AT&T CLIMATE RESILIENCY COMMUNITY CHALLENGE 2020

Inland Flood Risk and Municipal /Regional Resilience in Georgia: Data, Methodology, Case Studies & Recommendations

Prepared for: AT&T

Prepared by:
PI: Adjo Amekudzi-Kennedy, Ph.D.
Co-PIs: Russell Clark, Ph.D., Baabak Ashuri, Ph.D., Brian Woodall, Ph.D.
Students: Prerna Singh, Ty Parrillo, Derek Rizzi, Mandani Tennakoon

Georgia Institute of Technology

12/31/2020

Table of Contents

Executive Summary

Climate change in the Anthropocene era has introduced new challenges in infrastructure management. Under prevailing challenges of limited funding, fragmented data availability, methodological evolution, and a relatively slow-to-change institutional framework, local agencies must develop processes that enable them to anticipate and address evolving challenges while managing existing ones.

One such natural hazard, flooding has increased in frequency and impacts in several communities. Global warming has led to notable sea-level rise and altered rainfall patterns, increasing unexpected extreme rainfall events. The negative impacts of flooding have also increased due to urban development in floodplains, expansion of floodplains in some cases, and significant reductions in pervious land cover.

This project focuses on inland flooding hazards in the state of Georgia. It aims to develop and apply frameworks to assess the flood vulnerability of local communities, and provide tailored recommendations to strengthen community resilience. The project leverages Climate Projection Model data, developed by the Argonne National Laboratory for AT&T, and uses other available data sources to fill in existing gaps. The projections are used as hazard exposure data along with other vulnerability datasets (i.e., social, ecological, technical and institutional) developed to identify hot spots or focus areas to implement flood management solutions.

A case-study based approach was developed and applied to four cities that differ in their exposure and responses to inland flooding: Atlanta, Austell, Albany and Carrollton. A vulnerability assessment was conducted using the Social- Ecological-Technical Systems (SETS) approach, developed by researchers in the Urban Resilience to Extremes (UREx) Sustainability Research Network (SRN). By introducing institutional vulnerability as a formal consideration in the assessment, we expanded the approach to include institutional factors - resulting in an Institutional-SETS or I-SETS framework.

The assessment results along with the AT&T/Argonne inland flood risk exposure data were used to develop GIS-based hot spots - regions of high exposure and high vulnerability in the communities. Based on the vulnerability assessment, and current and future flood risk profiles, recommendations were developed tailored to the needs and existing capabilities of the different communities. This exercise with four different cities provides a framework to conduct similar assessments of other cities within the state and elsewhere and offers contextually relevant recommendations to strengthen community resilience.

The project involved multiple stakeholders from three different public agencies: the Atlanta Regional Commission (ARC), Metropolitan North Georgia Water Planning District (Metro District), and the City of Atlanta Department of Watershed Management. The agencies were engaged in an advisory and review capacity, providing their inputs at multiple stages of the project. This design decision was made to allow for the development of deliverables that would be practically useful to agencies involved in stormwater and flood risk management, while contributing to advancing existing knowledge and methodology in this interdisciplinary area.

The results show that there is a continuum of maturity in public awareness of inland flood risks, the multiple factors influencing vulnerability, knowledge of where the highest vulnerabilities and exposure to inland flooding risk occur in various communities, and in the institutional and fiscal

capabilities to address this hazard. The study shows that although some critical datasets are incomplete for formally addressing climate change in flood management, agencies can use various approaches to integrate multiple datasets, model and estimate risk exposure, and generate defensible vulnerability and risk exposure data to identify priority areas for appropriate interventions. The overarching finding of this study is that communities that have the highest exposures to inland flooding hazard also appear to have the highest vulnerabilities to flooding and tend to be communities with a history of flooding where minority populations are in the majority.

The recommendations of this project are tailored to be useful to agencies such as ARC, the City of Atlanta Department of Watershed Management and Metro District as they move forward with identifying vulnerabilities and implementing appropriate adaptations for sewer and stormwater management for system resilience in municipalities, metro and other areas in the state of Georgia. They are also tailored to be useful to municipal leaders and agencies searching for ways to enhance their existing capabilities to develop community resilience to inland flood threats.

The project also demonstrates an approach to modeling community and infrastructural vulnerability using precipitation projections, with formal considerations of uncertainty. It demonstrates the necessity of exploring practical and cost-effective hybrid (i.e., green and gray) infrastructure and technology solutions, and, improved policies and regulations to address inland flooding in the Anthropocene era. In addition, it demonstrates procedures for fusing incomplete datasets to characterize inland flood risk exposure.

Chapter 1: Report Overview

The report is presented in three main chapters. The first chapter provides an overview of the report. It includes explanation of the background and motivation of this research and outlines the subsequent chapters of the report. The second chapter presents the methodology and data development and application to conduct state and municipal level risk exposure and vulnerability assessments. Finally, the third chapter presents the analysis findings with recommendations to improve community resilience, and future work to strengthen existing analytical and data capabilities for managing inland flood hazards. All the chapters present the different aspects of the research conducted, which might be of interest to different stakeholders (i.e., practitioners and researchers). This chapter serves to direct the readers to the sections that are most relevant to their needs and interests, while also presenting the requisite background for the study.

Introduction and Motivation

The past several years and decades have brought more frequent and extreme floods, droughts, and heatwaves, along with stronger hurricanes, tropical storms and more intense wildfires, melting glaciers, reduction in sea ice, rise in sea levels and devastation to coastal and inland communities. Each year has also brought new record-breaking weather extremes (Arroyo 2019). According to the Insurance Information Institute, the overall losses from world-wide natural catastrophes in 2019 totaled $150 billion and 9,000 deaths. According to the National Oceanic and Atmospheric Administration (NOAA), since 1980, the US has sustained over 250 weather and climate disasters where overall damages and costs reached or exceeded 1 billion (including CPI adjustment to 2019), with the total cost exceeding $1.75 trillion.

In Georgia, climate-related extreme events are showing increasingly significant impacts on property value, infrastructure value, economic value and human life. In 2004, the remnants of Hurricane Frances caused $41 million dollars damage in Atlanta mostly from flooding owing to overburdened and outdated sewer and stormwater management systems. A recent study found that Georgia lost more than $15 million in property value from sea level rise flooding from 2005 to 2017 (Landers 2018). In the 2016 to 2018 timeframe, Georgia residents incurred over $5 billion in property and infrastructure damage, evacuation expenses, and recovery/clean-up through damage from major storms. Further, the Union of Concerned Scientists issued a report in 2017 warning that Georgia’s coastline faces chronic inundation (Kyler 2018).

The climate continues to change. With these changes, inland flood risks are growing, exacerbated by continuing development in floodplains, an expanding floodplain, and institutions lagging behind evolving floodplain management needs. Also, there are limited data for adequate floodplain management and methodological challenges in floodplain management. Floodplain management to strengthen system resilience continues to be critical for community development by reducing risks to assets such as homes, businesses, public infrastructure and ecological assets (i.e., built environment, community, economic, environmental assets), and by providing other wide-range benefits including climate change mitigation.

Agencies at all levels are attempting to incorporate resilience and risk-based approaches in their planning in order to reduce the potential impacts of extreme events on their systems. At the same time, various concepts of risk, vulnerability, and resilience have been defined across a vast spectrum of disciplines, and, hence, at times get conflated or are used interchangeably. This presents challenges in the application of these concepts in practice. The terminologies also are defined variably across technical, ecological, social, and institutional domains. Given that the public agencies will benefit from taking a holistic view of their systems, effective flood management is dependent on correctly applying and interpreting the concepts of risk, vulnerability, and resilience across these various domains.

This report presents an inland flood risk assessment of different cities in Georgia. The risk assessment incorporates exposure assessment using multiple data sources. The study also conducts a vulnerability assessment which spans across the institutional, technical, ecological, and social domains of the cities. The vulnerability and exposure assessments are combined to identify high-risk areas (i.e., high exposure-high vulnerability areas). Further, the report presents variations of exposure data over time, demonstrating the impact of climate change with respect to increasing the uncertainties in our exposure prediction capabilities, and community exposure to inland flood threat. The report concludes with recommendations tailored to enhance the resilience to inland flooding of the specific case study regions in this era of changing climate.

Background

In collaboration with the U.S. Department of Energy's Argonne National Laboratory, AT&T invited public and private colleges and universities to participate in a Climate Resiliency Community Challenge, which is designed to help local communities better predict, prepare for and adapt to the changing climate. In this challenge, universities were required to work with local governments in the Southeast United States to conduct a risk-based climate analysis using data from Argonne National Laboratory and commissioned by AT&T to address a problem that affects the Southeast Region. One university from each state in the Southeast Region (Florida, Georgia, South Carolina and North Carolina) was selected by an independent panel of non-profit climate and resiliency experts.

Georgia Tech is one of five universities selected for the AT&T's Climate Resiliency Community Challenge. Georgia Tech's Research Team partnered with Atlanta Regional Commission, Metropolitan North Georgia Water Planning District, the City of Atlanta Department of Watershed Management, Georgia Tech's Smart Cities and Inclusive Innovation Initiative, and, the Center for Serve-Learn-Sustain to address the challenge.

The team assessed the impacts of inland flooding (riverine and localized) on Metro Atlanta's communities and explored ways to strengthen resilience through institutional, social, ecological and technical interventions.

Extreme weather and related disasters have been studied extensively in literature in various fields In response to disasters, changing demand, and other uncertainties, researchers have developed and the literature has been extended with various concepts to define, measure, and assess the impacts of disasters on systems. Risk, vulnerability, reliability, robustness, flexibility, adaptability, survivability, resilience are the main keywords used in the disaster management literature. Depending on the type of system, similar concepts are named differently. Given the widespread use of these terms, a lot of them are used interchangeably, and lack of clear distinction leads to misinterpretation in different contexts. While each definition has value in the context it was developed, it is important to critically analyze the existing definitions and identify a definitions most suited to the context of this particular problem.
After reviewing the literature on resilience, risk, vulnerability, and disaster management, we applied the following definitions of the following keywords in this research:

- Hazard: In the context of climate change, hazard refers to any potential occurrence of a natural or human-induced physical event that may cause damage to property, infrastructure, livelihoods, service provision, environmental resources and other community assets. As an example, as sea level rises, increased frequency of inundation of an area during a storm event is a potential hazard for a low-lying coastal community.
- Risk: Risk is the potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events (likelihood) or trends multiplied by the impacts (or consequences) if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard (IPCC 2014). In this research, risk is characterized as the combination of the hazard exposure with the vulnerability of the region.
- Vulnerability: The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt (IPCC 2014). As an example, older populations are more sensitive to heat-stress and have limited physical capacity to adapt, therefore highly vulnerable during a heatwave. In this report, we categorize vulnerability of the system in terms of social, ecological, technical, and institutional vulnerability to inland flooding.
- Hazard Exposure: The term exposure refers to the degree to which a system is exposed to a given hazard (e.g., sea-level rise). As an example, a coastal community in a low-lying area can be exposed to certain degree of hazard of inundation during a storm event. In this report, exposure to inland flooding is characterized by the flood maps and other similar datasets providing a probability of flooding in different regions. Hence the AT&T data is considered hazard exposure data for this analysis.
- Resilience: Ability of a system to plan and prepare for, absorb, recover from, and more successfully adapt to actual or potential adverse events (National Research Council 2012)

Exposure and vulnerability assessment of the municipalities/regions is used in this research to identify opportunities and priority areas to enhance system resilience. A key aspect of vulnerability assessment conducted in this report that differs from most vulnerability assessments in the infrastructure sector is the utilization of the SETS approach. “The SETS framework simultaneously allows for the interdisciplinary analysis of the (uneven) economic benefits of infrastructure development while thinking more carefully about the environmental and social impacts of infrastructure (Monstadt 2009) by expanding on the idea of *infrastructure ecosystems* (Pandit et al. 2015). The infrastructure community must acknowledge that the negative impacts of infrastructure, previously considered as externalities, have transitioned from being simply impacts on the environment, to increasingly being felt as *stresses on human systems*, including risk to life and property, increased maintenance and operations costs, declining service levels, and disruptions to social life. The community must also acknowledge that there are enormous opportunities for increasing planning and design effectiveness through a more integrated approach to reduce costs, decrease system down-time, and maximize co-benefits of joint systems operation and maintenance.” (Grabowski et al. 2017). **Figure 1** presents an overview of the SETS framework as evident in the literature:

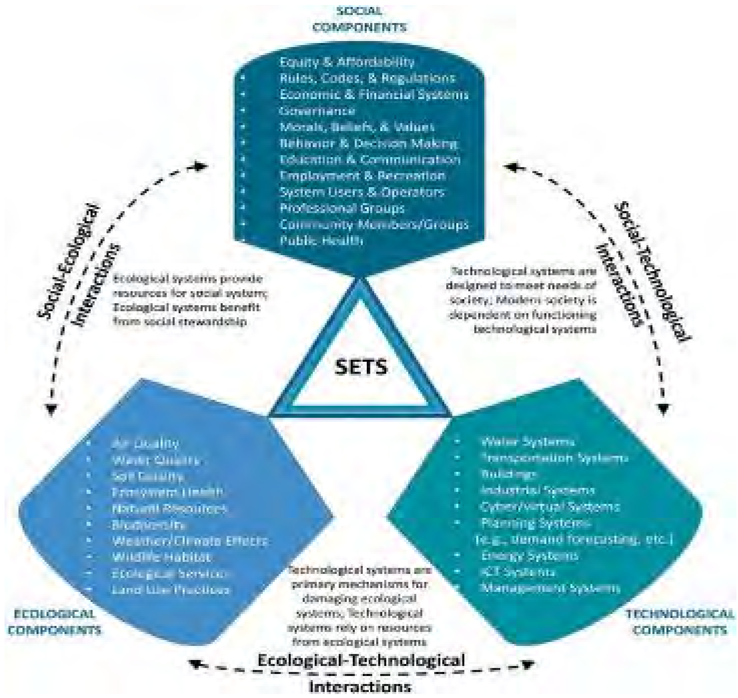


Figure 1: Overview of social, ecological, and technological components and interactions of infrastructure systems (Markolf et al. 2018)

In this report, we refer to the SETS model (Markolf et al. 2018) and its application to identify and categorize vulnerability indicators for flooding (Chang et al. In Review). We further enhance the framework by adding an institutional component to the vulnerability assessment, thereby working with the modified SETS approach, named the I-SETS approach. We also critically examine the variables from literature to identify the most suitable variables for this study.

Overview of Chapters

Chapter 2 presents the methodology and data used in this research. It describes the overall framework used to combine different aspects of the study to present the final results. As application of data from different sources is a key aspect of this study, a substantive discussion is presented in this section on the process of selecting various data sources, explanation of the meaning of the datasets as interpreted in literature and as applied in this research, and the process of data filtering used in the analysis in the subsequent sections. After an overview of the overall research framework, and a discussion of the data used in the study, the chapter further presents a detailed explanation of the methodologies of exposure analysis, vulnerability analysis, and risk analysis at the state and case-study levels. The exposure analysis presents the process of combining the AT&T data and other hazard exposure datasets to identify the most applicable flood exposure maps for the case study regions, in light of the changing climate. It uses the Topographic Wetness Index (TWI) as a surrogate measure for flood inundation potential and uses the available multiple exposure data sources to identify the appropriate TWI thresholds indicating flood exposure. The vulnerability analysis section presents the methodology used to assess the social, technical, ecological, and institutional vulnerability of the selected cities by applying the modified I-SETS approach. The section is divided into two separate vulnerability assessment sections – SETS vulnerability assessment, and Institutional vulnerability assessment. The first section follows the SETS methodology present in literature and applies it to the context of selected case studies. The institutional vulnerability section presents the process of modifying the SETS approach and conducting an assessment of the cities with respect to their institutional vulnerability to inland flooding. The next section covers the methodology of combining the exposure and vulnerability assessment to conduct a risk assessment of the case study cities. The discussed methodology is aimed at the scale of the selected case studies. Due to a much larger area, the same approach cannot be applied at the state level. However, an overview of inland flood risk at the state levels provides valuable inputs and understanding of the context of the challenges. Hence, the last section in this chapter presents the methodology for assessing inland flood risk for the state of Georgia.

Chapter 3 presents the findings of the assessments conducted as described in chapter 2. The chapter starts with the results of the overall statewide risk assessment, and then further presents the detailed findings of the four case studies. Prior to the discussion on individual case study results, an overview is presented explaining the format of the results, as well as some common findings on the different case studies. The chapter then leads to individual case study findings for Atlanta, Austell, Albany, and Carrollton. Each case study section presents an overview of the city, which leads to the institutional assessment of flood vulnerability. The section further presents the key results of the exposure, SETS vulnerability, and risk assessment of the city. The intermediate results emerging from the analysis for each case study are presented in the Appendix. After reviewing the assessment results for the case study, tailored recommendations are presented. The chapter ends with an overall conclusion and a discussion of future research.

Chapter 2: Research Methodology

Overall Methodology

The research takes a mixed-method approach to assess inland flood risk and resilience in the state of Georgia. A sequential-embedded research methodology **(Figure 2)** was applied.

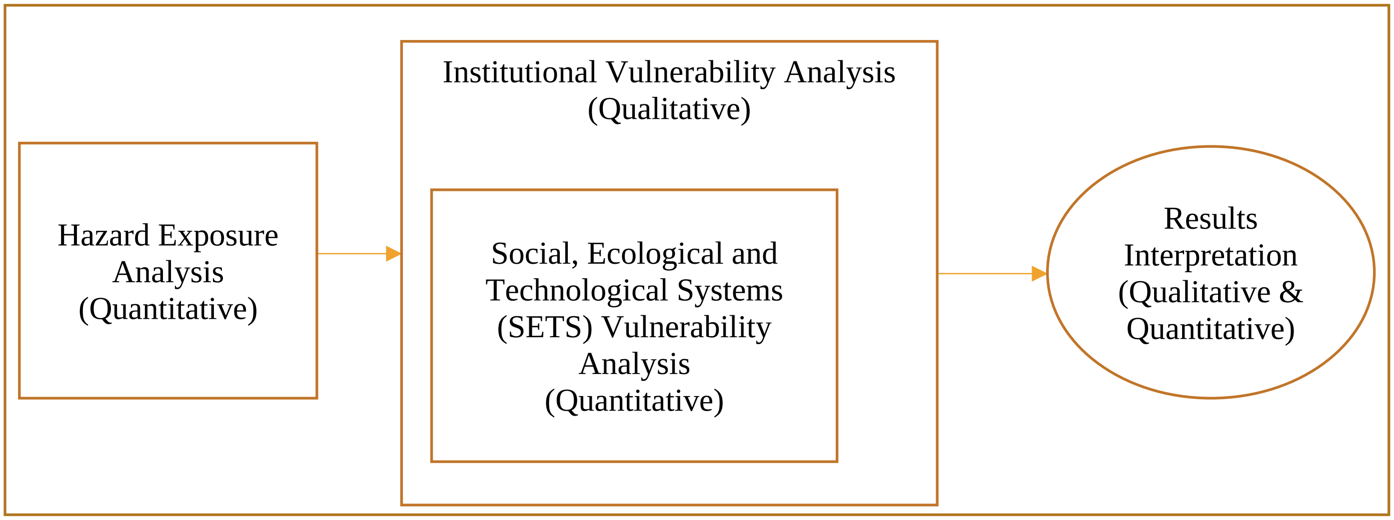


Figure 2: Research Design: Sequential-Embedded Mixed Method Approach

The quantitative portion of the methodology covers the flood exposure analysis - which includes reviewing exposure data from multiple sources, and application of statistical estimation methods to fill data gaps for a more robust exposure assessment. The quantitative portion of exposure analysis also assesses the changes in exposure over time using multiple datasets from different time periods. This is followed by an embedded approach for vulnerability assessment. The vulnerability assessment expands on the Social-Ecological-Technological Systems (SETS) approach developed by the Urban Resilience to Extremes (UREx) Sustainability Research Network (SRN). The SETS approach extends the traditional vulnerability assessment methods that focus on only one of the technical, ecological, or social capitals to an interdisciplinary approach. The SETS approach combines the three capitals to better represent the vulnerability of a city or other entity to any given threat. This research further expands on this approach by adding institutional capital as another important capital to be included in the vulnerability assessment of cities. Institutions refer to both formal and informal practices and customs including laws, policies and regulations. Within the embedded approach, the institutional analysis is qualitative, evaluating indicators of institutional strength and vulnerability that span across different levels of jurisdiction. The quantitative part of the embedded approach conducts the social-ecological-technical systems vulnerability analysis. The results from the quantitative exposure analysis, and the embedded vulnerability analysis are combined to present the risk analysis. The interpretations of the exposure analysis results also present the challenges of a risk-based approach dependent on a static exposure dataset and shed light on the need for a risk-to-resilience approach in planning, especially with the uncertainties associated with climate change in the future.

The research uses a case study approach for risk assessment. This provides leverage to the team for in-depth understanding of the threat exposure and vulnerabilities on a smaller scale. We conducted four case study assessments, where the subject cities differ on various aspects. A statewide risk analysis was also performed (see Chapter 3) to identify where inland flood vulnerability and exposure hot spots exist throughout the state. Using these results, past floods, and other quantitative and qualitative data available, we chose our four case studies. Carrollton was chosen because the AT&T model predicts there will be greater risk of flooding in the future in that area. Austell was also chosen for its high exposure to flooding. The city is near a conjunction of five area streams, and the Army Corps of Engineers have conducted multiple studies of the area, all of which suggest that the city needs to implement flood mitigation efforts. Additionally, Austell was devastated by the Catastrophic Flood of 2009, with thousands of properties being inundated and many locations experiencing 500-year flood levels. All of these reasons suggest that Austell should be studied further. Albany has also been exposed to severe flooding in the past, mainly due to its proximity to the Flint River, which makes it a good candidate for a case study. Atlanta, being the capital of Georgia and the largest city in the state, was chosen due to its size, influence, and the substantial amount of data available for flood risk exposure and vulnerability analysis.

Data

This section discusses the key datasets used in this research. We discuss the key challenges with the gaps and variability of data across the different disciplinary areas. This section also presents the rationale of using certain datasets and variables over others, in the assessments.

Exposure Data

Exposure is defined the degree to which system is exposed to a given hazard (reference?). In the context of cities, exposure is the presence of assets in places where they could be adversely affected (US Climate Resiliency Toolkit).

In the context of inland flooding in this research, we determine a region to be exposed to inland flood risk, if there is a probability that the region will get flooded in the event of extreme rainfall. The exposure is assessed in terms of the return periods of events. The regions that will get flooded in the event of a 100-year return period flood event are considered exposed to a 100-year flood risk. Return periods are generally used to describe extreme events in the risk and vulnerability literature. Although, a 100-year event does not indicate that an event of that intensity will only occur once every 100 years, it indicates there is a 1% chance of occurrence of the event every year. In order to reduce the confusion created by the nomenclature, we will be using the percentage probability of a flood event instead of the return period of a flood event, i.e., a 100 year-return period flood will be referred to as a 1%-probability flood event, a 50 year-return period flood and 500 year-return period flood events will be referred to as a 2% and a 0.2% probability event, respectively.

The data provided by AT&T for the project served as the base input data source. The 2% probability event (50 year-return period-high) data from the inland flooding dataset was used. The AT&T data provides the flood depth at different points in the region for different return period events. **Figure 2** presents a snippet of the AT&T dataset for a region in Carrollton. Some data gaps were observed in Metro-Atlanta region, and in some other regions in the study areas. To fill these gaps, and to understand the changes in the flood exposure over time, FEMA flood maps (1% and 0.2% probability events) were used. The FEMA maps primarily only provide information on the presence of floodplain over the region, but rarely provide complete information on the depth of flood inundation. **Figures 3** and **4** present snippets of the AT&T and

FEMA flood map data, respectively. While the AT&T data is new (2018) and provides more details, it is also sparse in some regions of the case studies, FEMA flood maps are available for all regions but provide less details and are relatively older (1976-2007).

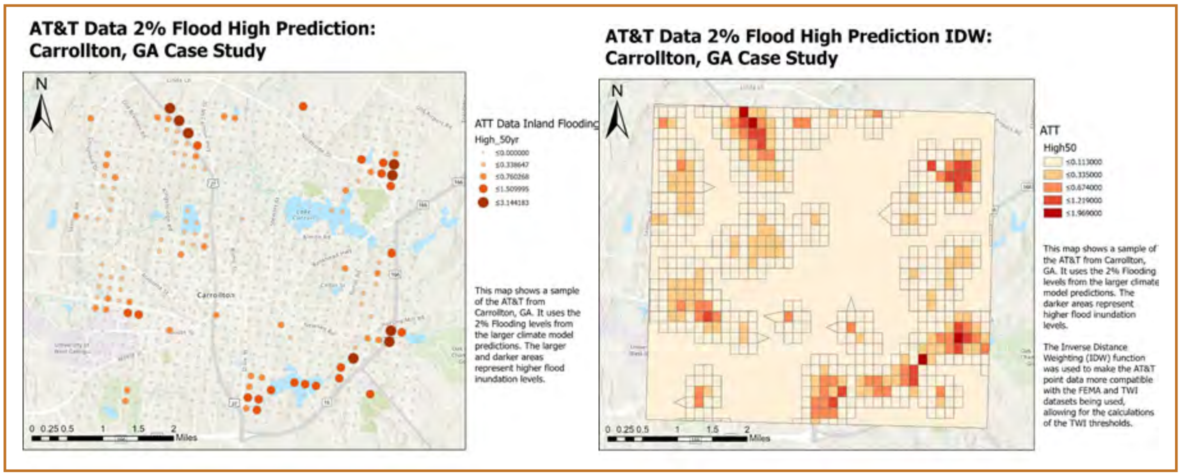


Figure 3: Example AT&T data for a spatial window in Carrollton

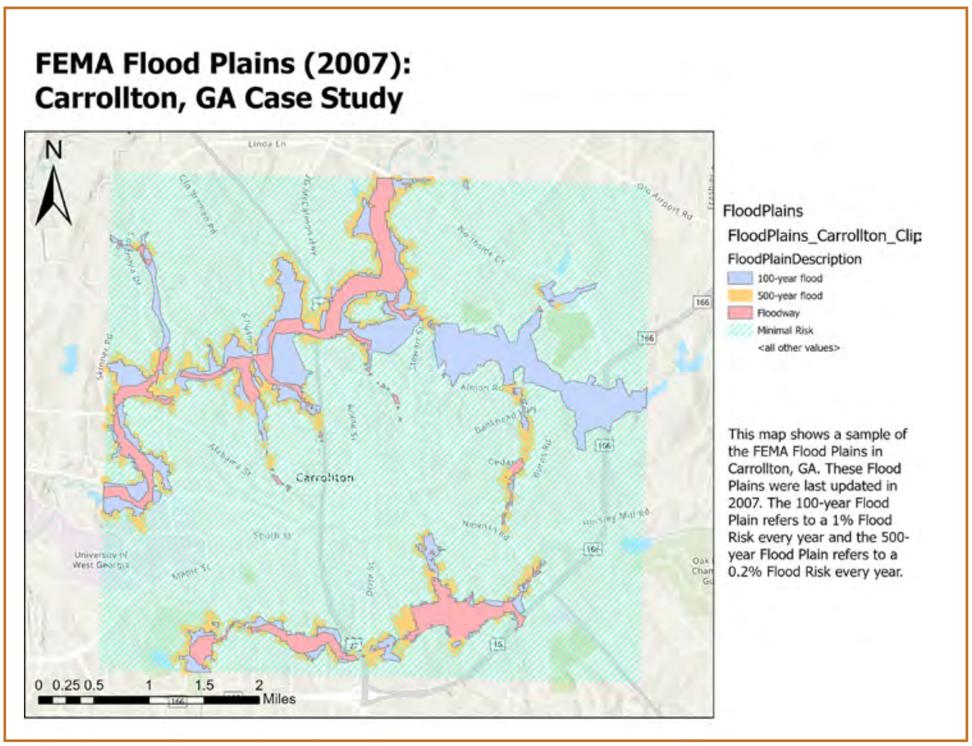
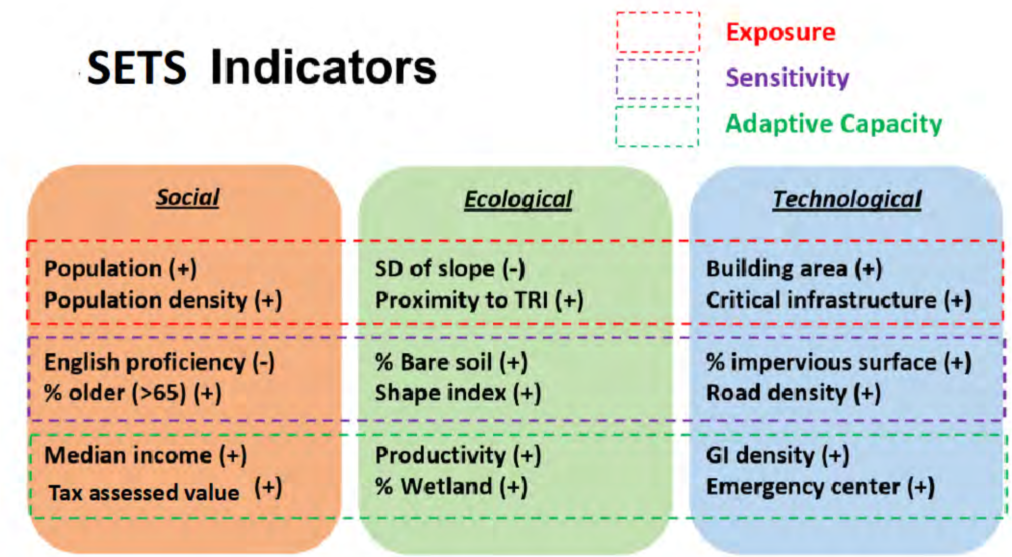


Figure 4: Example FEMA data for spatial window in Carrollton

As the FEMA data did not involve recent hydrologic and hydraulic updates, , and the AT&T data has gaps, we utilized Digital Elevation Modelling (DEM) to estimate potential flood exposure in the study areas (are we the first one who uses this approach? If not, I think we need proper referencing to justify our modeling choice.). The data was used to develop Topographical Wetness Index (TWI), which detects regions potentially exposed to flood inundation by identifying regions with a TWI higher than a given threshold (Jalayer et al., 2014). TWI is a purely topographical index presenting the capability of a region to accumulate water. The TWI threshold was calculated using prior information of flood zones identified using more accurate hydraulic calculations (FEMA and AT&T data) - for the areas where these datasets are available and provide an estimation of flood exposure in regions with data gaps. The DEM data obtained is from the US Geological Survey Interface. The data was last updated on 2020-03-19, and is of resolution of 1/3 arc second (approximately 10 m) (USGS, 2020).

Vulnerability Data

Vulnerability is generally defined as "the propensity or predisposition of assets to be adversely affected by hazards. Vulnerability encompasses exposure, sensitivity, potential impacts, and adaptive capacity" (US Climate Resiliency Toolkit). The SETS approach "considers that vulnerability consists of the exposure and sensitivity of a system/component/individual/group to a hazard or stressor (i.e., increased exposure and/or sensitivity to a stressor translate to increased vulnerability to that stressor)" (Markolf et al. 2018). The study by Markolf and others presents a list of indicators for the different categories as presented in **Figure 5.**



SD- Standard Deviation; GI- Green Infrastructure; TRI- Toxic Release Inventory

Figure 5: SETS Methodology Indicators (Chang et al. 2020)

This section reviews the Social, Ecological, and Technical variables from literature to identify the variables that best support the analysis of the Institutional-Social-Ecological-Technical Systems (I-SETS) model for vulnerability assessment. Institutional vulnerability is discussed separately given that the scale of its application is different than that of the SETS variables.

Social Vulnerability Data:

In applying the I-SETS methodology, our goal for the social portion was to determine the equity of inland flood exposure across various groups of people. Before finalizing the specific indicators for the social index, a few data sources were analyzed. First, the 2018 version of the Social Vulnerability Index (SVI), developed by the Center for Disease Control (CDC), was reviewed. The index combines 15 social factors, at the census tract or county level, categorized into four themes: Socioeconomic Status, Household Composition, Race/Ethnicity/Language, and Housing/Transportation. Each of the categories is then combined to create a total vulnerability score between 0 and 1, where 1 reflects the highest level of vulnerability for that county or census tract (CDC 2018). While the SVI is a valuable tool for an aggregate view of vulnerability, a more specific dataset can provide additional detail for flood vulnerability. The social index created by researchers in the UREx SRN (Markolf et al. 2018) was also considered, as shown in **Figure 5** above. The UREx researchers applied the index in a case study of Portland to the census block group scale (Chang et al., 2020). The approach is similar to the final index utilized in this research, but a few indicators were altered.

Multiple peer reviewed articles (Fahy et al. 2019, Chang et al. 2020, Rufat et al. 2015, and Gonzalez et al. 2020) were used to identify a portfolio of indicators which can be used to further filter indicators applicable for this study. The study by Gonzalez et al. (2020) surveyed an expert panel comprised of 15 geologists, engineers, geographers, and civil workers to determine weights for the indicators used. Population density was suggested to be weighted highest and percentage of elderly population was also in the top five of indicators by weight. Rufat et al. (2015) examined empirical studies pertaining to social vulnerability with flooding aiming "to identify and profile the leading drivers of social vulnerability to floods, with the underlying goal of strengthening the foundation for indicator development." In the demographic vulnerability drivers, elderly people were at the top of the list. Black and nonwhite populations were also toward the top of the list, suggesting race would be an important indicator to analyze. The socioeconomic vulnerability drivers featured both household income and no high school diploma in the top five. Aided by the findings of these studies, the final indicators chosen to comprise the social index we used are population density, median income, percent of people 65 and over, race, and percent of people with no high school diploma or limited English ability. Each individual indicator was then normalized and weighted equally to form the social component of the I-SETS model. One of the key criteria for choosing these indicators was to include at least one within each of the three categories developed by UREx: exposure, sensitivity, and adaptive capacity. **Table 1** presents the social vulnerability indicators used in this study and shows their distribution across the exposure, sensitivity and adaptive capacity categories. Five-year American Community Survey (ACS) estimates (2018 dataset) obtained from the U.S. Census Bureau's website were used for each indicator at the census block group level.

Table 1: Social Indicators for this Study's I-SETS Approach

Indicator Category	Indicator(s)
Exposure	• Population density
Sensitivity	• People 65 and Over • Race • No High School Diploma or Limited English Ability
Adaptive Capacity	• Median Income

Ecological Vulnerability Data:

The goal for the environmental portion of the I-SETS model was to classify the ecology of a region and determine vulnerability based on land composition. The Multi-Resolution Land Characteristics Consortium (MRLC) provides data for Land Use for Georgia at a 10m by 10m scale. This data supports the first ecological indicator we used: green space. Green space is defined differently across many research projects and across different disciplines (Qiang et.al., 2016). We used an ecological approach to defining green space and considered all land use categories that were light, medium, or heavily forested, or open space developed land to be green space and all other land use categories not to be green space. This procedure was also followed by researchers in the UREx network (Markolf et al. 2018) and is consistent with the green space calculation process used by Fahy et al. (2019) for Portland, Oregon.

The second indicator used was AB Soil Composition. Type A (e.g., clay, silty clay, sandy clay and clay loam) and Type B (e.g., angular gravel, silt, and silt loam) soils have higher infiltration rates and low runoff rates (Hydrologic Soil Groups), therefore regions with more Type A and Type B soils can absorb more water and reduce inland flood risk (it is not critical but a reference will be good here). Type C and Type D soil have lower infiltration rates and behave similarly to impervious surfaces (Hydrologic Soil Groups) (it is not critical but a reference will be good here). Therefore, our soil composition indicator determines the percentage of land covered by A and B soil types. This data was obtained from the National Resources Conservation Service (NRCS) and based off of a soil survey done in 2017.

Technical Vulnerability Data:

The technical portion of the I-SETS model attempts to characterize the human interactions that increase vulnerability to inland flooding. The indicators we have included in this study are Impervious Surface Percentage, Green Infrastructure Density and Building Data (Average Age of Building and Average Stories of Building). The fourth indicator we would have liked to include was Stormwater Infrastructure Density, but this data was unavailable as the City of Atlanta is currently rehauling the stormwater infrastructure and was unable to share the current data for this study.

Impervious surface percentage was found through the same source as green space: the Multi-Resolution Land Characteristics Consortium. This data was provided as a raster file with 10m by 10m resolution for all of Georgia. Impervious surface is an indicator for a similar reason as soil composition; higher percentages of impervious surface will result in more runoff, less infiltration, and a higher risk of inland flooding (it is not critical but a reference will be good here).

Green Infrastructure data was provided by the City of Atlanta's Department of Watershed Management (DWM). This data included all residential, commercial and city-owned green infrastructure projects in Atlanta. Green Infrastructure density was calculated to be the summation of all Green Infrastructure projects in a region divided by the area of such region. Higher Green Infrastructure regions are assumed to be more resilient to flooding due to the increase of absorbance capabilities provided by these projects, enhancing adaptive capacity (it is not critical but a reference will be good here). Building data was found through Fulton

County's GIS program. The City of Atlanta tracks building footprints throughout the city, including the year buildings are built and the number of stories in each building. In general, older buildings and buildings with less stories are hypothesized to be more susceptible to inland flooding damages. Older buildings are assumed to be built to older codes with less flood preventative measures as well as past damage that weakens the structure, increasing susceptibility, especially for buildings in relatively flat regions, or in low-lying regions. Buildings with more stories have the capability to allow for movement of contents to higher floors, putting the residents' possessions and persons in less danger in the case of an inland flood (it is not critical but a reference will be good here).

Methodology: Exposure Analysis

As the AT&T dataset and the FEMA dataset varied in format and did not overlap, a common format of exposure data was needed to compare and evaluate the flood exposure. TWI is used as a measure to present the flood exposure. TWI thresholds are calculated corresponding to the FEMA 1% and 0.2% probability events (2007 data), and the AT&T 2% probability flood event (2018 data). Exposure maps are developed using the TWI thresholds corresponding to the three % probability events, and the variations are assessed in the light of climate change and increasing flood risk over time.

The TWI threshold value depends on the resolution of the DEM, topology of the hydrographic basin and the constructed infrastructure. To calculate the TWI threshold, we employ a maximum likelihood estimation (MLE) based on inundation profiles provided by the various flood maps (FEMA and AT&T) for a specific spatial window of City of Carrollton. The specific spatial window is selected as the FEMA and AT&T datasets are relatively more comprehensive in the spatial window. Furthermore, the TWI threshold is calibrated using Bayesian Parameter Estimation based on inundation profiles calculated for more than one spatial window from other case study regions. The methodology of MLE and Bayesian Parameter estimation is adopted from Jalayer et al. (2014). The various MLE statistics of TWI (1% (2007) probability event, 0.2% (2007) probability event, and 2% (2018) probability event) are used to generate the maps of case studies with potential flood exposure based on the respective TWI thresholds, averaged over each census block. The process of TWI calculation, and TWI threshold estimation is presented below.

TWI Calculation

TWI has been shown to have a strong correlation with flood inundation, and is frequently used for initial screening of flood risk (Jalayer et al., 2014, Manfreda et al. 2007, 2008, 2011). TWI was initially introduced by Kirkby (1975), and can be calculated for a given point O within the hydrographic basin by:

$$TWI = \log\left(\frac{A_S}{\tan\beta}\right) \qquad \ldots\text{Eq 1}$$

where A_s is the specific catchment area expressed in meters, calculated as the local up-slope area draining through point *O* per unit contour length (*A*/*L*), and β is the local slope at the point in question expressed in degrees. **Figure 6** illustrates the main components used for the calculation of the TWI at a given point *O* within the hydrographic basin, namely the catchment area *A* for point *O*, the length *L* of the contour line and the specific catchment area A_s (Jalayer et al., 2014).

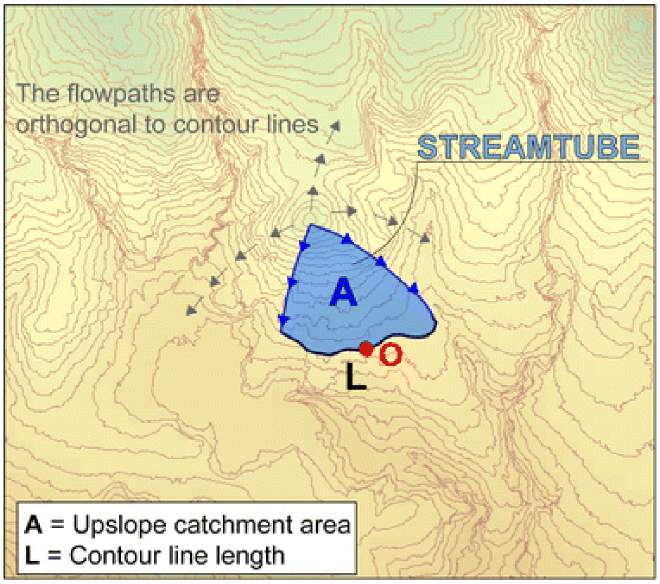


Figure 6: Main components of TWI calculation (Jalayer et al., 2014)

The calculation is done with ArcGIS using the standard procedure used in multiple peer-reviewed journal publications in the literature. The process is explained by Mattivi et al. (2019), and a guided tutorial by Geo Tech (2019) presents step by step guidance that is followed in this report.

Maximum Likelihood Estimation of TWI threshold using one spatial widow

Maximum likelihood parameter estimation is used to probabilistically calibrate the TWI threshold based on inundation profile information from various sources (of various % probability events) for a selected zone of interest within our case study areas.

Are the following descriptions and Equations 2-8 taken or adapted from a source in the literature? If yes, proper referencing needs to be followed. Description can be reduced if the equations and the related descriptions can be found somewhere else.

Let *W* represent the spatial window of a zone of interest (within the basin), where we have existing flood exposure data. For a specific TWI threshold T, any region with TWI higher than T is considered flood prone (represented by FP). All areas with TWI lower than T are considered not flood prone (NFP). Any areas that fall under the flood maps provided by FEMA and AT&T are considered inundated for the given event. Let IN(%pr) represent the areas inundated during an event of %pr probability. All areas that do not fall under the flood maps can be considered not inundated for a given % probability event (NIN(%pr)).

Figure 7 illustrates, in a schematic manner, spatial window *W* and the extents identified as FP and IN(%pr) **(Figure 7a),** and NFP and NIN(%pr)**(Figure 7b).**

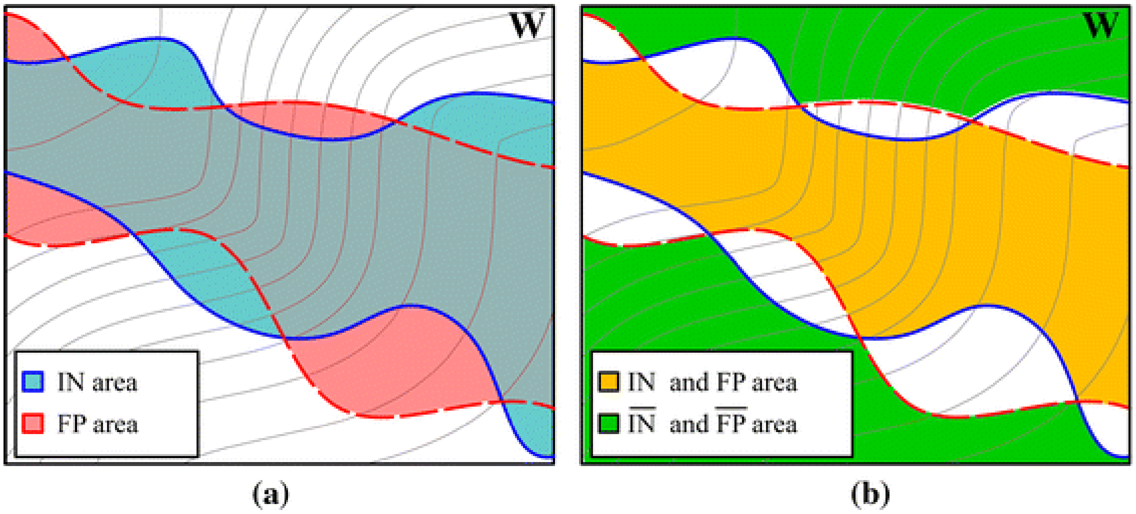


Figure 7: FP and IN areas (Figure a); NFP and NIN(%pr) areas (Figure b). IN and NIN areas for a given %pr event.

The likelihood function for TWI threshold (T) is the probability of the correct delineation of the flood prone areas for various values of T. The following formula presents the likelihood function (L(T|W)).

$$L(T|W) = P(FP, IN(\%pr)|T, W) + P(NFP, NIN(\%pr)|T, W) \quad \text{.......Eq 2}$$

where, L(T|W) is the likelihood function of TWI threshold T, for a given spatial window W, P(FP,IN(%pr)|T,W) is the probability that a given point within the zone W is both flood prone (TWI>T), and inundated (within the flood map for a given %pr event) and conditioned on a given value of T of the TWI threshold. The areas identified as both FP and IN(%pr) are indicated by the color orange in **Figure 7(b).** Similarly, P(NFP,NIN(%pr)|T,W) is the probability that a given point within the zone W is both, not flood prone (TWI<T), and not inundated (not in the flood map for a given %pr event), conditioned for a given value of T of the TWI threshold. These regions are indicated in the color green in **figure 7(b).**

The terms in equation 2 can be expanded using the product rule of probability theory as follows:

$$P(FP, IN(\%pr)|T, W) = P(FP|T, W) \times P(IN(\%pr)|FP, T, W) \quad \text{.....Eq 3}$$

$$P(NFP, NIN(\%pr)|T, W) = P(NFP|T, W) \times P(NIN(\%pr)|NFP, T, W) \quad \text{...Eq 4}$$

where the term P(IN(%pr)|FP, T, W) denotes the probability of being IN(%pr) given that it is identified as FP and P(NIN(%pr)| NFP,T,W) denotes the probability of not being inundated (NIN(%pr) conditioned on not being flood prone(NFP), given the threshold value T. The terms P(FP|T, W) and P(NFP|T,W) represent the probability of being FP or not being FP, respectively, given the TWI threshold value T.

We consider a small area in the City of Carrollton as the spatial extent (W) for TWI threshold estimation. The region is selected based on the availability of data from FEMA and AT&T. **Figure 8** shows the spatial extent used for this analysis.

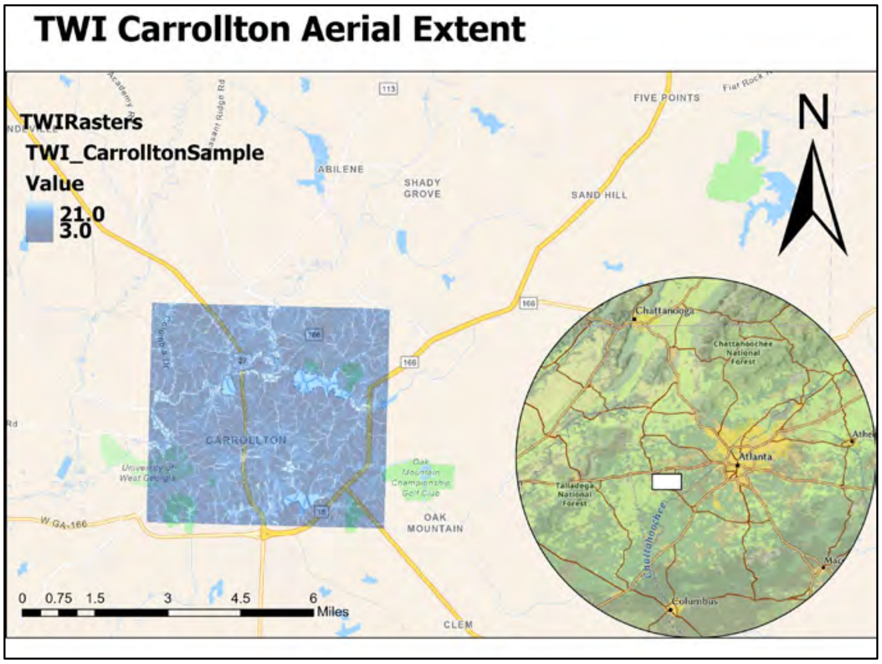


Figure 8: Spatial window (W1) used for MLE estimation of TWI threshold from Carrollton

Let A_W(FP) denote the areal extent of the flood-prone portion of the zone W identified via the TWI method (i.e., the extent of the portion colored as red in Fig. 7a). A_W(IN($\%pr$)) is the areal extent of the inundated portion of W, identified via existing flood exposure information from FEMA/ATT, for a given % probability (i.e. the extent of the portion colored as blue in Fig. 7a). Analogously, A_W(NFP) and A_W(NIN(%pr)) refer to the areas of the not flood-prone and not inundated portions, respectively. The probability terms $P(IN(\%pr)|FP, T, W)$ and $P(NIN(\%pr)|NFP, T, W)$ can be estimated by the ratio of areal extents, as expressed in the following:

$$P(IN(\%pr)|FP, T, W) = \frac{A_W(IN(\%pr), FP)}{A_W(FP)} \qquad \text{....Eq 5}$$

$$P(NIN(\%pr)|NFP, T, W) = \frac{A_W(NIN(\%pr), NFP)}{A_W(NFP)} \qquad \text{....Eq 6}$$

where A_W(IN($\%pr$), FP) denotes the areal extent of the portion of the area W that is both FP and IN(T_R) (i.e. the extent of the area colored as orange in Fig. 2b); A_W(NIN(%pr), NFP) denotes the areal extent of the portion of the area W that is neither FP nor IN(%pr) (i.e. the extent of the area colored in green in Fig .2b). As mentioned above, the areal extents A_W(IN(%pr), FP), A_W(NIN(%pr),NFP), A_W(FP) and A_W(NFP) are—by definition—all functions of the TWI threshold T.

The remaining two terms in the equation 3 and 4 can be estimated using the following two formulas:

$$P(FP|T) = \frac{A_W(FP)}{A_W} \qquad \text{...Eq 7}$$

$$P(NFP|T) = \frac{A_W(NFP)}{A_W} \qquad \text{...Eq 8}$$

The value of P(NFP|T) can also be calculated as a complement of the value of P(FP|T).

Finally, the likelihood function in Eq. 1 can be calculated by substituting the terms calculated in Eqs. 5, 6, 7 and 8 in Eqs. 3 and 4 and summing up these two last equations. The maximum likelihood estimate for the TWI threshold can then be calculated as the *T* value that maximizes the likelihood function in Eq. 2.

We calculate the TWI threshold values corresponding to 0.2% & 1% flood probability event data from FEMA (2007 data) and corresponding to 2% flood probability event from AT&T (2018 data). These threshold values correspond to the selected spatial window in the Carrollton study area.

Figure 9 presents the TWI map of Carrollton and the spatial window used for the TWI threshold calculation.

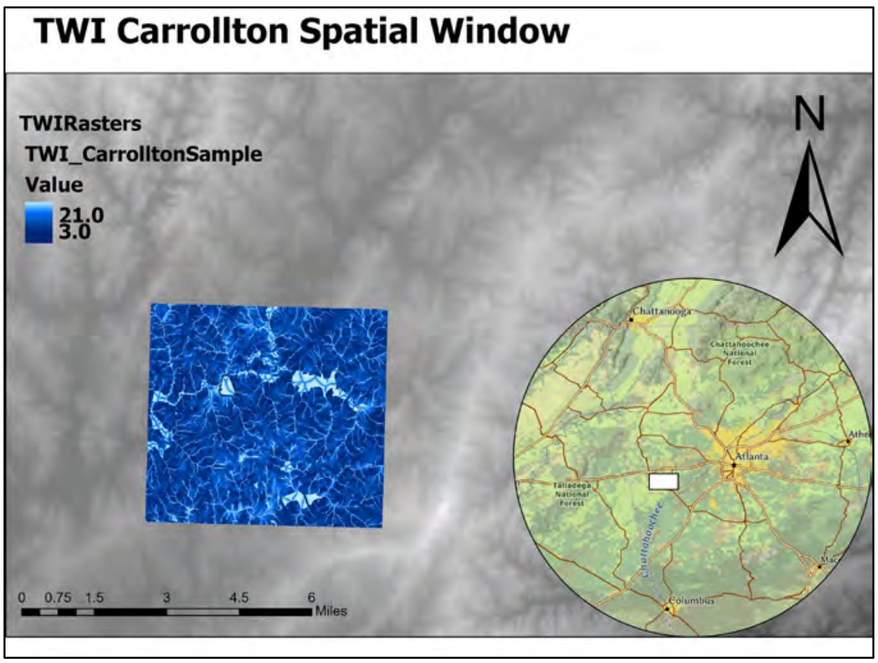


Figure 9: TWI map of Carrollton, and the selected spatial window (W) for analysis

The spatial window in **Figure 9** can be presented by W, with an area A(W). For all values of T, the probability of a given zone being flood prone is calculated as (P(FP|T) using Eq. 7, and plotted in **Figure 10** with black dots.

For a 1% probability event (100 year-return period), as identified by the FEMA flood map from 2007, the probability that a given point is inundated given that it is already indicated as flood prone (P(IN(1%)|FP,T,W1) for a given value of T is calculated using Eq. 5, and plotted in **Figure 10** with grey boxes. The probability that a point is both, flood prone based on TWI value, and inundated according to FEMA flood map for a given T is calculated using Eq. 3, and plotted in **Figure 10** with red dots. In a similar manner, the probability that a given point is not indicated as flood prone (based on the TWI method) is calculated as the complementary probability of being flood prone and plotted in **Figure 11** (as the black dots). The probability that a given zone is not indicated as inundated given that it is not flood prone, for a given value of T, is calculated using Eq. 6 and is plotted as the blue stars in **Figure 11**. Finally, the probability that a given point is not inundated and not flood prone, for a given value of T, is calculated using Eq. 4 and plotted as the red circles in **Figure 11**.

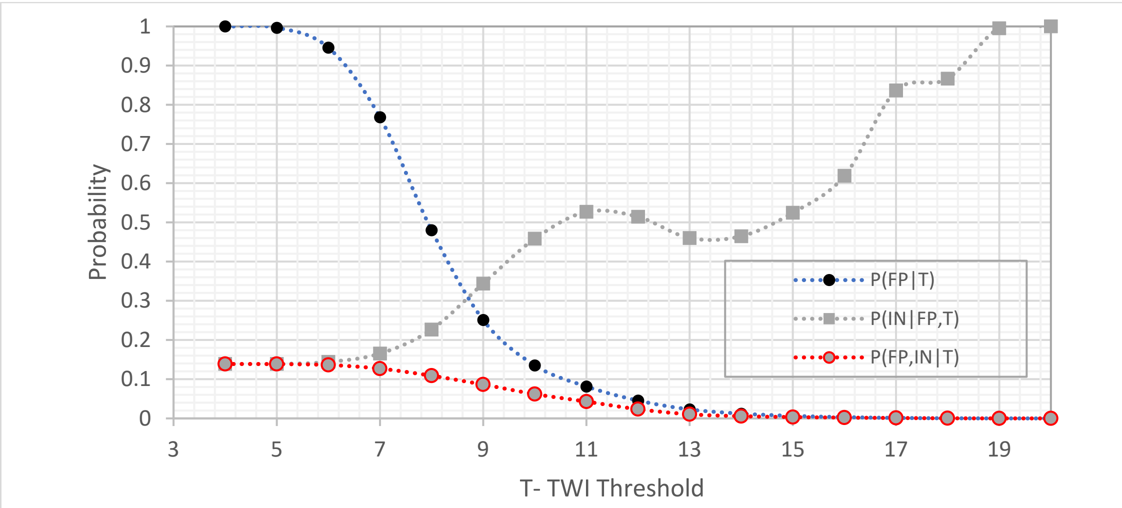


Figure 10: Probability results of equation 7, 5, and 3 for a 1%probability event based on FEMA (2007 data)

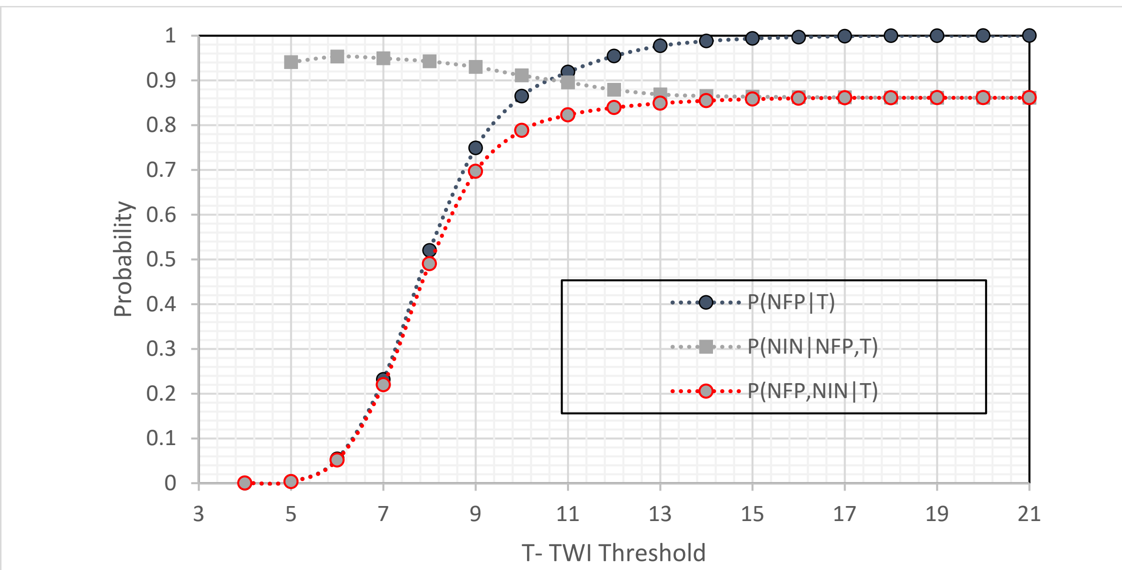


Figure 11: Probability results of equation 8, 6, and 4 for a 1%probability event based on FEMA (2007 data)

The likelihood function for threshold T (at $\%pr = 1\%$) is finally calculated from Eq. 2 by summing up the probability of being flood prone and inundated and the probability of not being flood prone and not being inundated, for all possible T values (i.e. summing up the curves illustrated by red circles in Figs. 8 & 9).

The maximum likelihood parameter estimation for T is identified as the T value corresponding to the maximum likelihood value.

The entire process is repeated with flood inundation information for 0.2% probability event (500 year return period) data provided by FEMA flood maps (2007 data), and for 2% probability event (50 year return period) data provided by AT&T (2018 data).

Table 2 presents the TWI thresholds calculated using the given methodology for the spatial window W1 in Carrollton, for 0.2% (2007 data), 1% (2007 data), and 2% (2018 data) probability events.

Bayesian estimation of TWI threshold using information from more than one spatial window

Jalayer et al. (2014) presented a method to further calibrate TWI threshold if prior information is present for multiple spatial windows. Suppose that some background information is available on the value of the TWI threshold T. In that case, the maximum likelihood method (MLE) presented in the previous section can be extended to a Bayesian parameter estimation, where the available background information is represented by a *prior* probability distribution. That is, the *posterior* probability distribution for T given the information provided by the inundation profile within the spatial window *W* can be expressed as:

$$p(T|W) = \frac{L(T|W)p(T)}{\sum_{\forall T} L(T|W)p(T)} \quad \text{.... Eq 9}$$

where $p(T|W)$ denotes the posterior probability distribution for *T* given spatial window *W*; $L(T|W)$ is the likelihood function for T calculated in the previous section, and $p(T)$ is the prior probability distribution for T (before having the information on the inundation profile for window *W*). Note that Eq. 9 is particularly useful for calculating the threshold T having information about the flooding extent for more than one spatial window within the basin. In that case, the posterior probability $p(T|W_1)$ can be used as prior probability distribution in order to calculate the posterior probability distribution $p(T|W_1, W_2)$, considering both spatial windows W_1 and W_2 (Jalayer et al. 2014).

We first calculate the posterior probability p(T|W1) for the spatial window from Carrollton region, considering the prior probability distribution to be uniform. We then use this p(T|W1) as prior probability to calculate the posterior probability of another spatial window (W2) in Gordon County (p(T|W2,W1). The T value corresponding to the maximum value of this posterior probability function is the TWI estimate from the second spatial window. This threshold estimation is done for all the three % probability events.
Table 2 presents the TWI thresholds calculated using the posterior probability function for likelihood estimation for W2 spatial window.

To estimate the flood exposure of all the case study regions with data gaps, an average of the two values of TWI threshold for each % probability event is calculated and presented in **Table 2.**

Table 1: TWI thresholds calculated using MLE and Bayesian Estimation methods

%Pr Event (return period)	0.2% (500-yr return period) | 2007 data	1% (100-yr return period) | 2007 data	2% (50 yr return period) | 2018 data
TWI Threshold (T) – W1	10	11	8
TWI Threshold (T) – W2 (considering W1 as prior)	9	11	8
Average TWI Threshold (Ta)	**9.5**	**11**	**8**

Discussion

As TWI represents flood risk, generally an expected trend for the thresholds is an increasing value of threshold for higher probability event (lower return period). For data from the same year, the TWI threshold for a 1% event (100-yr return period) will be higher than the threshold for a 0.2% event (500-yr return period), indicating that as we move farther from the river channels (lower TWI values), the probability of getting inundated decreases (1% to 0.2%). This is evident in the FEMA 2007 datasets for 1% and 0.2% events. The TWI thresholds for a 0.2% probability exposure are lower than that for a 1% probability exposure. This indicates that according to the 2007 FEMA flood maps, a smaller area has a 1% chance of flooding (higher TWI threshold), and a larger area has a 0.2% probability of getting flooded.

We observe an opposite trend with the AT&T dataset. The expected trend would be a higher TWI threshold for a 2% probability event (50-year return period) than that for a 1% or 0.2% probability event (100 or 500 year return period events). But we observe that the TWI threshold for a 2% probability event according to AT&T data is lower than both 1% and 0.2% events based on FEMA data. This indicates that per 2018 data, a much bigger region has a 2% chance of flooding than what the FEMA flood maps indicate to have less than a 0.2% chance of flooding. This increase in the flooding chances, indicating an increase in the spread of flood zones can be attributed to two main reasons:

Changes in floodplain and land use over last decade: As the FEMA data is from the year 2007, the historical data used for generating those flood maps dates older than at least a decade. In that time period, land use patterns have changed significantly, thus altering the elevation profile of the regions. As land use and elevation profiles are key in forming watersheds, identifying water discharge channels, and consequently generating flood maps, the changes in land use can significantly alter the flood maps.

Climate Change considerations: Over the past few decades, climate change has presented significant variability in rainfall patterns in comparison with the expected trends. The older versions of FEMA data do not account for climate change, and extrapolate the rainfall trends to identify future predictions. On the other hand, the AT&T data uses multiple climate change models along with historic rainfall data. Most of the current climate models indicate a significant rise in greenhouse gases (GHG), and an increase in extreme rainfall. This could indicate why according to the AT&T data, a much larger area is under a higher (2%) chance of flooding than what was anticipated based on the FEMA flood maps.

Methodology- Vulnerability Analysis

The SETS Vulnerability Methodology allows for the characterization and analysis of social, ecological, and technical indicators. However, we noticed that in our research, an overarching category of vulnerability was affecting inland flood resilience. The local, state, and national institutions in place have important roles and can drastically affect social, technical, and environmental vulnerability. Institutional vulnerability may influence the other vulnerability indicators and generally occurs at a larger scale, so we chose to add institutional vulnerability using a different methodology than the other vulnerability categories.

Institutional vulnerability is more appropriately characterized at the community scale. Therefore, we created an institutional assessment framework and conducted a qualitative analysis of each city to understand the institutional vulnerabilities faced at the city level. After conducting the qualitative, city-wide institutional vulnerability analysis, the SETS vulnerability assessment was performed. The SETS vulnerability assessment is more quantitative, comparing inland flood risk at the census block level.

Once both assessments are complete, the results can be interpreted by combining the qualitative and quantitative results. For example, a city that is highly vulnerable from the SETS analysis perspective and has a relatively undeveloped institutional framework will need more assistance than a city that is highly vulnerable based on the SETS analysis and has a relatively well established institutional framework. Both methods contribute to a mixed-methodology approach explained in the succeeding sections.

Institutional Assessment Methodology

Overview

Floodplain development policies and decisions affect the overall exposure of communities and their civil infrastructure assets to extreme events, particularly flooding. Federal policy, regulations, and guidance, as well as good engineering judgment regarding the location of facilities and infrastructure and their design in floodplains contribute to the frequency, nature and degree to which communities and their infrastructure assets experience flooding over their lifetimes. Federal floodplain policy provides the broad goals and limitations within which the U.S. conducts scientific, planning and engineering activities. Relevant statutes, regulations, executive orders and guidance shape federal floodplain policy (FHWA 2016). **Appendix B** presents a detailed overview of institutions at the federal level.

With fifty states – each with different policies and priorities – explaining state-level floodplain institutions in America’s federal system is necessarily complex. This complexity is clear to see in our assessment of institutions and resilience in four very different municipalities in the State of Georgia. The City of Atlanta is the state’s most populous city and the anchor of an expansive metropolitan area. The City of Albany is a medium-sized municipality, while the cities of Carrollton and Austell are smaller municipalities. Since our case study municipalities are all located in the State of Georgia, it is important to point out that, because of historical and regional differences, the state’s floodplain management system should not be construed as identical or similar those in other states.

The Constitution of the State of Georgia states that "government is instituted for the protection, security, and benefit of the people." Protecting the people and property of Georgia against all manner of threat – including floods – is, therefore, a fundamental responsibility of state government. But the Constitution goes on to state that the responsibility for adopting specific regulations to promote the public health, safety, and general welfare of the local citizenry is delegated to local governmental unit. Essentially, a range of different flood control-related approaches and priorities operate in counties and municipalities across the state. Our study reflects that a municipality's size and level of threat matters greatly when it comes to human and budgetary resources devoted to floodplain management.

To receive funds under the federal government's Hazard Grant Mitigation Program, each local jurisdiction in Georgia (and all other states) is required to adopt a Hazard Mitigation Plan. The Plan must secure approval by the Georgia State Department of Natural Resources as well as FEMA. In addition, each jurisdiction must participate in – and be in good standing with – the National Flood Insurance Program. Thanks to this federal regulation, each of Georgia local jurisdictions produce hazard mitigation plans.

Although the NFIP's Community Rating System (CRS) is a federal institution, participation is voluntary. This means that the decision to participate is *local*, and some 57 Georgia municipalities have elected to participate. As noted earlier, the CRS incentivizes local authorities to implement floodplain management activities that exceed the NFIP's minimum standards. Participating communities are awarded points for activities in four areas – public information, mapping and regulations, flood damage reduction, and warning and response. The scores are categorized in a 9-to-1 point-scale, which determines a community's CRS class. A community in the CRS Class 9 qualifies for a five-percent premium reduction of the Special Flood Hazard Area insurance, while a CRS Class 1 community receives a 45 percent premium reduction. Three of our four municipal case studies – Atlanta, Albany, and Austell – participate in the CRS, and each received a CRS Class 7 rating in 2020. This qualifies these communities for a 15 percent premium discount for building in Special Flood Hazard Areas (SFHA) and a five percent discount for structures in non-SFHA. Carrollton does not participate in the CRS.

Institutional Assessment Approach

The institutional assessment approach aims to understand policies, regulations and informal practices in place to address inland flooding in municipalities and cross jurisdictionally, in the context of the changing climate and broader development goals. **Figure 12** depicts the conceptual framework for assessing institutional resilience developed from our study of inland flooding threat in this era of climate change and institutions in a range of cities through a Social-Ecological-Technical systems (SETS) lens. Cities at higher maturity levels of inland flood resiliency will have more policies, regulations and informal practices in place to enable them to prepare for, withstand, rapidly recover from and continue to adapt to the threat of flooding. **Table 3** presents practical questions that and facilitate the development of institutions to foster maturity in inland flood resilience assembled to support municipal agencies tackle inland flooding under climate change. These questions were applied to assess the institutional resilience of our four case study municipalities to inland flooding.

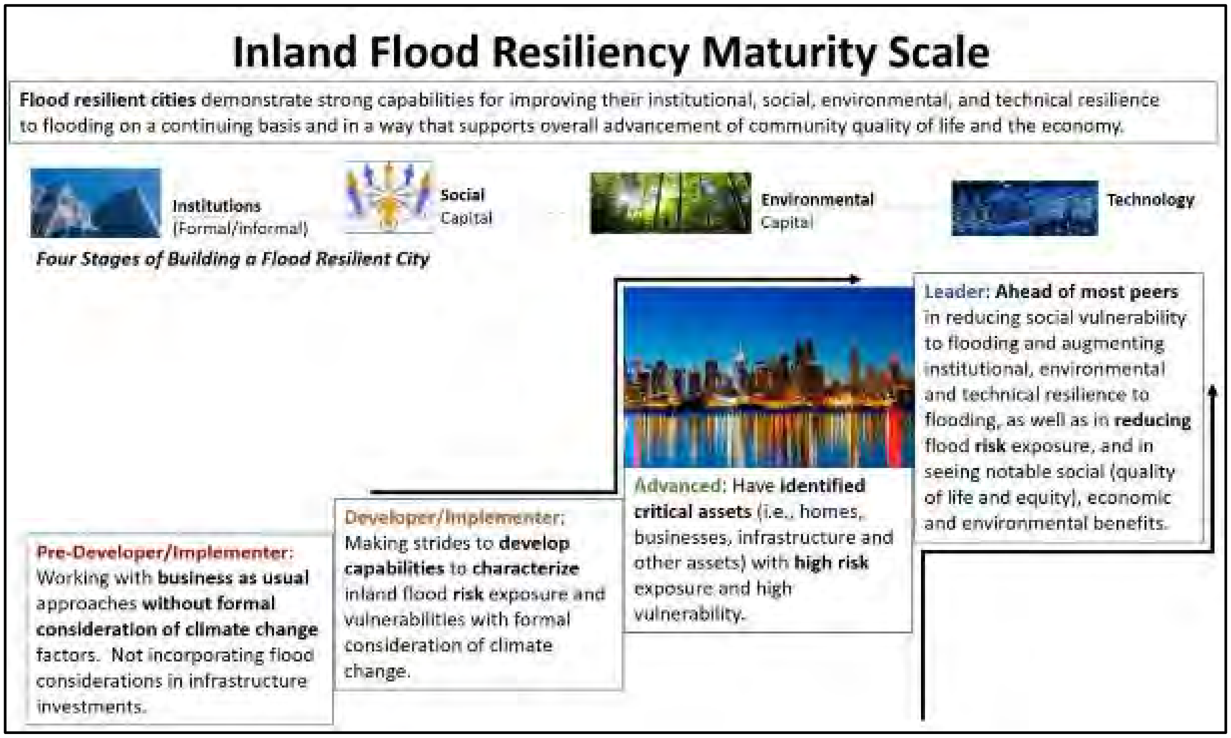


Figure 12: Inland Flood Resiliency Maturity Scale

Table 3: Indicators of Institutional Resilience to Inland Flooding under Climate Change

Measures of Performance (Categories)	Measures of Impact/Performance
Inputs	1. Does the City participate in the Community Rating System (CRS) of the National Flood Insurance Program? 2. Is there any government or other agency with responsibilities for floodplain management? Which agency? (I) 3. Does the agency formally include considerations of climate change in their decision making? (I) 4. Does the agency have a formal floodplain management plan/system? (I) 5. Does the agency's floodplain management/system include formal considerations of climate change? (I)
Process	6. Does the agency include climate-related flood risk as a criterion in resource allocation? (I, T) 7. Does the agency have informal or formal inter-jurisdictional/ multi-jurisdictional institutions to support floodplain management where the factors influencing flooding lie beyond the municipality boundaries? (I, S) 8. Does the agency have plans for improving the traditional stormwater infrastructure system to accommodate for increased inland flooding risk? (I, T) 9. Do the agency's land use regulations include regulations to address vegetative cover? (I, E) 10. Do the agency's zoning ordinances include rules on development in the floodplain? (I, S)

	11. Does the agency include green infrastructure treatments to complement the expansion of traditional stormwater infrastructure? (E, T) 12. Does the agency include public awareness/information campaigns as part of its strategy for addressing inland flooding risk? (I, S, T)
Outputs	13. Can the agency show expenditures for climate-resilience-related interventions to curb inland flooding risk? (S=Public awareness, E=Vegetative Cover, T=Green Infrastructure, Storm Water Infrastructure, T=Data, Tools, Other Capabilities to enhance inland flood resilience)?
Outcomes	14. Can the agency show a reduction in # of homes and businesses and percentage of critical infrastructure in floodplain over time? 15. Can the agency show a reduction in inland-flood-related damage over time? 16. Can the agency show enhanced public awareness of climate-related inland flooding risk over time? 17. Can the agency show expanded traditional stormwater infrastructure, over time? 18. Can the agency show expanded green infrastructure assets, over time? 19. Can the agency show expanded technical capabilities for addressing inland flood risk, over time? 20. Can the agency show new and pertinent regulations for addressing inland flood risk, over time? 21. Can the agency show *influence* in the development of new and pertinent regulations, policies and laws at the local, state and/or federal level for addressing inland flood risk, over time? (Leadership)

I: Institutional | S: Social | E: Ecological| T: Technical

SETS Vulnerability Assessment Methodology

To demonstrate assessment of vulnerability on social, ecological, and technical fronts, a case-study-based approach was used as discussed in the overall methodology. This section presents the step-by-step description of the approach used for the vulnerability assessment, and its relationship with the exposure analysis.

Step 1: Case Study Selection
Case studies were selected from the results of the Statewide Risk-Analysis results. The methodology of state-wide risk assessment is presented in the next section. The Statewide analysis results showed that Austell, City of Atlanta, and Albany were all in high exposure and high vulnerability regions. However, Austell and the City of Atlanta did not have AT&T data, so Carrollton was added as a case study due to its medium exposure and vulnerability, but extensive AT&T data coverage.

Step 2: Indicator, Hazard and Scale of Analysis Selection
For each case study, data was obtained at various scales and resolutions as discussed previously in the data section of the report. The next step of analysis was to determine the scales of analysis for each case study and available data. Every case study was performed at the Census Block scale and Census Block Group scale. Also, the same indicators were used for every analysis except for the City of Atlanta. For Atlanta, the study was conducted at the Census Block Group level due to more data being available at the Census Block Group level for the City.

Step 3: Mapping and Hot Spot Analysis
For each case study Hot Spot maps were generated for the identified vulnerability indicators and the TWI exposure data. These maps provide an initial visualization of the Social, Ecological and Technical Vulnerability landscapes of each city, as well as the clustering of TWI exposures. These results aided with the qualitative portions of the analysis, as well as with confirming the results of the quantitative analysis. The Hot Spot maps are generated using the ArcGIS Hot Spot Analysis (Getis-Ord Gi*) function with a fixed distance band and the Euclidean distance method. Mapping and Hot Spot Analysis Case Study Results may be found in Appendix A.

Step 4: Indicator-Indicator and Indicator-Hazard Correlations
Correlations were run through Python using Python's built in Pearson Correlation Coefficient. Correlation significance above $\alpha = 0.05$ were dismissed as insignificant correlations. Correlations were then confirmed using ArcGIS's Explanatory Regressions tool with TWI as the dependent variable. These results helped the qualitative portions of our report by understanding the interconnectivity of the indicators being used in our study. Also, the correlations of the indicators to the hazard data (TWI) furthered the qualitative results by understanding the indicators that potentially had a greater impact on vulnerability. Python correlations and Exploratory Regression correlations may be found in Appendix A.

Step 5: Generating Vulnerability Index
The Vulnerability Index was generated using the data used in the report and a separation of the three categories: Social, Ecological, and Technical Indicators. For each category, an indicator was marked as 'vulnerable' if it was in the top 25th percentile of vulnerability following the method by Chang et al. (2020). Each region in the case study was then generalized by the number of indicators where it was marked as 'vulnerable'. For example, if a Census Block Group was marked in the top 25th percentile for 3 out of the 5 social vulnerability indicators, it would be given a social vulnerability score of 3/5. Any rationale for using this ratio approach?

From the Vulnerability Index, Hot Spots were created using ArcGIS Hot Spot Analysis (Getis-Ord Gi*) function with a fixed distance band and the Euclidean distance method. Maps were created for Social, Ecological, and Technical Vulnerabilities. These maps represent the results of the Vulnerability Analysis. The Vulnerability Index values were used in the subsequent section of the report to generate the Risk-Analysis results by combining the Vulnerability Index values with the TWI exposure results.

Methodology: Case Study Risk Analysis

To assess the risk of inland flooding in the case study regions, we combine the exposure analysis results and the vulnerability analysis results to identify regions with high exposure and high vulnerability.

The Risk Analysis Results Maps shown at the conclusion of each case study represent the overlap of the vulnerability results and hazard data for each SETS Vulnerability Indicator. The risk analysis value is calculated by multiplying the normalized Vulnerability Indicator value by the normalized Hazard value. The multiplication of the values allows for a zero value when either factor is zero, and an exaggerated risk when one or both factors is at extreme. The multiplication overlap process is commonly seen in risk formulas as exposure multiplied by consequences. In our report, we are assuming vulnerability to be representative of consequences and therefore define risk to be exposure multiplied by vulnerability. Therefore, the Hot Spots in these maps show the areas with the highest vulnerabilities and exposures, and the Cold Spots show the areas with the lowest vulnerabilities and exposures. These maps help to concentrate hot spots on areas that have high vulnerability and exposure.

Areas with high vulnerability and low exposure are less visible in the Risk Analysis Results, but more visible in the Vulnerability Analysis Results. These maps show areas that are vulnerable to inland flooding, but do not currently experience inland flooding. These areas are not currently at risk of inland flooding, but if climate change causes floodplains to expand, these highly vulnerable, low exposure areas could become risk hot spots.

Areas with low vulnerability and high exposure are less visible in the Risk Analysis Results, but more visible in the Exposure Analysis Results. These show areas that currently experience flooding, but the populations, environment, and infrastructure in these areas allow for more resilience to these inland floods. These are still areas of concern, but the risk is lower because the vulnerability is lower.

Areas with high vulnerability and high exposure are visible in the Risk Analysis Results. These are the areas that are most critical for cities to focus upon, as they are experiencing flooding and do not have the socio-economic, environmental, or infrastructure resources to combat the flooding they experience. These areas are at critical risk for inland flooding, and the changing climate has the potential to increase these risks further and generate a greater need for action to be taken towards increasing resilience in these areas.

Methodology: State-Wide Risk Analysis

To provide an overview of inland flood vulnerabilities in the state of Georgia, a general analysis of inland flood vulnerability and exposure was conducted. The results of this analysis explain the importance of the regions chosen in the subsequent case study analysis. The larger scale of this analysis allowed for identification of the counties within the state that are most heavily exposed and vulnerable to inland flooding allowing for a finer scaled analysis in these selected communities.
The following steps present the methodology to conduct state-wide risk analysis:

Step 1: Choose Vulnerability Indicators

To accommodate for the large scale of this analysis the SETS Approach was reduced to a few key indicators that were more applicable on a county-scale. Additionally, an institutional component ('I') was introduced in the analysis to account for Institutional factors that are not applicable on a Census Block level but are important at the County level. **Table 4** shows the vulnerability indicators chosen and under which SETS category each indicator falls.

Table 4: Case Study Indicators

Indicator	SETS Category	Expected Correlation (hypothesis that will be tested using our 4 case studies)	Source
Population Density	Social	Positive correlation with inland flood risk	ACS
Percentage of Green Space	Ecological	Negative correlation with inland flood risk	MRLC.gov
Percentage of Impervious Surface	Technical	Positive correlation with inland flood risk	MRLC.gov
GDP per capita	Institutional	Negative correlation with inland flood risk	BEA.gov

Step 2: Choose Hazard Data

For the hazard data, TWI was not applicable because TWI is valid on a much smaller scale. TWI considers flow accumulation, so when a TWI analysis was run on the entire State of Georgia, the highest TWI values occurred in the coastal regions and lowest TWI values occurred at the highest elevations. These results are not representative of inland flood risk as inland floods occur on a smaller scale and thus state-wide flow accumulations are not useful for such purposes. Rather than run a TWI analysis on each county individually, 'Percentage of the County residing in a Floodplain' was used as the primary hazard data. Floodplain data from FEMA in certain regions date back to 1976 and may not incorporate the latest hydrological inputs, so to accommodate this uncertainty, FEMA Insurance data was included. The Insurance data represents the amount of money paid out to cover building and contents damage claimed over the last 50 years. Only one value is given per 6-mile by 6-mile square for data privacy reasons. This data therefore is less useful for small case studies, yet is a good reflection of risk exposure for a statewide analysis. **Table 5** presents the data used and its sources.

Table 5 Hazard Data:

Data		Source
Total FEMA Insurance Payouts	Positive correlation with inland flood risk	FEMA
Percentage of County in Floodplain	Positive correlation with inland flood risk	FEMA

Step 3: Initial Mapping

After vulnerability and hazard indicators are chosen, maps were generated to create an understanding of the indicators being used. The maps demonstrate the local vulnerabilities and hazards on a county scale for the state of Georgia.

Step 4: Hot Spot Analysis

Three Hot Spot Analysis maps were created, one for Combined Vulnerability, one for Combined Hazard, and the third for Combined Risk.

The first map, Combined Vulnerability, shows the overall vulnerability of each county. Each vulnerability indicator, social, ecological, technical, and institutional, were given equal weights and aggregated resulting in the 'Combined Vulnerability Indicator Score'. This score provides an estimate for where the most vulnerable regions to inland flooding occur in the state, and these results are visualized in the Hot Spot maps.

The second map, Combined Hazard, shows the overall hazard for each county. Both hazard indicators, Floodplain Percentage and FEMA Flood Insurance, were given equal weights and aggregated resulting in the 'Combined Hazard Score'. This score provides an estimate for where the most inland flooding occurs in the state, and these results are visualized in the Hot Spot maps.

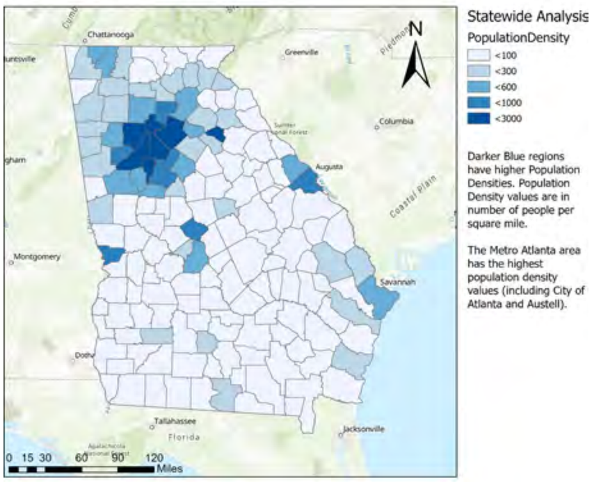
The third map, the Risk Analysis Results, shows the overlap of vulnerability and hazard to demonstrate the risk of inland flooding in the state of Georgia. The risk analysis value is calculated by multiplying the normalized Vulnerability Indicator value by the normalized Hazard value as was done in the Case Study Risk Analysis Methodology. The results of the third map, the Risk Analysis Results, influenced the selection of the Case Studies used for the remainder of the project.

Statewide Risk Analysis Results

The intent of the statewide risk analysis is to identify areas of high inland flood risk (that is, areas with high vulnerability and exposure to inland flood risk), and shed light on what makes different regions vulnerable. It is also to highlight regions that are highly vulnerable and exposed to the threat of inland flooding with low capacity to adapt. The results of the SETS (Social-Ecological-Technological Systems) analysis show High Population Density and Impervious Surface (Social and Technical vulnerability indicators) to be clustered in urban areas such as Atlanta, Albany, Columbus, and Savannah. These results reflect urban areas in the state showing higher flood vulnerability because of their relatively high population densities and impervious surfaces. At the aggregate level however, urban areas tend to have more fiscal resources than non-urban areas, reflecting a higher potential for adaptation. Non-urban areas generally showed a lower GDP per capita reflecting a higher potential for institutional vulnerability and therefore a lower adaptive capacity to inland flood disasters. Green space, an indicator of ecological vulnerability, was spatially correlated as less green space was found in the southern and eastern portions of the state of Georgia **(Figure 13).**

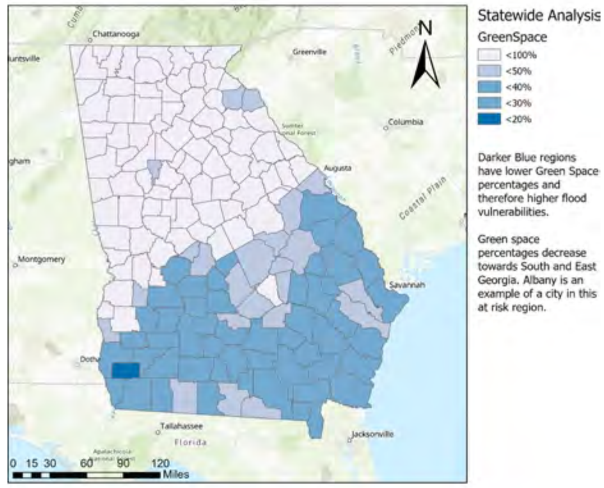
Social Vulnerability:

Statewide Analysis: Vulnerability Indicators
Population Density



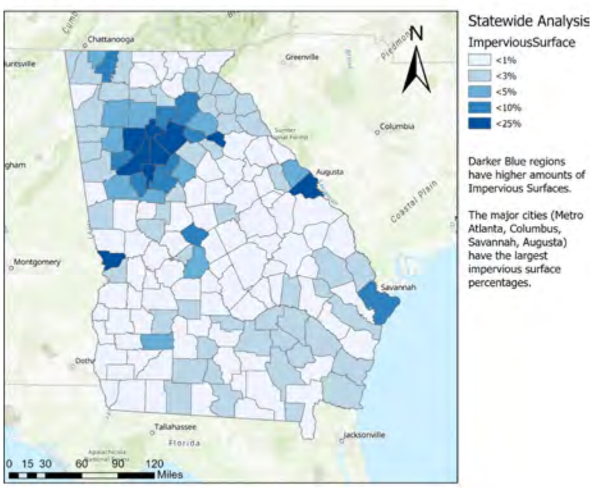
Ecological Vulnerability:

Statewide Analysis: Vulnerability Indicators
Green Space



Technical Vulnerability:

Statewide Analysis: Vulnerability Indicators
Impervious Surface



Institutional Vulnerability:

Statewide Analysis: Vulnerability Indicators
GDP per capita

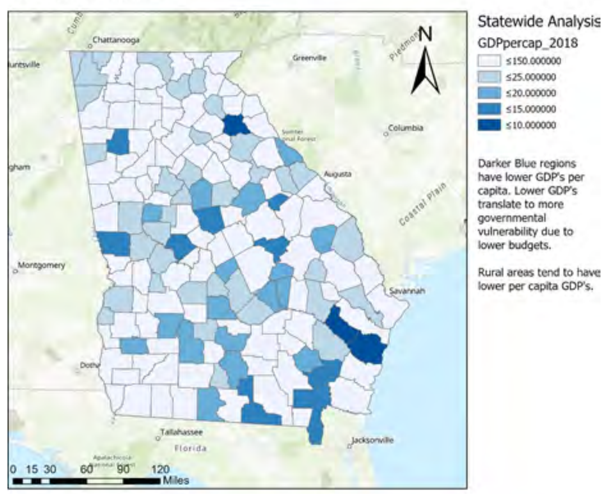


Figure 13: I-SETS Inland Flood Vulnerability Analysis - Statewide

Figure 14 shows the hazard indicator maps. The hazard exposure analysis results show insurance totals to be highest in urban areas (Atlanta, Albany, and Savannah). This follows a trend similar to the social and technical vulnerability indicators (population density and impervious surface, **Figure 13**). These results reflect that urbanized areas with more people and more development tend to experience higher flood risk and flood payouts. These results indicate that in urbanized areas, continuing uncontrolled development resulting in growing impervious surface will likely lead to increased inland flood risk. If populations continue to increase in these areas, more people will be at risk of flooding. And if there are communities with less resources in these areas, they will also have less capacity to adapt to these conditions resulting - in areas of high risk. The analysis results also show floodplains to be most prominent in the south and east regions of the State of Georgia. This follows a trend similar to the ecological vulnerability (Green Space) results. This supports the notion that regions in the southeast portions of the state have more water and less green space to absorb the water making cities in the southern and eastern portions of the state potentially at higher risk of inland flooding.

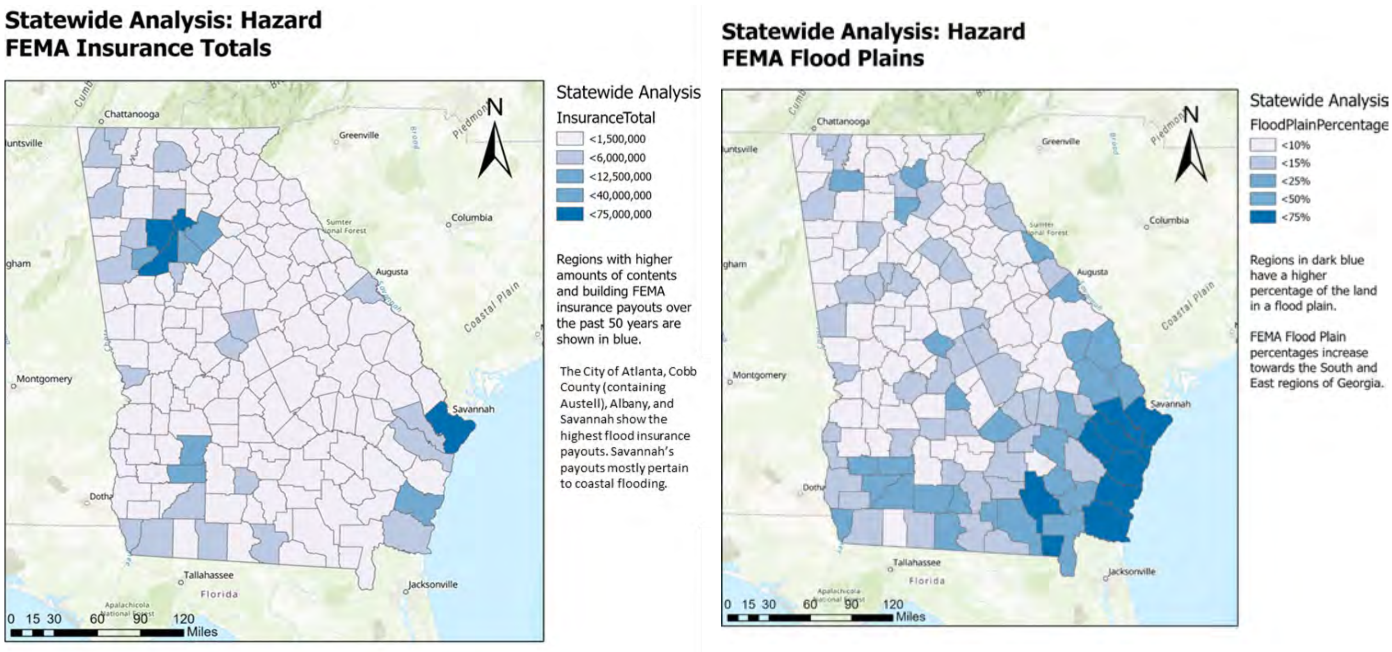


Figure 14: Inland Hazard Indicator Maps – Statewide

Figure 15 shows the results of the hot spot analysis. Combining all vulnerability and exposure indicators the hot spot maps indicate that the Atlanta and Albany regions appear to have the highest vulnerabilities and exposures to inland flooding. Combined vulnerabilities and exposures to inland flooding point to Albany and Metro Atlanta as inland flooding Hot Spots.

Based on the results of the hot spot analysis, the City of Atlanta and the City of Albany were selected as case studies in this initiative. Also, Cobb County shows high exposures and vulnerabilities. Austell is one of the most vulnerable regions in Cobb County due to the convergence of five streams in this city. Therefore, the City of Austell was also selected as a case study.

The final case study, Carrollton, was selected to demonstrate how the AT&T data could be combined with other data sources to conduct meaningful analyses. The dataset produced by AT&T and Argonne National Laboratory had significant gaps in results for Albany, Atlanta, and Austell, so Carrollton was chosen as a fourth case study because the dataset was mostly complete for this region. It was necessary to have a case study with comprehensive data from the AT&T and Argonne dataset to perform the TWI calculations shown in the Exposure Analysis Methodology section of this report. The hot spot analysis showed that Carrollton had the highest inland flood risk out of the cities that also had little missing data in the Argonne dataset.

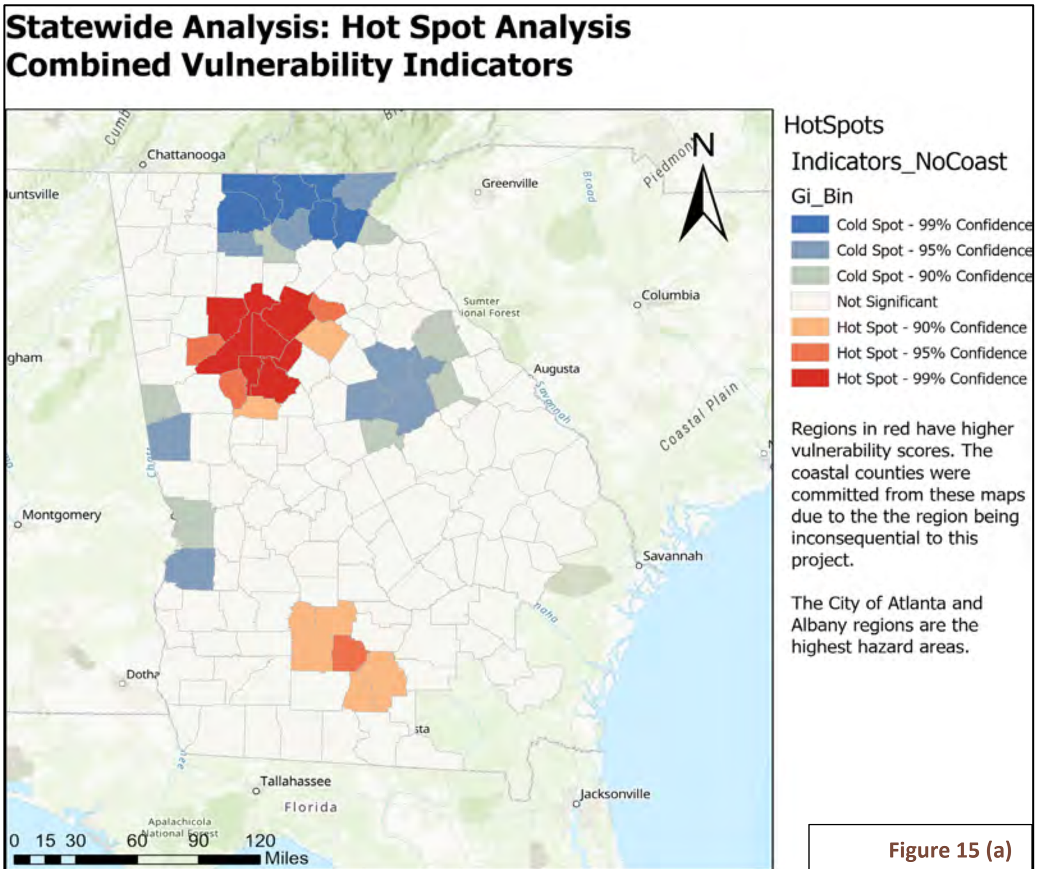


Figure 15 (a)

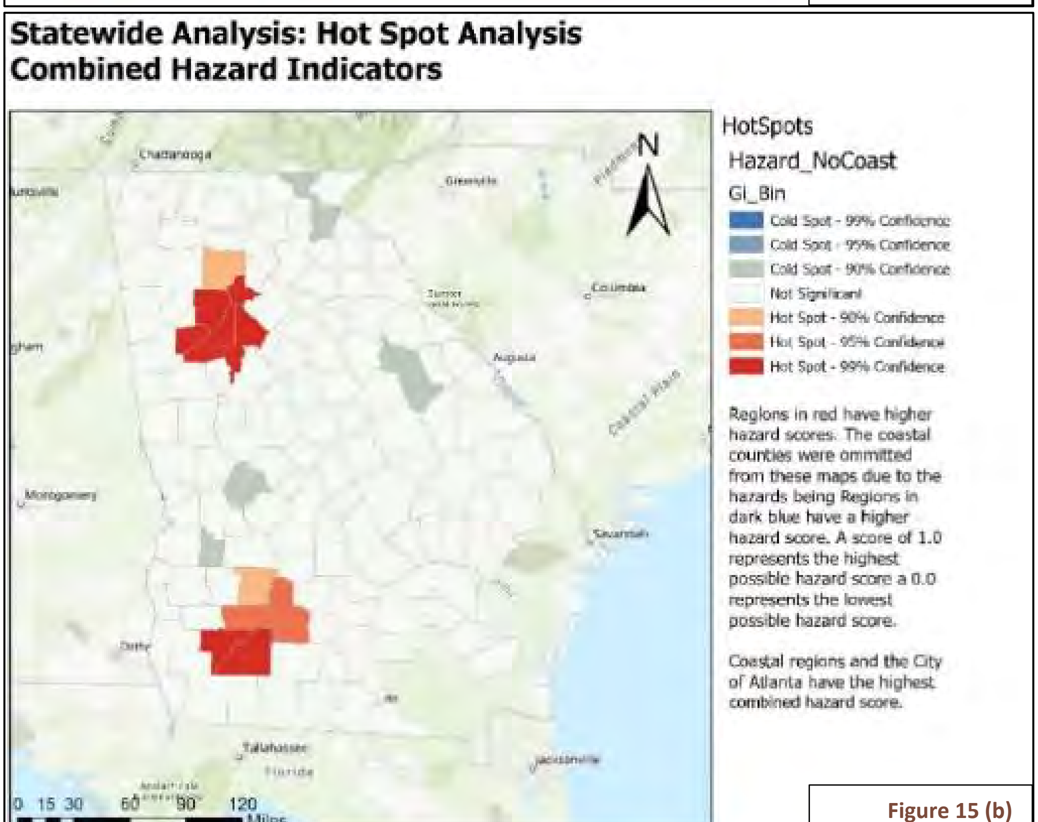


Figure 15 (b)

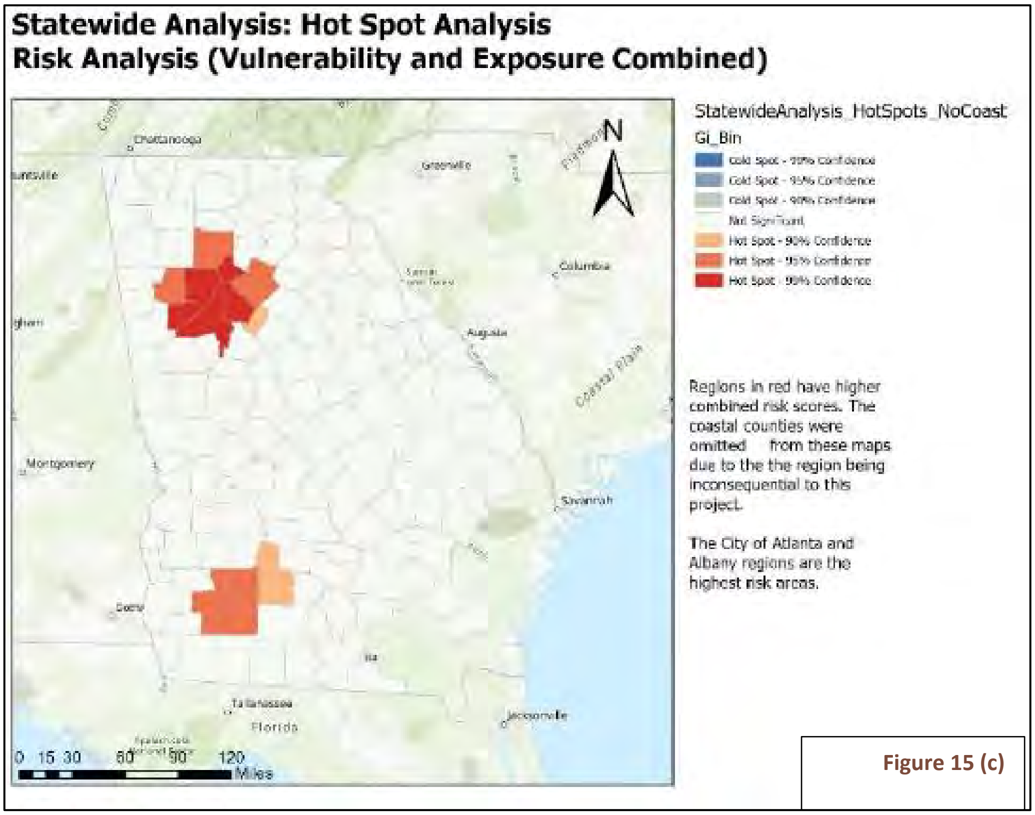


Figure 15: Hot Spots for Inland Flooding – Georgia

Case Study Findings

Case Study: Atlanta

Overview

Atlanta is the capital and most populous city of the state of Georgia and serves as the cultural and economic center of the Atlanta Metro Area. Originally founded as the terminus of a major state-sponsored railroad, it soon became the convergence point among multiple railroads, spurring its rapid growth **(Figure 16).** In modern times, Atlanta has attained international prominence as a major air transportation hub with Hartsfield-Jackson Atlanta International Airport as the world's busiest airport based on passenger traffic since 1998 (Wikipedia 2020).

One of the original 100 Resilient Cities, Atlanta defines resilience as the capacity of individuals, communities, institutions, businesses and systems within a city of survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience. Atlanta, both the city and metro region, has experienced explosive growth and prosperity over the past few decades (Resilient Atlanta 2017). Indeed, the Atlanta Metro region has the 10th highest GDP in the U.S. (Wikipedia). New residents and businesses are increasingly attracted to the region. The per capita gross domestic product for Atlanta Metro is above \$56,000 (Open Data 2019), and the median household income for the City of Atlanta is above \$55,000 in 2018 dollars (2014-2018 Data, census.gov). At the same time, the region is also one of the poorest in the nation: over 21% of the people in the City of Atlanta live in poverty (census.gov). The region has experienced segregation and lack of investment in infrastructure and affordable housing that has left some residents behind (Resilient Atlanta 2017). Indeed, the City and Metro Region of Atlanta have one of the highest levels of income disparity in the country. A recent report from the Brookings institution looked at income disparities in the 100 largest cities and surrounding metropolitan areas to determine where income inequality was the greatest: Atlanta topped the list (Berube 2018). Summarily, we can simultaneously view Atlanta as a very prosperous and very poor city and region.

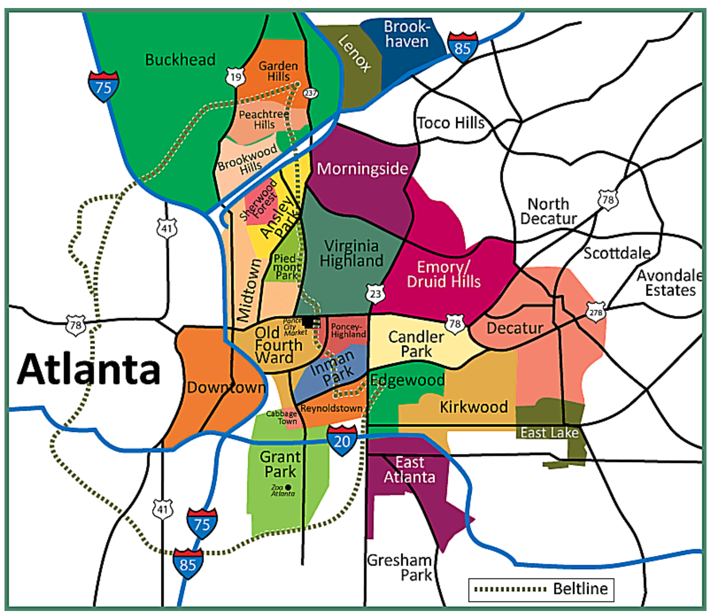


Figure 126: City of Atlanta

As of July 2019, the City of Atlanta had a population of over half a million people, experiencing almost 19% population growth between 2010 and 2019. The City of Atlanta is predominantly Black or African American (52%); whites make up 40% of the population, Hispanics and Asians constitute 4% each respectively of the population (census.gov). The Atlanta Metropolitan Region's 10-county population is over 4.6 million, according to the 2019 population estimates. The region's population grew by over 12% in the period from 2010 through 2019 (ARC). White Americans made up over 55% of the Metro Area's population, with Blacks making up a little over 32%, Hispanics a little over 10%, and Asians a little under 5% of the Metro Area's population in 2010 (Wikipedia).

City of Atlanta's Experience with Flooding

Rhone's article: "No simple solutions to stormwater challenges" in the July 11, 2020 edition of the Atlanta Journal Constitution paints a picture of the nature and type of inland flooding threats that affect the community in Atlanta. Continuing and rapid urban development has exacerbated and continues to exacerbate the threat of inland flooding.

> "It doesn't take much rain to turn small tributaries running through Johns Creek into rushing rivers. Tom Corrigan has watched for more than 20 years as increasing amounts of water drain from schools, shopping centers, office complexes and new subdivisions into his neighborhood. When he first moved to Medlock Bridge, he could jump over the creek behind his home. Now the creek is deeper and wider than it has ever been, he said.
>
> Above-average rainfall each month from January through May has left neighborhoods across metro Atlanta all wet with flooded homes and streets and overflowing creeks and streams and has highlighted the many problems municipalities face in managing stormwater.
>
> Stormwater runoff, rainwater that washes across hard surfaces such as streets and rooftops collecting pollutants before it flows into waterways, accounts for at least 80% of all water pollution, according to some estimates. Stormwater management programs have historically focused on cleaning up the water before discharging it into waterways, but what residents are most concerned with is the flooding it causes. Rapid development and outdated infrastructure along with the higher-than-average rainfall have led to overflows and flooding in many communities, making stormwater management one of the most challenging water quality issues in metro Atlanta."
>
> "The average resident is less concerned about phosphorus in the reservoir than they are about their driveway collapsing," said James Moore, stormwater specialist at the Georgia Association of Water Professionals. "There is a tension."
>
> That tension has led to countless court battles between metro area residents and local governments over stormwater with some cases dragging on for years. Residents have sued officials over development projects, crumbling sewers and faulty storm drains that have led to flooding. Relatively slow progress in addressing these issues has left residents in many communities feeling frustrated. But new regulations could force a more aggressive shift to solutions that would reduce the amount of water flowing into neighborhoods.
>
> …
>
> This week, Spencer Smith was still cleaning up water damage in his home on Ormond Street. On the trees nearby, police tape and signs from the state Environmental Protection Division indicated the area had been contaminated with sewage. Smith said this was the first time in years the water got up to 2 feet high. It was unclear exactly what caused the problem, and Smith was frustrated with the lack of communication from the city. "If you halfway fix the problem, then you don't fix the problem," he said
>
> One of the barriers to getting a handle on stormwater management can be funding. A 2019 report from the American Society of Civil Engineers found that Georgia spends $6 per capita each year on new or renovated stormwater infrastructure, substantially less than the $85 per capita recommended by the Environmental Protection Agency. There are more than 120 stormwater management programs

> throughout the state, but only 60 stormwater utilities that provide dedicated funding to those programs, Moore said.
> …
> In Atlanta, a proposed stormwater utility was defeated in 1999, but since 2004, a 1-cent sales tax on goods and services in the city has generated $1.876 billion to assist with the water and sewer improvements mandated by the federal government. Ten percent of the tax revenue is used for stormwater projects that address neighborhood flooding.
> …
>
> Jason Dozier, vice president of the Mechanicsville Civic Association who serves on a task force of developers, city officials and landowners to address the ongoing stormwater concerns in his area, said what is really needed to move forward on stormwater management is leadership. "People only think about stormwater when their house is flooding, and until it becomes a citywide issue, it won't get a lot of attention," he said. "Nobody is sounding the horns or making that their No. 1 campaign issue." (Rhone 2020)

Institutional Analysis Results

The City of Atlanta's Department of Watershed Management is responsible for integrated water management for the City of Atlanta. The DWM delivers 97 MG of drinking water per day and treats 150 MG of wastewater per day. The DWM serves 1.2 Million customers with an operating budget of $546 Million (FY 2017) and a 5-year capital improvement program of $1.22 Billion. **Table 6** below shows the City's water infrastructure inventory (Powell 2018).

Table 6: City of Atlanta Integrated Water Infrastructure (Powell 2018)

Water System	3,028 miles of pipeline 62,204 valves 24,385 fire hydrants 18 pump stations 3 water treatments plants
Wastewater System	1,900 miles of pipeline 47,327 manholes 22 pump stations 4 water reclamation centers 2 water quality control facilities
Watershed Protection	603 miles of pile 47,351 inlets 2,349 culverts 6,175 outlets 10 drainage basins

The DWM receives about 1,300 complaints about stormwater issues every year; these issues are citywide. Stormwater challenges include street flooding, damaged infrastructure and water quality issues (Powell 2018). An overhaul of the sewer and stormwater system completed in 2008, accruing to $2B in expenditures between 1998 and 2008, has reduced combined sewer overflows (CSOs) from ~100/year to an expected average of 4/year. The massive project rehabilitated 363 miles of collection system with a 97% reduction in spill volume. It has resulted in one of the highest water and sewer rates in the country (Powell 2018).

The Metropolitan North Georgia Water Planning District (Metro Water District) was created in 2001. Metro Water District is a regional water planning entity that is staffed by the Atlanta Regional Commission and includes 15 counties and over 95 cities. It is the only major metropolitan area in the country with more than 1000 jurisdictions implementing a long-term comprehensive water management program that is required and enforced. The Metro Water District establishes strategies for water supply and conservation, watershed and wastewater management, using an integrated and holistic approach to water resource management that protects water quality. Fulton County and the City of Atlanta are part of the Metro Water District participating in comprehensive and integrated water planning and management in the region. (Metro Water District)

In 2013, the City of Atlanta convened relevant city agencies, as well as partner groups, to promote and support the integration of green infrastructure into all types of public infrastructure investments. The City of Atlanta Department of Watershed Management with an interdepartmental **Green Infrastructure Task Force** has developed the **City of Atlanta Green Infrastructure Strategic Action Plan** to address the challenges associated with managing stormwater runoff that leads to flooding, degraded water quality, and property damage. The Plan, which the Atlanta City Council unanimously approved in 2017 suggests actions for removing institutional barriers to green infrastructure construction, increasing cost-effectiveness of green infrastructure, and engaging multiple City departments, citizens, developers and environmental groups to work toward the goal of goal of reducing City water runoff by 225 million gallons of runoff annually, incorporating stormwater management BMPs. Numerous projects have been completed. These include the Southeast Atlanta Permeable Pavers, Adair Park Rain Garden, and Historic Fourth Ward Park. Upcoming projects include the Proctor Creek Greenway, Boon Park West with the Atlanta Urban Ecology Center at Proctor Creek, and Rodney Cook, Sr. Park. Potential metrics/measures of success identified in the Atlanta Resilience Strategy include the following:

- Volume of pollutants captured by installed Green Infrastructure BMPs
- # of BMPs installed
- # of flooding incidents citywide and at U.S. Federal Emergency Management Agency recognized flood-prone areas
- $$$ collected through stormwater utility fee. (Resilient Atlanta 2017)

Action 4.1.4 in the Resilience Strategy leverages technology and crowdsourced data to improve responsiveness to stormwater flooding. The City of Atlanta’s DWM is developing a Smart H2O platform within a secure, permission-based system designed to capture real-time data and provide greater insight into the performance of the water system. Severe stormwater events place significant pressure on an already stressed infrastructure. The Smart H20 platform will allow the DWM to provide users and stakeholders that are part of the incident management team with real time information, including location, pictures and damage assessments to alert first responders. Through integration of existing WebEOC technology into the Smart H2O platform, this suite of information combined with historic data of severely impacted areas, aims to provide first responders with situational awareness to most effectively manage severe weather incidents. Furthermore, this program will function as a repository for data that can be used to identify potential flood and drought mitigation infrastructure projects. The project is being implemented by the DWM, the Mayor’s Office of Emergency Preparedness, and Atlanta-Fulton County

Emergency Management Agency. Potential metrics/measures of success identified in the Atlanta Resilience Strategy include the following:

- # of projects identified resulting in reduction of legacy stormwater projects
- # of projects identified and included in annual budgeting cycle
- # of projects identified for FEMA pre-disaster mitigation funding. (Resilient Atlanta 2017)

The use of Green infrastructure in Atlanta improves water quality, supports the city's sustainability initiatives, helps the city complies with NPDES permits, prepares the City for potential changes in federal stormwater rules, addresses drainage issues in redeveloping historic neighborhoods and maximizes infrastructure investments by further reducing combined sewer overflows and flooding. The City of Atlanta's integrated planning activities have prioritized 10 watersheds and completed watershed improvement plans undergirded by the Green Infrastructure Strategy, Clean Water Atlanta, Urban Waters Federal Partnership and the Water Supply Program. (Powell 2018)

The City of Atlanta Capital Improvement Program (2015) is a planning and budgeting tool for the Department of Watershed Management that organizes system needs and prospective funding requirements for a five-year period. It identifies requirements for sustaining, restoring, and modernizing the facilities and infrastructure that support the water system, wastewater system, combined sewer control facilities, and general maintenance and repair priorities in the Atlanta service area. (Resilient Atlanta 2017)

The City of Atlanta Climate Action Plan (2015) sets the goal for reducing greenhouse gas emissions by 20 percent below 2009 levels by 2020, and by 40 percent below 2009 levels by 2030. (Resilient Atlanta 2017)

The City of Atlanta Project Greenspace (2009) provides a framework and strategy for creating a world-class greenspace system in Atlanta by 2030.

The DWM has collaborated with Clean Water Atlanta and Watershed Protection to coordinate effective green and gray infrastructure development. CWA is a comprehensive initiative to improve water quality in Atlanta through capital construction programs and enhanced operation of the city's drinking and wastewater systems. The partnership works to identify opportunities to integrate cost-effective, mutually beneficial green infrastructure solutions into CWA "gray" projects to provide capacity relief and help attain water quality standards.

A Municipal Option Sales Tax (MOST) was passed generating approximately $12.5 – 13.5 Million per year for four years to address a backlog of drainage issues with coordination to integrate GI projects into future phases. (Powell 2018)

The Atlanta Resilience Strategy (2017) identifies flooding as one of the City's main resilience challenges. The City faces substantial risk from rainfall flooding. In September 2009, Atlanta experienced historic flash flooding which resulted in hundreds of millions of dollars in damages and the loss of at least ten lives. The flooding was so extreme that in one 24-hour period some counties in the region saw more than 20 inches, conditions that have a less than one percent chance of occurring each year. The severity of the flooding was in part attributed to the increased concrete surfaces, overfilled sewers, and blocked storm drains. Today, the city and region continue to face periods of intense flooding, and is vulnerable to flooding as climate change continues. (Resilient Atlanta 2017)

The City aims to create a stormwater utility fee to develop and fund a comprehensive stormwater management program designed to reduce surface flooding, address aging infrastructure, and improve the quality of water in the city's streams. This initiative aims to include funding projects identified in the City's Watershed Improvement Plans, leveraging partnerships through the Green Infrastructure Strategic Action Plan, and providing incentives for customers to install green infrastructure best management practices (BMPs) on private property to help manage on-site stormwater runoff. (Resilient Atlanta 2017)

The Department of Watershed Management has proposed a comprehensive stormwater management program to be supported by a sustainable stormwater utility fee established through the standard practice of billing property owners based on the amount of impervious surface present on a property. The program will be modeled after a combination of national best practices and programs from neighboring jurisdictions. Atlanta's stormwater utility fee will be designed to specifically address equity concerns by providing grant programs to ensure low-income residents are neither adversely affected by the cost nor unable to participate in BMP implementation programs. (Resilient Atlanta 2017)

Table 7 below summarizes the City of Atlanta and Metro Atlanta's management efforts in light of the changing climate using I-SETS considerations in a framework considering inputs, process, outputs and outcomes for flood management organizations.

Table 7: Institutional Capital for Flood Management Informed by Climate Change - Atlanta

	Measures of Impact/Performance	**Evidence**
Inputs	**1.** Does the City participate in the Community Rating System (CRS) of the National Flood Insurance Program? **Y**	The City of Atlanta has a rating of 7 on the CRS scale.
	2. Is there any government or other agency with responsibilities for floodplain management? Which agency/agencies? **Y**	-City of Atlanta Department of Watershed Management -Green Infrastructure Task Force -Other partners
	3. Does the agency formally include considerations of climate change in their decision making? **Y**	The City of Atlanta has identified flooding as one of its major resilience challenges and is undertaking multiple actions to mitigate this threat including the following: -Creation of Green Infrastructure Task Force -Development of Green Infrastructure Strategic Action Plan - Identification of the following potential measures/metrics of success: • Volume of pollutants captured by installed Green Infrastructure BMPs

		• # of BMPs installed • # of flooding incidents citywide and at U.S. Federal Emergency Management Agency recognized flood-prone areas • $$$ collected through stormwater utility fee. (Resilient Atlanta 2017)
	4. Does the agency have a formal floodplain management plan/system? **Y**	The City of Atlanta has a formal flood management strategy articulated in the 2017 Atlanta Resilience Strategy and related City plans.
	5. Does the agency's floodplain management/system include formal considerations of climate change? **Inconclusive**	The City's flood management system indirectly considers climate change by acknowledging the increase of extreme rain-related flood events and developing strategies to address this growing threat.
Process	6. Does the agency include climate-related flood risk as a criterion in resource allocation? **Inconclusive**	Increase in extreme rainfall events as the cause of flooding events is acknowledged but documents do not show explicit use of climate data in planning for future events.
	7. Does the agency have informal or formal inter-jurisdictional/ multi-jurisdictional institutions to support floodplain management where the factors influencing flooding lie beyond the municipality boundaries? **Y**	Metropolitan North Georgia Water Planning District
	8. Does the agency have plans for improving the traditional stormwater infrastructure system to accommodate for increased inland flooding risk? **Y**	The City is pursuing a combined green-gray infrastructure strategy to address flooding risk.
	9. Does the agency's land use regulations include regulations to address vegetative cover to support flood management? **Y**	Green Infrastructure Strategic Action Plan aims to substantially increase vegetative cover to address flooding.
	10. Does the agency's zoning ordinances include rules on development in the floodplain? **Y**	City of Atlanta's floodplain ordinance prevents development within floodplains, with development only allowed 15 ft horizontal distance and 2 ft vertical distance away from the base flood elevation.

	11. Does the agency include green infrastructure treatments to complement the expansion of traditional stormwater infrastructure? **Y**	The City has invested and continues to invest in multiple Green Infrastructure BMP projects to reduce the risk of flooding citywide.
	12. Does the agency include public awareness/information campaigns as part of its strategy for addressing inland flooding risk? **Y**	The City is developing a Smart H20 Platform using advanced technologies and crowdsourced data to support the management of flood risks in real time.
Outputs	13. Can the agency show expenditures for climate-resilience-related interventions to curb inland flooding risk? (S=Public awareness, E=Vegetative Cover, T=Green Infrastructure, Storm Water Infrastructure, T=Data, Tools, Other Capabilities to enhance inland flood resilience)? **Y**	Potential metrics/measures of success identified in the Atlanta Resilience Strategy include the following: • # of projects identified resulting in reduction of legacy stormwater projects • # of projects identified and included in annual budgeting cycle • # of projects identified for FEMA pre-disaster mitigation funding. (Resilient Atlanta 2017)
Outcomes	14. Can the agency show a reduction in # of homes and businesses and percentage of critical infrastructure in floodplain over time? **Y**	• Atlanta has been active in home buyouts which is consistently the most efficient way to reduce risk. The new Rodney Cook, Sr. park was built where Atlanta completed numerous buyouts
	15. Can the agency show a reduction in inland-flood-related damage over time? **Y**	• A Municipal Option Sales Tax (MOST) was passed generating approximately \$12.5 – 13.5 Million per year for four years to address a backlog of drainage issues with coordination to integrate GI projects into future phases (Powell 2018) • An overhaul of the sewer and stormwater management system completed in 2008, accruing to \$2B in expenditures between 1998 and 2008, has reduced combined sewer overflows (CSOs) from ~100/year to an expected average of 4/year. The massive project rehabilitated 363 miles of collection system with a 97% reduction in spill volume. It has resulted in one of the highest water and sewer rates in the country. (Powell 2018)

	16. Can the agency show enhanced public awareness of climate-related inland flooding risk over time? **Y**	The broad stakeholder process involved in the development of the Atlanta Resilience Strategy has led to increased public awareness of flooding as one of the City's main resilience challenges.
	17. Can the agency show expanded traditional stormwater infrastructure, over time?	Inconclusive
	18. Can the agency show expanded green infrastructure assets, over time? Y	• Completed development of BMP GI projects to address flooding including include Southeast Atlanta Permeable Pavers, Adair Park Rain Garden, and Historic Fourth Ward Park. Upcoming projects include the Proctor Creek Greenway, Boon Park West with the Atlanta Urban Ecology Center at Proctor Creek, and Rodney Cook, Sr. Park. • Potential metrics/measures of success identified in the Atlanta Resilience Strategy include the following: • Volume of pollutants captured by installed Green Infrastructure BMPs • # of BMPs installed • # of flooding incidents citywide and at U.S. Federal Emergency Management Agency recognized flood-prone areas • $$$ collected through stormwater utility fee. (Resilient Atlanta 2017)
	19. Can the agency show expanded technical capabilities for addressing inland flood risk, **including climate change,** over time? **Y**	Development of Smart H2O Platform
	20. Can the agency show new and pertinent regulations for addressing inland flood risk, over time? **Y**	The City of Atlanta Green Infrastructure Strategic Action Plan suggests actions for removing *institutional barriers* to green infrastructure construction, increasing cost-effectiveness of green infrastructure, and engaging multiple City departments, citizens, developers and environmental groups to work toward the goal of goal of reducing City water runoff by 225 million gallons of runoff annually.

	21. Can the agency show *influence* in the development of new and pertinent regulations, policies and laws at the local, state and/or federal level for addressing inland flood risk, over time?	Inconclusive
	22. Does the municipality participate in the National Flood Insurance Program's Community Rating System (CRS) Program? **Y**	Fulton County entered CRS April 2000 | Rating = 8

Exposure Analysis Results

TWI exposure results (**Figure 17**) indicate that the urban center of Atlanta is most exposed to flooding. The northern and western regions are the least exposed according to the TWI analysis results. The urban center of Atlanta that is highly exposed to flooding is centered around the intersection of I-20, I-85 and I-75. There is a large amount of impervious surface in this area, but the elevation is not significantly lower than the surrounding areas. These high TWIs are therefore likely the results of floodwaters not being absorbed and instead accumulating in these highly impervious areas.

The Census Block results add more specificity to these local TWI exposure hot spots. Downtown, Midtown and Atlantic Station are all hot spots based on TWI exposure whereas West Midtown, Buckhead, and other surrounding areas nearby show lower exposure levels. Again, these TWI exposure hot spots seem to not correlate with local elevations as much as with the impervious surface and therefore local accumulations in these areas. There are other local exposure hot spots throughout the City of Atlanta, yet it seems that the main exposure concern is the localized communities in the urban center of the city.

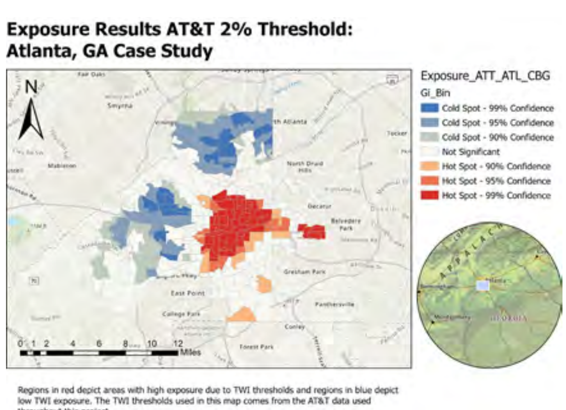
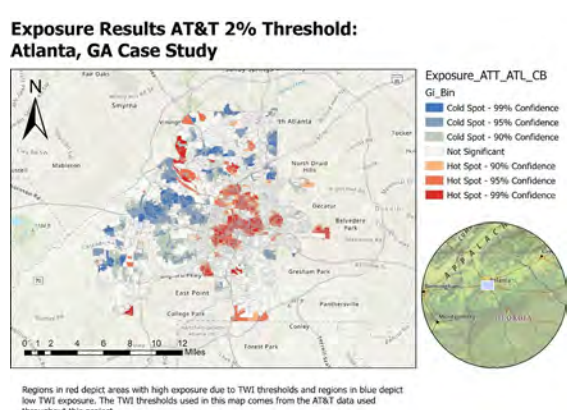
Census Block Group:	Census Block:
	

Figure 17: TWI Exposure Results - Atlanta

Social vulnerability indicators **(Figure 18)** showed two general patterns in the City of Atlanta. The first pattern can be seen in the median income, people with No HS Diploma, and black or African American population, where less affluent, less educated and black or African American populations appear to be largely concentrated in the southern and western portions of the city and more affluent, more educated and non-Black populations appear to be concentrated in the northern and eastern portions of the city. In essence, these three indicators were found to be highly correlated as shown in the correlation results in Appendix A.1. With these indicators, there is vulnerability in the south and west portions of the city, and much less vulnerability in the north and east regions. The diagonal divide can be seen in the indicator hot spot maps in **Figure 16**. The other pattern that can be seen is a high population density in the urban center of Atlanta. Other social indicators, such as Hispanic and Asian populations, Age over 65, Limited English, etc. appeared to have a more random distribution of Hot Spots throughout the city. The Census Block Group Analysis showed one singular major hot spot in the urban center of Atlanta, but the Census Block Group analysis brought forth social vulnerability hot spots in the southern and western regions of the city as well. These results suggest that socially vulnerable communities exist throughout the city of Atlanta; however, given the institutional vulnerability of the less affluent communities, it is important for us to highlight the vulnerable communities in the south and west parts of the city because of their relatively lower adaptive capacity.

Ecological vulnerability in Atlanta is relatively straightforward. The urban center of the city has little green space or AB Soil, and further away from the urban center the ecological vulnerability decreases. Furthermore, regions that are further from the major Interstate highways in Atlanta tend to have more green space and AB Soil.

Technical vulnerability in Atlanta follows a similar trend to social vulnerability where there are two major patterns. The first pattern is followed by the building data and green infrastructure density data. With these indicators, the northern and eastern regions are less vulnerable and the southern and western regions are more vulnerable. In the eastern portion of the city there is an abundance of green infrastructure, and in the northern portion the average number of stories is higher, reflecting a larger adaptive capacity to inland floods. The second pattern shows that impervious surfaces are concentrated in the city's urban center, the same pattern followed by population density, green space, and soil composition. Overall, the technical vulnerability results do show that the largest hot spot occurs in the urban center of the city.

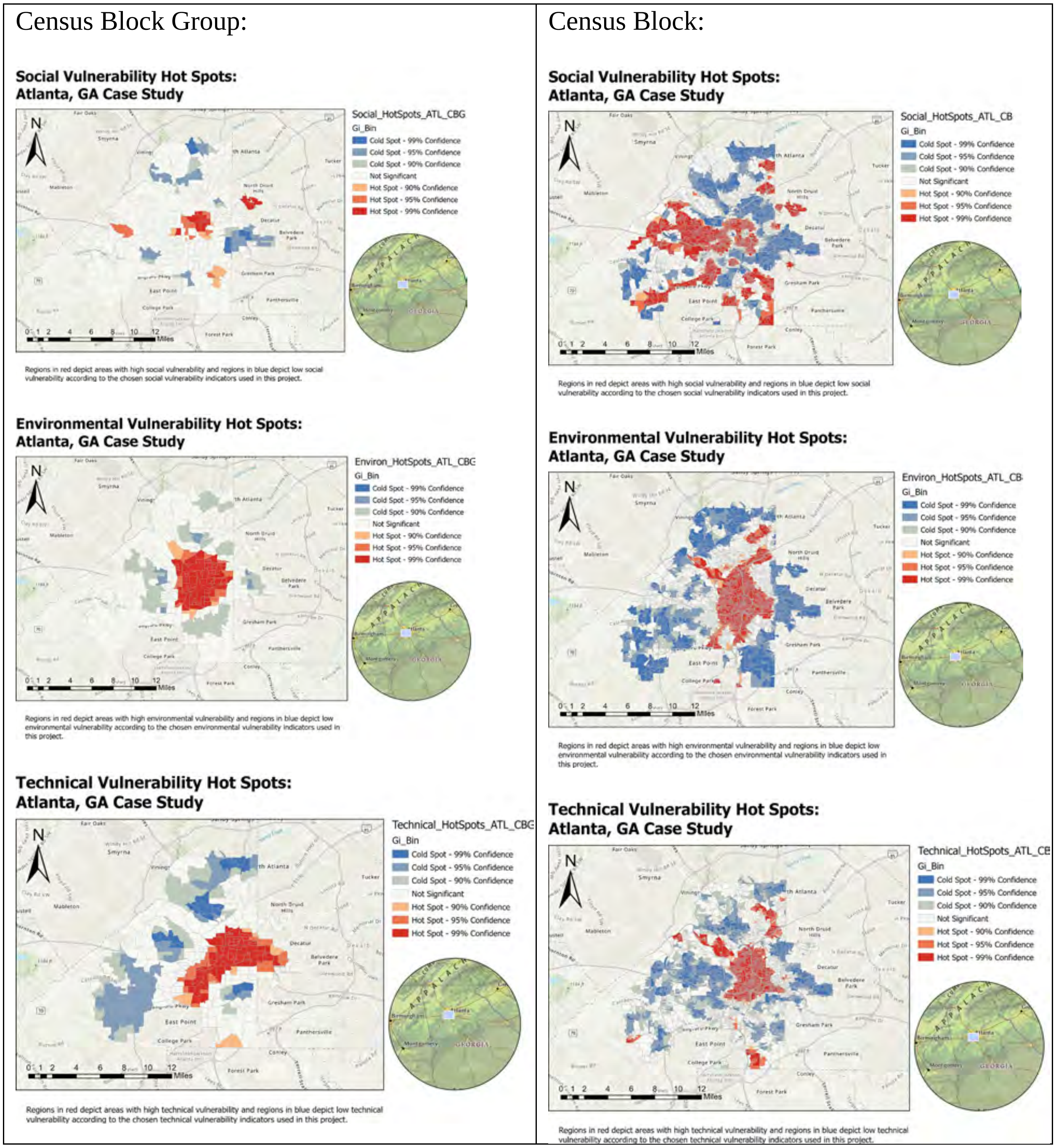


Figure 18: Social Vulnerability to Inland Flooding - Atlanta

Risk Analysis Results

The flood exposure results are reviewed alongside the social, technical, and ecological vulnerability to identify the regions with the highest risk (high exposure-high vulnerability).The results are presented at two scales of analysis: Census Block Group level, and more refined Census block level (**Figure 19**).

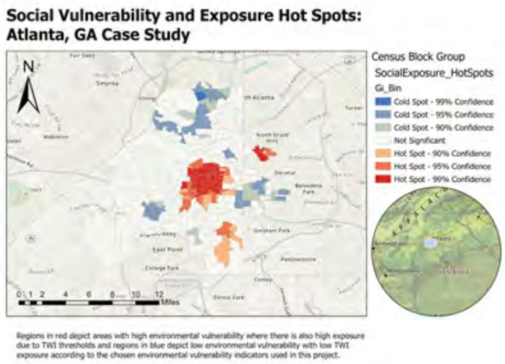
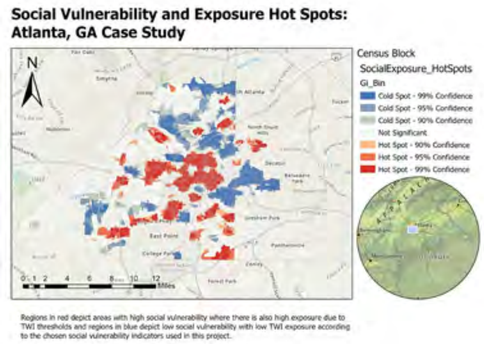
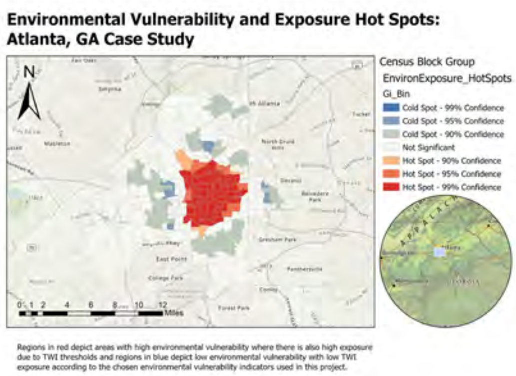
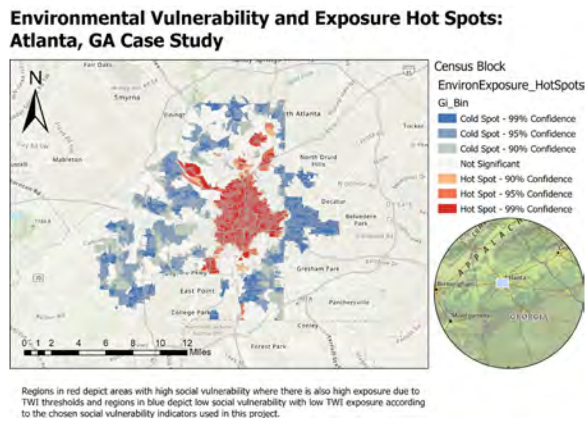
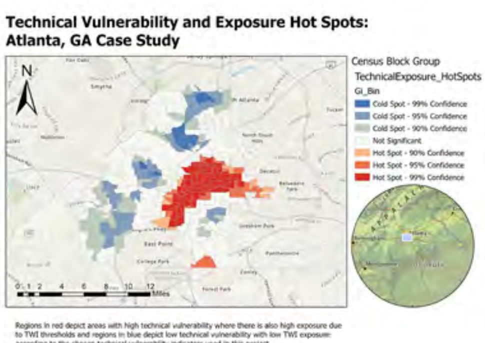
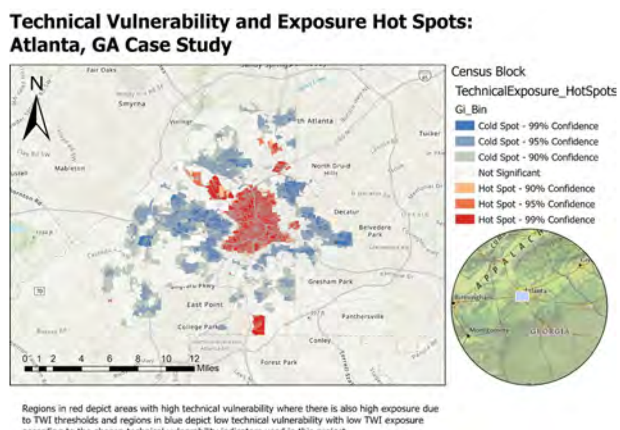
Census Block Group:	Census Block:
	
	
	

Figure 19: Inland Flooding Hot Spots – Atlanta

The Risk Analysis results of the City of Atlanta overall tell one unifying story: the urban center of Atlanta is most at risk of inland flooding. The vulnerability index used in this project had several indicators that showed vulnerability at the urban center of the city. Furthermore, the exposure results followed a similar trend in which the center of the city had the largest TWI values. The other regions that could be of interest are the localized socially vulnerable communities in the southern and western parts of the city. The northern regions of the city, above the urban center, repeatedly showed a lack of vulnerability with nearly all indicators. This would suggest more detailed analysis and efforts towards risk mitigation should be prioritized and directed towards downtown Atlanta, with some efforts also in pockets in south and west Atlanta.

Case Study: Austell

Overview

Austell is a small southern city located in Cobb County, Georgia, 18 miles west of the City of Atlanta (**Figure 20**). Founded in 1885 and historically recognized as a therapeutic city, Austell is 5.7 square miles with a relatively flat topography and the Sweetwater Creek flowing through it. It is famous as a natural health resort with a serene picturesque setting of parks and oak tree (Comp Plan).

The city has 7,235 people (2020), up from 6,581 in 2010 (10% increase). The median household income is $49,385 (2020, Comp Plan) compared with $58,716 (Georgia) and $61,937 (national) (ACS 2018). The city includes diverse racial and ethnic groups. According to the American Community Survey (ACS), Blacks or African Americans constitute about 53% of the population and Whites or Caucasian Americans constitute about 36% (WPV/Data USA). In 2017, 18.7% of the population lived below the poverty line, compared with 14.9% (Georgia, 2017) and 12.3% (US, 2017) (Wikipedia). The vast majority of workers, 74%, earn below $75,000 annually (Comp Plan). Thus, the Austell community is predominantly minority and has an annual income lower than the average in Georgia and in the nation.

Figure 20: Advantageous Location of Austell with respect to Transportation and Connectivity

Austell is located advantageously with respect to transportation. Georgia Pacific railways added to the eminence of the city by making it a transit station and a division node for the two routes of Birmingham and Chattanooga. The city is located 4 miles north of I-20 and is well connected with several major cities including Atlanta, Marietta, Douglasville and Hiram. Austell continues to be an important station division terminal, hosting several trains and transferring passengers every day. (Comp Plan) Based on ACS data (2004), Austell residents travel predominantly by personal vehicles (91.6%), with 3% estimated to use bicycle and 1.3% estimated to use public transportation. In 2015, Cobb County collaborated with the cities of Austell, Acworth, Kennesaw, Marietta, Smyrna and Powder Springs to develop the Cobb County Comprehensive transportation Plan: “Cobb in Motion”, reflecting capabilities to support inter-jurisdictional collaborative initiatives.

City of Austell's Experience with Flooding

As articulated by the Assistant Director of the Department of Community Affairs, Darrell Weaver, *there is a constant fear of flooding within the community.* While the city has an advantageous position with respect to transportation, it has a challenging position with respect to flooding **(Figure 21)**. In 2014, the city comprised about 2,500 housing units with a 91% occupancy rate. City officials desire to protect homes in the floodplain in order to preserve the largest generator of revenue for the city: property taxes. Other key economic activities include manufacturing, wholesale and retail trade. (Comp Plan)

Figure 21: Austell faces rising danger at the juncture of five creeks (Credits: AJC)

According to Darrell Weaver, Assistant Director for Community Affairs, the city floods every three or four years. With financial stability as a key priority, the city is keenly interested in continuing to grow revenue, enhance development standards and guidelines, and adopt new technologies that will allow inhabitants to maximize development in the floodplain, continue to advance economically and augment community quality of life. With several floodplains in the city, a growing population, and long-standing flood risk, the city is looking for better ways to use its land. (Weaver 2020)

According to Perry (2010), **Austell's tendency to flood has been recognized at least since 1964**, the first year the city asked the U.S. Army Corps of Engineers (USACE) for help. Between 1964 and 1995, the Corps studied Austell four times concluding each time that the city is built in a flood-prone location. "Austell has been described as the catch basin for Paulding, Cobb and Cherokee counties. The biggest of its five creeks, the Sweetwater, flows in from Paulding, Cobb and Cherokee counties (**Figure 22**). The other four creeks bunch into the Sweetwater from the north just as it flattens out and winds through Austell. In a big rain, water can get into Austell but it can't get out. The corps' studies offered four potential solutions, but deemed none worth the cost. 'Even the cheapest – dredging and draining

Figure 22: Sweetwater Creek in the Fall

out the creek - failed the dollar-to-dollar cost-benefit test then needed to get federal help,' said the corps spokesman Patrick Robbins." (Perry 2010)

"The final corps studies followed two back-to-back floods in 1990, both of a size hydrology experts consider rare. A 100-year flood is so big that hydrology experts give it one chance in 100 of happening any given year. It's the benchmark for national flood policy. The Sweetwater almost reached the 100-year mark in February 1990, then hit it the next month said Mayor Jerkins, who called in the corps in response. "I've lived here all my life, and in 1990 was the highest I have ever seen the water rise," he would tell residents 15 years later, after an even bigger flood. That was in 2005, when the Sweetwater rose "3 foot and 2 inches higher than in 1990," Jerkins said." (Perry 2010)

Mayor Jenkins called the event "a 500-year flood, although the U.S. Geological Survey says it didn't quite hit that. The 500-year flood has a 0.2% annual chance. When Jerkins blamed rain, other city officials wondered. "The 500-year floods have caught us all by surprise," city Councilwoman Beverly Boyd said. "It could be growth. But it's not just ours. If it was just ours, we wouldn't have much of a problem because we haven't grown that much." Four years later, the Sweetwater outdid itself again. The USGS couldn't rate September's flood, except to say it was much bigger than a 500-year event." (Perry 2010)

Major flooding occurred in July 2005 after Hurricane Dennis dumped enormous amounts of rain across the Sweetwater Creek watershed, just after it had been soaked by Hurricane Cindy a few days before. The Creek rose to one of its highest levels ever, flooding dozens of homes well beyond what was considered the 100-year floodplain. About 15 inches (380 mm) of rain fell at the gauge before it was ruined by the flood. (Wikipedia)

In late September 2009, the worst flooding ever occurred on the Creek, after days of heavy rain: the Catastrophic Floods of Atlanta. New records were set, and many roads were left underwater, including I-20, which was closed west of I-285 for nearly three days. The United States Geological Survey (USGS) stated that it was greater than a 500-year flood (it does not try to make any greater estimates). The National Weather Service said the chances of having more than 10 inches (25 cm) of rain in a 24-hour period were less than 0.01% per year. (Wikipedia)

Austell was one of the hardest hit cities in the 2009 Flood (Figure 23). Austell sits at the confluence of five creeks and in the bull's eye of a suburban building boom. "Rainwater that once soaked into fields and forests now washes off parking lots and roofs, then heads – it seems – to Austell." Austell's natural vulnerability to floods is aggravated by an expanse of impervious surfaces within the city, jurisdiction-by-jurisdiction planning, and development in the floodplain. As described in the Atlanta Journal

Figure 23: Sweetwater Creek flooding

Constitution "private property rights and litigation, or the threat of it, helped put in development in areas that conventional wisdom said would flood." (Perry 2010)

"When the floodwaters finally receded in Austell, city leaders, the federal government and a giant rail yard in the crook of two creeks all took the heat from angry victims. The small city's mayor had answers. "We had 20 inches of rain, and there's nothing you can do about it," said Mayor Joe Jenkins, adding that government had done all it could and the rail yard had absolutely nothing to do with the rain we had." The words will sound familiar to Austell residents who squeezed into civic meetings last fall, seeking an explanation for September's epic floods. But they (words they were seeking) were spoken more than four years ago. **Austell's creeks have made a mockery of flood prevention policy for decades**." (Perry 2010)

There is a sense that continuing development (i.e., homes and roads, driveways and shopping centers) in Austell and more so in the surrounding cities and counties has continued to create more impervious surfaces, changing the Sweetwater's drainage basin and making flooding worse. "A lot has changed in the Sweetwater's drainage basin during the years when its floods got worse." (Perry 2010) Nonetheless, development continues in Austell and at a faster rate in municipalities upstream. In some creek basins, e.g., Powder Springs Creek upstream of Austell, man-made surface area grew by more than 50% between 2000 and 2010 – leading to "flashier" streams that peak faster and higher after rains than in the past.

Community's More Recent Efforts with Flooding

Over the last two decades, the Sweetwater Creek Watershed in Georgia has experienced a series of flood events that have caused significant damage with notable economic losses throughout the basin. In response to the extensive damage, Cobb County submitted a request to the U.S. Army Corps of Engineers, Mobile District, to consider the possibility of conducting a Flood Risk Management Study. Reduction of flood risk is a critical mission under the USACE Civil Works authority. The Corps' Flood Risk Management Program mission is to reduce the overall flood risk and long-term economic damages to the public and private sector, and to improve the natural environment. (USACE 2019)

Published in May 2019, the USACE's Final Integrated Feasibility Report and Environmental Assessment offers six feasible improvements for the region's physical stormwater system: The No Action Alternative; The Brown Road Detention Alternative; The Austell Channel Modification Alternative; The Multiple Detention Structures on Sweetwater Creek Alternative; The Multi Sub-basin Detention Alterative; and, The South Paulding High Detention Short Alternative (USACE 2019).

The study area includes multiple jurisdictions within the Sweetwater Creek Basin. It is located in Paulding, Douglas, and Cobb Counties, Georgia, and encompasses approximately 264 square miles of the Sweetwater Creek Watershed. (**Figure 24)**. The main stem of Sweetwater Creek is 45.6 miles long and begins in Paulding County, Georgia. As the creek flows eastward towards Cobb County other tributaries join the main stem before it empties into the Chattahoochee River in Douglas County at the Fulton County line. It also passes through Sweetwater Creek State Park just before its confluence with the Chattahoochee River.

Figure 24: Study Area for 2019 USACE/Cobb County Flood Risk Management Study

The study determined buyouts to be the best alternative for protecting homes. **None of the other proposed alternatives were found to be cost-effective.** A majority of the neighborhoods studied were in Austell. Cobb County declined funding the next steps which include buying out properties primarily in Austell due to cost and because the homeowners did not want to be bought out either. **Thus, it appears the costly study has not provided feasible solutions for the City of Austell. The Cobb County and USACE study highlights that the causes of Austell's flooding threat lie across multiple jurisdictions, as do the solutions. It also highlights that there are cases where it is simply not cost-effective for a community to build its way out of flood risk solely via changes to the physical stormwater infrastructure system.**

As the climate has continued to change, it is evident that flooding has also intensified in the community. (**Figure 25**)

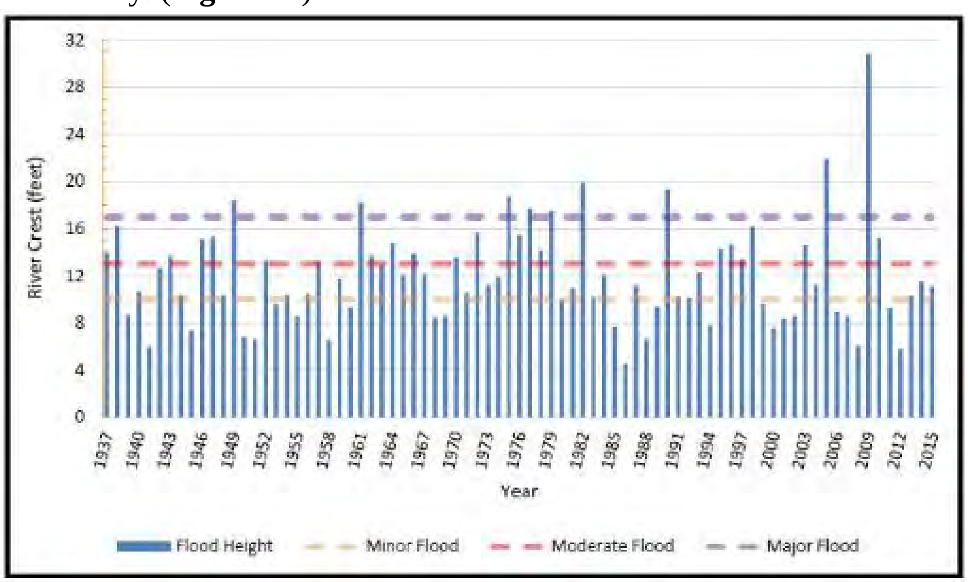


Figure 25: USGS Sweetwater Creek below Austell, GA historic river crests (USACE 2019)

Institutional Analysis Results

The City of Austell's Department of Public Works is responsible for floodplain management in the City of Austell. Cobb County Water System (CCWS) is responsible for floodplain management in Cobb County, which includes the City of Austell. CCWS' management efforts also include Paulding and Cherokee Counties, which form part of the drainage basin of the region. **Table 8** below summarizes the City of Austell and surrounding communities flood management efforts in light of the changing climate using I-SETS considerations in a framework considering inputs, process, outputs and outcomes for flood management agencies.

Table 8: Institutional Capital for Flood Management Informed by Climate Change - Austell

	Measures of Impact/Performance	Evidence
	1. Does the City participate in the Community Rating System (CRS) of the National Flood Insurance Program? **Y**	The City of Austell has a rating of 7 on the CRS scale.
Inputs	2. Is there any government or other agency with responsibilities for floodplain management? Which agency/agencies? **Y**	City of Austell Public Works Department and Cobb County Water System (CCWS)
Inputs	3. Does the agency formally include considerations of climate change in their decision making? **N and Y**	The City of Austell Public Works Department does not formally include climate change considerations in their decision making. CCWS/USACE 2019 Flood Risk Management Study for Cobb, Paulding and Cherokee Counties considered changing flood intensity over the past 75 years.
Inputs	4. Does the agency have a formal floodplain management plan/system? **Y**	The Department of Public Works provides floodplain maps to the City Engineer, which are used in reviewing developments in the floodplain.
Inputs	5. Does the agency's floodplain management/system include formal considerations of climate change?	Inconclusive
Process	6. Does the agency include climate-related flood risk as a criterion in resource allocation?	Inconclusive
Process	7. Does the agency have informal or formal inter-jurisdictional/ multi-jurisdictional institutions to support floodplain management where the factors influencing flooding lie	CCWS' flood management activities include the City of Austell. City of Austell is within the Metropolitan North Georgia Water Planning District.

	beyond the municipality boundaries? **Y**	
	8. Does the agency have plans for improving the traditional stormwater infrastructure system to accommodate for increased inland flooding risk? **N**	Several studies conducted by the U.S. Army Corps of Engineers since the 1960s have not identified any physical stormwater system improvements whose benefits outweigh the costs.
	9. Do the agency's land use regulations include regulations to address vegetative cover to support flood management?	Inconclusive
	10. Do the agency's zoning ordinances include rules on development in the floodplain? Y	All members of the Metropolitan North Georgia Water Planning District Must adopt the District's model ordinance for floodplain management
	11. Does the agency include green infrastructure treatments to complement the expansion of traditional stormwater infrastructure? **N**	The City has invested in green infrastructure treatments but not for the express purpose of complementing the physical stormwater infrastructure system for flood management. The city's status as a catchment basin for Cobb, Paulding and Cherokee Counties does not present green infrastructure as a strong viable alternative to enhance flood management.
	12. Does the agency include public awareness/information campaigns as part of its strategy for addressing inland flooding risk? **Y**	The City has a flood warning system.
Outputs	13. Can the agency show expenditures for climate-resilience-related interventions to curb inland flooding risk? (S=Public awareness, E=Vegetative Cover, T=Green Infrastructure, Storm Water Infrastructure, T=Data, Tools, Other Capabilities to enhance inland flood resilience)?	Inconclusive
Outcomes	14. Can the agency show a reduction in # of homes and businesses and percentage of critical infrastructure in floodplain over time?	Inconclusive

	15. Can the agency show a reduction of inland-flood-related damage over time?	Inconclusive
	16. Can the agency show enhanced public awareness of climate-related inland flooding risk over time?	Inconclusive
	17. Can the agency show expanded traditional stormwater infrastructure, over time?	Inconclusive
	18. Can the agency show expanded green infrastructure assets, over time? Y	Inconclusive
	19. Can the agency show expanded technical capabilities for addressing inland flood risk, including climate change**,** over time?	Inconclusive
	20. Can the agency show new and pertinent regulations for addressing inland flood risk, over time?	Inconclusive
	21. Can the agency show *influence* in the development of new and pertinent regulations, policies and laws at the local, state and/or federal level for addressing inland flood risk, over time?	Inconclusive

Exposure Analysis Results

Austell shows a significant exposure hot spot in the southern region of the city. This exposure hot spot is apparent for several reasons. First, there is a lower elevation in this region of the city. Second, Austell's river convergence occurs near the southern border of the City Limits. Lastly, this area shows significant impervious surface. All in all, this region is the main exposure concern, and is an extremely serious concern. These TWI values are very high and show that the exposure in the southern area of Austell constitute an extremely significant hazard.

The entire city of Austell has significant exposure concerns due to the convergence of five rivers in the area, but the western and eastern regions of the city have slightly less exposure concerns.

The northern region of the city has a larger exposure concern, and the southern region has the largest exposure concern (**Figure 26**).

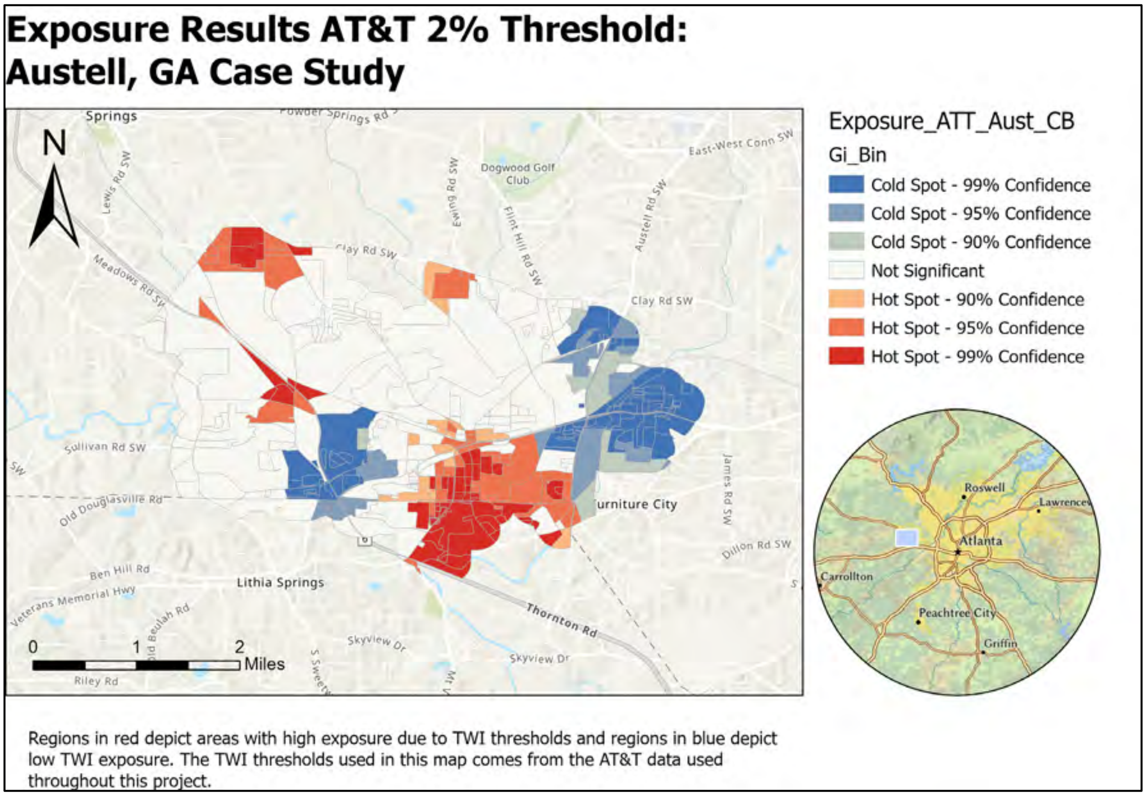


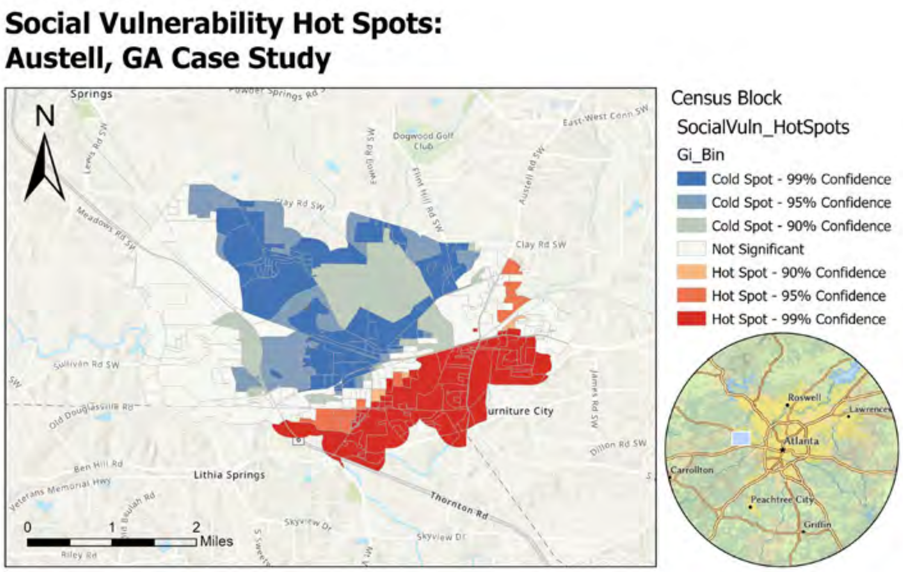
Figure 26: Inland Flood Exposure - Austell

Vulnerability Analysis Results

The Social Vulnerability analysis results for Austell **(Figure 27)** closely follow the major highway that runs through the city, Veterans Memorial Highway. The highway enters the city from the eastern side connecting Atlanta to Austell. After reaching the center of the city, Veterans Memorial Highway turns heading South towards Lithia Springs, while the Norfolk Southern Railway continues west. This effectively splits the city into a northern and southern region, with the southern region being split in two by Veterans Memorial Highway. Below the highway and railway, most of the social vulnerabilities of the city are apparent. To the Southeast there are greater numbers of Hispanics, and to the Southeast there are greater numbers of Black or African Americans and Asians. The southeast region also shows high vulnerabilities in nearly every other social vulnerability category as well including age, income, and education. The only social vulnerability hot spot that is apparent above this North-South line is population density where the major hot spot occurs in the northeast region of the city. It is interesting to note that Austell is the only one of the four case studies where Black or African American populations are positively correlated with having a high school diploma and a higher median income. This supports the idea that although the city appears to be segregated based on minority populations (White populations in the north, Black and Asian populations in the Southwest, and Hispanic populations in the Southeast), the major vulnerability concerns occur with the Hispanic population in the Southeast where all other vulnerability indicators are also apparent. These findings could also be skewed due to the smaller area of Austell compared to other cities, resulting in Hot Spot Analysis results that may have some error associated with them (more details in Limitations section).

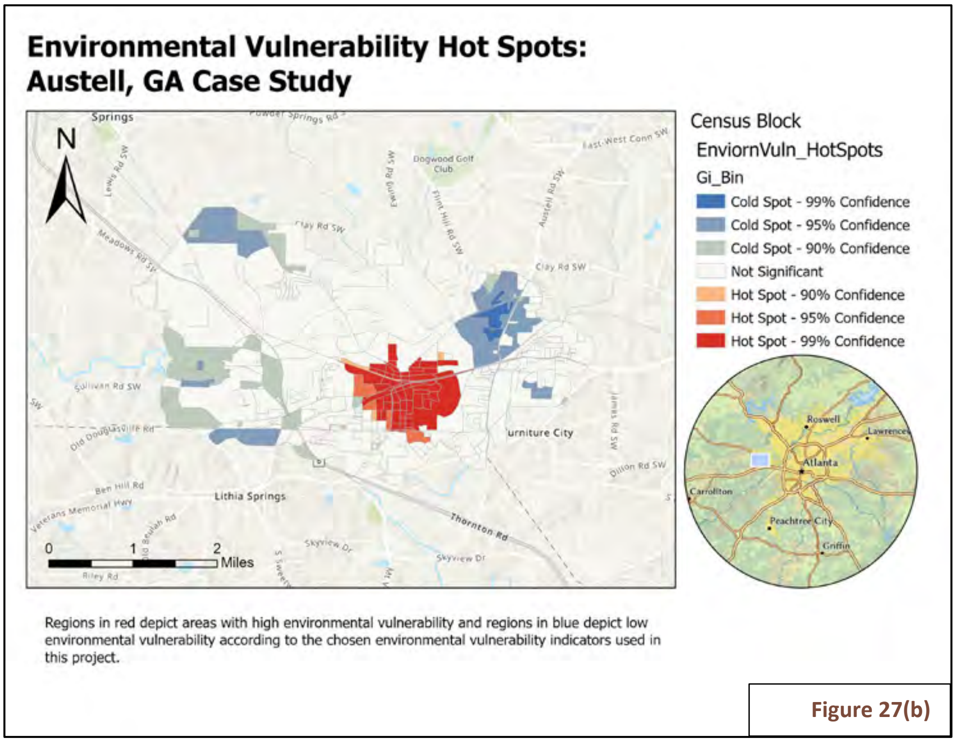
Ecological vulnerability is relatively straightforward, the major vulnerability occurs in the center of the city where the major roads and railways converge. Outside of downtown Austell, the rest of the city shows little environmental vulnerability.

Technical vulnerability for Austell is very similar to ecological vulnerability. The center of the city is vulnerable due to large impervious surface concentrations and the remainder of the city is less vulnerable.



Regions in red depict areas with high social vulnerability and regions in blue depict low social vulnerability according to the chosen social vulnerability indicators used in this project.

Figure 27(a)



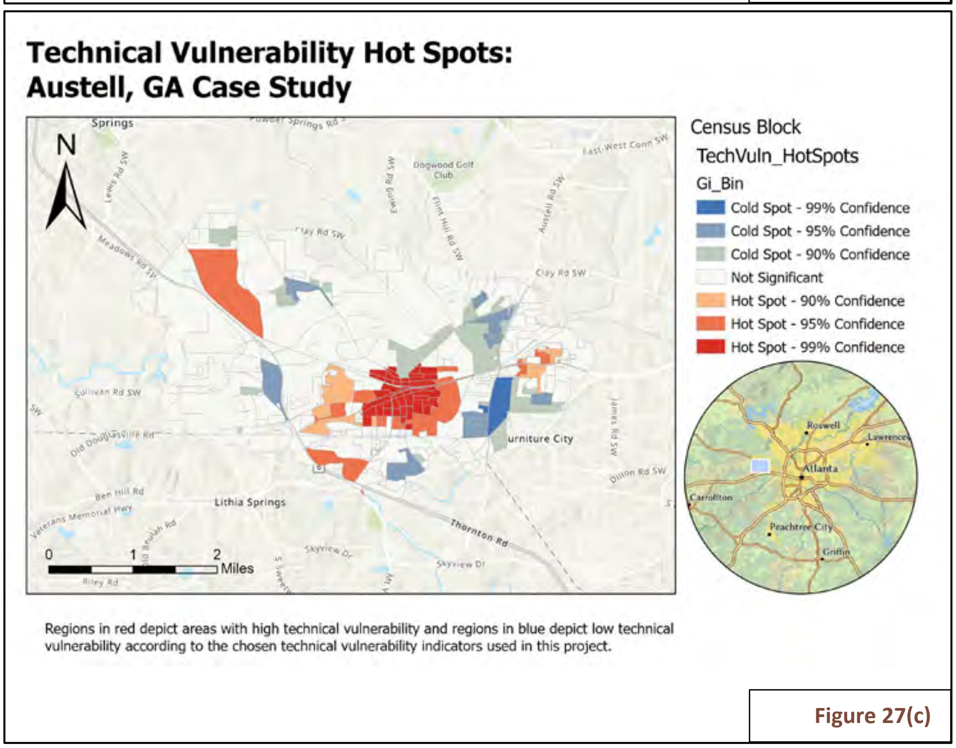


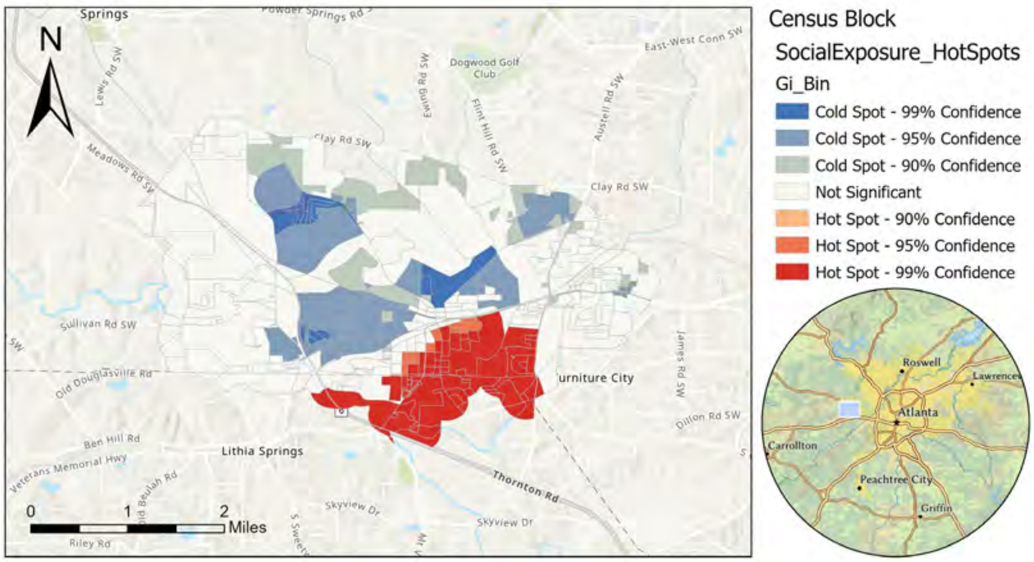
Figure 27: Social Vulnerability Analysis - Austell

Risk Analysis Results

The flood exposure results are reviewed alongside the social, technical, and ecological vulnerability to identify the regions with the highest risk (high exposure-high vulnerability).The results are presented at one scale of analysis: the more refined Census Block level.
Exposure analysis results showed hot spots in downtown Austell and localized exposure hot spots in northwestern Austell. Combining social vulnerability and exposure showed high risk in

the downtown and southeastern regions of Austell. The vulnerable Hispanic population in southeastern Austell is also near the exposure hot spot and therefore the risk results identified this area and did not show the exposed, but less vulnerable regions in the northeast as high-risk regions. The ecological vulnerability hot spots in downtown Austell were exaggerated by the high exposures in downtown Austell resulting in a high-risk in downtown Austell and the exposed northeast regions to be less at risk. Technical vulnerability and exposure were closely correlated, so risk was identified in downtown Atlanta and some localized regions in northeast Austell (**Figure 28**).

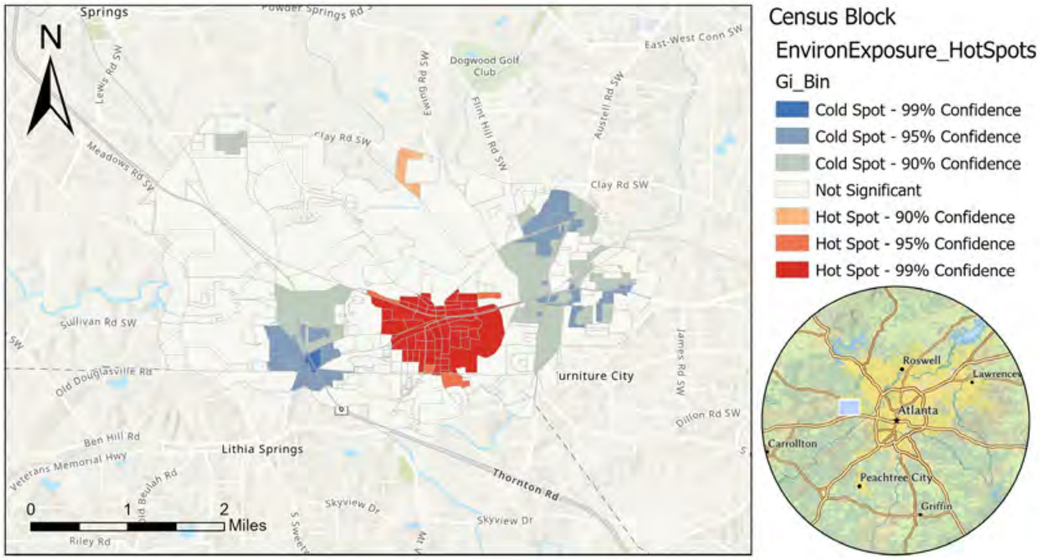
Social Vulnerability and Exposure Hot Spots: Austell, GA Case Study



Regions in red depict areas with high social vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low social vulnerability with low TWI exposure according to the chosen social vulnerability indicators used in this project.

Figure 28(a)

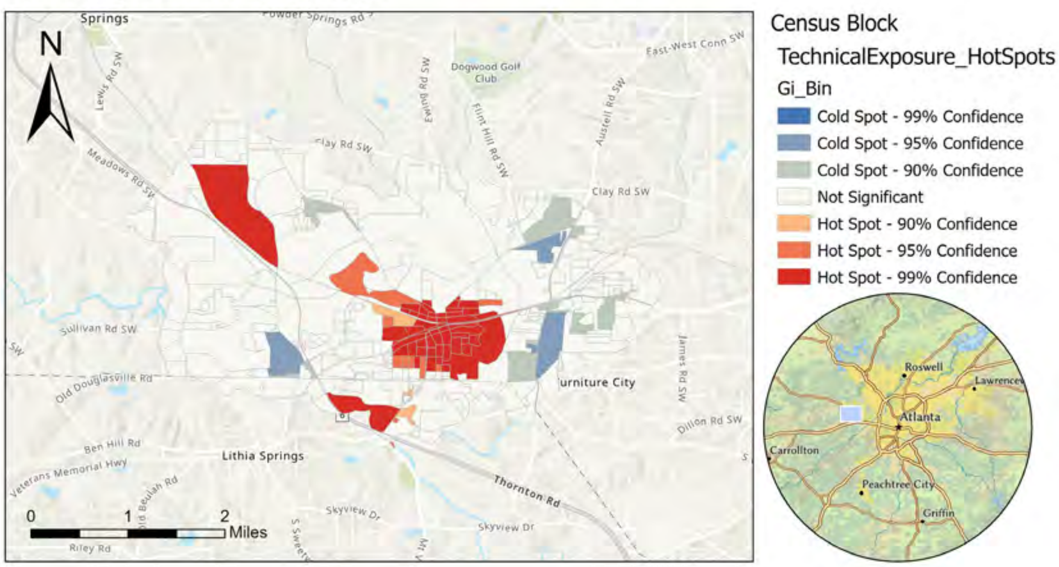
Environmental Vulnerability and Exposure Hot Spots: Austell, GA Case Study



Regions in red depict areas with high environmental vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low environmental vulnerability with low TWI exposure according to the chosen environmental vulnerability indicators used in this project.

Figure 28(b)

Technical Vulnerability and Exposure Hot Spots: Austell, GA Case Study



Regions in red depict areas with high technical vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low technical vulnerability with low TWI exposure according to the chosen technical vulnerability indicators used in this project.

Figure 28(c)

Figure 28: Inland Flood Exposure Analysis - Austell

Overview

The City of Albany – the seat of Dougherty County – is located in the Coastal Plain region of southwestern Georgia. It occupies a land area of 55.13 square miles situated approximately 70 miles north of the Florida State Line and a nearly equal distance east of the Alabama State Line. Former President Jimmy Carter's hometown of Plains lies 38 miles to the northwest, while the state capitol of Atlanta is 160 miles to the northeast. Albany rests on a bluff that is subdivided by the Flint River, at a point approximately 150 miles south of its headwaters. The Flint River and its tributaries have featured prominently in the long history of flooding that has afflicted – and continues to imperil – both the City of Albany as well as Dougherty County.

With a population of approximately 72,130 residents, Albany is Georgia's twelfth most populous city (American Community Survey). As such, it can be categorized as a mid-sized municipality. In the past decade, the population of Albany has decreased by nearly seven percent. Dougherty County has experienced an almost identical degree of population decline, dropping from 94,564 residents in 2010 to 87,956 residents in 2019. According to American Community Survey, the ethnic breakdown of the City of Albany is as follows: African American (73.5 percent), white (22.7 percent), and Hispanic or Latino (2.3 percent). The median household income for 2014-2018 was $34,493, and the median value for owner-occupied housing units stood at $101,100. Nearly one third of Albany's citizens – specifically, 32.3 percent – are below the poverty line. Over four-fifths of Albany's residents over the age of 25 have completed high school, while one-fifth have advanced to the level of Bachelor's degree or beyond.

The original inhabitants of the land on which the City of Albany rests were members of the Creek Tribe of Native Americans, who were attracted by deposits of flint – prized for use as tools and arrowheads – found near the eponymous river that flows through the region. Following Congress's enactment of the 1830 Indian Removal Act, the U.S. Army forcibly moved the Creek to lands west of the Mississippi River. In 1836, Nelson Tift founded Albany as a regional market town for cotton planters and their slaves. The local population grew rapidly, and, in 1853, Albany was made the seat of newly created Dougherty County. Until 1857, when railroad service arrived in Albany, the region's cotton crop was transported on barges down the Flint River to the Gulf of Mexico (Formwalt 2017). As time went on, local farmers diversified into the production of pecans, peanuts, wheat, vegetables, and other crops.

Albany emerged from the Civil War largely unscathed, but, predictably, its Caucasian elite pushed back against the emancipation of former slaves, who, until 1940, constituted a majority of the city's population. Like most cities and towns in the former Confederacy, Albany enforced "Jim Crow" laws to ensure that African American citizens did not achieve the equal treatment they were constitutionally guaranteed. With the outbreak of the Second World War, the building of two military airfields in the area brought an influx of white residents (Formwalt 2017). After the war, a number of major corporations established factories and facilities in and around Albany. By 1960, the city's population stood at nearly 56,000, and it continued to swell until 1990, when it crested at 78,000 residents.

Since the early 1990s, the population of Albany has been in decline. Yet the city continues to be home to a number of businesses, and remains the commercial hub of southwestern Georgia.

Although the nearest freeway (I-75) is 38 miles away, several major state roads and railway lines crisscross in or around Albany. In addition, the city hosts Albany State University, an historically black institution that, in 2015, absorbed the majority-white Darton State College. Today, Albany State University enrolls around 6,000 students, and is a unit of the University System of Georgia. In the spring of 2020, Albany attracted nationwide notoriety as a regional COVID-19 hot spot. The pandemic – which spread from a large funeral gathering – claimed a number of local lives and severely taxed the region's health care system.

City of Albany's Experience with Flooding

Both the City of Albany and Dougherty County are situated within a Flood Hazard District (FH). That FH zone lies in the floodplain of the Flint River and various of its tributaries, including Kinchafoonee Creek, Muckafoonee Creek, Muckalee Creek, Piney Woods Creek, and Dry Creek. Also lying within the FH zone are the Georgia Power Company Reservoir and Lake Worth, whose combined southern banks form the City of Albany's northern border, which are fed by the Flint River and some of these tributaries.

Before discussing the major floods that have afflicted the City of Albany and Dougherty County, it is necessary to understand their primary source. The Flint River seeps out of the northern Georgia Piedmont and flows on a south/southwesterly course for 212 miles (Morris 2017). From its headwater in Fulton County to its confluence with the Chattahoochee River at Lake Seminole on the Georgia-Florida border, the Flint River and its tributaries command a watershed that occupies land in 33 Georgia counties. These waters flow in a serpentine course through at least 20 counties in route to the City of Albany and Dougherty County. The Flint River system quenches rich farmland, offers recreational opportunities, and is home to a variety of unique flora and fauna. Yet while the river gives life to a vast area, it does so under the perpetual threat of destructive, sometimes deadly, flooding.

During the course of the past century, the Flint River system has inflicted a number of major floods on the City of Albany and Dougherty County. The first significant flood to impact Albany after the arrival of Caucasian planters and their black slaves struck in on March 9,1841. Because its timing was coterminous with the brief presidential tenure of William Henry Harrison (March 4, 1841 to April 4, 1841), it came to be known as the "Harrison Flood." An account republished in *History and Reminiscences of Dougherty County* contains the following description: "Flint River very high, it being 12 feet higher than ever known to be, having swept off Mercer's steam sawmill and all the outbuildings. A great deal of stock lost. John Jackson's cotton box went adrift" (Daughters of the American Revolution 1924; cited in Reiberg 2013). The deluge that struck Albany in December 1852 brought even higher water levels, yet did not prove as ruinous as the "Harrison Flood." It did, however, damage or destroy a great deal of property, infrastructure, and livestock, while disrupting mail delivery, railroad service, and steamship operation (Reiberg 2013).

Major, but less severe, floods struck in 1897 and 1908. In April 1897, the floodwaters that engorged the Flint River reportedly bloated to the point of inundating an area nearly one mile wide upriver near Americus. A little more than a decade later, the 1908 "red water" flood – which, presumably, earned its moniker because of the copious amounts of Georgia red clay sent churning in its floodwaters – topped railroad bridges between Albany and Americus. As a result, railway service in the area was disrupted for a time (Reiberg 2013).

The 1925 flood that struck Albany stood as the most devastating flooding event to impact the city for nearly seven decades. On January 21st of that year, the Flint River created at 37.84 feet, nearly twelve feet above flood stage (Carter 1951; National Weather Service 2020). In addition to causing enormous property damage, the floodwaters claimed at least two human lives (Rehberg 2012). But the legacy of the 1925 flood inflicted another form of enduring pain. By submerging the city in floodwater that forced residents to flee or seek shelter in the upper floors of their homes and places of work, it inspired many to sell their now much-depreciated property to relocate elsewhere. Of course, many of those who were able and willing to purchase the vacated property were from lower socioeconomic strata, and many were people of color (Eidson 2014). In signing the deeds to properties in the floodplain, these buyers put themselves and their descendants in harm's way of the next inevitable flood, thus assuring that it would have an inequitable impact on an already vulnerable demographic group.

Albany's next major flooding event occurred in early March 1966, when the Flint River crested at 34.7 feet (National Weather Service 2020). While it was severe enough to raise concerns and inflict some damage, it served merely as a reminder of the devastation that could be wrought by a flooding event of the magnitude of the 1925 flood. Few anticipated flooding that would dwarf that of the 1925 event.

The most devastating flood in Albany's long history of flooding surged into the city limits in early July 1994. It was spawned by Tropical Storm Alberto, which made landfall on the Florida panhandle on July 3rd. The following day only 1.5 inches of rain fell on Albany, but much greater amounts drenched areas farther upstream in the Flint River drainage basin. But the storm clouds continued to evacuate their contents, shedding 21 inches of rainfall on nearby Americus. The raging torrent of floodwater was augmented by water released by the bursting of more than 100 agricultural retaining dams and recreational ponds (Seegmueller 2019). By July 7th, the situation in the City of Albany and Dougherty Country was sufficiently dire to induce President Bill Clinton to declare it part of a national disaster area. Already the flooding had taken at least 16 lives, and forced more than 14,000 residents of Albany to flee for their lives. Two days later, the statewide death toll reached 22, with 40,000 citizens forced from their homes. Some 1,600 roads, 600 bridges, and 100 dams were damaged or destroyed by the floodwaters. On July 11, the Flint River crested at 43 feet, an all-time highwater mark, and, by the end of July, the death count climbed to 31 (Seegmuelleer 2019).

More recently, the City of Albany and Dougherty County experienced major flooding events in 2017 and 2018. In January 2017, two severe storm events – both declared Major Disasters by FEMA – struck the area and caused widespread damage. As a result, additional funds from FEMA's Hazard Mitigation Grant Program were made available to purchase or elevate homes in the floodplain. Some 32 homeowners availed themselves of the opportunity (Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report, 2017). In October 2010, Hurricane Michael – the first Category 5 hurricane since 1992 to make landfall in the US – struck the Florida panhandle. Michael remained a Category 3-plus hurricane as it ripped northward into Georgia, making it the first hurricane to directly impact the state since the 1890s (National Weather Service, 2018). The storm dumped up to five inches of rainfall on locations in the Flint River drainage, causing localized flooding.

Responsibility for floodplain management in the City of Albany and Dougherty County and the City of Albany is entrusted to the Floodplain Management Administrator and a Floodplain Management Review Board. The Floodplain Management Administrator concurrently serves as Director of Planning and Development Services for the county, while the Floodplain Management Review Board consists of seven members, three each from the county and city and one jointly appointed. **Table 9** below summarizes the flood management efforts of the City of Albany, taking account of the effects of climate using I-SETS considerations in a framework considering inputs, process, outputs and outcomes for flood management organizations.

Table 9: Institutional Capital for Climate Change Informed Flood Management

	Measures of Impact/Performance	Evidence
	- Does the City participate in the Community Rating System (CRS) of the National Flood Insurance Program? **Y**	Yes | Albany has a rating of 7 on the CRS.
Inputs	- Is there any government or other agency with responsibilities for floodplain management? Which agency/agencies? **Y**	**Dougherty County** - Board of Commissioners (seven elected officials, including chair) - County Administrator - Relevant county departments: Disaster Recovery, Public Works (Stormwater Management) - Floodplain Management Administrator (director of Planning and Development Services) + **F**loodplain Management Review Board (County/City) - County Public Works Department - Building Inspection Department of Planning and Development Services **City of Albany** - City Manager - City Departments – Community and Economic Development, Engineering; Planning, Development and Code Enforcement; Planning and Development Services, Planning and Zoning, Development Services (Inspection) - Planning Commission - Historic Preservation Commission

		- Floodplain Management Review Board (County/City): 7 members (3 from county + 3 from city + 1 joint) Flooding and Flood Prevention
	- Does the agency formally include considerations of climate change in their decision making?	- (Inconclusive)
	- Does the agency have a formal floodplain management plan/system? **Y**	- Albany Dougherty Flood Hazard Mitigation Plan (since 2009)
	- Does the agency's floodplain management/system include formal considerations of climate change? **N**	- No evidence found of formal consideration of climate change in decision making in Dougherty Country or the City of Albany
Process	- Does the agency include climate-related flood risk as a criterion in resource allocation? **N**	- No evidence found of formal consideration of climate change as a risk factor in Dougherty Country or the City of Albany
	- Does the agency have informal or formal inter-jurisdictional/ multi-jurisdictional institutions to support floodplain management where the factors influencing flooding lie beyond the municipality boundaries? **Y**	- There is a partnership between the City of Albany and Dougherty County. For example, the seven members of the Floodplain Management Review Board include three from the county (including the chairperson), three from city, and one jointly appointed. - No evidence identified of any broader multijurisdictional floodplain management-related institutions. As with the case of Austell, the floodwaters that strike Albany flow from many jurisdictions. For example, in the 1994 flood, much of the water came from rain that fell on the northern section of the Flint River near Macon.
	- Does the agency have plans for improving the traditional stormwater infrastructure system to accommodate for increased inland flooding risk? **Y**	- The *Albany-Dougherty Joint Flood Hazard Mitigation Plan* seems to indicate that planners are implicitly considering the probability of increased inland flood risk. For example, an action item in that Plan calls for the maintenance of a three-foot freeboard requirement in effect for Dougherty County since 1999 and the adoption of such in the City of Albany. Also, the County Greenspace

		Committee has modest efforts to purchase property to create greenspace along the Flint River and elsewhere. Albany recently created a stormwater and sanitary sewer master model to separate the combined sewer system as well as improve the level of service (LOS) of the stormwater system to a minimum 10-yr LOS.
	- Do the agency's land use regulations include regulations to address vegetative cover to support flood management? **Nothing identified. However, a number of related initiatives and actions identified.**	- The policy of Planning & Development Services seeks to "encourage developers to avoid environmentally sensitive lands such as flood hazard areas and wetlands." The stated reason for doing so is that the CRS rewards open space and low density in the floodplain. - "*Albany, Georgia - Stormwater Management Program - Green Infrastructure and Low Impact Development Program* (GI/LID) - February, 2020" (https://www.albanyga.gov/home/showdocument?id=8276) spells out the City's GI/LID thinking. For example: "As part of the plan review process, Albany will work with current applicants to ensure that any GI/LID components that can be implemented are incorporated early on in the conceptual phase" (p. 3). (Draft Document) - The *Zoning Ordinance of the City of Albany & Dougherty County, Georgia* (2013) calls for a 100-foot natural vegetative cover along the Flint River corridor: "The primary purposes of the River Corridor Protection criteria are to protect water quality, reduce erosion, encourage the protection of wildlife habitats, and reduce the risk of flood damage to properties near major rivers. Therefore, the protection criteria require the establishment and maintenance of a 100-foot natural vegetative buffer, containing flora and fauna native to the area. The 100-foot wide buffer, consisting of the area between the top of the bank and the edge of the river's low water line shall be treated by local governments in the same manner as the river corridor and shall be included within the River Corridor Protection Plan." - Flint River Trails – a 21-mile system of interconnected green way trails in the City of Albany, Dougherty County, Lee County, Tasser City, and Terrell County – is an example of land use regulation that addresses vegetative cover. However, it is justified not as a floodplain management device, but as something to appeal to Generation X citizens,

		who might find its existence an inducement to remain – or relocate to – the City of Albany or Dougherty County. - The Albany-Sasser Rail Trail – scheduled for completion in 2020 – is another example of policy concerning greenway land use; this too is rationalized an inducement to make living in Albany or Dougherty County attractive for Gen Xers and others.
	- Do the agency's zoning ordinances include rules on development in the floodplain? – **Nothing identified. However, a number of related initiatives and actions identified.**	- Passage from *Zoning Ordinance of the City of Albany & Dougherty County, Georgia* (2013): "It is the intent of the Flood Hazard District to prohibit intensive commercial, residential, industrial, and institutional use of lands lying within the floodway of the Flint River, Muckafoonee Creek, and the Georgia Power Company Reservoir in order to reduce costs to the general public for flood control and disaster relief. The Flood Hazard District includes lands that are part of the floodplain of the Flint River, Kinchafoonee, Muckafoonee Creek, Muckalee Creek, the Georgia Power Company Reservoir, Piney Woods Creek, and Dry Creek. The FH zone area depicted on the zoning map was established prior to mapping of the floodplains for flood insurance purposes and is intended only as estimates given to identify areas subject to flooding. In all situations, the requirements of the Floodplain Management Ordinance of the City of Albany and Dougherty County will take precedence when there are conflicts between those ordinances and the zoning ordinance." The document prohibits "intensive commercial, residential, industrial, and institutional use of lands lying within the floodway," but does not spell out penalties for violators.
	- Does the agency include green infrastructure treatments to complement the expansion of traditional stormwater infrastructure? **Y**	Spelled out in a draft document entitled "*Albany, Georgia - Stormwater Management Program - Green Infrastructure and Low Impact Development Program* (GI/LID) - February, 2020" (https://www.albanyga.gov/home/showdocument?id=8276).
	- Does the agency include public awareness/information campaigns as part of its	Example from *Albany-Dougherty Joint Flood Hazard Mitigation Plan*, "Increase the level of citizen education on flood issues in Albany and Dougherty County" (pp. 10-11). According to the official document, the city of

	strategy for addressing inland flooding risk? **Y**	Albany is using letters, brochures, and, increasingly, the internet to increase citizen awareness of flood risk.
Outputs	- Can the agency show expenditures for climate-resilience-related interventions to curb inland flooding risk? (S=Public awareness, E=Vegetative Cover, T=Green Infrastructure, Storm Water Infrastructure, T=Data, Tools, Other Capabilities to enhance inland flood resilience)? **Nothing identified.**	While climate resilience was not found anywhere in the City of Albany's official documents reviewed, the City has made some expenditures to improve stormwater management in the city and county. An assortment of examples is given in the *Albany-Dougherty Joint Flood Hazard Mitigation Plan* (pp. 13-16). To provide funding for these allocations – and proposed allocations – the City of Albany has been attempting to secure SPLOST funds.
Outcomes	- Can the agency show a reduction in # of homes and businesses and percentage of critical infrastructure in floodplain over time?	Inconclusive
	- Can the agency show a reduction of inland-flood-related damage over time?	Inconclusive
	- Can the agency show enhanced public awareness of climate-related inland flooding risk over time?	Inconclusive
	- Can the agency show expanded traditional stormwater infrastructure, over time?	Inconclusive
	- Can the agency show expanded green infrastructure assets, over time? **Y**	There appears to be some evidence of this; for example, from the 2019 *Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report*: "The County Greenspace Committee continues to seek funding to buy properties that are in the flood hazard area, when available. They were awarded $400,000 in funding for

		acquisition of property, planning and signage improvements from the SPLOST VI referendum. In 2012, Greenspace purchased 16 acres of land along the Flint River with about 2,000 linear ft. of river frontage. In December of 2012, Greenspace acquired an additional 32.27 acres of land along the Flint River, with about 5,000 linear feet of river frontage. All Greenspace land is permanently restricted from development."
	- Can the agency show expanded technical capabilities for addressing inland flood risk, including climate change**,** over time?	Inconclusive
	- Can the agency show new and pertinent regulations for addressing inland flood risk, over time? **Y**	-• Examples of this can be found in the 2019 *Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report*
	- Can the agency show *influence* in the development of new and pertinent regulations, policies and laws at the local, state and/or federal level for addressing inland flood risk, over time? **There appears to be ongoing learning about new regulations.**	• There appears to be some evidence that City of Albany authorities are at least cognizant of new and pertinent regulations for regulating inland flood risk. • **Example #1** -- In the 2019 *Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report*, it is noted that the "*Floodplain Management in Georgia Quick Guide* and a number of FEMA publications have been distributed to the staff for their reference in regard to regulations." • **Example #2**: The 2019 *Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report* states that "When the final report is received from Phase II of the USGS 2-dimensional model study of the Flint River corridor, carefully assess the resulting recommendations."

Exposure Analysis Results

Two major exposure hot spots occur in the southern and eastern portions of the city. The Flint River runs almost directly through the center of the city of Albany (**Figure 29**). From the river, the floodwaters run and accumulate in the south-eastern and south-central regions of the city. These exposure results are primarily due to the flow of the Flint River and the floodplains associated with this major river.

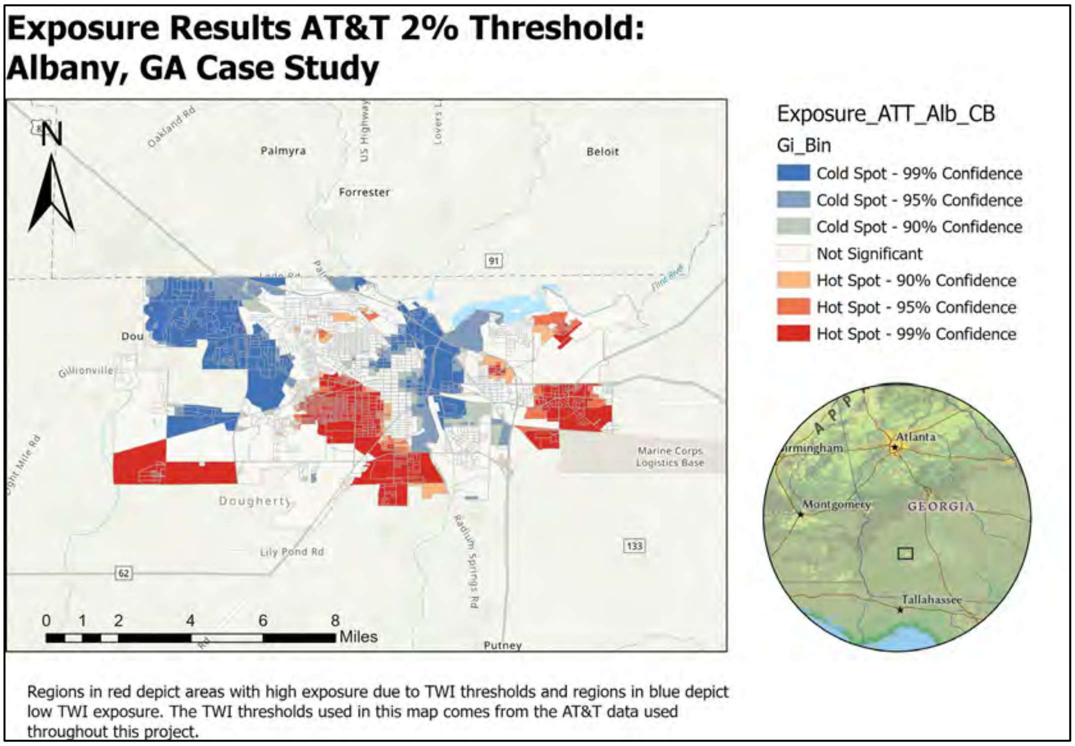


Figure 29: Exposure Analysis – Albany

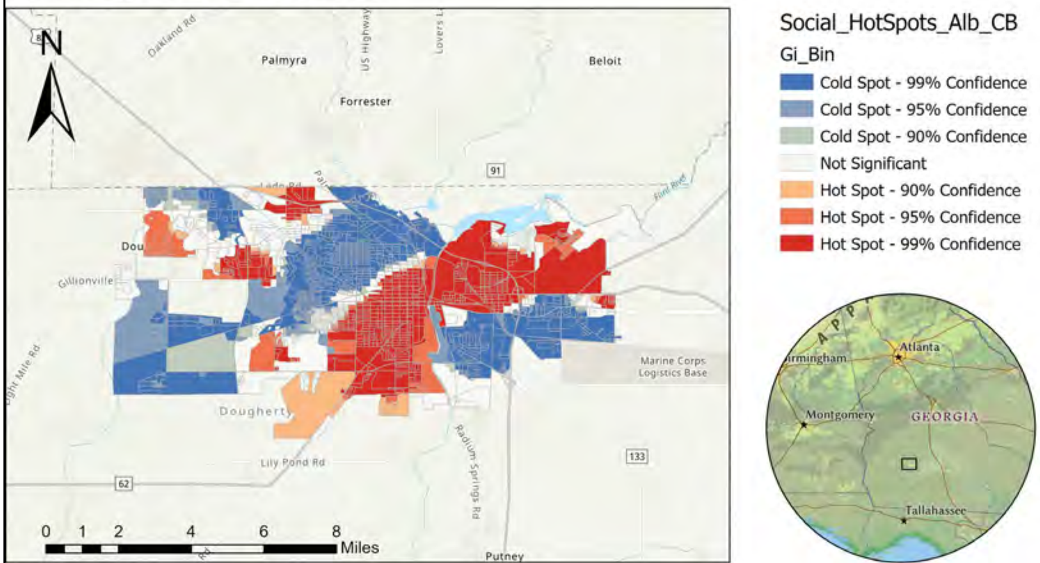
Vulnerability Analysis Results

Social Vulnerability in Albany **(Figure 30)** tells one major story. The southeastern portion of the city has high Black and African American populations with low median income. No HS Diploma and limited English follow this trend with high vulnerability in the southeast quadrant of the city and low vulnerability in the northwest. The major infrastructure divide in this city is the Southern Railway System which runs into the city from the north, then turns towards the southwest at the city center. North and east of the railway there are low vulnerabilities, whereas south and west of the railway there are very high vulnerabilities. It is important to note the Black or African American population consists 73.5% of Albany, and the remainder of the population is mostly white with small Asian and Hispanic populations. This city shows a massive racial divide, and the main social vulnerability issue is the equity concern in the southern and eastern portions of the city.

Ecological vulnerability follows the Flint River. Regions near the river have low AB Soil percentages and low amounts of green space. Outside of this area the ecological vulnerability improves, with the one exception being the southwest corner of the city. The river appears to have the largest influence on the environment with the urban areas also contributing to a small increase in ecological vulnerability due to the tendency for there to be less green space in urban areas.

Technical vulnerability also follows the Flint River, but there is a large dependence on the urban city center as well. Technical vulnerability is high alongside the river, with a large hot spot just to the west of the river in downtown Albany. This section of the city has the highest impervious surface percentage which results in a higher technical vulnerability than the surrounding areas.

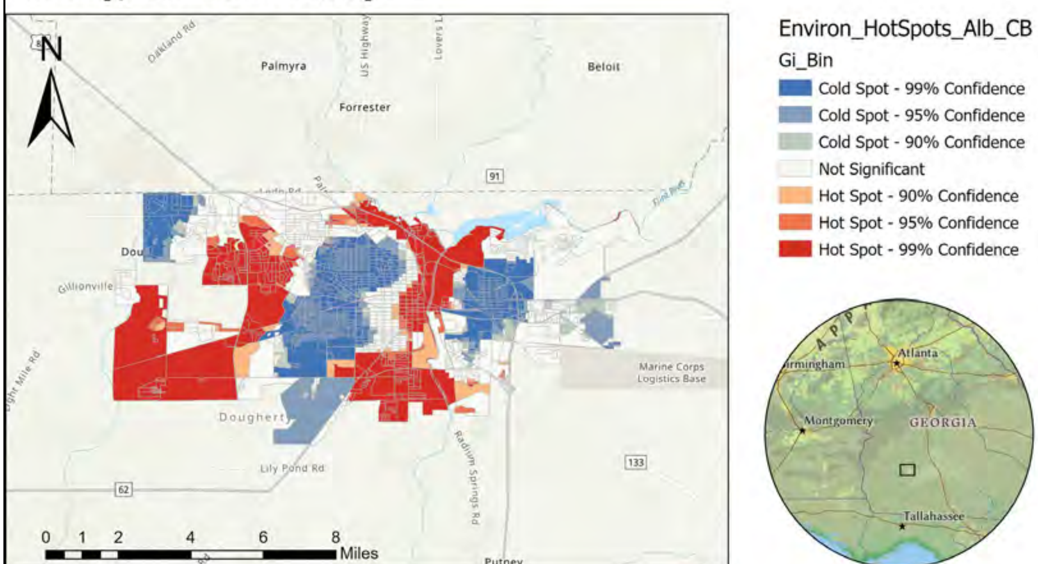
Social Vulnerability Hot Spots: Albany, GA Case Study



Regions in red depict areas with high social vulnerability and regions in blue depict low social vulnerability according to the chosen social vulnerability indicators used in this project.

Figure 30(a)

Environmental Vulnerability Hot Spots: Albany, GA Case Study



Regions in red depict areas with high environmental vulnerability and regions in blue depict low environmental vulnerability according to the chosen environmental vulnerability indicators used in this project.

Figure 30(b)

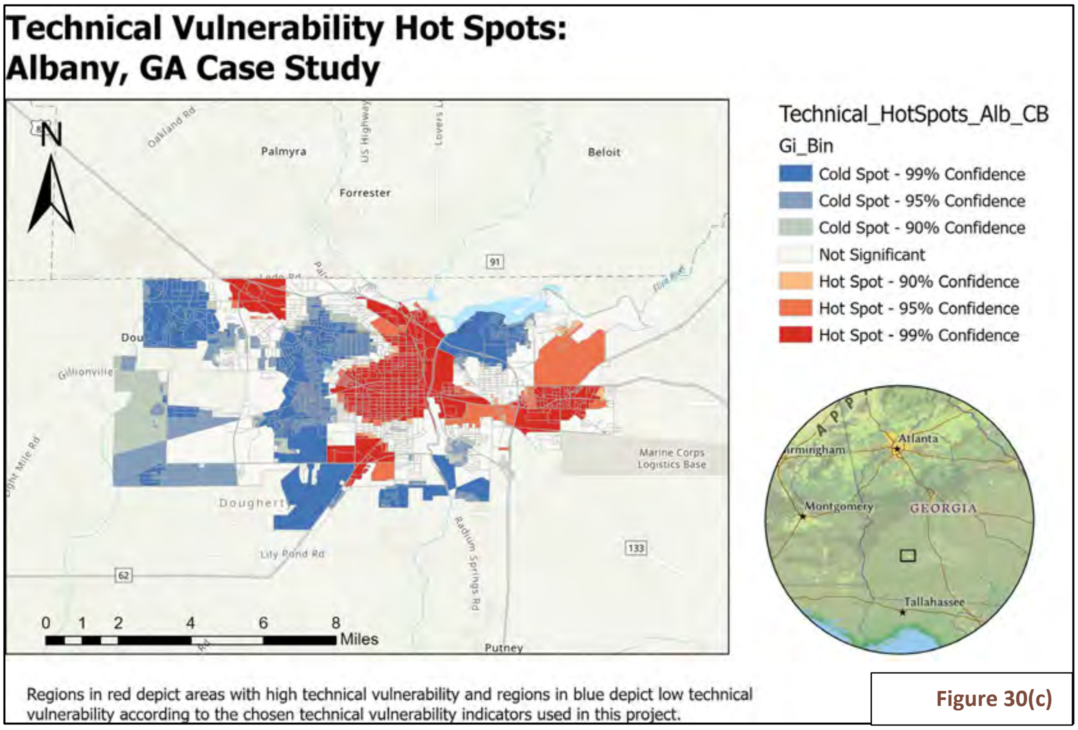
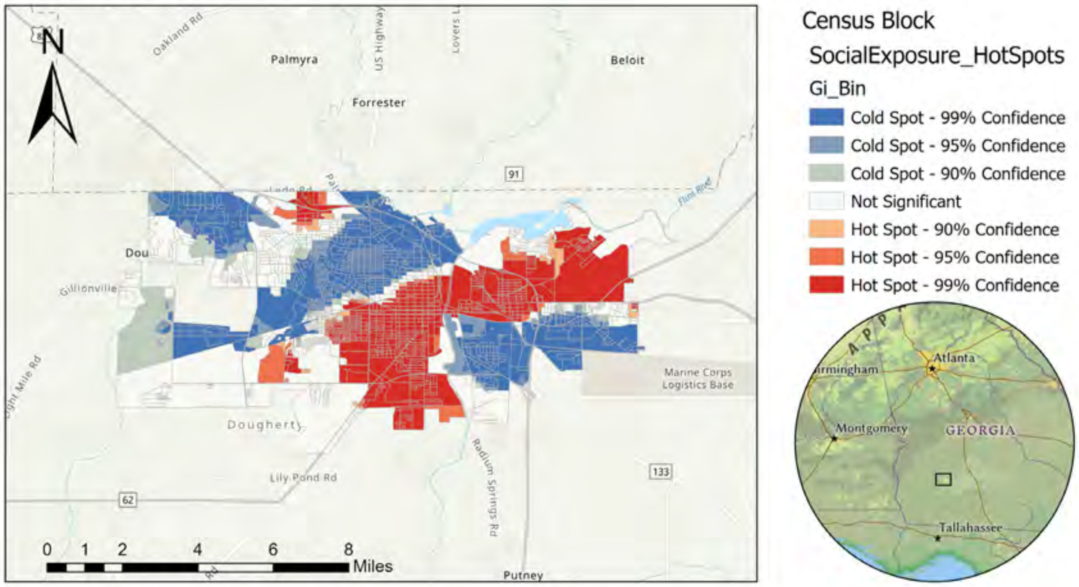


Figure 30: Vulnerability Analysis - Albany

Risk Analysis Results

The flood exposure results are reviewed alongside the social, technical, and ecological vulnerability to identify the regions with the highest risk (high exposure-high vulnerability).The results are presented at one scale of analysis: the more refined Census Block level. Inland flooding risk from social vulnerability in Albany is mostly determined by the large divide in the city due to the Norfolk Southern Railroad. Social vulnerabilities are layered with the inland flood exposure values resulting in high inland flood risks due to social vulnerability in the southeast and low inland flood risks in the Northwest. The inland flood risks due to ecological and technical vulnerability are very similar to each other. Ecological vulnerability, technical vulnerability, and exposure all followed the path of the Flint River with an exaggerated risk to the west of the river near the city center. Therefore, the city center and the regions surrounding the Flint River show high inland flood risk due to high ecological vulnerability and high technical vulnerability while areas further from the city center and river show lower risks (**Figure 31**).

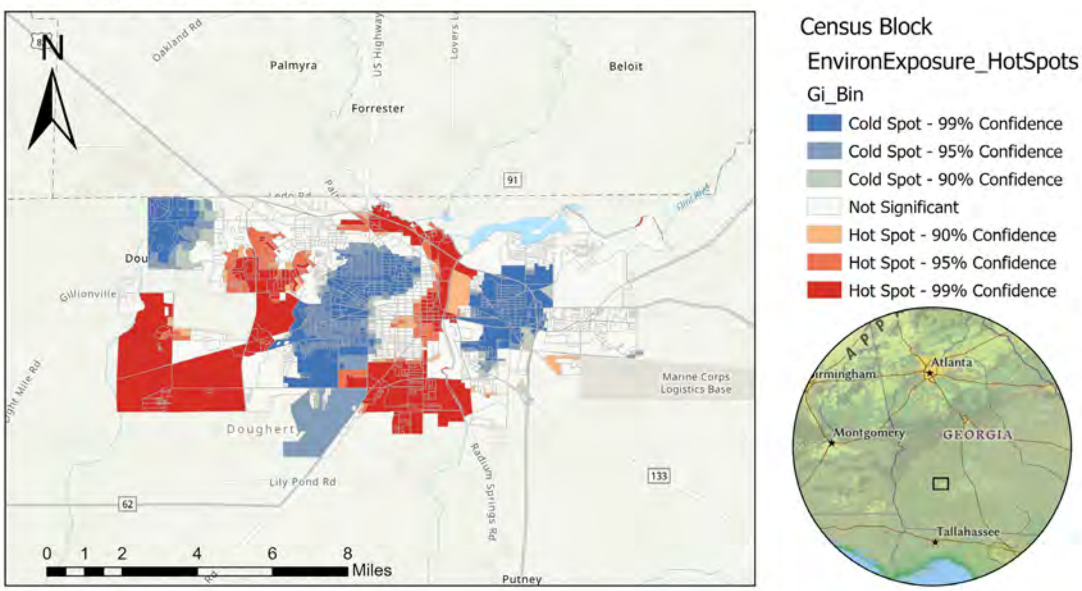
Social Vulnerability and Exposure Hot Spots: Albany, GA Case Study



Regions in red depict areas with high social vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low social vulnerability with low TWI exposure according to the chosen technical social indicators used in this project.

Figure 31(a)

Environmental Vulnerability and Exposure Hot Spots: Albany, GA Case Study



Regions in red depict areas with high environmental vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low environmental vulnerability with low TWI exposure according to the chosen environmental social indicators used in this project.

Figure 31(b)

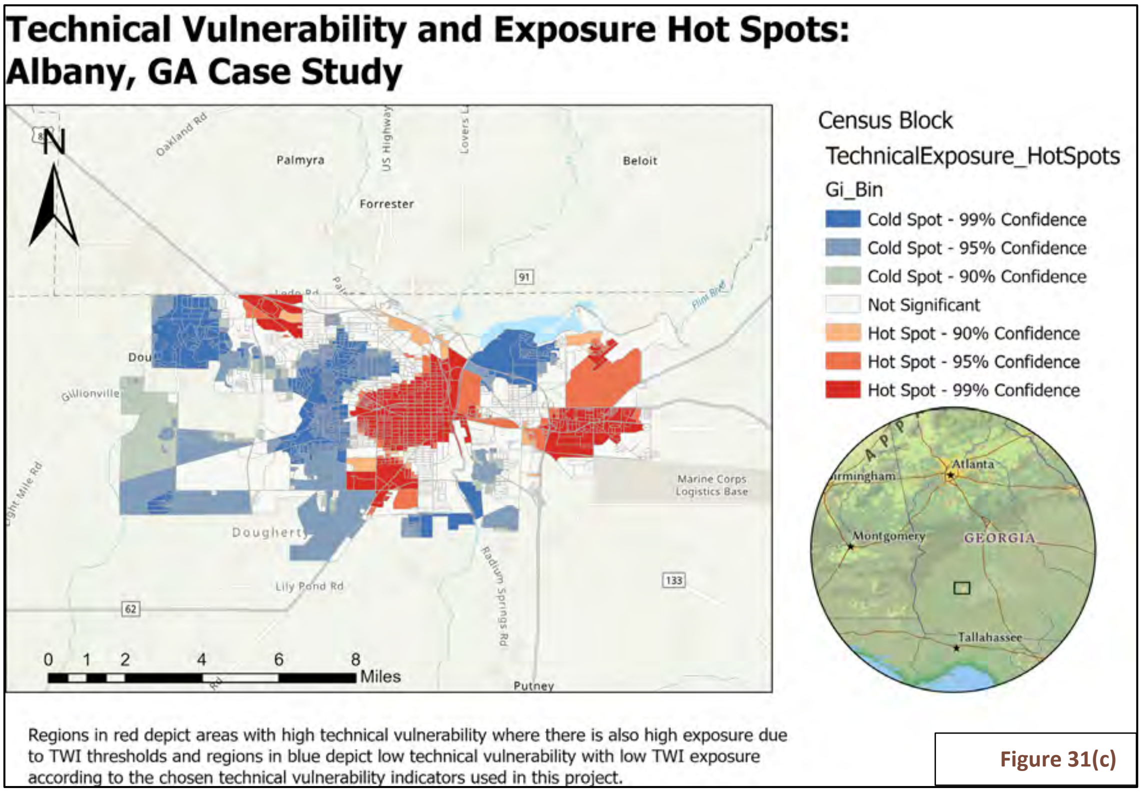


Figure 31: Exposure Analysis - Albany

Case Study: Carrollton

Overview

The City of Carrollton is located approximately 35 miles west of Atlanta and 15 miles east of the Alabama Line. It is the seat of Carroll County, which is part of the Atlanta Metropolitan Area. Carrollton is situated within the Piedmont plateau region, which lies in between northern Georgia's mountains, valleys, and ridges and the broad Coastal Plain to the south. Carrollton occupies a land area of 22.29 square miles through which the Little Tallapoosa River snakes in a southwesterly course. When it comes to flood risk, however, it is not the river itself, but, rather, flash floods from the creeks that feed it and localized flooding in low-lying areas that have been the source of most of Carrollton's flood-caused damage.

The City of Carrollton boasts a population of 27,259 residents (American Community Survey or ACS, 2019 estimate), making it Georgia's 44th most populous city. Carrollton experienced an 11.8 percent population increase between 2009 and 2019, although it remains a small municipality for purposes of this report. During the same time frame, Carroll County also experience population growth, expanding from 110,527 to 119,992, an 8.5 percent rise. In terms of ethnicity, 61.7 percent of Carrollton's citizens are white, while 28.7 percent are black. The median household income for 2014-2018 was $40,996, and the median value for owner-occupied housing units stood at $149,200. Thirty percent of Carrollton's citizens live below the poverty line. In excess of four-in-five (81.5 percent) of Carrollton's residents over the age of 25 have completed high school, and 29.9 percent have advanced to the level of Bachelor's degree or beyond.

When white settlers arrived in the area that is present-day Carrollton, the region was inhabited by members of the Creek Tribe of Native Americans. The Creek were one of the so-called "five civilized tribes," owing to the fact that many of members became literate, appreciated Occidental laws and constitutions, embraced Christianity, and intermarried with white settlers. In fact, Chief McIntosh, leader of the band of Creek who resided in the area, was the son of a Scottish father and a Creek mother. McIntosh was assassinated by members of a rival group for his assent to an 1825 treaty that led to the removal of the Creeks and other local tribes to territories west of the Mississippi River (White 2015).

Carrollton was incorporated in its present location in 1829, and was designated country seat. Both Carrollton and Carroll County derive their names from Charles Carroll of Maryland, the last surviving signer of the Declaration of Independence (White 2015). By the late 1800s, the area had become an important point for growing, gathering, and shipping cotton. Mandeville Mills, established in 1890, was the first major industrial concern to establish itself in Carrollton. Mandeville shut down production in 1954. Six years later, Southwire, a major manufacturer of wire and cable established itself in Carrollton and continues to maintain its worldwide headquarters in the city (White 2015).

Since 1907, Carrollton has been a regional center for higher education. That year, by decree of the state legislature, an agriculture and mining school was established. By 1933, that "A&M school" had evolved into the two-year West Georgia College, which, in 1957, then morphed into a four-year institution. In 2005, following a couple of name changes, the school became the University of West Georgia, and today offers bachelors, masters, and doctoral programs (White 2015). Today, UWG enrolls more than 13,200 students and the boasts an annual economic impact in excess of $605 million (UWG website). Carrollton is also home to West Georgia Technical College.

Carrollton plays host to a variety of transportation infrastructure. The West Georgia Regional Airport is located just outside the city's northwest boundary. In addition, several important state roads pass through Carrollton, but Interstate 20 – the nearest freeway – is located about 15 miles to the north. The Norfolk Southern Railroad serves the area (House 2015).

Carrollton's Experience with Flooding

The main source of flood risk for Carrollton is localized flash flooding. At the point at which the Little Tallapoosa River arrives in Carrollton, it is fed by a drainage basin of only 89 square miles (Carter 1951, p. 44). By way of contrast, the drainage basin of Sweetwater Creek near Austell is 246 square miles, while that of the Flint River at Albany encompasses 5,230 square miles (Carter 1951, p. 55). This is a major reason for the fact that Carrollton has not been victimized by large scale floods, as has been the case in Austell, Albany, and many other municipalities in Georgia. In fact, the Little Tallapoosa at Carrollton has crested at "action stage" or above – i.e., when it rises to a level in excess of 16 feet) only twice – in 1948 (19.3 feet) and then in 2009 (17.05 feet) (National Weather Service).

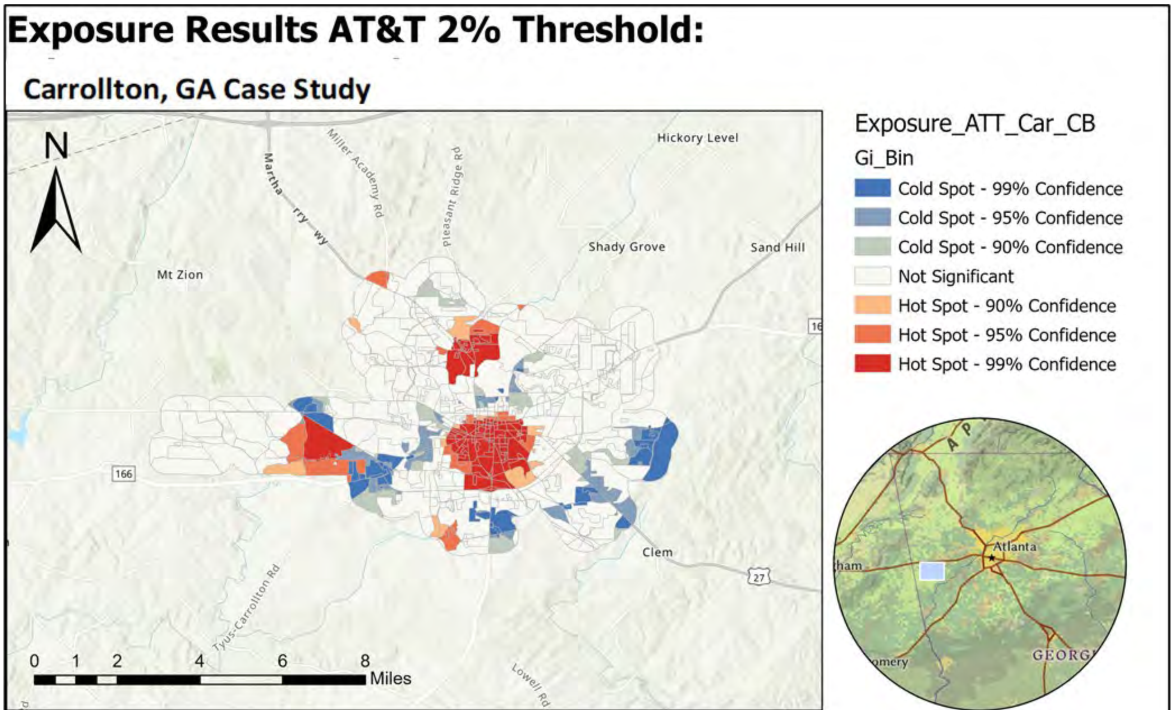
Three localized flooding events illustrate Carrollton's challenges. The first occurred in October 1995, when the remnants of Hurricane Opal arrived with heavy rain and tropical storm force winds. One resident was killed when a tree collapsed onto a mobile home (CDC 1996). The second took place on the night of 21 September 2009, part of the same weather system that swamped the City of Austell and other Metro Atlanta municipalities, passed over Carrollton. At around midnight, Snake Creek, on the city's eastern fringe, suddenly transformed from a peaceful stream into a raging torrent. The rushing floodwaters washed out a bridge and crushed a mobile home with a family of four sleeping inside. Tragically, while the parents managed to escape with their baby, a two-year-old son was swept away in the flash flood (Ravitz 2009). A more mundane instance of flash flooding occurred on 15 July 2018, when heavy rains flooded city streets. As the rainwater rose, units from the Carrollton Police Department were dispatched in Humvees to rescue numerous stranded motorists. As a veteran police office observed, "I've only seen it flood like this one other time, but this was unbelievable" (Karr 2018).

Throughout this report, we have analyzed various aspects of flood vulnerability in the City of Carrollton, Georgia. The Carrollton case provides insights into the social, environmental, and technical vulnerabilities faced by a small municipality with no history of the sorts of major flooding incidents experienced by Atlanta, Albany, and Austell. We have not identified comparable data concerning Carrollton's floodplain management strategy and institutional arrangements and therefore have not compiled an Institutional capital table for inland flood resilience in the City of Carrollton to serve as a comparative reference for the tables assembled for other three Georgia municipalities examined in this report.

Exposure Analysis Results

The Little Tallapoosa River causes a decrease in elevation and floodplains that run from northeastern Carrollton to southwestern Carrollton. This results in the TWI Exposure hot spots in the north, central, and southwest regions of the city. Also, Carrollton has a significant amount of impervious surface in the center of the city resulting in higher floodwater accumulations.

The main concern with Carrollton's TWI Exposure is the center of the city has an accumulation of high TWI values. This is likely due to the accumulation of impervious surfaces and infrastructure in this area, combined with being in the Little Tallapoosa River floodplain (**Figure 32**).



Regions in red depict areas with high exposure due to TWI thresholds and regions in blue depict low TWI exposure. The TWI thresholds used in this map comes from the AT&T data used throughout this project.

Figure 32: Exposure Analysis - Carrollton

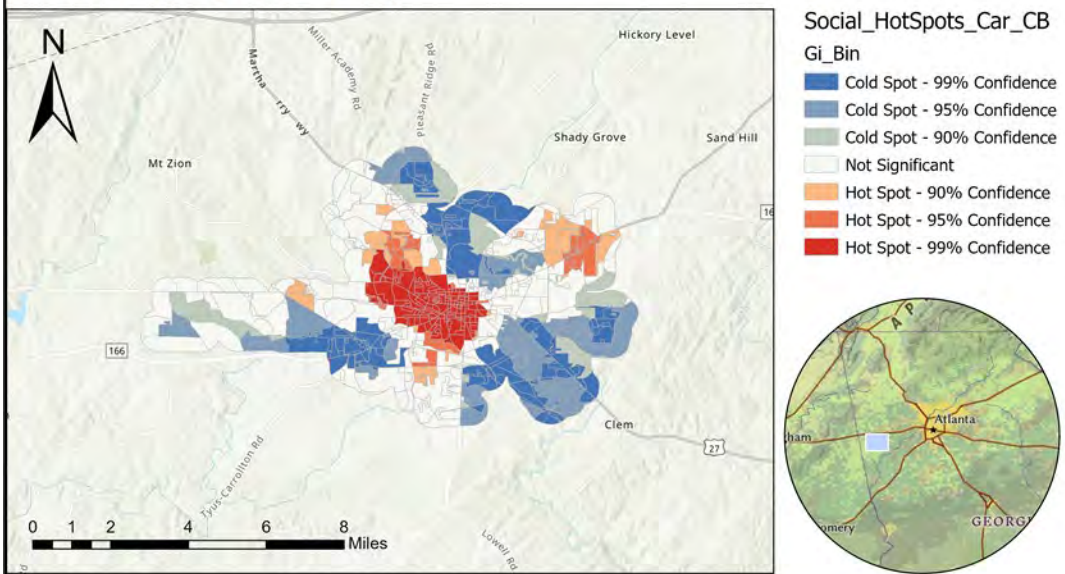
Vulnerability Analysis Results

Social vulnerability in this city follows two major trends. The first trend is associated with the highways that connect the city. Route 27 splits the city into an eastern and western portion, cutting down from I-20 to the north and connecting to cities such as LaGrange and Columbus in the South. Bankhead Highway splits the city into a northern and southern region, entering from the east connecting Carrollton to West Atlanta, and exiting in the west towards Alabama. These regions defined by the highways correlate with the social vulnerability story in the city. In Carrollton, the northwestern potion of the state (north of Bankhead Highway and west of Route 27) shows high social vulnerability with low median income and high minority populations. In fact, Carrollton is the only case study in which the majority of citizens are white, compared to the other case studies in which the majority was Black or African American resulting in majority-minority cities. The second trend in Carrollton is the developed urban center leading to a higher social vulnerability trending towards the center of the city. The center of the city shows high population densities compared with the surrounding, more rural areas.

Ecological vulnerability tells a very simple story. The city center is highly vulnerable due to the lower amounts of green space and AB Soil. This is associated with the high population densities (part of the social indicators (and the impervious surface percentages (part of the technical indicators). Outside of the city center the ecological vulnerability lessens.

The technical vulnerability in Albany is nearly identical to the ecological vulnerability. The technical vulnerability is highest in the city center where the impervious surface percentages are highest (**Figure 33**).

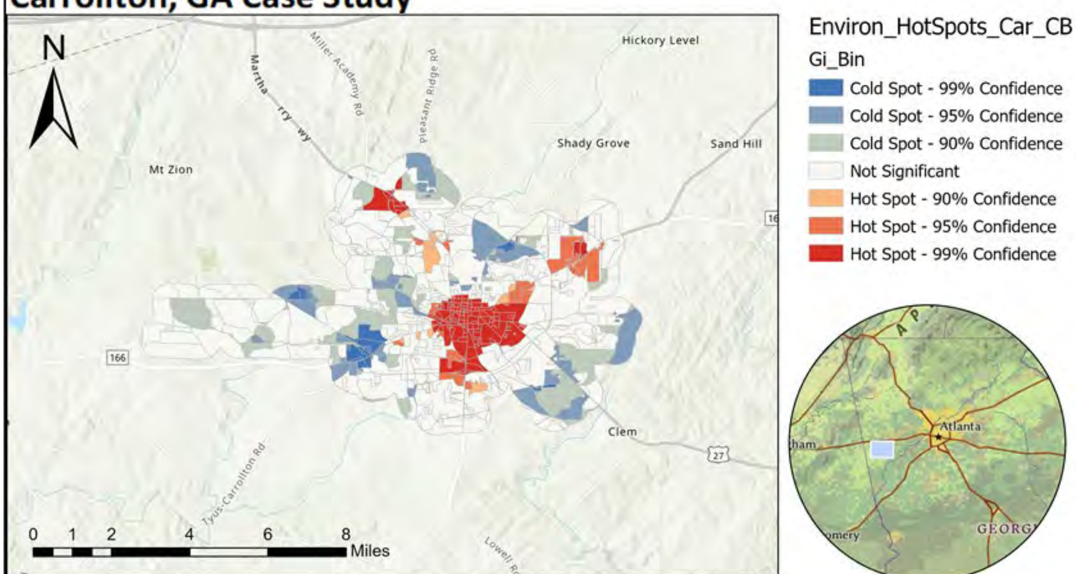
Social Vulnerability Hot Spots:
Carrollton, GA Case Study



Regions in red depict areas with high social vulnerability and regions in blue depict low social vulnerability according to the chosen social vulnerability indicators used in this project.

Figure 33(a)

Environmental Vulnerability Hot Spots:
Carrollton, GA Case Study



Regions in red depict areas with high environmental vulnerability and regions in blue depict low environmental vulnerability according to the chosen environmental vulnerability indicators used in this project.

Figure 33(b)

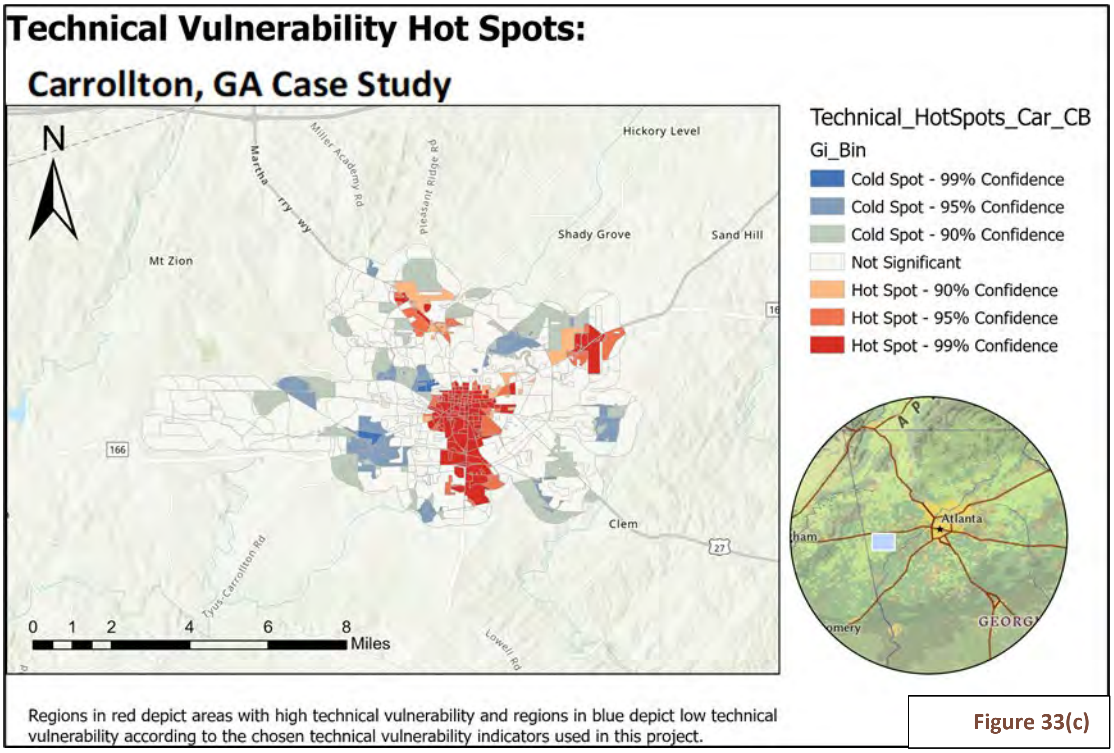


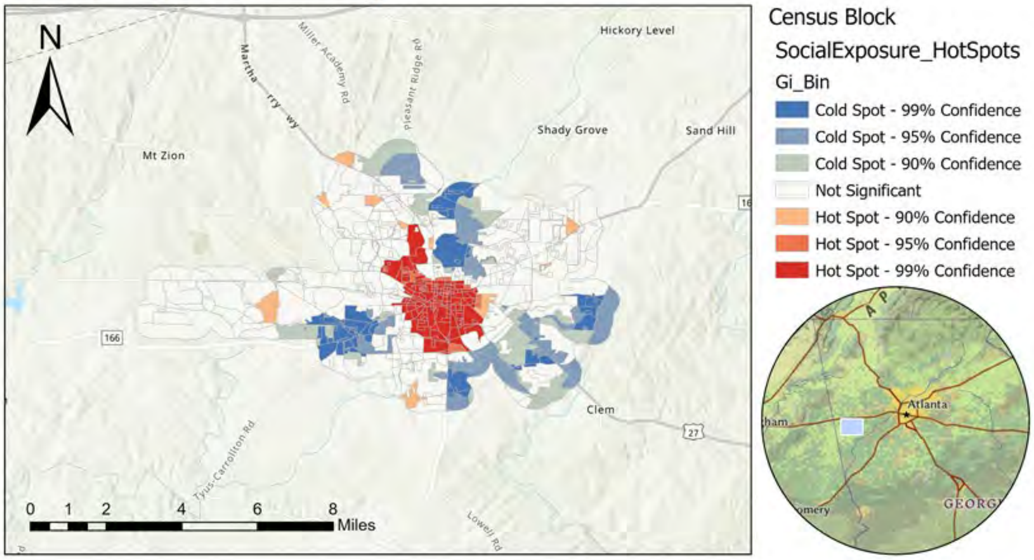
Figure 33: Vulnerability Analysis - Carrollton

Risk Analysis Results

The city center of Carrollton dominates the high-risk concerns in this case study. Exposure, ecological vulnerability (from relatively low green space and AB soils), technical vulnerability (from relatively high percentages of impervious surface), and social vulnerability (from population density) all converge in downtown Carrollton resulting in high inland flooding risk (from high social, ecological, and technical vulnerabilities) in the city center. Also, flooding risk from high social vulnerability extends towards the northwestern region of the city where the minority populations are higher and median incomes are lower than the rest of the city. Inland flood risks from ecological and technical vulnerabilities are contained primarily to the city center with a small hot spot for inland flooding risk north of downtown along Route 27 due to both ecological and technical vulnerabilities (**Figure 34**).

Social Vulnerability and Exposure Hot Spots:

Carrollton, GA Case Study

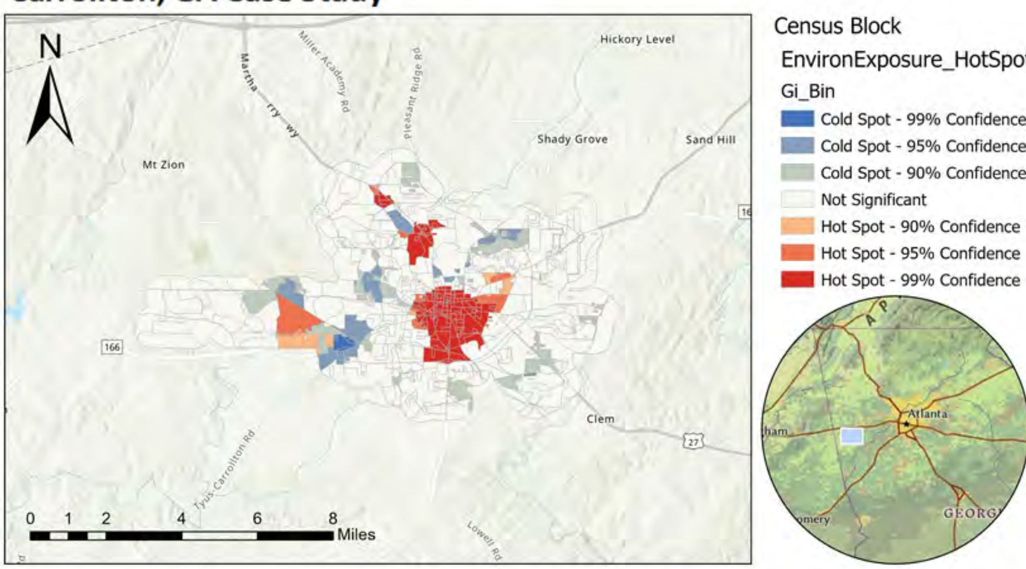


Regions in red depict areas with high social vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low social vulnerability with low TWI exposure according to the chosen social vulnerability indicators used in this project.

Figure 34(a)

Environmental Vulnerability and Exposure Hot Spots:

Carrollton, GA Case Study



Regions in red depict areas with high environmental vulnerability where there is also high exposure due to TWI thresholds and regions in blue depict low environmental vulnerability with low TWI exposure according to the chosen environmental vulnerability indicators used in this project.

Figure 34(b)

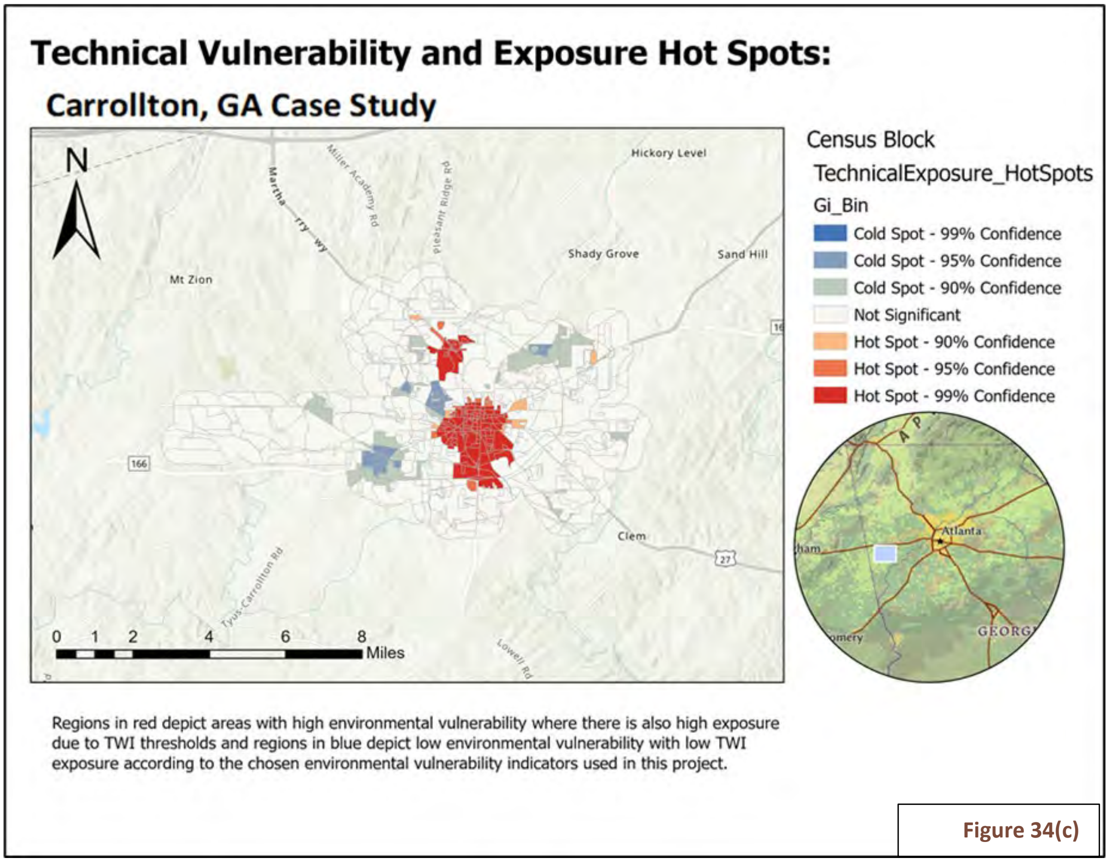


Figure 34: Inland Flood Risk – Carrollton

Conclusion

Comparison Across Cases

All case studies in this report followed a very similar trend. In every case study, technical vulnerability was highest toward the city center and major highways due to the large impervious surface percentages. Ecological vulnerability was also high toward the city center due to the absence of green spaces, and in case studies with large rivers the ecological vulnerability was high surrounding the rivers. Exposure data tended to correlate closely with ecological and technical data. Furthermore, some categories of social vulnerability such as population density correlated strongly with exposure, ecological, and technical vulnerabilities.

The other similarity in the I-SETS approach for all cities was there was generally a story that unfolded regarding social vulnerability. In all case studies, there was physical infrastructure that divided the city creating communities (usually found to the south) correlated with low median incomes, and other communities (usually found in the north) correlated with high median incomes. These areas of low median incomes also had high percentages of minority populations, especially Black or African American populations, and lower percentages of High School Diplomas and English-Speaking populations. These regions of the city are underrepresented in local, statewide, and national governance, creating a social equity issue with various types of social vulnerability. This vulnerability was apparent in this study's inland flood risk analysis, but these regions of the city are likely at risk for a long list of natural, economic and other hazards that have shown up in the past and will continue to show up in the future. As the Recommendations section of this report states, it is vital that local and statewide agencies focus appropriate resources on these regions of the city, as these populations are some of the most vulnerable and also have the lowest capacity to adapt to hazards such as inland flooding. This is particularly urgent as the frequency and magnitude of these hazards are expected to increase with the changing climate.

An important institutional observation is that most of the case studies examined in this report are majority-minority cities. The case studies in this project were selected from an initial statewide analysis to identify major hot spots for inland flooding in the state of Georgia. A noteworthy finding from this initial analysis is that Atlanta, Austell, and Albany, which were found to be the three most visibly risk-prone cities to inland flooding, also have populations that are majority-minority, with much higher percentages of Black or African American populations in comparison with state and national averages. The one case study that was not majority-minority, Carrollton, was selected because there was relatively good quality data in the AT&T/Argonne dataset for this city; Carrollton was not selected as a case study based on the results of the statewide analysis. These findings indicate that cities with higher minority populations also appear to have higher overall inland flood risks.

Summary of Findings with Recommendations

<u>1. Racial minority communities are hot spots for inland flood risk.</u>
Finding: The overarching finding from this study is that communities that have a history of flooding with majority racial minority populations are likely to be most at risk to inland flooding in the state of Georgia, and possibly elsewhere, and ought to be prioritized for the development of community resilience to inland flooding.| *Recommendation - to agencies involved in*

comprehensive planning (i.e., Metropolitan Planning Organizations (MPOs), Regional Commissions and others): In addressing community resilience to inland flooding, prioritize communities that have racial minorities in the majority with history of inland flooding.

2. Inland flooding vulnerabilities and interventions are both interdisciplinary.
Finding: The study indicates that solutions to inland flooding risk must necessarily include technical and non-technical interventions in order to be effective and cost-effective. In particular, combinations of social, ecological and technical interventions to reduce vulnerability and adapt communities to existing and changing hazards are likely to serve communities better in the long run. Viewing the inland flooding problem solely as a social or technical or ecological problem can come with potentially significant opportunity costs. Solutions to this problem do not lie neatly within any particular discipline: they cut across multiple disciplines and thus require interdisciplinary efforts for superior solutions. The findings from the Austell case study in particular indicate that it may be extremely difficult to find cost-effective technical solutions to inland flooding threat in some communities. *Recommendation – to communities, municipal agencies, MPOs and RCs, and state-level and federal-level agencies supporting comprehensive planning and hazard mitigation*: Adopt robust transdisciplinary approaches (holistic approaches including multiple disciplines and stakeholders) to address inland flooding.

3. Innovative institutions necessary to address inland flooding in a timely manner.
Finding: Innovative institutions will be helpful for timely development of community resilience Institutional capacity to address inland flooding is correlated with the relative affluence of communities. This finding indicates that it is highly likely that the populations at the highest risk to inland flooding in the state of Georgia, and possibly elsewhere, are also those that are least equipped institutionally to address these risks. Addressing inland flooding risks in a timely manner may therefore require institutional innovations. High-risk communities with minority populations in the majority can work though appropriate civic organizations to partner with academic institutions, private consultants and public agencies creating innovative arrangements to co-produce and implement appropriate community resiliency strategies. These interventions will necessarily aim to reduce social, technical and ecological vulnerability in hot spots. Referenced as a megacommunity model in some contexts (Gerencser et al. 2008), such innovative institutions are already in operation. Examples include the Smart Cities and Inclusive Innovation model at Georgia Institute of Technology, the United States Department of Transportation's Smart Cities Challenge model, the AT&T Climate Resilience Community Challenge model, and others. While the examples given were initiated by entities in the academic sector, the public sector and private sector, respectively, addressing inland flooding risk in some of the highest-risk communities, with the urgency it requires, may also call for civic organizations to lead the efforts needed to create appropriate megacommunities to address critical flooding risks within these communities. *Recommendation – to civic organizations that work with communities where racial minorities are in the majority*: Prioritize and lead the development of megacommunities to address inland flood risks in communities where racial minorities are in the majority, in a timely manner.

4. Climate change considerations must be formally incorporated in planning.
Finding: For communities with moderate to high levels of exposure to inland flooding hazards, moderate to high levels of vulnerability, and the capacity to adapt, there will be value in incorporating climate change as a formal consideration in the comprehensive planning and decision making process, as the climate continues to change in the future. The uncertainties that

make it difficult to predict climate-related hazards with high confidence levels also make it wise to explore and understand the major sources of a community's vulnerability to climate hazards, and to assess, prioritize and make investments in adaptations and mitigation to reduce the community's vulnerability to these hazards. *Recommendation – to planning agencies in communities with urban flooding as an emerging threat*: Incorporate climate considerations in comprehensive planning.

<u>5. It is important for stakeholders to be aware of, identify and incorporate in planning and decision making the physical-vulnerability divides within communities.</u>
Finding: The results of this analysis show there are distinct divides in areas that are highly vulnerable to inland flooding and these divides generally held throughout the indicators. Many times, these divides were associated with physical barriers such as major roadways, railways, and rivers. Understanding these physical-vulnerability barriers can help guide city resources toward vulnerable regions in a city. Improving inland flood vulnerability in a highly vulnerable region of the city may also decrease vulnerability to a variety of other hazards. *Recommendation – to city planners and other practitioners, academics, government officials and civic leaders*: Incorporate geographical divides (e.g., physical infrastructure, natural features) as possible delineators of vulnerable communities in climate vulnerability and risk assessments.

<u>6. Data limitations abound in vulnerability and risk analyses for inland flooding.</u>
Finding: Vulnerability analyses such as the SETS approach become much more difficult to perform with limited data. For many of the case studies, we used eight social indicators, two ecological indicators, and one technical indictor (the one exception being Atlanta, which had 4 technical indicators). The lack of available ecological and technical indicators made this approach less conclusive than if extensive data has been available. Collecting and harvesting data allows for studies that can determine the geographical strengths and weaknesses of a region with a variety of risks. Investments in data downscaling and big data analysis will allow communities to take advantage of the latest datasets to appropriately understand existing and changing threats, and prepare better for them. *Recommendation – to public agencies and other stakeholders*: Create public data warehouse to increase data availability for conducting vulnerability and risk analysis for climate hazards.

<u>7. Vulnerability indicators are correlated.</u>
Finding: Several vulnerability indicators were found to be correlated. For example, in nearly every case study there were certain populations correlated with low high school diploma rates, which was then correlated with low median incomes. Improving one vulnerability indictor has the potential to impact other correlated indicators. Results from this study only show correlation, not causation, but it is likely there is causation between many of these indicators. *Recommendation – to city planners*: Explore correlations between vulnerability indicators to further to understand which root causes can be addressed to positively impact vulnerability in several indicators.

<u>8. Institutions are a key factor in climate vulnerability and risk analyses.</u>
Finding: Formally adding institutional consideration to the SETS approach resulted in a variety of key findings. Institutional vulnerability is likely to be a factor that contributes to elevated inland flood risk in less affluent jurisdictions. The study identified essential governance functions for communities with elevated inland flood risk, including climate resilience planning, stormwater management as part of integrated water management, green infrastructure planning

and implementation, floodplain management including zoning ordinances and land use regulations to control development in the floodplain, and multi-jurisdictional cooperation for floodplain management. *Recommendations – to communities, public agencies, researchers and other stakeholders*: Incorporate institutions formally in climate vulnerability and risk analysis and develop institutions to support local communities to prepare for, withstand, quickly recover from, adapt to and mitigate the causes of inland flooding and other climate hazards.

9. <u>Public awareness is a key strategy for developing community resilience to inland flooding</u>.
Finding: Public awareness of climate hazards is a key foundation for the development of community resilience. Governmental programs such as the Community Rating System have been established to help increase awareness of floodplains, and it is important local governments are communicating with their citizens. While there is a growing number of small locations where property values are increasing as a function of elevation, there is a general lack of awareness of the heightening risk of inland flooding reflected in the continuing appreciation of property in high-risk zones. FEMA flood maps are difficult to read and require a level of computer savvy that many people do not have. However, conducting online searches using "Flood Maps", "Flood zones", "How do I know if I am in a flood zone?", etc., all return FEMA flood maps for the user to determine their level of risk. Flood Factor is an example of a much better tool that is user friendly and gives clear descriptions and data. The accessibility of flood risk data and floodplain information is essential in addressing the issue of inland flooding. Enhanced community awareness, coupled with early warning systems, can augment community resiliency appreciably.
Recommendation – to communities and local agencies involved in flood and floodplain management: Create effective local campaigns on inland flood risk coupled with early warning systems. Use of increasingly available visualization tools can be helpful - e.g., making information readily available through mobile apps.

10. <u>Technology applications are a key part of an effective strategy to develop community resiliency to inland flooding.</u>
Finding: Technology, together with stormwater infrastructure expansion, and the reduction of social and ecological vulnerability can aid in the development of community resiliency to inland floods. Multi-faceted interventions to develop community resilience to inland flooding are more robust than single-faceted solutions. For example, the use of sensors in improved flood monitoring, enhanced flood warning systems augmented with local data collection, increased uses of porous/pervious pavements for appropriate functions, incorporation of green infrastructure projects with appropriate stormwater infrastructure expansion projects, enhancing public awareness, incorporating citizen science, and disincentives to building in the floodplain can all be part of an effective strategy to reduce vulnerability to inland flooding.
Recommendation – to communities, public agencies and other stakeholders: Incorporate appropriate established and advanced technologies in the creation of a robust multi-dimensional strategy for developing community resilience to inland flooding. Real-time information delivery from sensors to key decision makers and possibly the public can notably augment community resilience.

11.<u>Historical analysis is a key element of climate hazard and vulnerability analyses.</u>
Finding: Historical analysis is a key element of climate hazard and vulnerability analyses to avoid piecemeal actions and reduce opportunity costs of actions in the system. The analysis results indicate that snapshot analyses may be insufficient to properly characterize the nature of

the threat. *Recommendation – to communities, public agencies and other stakeholders*: Incorporate historical analysis to properly characterize the nature of the threat.

12. Analysis approach must be both problem-focused and opportunity-driven.
Finding: The study indicates it is important to approach climate hazard analysis, vulnerability analysis and system resilience development in both a problem-focused and opportunity-driven manner in the context of broader quality of life, economic advancement and environmental preservation/restoration goals in order to aim for superior solutions in this multi-objective space and reduce the opportunity costs of actions taken. To treat flood resilience as a single objective problem may produce short-term fixes, unintended consequences on other critical community goals, and/or exacerbations of the problem in the long run with avoidable opportunity costs. For example, in some cases, development in the floodplain will have to be curtailed to address inland flooding threat effectively. Devising superior and long-term solutions in this context will necessarily require a good understanding of the forces at play in floodplain development, and a willingness to explore, and adopt a portfolio of strategies including effective public awareness programs, zoning ordinances, land use regulations, enhanced warning systems, applications of sensor networks for enhanced data collection, and drainage system cleaning and expansions. *Recommendation to communities, public agencies and other stakeholders – Incorporate flood resilience considerations as part of the overall formal comprehensive planning process for municipalities and metropolitan regions, with an intentional dual focus on negative risks and positive opportunities*.

Limitations

The first major limitation to the report was vulnerability data availability. Ecological and technical data was difficult to access in all case studies except for Atlanta. The ecological and technical indicators chosen in the case studies used nationally collected data on land. This data provided valuable insight to inland flood vulnerabilities but could have been improved upon by including in critical infrastructure. Even in the City of Atlanta case study we were unable to obtain some of the necessary data - such as Stormwater Infrastructure data. The City of Atlanta was overhauling its Stormwater Infrastructure and therefore could not share the data for our research. Ideally, this type of analysis could be performed with unlimited data and the most relevant data sources would be chosen from a wide range of options. Due to data limitations, we were not able to perform the analysis in this manner and instead used the literature to support the data we chose and left out the data we could not obtain.

The second limitation to consider is AT&T's inland flood dataset. There were large gaps in the AT&T dataset, mostly surrounding large cities. The dataset contained approximately 100 flood inundation levels per 1 square mile with each adjacent point value approximately 600 feet apart. Of the total number of possible points in the dataset, 3% contained an inundation level and 97% had a null value. AT&T's data did not include all flood inundation values less than 0.5 feet, and this led to the issue where there were large regions without any data. Future datasets will add more value if inundation levels are included for all points, or if the threshold value is lowered. The AT&T data provided 10% and 2% (10-year and 50-year) flood return periods whereas the standard is 1% and 0.2% periods (100-year and 500-year) flood return periods. The AT&T data can be extrapolated to the standard flood return periods. However, future datasets will be more accessible to communities and public agencies they are aligned with the flood return period standards set by FEMA.

The third limitation that must be addressed is scale. Social vulnerability data is available for the entire state of Georgia at the Census Block Group level; however the values for many social vulnerability factors have large margins of error. The Census Blocks with lower populations had noticeable error margins which can contribute to inaccuracies in the results. Furthermore, we conducted the analysis at the Census Block level which provided a more detailed analysis for the ecological and technical indicators, but not for the social indictors as the social data was not available at the smaller scale. Also, the scale selection resulted in effective hot spot maps for larger cities such as Atlanta and Albany, but less effective hot spot maps for smaller cities such as Austell and Carrollton. Hot Spot Analyses work better with many elements in the analysis. The larger cities had enough Census Blocks and Census Block Groups that abnormalities in the data could be overlooked, but the smaller cities had a greater potential for error in the Hot Spot Analysis results.

The final limitation to consider is the exposure data used in this report. TWI values are related to inland flood exposure, but TWI values are not directly representative of these exposures. Climate change can have a massive impact on which regions are exposed to flooding. Furthermore, localized flooding can be impacted greatly by malfunctions to stormwater systems, new critical infrastructure, construction sites and other factors. By utilizing AT&T's dataset we were able to improve the exposure data used in this report by considering climate change. However, inland flood exposure is very difficult to determine and while most this report is focused upon inland flood vulnerability, predicting inland flood exposure is just as challenging a task.

Acknowledgement

The Research Team acknowledges and expresses appreciation to AT&T for sponsoring this study and to Argonne National Laboratory for their role in developing pertinent climate hazards exposure data for resilience planning. The team also acknowledges and thanks internal and external partners for their high levels of engagement with and support of the project. In particular, we acknowledge and thank the Atlanta Regional Commission, Metropolitan North Georgia Water Planning District, City of Atlanta Department of Watershed Management, and the Center for Serve-Learn-Sustain and the Smart Cities and Inclusive Innovation Initiative at Georgia Institute of Technology - for their collaboration and support of the project, The Team also acknowledges the following academics and practitioners for their detailed review of the report: Dr. Heejun Chang, Professor, Department of Geography, Portland State University, and Emma Bones, P.E., Water Resources Engineer, Dewberry, Atlanta. Finally, we acknowledge Jenna Krieger, M.S. student in City Planning and Civil Engineering, and, Ashlee Bryant, B.S. student in the School of Architecture at Georgia Institute of Technology for their contributions to the research. The authors remain exclusively responsible for the contents of the report.

References

American Institutes for Research. 2005. *A Chronology of Major Events Affecting the National Flood Insurance Program*. Washington, DC: Federal Emergency Management Agency.

Arnold, Joseph L. 1988. *The Evolution of the Flood Control Act of 1936*. Fort Belvoir, VA: Office of History United States Army Corps of Engineers.

Atlanta Regional Commission. *Atlanta Region Population Estimates*. https://atlantaregional.org/atlanta-region/population-forecasts-estimates/atlanta-region-population-estimates/ Accessed: August 4, 2020.

Berube, A. City and metropolitan income inequality data reveal ups and downs. *Blog on Report.* Brookings Institution, February 5, 2018. https://www.brookings.edu/research/city-and-metropolitan-income-inequality-data-reveal-ups-and-downs-through-2016/ Accessed August 4, 2020.

Bourget, Lisa. 2011. *Flood Risk Management Approaches: As Being Practiced in Japan, Netherlands, United Kingdom, and United States*. Alexandria, VA: United States Army Corps of Engineers Institute for Water Resources.

Bureau of Public Roads (BPR). Policy on Interstate System Projects. PPM 20-4, August 10, 1956.

City of Atlanta. Resilient Atlanta. Actions to Build an Equitable City. 2017.

City of Austell. Envision Austell Comprehensive Plan Update 2017.

Chang, H., Baker, A. M., Starry, O., and Chen, J. (2020). "Seasonal variation in hydrologic performance of Eco roofs of multiple depths– a case study in Portland, Oregon, USA." Urban Water Journal, Taylor & Francis.

Chang, H., Pallathadka, A., Sauer, J., Grimm, N., Zimmerman, R., Cheng, C., Iwaniec, D., Kim, Y., Lloyd, R., McPhearson, T., Rosenzweig, B., Troxler, T., Welty, C., Brenner, R., Herreros-Cantis, P. (in review) Assessment of Urban Flood Vulnerability Using the Social-Ecological-Technological Systems Framework in Six US cities, Sustainable Cities and Society.

Chang, H., Pallathadka, A., Sauer, J. Grimm, N., Zimmerman, R. et al. (2020). Urban flood vulnerability analysis: From vulnerability mapping to resilience planning. presentation at the UREx All hands virtual meeting. April 2, 2020.

Carter, R.W. 1951. *Floods in Georgia: Frequency and Magnitude*. State Highway Department of Georgia and the Georgia Department of Mines, Mining, and Geology.

Centers for Disease Control and Prevention. 1996. "Deaths Associated with Hurricanes Marilyn and Opal – United States, September-October 1995" (January 19). Online at: https://wonder.cdc.gov/wonder/prevguid/m0040000/m0040000.asp

City of Carrollton. 2020. "Our History." Online at: https://carrolltonga.com/about-carrollton/our-history/

Daughters of the American Revolution, Thronateeska Chapter, 1924. *History and Reminiscences of Dougherty County*.

Data USA. https://datausa.io/profile/geo/austell-ga/, Accessed June 5, 2020.

Department of Numbers. Georgia Household Income. https://www.deptofnumbers.com/income/georgia/, Accessed June 6, 2020.

Eidson, Stacy. 2014. "The Great Flood," Metro Spirit Newsletter (December 17). Online at: http://metrospirit.com/great-flood/).

Formwalt, Lee W. "Albany." *New Georgia Encyclopedia*. 04 May 2020. Web. 21 July 2020.

Fahy, B., Brenneman, E., Chang, H., and Shandas, V. (2019). "Spatial analysis of urban flooding and extreme heat hazard potential in Portland, OR." *International Journal of Disaster Risk Reduction*, 39, 101117.

Federal Emergency Management Agency (FEMA). The National Flood Insurance Program. https://www.fema.gov/flood-insurance, Accessed: July 30, 2020.

Federal Highway Administration (FHWA), U.S. Department of Transportation. Highways in the River Environment – Floodplains, Extreme Events, Risk and Resilience. Hydraulic Engineering Circular No. 17, 2nd Edition. June 2016.

Gerencser, M., Kelly, C., Napolitano, F., and R. Van Lee. How Leaders of Government, Business and Non-Profits can Tackle Today's Global Challenges Together. Booz, Allen & Hamilton, Inc. 2008NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2020).
https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73, Accessed May 4, 2020.

Haeuber, Richard A; Michener, William K. 1988. "Natural flood control," *Issues in Science and Technology*, Vol 15 (No. 1), pp. 74-80.

House, Myron W. "Carrollton." New Georgia Encyclopedia. 08 October 2015. Web. 31 July 2020.

Karr, Donny. 2018. "Flash Floods Impact Carrollton," *The City Menus* (July 15). Online at: https://thecitymenus.com/2018/07/16/severe-flooding-impacts-carrollton/.

Morris, Susan D. "Flint River." *New Georgia Encyclopedia*. 26 July 2017. Web. 21 July 2020.

Markolf, S., Chester, M., Eisenberg, D., Iwaniec, D., Ruddell, B., Davidson, C., Zimmerman, R., Miller, T., Chang, H. (2018) Interdependent Infrastructure as Linked Social, Ecological, and Technological Systems (SETS) to Address Lock-In and Improve Resilience, Earth's Future 1638-1659.

National Weather Service. 2018. "Hurricane Michael Hits Georgia" (October 10). Online at: https://www.weather.gov/ffc/2018_hurricane_michael

National Weather Service. 2020. "Flint River at Albany" (July 30). Online at: https://water.weather.gov/ahps2/hydrograph.php?gage=abng1&wfo=tae

National Weather Service: https://water.weather.gov/ahps2/hydrograph.php?wfo=ffc&gage=cang1

National Research Council. 2015. *Affordability of National Flood Insurance Program Premiums: Report 1*. Washington, DC: The National Academies Press.

NOAA National Centers for Environmental Information (NCEI) U.S. Billion-Dollar Weather and Climate Disasters (2020). https://www.ncdc.noaa.gov/billions/, DOI: 10.25921/stkw-7w73, Accessed May 4, 2020.

Open Data Network. *Data for Atlanta Metro*. https://opendatanetwork.com/entity/310M200US12060/Atlanta_Metro_Area_GA/economy.gdp.per_capita_gdp?year=2017 Accessed August 4, 2020.

Perry, J. Austell faces rising danger at juncture of five creeks. AJC special investigation: Developers ignore years of warnings about this Cobb city and its 5 creeks. https://www.ajc.com/news/local/austell-faces-rising-danger-juncture-creeks/ln7ONviQMbQfcSntlddHnN/, Accessed June 5, 2020.

Planning, Development Services & Code Enforcement, City of Albany, Georgia. 2017. *Albany Dougherty Flood Hazard Mitigation Plan Annual Progress Report*. Online at: https://www.albanyga.gov/home/showdocument?id=566.

Planning for Hazards – Land Use Solutions for Colorado. Accessed at: https://planningforhazards.com/community-rating-system, Accessed: July 29, 2020.

Powell, K. L. *Atlanta's Stormwater Management Program.* National Stormwater Roundtable, City of Atlanta Department of Watershed Management, February 20, 2018.

Qiang, Y., Lam, N. S. N., Cai, H., and Zou, L. (2017). "Changes in Exposure to Flood Hazards in the United States." *Annals of the American Association of Geographers*, Taylor & Francis, 107(6), 1332–1350.

Ravitz, Jessica. 2009. "Mother recalls night flood changed everything," CNN.com. Online at: https://www.cnn.com/2009/US/09/23/carroll.county.flood.death/index.html

Rhone, N. *No simple solutions to stormwater challenges*. Atlanta Journal-Constitution. Local Spotlight: Too much Water. July 11, 2020.

Reiberg, Beth. 2013. “Vintage Albany – Historic Floods,” *The Albany Journal*, September 26, 2013.

Seegmueller, Tom. 2019. “The Flood of 1994,” *The Albany Herald* (July 6).

Sayers, Paul; Yuanyuan, Li; Galloway, Gerald; Penning-Rowsell, Edmund; Fuxin, Shen; Kang, Wen; Yiwei, Chen; Quesne, Tom Le. 2013. *Flood Risk Management: A Strategic Approach*. © Asian Development Bank, GIWP, UNESCO and WWF-UK.

Tarlock, A. Dan. 2012. “United States Flood Control Policy: The Incomplete Transition From the Illusion of Total Protection to Risk Management, *Duke Environmental Law & Policy Forum*, Vol. 23 (Fall), pp. 151-183.

Tarlock, A. Dan; Chizewer, Deborah M. 2016. “Living with water in climate-changed world: Will federal flood policy sink or swim,” Environmental Law, Vol. 46 (3), pp. 491-536.

United States Army Corps of Engineers. South Atlantic Division. Mobile District.
Sweetwater Creek Flood Risk Management Feasibility Study. Final Integrated Feasibility Report and Environmental Assessment. May 2019.

U.S. Department of Transportation Federal Highway. 2016. Hydraulic Engineering Circular No. 17, 2nd Edition. Publication No. FHWA-HIF-16-018 June 2016.

United States Census Bureau. American Community Survey. Household Income: 2018. https://www.census.gov/content/dam/Census/library/publications/2019/acs/acsbr18-01.pdf, Accessed June 6, 2020.

USGS. (2020). “TNM Download v2.” <https://viewer.nationalmap.gov/basic/#/productGroupSearch> (Dec. 6, 2020).

Urban Resilience to Extremes (UREx). Challenges and Solutions. https://sustainability.asu.edu/urbanresilience/, Accessed June 7, 2020.

United States Census Bureau. QuickFacts, Atlanta City, Georgia. https://www.census.gov/quickfacts/atlantacitygeorgia Accessed August 4, 2020.

United State Environmental Protection Agency. What Climate Change Means for Georgia. EPA 430-F-16-012. August 2016.

University of West Georgia website. Online at: https://www.westga.edu/about-uwg/index.php.

Vanishing Georgia, Georgia Archives, University System of Georgia. Online at: https://vault.georgiaarchives.org/digital/collection/vg2/id/5373.

Wikipedia, https://en.wikipedia.org/wiki/Atlanta_metropolitan_area#Demographics

Weaver, D. Remarks on the City of Austell's Economic Development Plans and Flood Risks made during a proposal development meeting for the Georgia Tech Smart Cities Challenge. June 5, 2020.

White, G. F. "Human Adjustment to Floods – A Geographical Approach to the Flood Problem in the United States." Research Paper 29, The University of Chicago, Dissertation (dissertation completed 1942), 1945, pp. 179 – 181.

Wikipedia. List of U.S. States and Territories by Poverty Rate. https://en.wikipedia.org/wiki/List_of_U.S._states_and_territories_by_poverty_rate, Accessed June 6, 2020.

Wikipedia. Sweetwater Creek (Chattahoochee river tributary). https://en.wikipedia.org/wiki/Sweetwater_Creek_(Chattahoochee_River_tributary), Accessed June 7, 2020.

Wolf, G. "FHWA Information – Disaster losses and other hazard related statistics," personal communication, FHWA Office of Program Administration, Emergency Relief program, Washington, D.C., March 30, 2016.

World Population View (WPV). https://worldpopulationreview.com/us-cities/austell-ga-population/, Accessed June 5, 2020.

Appendix

Appendix A: Case Study Method Details

The section below provides an overview of key steps and useful notes for in conducting the case studies.

Step 1: Assemble Case Study Details

Case Study	Scale 1: (Census Block Group)	Scale 2: (Census Block)	Justification
City of Atlanta	321 CBGs	7063 CBs	Statewide Risk-Analysis Results
Albany	61 CBGs	2283 CBs	Statewide Risk-Analysis Results
Austell	10 CBGs	442 CBs	Quality of AT&T data
Carrollton	27 CBGs	883 CBs	Statewide Risk-Analysis Results

Step 2: Select Indicator, Hazard and Scale of Analysis

<u>Data Resolution summaries:</u>

Hazard Data:

TWI data was used for all case studies. The process of obtaining TWI values is expanded upon in (Section X). TWI data was available at a 10m by 10m resolution, so the Census Block analysis has more accurate values than the Census Block Group analysis.

Social Vulnerability Data:

The same social data and categories were used for all case studies. The social vulnerability data was available at a Census Block Group level. Therefore, the social data for the Census Block analysis is the same as the social data for the Census Block Group analysis. All Census Blocks that lie in the same Census Block Group have the same social vulnerability values.

Ecological/Technical Data:

Green Space, Impervious Surface, and AB Soil percentage were available and used for all case studies. Green Space and Impervious Surface data is available at the 30m by 30m resolution. Therefore, the Census Block analysis has more accurate values than the Census Block Group analysis for all case studies. The AB Soil is available at a 10m by 10m scale and therefore also has more accurate results for the Census Block scale than Census Block Group scale

For the City of Atlanta Census Block Group analysis there was additional data available. Green Infrastructure was available as point data for the city. Also, building data was available as a shapefile (each polygon of the shapefile being a building). This data was only used at the Census Block Group scale due to the number of elements in these datasets compared to the Census Blocks in the City of Atlanta.

Step 3: Conduct Mapping and Hot Spot Analysis

Indicators:

Indicator	Vulnerability
Population Density	Red Region
Median Income	Blue Region
Age Over 65	Red Region
No HS Diploma	Red Region
Limited English	Red Region
Black or African American	Red Region
Asian	Red Region
Hispanic	Red Region
Green Space	Blue Region
AB Soil	Blue Region
Impervious Surface	Red Region
Green Infrastructure Density	Blue Region
Building Age	Blue Region
Building Stories	Blue Region

Indicators that have Red Regions listed as vulnerable have a positive correlation between such indicator and inland flood vulnerability (i.e. Higher Population Densities show Higher Inland Flood Vulnerability).
Indicators that have Blue Regions listed as vulnerable have a negative correlation between such indicator and inland flood vulnerability (i.e. Higher Median Incomes show Lower Inland Flood Vulnerability).

Step 4: Analyze Indicator-Indicator and Indicator-Hazard Correlations

Correlations determined using Pearson Correlation Coefficient and ArcGIS's Exploratory Regression tool.

Step 5: Generate Vulnerability Index

Social:

Category 1: Population Density
Vulnerable if region is in **highest** 25th percentile of population density.

Category 2: Median Income
Vulnerable if region is in **lowest** 25th percentile of median income.

Category 3: Age over 65
Vulnerable if region is in **highest** 25th percentile of people aged over 65.

Category 4: Education Level (No HS Diploma -OR- Limited English)
Vulnerable if region is in **highest** 25th percentile of without a High School Diploma OR in the **highest** 25th percentile of households that speak limited English.

Category 5: Race/Ethnicity (Black/African American -OR- Asian -OR- Hispanic)
Vulnerable if region is in **highest** 25th percentile of Black or African American populations OR in the **highest** 25th percentile of Asian populations OR in the **highest** 25th percentile of Hispanic populations.

The index value is determined by counting the number of categories the region is socially vulnerable in, then dividing the value by ‘5’ for the 5 categories considered.

Ecological:
Category 1: Green Space
Vulnerable if region is in **lowest** 25th percentile of Green Space.
Category 2: AB Soil
Vulnerable if region is in **lowest** 25th percentile of AB Soil.

The index value is determined by counting the number of categories the region is ecologically vulnerable in, then dividing the value by ‘2’ for the 2 categories considered.

Technical:
Category 1: Impervious Surface
Vulnerable if region is in **highest** 25th percentile of Impervious Surface.
Category 2 (ATL, CBG only): Green Infrastructure Density
Vulnerable if region is in **lowest** 25th percentile of Green Infrastructure Density.
Category 3 (ATL, CBG only): Building composition (Building Age -OR- Building Stories)
Vulnerable if region is in **lowest** 25th percentile of building ages OR in the **lowest** 25th percentile of building stories.

The index value is determined by counting the number of categories the region is ecologically vulnerable in, then dividing the value by ‘1’ for the 1 category considered, or dividing the value by ‘3’ for the 3 categories considered in the City of Atlanta Census Block Group analysis.

Table A1 provides a summary of the case study indicators and their sources.

Table A1: Case Study Indicators

Indicator	SETS Category	Source
1. Population Density 2. Median Income 3. Age over 65 4. Education a. Limited English b. No High School Diploma 5. Race/Ethnicity a. Black or African American b. Asian c. Hispanic	Social	ACS
1. Percentage of Green Space 2. Percentage of A/B Soil Type	Ecological	MRLC.gov
1. Percentage of Impervious Surface	Technical	MRLC.gov

2. Green Infrastructure Density 3. Building Data a. Average Building Age b. Average Building Stories		

Appendix B: Evolution of National Floodplain Institutions

Floodplain development policies and decisions affect the overall exposure of communities and their civil infrastructure assets to extreme events, particularly flooding. Federal policy, regulations, and guidance, as well as good engineering judgment regarding the location of facilities and infrastructure and their design in floodplains contribute to the frequency, nature and degree to which communities and their infrastructure assets experience flooding over their lifetimes. Federal floodplain policy provides the broad goals and limitations within which the U.S. conducts scientific, planning and engineering activities. Relevant statutes, regulations, executive orders and guidance shape federal floodplain policy (FHWA 2016).

Floodplain management in the U.S. stems largely from the federal system, with power shared among federal, state and local governments. The evolution of federal flood management policy may be viewed across four eras: Pre-Federal Flood Policy (1789 – 1935), Recognizing the Need for Federal Flood Policy (1930 – 1970), Maturing Federal Flood Policy (1970 – 2000) and 21st Century Policy (2000 onwards) (FHWA 2016, Other citations). The period prior to 1935 was characterized by debates between advocates of an increased federal role in flood control and those who believed that the U.S. Constitution forbade it. A succession of path-breaking laws and executive orders followed the Federal Flood Control Act of 1936 through 1969. The third stage (1970 – 1999) was characterized by efforts to create a coordinated system of flood control and an emerging focus on environmental protection. The ongoing fourth stage is characterized by efforts to modify floodplain management to address the challenges posed by climate change.

Phase I: State-Directed Federal Flood Policy (1789 – 1935): From the convening of the first Congress in 1789 through 1936, no legislation was enacted to create a nationwide system of flood control owing to the founding fathers believing that the Constitution forbade expenditure of federal tax monies on projects that benefited only a local constituency (Arnold 1988, 4). The Flood Control Act of 1917 marked the first time that Congress appropriated funds specifically for flood control and improvements in riverine navigation, requiring local governments to allocate one dollar for every two dollars authorized by Congress. Simultaneously, the Corps of Engineers were authorized to undertake surveys to assist in flood control, navigation and other uses (Tarlock 2012, 158; Tarlock and Chizewer 2016, 502; and Arnold 1988).

Massive flooding on the Mississippi River in 1927 moved Congress to pass the Flood Control Act of 1928 focused on reservoirs, channel improvements and floodways on the Mississippi (Tarlock 2012, 159); however major flooding in 1935 and 1936 led to the passage of the Flood Control Act of 1936 a wide-ranging legislation marking a shift in state-federal responsibility.

Phase II: Recognizing the Need: Prior to 1936, there was no national flood-control program. Significant devastation caused by flooding drove home the need for a national program: floods caused roughly 9,000 highway bridge failures from 1900 to 1937, with the floods occurring between 1935 and 1936 alone resulting in the loss of over 900 highway bridges (White 1945). Marking the beginning of flood control legislation and the period of recognition of the need for flood management, the Flood Control Act of 1936 tasked the Department of Agriculture with developing plans to retain more rainfall upstream while the Corps of Engineers was tasked with constructing dams, levees and other flood control measures downstream (Tarlock 2012, 162).The law was augmented by the Watershed and Flood Protection act of 1954 which required the construction of flood control infrastructure in upstream drainage systems.

In 1966, President Johnson transmitted to Congress House Document (HD) 465: "A Unified National Program for Managing Flood Losses" – the beginning of a coordinated national floodplain management program in the U.S. to reduce flood losses and provided Congress with a report prepared by the Task Force on Federal Flood Control Policy (Task Force on Federal Flood Control Policy 1966.) The Task Force made a case for the use of nonstructural and structural approaches to reduce flood losses. HD 465 recommended the development of uniform national flood frequency guidelines, establishment of a federal flood insurance program, and that federal agencies conduct flood hazard evaluations before taking actions in a floodplain.

Simultaneously in 1966, President Johnson issued Executive Order (EO) 11296: "Evaluation of Flood Hazard in Locating Federally Owned or Financed Buildings, Roads and Other Facilities, and in Disposing of Federal Lands and Properties (EO 11296, 1966)". The Order required executive agencies in the federal government to lead in encouraging an effort to prevent uneconomic use and development of floodplains in order to reduce the risk of federal-level flood losses.

In 1968, Congress passed the National Flood Insurance Act, a piece of landmark legislation that dramatically expanded the federal government's role in floodplain management. Groundwork for the law was laid in the Federal Flood Insurance Act of 1956, which directed "the Housing and Home Finance Agency to establish a program of federal insurance and reinsurance against the risks of losses resulting from floods and tidal disasters" (AIR 2005, 7). The National Flood Insurance Program of 1968 created National Flood Insurance Program (NFIP) and the Federal Insurance Administration to be housed within the Department of Housing and Urban Development (Tarlock 2012, 167; and Tarlock and Chizewer 2016, 505). Congress's purpose of the NFIP was twofold: to prod state and local governments to restrict development in areas prone to flooding, and to provide flood insurance through a cooperative public–private partnership funded by equitable cost sharing between the public and private sectors (National Resource Council 2015, 66).

Recognizing the risks associated with flooding and changing land use conditions, various federal agencies developed flood management policies and approaches with wide variation in scope and focus. The Bureau of Public Roads (BPR) for example required designs for all culverts and bridges over streams to "accommodate floods at least as great as that for a 50-year frequency or the greatest flood or record, whichever is greater, with the runoff based on the land development expected in the watershed 20 years hence and with backwater limited to an amount which will not result in damage to upstream property or to the highway." (BPR 1956)

Phase III: Coordinating Flood Control and Environmental Protection: From 1970 to 2000, efforts were made to coordinate federal, state, and local activities and to link flood control with environmental protection. The National Environmental Policy Act of 1970 explicitly coupled flood control and environmental protection by creating an institutional framework for assessing environmental concerns associated with river systems and coastal areas (AIR 2005, 14). Passage of the Flood Disaster Protection Act of 1973 further consolidated the federal government's role in flood control by prohibiting federal agencies from providing floodplain management assistance to communities that do not participate in the NFIP.

Several important policy developments took place during the Carter Administration. In 1977, Executive Order 11988 stipulated that federal agencies play an expanded role in reducing floodwater runoff by protecting and restoring wetlands (HEC-17, 2-3). EO 11988 required an environmental impact assessment of all proposed actions undertaken by federal agencies in a floodplain. EO 11988 required each federal agency to evaluate potential impacts of any proposed actions in the floodplain and ensure that planning, programs and budget requests reflect consideration of flood hazards and floodplain management. It required agencies to consult the Department of Housing and Urban Development's (HUD) floodplain maps in evaluating flood risk. EO 11988 defined "floodplain" as that area subject to a 1-percent chance of flooding in any given year. EO 11988 also required that construction of federal structures and facilities in the floodplain must be in accordance with the standards and criteria consistent with the intent of those under the National Flood Insurance Program (NFIP).

In addition, EO 11988 required federal agencies to consult with the Water Resources Council (WRC) and the Council for Environmental Quality, a pair of White House-related divisions, groups, to ensure proper policy coordination (HEC-17, 2-3). Considered a milestone in federal floodplain policy and direction, EO 11988 changed and unified the manner in which federal agencies addressed floodplain management. In 1978 the WRC issued guidance "Floodplain Management Guidelines for Implementing EO 11988" providing agencies with consistent implementation guidance. The WRC report acknowledged that the nation's floodplains are experiencing (1) unacceptable and increasing flood losses and (2) degradation of the natural and beneficial values of floodplains. (FHWA 2016)

The Federal Emergency Management Agency (FEMA) was created in 1978. As stated in FEMA's mission statement, the agency's primary objective is to "reduce the loss of life and property and protect our institutions from all hazards by leading and supporting the nation in a comprehensive, risk-based emergency management program of mitigation, preparedness, response, and recovery." HUD's floodplain maps, now called "Flood Insurance Rate maps", are administered by FEMA.

In 1988, Congress passed the Robert T. Stafford Disaster Relief and Emergency Assistance Act. The chief aim of the Stafford Act aims to ensure a coordinated division of labor between federal agencies and state and local governments in mitigating exposure to flood risk and mounting an effective response in the event that disaster should strike. It directs state and local governments to prepare disaster mitigation plans and to encourage their citizens to purchase flood insurance coverage. The Act provides federal funds for disaster reconstruction and the acquisition of properties located in FEMA-designated Special Flood Hazard Areas (AIR 2005, 43). Two years after passage of the Stafford Act, the Community Rating System (CRS) of the NFIP was launched. This voluntary program incentivizes local communities to implement flood control measures that exceed the NFIP standards.

The catastrophic Midwest floods of 1993 prompted the Clinton Administration to create the Interagency Floodplain Management Review Committee. In 1994, that Committee issued the

Galloway Report, which emphasized the importance of protecting wetlands and called for more coordinated sharing of floodplain management responsibility among federal, state, and local governments and for restriction in areas prone to flooding (AIR 2005, 52).

Phase IV: Linking Flood Control with Climate Change (2000 – Present): During the past two decades, government's approach to floodplain management has begun to anticipate the effects of climate change and the need for increased stakeholder involvement. In 2000, Congress passed the Disaster Mitigation Act, amending the Stafford Act, with the aim of establishing a national program for pre-disaster mitigation, controlling federal costs for disaster assistance, and streamlining the administration of disaster relief. Most of the activity at the federal level in this fourth phase has come about from executive orders. In 2005, the Bush Administration's response to devastation wrought by Hurricane Katrina on New Orleans and the Gulf Coast in 2005 shed light on existing gaps. Among other things, Katrina drew attention to the inequitable vulnerabilities borne by the affected region's poorest residents and minority communities.

With a firm legal foundation laid, executive orders became the mode of choice in modifying the federal government's approach to floodplain management. In 2013, President Barak Obama issued an executive order establishing the Mitigation Framework Leadership Group (MitFLG), which was charged with developing a Federal Flood Risk Management Standard (FFRMS). The intention behind the creation of the FFRMS, issued in 2015, was that it serve as the basis of a national minimum flood risk management standard. That standard would set through a climate-informed science approach that would guide decision making in federal floodplain management.

The FFRMS considers future climate conditions with the aim of reducing the risk and costs of future floods on federal investments. MitFLG planned that FFRMS would be the basis of a national minimum flood risk management standard to ensure that federal actions located in or near the floodplain consider risks, changes in climate, and vulnerability. The FFRMS encourages use of natural features and nature-based approaches (generally known as 'green infrastructure') in alternatives development for federal action. In addition, FFRMS provides for an expanded floodplain to address current and future flood risks,

The FFRMS proposes that federal actions use one of the following three approaches to identify areas subject to flooding:

1. Apply the elevation and flood hazard area resulting from a climate-informed science approach (CISA) using the best-available, actionable hydrologic and hydraulic data and methods that integrate current and future changes in flooding based on climate science.
2. Apply the elevation and flood hazard area that result from using the elevation determined by adding 2 feet of freeboard to the base (that is, 1-percent change or 100-year) flood elevation for non-critical actions and by adding 3 feet of freeboard to the base flood elevation for critical conditions;
3. Apply the elevation and flood hazard area subject to flooding by the 0.2 percent chance flood (that is 500-year flood).

While the FFRMS prefers the climate-informed science approach (the other two approaches are considered surrogates of the first) it provides each agency with the freedom to decide on which approach(es) they wish to implement on a project-by-project basis. The FFRMS thus allowed agencies to choose on a project-by-project basis whether to stipulate that determination of flood elevation include additional freeboard on structures located in hazard zones or to apply the elevation and flood hazard area subject to a 0.2 percent chance of flooding (HEC-17).

Executive Order 13690 – issued in 2015 under the title "Establishing a Federal Flood Risks Management Standard and a Process for Future Soliciting and Considering Stakeholder Input" – established a process to seek public input on the environmental impact assessment of proposed action to be taken by federal agencies in the floodplain (HEC-17)

The National Flood Insurance Program (NFIP) had been modified several times over the years. The Biggert-Waters Flood Insurance Reform Act of 2012 was intended to reduce the NFIP's enormous cumulative debt by bringing insurance premiums better into line with the actual losses associated with flooding. Meanwhile, the Homeowner Flood Insurance Affordability Act of 2014 delayed the increases in flood insurance premiums dictated by the Biggert-Waters Act and spread the cost of lost premiums over the pool of about five million policy owners.

EO 13690 (2015): "Establishing a Federal Flood Risks Management Standard and a Process for Future Soliciting and Considering Stakeholder Input" does the following: (1) it amends the 1997 EO 11988 on Floodplain Management; (ii) institutes the FFRMS; and (iii) sets up a process to seek public input on associated updates to the 1978 Guidelines for Implementing EO 11988. EO 13690 replaces EO 11988's base (1 percent chance) flood elevation with the FFRMS approaches. The Executive branch of the federal government tasked the MitFLG to update the guidelines to aid agencies with implementing EP 11988, as amended. (FHWA 2016)

Despite the large investment in flood protection and prevention projects, flood damage continues to increase. As an example, while federal law currently provides for a Federal Highway Administration (FHWA) emergency relief program with an annual budget of $100 Million (Title 23 Section 125(c)(2)(A), the FHWA estimates the provision of $700 Million annually in emergency relief with the majority of those funds targeted to floods (Wolf 2016). The FHWA (2016) references the National Weather Service estimates that the 30-year average annual flood losses (through 2014) for the entire U.S. are $8 Billion in damages. National Oceanic Atmospheric Administration (NOAA) data shows that over the period from 1980 – 2019, the years with 10 or more separate billion-dollar disaster events include 1998, 2008, 2011-2012, and 2015-2019. In 2019, the U.S. had sustained 265 major weather and climate disasters since 1980 with the total costs of these events exceeding 1.775 trillion (NOAA 2020). Thus, federal floodplain policy has continued to evolve with growing recognition of the significant costs and implications of flooding threat to communities.

*The National Flood Insurance Program and the Community Rating System***:** The National Flood Insurance Program (NFIP) provides flood insurance to property owners, renters and businesses to enable them recover faster after flooding events. The NFIP also encourages communities to adopt and enforce floodplain management regulations that help mitigate the effects of flooding. Flood damages can be significant: an inch of floodwater may cause up to $25,000 in damage. As most homeowner's insurance does not cover flood damage, flood insurance can be purchased as a separate policy to cover buildings, the contents in a building, or both (FEMA).

The NFIP is managed by the Federal Emergency Management Agency and delivered to the public by a network of approximately 60 insurance companies and an online portal: NFIP Direct. National flood insurance is available to anyone living in one of the 23,000 participating NFIP communities. In high-risk flood areas, homes and businesses with mortgages from government-backed lenders are required to have flood insurance. Although FEMA administers the NFIP, it is really a partnership between the federal government, the property and casualty insurance industry, states, local officials, lending institutions and property owners. FEMA retains responsibility for underwriting flood insurance coverage sold under the NFIP and by the NFIP Direct. There are more than five million policyholders nationwide and the NFIP is the nation's largest single-line insurance program providing nearly $1.3 Trillion in coverage against flooding (FEMA).

The Community Rating System (CRS) of the NFIP was implemented in 1990 as a voluntary program to encourage communities to adopt and implement floodplain management activities that exceed the NFIP standards. The CRS is a voluntary, incentive-based community program that recognizes, encourages, and rewards local floodplain management activities that exceed the minimum standards of the NFIP. The CRS provides a framework and a variety of technical resources to help participating communities implement a comprehensive flood risk management program designed to reduce and avoid flood losses and to strengthen the insurance aspects of the NFIP. In return, flood insurance rates for existing policyholders community-wide are discounted to reflect the reduced flood risk resulting from community actions. (Planning for Hazards).

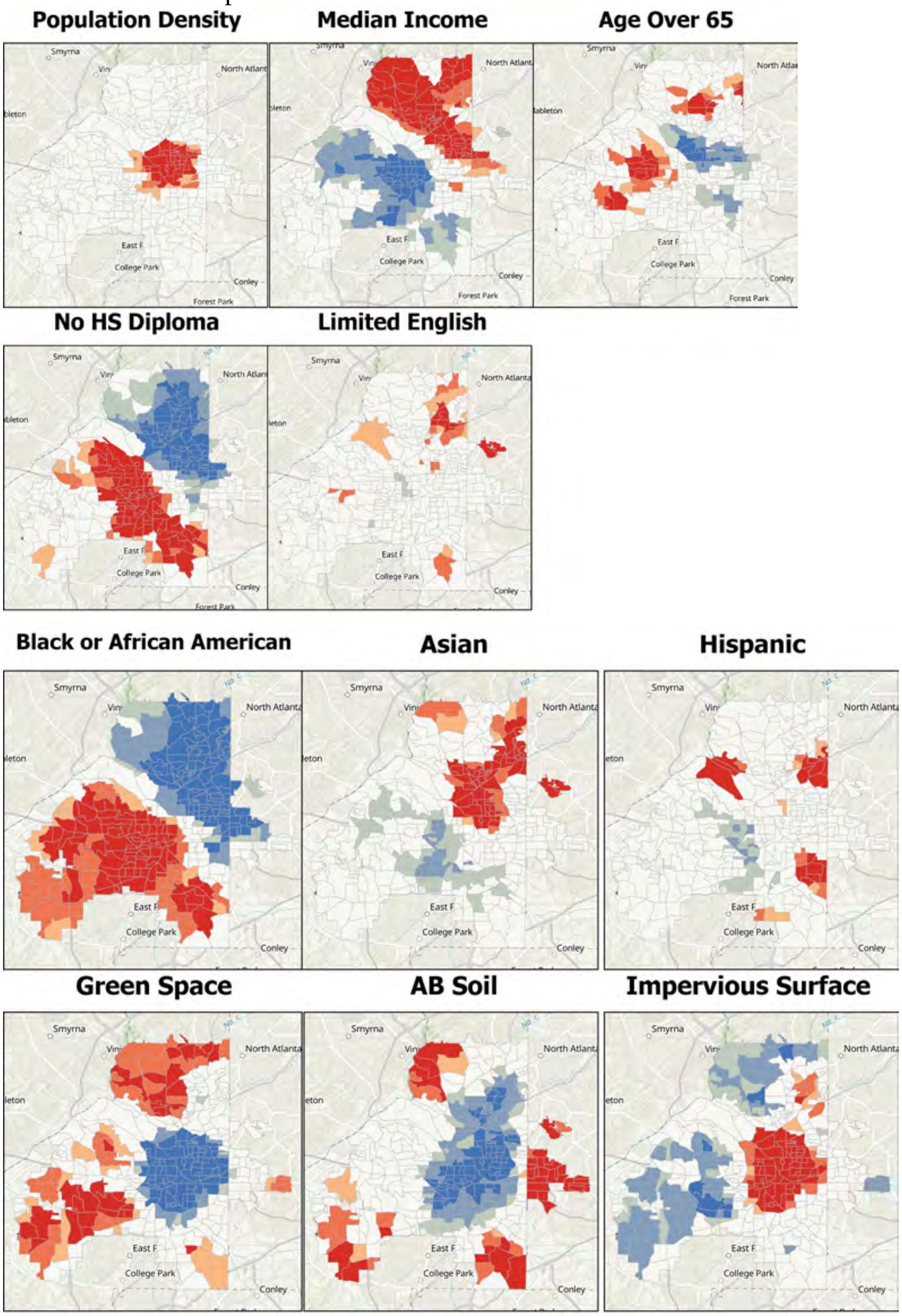
The CRS Program is administered by FEMA support from Insurance Services Office, Inc. (ISO). The Program applies class rating system similar to fire insurance ratings to determine flood insurance premium reductions for properties located in and outside the Special Flood Hazard Area (SFHA). Communities earn credit points based on the local implementation activities recommended in the CRS Coordinator's Manual. The number of points earned determines the CRS class. Classes are rated from 9 to 1, with each incremental improvement providing an additional 5% insurance premium discount. A community in the CRS Class 9 qualifies for a premium reduction of the SFHA of 5%, while a community in the CRS Class 1 receives the highest possible reductions of 45%. (Planning for Hazards)

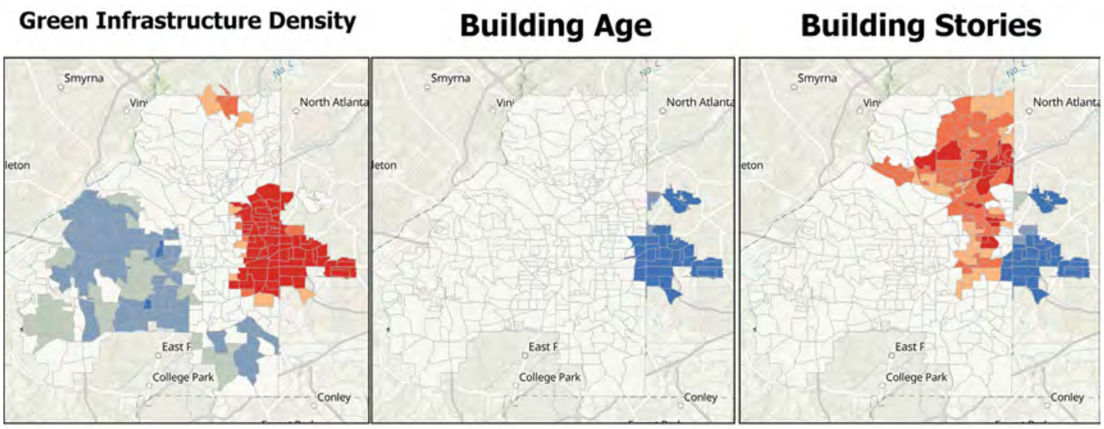
There is a total of nearly 100 distinct elements eligible for credit under the CRS organized under four categories:

1. *Public Information Activities*: Includes local activities that educate people (that is, residents, property owners, insurance or real estate agents, and other stakeholders) about flood hazards, protection and insurance. Examples include elevation certificates, map information service, outreach projects, hazard disclosure, flood protection information, flood protection assistance, and flood insurance promotion.
2. *Mapping and Regulations*: Includes activities that exceed the NFIP's minimum standards to offer flood protection for new and existing development. Include floodplain mapping, open space preservation, higher regulatory standards, flood data maintenance, and stormwater management.
3. *Flood Damage Reduction Activities*: Focus primarily on reducing flood damage to existing buildings. Examples include floodplain management planning, acquisition and relocation, drainage system maintenance, and retrofitting existing buildings.
4. *Warning and Response*: These activities focus on emergency warnings and response to save lives and minimize property damage. Examples include flood threat recognition systems, critical facilities planning, levee or dam failure warning systems and response operations planning. (Planning for Hazards)

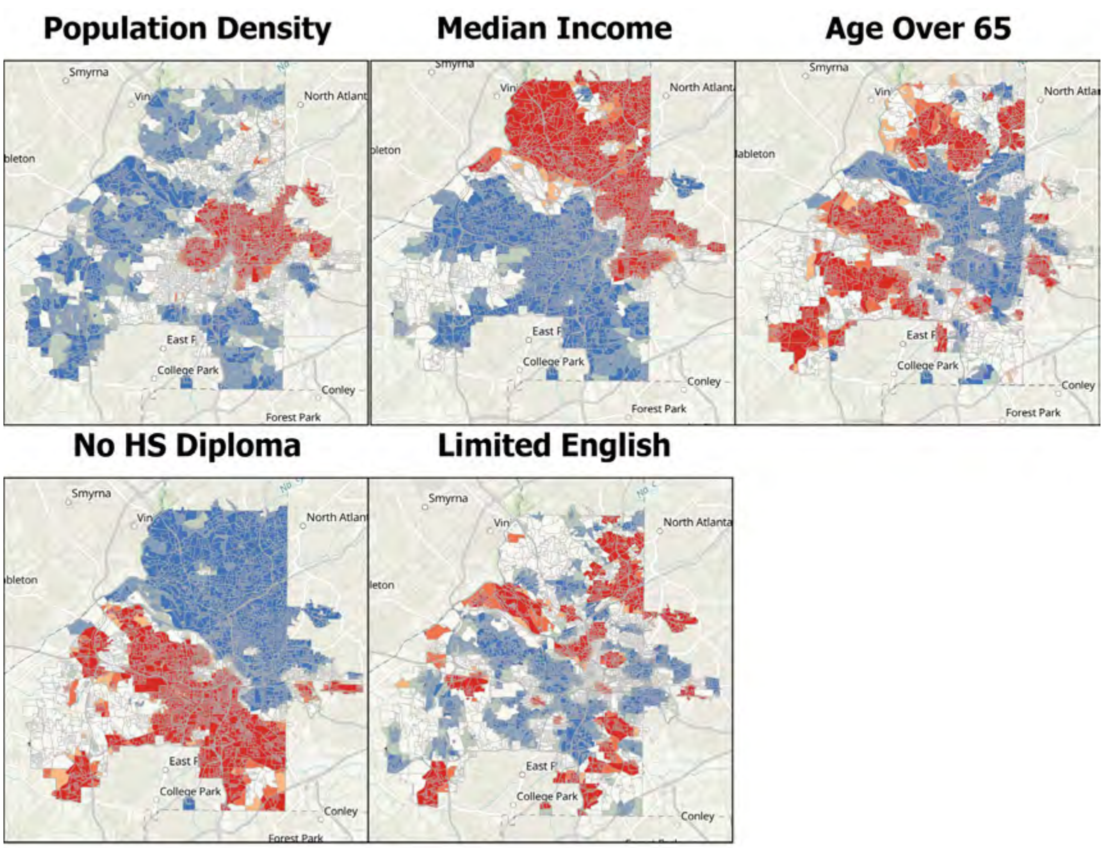
Indicator Hot Spot Analysis:

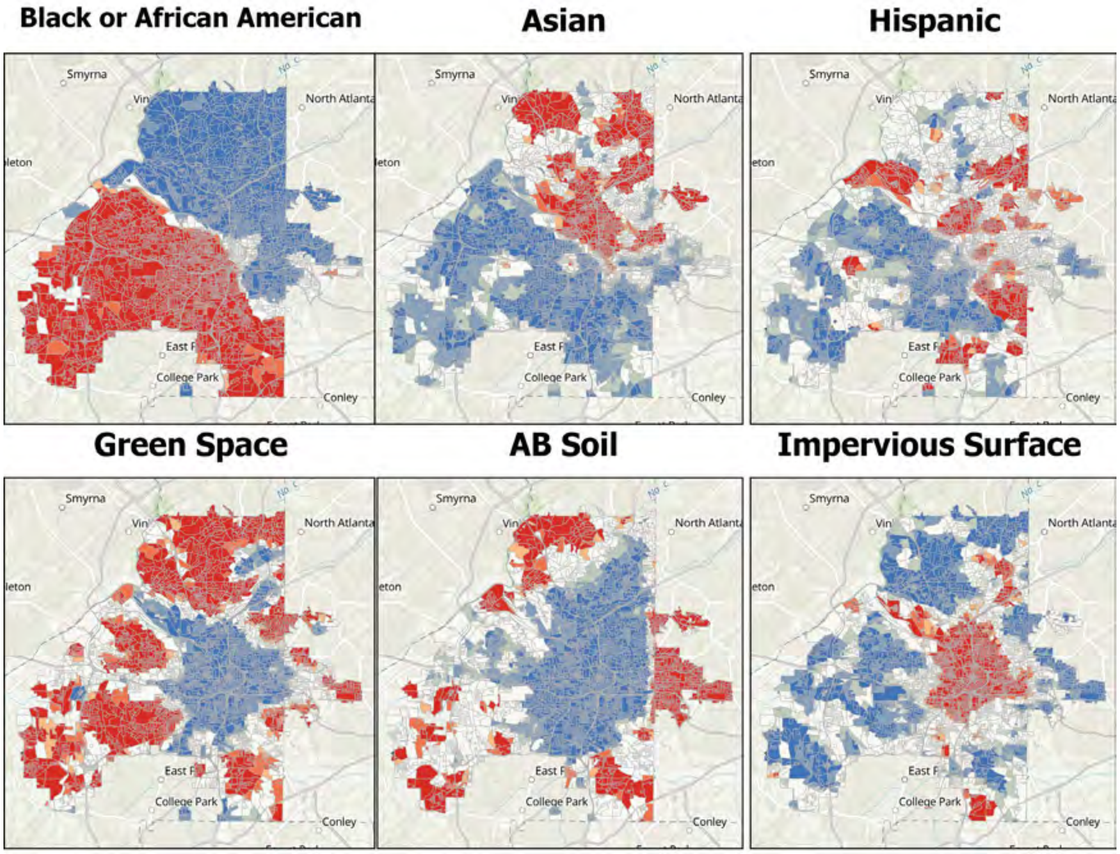
Census Block Group Scale:



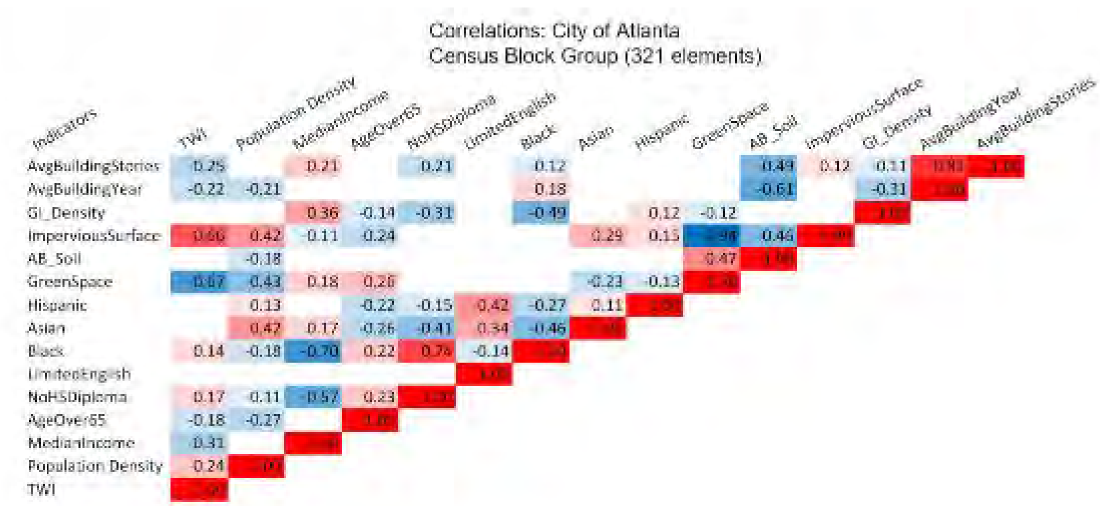


Census Block Scale:





Pearson Correlations:



Correlations: City of Atlanta
Census Block Group (321 elements)

Indicators	TWI	Population Density	MedianIncome	AgeOver65	NoHSDiploma	LimitedEnglish	Black	Asian	Hispanic	GreenSpace	AB_Soil	ImperviousSurface	GI_Density	AvgBuildingYear	AvgBuildingStories
AvgBuildingStories	0.25		0.21		0.21		0.12				0.49	0.12	0.11	0.93	1.00
AvgBuildingYear	-0.22	-0.21					0.18				-0.61		-0.31	[illegible]	
GI_Density			0.36	-0.14	-0.31		-0.49		0.12	-0.12			1.00		
ImperviousSurface	0.66	0.42	-0.11	-0.24				0.29	0.13	[illegible]	0.46	1.00			
AB_Soil		-0.18								0.47	1.00				
GreenSpace	0.67	0.43	0.18	0.26				-0.23	-0.13	1.00					
Hispanic		0.13		-0.22	-0.15	0.42	-0.27	0.11	1.00						
Asian		0.42	0.17	-0.26	-0.41	0.34	-0.46	[illegible]							
Black	0.14	-0.18	-0.70	0.22	0.74	-0.14	[illegible]								
LimitedEnglish						1.00									
NoHSDiploma	0.17	0.11	-0.57	0.23	1.00										
AgeOver65	-0.18	-0.27		1.00											
MedianIncome	0.31		[illegible]												
Population Density	0.24	[illegible]													
TWI	[illegible]														

Correlations: City of Atlanta
Census Blocks (7063 elements)

Indicators	TWI	PopulationDensity	MedianIncome	AgeOver65	NoHSDiploma	LimitedEnglish	Black	Asian	Hispanic	GreenSpace	AB_Soil	ImperviousSurface
ImperviousSurface	0.12	0.29	-0.16	-0.22	-0.04	0.03		0.16	0.10	-0.40	-0.24	[illegible]
AB_Soil	-0.10	-0.12	0.15	0.08	-0.07		-0.09	-0.05	-0.06	0.37	[illegible]	
GreenSpace	-0.29	-0.28	0.22	0.27	-0.04	-0.07	-0.04	-0.16	-0.09	[illegible]		
Hispanic		0.14	0.03	-0.26	-0.19	0.49	-0.29	0.15	[illegible]			
Asian	0.03	0.42	0.15	-0.29	0.43	0.26	0.47	[illegible]				
Black		-0.20	[illegible]	0.24	0.74	-0.14	[illegible]					
LimitedEnglish		0.05	-0.06	-0.11	-0.08	[illegible]						
NoHSDiploma		-0.22	-0.55	0.26	1.00							
AgeOver65	-0.08	-0.32	-0.03	[illegible]								
MedianIncome	-0.07	-0.09	[illegible]									
PopulationDensity	0.07	[illegible]										
TWI	[illegible]											

Exploratory Regression Correlations:

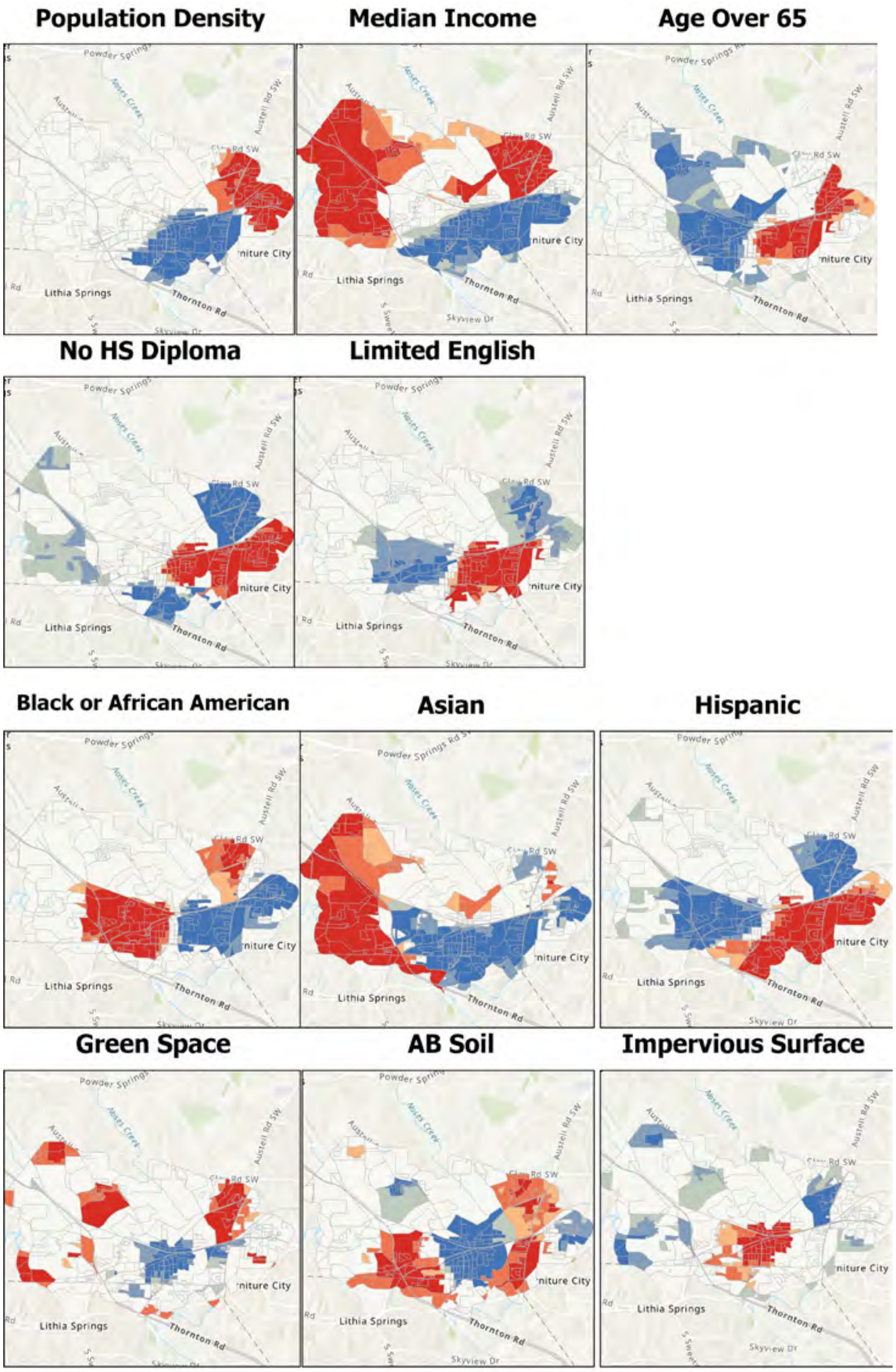
Exploratory Regressions: Atlanta

Indicators	Atlanta: Census Block Group			Atlanta: Census Block		
	% Significant	% Negative	% Positive	% Significant	% Negative	% Positive
ImperviousSurface	100	0	100	66.32	0	100
ABSoil	71.36	51.42	48.58	66.32	66.32	33.68
GreenSpace	99.09	100	0	100	100	0
Hispanic	7.14	38.52	61.48	0	83.94	16.06
Asian	53.61	77.68	22.32	25.65	38.08	61.92
Black	61.85	17.02	82.98	30.57	57.51	42.49
LimitedEnglish	8.6	84.81	15.19	25.65	100	0
NoHSDiploma	51.14	4.57	95.43	39.9	3.89	96.11
AgeOver65	44.74	93.6	6.4	66.32	85.75	14.25
MedianIncome	97.35	100	0	66.06	84.97	15.03
PopulationDensity	71.82	41.81	58.19	66.32	33.68	66.32
Avg. Building Stories	87.74	99.63	0.37			
Avg. Building Age	78.68	95.52	4.48			
Green Infrastructure Density	31.84	29.83	70.17			

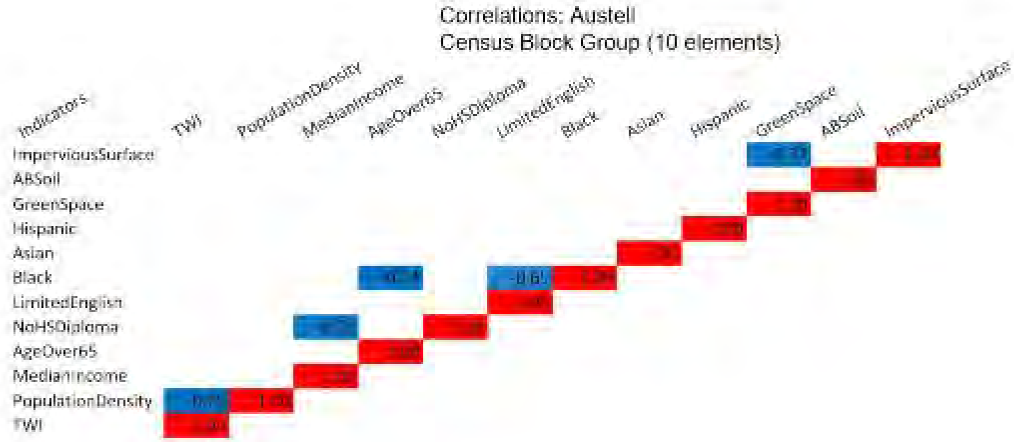
Appendix D: Austell Results

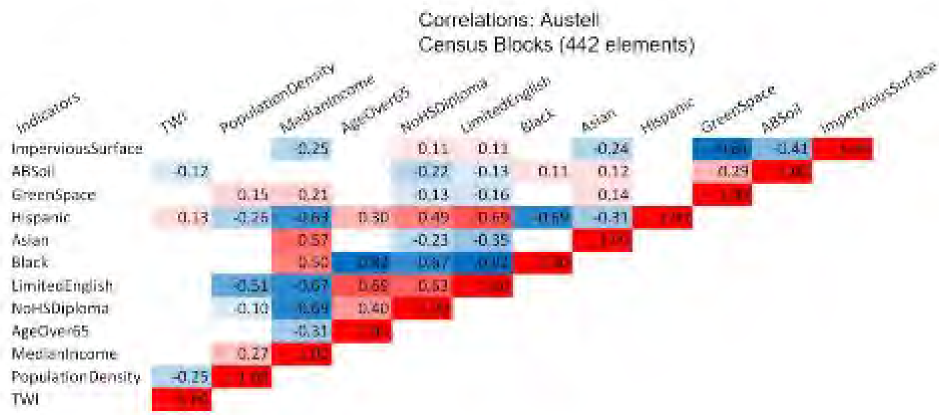
Indicator Hot Spot Analysis:

Census Block Scale:



Pearson Correlations:





Exploratory Regression Correlations:

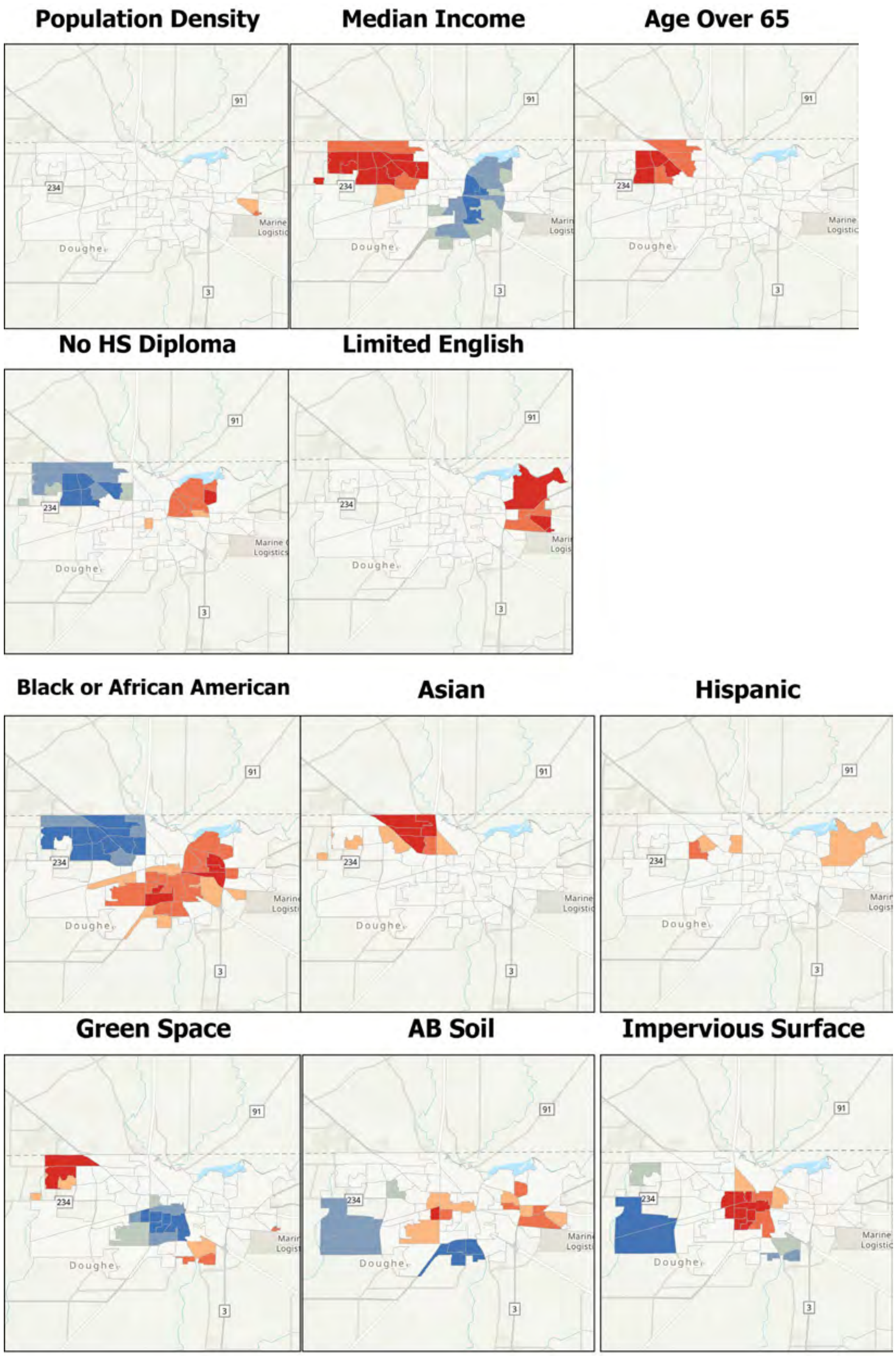
Exploratory Regressions: Austell

Indicators	Austell: Census Block Group			Austell: Census Block		
	% Significant	% Negative	% Positive	% Significant	% Negative	% Positive
ImperviousSurface	1.55	87.31	12.69	16.06	100	0
ABSoil	0.52	92.49	7.51	97.67	100	0
GreenSpace	3.37	76.68	23.32	4.4	31.09	68.91
Hispanic	0.78	3.11	96.89	91.19	0	100
Asian	2.33	12.69	87.31	12.95	21.5	78.5
Black	2.85	54.66	45.34	45.08	39.64	60.36
LimitedEnglish	7.25	13.99	86.01	55.44	30.57	69.43
NoHSDiploma	7.25	100	0	66.06	99.74	0.26
AgeOver65	4.4	86.79	13.21	59.33	91.71	8.29
MedianIncome	0.78	36.53	63.47	25.91	17.88	82.12
PopulationDensity	51.81	99.22	0.78	99.48	100	0

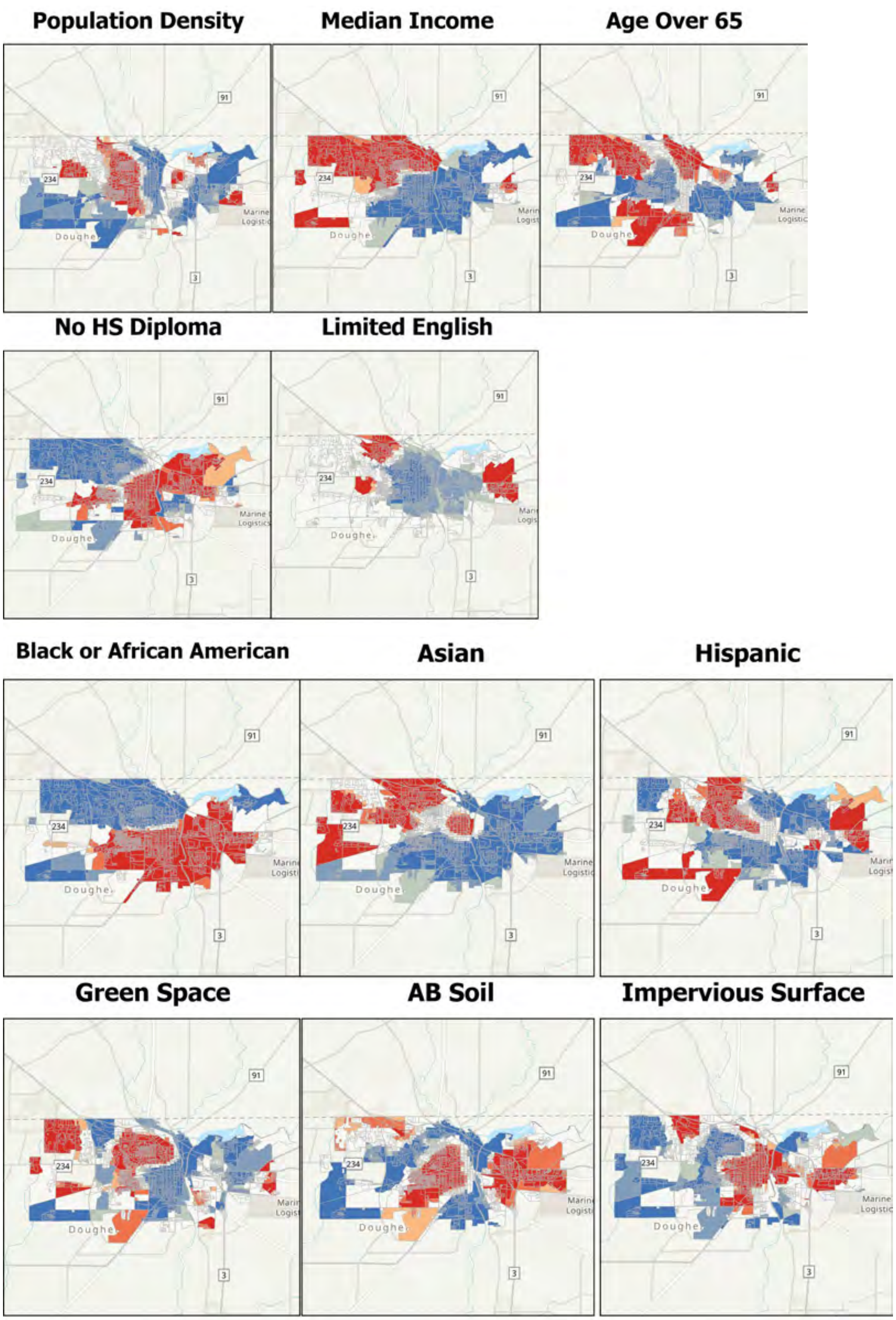
Appendix E: Albany Results

Indicator Hot Spot Analysis:

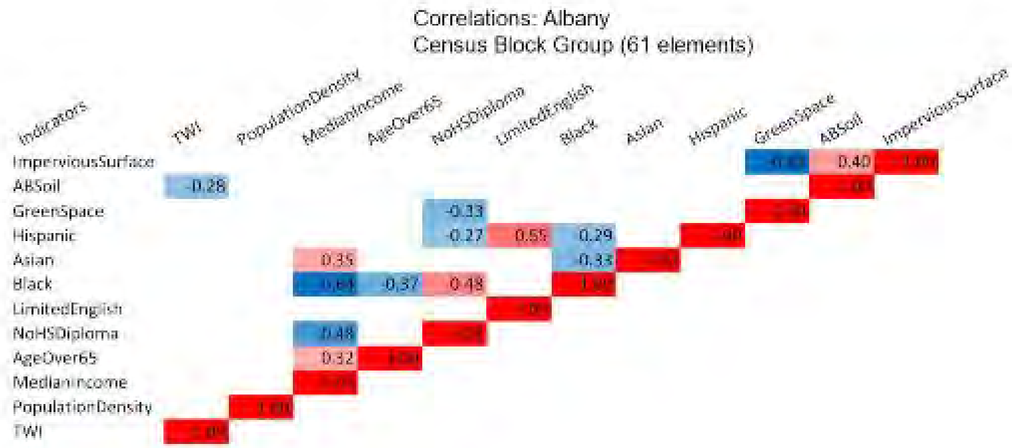
Census Block Group Scale:

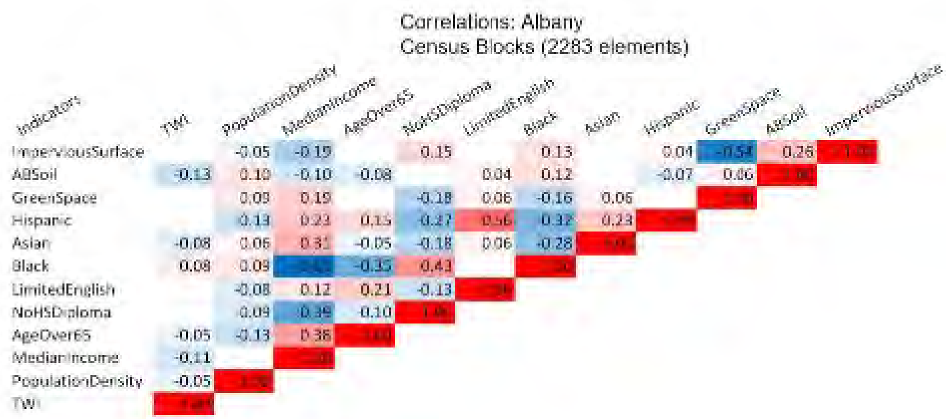


Census Block Scale:



Pearson Correlations:





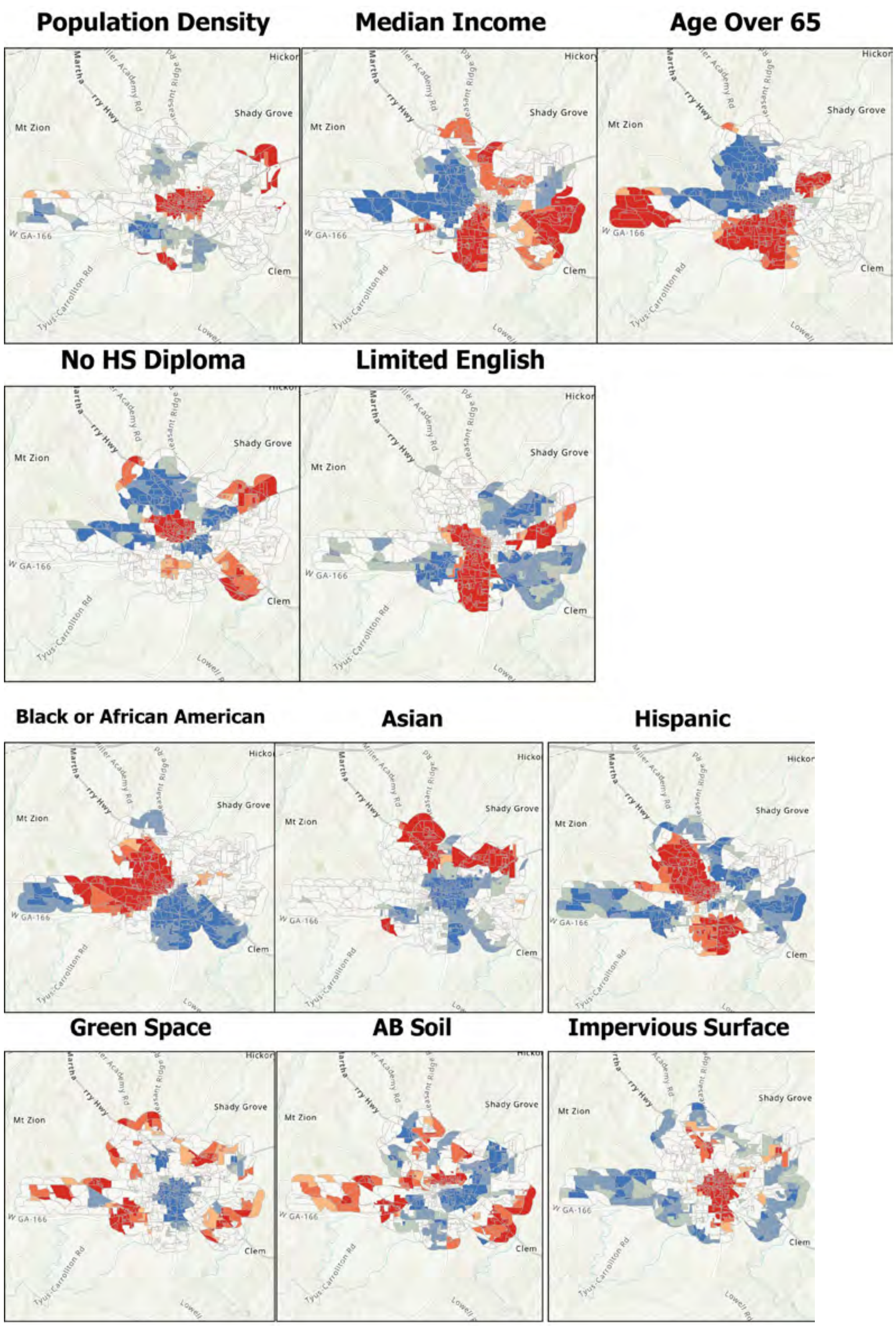
Exploratory Regression Correlations:

Exploratory Regressions: Albany

Indicators	Albany: Census Block Group			Albany: Census Block		
	% Significant	% Negative	% Positive	% Significant	% Negative	% Positive
ImperviousSurface	0	73.32	26.68	0.52	66.32	33.68
ABSoil	92.75	100	0	100	100	0
GreenSpace	0	100	0	5.7	0	100
Hispanic	0	15.03	84.97	2.07	24.35	75.65
Asian	10.62	100	0	98.19	100	0
Black	0	10.36	89.64	69.69	0	100
LimitedEnglish	0	0	100	0	100	0
NoHSDiploma	0	0	100	2.85	66.06	33.94
AgeOver65	0	88.6	11.4	41.71	98.7	1.3
MedianIncome	0	100	0	100	100	0
PopulationDensity	0	99.74	0.26	73.32	100	0

Indicator Hot Spot Analysis:

Census Block Scale:



Pearson Correlations:

Correlations: Carrollton
Census Block Group (27 elements)

Indicators	TWI	PopulationDensity	MedianIncome	AgeOver65	NoHSDiploma	LimitedEnglish	Black	Asian	Hispanic	GreenSpace	ABSoil	ImperviousSurface
ImperviousSurface	0.46					0.39			0.61	-0.89		1.00
ABSoil	-0.51										1.00	
GreenSpace	-0.47					-0.40			-0.51	1.00		
Hispanic				-0.50	0.45	0.52	0.39		1.00			
Asian								1.00				
Black			-0.55	-0.46	0.40		1.00					
LimitedEnglish					0.40	1.00						
NoHSDiploma					1.00							
AgeOver65				1.00								
MedianIncome			1.00									
PopulationDensity		1.00										
TWI	1.00											

Correlations: Carrollton
Census Block Group (883 elements)

Indicators	TWI	PopulationDensity	MedianIncome	AgeOver65	NoHSDiploma	LimitedEnglish	Black	Asian	Hispanic	GreenSpace	AB_Soil	ImperviousSurface
ImperviousSurface	0.14	0.11			-0.07	0.17	-0.10	-0.07	0.18	[illegible]	-0.24	1.00
AB_Soil	-0.14			-0.11	0.12	-0.13	0.08			0.19	1.00	
GreenSpace	-0.20	-0.10				-0.16		0.09	-0.10	1.00		
Hispanic			-0.34	-0.48	0.35	0.45	0.34		1.00			
Asian	-0.11			-0.19	-0.13	-0.15		1.00				
Black			-0.68	-0.59	0.16		1.00					
LimitedEnglish	0.15		0.12		0.30	1.00						
NoHSDiploma		0.22			1.00							
AgeOver65		-0.15	0.52	1.00								
MedianIncome			1.00									
PopulationDensity		1.00										
TWI	1.00											

Exploratory Regression Correlations:

Exploratory Regressions: Carrollton

Indicators	**Carrollton: Census Block Group**			**Carrollton: Census Block**		
	% Significant	**% Negative**	**% Positive**	**% Significant**	**% Negative**	**% Positive**
ImperviousSurface	53.37	5.7	94.3	66.32	33.68	66.32
ABSoil	100	100	0	100	100	0
GreenSpace	63.47	97.67	2.33	100	100	0
Hispanic	0	58.29	41.71	10.36	54.92	45.08
Asian	0	87.56	12.44	100	100	0
Black	0.26	0	100	0.26	89.12	10.88
LimitedEnglish	0	51.81	48.19	100	0	100
NoHSDiploma	0	100	0	38.6	100	0
AgeOver65	0	14.51	85.49	1.04	9.84	90.16
MedianIncome	0	50.26	49.74	1.3	76.42	23.58
PopulationDensity	0	95.6	4.4	0	81.61	18.39