disruptions on the Colonial Pipeline, all of which were due to Gulf Coast hurricane impacts that disrupted the operations of major refineries in Texas and Louisiana. Regional tanks allow storage of some liquid hydrocarbons, but an additional study should be conducted to determine how long the regional supply would last if a longer-duration disruption occurs.

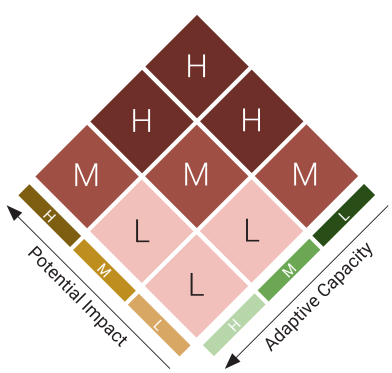
The dark blue lines on the map show the location of natural gas pipelines, with trunk line extensions from Greensboro. There is a local redundancy of lines; therefore, a local interruption should not impact supply. However, the lines are connected to natural gas supplies in both the Gulf Coast and mid-continent. Unlike gasoline and other liquids, natural gas cannot be stored, requiring different forms of energy in the event of a disruption or shortage. One alternative is hydrocarbon gas liquids (HGL). The Triangle Region has an HGL line (shown in light blue on the map) that could provide some backup if properly planned.

Telecommunication systems are also an important part of supply chains: communication services are essential for tracking and coordinating inventories and orders. Telecommunication outages can result in untold delays to supply chain operations.

With modern consumer products now including services and intellectual property, negative impacts on telecommunication systems could have broad impacts on certain supply chains. For instance, Hurricane Sandy inflicted $1 billion in damages to Verizon—the single largest financial impact sustained by the company in its history. Impacts to service providers are multiplied when customers of those systems cannot access their services. As climate scientists project the frequency of conditions that can cause disruptions to transportation and telecommunication systems to increase, they expect risks to supply chain security to increase as well.[21]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities serving a population with power • Facilities with medical equipment and no backup power • Medicare/Medicaid patients • Water treatment facilities and facilities with chemicals on site • Senior care facilities with no backup power • Low- and fixed-income individuals • Individuals relying on public transit • Individuals with long-term shelter needs	• Facilities with communication available • Facilities with water available under mutual aid agreements
Medium	• Facilities with wireless property • Water and sewage utilities with increasing backup, up to 7 days	• Facilities such as county shelters acting as a short-term solution • Short-term warming shelters going into effect given a white flag below 32°F
Low	• Facilities with government communication equipment • Mobile command • Amateur radios	• Facilities without communication or water available • Facilities without mutual aid agreements



Supply Chain Interruption

Food Infrastructure (and Other Freight)

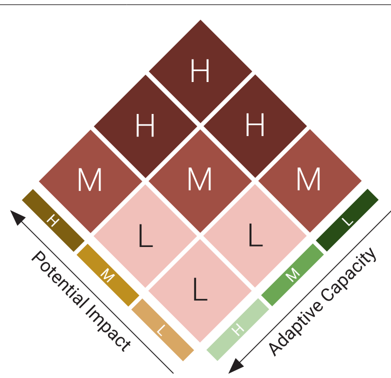
Adverse climate events impact transit time, delivery reliability, and efficiency, which affect the cost of all goods moving through the transportation system—including food.[46] Food and other freight come into the Triangle Region primarily by truck and rail, with some also brought in by plane. Of course, some food and freight are not domestic, so larger supply chain issues would also need to examine connections to ports.

An examination of supply chain interruption must include the impact of disruptions to transportation networks as well as regional warehouses. The regional highway network is well understood by planners, but the importance of rail may sometimes be overlooked. Fortunately, several rail lines in the Triangle Region provide redundancy, limiting the region's vulnerability and risk. Also see Figure 64 in the Transportation–Flooding assessment.

Food access can also be impacted by a supply chain interruption. The Triangle Region is adjacent to one of North Carolina's major agricultural production centers, located to the east; however, coastal storms and other major events could disrupt food supply chains.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Facilities serving the general public for several days or weeks at a time • Facilities that serve budget-constrained populations	• Facilities working with food centers, the Army, the Red Cross, food banks • Facilities that have non-budget-constrained staff • Facilities with continuity of operations (COOP) plans
Medium	Facilities serving schools, prisons, day-care centers, long-term care centers, and hospitals for several days	Facilities with emergency food and mutual aid programs
Low	• Facilities that do not serve budget-constrained populations • Facilities that serve small populations rather than the general public	• Facilities that do not have cooperative systems with food centers or organizations such as the Red Cross • Facilities with budget-constrained staff • Facilities that do not have emergency food or mutual aid programs



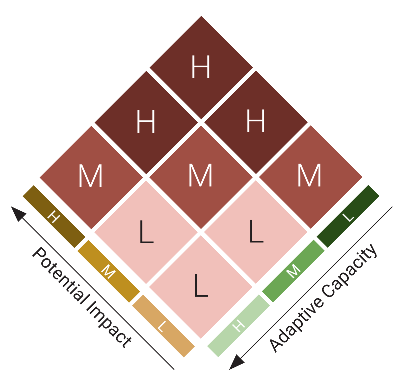
Supply Chain Interruption

Hospitals and Medical Facilities

Hospitals must prepare and stockpile supplies—more supplies than their "just in time" system inventories anticipate—to remain operational through extended transportation and supply chain disruption. Just as critical, hospitals require health care workers from medical professionals to environmental services workers to deliver both direct patient care and necessary support services, such as meal preparation and laundry. In extreme weather events, hospitals must house large numbers of workers, their families and even their pets, in order to continue to deliver high-quality, uninterrupted care while cut off from transportation systems and re-supply infrastructure.[8]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Intensive Care Units and Emergency Rooms • Facilities with local capacity for 3 days • CDC strategic	• Facilities that have backup facilities • Facilities located within proximity to other hospitals that can be of assistance in an event
Medium	Facilities serving 3 level-1 trauma centers	Mobile pharmacies
Low	Facilities serving non-emergency patients	• Facilities that are within such close proximity that they risk being affected simultaneously • Facilities that are located too far from other hospitals that could provide assistance



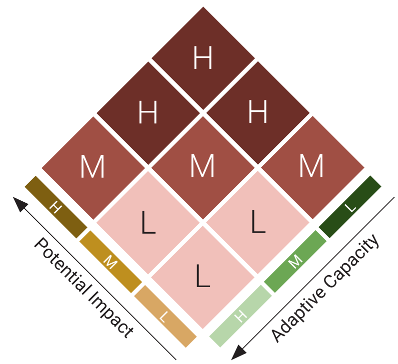
Water Shortage

Emergency Services

Diminished water supply can affect the ability to safely and effectively provide public services, whether it is used in the process of service provision or to protect the health and safety of service providers. An adequate supply of water to facilitate services can often be linked to a particular facility's water storage capacity.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Fire departments and other high water users	Users with access to alternate sources of water, through means such as shortage agreements, well water, or tanker trucks
Medium	EMTs and moderate water users	
Low	Police and low water users	Users without access to alternate sources of water



Water Shortage

Energy and Utilities

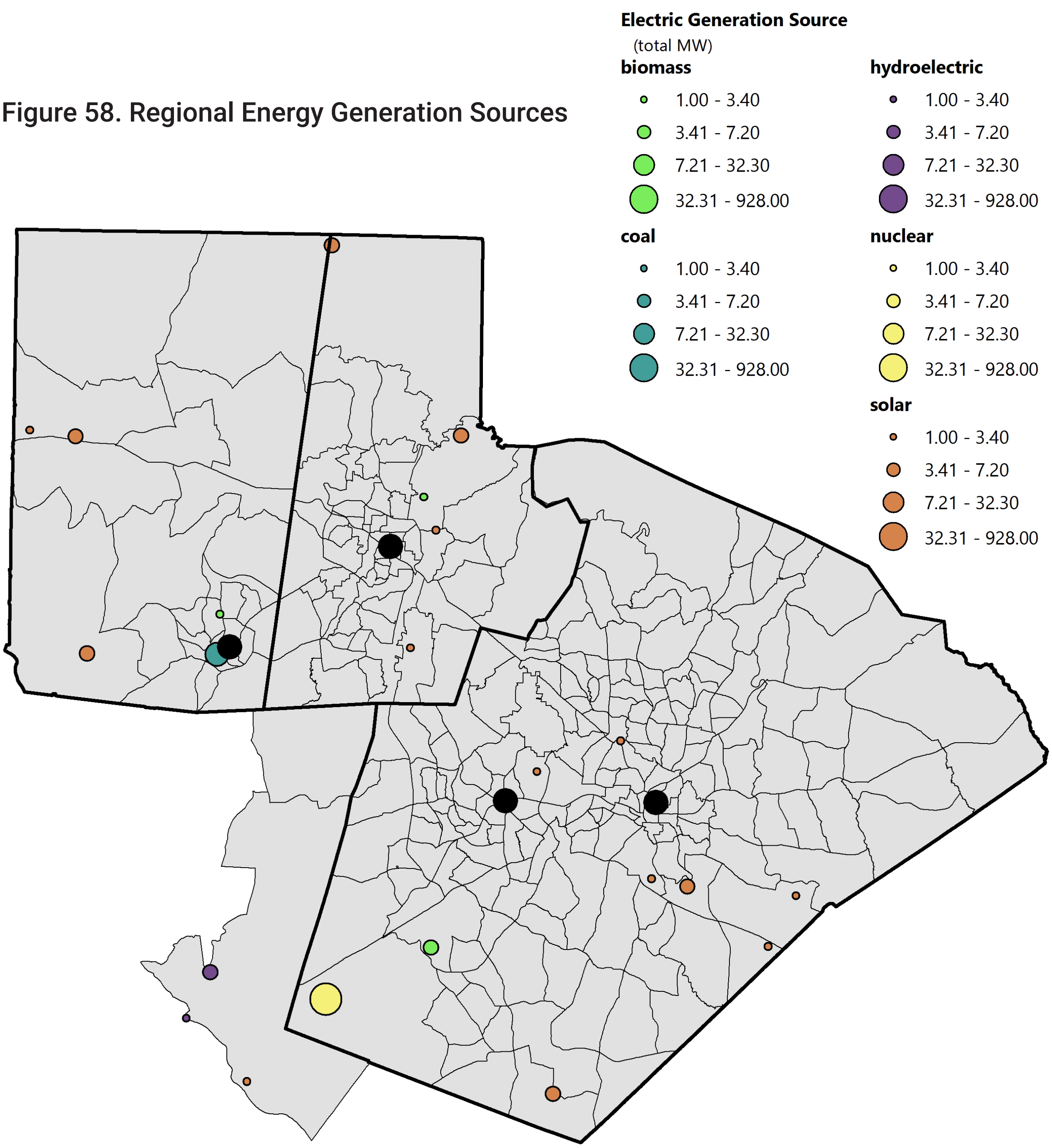
Present day water and energy systems are tightly intertwined. Water is used in all phases of energy production and electricity generation. Energy is required to extract, convey, and deliver water of appropriate quality for diverse human uses, and then again to treat waste waters prior to their return to the environment.[50]

Producing energy from fossil fuels (coal, oil, and natural gas), nuclear fission, biofuels, hydropower, and some solar power systems requires adequate and sustainable supplies of water. Plants fueled by coal, natural gas, oil, nuclear fission, and some renewable energy technologies boil water to produce steam, which then turns a turbine to generate electricity. After it passes through the turbine, more water is needed to cool the steam back into water to reuse for generation; this steam-cooling step accounts for virtually all of the water used in most power plants.[51] Power plants also intake water to cool service equipment, such as chillers for air conditioning units or lubricating oil coolers for the main turbine.[50]

Generation of a kilowatt hour of electricity generated via the steam cycle can require up to 25 gallons of water for cooling. Since energy generation is less efficient under warmer temperatures and higher-than-normal demand, this water intensiveness could increase with the warmer temperatures usually associated with drought and resulting water shortage.[52] If drought impacts the ability of a facility to have reliable access to water, the capacity to supply energy according to demand may be diminished.

Figure 58 shows the locations of all of the region's energy generation sources, by production type and amount. The Shearon Harris Nuclear Power Plant—the large yellow dot on the map—is the Triangle region's primary energy production facility. Nuclear fission is the most water-intensive method of power generation in terms of the amount of water withdrawn from sources. In 2008, nuclear power plants in the United States withdrew eight times as much freshwater as did natural gas plants per unit of energy produced, and up to 11 percent more than the average coal plant.[50] Therefore, the region is highly reliant on this facility having an adequate water supply for cooling—currently supplied through Harris Lake.

Figure 58. Regional Energy Generation Sources

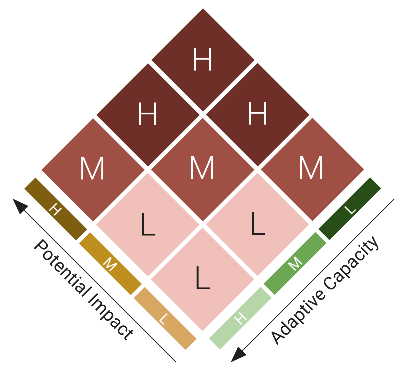


Regional energy generation sources, by production type and amount. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Energy Information Administration, Power Plants.)

Water cooling systems can also pose significant problems from an economic standpoint. When water is warmed, either by plant discharge or ambient temperatures, cooling requires even more water and power plants operate less efficiently. Moreover, if water cannot be cooled, it can neither be recirculated nor returned to the river or lake without threatening aquatic life. Therefore, during hot summers or heat waves, the problem compounds: during times of extreme heat, nuclear power plants operate less efficiently and are dually under the stress of increased electricity demand from air conditioning use. When cooling systems cannot operate, power plants are forced to shut down or reduce output. The combination of high electricity demand and reduced output can result in higher energy prices for ratepayers. Droughts can have a similar effect as heat waves, limiting the amount of water available for cooling.[50]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Nuclear power sites • Hydroelectric power sites	Sites with access to alternate sources of water, through efforts such as shortage agreements, well water, or tanker trucks
Medium	Steam turbine sites	
Low		Sites without access to alternate sources of water



Water Shortage

Food Infrastructure

Vulnerability

	Potential Impact	Adaptive Capacity
High	Facilities that require significant volumes of water for storage, processing, and transport (e.g., grocery stores, food distribution centers), production, harvesting and processing, and distribution and sale	• Facilities with alternative water supply • Facilities with lower water-intensity processing, storage, or transport options • Facilities with alternative regional supply options • Facilities with options to transition to more local farms
Medium		Facilities with priority supply contracts with water utilities
Low	Facilities that do not require significant volumes of water	• Facilities without alternative water supply • Facilities without regional supply alternatives • Facilities without flexibility options to transition to more local farms

Water Shortage

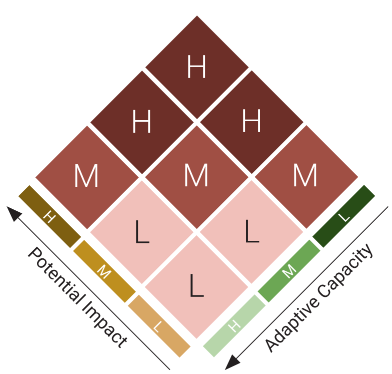
Hospitals and Medical Facilities

The loss of clean, plentiful water can have a huge impact on hospitals and other health care facilities. Beyond the hazards of losing water for clinical needs and operational functions such as instrument sterilization, food preparation, and environmental services, a loss of water also could damage or render inoperable crucial medical and infrastructure equipment. Infrastructure and medical equipment dependent on water include radiology, fire-protection sprinkler systems, water-cooled medical gas and suction compressors, and HVAC systems, among others. Other water requirements to be considered include hand washing and hygiene, food service, laundry, central services, cleaning and infection prevention, and decontamination and hazardous materials response—as well as patient care needs such as bathing and flushing toilets.[53]

There is no national standard for quantity of reserve water backup for hospitals and other medical facilities; one of the key challenges with fixed-quantity emergency water supplies is accurately estimating demand. Storage of large quantities of water is often difficult and impractical, but ensuring 24/7 availability of water delivery is equally challenging. Finding reliable alternative sources of water is a key element of enhanced resilience in a future with stressed potable water supplies.[54]

Vulnerability

	Potential Impact	Adaptive Capacity
High	Facilities with high water use	• Facilities that have an alternative source of water • Facilities with alternatives to water use
Medium		Facilities that have a priority supply contract with water utility
Low	Facilities with low water use	• Facilities that do not have an alternative water supply • Facilities that do not have priority supply contracts with water utility • Facilities that do not have alternatives to water use



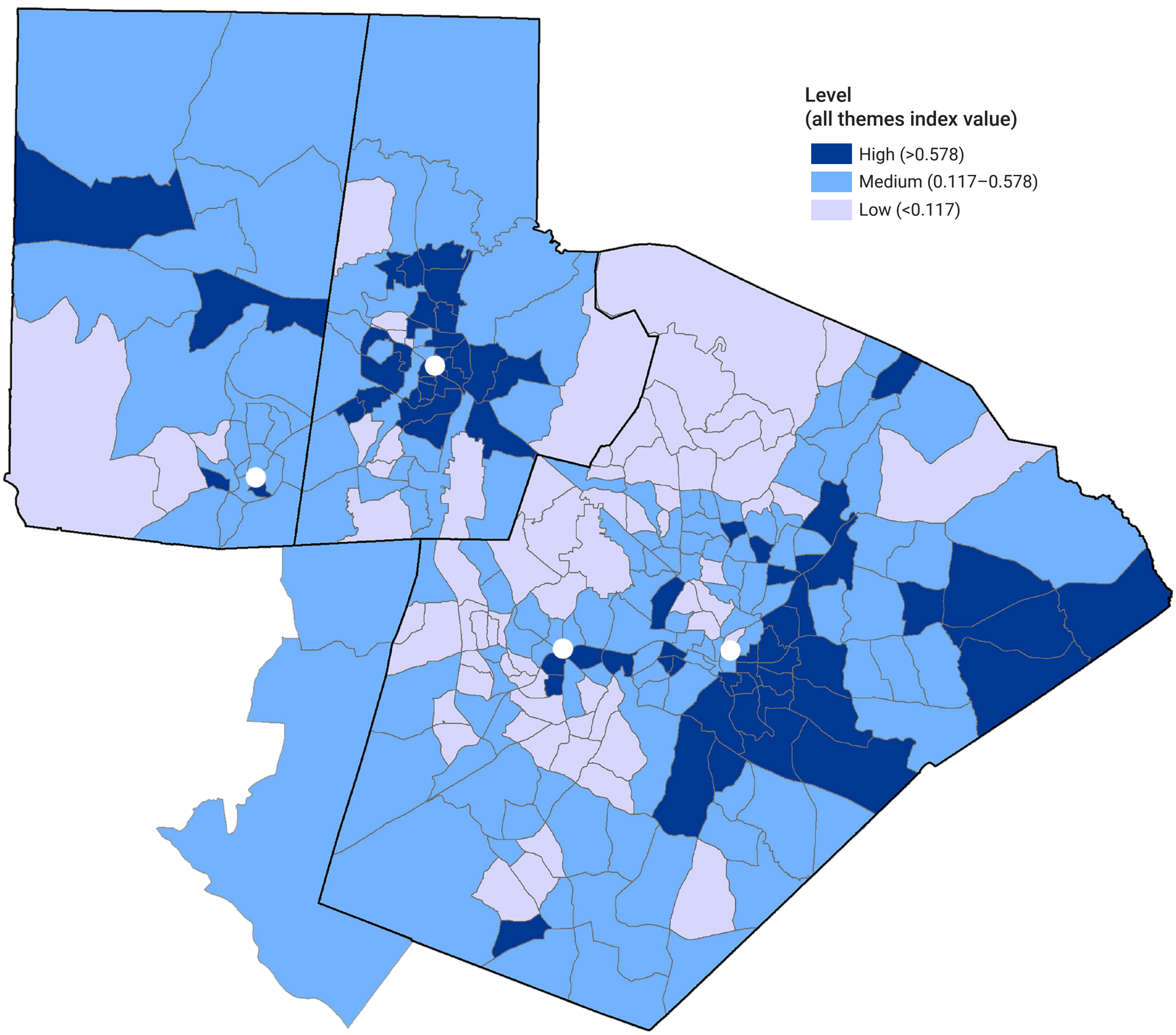
Water Shortage

People and Human Health

For humans, the health implications of drought and subsequent water shortage are numerous and far reaching. Some health effects are experienced in the short-term and can be directly observed and measured; however, the slow rise or chronic nature of drought and water shortage can result in longer term, indirect health implications that are not always easy to anticipate or monitor.[55]

Health-related impacts from water shortage can include compromised quality and quantity of potable water, compromised food and nutrition, diminished living conditions (as they pertain to energy, air quality, and sanitation and hygiene), recreational risks, mental and behavioral health, and increased disease incidence (for infectious, chronic, and vector-borne/zoonotic diseases).[55]

Figure 59. CDC Social Vulnerability Index



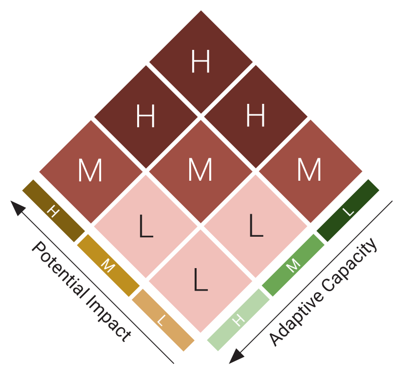
Social vulnerability in the Triangle region, as determined using the Centers for Disease Control and Prevention's Social Vulnerability Index. (Figure source: UNC Asheville's NEMAC. Data source: CDC.)

As with most natural and man-made disasters, drought and resulting water shortage can impact a variety of populations in different ways based on the unique circumstances they face. For purposes of this assessment, the CDC's Social Vulnerability Index was used to identify populations that might have special needs in the event of a public health emergency. Figure 59 identifies such populations in the Triangle region.

Factors used to determine the SVI include socioeconomic status, household composition and disability, minority status and language, and housing and transportation.[37] In addition to the populations identified by the SVI, people living in rural or remote areas who depend on water from private wells and from small or poorly maintained municipal systems, the quality of which is more susceptible to environmental changes, are at increased risk for adverse health effects.[55]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• People dependent on wells for water • Vulnerable populations, such as the very young and the old, those with language barriers, and dialysis patients	Properties with access to utility water
Medium		
Low	• People not dependent on wells for water • Non-sensitive populations	Properties without access to utility water



Wildfire

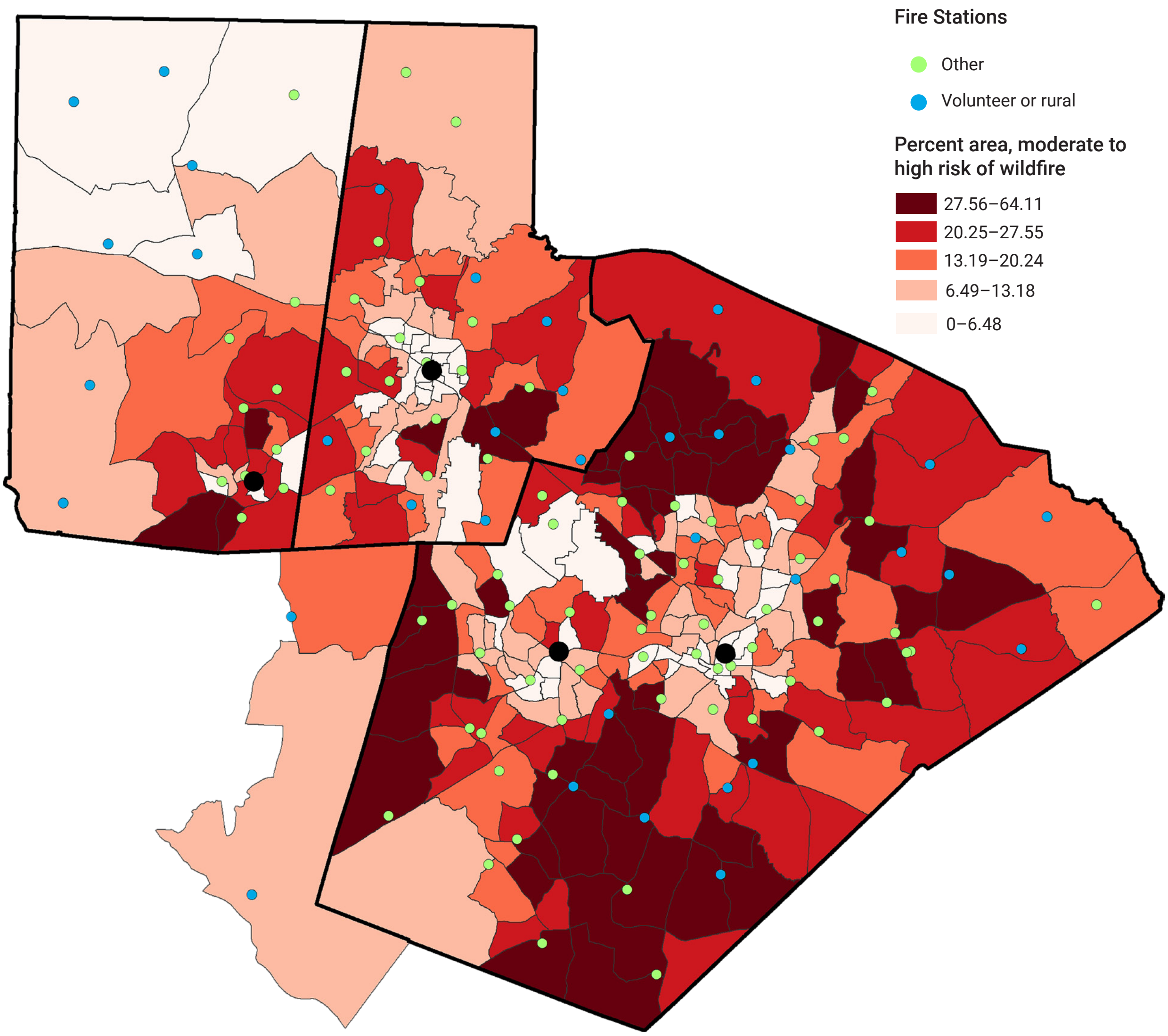
Emergency Services

Many cities in the U.S. are incorporating areas that contain environments with which city fire department personnel are inexperienced. Expanding cities typically incorporate suburban and rural areas, and many firefighters—while experienced in responding to urban emergencies—are unfamiliar with the alternate firefighting tactics that suburban and rural environmental hazards require.[56]

The increasing frequency and intensity of wildland and wildland-urban interface (WUI) fires have become a significant concern in many parts of the United States. There is also growing recognition of the importance of wildfire mitigation and public outreach about community risk reduction.[57] Communities may face additional WUI fire risk without appropriate equipment and training in wildfire response and suppression.

Figure 60 shows locations of regional fire stations, including volunteer or rural stations, over the WUI risk areas as defined by the Southern Group of State Foresters. Note that many volunteer-based stations are not staffed full-time. In some cases, these are the only stations in proximity to areas with high wildfire risk.

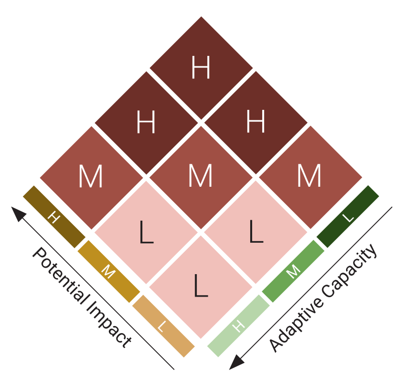
Figure 60. Regional Fire Station Locations and WUI Risk Areas



Regional fire stations over the wildland-urban interface risk areas as defined by the Southern Group of State Foresters. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Geological Survey "National Structures" and Southern Group of State Foresters.)

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Structures in proximity to wildfire threats • Major facilities • Facilities built in a year with building codes that do not ensure sufficient levels of internal fire suppression or the use of materials with low flammability and toxicity when combusted	• Sites that have complete and updated continuity of operations plans (COOP) • Facilities that are within a 5-minute drive time of fire and emergency medical services plus distance to water sources • Mandatory Firewise Community or similar measures in the Wildland Urban Interface area (WUI) • In the jurisdiction of a fire department with consistent training on wildfire response
Medium	Structures in proximity to wildfire threats and single residences	Sites that incentivize Firewise Community or similar measures in the WUI
Low	• Structures not in proximity to wildfire threats • Facilities built in a year with building codes that ensure sufficient levels of internal fire suppression and the use of materials with low flammability and toxicity when combusted	• Sites that do not have continuity of operations plans (COOP) • Facilities that are further than a 5-minute drive time of fire and emergency medical services plus distance to water sources • No Firewise Community or similar measures in the WUI • In the jurisdiction of a fire department with no training on wildfire response



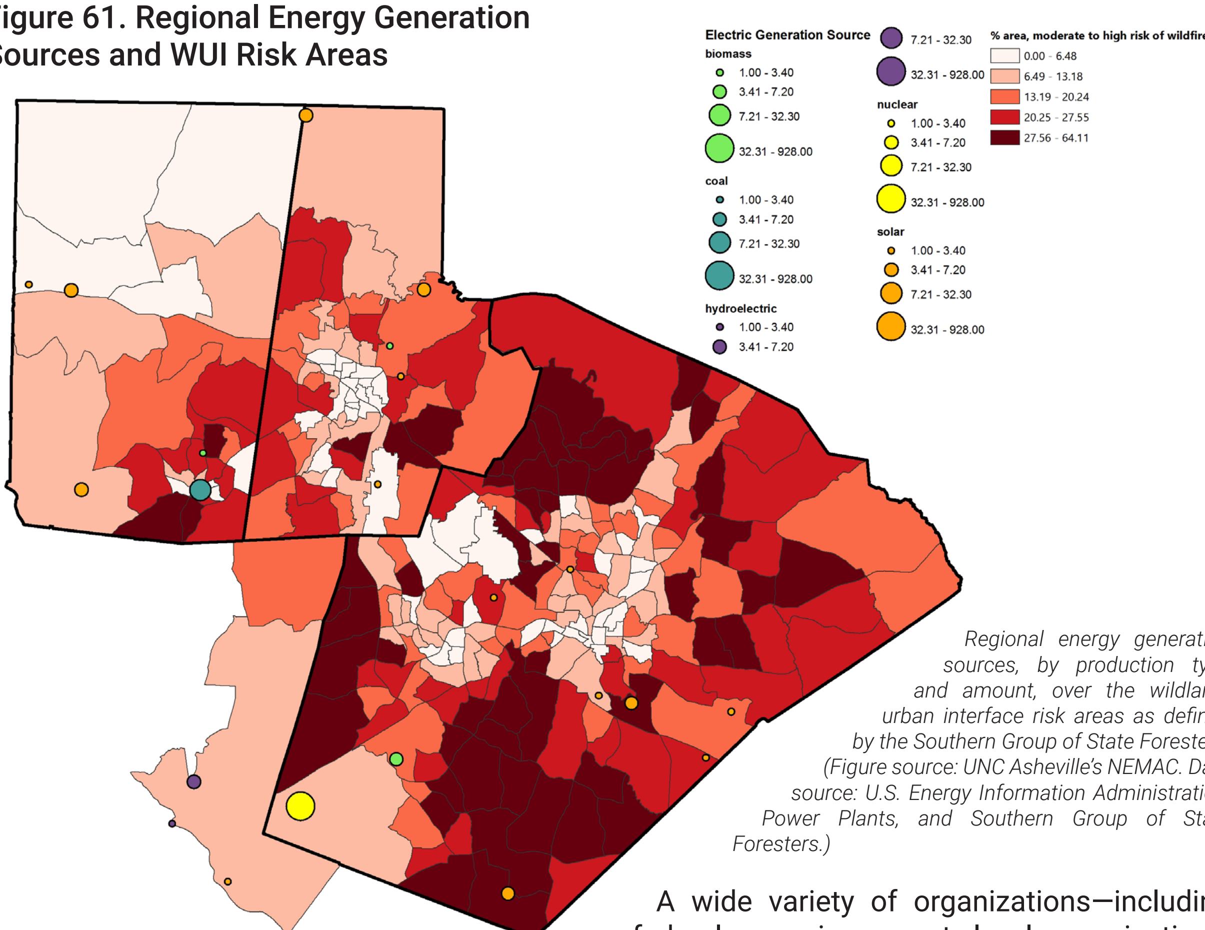
Energy and Utilities

Energy transmission, storage, and distribution infrastructure are vulnerable to physical damage from wildfires. Fires can damage wooden transmission line poles, and the associated heat, smoke, and soot can affect transmission line capacity. Soot can also reduce the electrical resistance of the air, increasing the risk of transmission lines arcing to other lines or to nearby vegetation.

Other lasting effects from wildfires that can impact the energy system include increased soil erosion and risk of landslides and changes in water quality (through increased amounts of sediment).[58]

Figure 61 shows the locations of all of the region's energy generation sources, by production type and amount, over the WUI risk areas as defined by the Southern Group of State Foresters.

Figure 61. Regional Energy Generation Sources and WUI Risk Areas



Regional energy generation sources, by production type and amount, over the wildland-urban interface risk areas as defined by the Southern Group of State Foresters. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Energy Information Administration, Power Plants, and Southern Group of State Foresters.)

Wildfires also frequently damage other community infrastructure, including communication facilities (such as cell phone towers and phone lines).[59] Research has shown that frequent and effective communication between response organizations and individuals is critical to ensuring the most effective response during wildfire incidents.

A wide variety of organizations—including federal agencies, county-level organizations, and fire departments—are responsible for responding to wildfire incidents, and communication often occurs between individuals holding diverse positions within responding organizations. Understanding factors that lead to effectiveness or failure of communication between individual disaster responders is important to ensure the best possible outcomes during wildfire incidents. Key findings from this research include the fact that the least problematic communication during wildfire incidents were among responders who (a) communicated frequently during the incident, and (b) were more familiar with each other prior to the incident.[60]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Sites where lines are above ground • Facilities built in a year with building codes that do not ensure sufficient levels of internal fire suppressions or the use of materials with low flammability and toxicity when combusted • Facilities in inaccessible areas • Structures in proximity to wildfire threat and in proximity to multiple residences • Major distribution sites • Critical lines/nodes	• Sites with generator backup for communications equipment (i.e. servers, switches, etc.) • Mandatory Firewise Community or similar codes and measures at the Wildland Urban Interface (WUI) area • Continuous ring of defensive land used as a buffer around development to WUI (i.e. cemeteries, open parkland, etc.), with a good tree maintenance plan • Within 5 minutes drive-time of fire or emergency medical services, including distance to water source • Facilities with high energy diversity (i.e., distributed solar availability, energy storage, multiple sources)
Medium	• Sites where lines are below ground but shallow • Facilities in somewhat accessible areas • Structures in proximity to wildfire threat and in proximity to a single residence • Medium-sized facilities • Somewhat critical lines/nodes	• Sites with battery backup for communications equipment • Incentives for Firewise Community or similar codes and measures at the WUI • Some defensive land used as a buffer around development to WUI
Low	• Sites with buried utilities • Facilities built in a year with building codes that ensure sufficient levels of internal fire suppression and use of materials with low flammability and toxicity when combusted • Facilities in a highly accessible area • No structures in proximity to wildfire threat • Small or non-critical lines/nodes	• Sites with no battery or generator backup for communications equipment • No Firewise Community or similar codes and measures at the WUI • No defensive land used as a buffer around development to WUI • No tree maintenance plan • Further than 5 minutes from fire or emergency medical services plus distance to water source • Medium energy diversity

Wind

Emergency Services

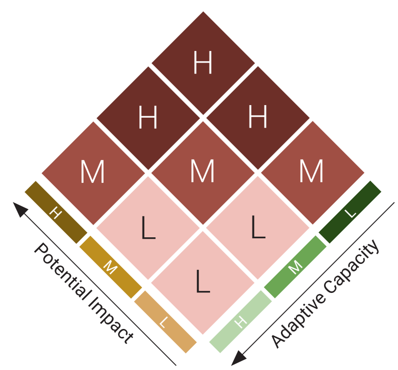
Some municipalities have policies stating that emergency services cannot operate in high winds, where the continuance of operations may put both responders and those requiring help at risk of death or injury. Hurricanes are events of particular concern.

Risks from high winds vary depending on whether the responder is on foot and in the path of debris, in a vehicle that may be difficult to control in high wind, or is above the ground, such as on a ladder.[61]

Extreme wind events can cause damage to transportation networks from downed trees and blocked roads. There are residential properties within the Triangle region that are outside an eight-minute drive time for emergency responders; residents of these properties could potentially face longer emergency response times if the transportation or road network was compromised due to wind damage. Refer also to Figure 47 and the discussion under Extreme Cold.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Services that are complicated by or cannot be carried out due to winds, such as medevac or fire-fighting	Facilities not surrounded by older trees
Medium		
Low	Ground-based operations, such as EMT and police services	Facilities surrounded by older trees



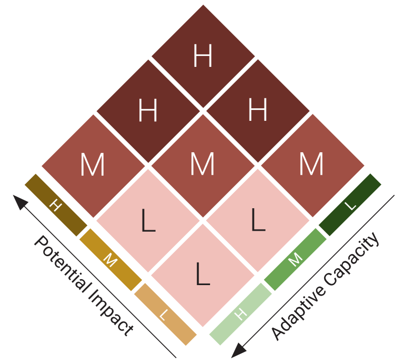
Wind

Energy and Utilities

Like much of the nation's infrastructure affected by major weather events (with estimated economic damages greater than $1 billion), U.S. energy facilities and systems, especially those located in coastal areas, are vulnerable to extreme weather events. Wind and storm surge damage by hurricanes already causes significant infrastructure losses on the Gulf Coast, which can affect oil and gas production for the entire Southeast.[49] However, the Triangle region may also experience damage to energy and utility infrastructure in cases of extreme wind events.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Infrastructure is surrounded by tree canopy and consists of above-ground utilities, such as light poles	• Infrastructure uses wind energy generation • Smart grid technologies • Redundancy of communication lines
Medium	Infrastructure is a solar farm	
Low	Infrastructure is not surrounded by tree canopy and has below-ground utilities	• Infrastructure does not have smart grid technology • No redundancy of communication lines



Wind

Food Infrastructure

Rising global temperatures and the subsequent changes in weather patterns and extreme climate events have consequences for contamination, spoilage, and the disruption of food distribution.[47] Many of these impacts are thought to be related to rising temperatures and humidity; however, high wind events can potentially impact supply chain, power supply, and access to food locations and distribution centers.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Structures built in a year during which building codes do not ensure sufficient wind-resistance • Structures that use poor wind-resistant materials, such as glass	• Facilities with backup power supply • On-call contracts for storm cleanup • Wind-resistant retrofits on older structures
Medium		
Low	• Structures built in a year during which building codes ensure sufficient wind-resistance • Structure uses wind-resistant materials	• Facilities without backup power supply • No on-call contracts for storm cleanup • No wind-resistant retrofits on older structures

Wind

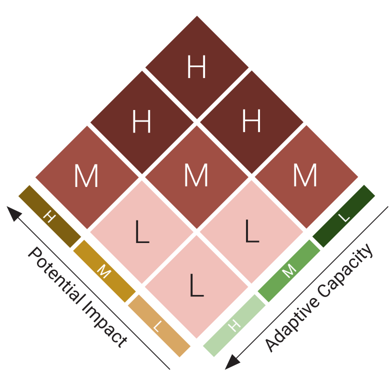
Hospitals and Medical Facilities

Tornadoes and extreme wind events wreak havoc on buildings, particularly those constructed prior to the 1970s, when building codes began to focus on wind resistance of structural elements such as windows and roofs. Wind tunnel modeling has become much more advanced, allowing predictive modeling of the impact of high wind on building designs and air flow.[8]

In order to survive the most severe tornadoes (EF-5), facilities must be built to withstand wind velocities of 200 miles per hour, with particular attention to fastening equipment and façade elements to minimize the risk of airborne debris becoming projectiles in the wind. Many U.S. Critical Access Hospitals in tornado-prone regions date from the 1950s or 1960s, prior to contemporary codes and standards. Retrofits of façades and mechanical systems are expensive and complex, particularly for hospitals that must remain operational. More wind resistant requirements for new residential care settings, including nursing homes and intermediate care facilities, must also be in place for a generation before resilient care settings are the norm.[8] Refer also to Figure 48 depicting the distribution of hospitals throughout the Triangle region and population density in the discussion of Extreme Cold.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Multi-story structures • Facilities built in a year for which building codes do not ensure sufficient wind-resistance • Facilities that use poor wind-resistant materials, such as glass	• Facilities with backup power • Severe weather staffing plans • Contingency plans for grounded helicopters • Ability to close off damaged parts of buildings
Medium		
Low	• Low structures • Facilities built in a year for which building codes ensure sufficient wind-resistance • Facilities using wind-resistant materials	• Facilities without backup power • No severe weather staffing plans • No contingency plans for grounded helicopters • No ability to close off damaged parts of buildings



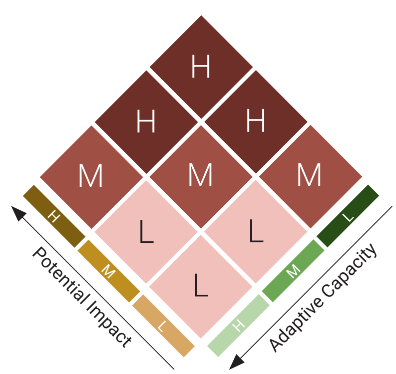
Wind

Jurisdictional- and State-Owned Properties

It is anticipated that various services provided by jurisdictional facilities would be impacted by high wind events. Buildings can be impacted by direct gusts, by persistent wind, and by windblown debris or rain. Even if the building is not structurally damaged by wind, services such as power supply may be disrupted due to damage to power supply infrastructure, or internal damage may result from water intrusion.[62]

Vulnerability

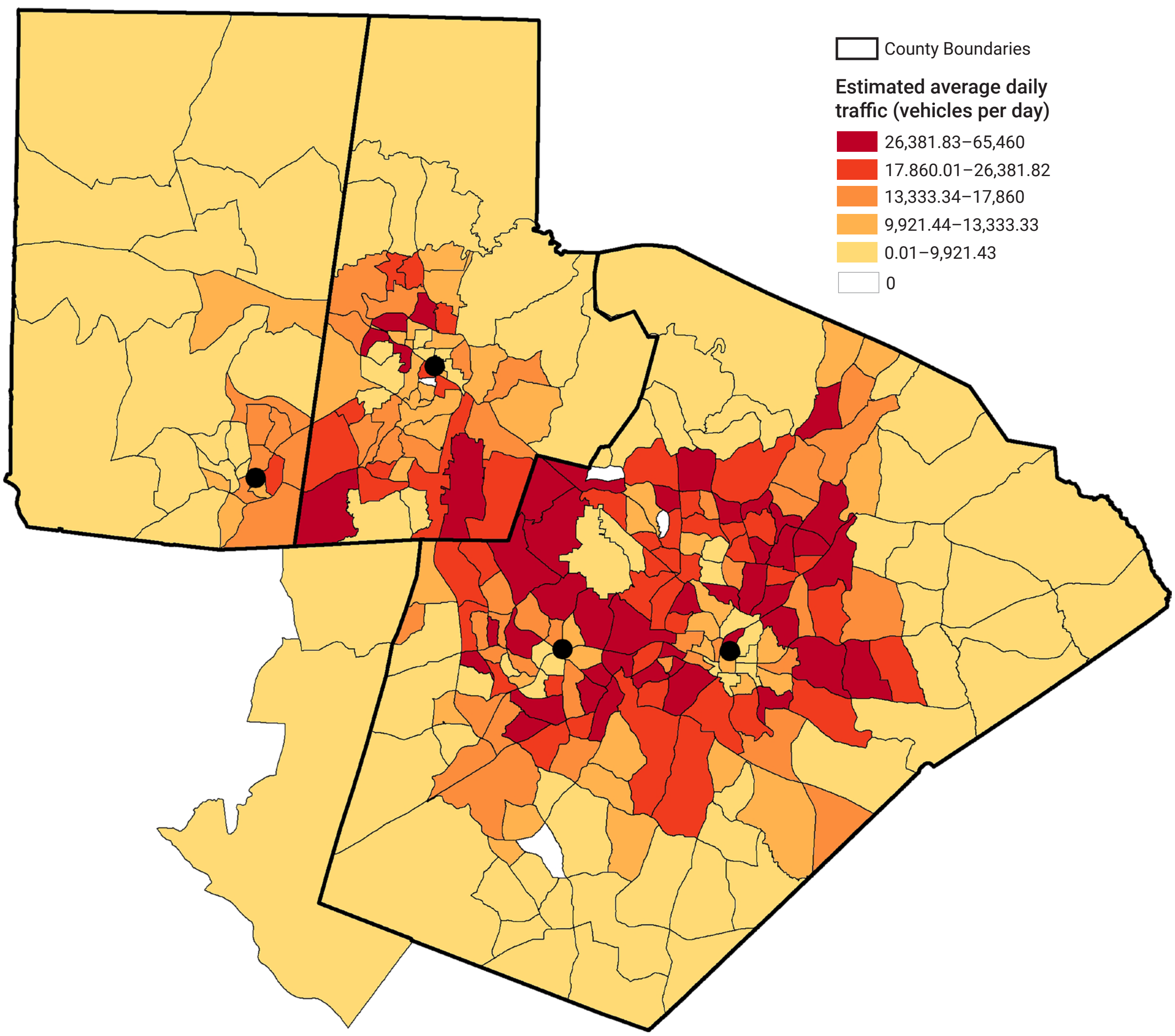
	Potential Impact	Adaptive Capacity
High	• Multi-story structure • Facility built in a year for which building codes do not ensure sufficient wind-resistance • Facility uses poor wind-resistant materials, such as glass	• Facilities with backup power • Severe weather staffing plans • Evacuation plans • Ability to close off damaged parts of buildings
Medium		
Low	• Low structures • Facility built in a year for which building codes ensure sufficient wind-resistance • Facility uses wind-resistant materials	• Facilities without backup power • No severe weather staffing plans • No evacuation plans • No ability to close off damaged parts of buildings



Transportation

Increased temperatures can cause asphalt road degradation, rail buckling, and thermal expansion of bridges. Road and rail systems are typically engineered to withstand particular temperature ranges based on anticipated future weather; when temperatures exceed the range for which they were designed, pavement can soften, rails can kink, and steel structures can expand, leading to pavement failure, derailments, and accelerated deterioration.[63] For aviation, higher temperatures can reduce maximum takeoff weights or require longer takeoff distances for airplanes, and can soften or damage pavement on runways and taxiways, requiring more frequent repair or resurfacing.[64]

Figure 62. Regional Estimated Maximum Average Daily Traffic



Estimated maximum average daily traffic for the Triangle region calculated by number of vehicles per day, averaged for the time period 2014–2016. (Figure source: UNC Asheville's NEMAC. Data source: Connect NCDOT Traffic Volume Maps.)

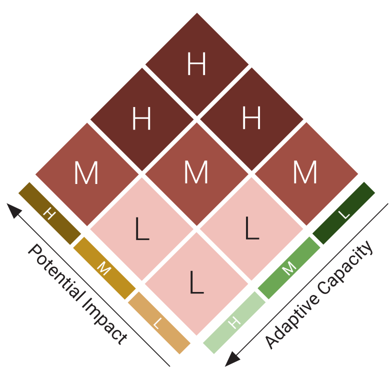
Increased temperatures can also impact maintenance schedules of roads, railways, and runways/taxiways due to concerns over the health and safety of outdoor workers, who could face heat exhaustion if required to work in high temperatures.[63]

When drought conditions are present, increased temperatures increase the risk of wildfire. Increasing frequency, magnitude, and duration of wildfires (with associated smoke) pose risks to roads, bridges, railroads, and airports.[63]

In the Triangle region, heavily traveled roads were identified as one condition of potential high vulnerability. Figure 62 shows regional estimated average daily traffic by number of vehicles.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Roads with many critical access points • Roads paved with new asphalt • Roads that are heavily traveled, particularly if traveled primarily by old cars	• Improved roads with a larger tree canopy • Adequate materials and maintenance
Medium	Roads paved with old asphalt	
Low	• Roads with limited critical access points • Roads paved with concrete • Roads that are lightly traveled, or traveled by primarily new cars	• Roads that have no tree canopy • Roads that receive inefficient maintenance and materials



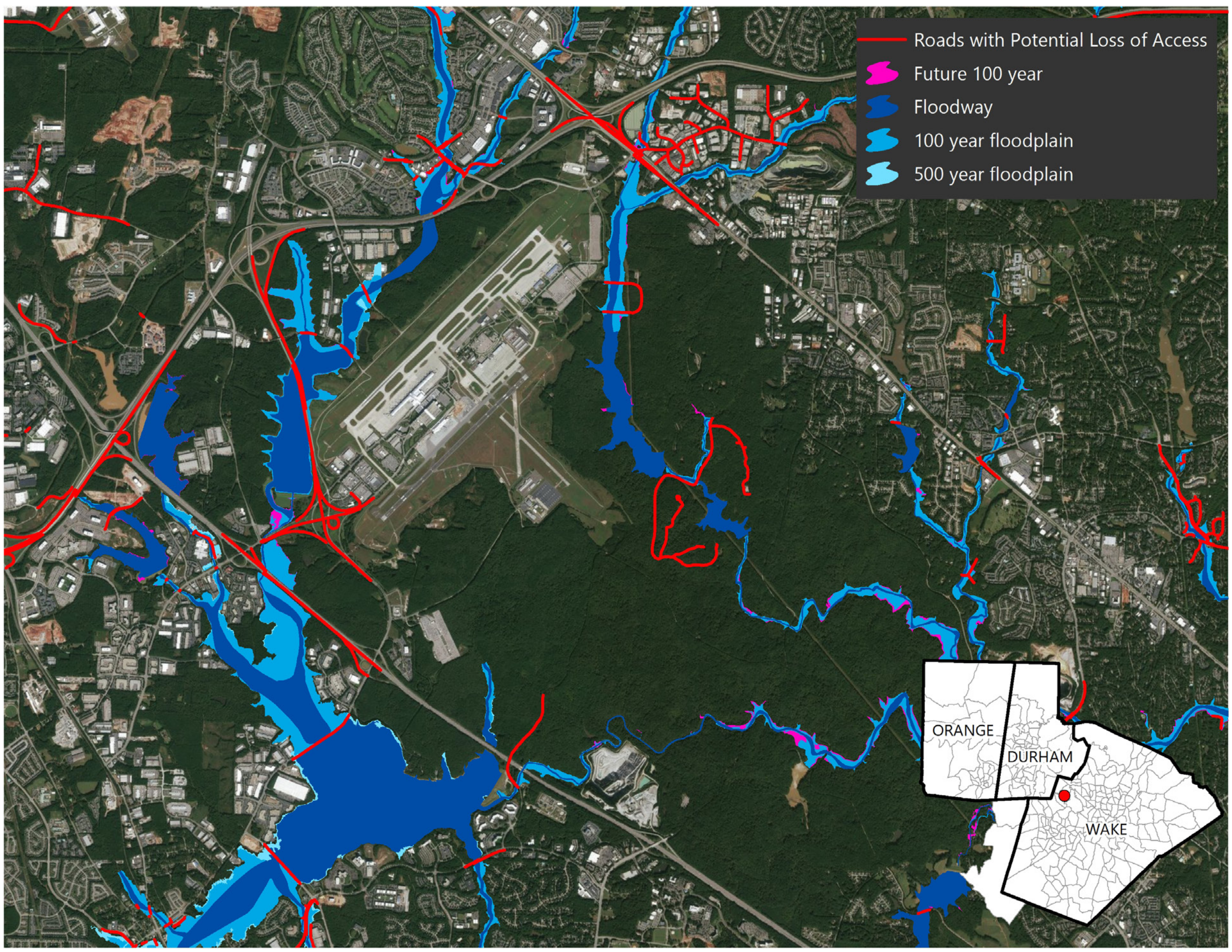
Flooding

Airport

Changes in precipitation patterns, including more extreme precipitation events, will affect transportation systems across the country. Delays caused by severe storms disrupt almost all types of transportation, including aviation.[65]

Flooding as a result of extreme precipitation events at the airport could cause delays and cancellations in airline schedules, as well as damaging airport facilities and infrastructure. Storm drainage systems could also be inadequate, resulting in localized flooding.

Figure 63. Raleigh-Durham International Airport and Floodway/Floodplain Levels



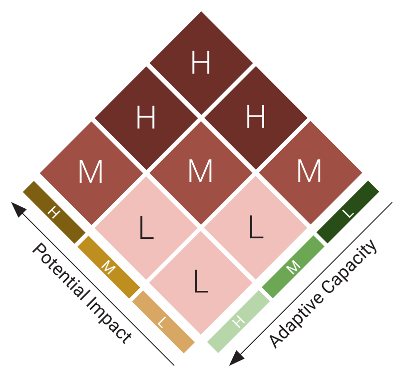
Aerial image of the Raleigh-Durham International Airport shown with roads and floodway and floodplain levels for the surrounding area. Red lines indicate roads that are either inundated or potentially cut-off or isolated. (Figure source: UNC Asheville's NEMAC. Data sources: NC Floodplain Mapping Program 2017, Open Street Map.)

Figure 63 shows facilities and infrastructure at the Raleigh-Durham International Airport, along with floodway and floodplain levels. One potential impact from flooding may not be directly related to airport buildings and runway infrastructure—as can be seen on the map, road access to and from the airport in the surrounding high traffic-volume area may be adversely impacted in a flood event.

An exposure and road access analysis was performed for this asset-threat pair. Additional vulnerability criteria shown below were determined by the Core Team; however, data were not available to use these in the assessment.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Infrastructure such as runways or fuel sources (fuel depot)	• Follows FAA regulations for emergencies, has partnerships with emergency response and local jurisdictions • Has alternate plan for airline take-off and landing during flooding event
Medium		
Low	Runways or non-critical buildings (storage, parking, etc.)	



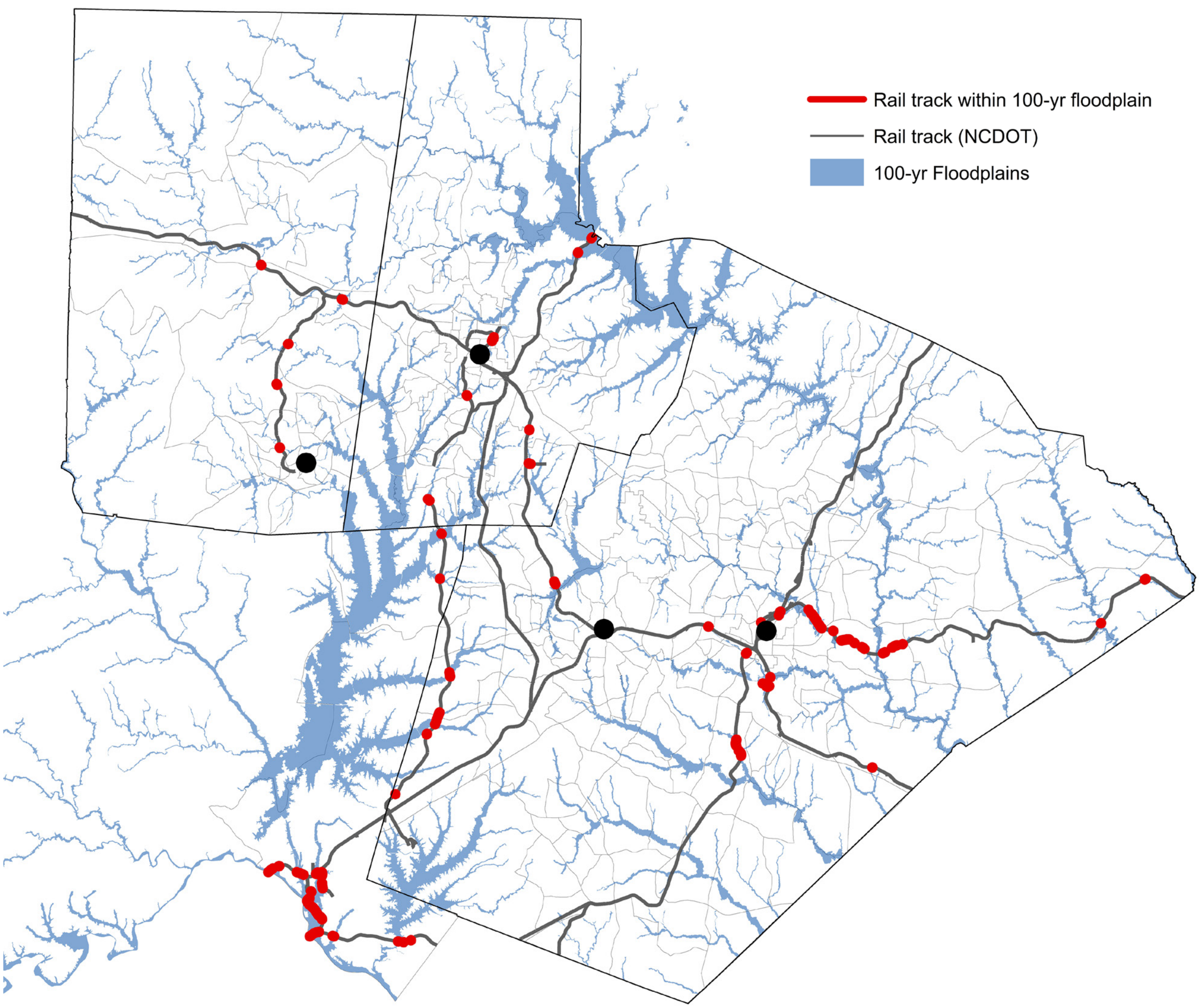
Flooding

Railways

Inundation from flooding presents significant risks to rail assets by restricting access, undermining foundations, damaging assets, and increasing maintenance and repair requirements.

Figure 64 shows the rail track in the region that lies within the 100-year floodplain. Based on floodplain mapping, the red areas indicate sections that would be potentially inundated in a 100-year flood event. Every major railway branch in the region—and most rail operators—have at least one segment that could potentially be inundated in a 100-year event.

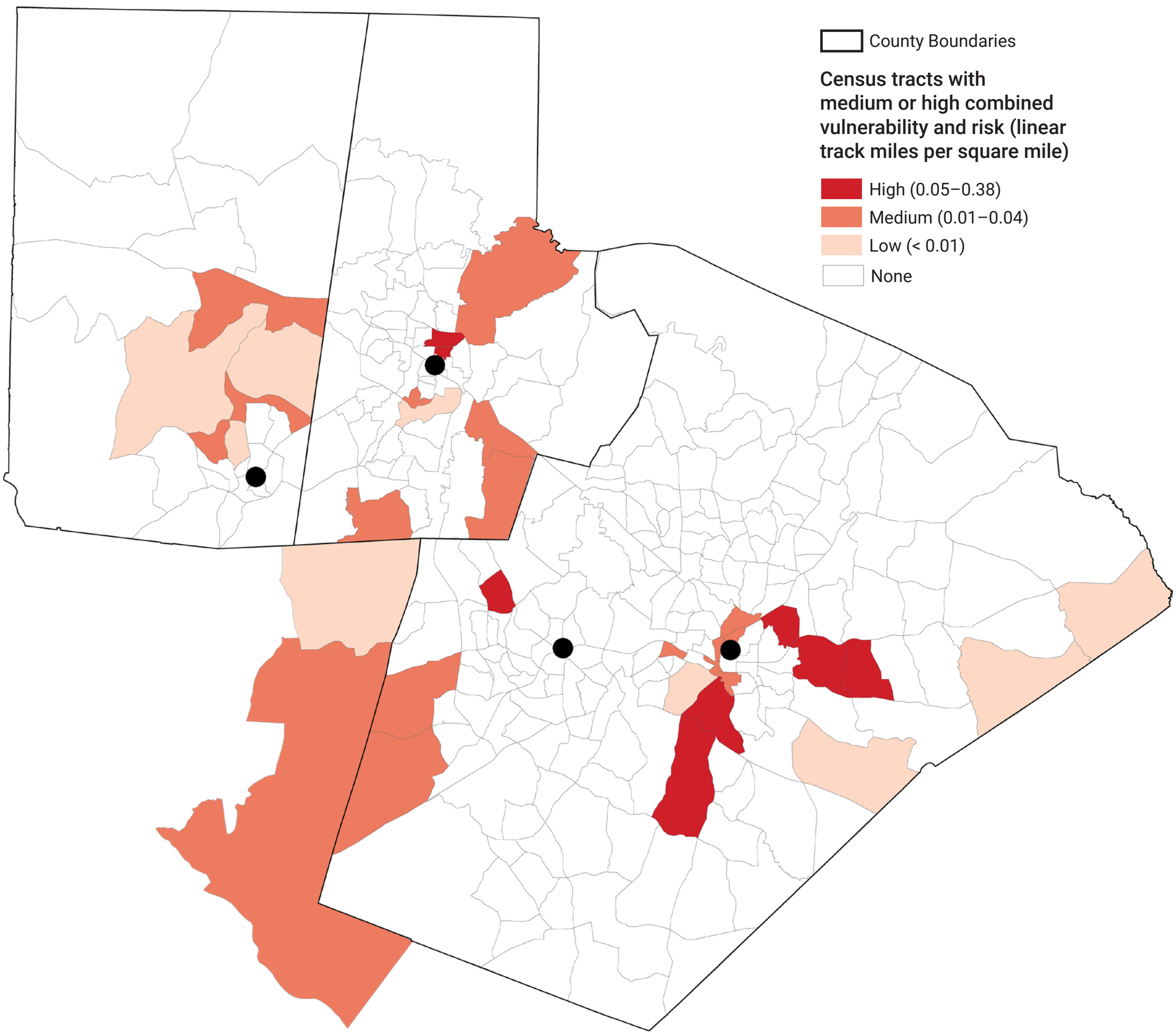
Figure 64. Regional Rail Track Within the 100-Year Floodplain



Regional rail track within the 100-year floodplain. (Figure source: UNC Asheville's NEMAC. Data source: North Carolina Department of Transportation (railways), FEMA (floodplains).

Figure 65 shows the number of linear track miles per square mile for the region; dark red areas have the highest track miles per square mile. These areas have the most exposed rail infrastructure.

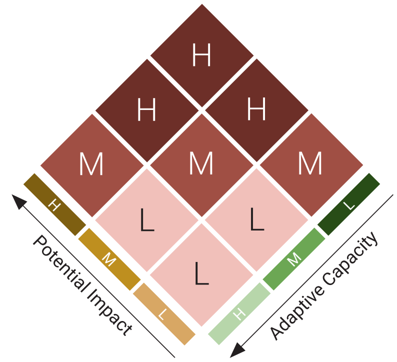
Figure 65. Assessment: Railways and Flooding



An exposure analysis was performed for this asset-threat pair. Additional vulnerability criteria shown below were determined by the Core Team; however, data were not available to use these in the assessment.

Vulnerability

	Potential Impact	Adaptive Capacity
High		Alternate rail routes available
Medium		
Low		



Flooding

Roads

Road Access

One of the most important functions that roads provide is access for safety and for emergency services. Areas with potential loss of access are where a flooding event could result in properties being inaccessible from fire/EMS stations due to inundated or damaged roads. Many of these are areas with single access points that have the potential for being inundated. The numbers of properties are general estimates, but the red areas on the map in Figure 66 have the highest number of properties with the potential for loss of access.

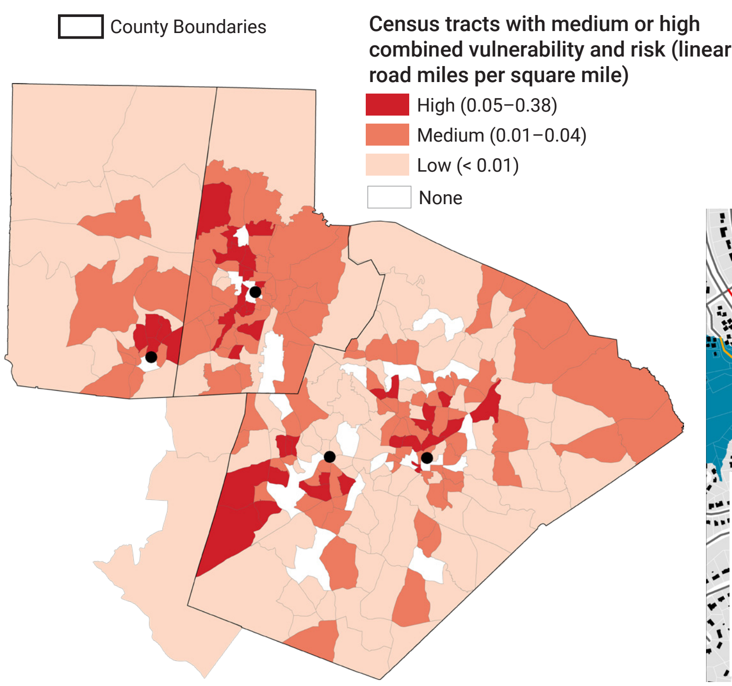


Figure 66a. Potential Loss of Access for Residential Properties Due to 100-Year Event

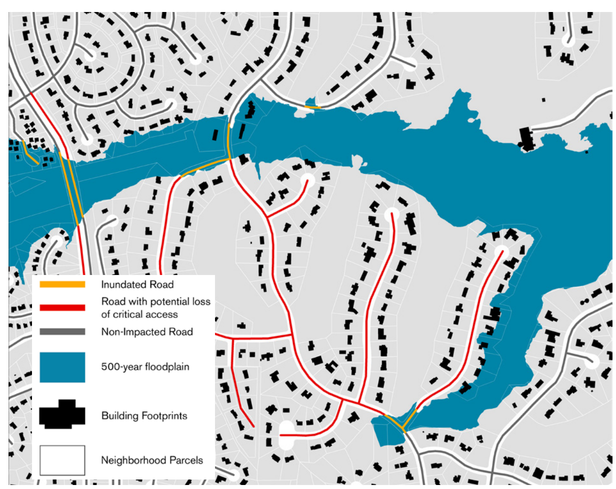
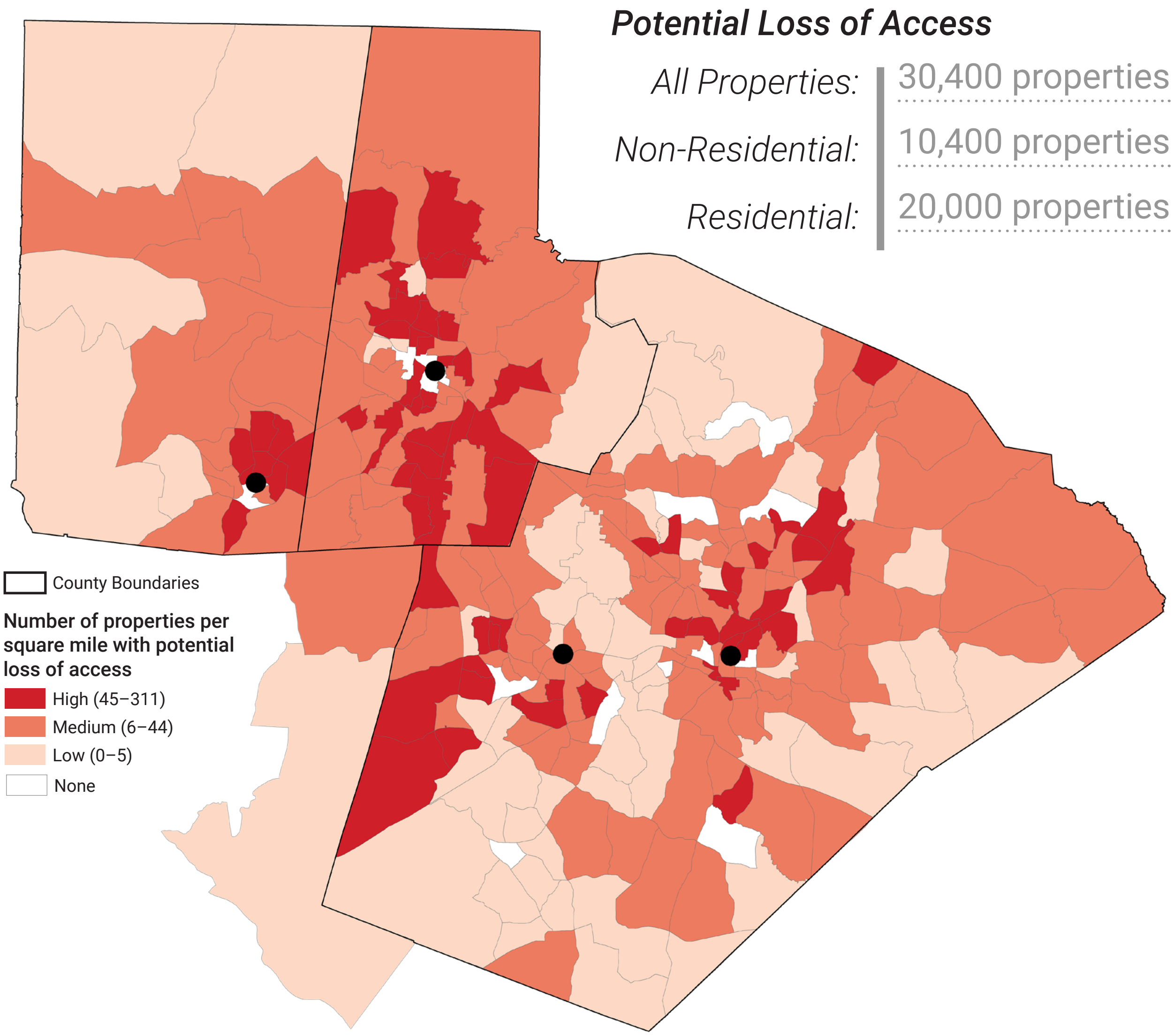


Figure 66b. Illustration of Inaccessible and Inundated Roads

Figure 66. Assessment: Roads and Flooding—Potential Loss of Access



The map above shows the estimated number of properties (of all types) that have the potential for loss of access in a 500-year flood event. At left, Figure 66a is a subset of the above map, showing only the estimated number of residential properties that could potentially lose access in a 100-year flood event. Figure 66b illustrates how the assessment evaluated properties that could potentially lose access due to inundated or inaccessible roads.

Road Inundation

Inundated road infrastructure can cause temporary loss of transportation service, or flood waters can erode and damage roads resulting in more significant impacts. Road infrastructure includes all major and minor roads, and road bridge segments. The areas with a high ranking have the most road miles potentially inundated per square mile.

Figure 67. Assessment: Roads and Flooding—Inundation

Vulnerability & Risk	158 road miles
Major:	71 road miles
Minor:	87 road miles

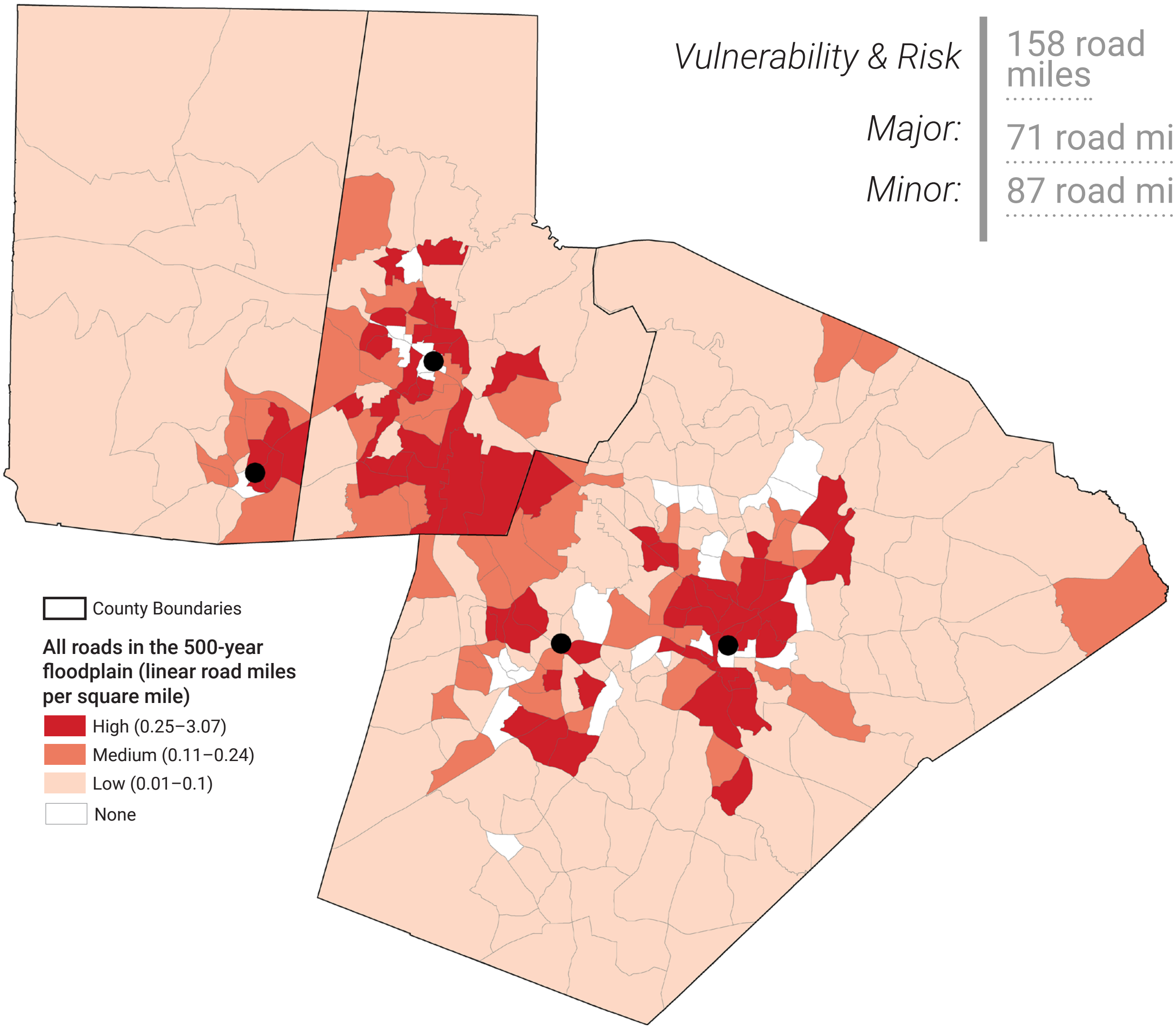


Figure 67a. Major Roads in the 100-Year Floodplain

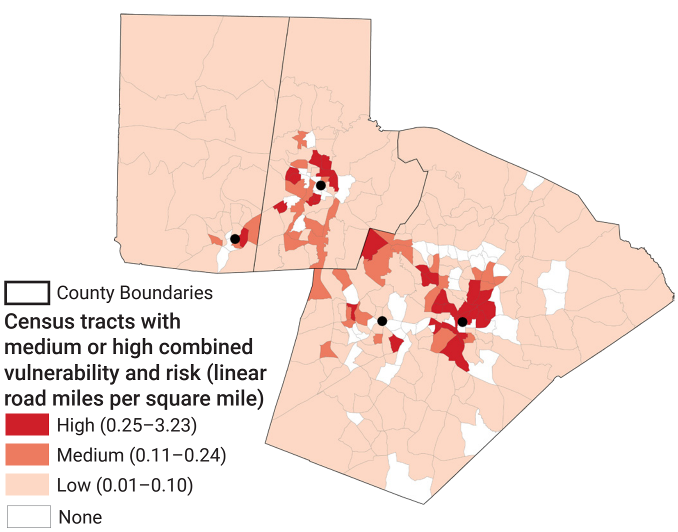


Figure 67b. Major Roads in the Floodway

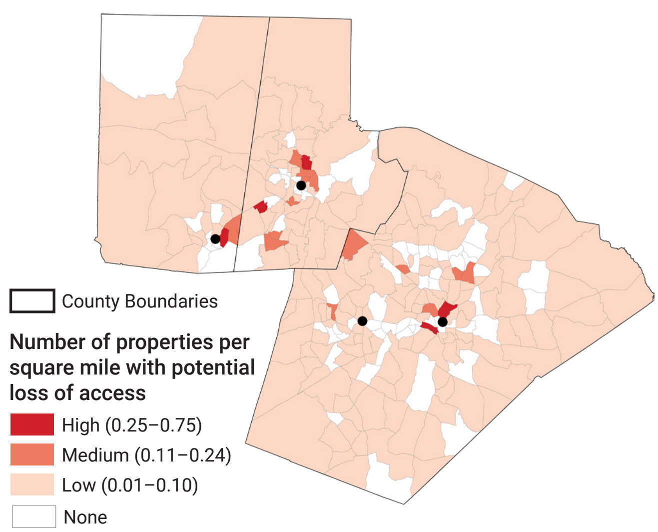


TABLE 11. ROAD TYPES AND INUNDATION RISK PROBABILITY

Road Type	Flood level (Risk propability)		
	500 year	100 year	Floodway
Major	71 road miles	61 road miles	19 road miles
Minor	87 road miles	75 road miles	16 road miles
Bridges (insufficient)	312	265	125

An exposure and road access analysis was performed for this asset-threat pair. Additional vulnerability criteria shown below were determined by the Core Team; however, data were not available to use these in the assessment.

Vulnerability

	Potential Impact	Adaptive Capacity
High	High amount major and secondary roads affected	• Road built at higher elevation (2' above 100-year floodplain) • Roads with engineered drainage AND preventative maintenance • Multiple alternative routes (access points) • Roads that are not flood-prone
Medium	Moderate or High amount of major or secondary roads affected	• Road built between 100-year floodplain and 2' above • Roads with engineered drainage
Low	Low amount of major and secondary roads affected	• Roads at grade in floodplain • Roads without engineered drainage • Single route with no alternatives (access points)

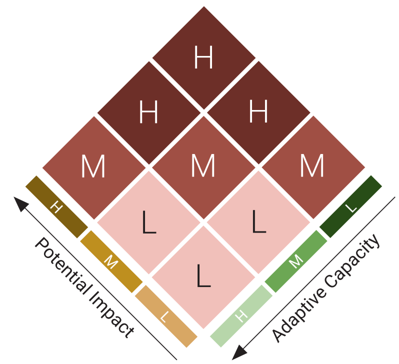
Snow/Ice Event

Airport

Generally, severe storms and large snow events can cause delays and cancellations of airport services,[65] with occasional impacts on airport facilities, structures, and runways. High adaptive capacity can be defined as those airports with adequate staff and supplies for these events (including an ability to house or transport staff to offsite locations) and install backup power sources in the event of power outages.

Vulnerability

	Potential Impact	Adaptive Capacity
High		• Adequate staff and supplies • Ability to house and/or transport staff • Backup power supply
Medium		
Low		• Inadequate staff and supplies • Cannot house and/or transport staff • No backup power supply



Snow/Ice Event

Railways

Freight rail operations are able to continue in snow conditions as locomotives act as de facto snow plows. However, snow drifts on rail tracks could cause short-term service interruptions, and snow blown into rail switches may impede the switch action, which could slow overall operations. The railroads typically do not issue speed restrictions for snow, but may cancel or delay services in areas experiencing severe winter weather.[40]

Regional, local, and commuter rail systems can be affected. Commuter rail systems powered using the "third rail" (electrified rail) are likely to see disruptions if snow accumulations are greater than six inches due to the inability to receive power from the third rail. These systems will typically shut down their above-ground operations under these conditions. Amtrak may delay or suspend service in areas affected by winter storm activity.[40]

Railways and rail lines will be affected by milder winters. A gradually warming climate will accelerate asphalt deterioration and cause buckling of pavements and rail lines. Streamflows based on increasingly more frequent and intense rainfall instead of slower snowmelt could increase the likelihood of bridge damage from faster-flowing streams. However, less snow in some areas will reduce snow removal costs and extend construction seasons.[65]

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Railways surrounded by large trees • Railways critical for supply chain or transportation • Steep railways • Electrified light rails	• Railways that have equipment and staff available to prep and clear in an event • Electrified light rail with backup power source
Medium		
Low	• Railways clear of overhead hazards such as large trees • Railways that are not critical for the supply chain or transportation	• Railways that do not have equipment and staff available to prep and clear in an event • Electrified light rail without backup power supply

Snow/Ice Event

Roads

Exposure to extreme snow events can shorten the life expectancy of highways and roads; the stress of snow and subsequent melt may cause damage, requiring more frequent maintenance, repairs, and rebuilding. Some areas of the country, however, may experience cost savings and improved mobility from reduced snowfall and less frequent winter storms, as projected warmer winters may lead to reductions in requirements for salting and snow and ice removal.[21]

In the Triangle region, heavily traveled roads were identified as one condition of potential high vulnerability, particularly when they are traveled primarily by older cars and trucks. Older vehicles are assumed to be more susceptible to breakdown and to have little or no climate control to protect drivers in heavy snow and ice events. However, milder winters, reductions in the number of cold days, delays in winter freezing, and earlier spring thaws may reduce cold-weather damage to vehicles.[21] Refer also to Figure 62 showing regional estimated average daily traffic by number of vehicles and accompanying discussion under Extreme Heat.

When large snow or ice events do occur, there are areas within the Triangle region that may be impacted due to their location and dependency on road infrastructure for emergency services. Refer also to the map (Figure 47) and discussion of residential properties located outside an eight-minute drive time window from emergency and response services in the Public Services and Health-Extreme Cold assessment. These properties may be more vulnerable if road infrastructure is significantly impacted during a snow and ice event.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Main transportation routes • Evacuation routes • Transit routes • Roads around shelters and hospitals • Roads with hazards, such as surrounding trees • Steep roads	Roads with equipment and staff available to prep and clear in an event
Medium		
Low	• Minor roads that are not main transportation routes, evacuation routes, transit routes, or not located around shelters or hospitals • Roads that do not have hazards, such as surrounding trees • Roads that are not steep	Roads without equipment and staff available to prep and clear in an event

Wildfire

Roads

This assessment considers road traffic volume and wildland-urban interface (WUI) wildfire risk. Areas with the highest vulnerability have a high average daily traffic volume and also have a high percentage of the area with high WUI risk.

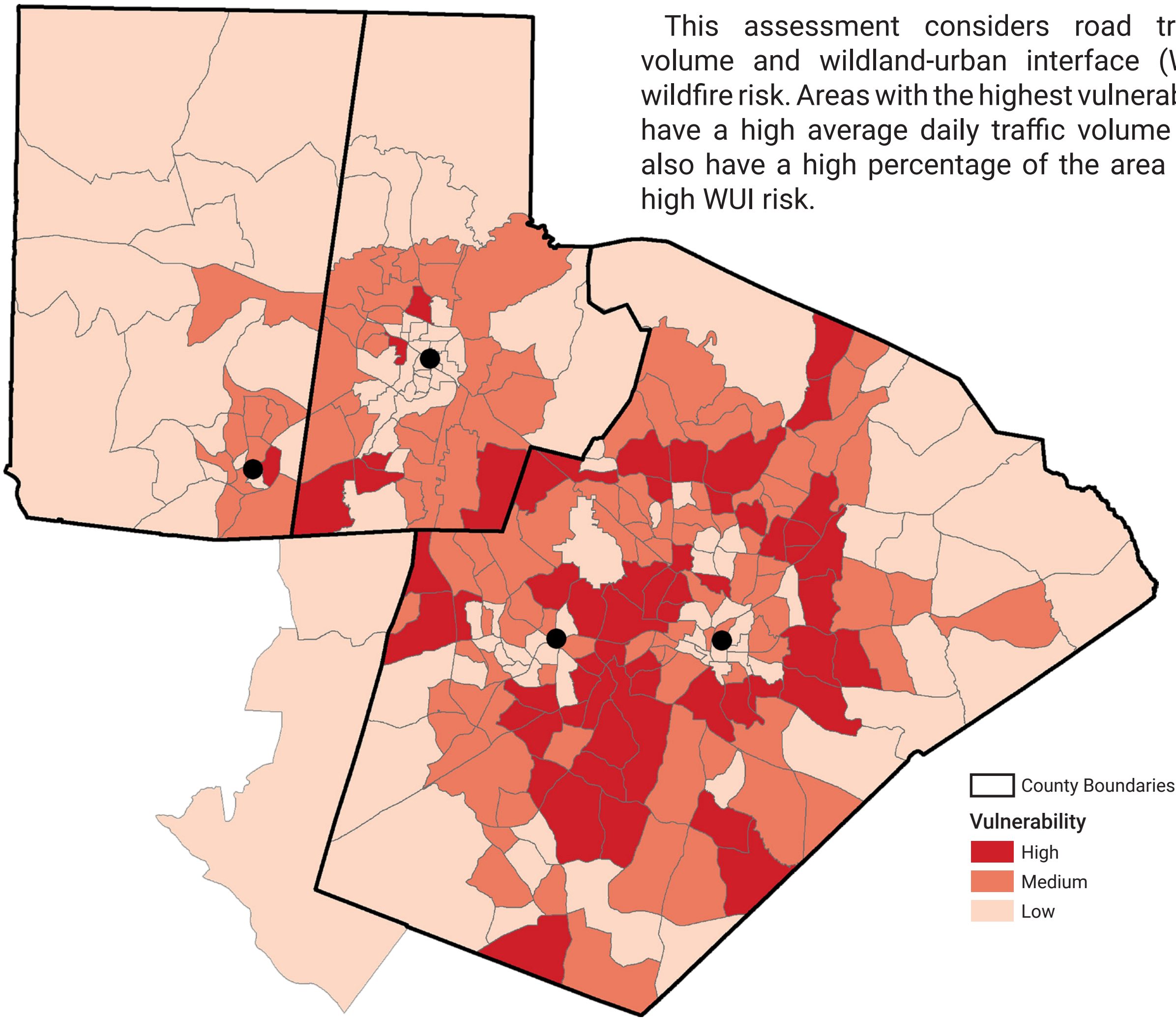


Figure 68. Assessment: Roads and Wildfire

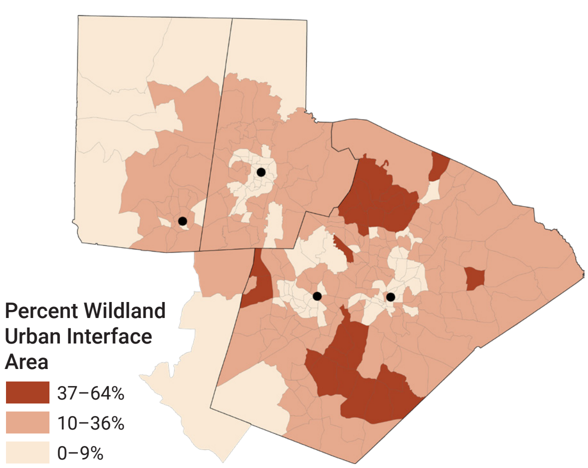


Figure 68a. Percent WUI Area

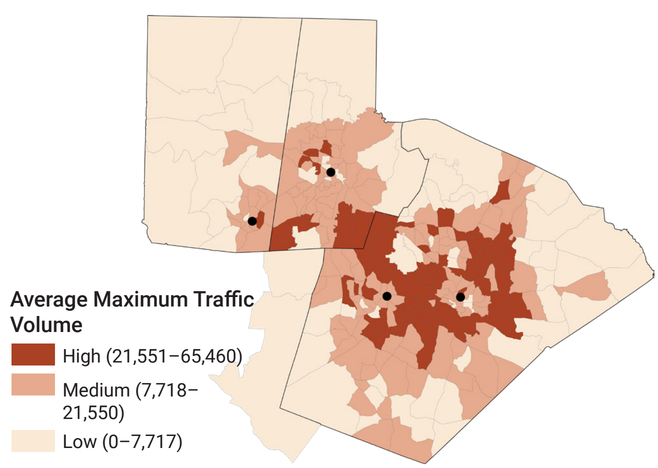
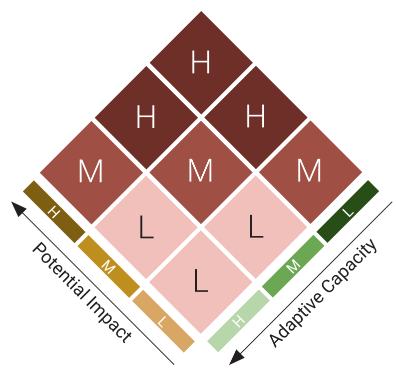


Figure 68b. Average Maximum Traffic Volume

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Critical access route or high traffic volume • Road/bridge in proximity to or passess through wildfire threat • Many people impacted	• Excellent road/bridge condition • Bridge is within 5-minute fire/EMS drive time plus distance to water source
Medium	• Less traffic volume • Fewer people impacted	Decent road/bridge condition
Low	• Not critical access route or low traffic volume • Road/Bridge not in proximity to or passess through wildfire threat • Few people impacted	• Poor road/bridge condition • Little tree maintenance, road/bridge maintenance regime • Bridge is outside of 5-minute fire/EMS drive time plus distance to water source



Wind

Airport

Generally, severe storms and high wind events can cause delays and cancellations of airport services,[62] with occasional impacts on airport facilities, structures, and runways. If wind is associated with an extreme event, the ability for the runways to be cleared may be diminished. These events may also increase maintenance and repair requirements.

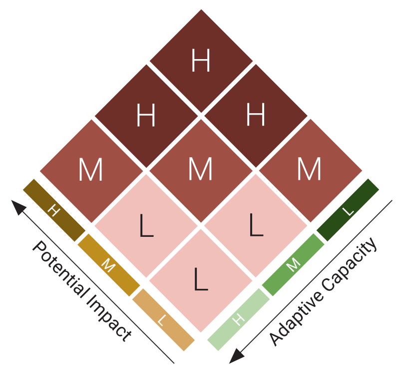
Wind

Railways

High winds can significantly impact railway infrastructure. Wind can affect the stability of trains, especially on bridges, and increase the risk of debris causing obstructions on railways, especially if a pathway has overhead structures or trees nearby. If wind is associated with an extreme event, the ability for the pathways to be cleared may be diminished. These events may also increase maintenance and repair requirements.

Vulnerability

	Potential Impact	Adaptive Capacity
High	• Railways with adjacent tree cover • Open water crossings • Elevated crossings • Older structures	• Multiple tracks • Well-maintained row corridors • Alternative routes available
Medium		
Low	• Railways with little adjacent tree cover • Newer structures	• Single tracks • Poorly maintained row corridors • No alternative routes available



Wind

Roads

High winds can increase the risk of debris causing obstructions on roads, especially if a pathway has overhead structures or trees nearby. If wind is associated with an extreme event, the ability for the pathways to be cleared may be diminished. Further, wind can affect the stability of vehicles such as trucks, especially on bridges.

Extreme winds can have an impact on emergency response due to impacts on roads and highways. Refer to the map (Figure 47) in the Public Services and Health-Extreme Cold assessment that shows residential properties located outside an eight-minute drive time window from emergency and response services and social vulnerability. If a high wind event impacts transportation networks, it is likely that response time could increase.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Roads with lots of older tree canopy	Roads surrounded by fewer trees (particularly older ones) and power lines
Medium		
Low	Roads with younger, smaller tree canopy	Roads surrounded by many trees (particularly old ones) and power lines

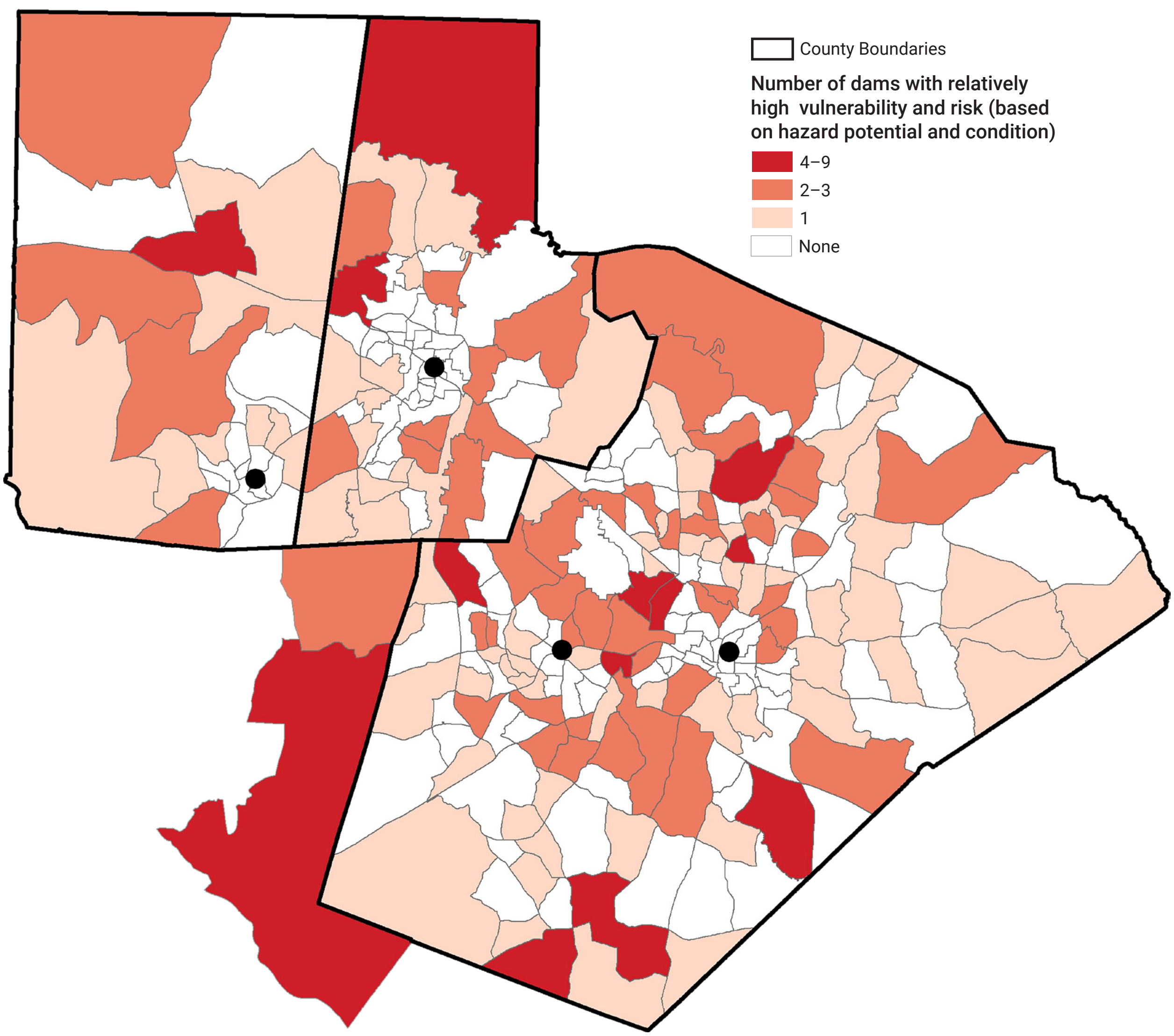
Flooding

Dams

Dams and the reservoirs created by them can serve multiple purposes, including water storage for drinking water supply, power generation, irrigation, agriculture, and the creation of lakes for recreation. Some dams also function as flood control and, along with other infrastructure, can prevent the flow of water to certain areas.

Flooding and increased water levels from storms can affect dam integrity. This assessment used data from the North Carolina Department of Environmental Quality and the North Carolina Dam Safety Program to consider vulnerability and risk of regional dams to flooding.

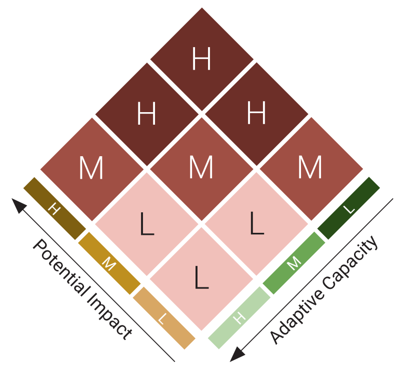
Figure 69. Assessment: Dams and Flooding



Two components were used to consider vulnerability and risk to North Carolina-regulated dams: the condition assessment and the hazard potential. The condition assessment evaluates dams with classifications of “poor,” “fair,” “satisfactory,” and “unknown.” Dams with a condition assessment of “poor” were considered to be the most vulnerable to flooding. Hazard potential is classified according to levels of low, intermediate, and high, which are based on potential interruption to road service, economic damage, and loss of human life. Dams with a hazard potential of “high” were considered to have the highest level of risk. Dams with the highest vulnerability and risk were those with both a “poor” condition assessment and a “high” hazard potential.

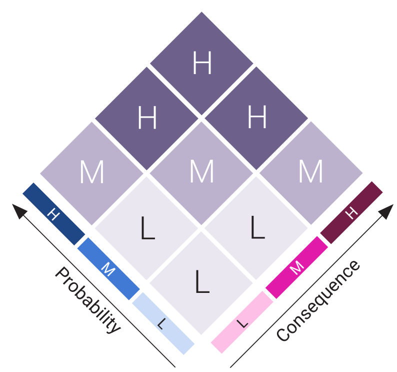
Vulnerability

High	Poor or unknown condition rating
Medium	Fair condition rating
Low	Satisfactory condition rating



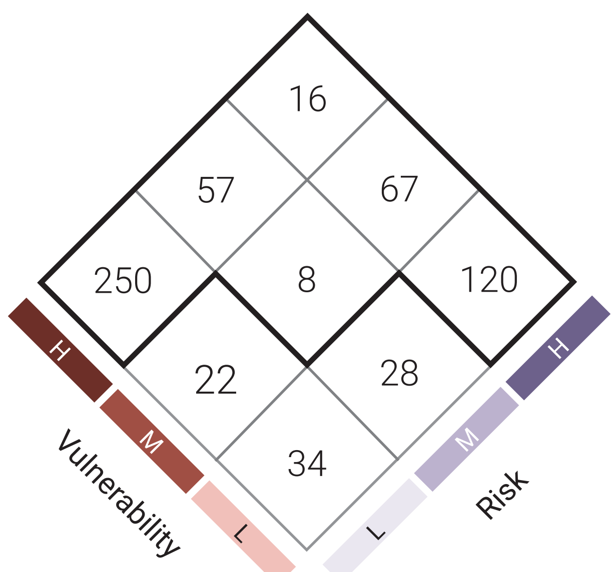
Risk

High	High hazard potential
Medium	Intermediate hazard potential
Low	Low hazard potential



Combined Vulnerability and Risk

(Number of parcels)



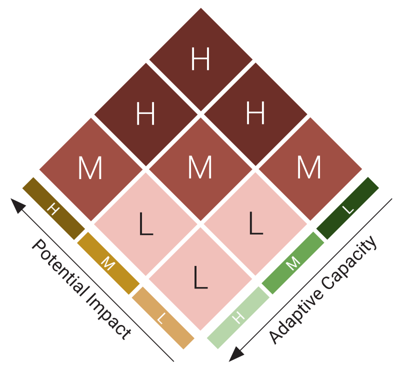
Flooding

Stormwater Infrastructure

The volume of runoff associated with increasingly heavy precipitation events has the potential to overwhelm decades-old drainage infrastructure. Higher volumes of runoff can overflow existing retention basins, challenging the capacity of stormwater systems. Stormwater runoff may also result in water quality issues; this has prompted some communities to adopt strategies to keep more precipitation where it lands.[66] When heavy precipitation events occur where the capacity of aging stormwater drainage systems has been reduced over time, flooding can disrupt local businesses, leading to economic losses and further deterioration of stormwater infrastructure, roads, and buildings.[67]

Vulnerability

	Potential Impact	Adaptive Capacity
High		• Stormwater control measure (SCM) ponds with a passing annual inspection • Surrounding structures built within the last 10 years
Medium		Structures with stormwater infrastructure built within 10 to 30 years
Low		• SCM ponds with a "failing" inspection • Surrounding structures or subdivisions built more than 30 years ago



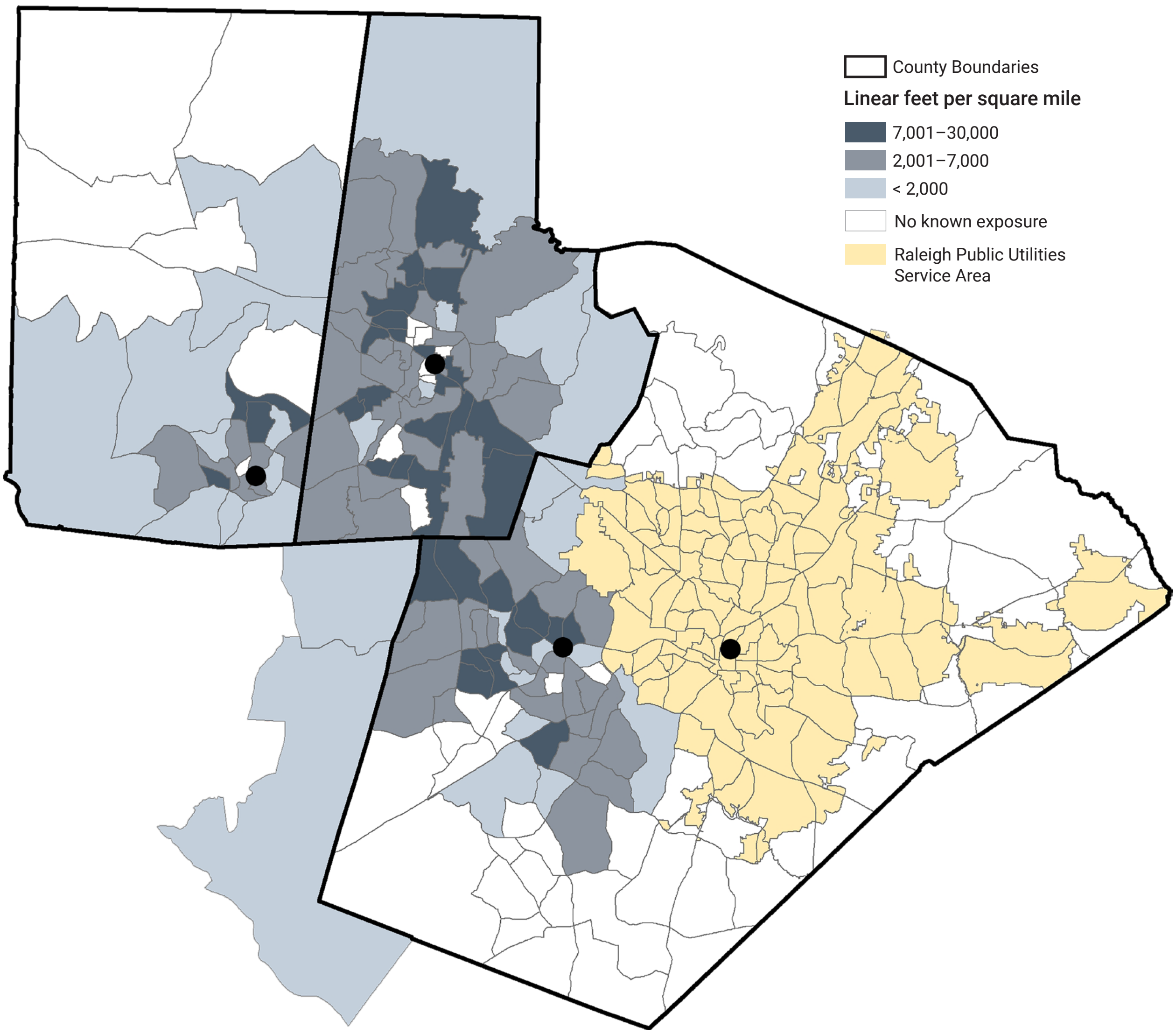
Flooding

Water Infrastructure

Water infrastructure and facilities include the water plants, pumps, tanks, and lines that provide the treatment and distribution of water. Failures or interruptions in service can occur when facilities and infrastructure are either inundated or damaged by flood waters—such as scouring or washouts of water lines, which can happen especially along roads when culverts and stormwater structures become overwhelmed. Facilities in flood-prone areas are often elevated. For this assessment an exposure analysis was conducted to identify the water infrastructure and facilities that are in harm's way to flooding. In addition to this, different flood risk probabilities were also identified for assets that were exposed. This exposure assessment only evaluated the presence of these water assets in floodplain areas and did not evaluate other characteristics of these assets that may make them more or less susceptible to flooding.

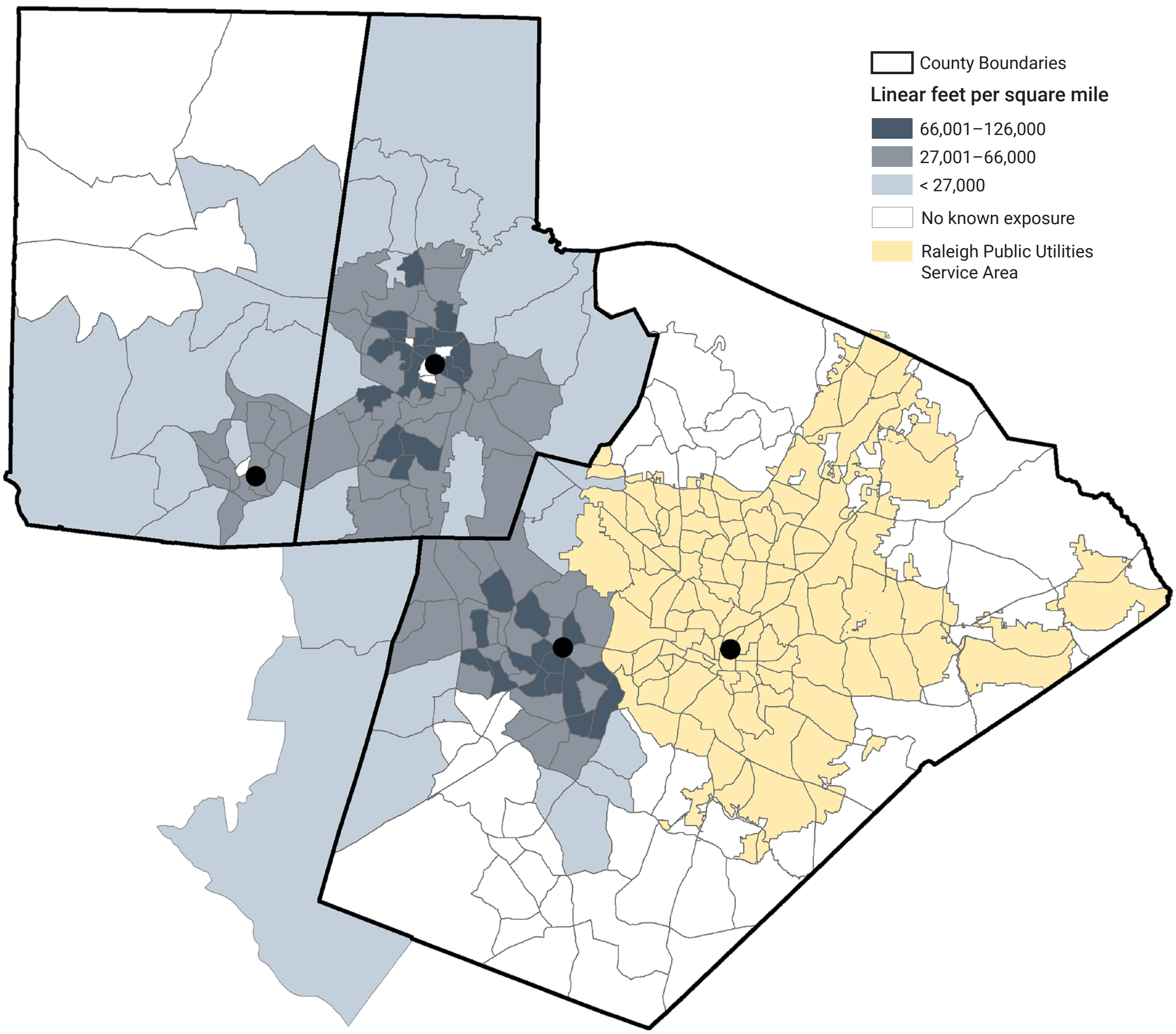
The maps show the amount of major (Figure 70) and minor (Figure 71) water lines (in linear feet) that are exposed to flooding. Major water lines include major transmission lines and lines with pipes that are at least 16 inches in diameter. Minor water lines include all other lines that are less than 16 inches in diameter.

Figure 70. Exposure of Major Water Lines to Flooding



These maps and summaries include only the water systems of Durham, the Orange Water and Sewer Authority (OWASA), and Cary.

Figure 71. Exposure of Minor Water Lines to Flooding



Raleigh's Public Utilities Department—which provides water and wastewater services to the residents of Raleigh, Garner, Wake Forest, Rolesville, Knightdale, Wendell, and Zebulon—has performed an internal risk-threat assessment separately from the Triangle Regional Resiliency Assessment process under the auspices of several pipe system modeling projects and departmental operational resiliency activities. The data from Raleigh's assessment has been withheld from this report for security purposes, but mitigation projects are underway within the city's Capital Improvement Plan. The maps show the Raleigh Public Utilities service area communities for which the separate assessment was performed.

Table 12 shows for the included water systems (Durham, OWASA, and Cary) the total number of water facilities by type and the number of facilities exposed to each flood risk level (floodway, 100-year, and 500-year).

TABLE 12. REGIONAL WATER FACILITIES

Facility Type	Total Number of Facilities	Number Exposed			
		Floodway	100-year	500-year	Total
Durham					
Interconnects	9	1			1
Pump stations	36	1	3		4
Tanks	13		1		1
Treatment plants	2				0
Owasa					
Interconnects	4				0
Pump stations	8	1			1
Tanks	5				0
Treatment plants	1				0
Cary					
Interconnects					0
Pump stations	6				0
Tanks	7				0
Treatment plants	1				0

Flooding

Wastewater infrastructure

Heavy precipitation events can overwhelm the capacity of sanitary wastewater systems (which collect wastewater only), as they are not designed to handle large volumes of stormwater and can have structural issues such as cracks, faulty seals, and/or improper connections. This can result in infiltration and inflow (I/I) into the system during precipitation events. Large volumes of I/I can cause overflows and/or operational problems at wastewater treatment facilities.[68]

Wastewater infrastructure and facilities can also be affected or damaged when inundated by flood waters. For this assessment, an exposure analysis was conducted to identify the wastewater infrastructure and facilities that are in harm's way to flooding. The flood risk probabilities were also identified for assets that were exposed. This exposure assessment only evaluated the presence of these water assets in floodplain areas and did not evaluate other characteristics of these assets that may make them more or less susceptible to flooding.

Table 13 shows for each water system the total number of wastewater facilities by type, identification of publicly and privately owned wastewater pump stations, and the number of facilities exposed to each flood risk level (floodway, 100-year, and 500-year). The table includes the water systems of Durham, the Orange Water and Sewer Authority (OWASA), and Cary. As mentioned earlier, Raleigh's Public Utilities Department, which provides water and wastewater services to the residents of Raleigh, Garner, Wake Forest, Rolesville, Knightdale, Wendell, and Zebulon, has performed an internal risk-threat assessment separately from the Triangle Regional Resiliency Assessment.

TABLE 13. REGIONAL WASTEWATER FACILITIES

Facility Type		Total Number	Number Exposed			
			Floodway	100-year	500-year	Total
Durham						
Pump stations	Public	70	5	14		1
	Private	40		2		4
Treatment plants		2	1	1		0
Owasa						
Pump stations	Public	21	3	5		0
	Private	4	1			1
Treatment plants		1				0
Cary						
Pump stations	Public	42	3	9		12
	Private	26		1		1
Treatment plants		3				0

An exposure analysis was performed for this asset-threat pair. The criteria below were determined by the Core Team; however, data were not available to perform a full vulnerability and risk assessment.

Vulnerability

	Potential Impact	Adaptive Capacity
High	Critical infrastructure (plants, pump stations, pipeline aerial crossings, manholes, generators) that serves a large area	Infrastructure that includes portable generators, portable pumps, supervisory control and data acquisition (SCADA) systems, equalization storage at wastewater plants
Medium		
Low	Non-critical infrastructure (plants, pump stations, pipeline aerial crossings, manholes, generators)	Infrastructure that does not have portable generators or power redundancy

Water Shortage

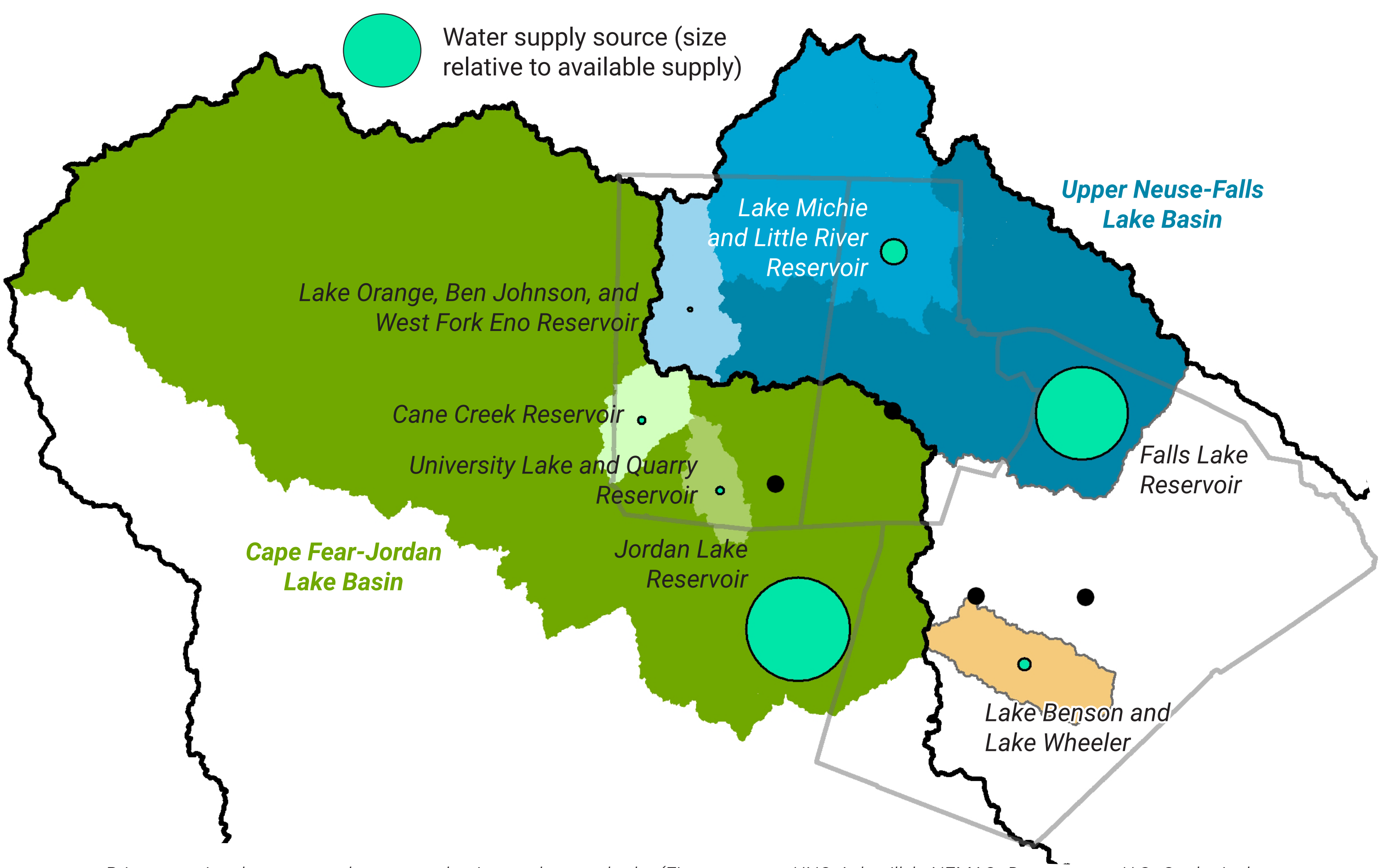
Water Supply

Changes in the amount and intensity of rainfall can affect the quality and quantity of regional water supplies. Non-climate factors—such as increased demand from growing populations and aging infrastructure—can compound climate-related issues, threatening the ample supply of clean, safe water and reliable wastewater services many take for granted.[69]

In day-to-day operations, some utilities draw water from multiple sources to serve their customers through the year. As climate and non-climate stressors change, optimizing the use of supplies from different sources while meeting water-quality standards may present new challenges, even to veteran managers. Considering their range of water sources, status of infrastructure, and operational decisions and costs under changing conditions can help utilities continue serving their customers into the future.[69]

Figure 72 shows each of these primary water supply sources and their respective basins and watersheds. In some cases multiple supply sources share drainage areas and some sources are upstream from others, which highlights the interdependency among sources of water in the region.

Figure 72. Regional Water Supply Sources



Primary regional water supply sources, basins, and watersheds. (Figure source: UNC Asheville's NEMAC. Data source: U.S. Geological Survey, National Hydrology Dataset.)

The Upper Cape Fear is the largest water supply drainage basin in the region by area and has three sources: Jordan Lake; University Lake and Quarry reservoir; and Cane Creek reservoir.

The Upper Neuse is the second largest basin and includes Falls Lake; Lake Michie and Little River reservoir; and Lake Orange, Lake Ben Johnston, and West Fork Eno reservoir.

Other sources outside of the aforementioned supply source basins make up about 14 percent of the region's available water supply, and includes lake systems and river intakes.

Sensitivity

Several factors can be considered for understanding the sensitivity of water supply sources to water shortages due to drought, including available water supply, the drainage area of water supply watersheds, and water use/demand. Table 14 summarizes these factors using metrics for each of the water supply sources in the region, which are described in more detail following the table.

TABLE 14. WATER SUPPLY SOURCE SENSITIVITY FACTORS

Water Supply Source	Type of Source	Average Available Supply (MGD)	Percent of Available Supply for Region (%)	Watershed Drainage Area (sq mi)	Usable On-Stream Raw Storage Volume (MG)*	Watershed Drainage Area to Volume Ratio (sq mi/MG)	Average Annual Demand 2014-2016 (MGD)	Average Annual Demand/ Available Supply (Consumption to Storage Ratio)
Falls Lake	Reservoir	66.1	27.66	772	34,645	0.022	40.00	0.61
Lake Michie	Reservoir	10.5	4.39	168	2,812	0.060	10.09	0.96
Little River	Reservoir	17.4	7.28	97	4,826	0.020	17.34	1
Lake Orange, Ben Johnson, & W. Fk. Eno Res.	Multiple lake system	2.6	1.09	83	1,288	0.064	1.32	0.51
Jordan Lake	Reservoir	100	41.84	1,690	70,100	0.024	22.58	0.23
University Lake, and Quarry Res.	Multiple lake system	2	0.84	30.00	449	0.067	1.72	0.86
Cane Creek Res.	Multiple lake system	8.5	3.56	31.00	2,909	0.011	4.97	0.58
Lake Benson and Lake Wheeler	Multiple lake system	11.2	4.69	36	2,085	0.017	9.88	0.88

**Percent available supply for region factors in a total supply that includes three additional river intake sources (Harnett County, Cape Fear River, and Haw River) with a total average available supply of about 21 MGD.*

**For storage volume, the two multipurpose reservoirs, Falls Lake and Jordan Lake, use conservation storage volumes. All other sources report usable on-stream raw water supply storage from Local Water Supply Plans (2014-2016).*

Table metric descriptions:

- Average Available Supply (MGD): total average available supply for each supply source
- Percent of Available Supply for Region (%): percent of the region's available supply that each source provides
- Watershed Drainage Area (sq mi): the water supply drainage area, taken from the local water supply plan (LWSP)
- Usable On-Stream Raw Storage Volume (MG): the usable storage from the LWSP (2014–2016). For the two multi-purpose reservoirs (Falls Lake and Jordan Lake), the conservation storage amount was used (ACE). For all other sources, the usable on-stream raw water supply storage from LWSPs (2014–2016) was used.
- Watershed Drainage Area to Storage Volume Ratio (sq mi/MG): the ratio of watershed drainage area (sq mi) to storage volume (expressed as MG). Smaller ratio values indicate the supply source drainage area is relatively small for the storage volume it is supporting, or that the storage volume is relatively high for the source's drainage area.
- Average Annual Demand 2014–2016 (MGD): average annual withdrawals for 2014–2016 from LWSP. This metric uses the average daily withdrawal (MGD) and days used to determine the total withdrawal (average daily withdrawal*days used), then the average of years 2014–2016 was taken.
- Average Annual Demand/Available Supply (Consumption to Storage Ratio): the ratio of average annual demand (MGD) to average available supply (MGD). Higher ratio values indicate demand is a relatively high proportion of the average available supply.

Drainage Area to Storage Volume

Considering the region's supply sources in relation to their drainage areas provides insight into the areas supporting available supplies in the region. Sources with larger drainage or catchment areas can generally support greater volumes; however, many other environmental factors can also influence water supply volumes.

In the Triangle Region, Jordan Lake provides the largest available supply in the region and has the largest drainage area. Falls Lake provides the second largest available supply, but has less than one-half of the drainage area of Jordan Lake. Therefore, in comparing those two major sources from the perspective of drainage area to storage volume, Falls Lake is likely to be more sensitive due to its relatively large supply and smaller drainage area. Of all the supply sources for the region, Cane Creek Reservoir, Lake Benson/Lake Wheeler, and Little River have relatively low drainage area to volume ratios, however, they are each providing only about four, five, and seven percent, respectively, of the available supply for the region.

Consumption to Storage Volume

Water use and demand is considered to be the primary non-climate stressor on water supply sources. Sources that have a higher demand—and greater reliance—will result in greater impacts if they are affected by water shortages.

Demand for sources vary across the region, with Falls Lake having the highest demand (about 40 MGD), and Jordan Lake with the second highest demand (about 23 MGD). However, when the demand on available supply (the consumption-to-storage ratio) is considered, some of the smaller sources including Lake Michie, Little River, and Lake Benson/Lake Wheeler have the highest ratios (1, 0.96, and 0.88 respectively). Thus, these sources may be more sensitive due to their higher consumption to storage ratios.

The sensitivity of water supplies to water shortages can be viewed from different perspectives by considering drainage to storage volume and consumption to storage volume. Of the two major sources, Falls

Lake may be more sensitive than Jordan Lake to water shortages due to its lower drainage area to storage volume ratio and its higher consumption to storage volume ratio. However, some of the smaller, yet important, supply sources in the region may be the most sensitive to water shortages with Little River and Lake Benson/Lake Wheeler being the most sensitive due to having both relatively low drainage area to storage volume ratios and high consumption to storage ratios.

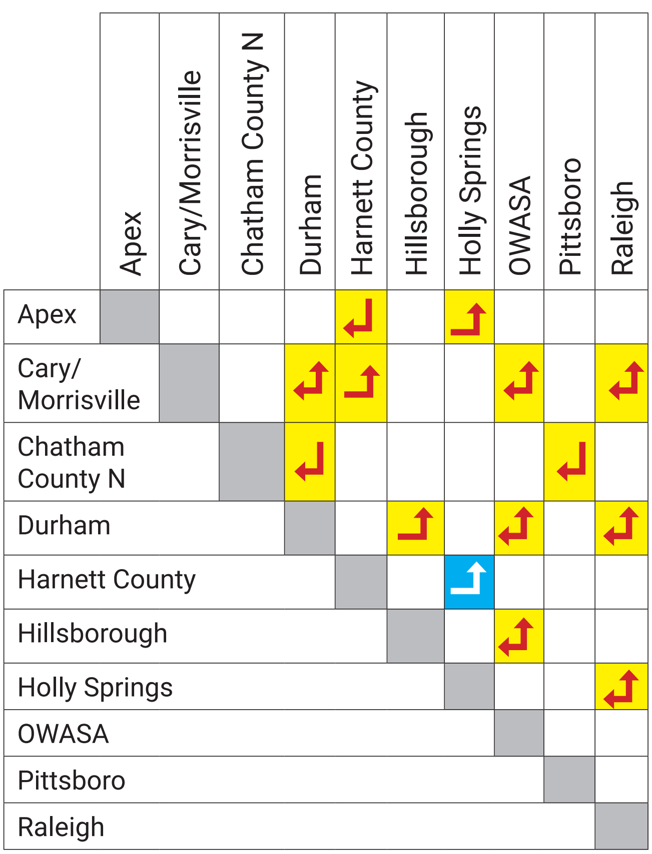
Adaptive Capacity

The region has a strong history of partnership, such as that undertaken through the Jordan Lake Partnership and other continued efforts. These partnerships have done a considerable amount of work towards understanding available water supplies, current use, and projected future demand throughout the region.

Investments in the connectivity of regional water distribution systems—both at the planning level and in infrastructure development—have resulted in the region having the capacity to treat, distribute, and transfer water to meet a certain amount of supply needs. Having this infrastructure capacity and existing water sharing agreements helps the region cope with emergencies and will help the region in mitigating the impacts from drought and becoming adaptive to meeting water supply needs in the future.

Figure 73, modified from the 2014 Regional Water Supply Plan, highlights the connectivity and possibility for water sharing throughout the region. While the figure identifies whether or not sharing agreements and that some sharing capacity may be in place, it does not identify the possible transfer amounts within these capacities.

Figure 73. Inter-Utility Water Supply Agreements



Using the Jordan Lake Potable Water Interconnection Study (2011), Table 15 shows a summary of the regular and emergency water system interconnections among the TRRP jurisdictions. The summary shows the number of interconnections between systems along with the smallest pipe diameter at each interconnection. Note that this summary focuses only on TRRP jurisdiction interconnections and that other interconnections for other jurisdictions or water systems do exist in the region. This summary does not take into account specific amounts that could be transferred through interconnect waters systems and does not account for improvements since the 2011 study or future infrastructure scenarios which could increase interconnections and capacities.

Red arrows on a yellow background indicate emergency connections, and white arrows on a blue background indicate a contract for regular supply. Arrow direction indicates flow from the provider to the recipient. (Figure/data source: [35])

TABLE 15. SUMMARY OF REGULAR AND EMERGENCY INTERCONNECTIONS BETWEEN WATER SYSTEMS

System A	System B	Number of interconnections	Smallest diameter pipe at interconnection
Cary	Apex	4	12”,16”, 16”, 30”
Cary	Durham	3	each 16”
Cary	RDU	1	16”
Durham	Chatham County	1	16”
Durham	Hillsborough	1	12”
Durham	OWASA	2	8” and 12”
Durham	Raleigh	2	16” and 24”
Orange County	Mebane	1	16”
Orange County	Hillsborough	1	12”
OWASA	Chatham County	1	16”
OWASA	Hillsborough	1	16”
Raleigh	Cary	1	24”
Raleigh	Fuquay-Varina	1	16”
Raleigh	Johnston County	2	12” and 16”
Raleigh	RDU	1	16”
Raleigh	Holly Springs	1	16”

From the Jordan Lake Potable Water Interconnection Study (2011).

Wastewater

During times of water shortage, conservation strategies are often enacted that result in a reduction of water flow into wastewater treatment facilities. Decreased volumes and resultant increased pollutant concentrations may cause the system to operate inefficiently and less effectively.[70]

Where municipalities and regulatory agencies are nimble and supportive of innovative start-ups, corporations, or agencies that seek to use wastewater for new purposes, treated wastewater can become part of the water supply.[51]

Vulnerability

	Potential Impact	Adaptive Capacity
High	Supply sources with low drainage area to supply ratio and high consumption to storage ratio	High capacity for water sharing though regional partnership and interconnections
Medium		
Low	Supply sources with high drainage area to supply ratio and low consumption to storage ratio	Low capacity for water sharing though regional partnership and interconnections

Minor Flooding, Runoff, and Erosion

All Assets

The threat of minor flooding includes events caused by extreme or heavy precipitation that results in runoff and erosion. These events are usually less severe than major flooding, but can still cause significant impacts.

More than half of the watersheds in the Triangle region are headwater areas, or are upstream areas within the watershed basin (Figure 74a).

The major system is comprised of natural waterways and receiving areas. These include stream areas, swamps and marshes, and inundation areas (Figure 74b).

This threat is greatly influenced by the amount of development and impervious surfaces that contribute to runoff (Figure 74c). The ability to manage stormwater runoff depends on both the major (waterways and receiving areas) and minor (pipes, culverts, channels) drainage systems.

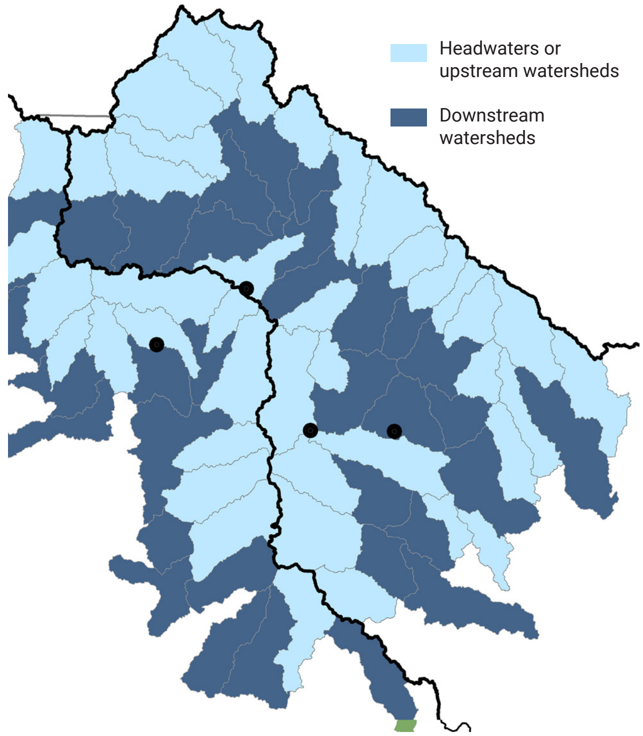


Figure 74a. Headwaters vs. Downstream Watersheds

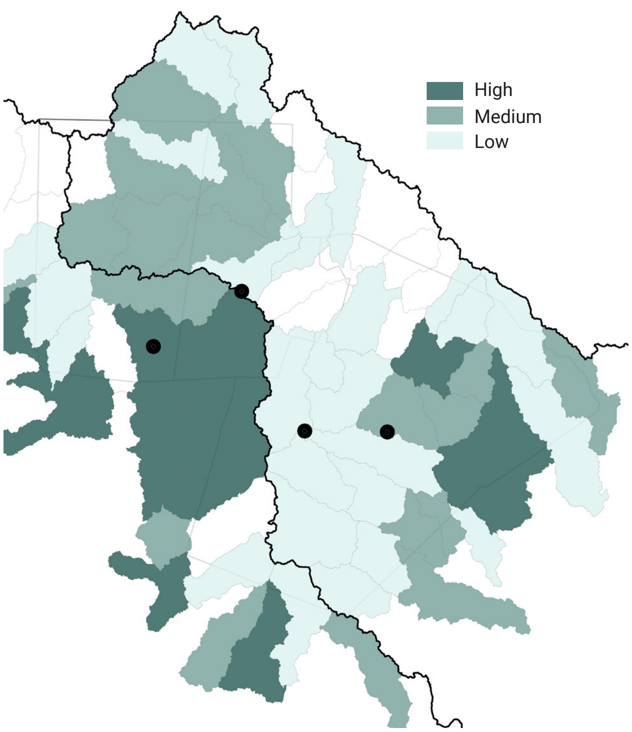


Figure 74b. Major Drainage Systems for Receiving and Conveying Stormwater

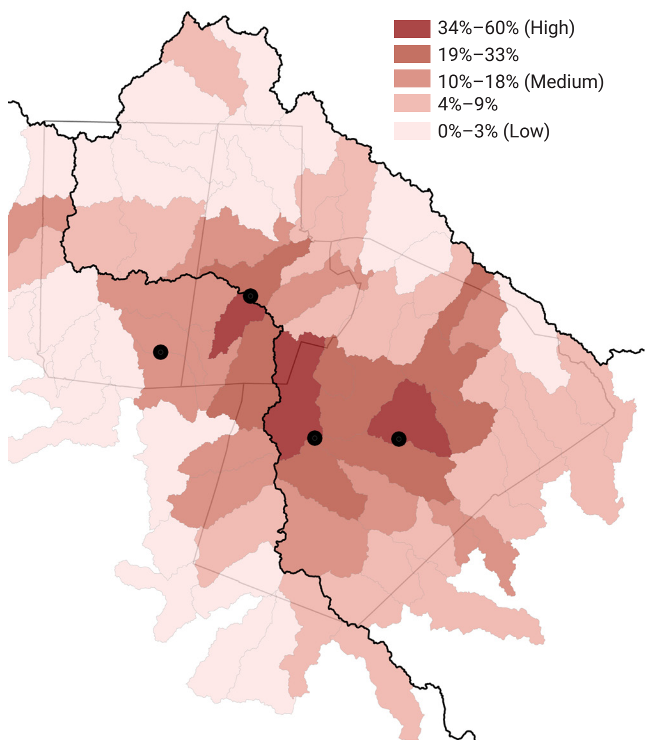
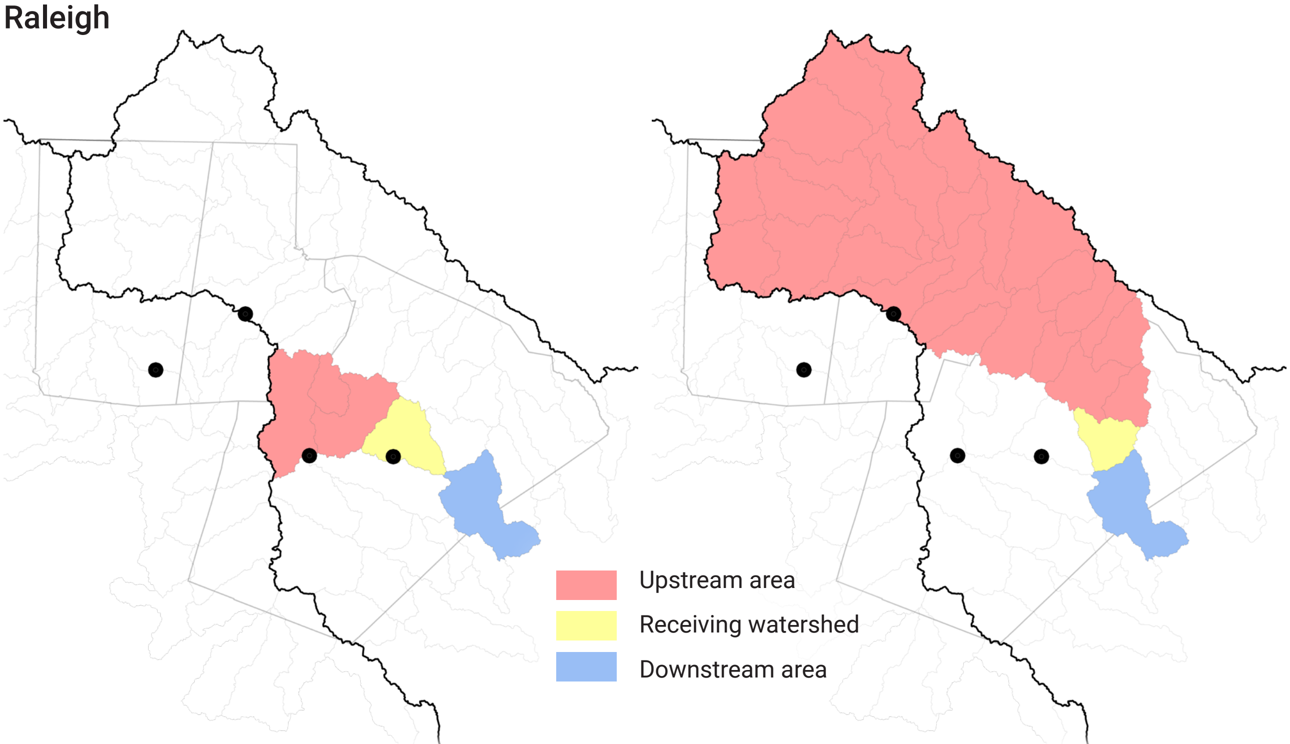


Figure 74c. Developed Land Cover

The problems related to minor flooding are regional due to the connectivity of shared watersheds in the region. Figure 74d and Figure 74e provide two example areas that illustrate how certain areas in the region potentially receive more runoff than others. Note: this does not consider stormwater mitigation or control measures within the watershed areas.

Figure 74d. Shared Watersheds and Sensitive Areas: Northeast/Central Raleigh

Figure 74e. Shared Watersheds and Sensitive Areas: East Raleigh/Knightdale



NORTHEAST/CENTRAL RALEIGH

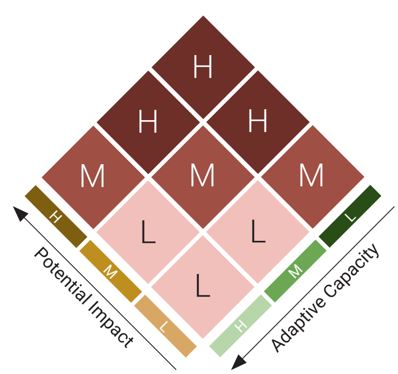
Total Upstream Area	92,971 acres
Total Upstream Developed Land Cover	35%

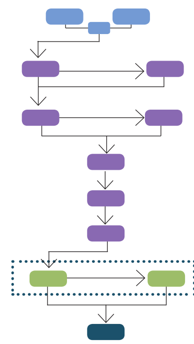
EAST RALEIGH/KNIGHTDALE

Total Upstream Area	479,926 acres
Total Upstream Developed Land Cover	7%

Vulnerability

	Potential Impact	Adaptive Capacity
High	High amount of developed land cover upstream and potential for runoff	High capacity of major and minor systems to convey stormwater
Medium		
Low	Low amount of developed land cover upstream and potential for runoff	Low capacity of major and minor systems to convey stormwater

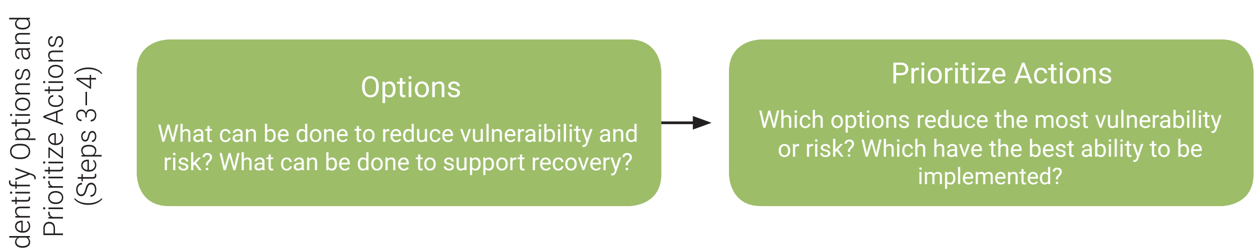




Step Three | Investigate Options

The assessment in Step Two showed that some assets are more vulnerable than others. By the end of Step Two, each jurisdiction was able to ask questions related to its tolerance of risk and vulnerability, and was also able to identify specific assets and areas with higher risk or vulnerability as potential areas in which to build resilience.

The ultimate goal of Step Three for the TRRP was to identify options and strategies to build resilience for the assets that were determined to be most vulnerable and at risk. To be actionable, an option or strategy should have the potential of building resilience by either (1) reducing exposure (removing assets from harm's way), (2) increasing adaptive capacity (increasing the asset's ability to cope with impacts), or (3) supporting response and recovery. Options and strategies also may build resilience by being proactive in dealing with future change.



As the TRRP entered Step Three, the following questions were considered:

- What are the key vulnerabilities and risks that need to be addressed?
- What are the future changes that need to be considered? (These include not only climate-related changes, but also non-climatic changes such as population growth, demographic change, economic projections, etc.)
- What have other communities done to address similar issues?
- Are there vulnerabilities and risks that cannot be addressed?
- For a given option, what is the expected benefit?

In facilitated group brainstorming exercises, the TRRP worked to identify possible solutions and explored what other, similar municipalities and jurisdictions have done.

Due to the inability of the TRRP to represent all of the interests, perspectives, and areas of expertise held by the residents and staff of the participating jurisdictions, this list of options cannot be considered complete. The TRRP itself will address some options that can and should be approached at a regional scale. For local actions, the TRRP recommends that the process of using the analysis to generate and prioritize options to increase resilience be replicated on the local level with the input of all stakeholders. The options identified in this process represent a starting point for local actions to increase resilience.

Step Three often yields a large number of options, and it can be difficult to evaluate and compare them all. The project team examined 20 key assets and 12 threats identified during the Step Two workshops, and used the vulnerability assessment and risk scoping exercises to create more focused resiliency options. While many options were identified as being applicable region-wide, some options were examined for city, jurisdictional, neighborhood, or similar smaller scale. Nine types—or themes—of options were identified:

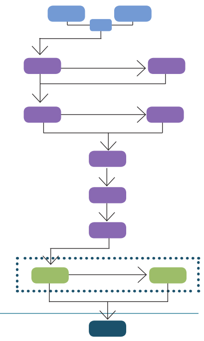
- Communication, Education, and Outreach
- Further Analysis
- Hazard Mitigation and Emergency Response (Response and Recovery)
- Infrastructure
- Natural Areas
- Ordinances and Design Standards
- Partnerships and Stakeholders
- People and Communities
- Other

Each jurisdiction of the TRRP contributed to the process of developing options and strategies to address resilience. During Step Three, the TRRP developed a comprehensive list of 135 options and strategies for the TRRP to consider to address resilience (see Appendix B).

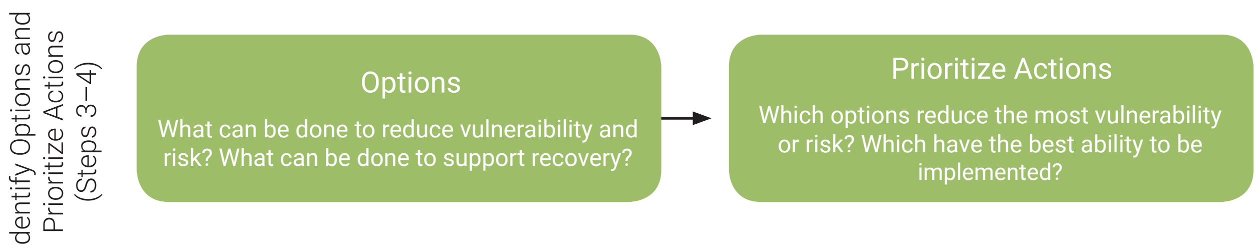
As with the assessment from Step Two, the intent of Step Three is to not only provide regional guidance, but also to allow local jurisdictions to find inspiration for local application. Thus, the larger aim for the options and strategies found in Appendix B is to inspire each of the TRRP jurisdictions to develop projects that could address resilience issues in their area.

As each jurisdiction embarks on new resilience projects, the goal of this assessment and strategy document is to serve as a platform for the TRRP's continued partnership to build resilience region-wide.

Step Four | Prioritize & Plan



Step Four—Prioritize & Plan—is a process that begins with developing criteria on which to evaluate the options and strategies. These criteria were developed based on lessons learned from other jurisdictions, both here in the U.S. and across the globe, and on principles considered by the TRRP partners to be important to the Triangle region.



The final criteria selected by the TRRP included:

- Ability to Increase Regional Resilience
    - Does this option or strategy address the vulnerabilities and risks presented in the TRRP assessment? That is, will it increase resilience for the region for the particular threat? Regional resilience can result from multi-jurisdictional collaboration or strategies that are replicated within each community.
- Provides Co-Benefit (Environmental or Other)
    - Will this option or strategy serve any additional benefit other than what it is intended for? That is, will this option or strategy address multiple threats? multiple assets? or other issues of value (e.g., environmental issues, social justice issues, etc.)?
- Socially Responsible (Equity)
    - Does the option or strategy promote fairness, equity, and social responsibility to all people of the TRRP region? An equitable strategy is one where everyone has access to the same opportunities.
- Ability to Implement (Financial)
    - Will this option or strategy be financially feasible with current resources or will additional work be needed to find a way to fund it?

During the prioritization workshops, final criteria were used to evaluate the 135 options and strategies identified in Step Three. In addition to those criteria, the TRRP also noted potential stakeholders, whether it was an existing effort, and suggestions for implementation leads for each option.

To complete the prioritization exercise, participants assigned a red, green, or yellow value—similar to a traffic light—to indicate how the options fit with each criteria. Figure 75 shows an example of how each option was evaluated using the traffic light approach.

Figure 75. Example Option Evaluation Approach

	Ability to increase resilience	Economic feasibility	Low environmental impact	Ability to implement
Option 1	🟢	🟡	🟢	🔴
Option 2	🟢	🟢	🟡	🔴
Option 3	🟢	🟢	🟡	🟡
Option 4	🟡	🟡	🟢	🟢

After the completion of the prioritization exercise, the TRRP identified options and strategies that are of regional significance. The items listed below indicate options that could be addressed at a regional level through the coordination of the TJCOG and/or other regional collaborations. They represent the options that illustrate the best use of joint planning, joint action, and joint communication efforts and should be taken as regional considerations from this resilience effort.

Additionally, in the process of identifying and prioritizing resilience strategies, it was important to recognize steps the region or different jurisdictions have already taken, and the strategies that the region and stakeholders are already working on to implement; these are highlighted in blue.

Regional Options and Strategies

a) Transition public fleets to be less dependent on fossil fuel through actionable collaboration (i.e., joint purchases, establish collective goals, etc.) in order to address supply chain interruption.

b) Develop a regional outreach program for elected officials, managers, children, vulnerable populations, and citizens that addresses issues related to: (a) flooding and property ownership; (b) wildfire in the Wildland Urban Interface; (c) smoke risks and air quality health impacts from wildfire smoke; (d) impacts of weather variation on crops and the importance of diversifying crops; (e) water conservation and strategies during water shortages; (f) air quality alert systems; (g) energy use during peak consumption periods; (h) extreme cold events, impacts on utility bills, and available resources for relief; and (i) the importance of pollinator gardens.

c) Establish a regional effort to evaluate and monitor creek flooding potential to improve natural creek conditions. This will improve water flow, reduce erosion, improve habitat, and protect the adjacent neighborhoods and commercial areas due to the impacts caused by increased rainfall severity and frequency, and an increase in development and impervious surfaces.

d) Develop a regional best practice for mapping and assessing the condition of stormwater conveyances, while paying special attention to areas in which stormwater infrastructure intersects with the 500-year floodplain (these are areas that will be strained the most during a flood event).

e) Use a map that overlays social vulnerability index (SVI) with residential flooding to identify areas of greatest vulnerability and risk, and work locally to develop strategies to mitigate. Share these strategies and outcomes regionally.

f) Implement a stream monitoring system that alerts regional and jurisdictional emergency management about rising water levels so that regular monitoring can occur, but also to alert staff about the need for evacuation.

g) Establish regional "resiliency centers" in partnership with faith-based and/or other local organizations to provide relief during extreme events (e.g., cooling, heating, evacuation) for vulnerable populations and locate these centers outside out of the 500-year floodplain with redundant electrical and water systems.

h) Utilize regional water supply planning for long-term demands.

i) Identify socially vulnerable populations and develop mapping and language-appropriate communications materials to direct and aid emergency services personnel when assistance is needed during an emergency and extreme weather events. Emergency personnel can utilize neighborhood networks (e.g., Baltimore's Resiliency Project (DP3)) and community groups to reach these vulnerable populations.

j) Enhance the capacity of regional water system inter-connects and validate and maintain them regularly.

k) Establish regional design standards to reduce heat absorption from roofs and other surfaces by using white paint on roofs and building sides.

l) Develop a regularly updated flood risk mapping system that can direct citizens to the most accurate elevation data for their parcels, with instruction on how to understand their parcels' true elevation. This information would lead to more informed management decisions, greater citizen outreach and education opportunities, as well as the possibility of lowering flood insurance premiums.

m) Promote and implement green stormwater infrastructure programs and create fee credit programs for stormwater retention with possible expansion to include water treatment. Examples of this green infrastructure program could include converting vacant lots to rain gardens and/or removing invasive exotics to avoid competition during extreme drought or wet periods.

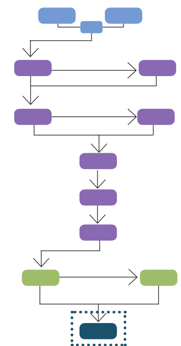
n) Increase the number of trees and amount of tree canopy by implementing urban forestry programs and changing ordinances to require less cutting and/or more vegetation replacement, while emphasizing the use of species that support pollinators.

o) Create green stormwater infrastructure incentives and/or policies for new development to address regional flooding and minor flooding issues.

p) Develop cross-boundary watershed solutions through comprehensive regional collaboration. These solutions can include dedicating ongoing staff and/or reviewing levels of service standards for stormwater across the region by doing a comparison of design standards (i.e., low levels of service upstream can negatively affect a neighboring jurisdiction, and vice versa).

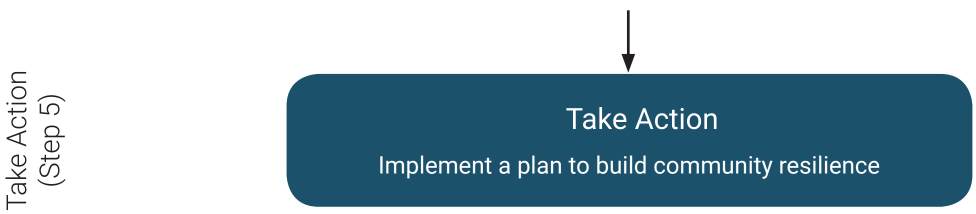
q) Establish regional coordination of fire station locations to serve key areas that are outside of the reasonable response time.

r) Conduct a study of opportunities for the use of distributed energy resources to provide backup power to critical facilities to augment conventional generators and provide at least minimal electrical power in the event of a long-term outage. If current renewables technology is shown to provide significant and cost-effective benefits in emergency scenarios, explore regional group purchasing and institutionalize uniform best practices throughout the region. For example, install solar on emergency service stations and emergency response shelters with battery backup and/or emergency power inverters.



Step Five | Take Action

The last step of the Steps to Resilience is Step Five—Take Action. In the context of this regional planning effort, Step Five involves implementing a plan to build community resilience. The formation of the TRRP and the resulting resilience assessment provides a path to this last step of the resilience process. Ultimately, it provides a roadmap for the Triangle region to become better prepared as it faces both existing threats and a changing environment.



The results of this assessment should be integrated into a regional perspective for future planning purposes. This assessment identifies potential options and strategies that may be approached at the regional scale to enhance resilience and provides the basis to inform more detailed local plans and investments. The strategies represent a starting point for planning and implementing local actions to increase resilience.

Next steps should involve incorporating these resilience concepts and potential options and strategies into local hazard mitigation plans, comprehensive plans, emergency management plans, and other similar local efforts. Each jurisdiction should determine specific tasks required for the adoption of the resilience assessment in its local plans, how the regional options and strategies can relate to local action and implementation, who would implement each option or strategy, the long-term maintenance of the identified option or strategy, and how each option or strategy will be monitored and evaluated. To move toward implementation of these resilience concepts at the local level, there should be concerted effort from the regional jurisdictions for community involvement and promotion of communication, education, and awareness of the results of this resilience process to all stakeholders who may be impacted.

The TRRP will continue to assess the impacts of climate and non-climate stressors, explore regional collaborative approaches to address these impacts, and support the identification of supplemental local actions.

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Appendix A | Glossary

Term	Definition	Example
Adaptation	The process of adjusting to new (climate) conditions in order to reduce risks to valued assets.	Relocating buildings out of flood plains or further inland from rising seas are examples of physical adaptations. Using smaller amounts of water during times of drought is an example of behavioral adaptation.
Adaptive capacity	The ability of a person, asset, or system to adjust to a hazard, take advantage of new opportunities, or cope with change.	Increasing the diameter of culverts that channel stormwater away from assets enhances the adaptive capacity of places that face flooding from increasingly heavy rainfalls.
Assets	People, resources, ecosystems, infrastructure, and the services they provide. Assets are the tangible and intangible things people or communities value.	The infrastructure of roads, airports, and seaports are assets. The service of supply chain stability (supported by transportation infrastructure) is an asset. A community's local "charm" is an example of an intangible asset.
Climate stressor	A condition, event, or trend related to climate variability and change that can exacerbate hazards.	Increasing frequency and intensity of drought conditions can be a climate stressor for forests and crops. Rising sea level is another climate stressor.
Consequence	A subsequent result (usually negative) that follows from damage to or loss of an asset. Quantifying potential consequences is an important part of determining risk.	The destruction of commercial buildings in a flood event could result in the consequence of a reduced tax base for a community.

Term	Definition	Example
Ecosystem services	Benefits that humans receive from natural systems.	Humans draw food and fiber from ecosystems. Ecosystems also filter water and air, sequester carbon, and provide recreation and inspiration for people.
Exposure	The presence of people, assets, and ecosystems in places where they could be adversely affected by hazards.	Homes and businesses along low-lying coasts are exposed to coastal flooding from storms.
Impacts	Effects on natural and human systems that result from hazards. Evaluating potential impacts is a critical step in assessing vulnerability.	In the West, wildfires are among the impacts of hotter and drier conditions and earlier snowmelt.
Mitigation	Processes that can reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing them from the atmosphere.	Carbon-neutral energy sources such as solar and wind represent mitigation efforts.
Non-climate stressor	A change or trend unrelated to climate that can exacerbate hazards.	Altering drainage patterns and replacing open land with roads and buildings are non-climate stressors for flooding hazards. Population growth along exposed coasts is another non-climate stressor.
Probability	The likelihood of hazard events occurring. Probabilities have traditionally been determined from the historic frequency of events. With changing climate and the introduction of non-climate stressors, the probability of hazard events also changes.	Locations within a 100-year flood zone have a greater probability for a flood hazard than locations in the same region’s 500-year flood zone.

Term	Definition	Example
Projections	Potential future climate conditions calculated by computer-based models of the Earth system. Projections are based on sets of assumptions about the future (scenarios) that may or may not be realized.	Climate projections indicate that if human emissions of heat-trapping gases continue increasing through 2100 (a scenario, or possible future), most locations will see substantial increases in average annual temperature (potential future conditions).
Resilience	The capacity of a community, business, or natural environment to prevent, withstand, respond to, and recover from a disruption.	Installation of backflow preventers in the stormwater systems of a coastal city increased their resilience to flooding from extreme high tides.
Risk	The potential total cost if something of value is damaged or lost, considered together with the likelihood of that loss occurring. Risk is often evaluated as the probability of a hazard occurring multiplied by the consequence that would result if it did happen.	Warehouses sited on a floodplain represent a higher risk for flooding when they are filled with products than when they are empty.
Sensitivity	The degree to which a system, population, or resource is or might be affected by hazards.	The yield of crops with a high sensitivity may be reduced in response to a change in daily minimum temperature during the pollination season.
Threat/Hazard	An event or condition that may cause injury, illness, or death to people or damage to assets.	Extended periods of excessive heat are likely to be an increasingly common hazard in the coming decades.

Term	Definition	Example
Uncertainty	A state of incomplete knowledge. Uncertainty about future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make.	Though climate model projections are uncertain about how much precipitation will change in the future, they generally agree that wet places are likely to get wetter, and dry places are likely to get drier.
Vulnerability	The propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive capacity.	Despite the thick walls of the aging lighthouse, its location on a barrier island made it vulnerable to shoreline erosion.

Appendix B | Options

The table below outlines options and strategies to provide inspiration and ideas to the TRRP jurisdictions for projects that could address resilience issues in their area. The table is organized into three categories based on the evaluation criteria outlined in Step Three | Investigate Options: (a) meets criteria; (b) somewhat meets criteria; and (c) doesn't meet criteria. Each option or strategy is assigned a threat, asset category, and asset based on the vulnerability and risk assessment (Step Two | Assess Vulnerability and Risks) and a theme based on the type of option. Finally, those options or strategies colored grey indicate efforts already underway in at least one jurisdiction within the TRRP region.

Threat	Asset Category	Asset	Theme	Option or Strategy
			Fewest Barriers to Implementation	
Air pollution	Public Services and Health	Hospitals and Medical Facilities	Partnerships and Stakeholders	Develop a stronger partnership between the health care community and State of North Carolina, environmental and health non-profits, weather prediction technology companies and TV stations to address air quality and health issues.
Disease	Public Services and Health	Hospitals and Medical Facilities	Partnerships and Stakeholders	Provide education and training for smaller clinics on infectious diseases and the link of increased disease incidence to climate threats.
Extreme cold	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Plans)	Communicate and coordinate where first responders can step out of cold and recuperate (i.e. schools, churches, shops) during events.
Extreme cold	Public Services and Health	People and Human Health	Communication, Education and Outreach	Expand education and carbon monoxide (CO) detector distribution to reduce carbon monoxide poisoning.
Extreme cold and heat	Public Services and Health	Energy and Utilities	Partnerships and Stakeholders	Partner with utilities and building developers to lobby for stronger building codes.
Flooding	Public Services and Health	Energy and Utilities	Ordinances and Design Standards	Require flood proofing as a condition of a certificate of occupancy (C.O) in floodplain (i.e. when renovation costs 25% of the value of building).

Threat	Asset Category	Asset	Theme	Option or Strategy
			Fewest Barriers to Implementation	
Flooding	Public Services and Health	Food Infrastructure	Ordinances and Design Standards	Educate property owners, municipalities, developers about the benefits of elevating food, supplies and equipment due to possibility of flood. Tactics could include shelves, elevation of equipment like generators, refrigerators, etc.
Flooding	Public Services and Health	Food Infrastructure	Ordinances and Design Standards	Change zoning to disallow placement of key food infrastructure in floodplains.
Flooding	Transportation	Railways	Communication, Education and Outreach	Include rail lines and airports in communication during rapidly rising flood waters events.
Flooding	Water	Water Distribution	Communication, Education and Outreach	Develop comprehensive maintenance and training program for facility generator connection (mobile vs. on-site).
Flooding	Water	Stormwater Infrastructure	Further analysis	Develop a regional best practice for conditions assessment of dams (lead: Water Authority) and berms (lead: Stormwater).
Heat	Properties	Jurisdictional- and State-Owned Properties	Ordinances and Design Standards	Create policies and ordinances to increase shade in parking lots by using more, larger and shadier trees based on best practices.
Minor Flooding	Water	Water Distribution	Ordinances and Design Standards	Create watershed-based development ordinances using overlay zone (i.e. Swift Creek land management plan).
Snow/Ice	Transportation	Roads	Hazard Mitigation and Emergency Response (Plans)	Prioritize treatment for access (e.g. streets, sidewalks) to critical facilities (i.e. hosp., EMS, Police, Fire, DOT, maint. stations, food suppliers)
Snow/Ice	Transportation	Roads	Hazard Mitigation and Emergency Response (Plans)	Prioritize critical access points for treatment/clean-up and transportation for socially vulnerable populations (e.g. transit).
Supply Chain Interruption	Properties	Jurisdictional- and State-Owned Properties	Infrastructure	Create protocols to restrict the use of fuel at government fleet fueling stations to necessary vehicles only during a fuel shortage, while other fleet vehicles can refuel at commercial fueling stations.

Threat	Asset Category	Asset	Theme	Option or Strategy
			Fewest Barriers to Implementation	
Water shortage	Public Services and Health	People and Human Health	Communication, Education and Outreach	Create emergency communication plans and tools to quickly and effectively save water during a water shortage. For example, Ever-bridge is a critical event management system that allows for customer communication in an emergency. Communication is tied to critical service during a shortage when the communication is about conserving non-essential usage.
Water shortage	Public Services and Health	People and Human Health	Partnerships and Stakeholders	Implement proactive regional community planning and identify critical customers (i.e.scenario training, emergency mutual aid, continuity planning) to prepare for water shortages.
Water shortage	Water	Water Supply	Further analysis	Investigate water supply variability with more recent, large-precipitation events.
Water shortage	Water	Water Supply	Hazard Mitigation and Emergency Response (Plans)	Enable Triangle J COG to host drills and table top exercises for water shortage response regionally and across jurisdictional departments.
Water shortage	Water	Water Supply	Hazard Mitigation and Emergency Response (Response and Recovery)	Develop mutual aid for emergency water supply.
Water shortage	Water	Water Supply	Hazard Mitigation and Emergency Response (Response and Recovery)	Develop mutual aid for water and wastewater service in emergencies (i.e. NC Water WARN).
Water shortage	Water	Water Supply	Partnerships and Stakeholders	Leverage University and private research partnerships to understand technology improvements for water infrastructure (i.e. Urban Water Consortium).

Threat	Asset Category	Asset	Theme	Option or Strategy
			Fewest Barriers to Implementation	
Wildfire	Properties	All Properties	Hazard Mitigation and Emergency Response (Response and Recovery)	Reduce response time by :1) increasing staffed hours requirement in fire stations in key areas;
Wildfire	Properties	All Properties	Hazard Mitigation and Emergency Response (Response and Recovery)	Reduce response time by: 2)speed up reporting of wildfire ignition through community watch or remote sensing (if available).
Wildfire	Properties	All Properties	Hazard Mitigation and Emergency Response (Response and Recovery)	Train urban firefighters to respond to WUI and wildfire events.
Wind	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Response and Recovery)	Increase awareness training during high-wind conditions for drivers of high profile vehicles (i.e. trucks, vans, SUVs, or vehicles towing trailers).
Wind	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Response and Recovery)	Review standard operating procedures for drivers of high profile vehicles (i.e. trucks, vans, SUVs, or vehicles towing trailers) for normal response during abnormal high-wind conditions.
Wind	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Response and Recovery)	Increase training for staff focusing on staying safe in field during an event and responding after an event (i.e. Storm Ready).
	All	All	Communication, Education and Outreach	Develop a one-page guide on how to use this assessment in concert with the US Climate Resilience Toolkit to launch a local Resilience Planning Effort.
	Water	Water Supply	Further analysis	Identify and prioritize at-risk communities who are impacted by water shortages.

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Changing seasons	Natural	Agriculture	Partnerships and Stakeholders	Support small farms with assistance to help protect crops from frost/freeze effect after an early warming.
Changing seasons	Natural	Agriculture	Further analysis	Research ways of protecting pollinators from changing seasons, extreme heat, habitat loss and monoculture food sources in the Triangle region.
Extreme cold	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Response and Recovery)	Regulate shift schedules for emergency services to be safe in extreme conditions.
Extreme cold	Public Services and Health	Emergency Services	Partnerships and Stakeholders	Develop comprehensive outreach and provide adequate clothing and knowledge to homeless population to deal with exposure to extreme cold. Provide resources to programs for homeless populations in extreme weather events.
Extreme cold and heat	Public Services and Health	People and Human Health	Communication, Education and Outreach	Expand and increase marketing for low income retrofits to address extreme cold and extreme heat events.
Extreme heat	Transportation	Roads	Further analysis	Install pavement sensors to indicate road failures during extreme heat events.
Extreme heat	Transportation	Roads	Ordinances and Design Standards	Prioritize transportation corridors and urban heat island mitigation strategies to reduce risk of extreme heat on roads (i.e. trees, green roofs for buildings in transportation corridors , painting roofs white to absorb heat and light).

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Flooding	Properties	All Properties	Natural Areas	In dedicated and protected (easement) open space, use volunteers to reestablish and revegetate stream buffers. After purchasing and demolishing the damaged structures (i.e home buyout), the jurisdiction uses its non-profit partners and/or volunteers to re-establish stream buffers along creeks by planting trees and shrubs or by allowing the properties to re-establish naturally.
Flooding	Properties	All Properties	Ordinances and Design Standards	Update flood ordinances so that new construction shall have the lowest floor, including basement, elevated no lower than the 500 year floodplain "future condition" or four feet above the base flood elevation (BFE), based on national best practice.
Flooding	Transportation	Roads	Further analysis	Assess culvert structures for structural integrity on flood prone streets in neighborhoods with isolating potential.
Flooding	Transportation	Roads	Hazard Mitigation and Emergency Response (Response and Recovery)	Develop "flood early warning system" (similar to City of Austin, TX) that has gauges in strategic locations to monitor water levels at culverts and provides alert when roads may be flooding to let people know when to evacuate (to see roads closures and predictions). This system would incorporate streaming data sources (e.g. transportation options plus flooding and road closures, predictions, etc) to create real time data for citizens and decision makers.
Flooding	Transportation	Roads		To increase flow rate and enhance riparian areas during flood events, implement and install more bridges, multiple culverts and floodplain culverts instead of single culverts when possible.

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Flooding	Transportation	Roads	Ordinances and Design Standards	Address flood prone roads by implementing green stormwater practices, preventing building new roads in flood prone areas and converting stormwater prone lots for multiple benefits (e.g pollinator habitat in Raleigh).
Flooding	Transportation	Roads	Ordinances and Design Standards	Develop transportation access plan required for all large future development to ensure there are multiple entrances.
Flooding	Transportation	Roads	Ordinances and Design Standards	Create requirement that access-limited communities have right-of-way access point to be used in time of emergency (i.e. a greenway with bollards that release for driving when flooding event occurs).
Flooding	Transportation	Roads	Partnerships and Stakeholders	Identify other funding tools to buyout flood prone properties.
Flooding	Water	Stormwater Infrastructure	Ordinances and Design Standards	Require and incentivize additional stormwater detention efforts (e.g green streets, swales, underground storage tanks).
Flooding	Public Services and Health	Food Infrastructure	Further analysis	Locate key food infrastructure in floodplain (i.e. distribution centers) and identify which food infrastructure is associated with vulnerable populations.
Flooding	Public Services and Health	Food Infrastructure	Infrastructure	Install flooding control equipment for buildings in vulnerable areas (i.e. flood gates at Crabtree Valley Mall in Raleigh).
Flooding	Transportation	Railways	Partnerships and Stakeholders	Collaborate with rail lines and airports to identify and address critical flooding areas (i.e. capital projects for stormwater infrastructure adjacent to rails, culvert improvements, etc.).

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Flooding	Water	Stormwater Infrastructure	Communication, Education and Outreach	Develop free rain garden program using fees and grants to provide materials and training to participants.
Flooding, water shortage	Water	Water Distribution	Further analysis	Identify the locations and condition (e.g age, material) of water distribution, water treatment and stormwater infrastructure (similar to an "infrastructure conditions assessment").
Growing season and heat	Natural	Agriculture	Partnerships and Stakeholders	Broaden regional discussion to include people who know more about the impact of heat and growing season changes on agriculture.
Heat	Public Services and Health	Energy and Utilities	Other	Advocate for more renewable energy sources at state level.
Heat	Public Services and Health	People and Human Health	People and Communities	Expand programs to distribute fans and air conditioning units to residents and increase funds for utility assistance for extreme heat events.
Heat	Public Services and Health	People and Human Health	People and Communities	Implement weatherization programs for rental properties and mobile homes in a way that protects people in addition to the property (i.e. programs that deal with increased energy bills).
Heat	Public Services and Health	People and Human Health	People and Communities	Create a new program that provides energy retrofit for public housing and as a best practice require that all public funded properties need to be energy efficient.
Heat	Public Services and Health	Energy and Utilities	Infrastructure	Increase the amount of energy sources that do not depend on water.

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Heat, cold	Properties	Jurisdictional- and State-Owned Properties	Infrastructure	Install more geothermal systems in public buildings.
Heat, cold	Public Services and Health	People and Human Health	People and Communities	Develop mechanisms to alert and protect outdoor workers and vulnerable populations from extreme heat and cold.
Minor Flooding	All	All	Ordinances and Design Standards	Adopt at least 100’ stream buffers on any perennial stream as regional best practice.
Minor Flooding	Properties	All Properties	Communication, Education and Outreach	Buyout properties with potential to flood for the purposes of restoration which strategically could be used for daylighting or education.
Minor Flooding	Properties	All Properties	Ordinances and Design Standards	Create incentives for developers to maintain riparian corridors.
Minor Flooding	Water	Stormwater Infrastructure	Infrastructure	Create dedicated funding source and staff stormwater utility as a best practice.
Minor Flooding	Water	Stormwater Infrastructure	Infrastructure	Create system-based solution funded by stormwater utility that ranks projects using water quality, water quantity, heat island mitigation, regional wildlife corridor, and regional recreational corridor (safety).
Minor Flooding	Water	Stormwater Infrastructure	Partnerships and Stakeholders	Keep stormwater issues related to economy and quality of life on legislative agenda at the state level.
Minor Flooding	Water	Stormwater Infrastructure	Partnerships and Stakeholders	Use local government as a proactive convener on area-based stormwater infrastructure improvement, rather than plot or parcel-based.

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Minor Flooding	Water	Stormwater Infrastructure	Partnerships and Stakeholders	Create private property solutions funded by stormwater utility (i.e.City of Durham rain catchers program, City of Raleigh matching and incentives, etc.).
Minor Flooding	Water	Stormwater Infrastructure	Partnerships and Stakeholders	Develop partnership projects between municipalities (i.e. restoring stream corridor between Cary and Raleigh) with incentives to private property owners as needed. Include parks and/or educational facilities/or recreational facilities.
Snow/Ice, Flooding	Water	Stormwater Infrastructure	People and Communities	Create a community-based approach to engage community in regional stormwater solutions using regional baseline best practices that could be beyond state minimum.
Supply chain Interruption	Transportation	Roads	Communication, Education and Outreach	Create a backup communication and road access plan for residents to access medical care who rely on public transportation (e.g. some dialysis patients, a portion of the aging community, persons with some types of disabilities, etc)
Supply chain Interruption	Properties	Jurisdictional- and State-Owned Properties	Infrastructure	To prepare for supply chain interruptions, review existing and create new protocols to address funding needs and to facilitate response in the event of a price spike in vehicle fuel, natural gas, or electricity, so that other budgetary items are not strained.
Supply chain Interruption	Properties	Jurisdictional- and State-Owned Properties	Infrastructure	Diversify fuel supply/mix for generators by moving to natural gas and diesel.

Threat	Asset Category	Asset	Theme	Option or Strategy
Moderate Barriers to Implementation				
Water shortage	Natural	Natural Areas	Natural Areas	Identify and educate municipalities and the public about natural and native drought tolerant species for management in order to avoid competition from invasive species.
Water shortage	Natural	Agriculture	Ordinances and Design Standards	Include water efficient strategies (i.e. efficient landscapes, sprinkler systems, xeriscape, cooling tower systems) in public awareness campaigns.
Water shortage	Natural	Natural Areas	Further analysis	Consider wildlife needs for water when doing water planning on public lands.
Water shortage	Water	Water Supply	Further analysis	Monitor water loss in water supply systems through leak detection programs and sensors, and asset management.
			Infrastructure	Use reclaimed water (e.g. highly treated wastewater effluent) for irrigation and cooling towers, toilet flushing, etc.
			Infrastructure	Increase number of peak flow diversions into offline quarry storage in water supply systems.
Water shortage	Water	Water Supply	Further analysis	Investigate other uses for reclaimed water (i.e. crop irrigation).
Water shortage	Water	Water Supply	Infrastructure	Increase the use of cisterns on public buildings for rainwater capture.
Wildfire	Public Services and Health	Energy and Utilities	Infrastructure	In preparation for threat events, establish wireless backup options for key communication lines for public use and if not possible consider burying communication lines.
Wind	Public Services and Health	Energy and Utilities	Infrastructure	Bury distribution lines and report on excess woody growth in easements to prepare for high wind events.

Threat	Asset Category	Asset	Theme	Option or Strategy
Significant Barriers to Implementation				
Air quality	Public Services and Health	Hospitals and Medical Facilities	Hazard Mitigation and Emergency Response (Plans)	Make sure medical facilities have adequate equipment, medicines, and expertise to handle increased asthma and heart disease cases.
Extreme cold	Public Services and Health	Energy and Utilities	Communication, Education and Outreach	Retrofit programs for high energy use properties and vulnerable populations.
Extreme cold	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Plans)	Prevent fire suppression and sprinkler systems from freezing, which would require conditioned space.
Extreme cold	Public Services and Health	Energy and Utilities	Infrastructure	Bury electrical lines underground.
Extreme heat	Transportation	Roads	Communication, Education and Outreach	Educate community and municipalities about reducing single occupancy driving at extreme heat peak times and when operating loading zones (i.e. restrict large semi-trucks from parking in high traffic zones during high heat to reduce traffic congestion).
Extreme heat	Transportation	Roads	Partnerships and Stakeholders	Create partnership agreement with rideshare and bus system to pick up residents and guests from vulnerable areas more susceptible to extreme heat and transportation issues.
Flooding	Natural	Natural Areas	Natural Areas	Plant dense vegetation along riparian corridors to create a buffer from intensely flowing waters during flood events.

Threat	Asset Category	Asset	Theme	Option or Strategy
Significant Barriers to Implementation				
Flooding	Properties	All Properties	Ordinances and Design Standards	Integrate natural buffer requirements, such as wetlands and soft shorelines, into new development or redevelopment for all properties (design should go beyond just open park spaces and include proactive elements and above state regulations).
Flooding	Properties	All Properties	Ordinances and Design Standards	Implement plan to retrofit liquid fuels and storage tanks which includes: 1) educational outreach for city-owned, residential, commercial, and industrial buildings about proper storage; 2) require hazardous materials stored in city-owned, residential, commercial, and industrial buildings within the floodplain to be elevated a minimum of three feet above the freeboard.
Flooding	Properties	All Properties	Ordinances and Design Standards	Provide protection of floodplain, flood prone, wetland areas with the dedication of easements (often identified as greenway corridor on local PRCR Master Plans) to prevent any damage to structures or amenities that can't withstand flooding. These areas also act as storage "sinks" of flood waters minimizing large scale flood events downstream. These easements also enable natural resource migration (wildlife/natural corridors) during climate variations and extreme weather events.
Flooding	Transportation	Roads	Natural Areas	Provide incentives (i.e. density bonuses, permitting fees, faster review process, etc.) to developers to reduce impervious surfaces beyond riparian buffer rules and leave riparian areas in place.

Threat	Asset Category	Asset	Theme	Option or Strategy
Significant Barriers to Implementation				
Flooding	Transportation	Roads	Partnerships and Stakeholders	Create agreements with AirBnB and other homeshare platforms to educate guests on hazards and emergency exit strategies.
Flooding	Transportation	Roads	Partnerships and Stakeholders	Develop agreements with Uber and other rideshare platform users to provide emergency egress and evacuation services to residents and guests vulnerable to road access issues.
Flooding	Transportation	Railways	Ordinances and Design Standards	Encourage federal authorities to consider issues of critical access when establishing standards of rail design.
Heat	Properties	All Properties	Ordinances and Design Standards	Encourage and install white parking lots or more reflective surfaces, other than concrete.
Heat	Properties	Jurisdictional- and State-Owned Properties	People and Communities	Establish community solar programs in public housing and affordable housing areas.
Heat	Properties	Jurisdictional- and State-Owned Properties	People and Communities	Require use of solar power on new affordable housing that uses public funds.
Heat	Public Services and Health	People and Human Health	People and Communities	Establish methods of relief for extreme heat events including shade options and spray and cooling features in parks with fan “misters”.
Heat	Transportation	Roads	Infrastructure	Use new pavement materials that can withstand extreme heat and high temperatures.

Threat	Asset Category	Asset	Theme	Option or Strategy
		Significant Barriers to Implementation		
Minor Flooding	Properties	All Properties	Communication, Education and Outreach	Promote practices to encourage daylighting streams for environmental function, education and beauty and amenity benefits.
Minor Flooding	Water	Stormwater Infrastructure	Infrastructure	Ensure proactive maintenance of stormwater infrastructure.
Snow/Ice	Natural	Natural Areas	Natural Areas	Create timely clean-up program to avoid impacts on natural areas (e.g. waterways and bodies) that includes salt and sand clean-up and monitoring after snow and ice events.
Snow/Ice	Public Services and Health	People and Human Health	Hazard Mitigation and Emergency Response (Plans)	Target activity centers (e.g. downtown) to maintain access to homes and businesses during snow and ice events.
Snow/Ice	Public Services and Health	People and Human Health	Natural Areas	Optimize the use of salt and sand to reduce impacts on natural areas and roadway maintenance.
Snow/Ice	Transportation	Road	Hazard Mitigation and Emergency Response (Plans)	Develop new program that requires private property owners to maintain sidewalks or accessible route to property.
Snow/ Ice, Wind, Supply Chain Interruption	Public Services and Health	Energy and Utilities	Infrastructure	Increase adoption of distributed energy resources such as solar and wind by lowering financial and regulatory barriers to permitting and development. When installed with battery backup and/or emergency power inverters, at least minimal electrical power will be provided in the event of a long-term outage. For those on well or septic, these backups can be sized to run the well pump.

Threat	Asset Category	Asset	Theme	Option or Strategy
Significant Barriers to Implementation				
Supply Chain Interruption	Properties	Jurisdictional- and State-Owned Properties	Infrastructure	Diversify the fuel sources used by essential fleet vehicles to allow for at least minimal travel in the event of a long interruption in the fuel supply. Examples include electricity, natural gas, propane, and ethanol. Or create a protocol by which alternative-fueled vehicles used for non-essential functions can be called into service by essential personnel in the event of an emergency.
Supply Chain Interruption	Transportation	Roads	People and Communities	Ensure alternate transportation facilities and equipment are in place (i.e. trails, separated bike paths, carpools, ad hoc ride shares, etc.) to enable impacted populations to access public service needs without requiring a vehicle.
Water shortage	Natural	Agriculture	Further analysis	Investigate use of backup water supply sources (e.g. well versus surface water) for agriculture.
Water shortage	Natural	Natural Areas	Natural Areas	Develop a program to remove invasive exotics to avoid competition during extreme drought or wet periods.
Water shortage	Natural	Agriculture	Partnerships and Stakeholders	Create private partnerships focusing on drought resistant crops.
Water shortage	Properties	All Properties	Ordinances and Design Standards	Require and incentivize pervious materials in new construction and maintenance to ensure aquifers are restored during rain events, as opposed to generating runoff due to hard stormwater infrastructure.
Water shortage	Properties	Residential Properties	Partnerships and Stakeholders	Create state, regional and local level partnership and monitoring program to manage water use for “reasonable use” of surface water.

Threat	Asset Category	Asset	Theme	Option or Strategy
Significant Barriers to Implementation				
Water shortage	Public Services and Health	People and Human Health	Further analysis	Determine where medical needs are (e.g. dialysis) and how to notify public of water shortages.
Water shortage	Water	Water Supply	Communication, Education and Outreach	Create technology for real-time feedback about water supply to customers.
Wildfire	Properties	All Properties	Hazard Mitigation and Emergency Response (Plans)	Implement natural fuel reduction activities in Wildland Urban Interface (WUI) areas (i.e grubbing out or controlled burns underneath mature forests).
Wildfire	Properties	Energy and Utilities	Ordinances and Design Standards	Limit open recreational fires (i.e. several jurisdictions limit non-vegetal fuels (trash) inside city limits, fire pits, fireworks).
Wildfire	Properties	Energy and Utilities	Ordinances and Design Standards	Require fire-safe protective site design (i.e leave fire-breaks around structures such as as parking lots or lawns).
Wildfire	Properties	Energy and Utilities	Ordinances and Design Standards	Limit fire sources in residential and commercial areas related to landscaping materials (i.e. pine straw), type and proximity to structures.
Wildfire	Public Services and Health	Energy and Utilities	Communication, Education and Outreach	Increase reporting to utilities by residents and local governments of needed distribution line easement maintenance (i.e. clearing woody plants).
Wind	Properties	Residential Properties	Ordinances and Design Standards	Review and update nuisance ordinances to minimize chance of damage (e.g. leaning or dead trees, debris).
Wind	Properties	Residential Properties	Ordinances and Design Standards	Institute homeowner association (HOA) policies to clean up debris before expected wind event (i.e. hurricanes).

Threat	Asset Category	Asset	Theme	Option or Strategy
		Significant Barriers to Implementation		
Wind, Fire	Public Services and Health	Emergency Services	Hazard Mitigation and Emergency Response (Response and Recovery)	Harden existing 911 centers to withstand strong winds (see FEMA Building Code fact sheet for standards) and/or build a backup 911 center where operations can be transferred in the event the main 911 center is inoperable.

Appendix C | Data Sources

Threats

- Flooding: Preliminary Effective flood maps for Chatham, Durham, Orange and Wake Counties. North Carolina Floodplain Mapping Program, https://fris.nc.gov (accessed October, 2017)
- Wildfire: Southern Wildfire Risk Assessment WUI Risk Index. Southern Group of State Foresters. 2015

Assets

- Biodiversity/Wildlife Habitat Assessment: North Carolina Department of Environmental Quality and North Carolina Natural Heritage Program, https://ncnhde.natureserve.org/content/data-download (accessed May 2017)
- Bridges: NCDOT Structure Locations, https://connect.ncdot.gov/resources/gis/pages/gis-data-layers.aspx (accessed August 2016)
- Building footprints (structures): North Carolina Floodplain Mapping Program and multiple county GIS sources (Chatham, Durham, Orange, and Wake Counties, accessed October 2017)
- CDC Social Vulnerability Index: Centers for Disease Control and Prevention/Agency for Toxic Substances and Disease Registry/Geospatial Research, Analysis, and Services Program, Social Vulnerability Index 2016 Database for North Carolina, http://svi.cdc.gov/SVIDataToolsDownload.html (accessed January 2018)
- Census tract demographics: U.S. Census Bureau, American Community Survey 2015 5-year estimates
- Dams: NC Dam Safety Program, North Carolina Dam Inventory 2/21/17 (accessed December 2017)
- Developed Land Cover: National Land Cover Database 2011 (2014 edition)
- Food locations: U.S. Department of Agriculture Food and Nutrition Service, http://www.fns.usda.gov/pd/supplemental-nutrition-assistance-program-snap (accessed September 2017)
- Local water supply plans: Multiple water supply system plans (Cary, Durham, Hillsborough, Raleigh, Apex, Chatham North, OWASA) https://www.ncwater.org/Water_Supply_Planning/Local_Water_Supply_Plan (accessed May 2018)
- Managed Areas/GAP Status: North Carolina Department of Environmental Quality and North Carolina Natural Heritage Program, https://ncnhde.natureserve.org/content/data-download (accessed February 2018)
- Property parcels: Multiple county GIS sources (Chatham, Durham, Orange, and Wake Counties, accessed October 2017)
- Roads: Street centerlines, OpenStreetMap, GEOFABRIK downloads, https://download.geofabrik.de/north-america/us/north-carolina.html (accessed January 2018)
- Tree Canopy: Analytical Tree Canopy, National Land Cover Database 2011 (2014 edition)
- Wastewater facilities: Multiple water system sources (Cary, Durham, OWASA, received February-April 2018)
- Water supply distribution lines and facilities: Multiple water system sources (Cary, Durham, OWASA, received February-April 2018)

TRIANGLE J COUNCIL OF GOVERNMENTS

UNC Asheville | NEMAC National Environmental Modeling & Analysis Center

Town of Cary

Orange County North Carolina

Raleigh

Town of Chapel Hill

Durham County DCo NC 1881

City of Durham