5-8-2020

An Analysis of Climate Resilience Planning in Atlanta, Georgia

Nkosi Mark Muse MS
Georgia State University

AN ANALYSIS OF CLIMATE RESILIENCE PLANNING IN ATLANTA, GEORGIA

by

NKOSI MUSE

Under the Direction of David Iwaniec, PhD

ABSTRACT

This research focused on identifying the spatial distribution of two potential climate hazards in the City of Atlanta, Georgia. Extreme heat (1) is one of Atlanta's most significant threats, and flooding (2) continues to plague its communities. Potential socioeconomic predictors of extreme heat (poverty, percent of black residents) proved not to have strong relationships with high land surface temperature (LST) at the census tract level. Urban flooding was found to be at its highest risk in southern areas of the city. A content analysis of city governance was performed to see how much of the previously identified hazards are addressed in Atlanta city planning. Analysis showed that flooding is the most planned for, followed by drought, and then heat. Despite heat posing the largest threat, there were minimal climate resilience strategies to explicitly address it. These results can inform improved climate planning and policy within the city of Atlanta.

INDEX WORDS: Planning, Sustainability, Resilience, Heat, Flood, Adaptation, Policy

AN ANALYSIS OF CLIMATE RESILIENCE PLANNING IN ATLANTA, GEORGIA

by

NKOSI MUSE

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Science

in the College of Arts and Sciences

Georgia State University

2020

AN ANALYSIS OF CLIMATE RESILIENCE PLANNING IN ATLANTA, GEORGIA

by

NKOSI MUSE

Committee Chair: David Iwaniec

Committee: Richard Milligan

Chris Wyczalkowski

Electronic Version Approved:

Office of Graduate Studies

College of Arts and Sciences

Georgia State University

May 2020

DEDICATION

To all those who came before me, allowing me the opportunity to perform this work at this level and to earn a master's degree. To the citizens and residents of the City of Atlanta, in order to make this great city more equitable place for all.

ACKNOWLEDGEMENTS

Thank you to my committee for holding this thesis work to a high standard. Thank you to my advisor, David Iwaniec, for pushing me to do more and more. Lastly, thank you to family and friends who frequently checked on me during this process—especially Aunt Nellie and Martha!

TABLE OF CONTENTS

ACKNOWLEDGEMENTS V

LIST OF TABLES VIII

LIST OF FIGURES IX

1 INTRODUCTION 1

1.1 History of Atlanta 5

1.2 Research Questions 12

1.3 Approach and Literature Review 14

1.3.1 Heat Exposure Analysis 14

1.3.2 Flood Map Assessment 17

1.3.3 Climate Governance Analysis 22

2 DATA AND METHODS 24

2.1 Landsat 8 24

2.2 Time Period 24

2.3 Mapping LST 25

2.4 LST Validation 27

2.5 Socioeconomic Data 28

2.6 Statistical Analysis 28

2.7 Review of Flood Maps 28

2.8 Climate Governance Analysis 29

2.8.1 Review of Governance Document Analysis *32*

3 RESULTS **33**

3.1 Heat Exposure Analysis **33**

3.2 Flood Map Analysis **38**

3.3 Climate Resilience Governance Document Analysis **40**

3.3.1 Flood in Climate Governance Documents *42*

3.3.2 Heat in Climate Governance Documents *49*

4 DISCUSSION AND CONCLUSION **51**

REFERENCES **57**

APPENDIX A **67**

APPENDIX B **69**

APPENDIX C **73**

APPENDIX D **74**

APPENDIX E **75**

APPENDIX F **76**

LIST OF TABLES

Table 1. Change in total White and Black populations, 1850-2010, (Heath & Heath, 2014). 9

Table 2. Strategy and target extraction for coding analysis. 30

Table 3: Correlation results for majority black census tracts (≥ 70% black) vs average LST per census tract. The negative correlation (~-0.45) indicates that as the percentage of blacks increase, temperature decreases. 37

Table 4: Correlation results for census tracts with at least 20% of population below poverty level vs average LST per census tract. A weak correlation between the two variables was found—temperature slightly increasing as the percentage of poverty increases. 37

LIST OF FIGURES

Figure 1. City of Atlanta vs the Atlanta Metropolitan Statistical Area (MSA) (ARC). 1

Figure 2. Decadal anomalies in Georgia surface temperature. Note the largest increase in the Atlanta Metro area (KC et al. 2015). 2

Figure 3. Metropolitan Atlanta land use classification map, observed 1999 projected to 2030 (Smoot, NASA 2019)... 3

Figure 4. Vincent subdivison of the City of Atlanta, 1853 (Vincent)... 6

Figure 5. Atlanta Metropolitan Statistical Area (MSA) segregation and integration by census tract, 2010 (Pooley 2015)... 11

Figure 6. Daily average temperatures across the Atlanta Metro area are projected to continue increasing (Kunkel 2019)... 14

Figure 7. Energy balance at the surface, triggered by the sun's radiation (Kim 2014)................ 16

Figure 8. FIRM panel (fema.gov). 18

Figure 9. Fulton County Flood Risk map (fema.gov).. 19

Figure 10. Dekalb County Flood Risk map (fema.gov)... 20

Figure 11. LST calculation flowchart from Avdan & Jovanovska (2016), as followed in this study. 27

Figure 12. Average Summer LST (2013-2019). 33

Figure 13. NDVI (2019) vs average LST. 34

Figure 14. Average June, July, and August LST. 35

Figure 15. Average LST per census tract. Census tracts that are equal to or over 70% black are overlaid. 36

Figure 16. Average LST with census tracts where at least 20% of the population lives below the poverty level overlaid. 38

Figure 17. Breakdown of number of strategies per climate hazard (note that some strategies can address more than one climate hazard). 41

Figure 18. Types of flooding coded for. 42

Figure 19. Breakdown of flooding strategies coded as implementing social, ecological, or technological solutions. 43

Figure 20. Breakdown of social strategies coded for heat and flood. 44

Figure 21. Breakdown of ecological strategies coded for heat and flood. 45

Figure 22. Proctor Creek. 46

Figure 23. Breakdown of technological strategies for heat and flood. 47

Figure 24. South River. 48

Figure 25. Utoy Creek. 49

Figure 26. City of Atlanta average summer LST, with downtown region highlighted. Note the cluster of higher temperatures. 50

Figure 27. Peoplestown and Mechanicsville neighborhoods. 53

1 INTRODUCTION

Climate change, as defined by the Environmental and Energy Institute, is the rise of the planet's average temperature, which will result in numerous climatic shifts around the globe (EESI 2019). The effects of climate change will affect different areas, environments, and biomes of the planet in unique ways. Similar to climate change, the boundaries of these different environments have no regard for geopolitical boundaries. Thus, the contiguous United States of America is composed of several different biomes and transitional ecotones across states (Kamel 2003). In these different regions of the United States, human activity has also altered the natural environment. Urbanization and urban expansion have changed the biophysical traits of their respective regions, creating microclimates with more distinct and pronounced characteristics than surrounding rural or suburban areas (Ali et al. 2017).

Figure 1. City of Atlanta vs the Atlanta Metropolitan Statistical Area (MSA) (ARC).

The City of Atlanta, Georgia is one of many of cities that has begun to feel the effects of climate change, especially in the southeastern United States. Atlanta exhibits the characteristics of an urban heat island (UHI)—an example of an urban microclimate. Yao et al. (2011) define a UHI as an area where its "effect results in increased local atmospheric and surface temperatures in urban areas compared to the surrounding rural areas" (p. 253). The ambient temperature of Metropolitan Atlanta's UHI has been found to range between 0.8 to 2.5 degrees Celsius warmer than surrounding areas (Zhou and Shepherd 2010). Urbanized areas and their corresponding impervious surfaces absorb more radiation during the day than forested areas, while also reemitting this heat to increase air temperatures during the day, and at night (Stone et al. 2010).

Compounding the UHI effect, is the increased frequency of heat waves in Atlanta, as well as an overall warming trend for Georgia (KC et al. 2015). Georgia currently averages 20 dangerous heat days a year (NWS Heat Index) and is projected to have more than 90 dangerous heat days a year (States at Risk: America's Preparedness Report Card 2015). This warming trend

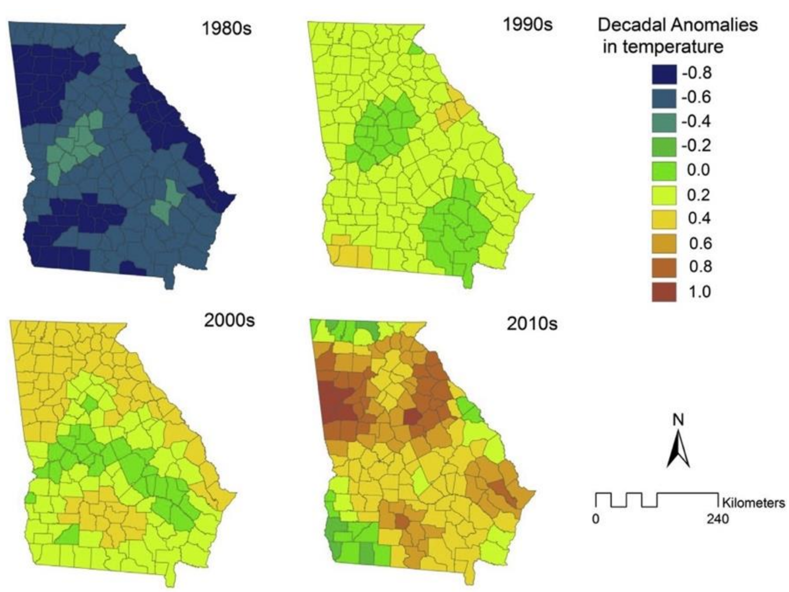


Figure 2. Decadal anomalies in Georgia surface temperature. Note the largest increase in the Atlanta Metro area (KC et al. 2015).

coupled with the urban heat island effect in the Metropolitan Atlanta area can amplify the typical heat waves that usually take place during the summer months.

Atlanta is one of the country's fastest growing cities in terms of population (US Census 2019). Although since the 1970s, the overall growth rate of Atlanta's metropolitan area has slowed (correlating with the slowing trend of city's populations growth rate), there has been in an increase in residential and industrial/commercial area. However, as urban infill becomes less of an option, the metro area will begin to expand again (Figure 3). Urbanization has largely been at the cost of forest and grassland removal—at a rate that was at one point faster than anywhere in the world (Dixon & Mote 2003; Liu & Yang 2015).

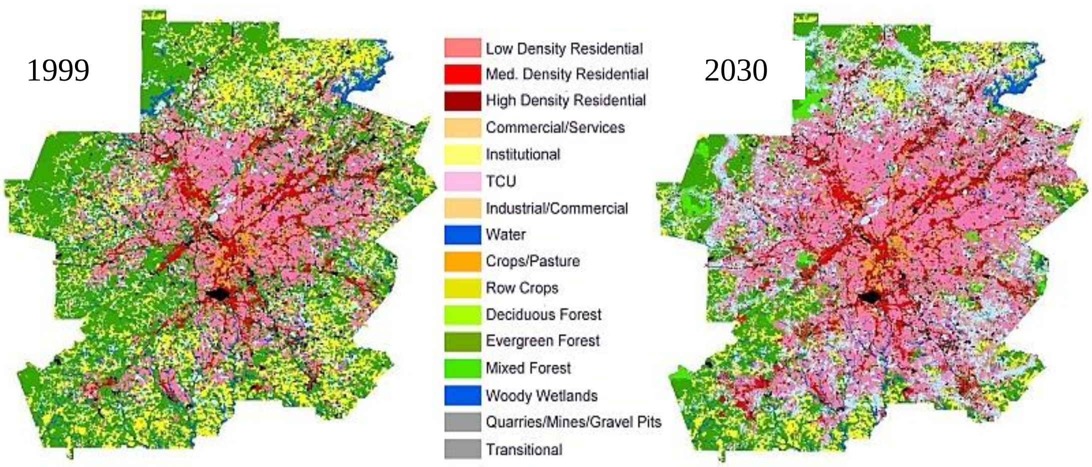


Figure 3. Metropolitan Atlanta land use classification map, observed 1999 projected to 2030 (Smoot, NASA 2019).

What typically replaces this greenspace is land use/land cover characterized by a high percentage of impervious surface, commonly associated with urban expansion. Impervious surfaces increase thermal mass of the land surface resulting in higher urban temperatures, and limit groundwater infiltration that can accelerate the conveyance of water during a precipitation event, increasing the risk for flash flooding and other flooding hazards (USGS 2019).

Worldwide, a growing population and a growing threat of climate change fueled extreme events have made resilience planning more important than ever. The Urban Resilience to Extremes Sustainability Research Network (UREx SRN) utilizes an interdisciplinary approach developed by its researchers to brainstorm and determine resilience planning solutions in a city like Atlanta, a place that is a microcosm of this worldwide phenomenon. These solutions are especially important for a city like Atlanta, as it lies in a region that has become a prime destination for climate-change refugees (Sastry & Gregory 2014; Hauer et al. 2016). It is a city that has avoided large-scale natural disasters due to its elevation and distance from coasts but is not immune to dangerous and severe weather events. Research conducted at the county-level suggests that climate hazard exposure is highest in urban Atlanta compared to other regions in the state of Georgia (KC et al. 2010). The remnants of Hurricane Irma caught Atlanta by surprise in 2017 when it brought widespread flooding and damage, and a subsequent shut down of the city (National Weather Service 2017). Extreme precipitation in 2009 exposed and overwhelmed poor and aged infrastructure, totaling close to $500 million in damages and leading to several lives lost (National Weather Service 2009). Additional flooding in July 2012 provoked the city (under Mayor Kasim Reed) to start thinking more about its neighborhoods that lie in flood prone regions (Kinney 2016). Even with large uncertainty in precipitation projections, flooding hazards will continue to threaten the region and are likely to be more common in the future (Bierbaum et al. 2013, Kunkel 2019). These impacts are felt most significantly in lower-income, predominantly African American neighborhoods, many of which had been developed historically in low-lying, flood-prone areas (Spikes 2019). Atlanta's racially segregated spaces exacerbate the uneven risks of vulnerability to climate-driven extreme events in this southeastern city. Thus, preparation for these hazards will have to largely take into account the socio-demographic characteristics of the Metropolitan Atlanta region (KC et al. 2015).

1.1 History of Atlanta

The history of Atlanta's growth, formation, and planning have roots that date back to the early to middle 19th century, and are still exposed today. What started out as a settlement named "Terminus", established by John Thrasher at the planned intersection of four railroads (City of Atlanta 2019; Etienne & Faga 2014), Atlanta has now become what many refer to as the "metropolis of the Southeast", or the "capital of the South" (Allen 2014). With the exception of the fires of 1864 and 1917 that either destroyed the city or major parts of it (Pollock 2014), the region has almost always been on a trend of growth since its incorporation in 1847. Controversial "slavery" after the civil war (National Park Service 2019) and unjustly incarcerated African Americans who were forced into uncompensated labor were responsible for much of the city's development (Blackmon 2009). Atlanta's young economy was largely reliant on its railroads, making transportation an economic staple that the city is still strongly associated with today. Construction and mercantile trades also dominated economics sectors within the region (Allen 2014). Atlanta has more in common with western cities such as Los Angeles, that were primarily railroad "fed" areas, than it does with cities along the eastern seaboard (Feldman 2009). Rather than a city that was inhabited and planned out, such as in the New England region or the Philadelphia region, future Atlanta land was seized and sold (Allen 2014). Areas of urban Atlanta today maintain characteristics similar to land lots that were sold in the 1800s. For example, Land Lot 51 (displayed in Figure 4) included what would become the Old Fourth Ward, which contained historic districts like the Sweet Auburn Historic District—a major

African American business center that continues to resonate aspects of African American culture today. It was there that the Southern Christian Leadership Conference (SCLC) came to be, and Martin Luther King, Jr. would begin his campaign for equality from his church home (Allen 2014).

Figure 4. Vincent subdivison of the City of Atlanta, 1853 (Vincent).

The racial tones of a young Atlanta would continue on throughout the course of the city's history to the present. Following the civil war, a large number of blacks hoping to find work and escape the racial perils of reconstruction in the south, migrated to northern cities such as Philadelphia, Chicago, and New York (Lloyd 2012). The presence of Jim Crow laws and other prejudicial practices maintained a southern urban landscape that was different than that of the North. Blacks that did not participate in the "Great Migration" to northern cities remained dispersed among poorer, working-class whites in the South (Silver & Moeser 1995). In contrast, blacks that migrated to northern cities lived together in urban communities segregated from whites, such as the ghettos in Chicago and Harlem (Logan et al. 2015). As the Civil Rights movement gained momentum in the mid-20th century however, minorities started to gain political power in the South and the northward migration of blacks began to reverse (Lloyd 2012). Kromm (2011) wrote: “The civil rights movement didn't end racism, of course, but it did change the South enough to entice many African-Americans to come back, igniting a reverse migration movement that continues to gain steam.” From that point on and into the 21st century, an influx of African Americans would return back to the South, including the City of Atlanta and its greater metropolitan area:

> “Eleven of the Atlanta region's twenty-eight counties accounted for nearly all (98 percent) of the metro area's increase in African American residents between 2000 and 2010; by 2010, these counties housed 79 percent of the metro's black population” (Pooley 2015).

The variation between the percentages of black and white populations between 1850 and 2010 are largely attributed to these migration trends (Table 1). The years 1870 to approximately 1950 saw this northward migration of blacks out of the City of Atlanta, until the trend reversed, and blacks quickly returned to within Atlanta city limits.

Prior to 1970, a large white population resided in the city of Atlanta (over 60 percent), as housing opportunities for minorities that already lived in Atlanta were limited due to high “…costs, restrictive zoning practices, and the unwillingness of realtors to sell to African Americans” (Heath and Heath 2014). However, with increasing economic and employment opportunities for minority populations, and a recognition of housing shortages in the city of Atlanta, city officials developed programs to establish new residential areas for blacks and nonwhites. These new residential areas ultimately became substandard public housing units, which led to a trend of poor living conditions and high crime rates for those who lived in these western and southern parts of the city. These black communities were highly segregated from those of whites, appearing as a "city within a city" (Adams 2006). With limited access to resources in these communities such as the lack of quality schooling, conflict arose and pressure from the Civil Rights movement began to desegregate urban Atlanta communities (Kruse 2013).

For black families that could afford to leave sub-standard housing, moving into better housing became even more difficult. At this time, according to the Federal Housing Administration (FHA), as regions became more diverse, property values "decreased". However, the opposite was actually true. In fact, the federal government's Home Owners Loan Corporation (HOLC) created a residential "security map", dividing the City of Atlanta into 111 neighborhoods, each with a "grade" from A-D (Rhodes 2017). These grades indicated an interpreted trend in property values, which largely involved the amount of non-white populations living within or nearby the neighborhood. Real estate agents and housing authorities employed prejudicial economic tactics to keep neighborhoods segregated, convincing whites to leave quickly by selling their homes at low prices, unrepresentative of actual property value, but forcing blacks to buy at high prices in order to move in (Rothstein 2017). In short, these tactics were part of a scheme known as "blockbusting". The FHA's policies actually increased neighborhood property values rather than decreased them, as middle-class blacks moved in. In addition, many blacks were not qualified for mortgages via FHA and bank policies. These tenants paid for their homes in inflated, typically unaffordable installment plans. Rothstein (2017) also writes: "The full cycle went like this: when a neighborhood first integrated, property values increased because of African Americans' need to pay higher prices for homes than whites.

But then property values fell once speculators had panicked enough white homeowners into selling at deep discounts" (p. 187). Many of these whites who fled their inner-city homes migrated to the city's outskirts and suburban areas around 1960 (Frey 1980), attributing to the drastic drop in the percentage of whites within the City of Atlanta (Table 1). The growth of these "exurbs" in counties surrounding the City of Atlanta was and is still largely dependent on this small-scale white migration from the city (Frey 2011). This was referred to as the "white flight" or a white "exurbanization", that white communities later defended by indicating that the problem "was not integration", but a deprival of their "freedom of association" (Kruse 2013). By the late 20th century, many urban Atlanta census tracts became nearly 100 percent black or non-white—especially in the southwestern region of the city (Pooley 2015).

Table 1. Change in total White and Black populations, 1850-2010, (Heath & Heath, 2014).

Historical Racial Characteristics, City of Atlanta, 1850-2010		
Year	Total Population – White	Total Population – Black/African American
1850	80.1	19.9
1860	79.7	20.3
1870	54.4	45.6
1880	56.3	43.7
1890	57.1	42.9
1900	60.2	39.8
1910	66.4	33.5
1920	68.7	31.3
1930	66.7	33.3

1940	65.4	34.6
1950	63.4	36.6
1960	61.7	38.3
1970	48.4	51.4
1980	32.4	66.6
1990	31.0	67.1
2000	33.2	61.4
2010	38.4	54.0
Source: Data from Gibson and Jung 2005; U.S. Census Bureau 2013		

Leading up to and following the Atlanta Olympics in 1996, the increasing black population trend in Atlanta slowed and even decreased, as the introduction of new highways decimated and displaced some black communities to make space for redevelopment (Heath & Heath 2014). This new space, mostly in the northern region of the city of Atlanta, was quickly populated by a majority white population (note the northern Atlanta region in Figure 5). These Buckhead and Midtown neighborhoods areas saw a spike in housing and job opportunities (Hotchkiss et al. 2003). After this mid-1990 economic boom, white populations began to slowly rise again. As of 2018, the black population within the City of Atlanta fell slightly to 52.3 percent, while the white population rose to 40.1 percent compared to the previous year (US Census Bureau 2019).

Even with the turbulent trends in the City of Atlanta's racial demographics, this history has set the stage for a city that remains highly segregated. The initial, post-civil war racial atmosphere in Atlanta utilized segregation as a means to oppress minority populations, which encountered resistance from the Civil Rights movement in the mid 20th century calling for desegregation. Despite the valiant efforts of civil rights leaders on a national scale to integrate the City of Atlanta, an eventual and gradual "resegregation" took place dividing the city once again (Kruse 2013).

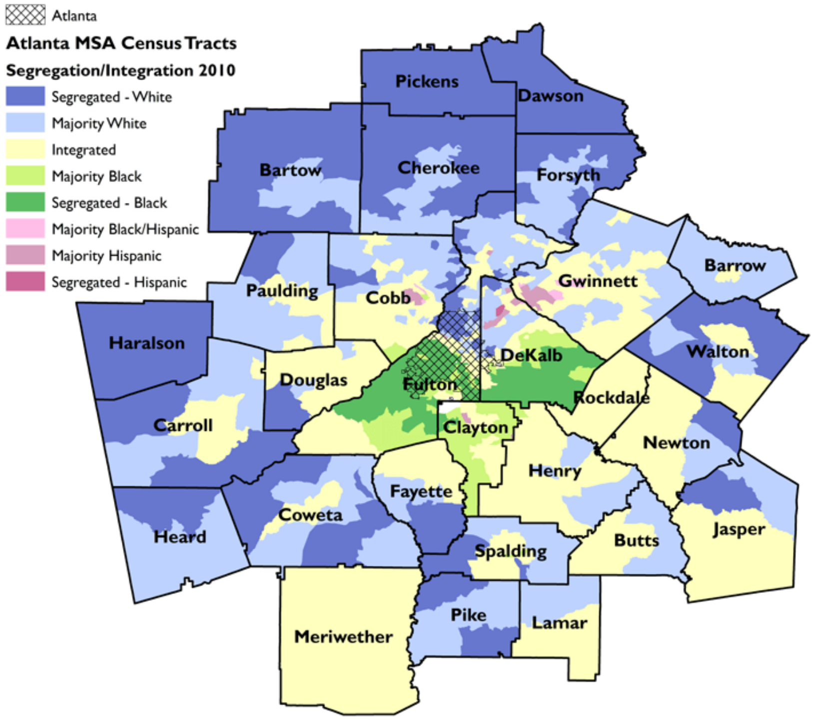


Figure 5. Atlanta Metropolitan Statistical Area (MSA) segregation and integration by census tract, 2010 (Pooley 2015).

Much of these derelict and segregated, predominately minority communities are the sites of high climate hazard exposure in urban Atlanta (Runfola & Hankins 2010). Similar to the deteriorating condition of buildings and housing units, who's maintenance was left to occupants who could barely afford rent or payments (Rothstein 2017), infrastructure to mitigate climate hazards such as flooding or extreme heat also deteriorated or was non-existent. While other areas of the city with continued investment may have continued to improve climate resilience infrastructure, neglected neighborhoods likely did not share the same privilege. This environmental injustice is commonplace in cities around the United States, including Chicago, Illinois who experienced shockingly high death rates during a July 1995 heat wave that killed over 700 people—the majority of victims in black neighborhoods with sub-standard housing (AdaptNY 2016). Although to a lesser and different extent, Atlanta is no stranger to this as well, as the majority of urban Atlanta flooding affects predominately black neighborhoods (Kinney 2016). With the current implications and projections of climate change related hazards, it is only a matter of time before tragedy strikes the City of Atlanta in a similar fashion.

1.2 Research Questions

One overarching question for climate resilience of the City of Atlanta guides the investigation, methods, and approaches of this study: how is local climate resilience planning addressing climate hazards of extreme heat and flooding in the City of Atlanta? The first step in answering this main research question required determining the spatial distribution of heat and flood exposure within the city's municipal boundaries. An analysis of heat, and a review of flood mapping can provide deeper insight into the specific problems urban Atlanta faces with these climate threats. The city of Atlanta has yet to conduct intensive heat adaption planning despite local institutions providing recommendations for conducting heat mapping and vulnerability assessments (ARC 2018). Mapping temperature helps answer the sub-question: "Where in the city of Atlanta is it hottest?" From there, the potential determinants of increased heat were explored, providing insight to increased extreme heat exposure. These potential determinants may be related to the history of Atlanta's development, briefly discussed in Section 1.1. Across different Atlanta communities, heat may be higher in a majority black neighborhood than it may be in a majority white neighborhood. Such social variables potentially have more indirect relationships to heat. For example, studies have shown that communities within the United States with less tree cover (to mitigate heat) tend to have larger minority populations and are likely less affluent (Jesdale et al. 2013). Unlike heat maps, the city does have flood maps readily available via the Federal Emergency Management Agency (FEMA). These maps were used to identify flood prone areas of the city by level of flood risk, which may also have indirect relationships to the City of Atlanta's developmental history.

With a knowledge of the spatial extent to which extreme heat and flood exposure are at their highest in the City of Atlanta, the second step in answering the main research question could be completed. A compiling of the various resilience, sustainability, and climate plans within the city of Atlanta allowed for analysis of Atlanta's short to long-term planning to prepare for the potential extreme heat and flooding hazards brought about by climate change. From this research question, the results of examining city and local governance for climate resilience can inform opportunities to enhance climate resilience and equity in environmental justice.

1.3 Approach and Literature Review

1.3.1 Heat Exposure Analysis

Extreme heat is of particular importance among climate change projections for Atlanta, Georgia, and the urban heat island will exacerbate this increase in temperature. Among climate change extremes, extreme heat is responsible for the most deaths (Center for Climate Change Solutions 2019). As previously stated, heat is projected to increase in Atlanta, and the frequency of heat waves are also expected to increase (Figure 6) (Kunkel 2019). However, there are no explicit plans for heat in Atlanta, such as New York City's "Cool Neighborhoods Plan" (de Blasio & Shorris 2017). In some areas of the city, temperature will be higher than others, and in areas where infrastructure is not in place to mitigate heat, this can exacerbate the dangerous effects of increased temperatures and heat waves.

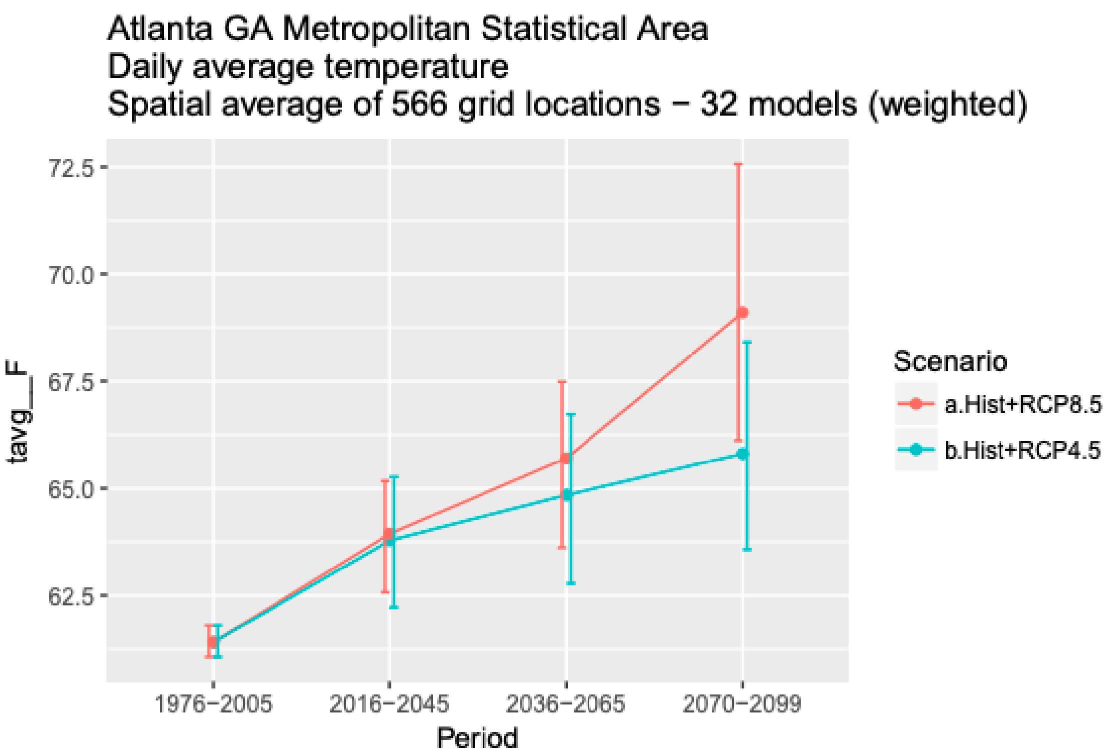


Figure 6. Daily average temperatures across the Atlanta Metro area are projected to continue increasing (Kunkel 2019).

Land surface temperature (LST) was used as a measure of spatial temperature for the purpose of this study. Although not a direct measure of ambient air temperature (the temperature that one would feel when outdoors) LST has a direct effect on air temperature via radiative processes (NASA 2019). LST, also known as brightness temperature of the surface, can be a strong indicator of UHI (Quan et al. 2014). Because UHI is the result of a region that has undergone an extensive change over time in land use or land cover, changes in energy flux and balances are created, which differ from rural, unchanged surroundings (Ogunjobi et al. 2018). This will increase how much radiation is absorbed and thus reemitted by the surface (Figure 7) (Kim 2014). Previous studies have used LST to determine the intensity of UHI and its spatial extent. Although most effective on sunny days where solar irradiance is at its strongest, LST is a strong indicator of UHI compared to surrounding, less urban areas (Imhoff et al. 2010; Sheng et al. 2017). Studies have used LST for spatial analysis to identify patterns with socioeconomic variables. In Baltimore, Maryland, it was found that even with high spatial variation in LST, LST tended to be higher in census-based block groups with lower income and levels of education, and higher levels of poverty and minorities (Huang et al. 2011).

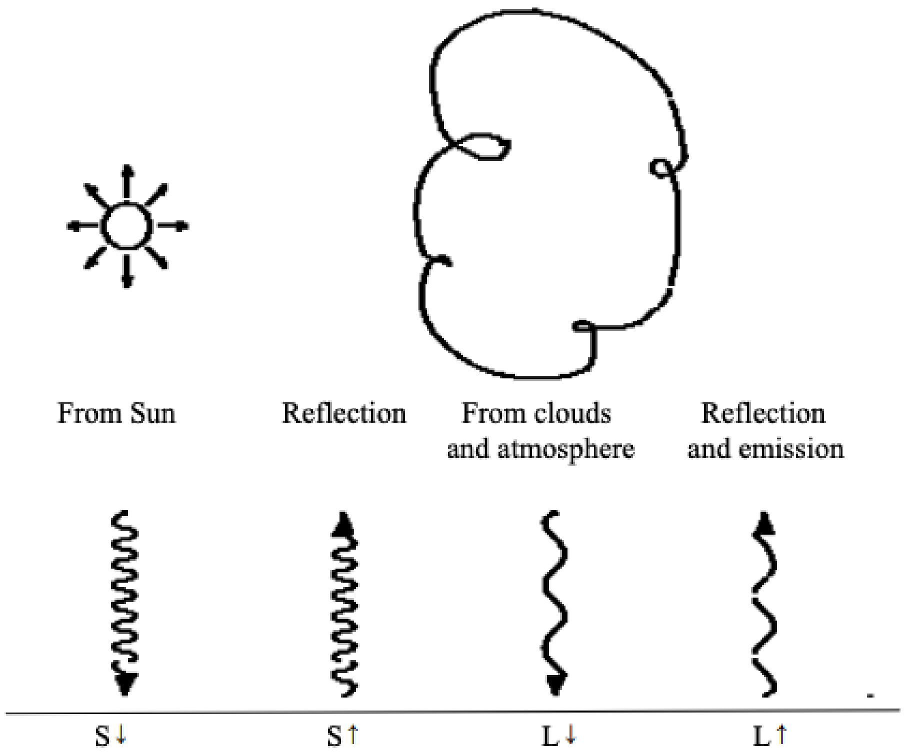


Figure 7. Energy balance at the surface, triggered by the sun's radiation (Kim 2014).

In the Phoenix metropolitan area region, similar results were found with strong correlations between LST values and median family income (Buyantuyev & Wu 2009). Although in years past Atlanta, Georgia has had LST mapped to identify the UHI, such studies have not been recent (Quattrochi & Lavall 1997) and have not explored socioeconomic variables as potential determinants for LST.

As temperatures continue to rise in Georgia and the City of Atlanta continues to grow, the radiative processes that create the UHI will intensify, further increasing temperatures in urban

Atlanta. By mapping LST, heat across the city can be visualized, and projections can be made as to where it will be the warmest across the city during extreme heat events (USGS 2019).

1.3.2 Flood Map Assessment

Flood maps are typically used to visualize flood prone areas of a region. Such maps should highlight the typical reasons for flooding in their respective regions, such as rivers, streams, or creeks that are chronically inundated, low elevation areas that waters naturally flow into, and coastal flooding vulnerabilities. However, in an urban region such as Atlanta, impervious surface that dominates much of the urban landscape accounts for much of a city's flooding issues. Sewers and water management tools also play a large role in urban water flows that potentially may not be represented in a still flood map.

The National Flood Hazard Layer (NFHL), created by the Federal Emergency Management Agency (FEMA), displays areas of flood risk and hazard across the United States. It combines hydrologic data from natural water flows, as well as from anthropogenic infrastructure built to direct urban water flows. This geospatial database can be accessed online and is used by the National Flood Insurance Program, also run by FEMA. The NFHL can be broken down by Flood Insurance Rate Map panels or "FIRMettes", each with their own identification number (Figure 8). This tool is widely used by local governments for identifying flood prone areas in urban regions and has also been used for a number of studies that involve flood risk inequity based on socioeconomic variables (Debbage 2019). FEMA also produces flood risk products by county (Figures 9 and 10). Like the FIRM panels, these maps show flood risk, but on the county scale. County flood risk maps are illustrated and do not display actual surface features that are shown in FIRM panels.

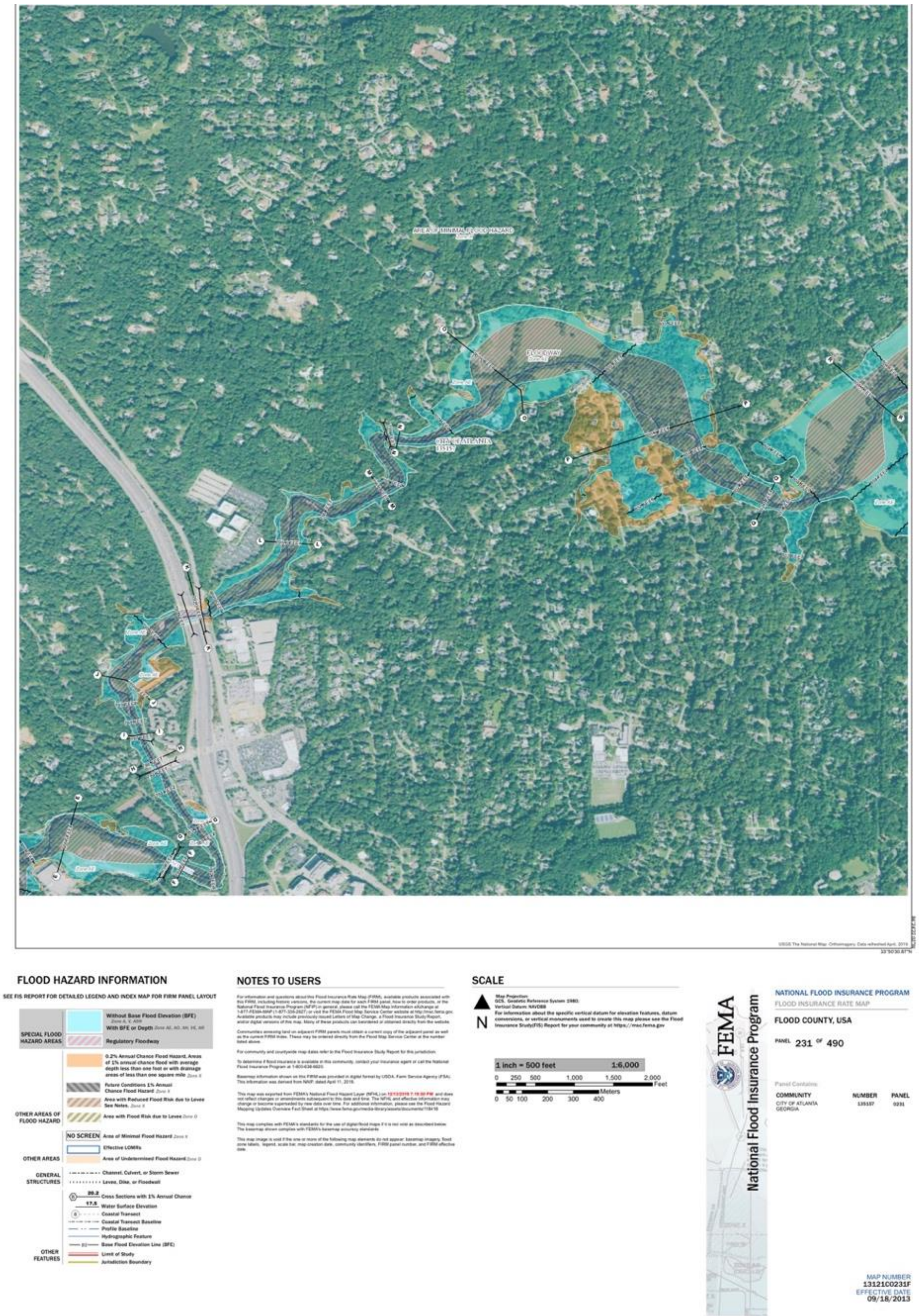


Figure 8. FIRM panel (fema.gov).

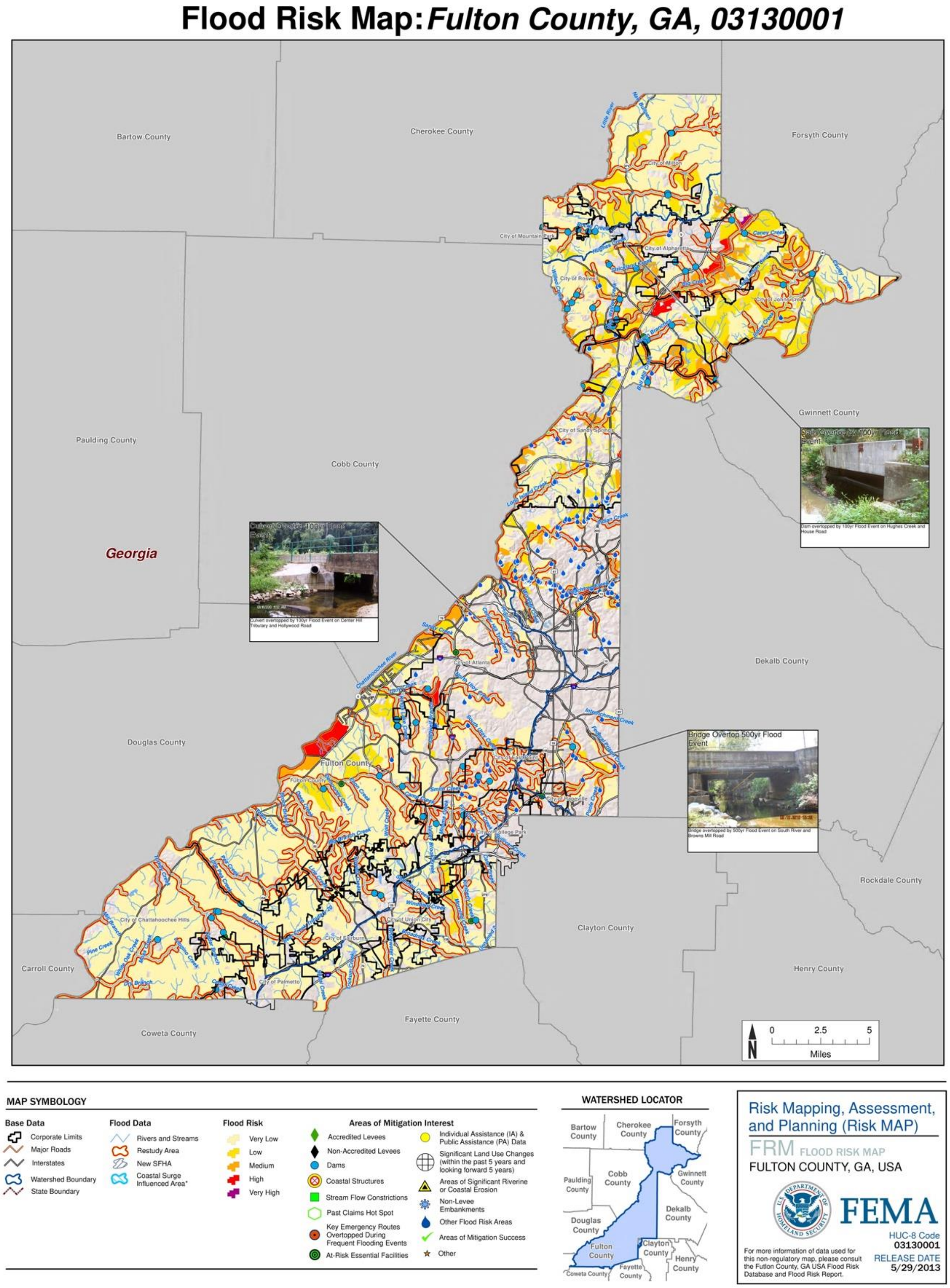


Figure 9. Fulton County Flood Risk map (fema.gov).

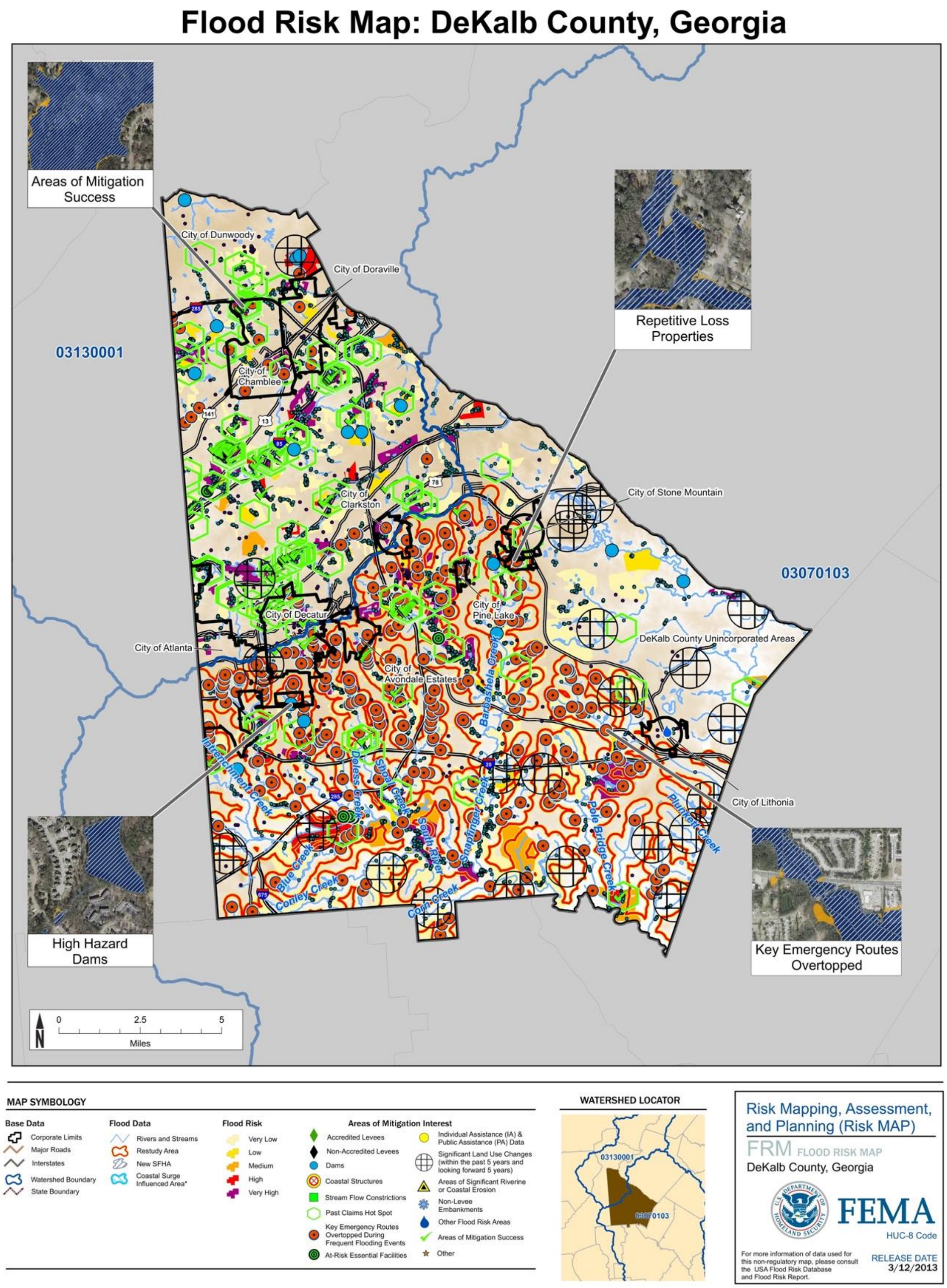


Figure 10. Dekalb County Flood Risk map (fema.gov).

Like any climate or weather-related product, these maps possess a margin of error and cannot accurately predict the complete likelihood of flood event. Flood maps are designed under the assumption that infrastructure built to manage flooding is fully functional (Caradot et al. 2011). In addition, the polygons used to define flood prone areas are subject to change due to natural conditions or the erratic flows of water. Limiting the zone to which flooding can occur can potentially be disastrous (Ferguson & Ashley 2017). To accommodate for this, FEMA updates local spatial flood information daily to keep up with any changes that can have an effect on potential flooding. FEMA also diagnoses flood prone areas as “areas with an annual 0.2% chance of flooding” or “areas with an annual 1% chance of flooding”, known as 500 and 100-year flood zones, respectively (Massachusetts Office of Coastal Zone Management 2019; fema.gov).

In the literature, the results of flood risk assessment utilizing maps are mostly consistent with FEMA’s NFHL, in identifying areas of high flood exposure. The National Flood Insurance Program (informed by NFHL) has been “marginally effective” at slowing down public and residential exposure to flooding in Metropolitan Atlanta by informing city ordinances that prohibit floodplain development (Ferguson & Ashley 2017). However, under the continuous expansion and infill of Atlanta, city officials have the right to overrule ordinances and allow floodplain development (Morsch 2010).

This study aimed to identify how Atlanta climate resilience planning may or may not address flood prone areas (using NFHL maps to identify flood prone areas/communities) to mitigate flooding in its communities, especially under the implications of climate change.

1.3.3 Climate Governance Analysis

This research relies on content analysis methods, an analytical technique to code and evaluate qualitative material into quantitative data (Bernard and Ryan 2010). Content analysis is used within the Urban Resilience to Extremes Sustainability Research Network (UREx SRN) to understand how cities are preparing for climate change across North and Latin America (Iwaniec et al. in review). Similar research frameworks have been used in Europe (Damsø et al. 2016), and Asia (Dola 2012).

In Denmark, Damsø et al. (2016) sought to assess the effect local climate change planning has on mitigating global climate change, by “examining the propagation and scope” of local climate action plans (CAPs). An identification of the “extent, variation, and targets” of 103 local governments (LGs) climate action planning served as motivation for the study. An analysis of the extent of local climate action planning across Denmark revealed spatial variation among municipalities that actually participated in CAP and issued plans. Like the US, there are some regions of Denmark that do not work to issue CAPs. Content analysis involved a coding manual for “Targets”, “Plan Elements”, “GHG Account Coverage”, “CAP Coverage”, and “Modes of Governance”. Results were largely attributed to greenhouse gas (GHG) emissions reduction targets within the mid 21st century.

Noor (2012) applied a similar, but distinctly different content analysis approach of the environmental planning in Malaysia. Plans were scored rather than coded, by indicating evaluation scores for the strength of the planning strategies and complimentary targets. For example, targets listed with no strategy or plans of action that include key words, were given a score of 0. The same applied to higher scores:

> "A score of 1 is awarded when a key word was stated, but maybe only once or twice. For example, Pontian/Pekan Nanas Local Plan mentioned the need to interpret policies and general proposals from the Structure Plan that reflects sustainable development concept. However, action or strategy was not found in further discussion. When no supportive statement was found a score of 1 was given" (p. 4).

Dola and Noor found the strongest scores for plans that addressed landscape and greenspace, to restore natural functions and ecosystem services.

Despite the importance of the work by Damsø et al. (2016) and Noor (2012) to identify the level of climate action planning in a region, or to evaluate the strength of sustainability and environmental planning, an enhanced approach and coding manual is used for this study. Although Dola and Noor addressed the overlap of many strategies and targets in different categories or sectors of the environment, these approaches address only certain components of sustainability (i.e., low carbon or carbon neutral strategies).

Planning documents in the City of Atlanta have begun to reach the desks of policy makers and stakeholders, in order to create a more sustainable[1] and resilient[2] city in the face of the effects of climate change. However, it is important that these municipal plans explicitly focus on problem areas of the city (i.e., heat and flood exposure/vulnerability). This study sought to analyze climate governance via content analysis to identify whether or not climate resilience planning in Atlanta, Georgia will address identified climate hazards in flood or extreme heat. Such climate hazards are threats that inhabitants of the city may be likely exposed to during the onset and potential intensification of climate change.

---

[1] https://www.epa.gov/sustainability/learn-about-sustainability#what

[2] https://agsci.psu.edu/research/areas/environmental-resilience

2 DATA AND METHODS

2.1 Landsat 8

Data was retrieved from the NASA/USGS Landsat 8 Satellite, equipped with Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) instruments. Launched in February 2013, the satellite orbits Earth on a 16-day cycle, recording images of the planet at 30-meter resolution with the OLI instrument, and 100-meter resolution with the TIRS instrument (TIRS data is resampled to 30-meter resolution to match OLI multispectral bands) (USGS 2019). Data from the satellite was downloaded by individual recorded day from the USGS Earth Explorer website, packaged with GeoTIFF images the represent each satellite band and a metadata file containing satellite thermal constants, rescaling factors, and corrections. The image for Band 10 (characterized by 16-bit digital numbers (DNs) that measure energy at the sensor), which is less contaminated with stray light than Band 11, is used for mapping surface temperature (Jiang 2017). Landsat 8 bands and observation parameters are presented in Appendix D. In ArcGIS Geospatial Information System software, the GeoTIFF image can be inserted as raster data, which can be manipulated using the software's tool, raster calculator. The City of Atlanta was specifically used for this study, which falls within Path 19, Row 37 in the Landsat record database. The city's official boundaries are within Fulton and DeKalb counties of the state of Georgia (Figure 5).

2.2 Time Period

The warmest temperatures of the year occur during the months of June through August in Atlanta, peaking in July. The satellite typically records images of the Atlanta area twice a month, as it operates on a 16-day cycle. Due to data availability and cloud interference, LST was mapped from the satellite images at least once each month per year, when available. Thirteen days without cloud interference fell within the time period for this study. LST on days of the same month were averaged for a monthly average LST. Average monthly LST was then averaged for the mean "summer" (June-August) LST for the years 2013-2019.

2.3 Mapping LST

A series of calculations and conversions were required to convert the image to surface temperature, with equations provided by USGS (USGS 2019). The steps for calculating LST were followed as in Avdan & Jovanovska (2016). The first step was a conversion to top of atmospheric (TOA) spectral reflectance or radiance (L_λ):

$$L_\lambda = M_L \times Q_{cal} + A_L - O_i, \tag{1}$$

where M_L is the band-specific multiplicative rescaling factor (known as "RADIANCE_MULT_BAND_10" in the metadata file), Q_{cal} is the quantized and calibrated standard product pixel values measured in DNs, A_L is the band-specific additive rescaling factor (known as "RADIANCE_ADD_BAND_10" in the metadata file), and O_i is the band-specific correction constant. Once radiance is determined, the next step involves the conversion to TOA brightness temperature (BT). The equation to calculate BT is as follows:

$$BT = \frac{K2}{\ln\left[(K1/L\lambda) + 1\right]} - 273.15, \tag{2}$$

Where K1 and K2 are band-specific thermal conversion constants (known as "K1_CONSTANT_BAND_10" and "K2_CONSTANT_BAND_10", respectively, in the metadata file). For the purposes of calculating temperature in Celsius, temperature was converted from Kelvin by subtracting 273.15.

To complete the final step in calculating land surface temperature (LST), land surface emissivity (ε_λ) must first be determined, which in itself requires calculating the proportion of vegetation (P_v). P_v is obtained by using the Normal Difference Vegetation Index (NDVI), which is calculated using the satellite's 4th and 5th bands, near-infrared (NIR) and red (R), respectively, where NDVI represents the density of a region's vegetation (NASA 2000). The equation is as follows:

$$NDVI = \frac{NIR(band\ 5) - R(band\ 4)}{NIR(band\ 5) + R(band\ 4)}, \tag{3}$$

Once NDVI is calculated, P_v can be determined:

$$P_v = (\frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}})^2, \tag{4}$$

With P_v determined, it can be substituted into the appropriate land surface emissivity equation:

$$\varepsilon_\lambda = 0.004 \times P_v + 0.986, \tag{5}$$

After all above equations were utilized within ArcGIS's raster calculator to determine the necessary variables, land surface temperature (LST), could be calculated:

$$LST = \frac{BT}{[1 + \left(\frac{\lambda BT}{\rho}\right) \ln{(\varepsilon_\lambda)}}, \tag{6}$$

with ρ defined as:

$$\rho = h\frac{c}{\sigma}, \tag{7}$$

where h is Planck's constant (6.626 × 10^{-34} J s), c is the speed of light (2.998 × 10^{8} m/s), and σ is Boltzmann's constant (1.38 × 10^{-23} J/K).

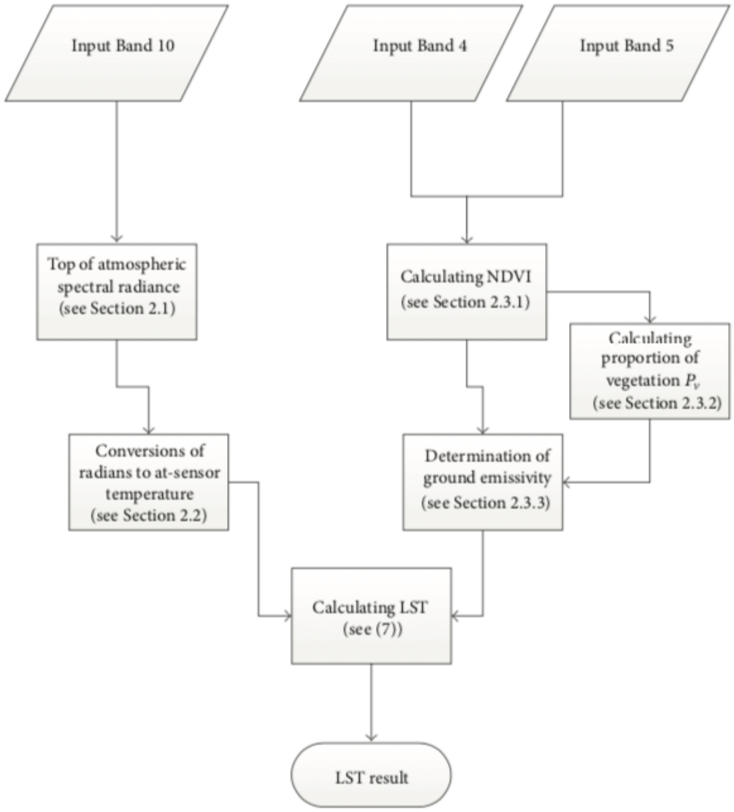


Figure 11. LST calculation flowchart from Avdan & Jovanovska (2016), as followed in this study.

2.4 LST Validation

Weather Underground (https://www.wunderground.com/history/) stores records for air temperature from hourly to monthly observations at the Atlanta Hartsfield-Jackson Airport weather station. Hourly temperature data was retrieved from the site's archive for validation via comparisons with calculated LST pixel values, on the dates of LST mapping. LST pixel values used for comparison were retrieved from the airport weather station's coordinates (33.74 °N, 84.38 °W). The differences between the LST values and recorded observations at the weather station are shown in Appendix F.

2.5 Socioeconomic Data

Two key socioeconomic variables were used for visual and statistical analysis. Poverty levels per census tract (percent) were obtained from 2017 5-year estimate American Community Survey (ACS) data (2013-2017). This ACS data is an aggregation estimate over the five-year period and was not a sole measurement taken in 2017. Although the black population has not been the minority demographic in urban Atlanta since the 1960s (51.8% of the City of Atlanta's population in 2019), they are still the minority in the state of Georgia (32.4% black) and nationwide (13.4% black) (US Census Bureau 2019). Racial demographic data was retrieved from the US Census Bureau (2010) per census tract (percent). Overlaying census tracts on heat maps allowed for temperature versus socioeconomic variable comparisons and statistical analysis.

2.6 Statistical Analysis

A correlation was run to analyze the relationship between LST and obtained socioeconomic data (Zou et al. 2003). Census tracts within City of Atlanta boundaries were laid over calculated LST maps. For a correlation with percent black and percent below poverty values per census tract, LST was aggregated to the census tract level by the mean LST value within the tract. This statistical analysis was performed in Microsoft Excel using the Analysis ToolPak package.

2.7 Review of Flood Maps

To determine flood prone areas within the City of Atlanta, the National Flood Hazard Layer was used. The city is broken down by FIRM panels, which were used to identify regions where there is a flood hazard. For the purposes of this study, two flood hazard levels were used: a 1% annual chance flood hazard or "100 year flood hazard" (flood zone highlighted by a blue polygon) and a 0.2% annual flood chance hazard or "500 year flood hazard" (flood zone highlighted by an orange polygon). Observations were cross referenced with political maps to determine the exact location of flood zones within city limits, as they may be listed and addressed in planning and governance documents.

2.8 Climate Governance Analysis

For Atlanta, municipal-scale governance plans and documents were analyzed, as well as non-profit and private organization plans, for their strategies and targets addressing the major threats to climate resilience. Examples of plans that include climate resilience strategies for the Atlanta metropolitan area are citywide plans such as *Resilient Atlanta: Actions to Build an Equitable Future* and *City of Atlanta Climate Action Plan* (Appendix A). Once a "climate resilience hazard" (i.e., a strategy or target to address flood, drought, or heat) was explicitly identified, the quote (and associated metadata) from the planning document was extracted and placed into a formatted coding database (Table 2). The codebook for this analysis was slightly modified from the Urban Resilience to Extremes Sustainability Research Network (UREx SRN) governance document analysis codebook (Iwaniec et al. *in review*; Kim et al. *in review*). Specifically, the code for "non-specific hazards" was renamed and its criteria modified to capture "general capacity" climate resilience strategies. "General capacity" strategies are interpreted as strategies that address climate hazards aside from heat, flood, or drought, or address more than two or more of these climate hazards. For example, a green infrastructure strategy may be identified in a municipal plan but without explicit mention of a single climate resilience hazard. The new code for "general capacity" now captures this strategy as it can provide ecosystem services to address both flooding and heat.

Strategies, extracted from governance documents, were identified as action items, specific goals, and intervention to address climate resilience. Targets were identified as quantitative or qualitative descriptions (i.e., how much, where, and when) provided as metrics for the implementation of identified strategies. Additional notes were also extracted from the governance documents to capture associated information describing normative criteria (i.e., why the strategy/target is needed). Metadata for the strategies and targets were organized by: 1) the city they are to be implemented in, 2) the document they were extracted from, 3) a unique identifier for each strategy (in reference to how many strategies have been extracted from a document); (see Table 2 for an example).

Table 2. Strategy and target extraction for coding analysis.

City ID	Doc ID	Strategy ID	Strategy Description (Quote)	Strategy Page #	Notes	Target	Target Page #
ATL	ATL01	ATL01-03	Action 3.4.1: Complete construction of the first segment of the Proctor Creek Greenway	84	The communities surrounding Proctor Creek are in an environmental justice hot zone due to rapid growth of brownfields resulting from vacant and underutilized industrial properties, limited greenspace, food deserts, and public health threats resulting from frequent flooding	Create 500 new acres of publicly accessible greenspace by 2022 / Develop the first three miles of the Proctor Creek Greenway by Jan 2018	70

After the strategies were extracted based on the explicit mention of a climate hazard, additional coding was conducted to identify Social, Ecological, and Technological Systems (SETS) features, knowledge system type, geographical/spatial scale, intended beneficiaries, resilience scope of the strategy (Appendix B):

- Social, Ecological, and Technological Systems (SETS) features: Aspect of the urban system the strategy is intended to change (i.e., Social, Ecological, or Technological) and coding for key types of social, ecological, or technological changes (e.g., For Social, these may include is it an Education; Behavioral, or Legal strategy).
- Knowledge system type: Forms of local, practitioner, and academic knowledge relevant to this strategy.
- Geographical/spatial scale: Where the strategy is to be implemented.
- Intended beneficiaries: For whom, are the benefits of the strategy intended.
- Implementation scope of the strategy: How the intended changes will be implemented (i.e., change in governance norms, programmatic implementation, etc.).

Analyzing a plan for its different strategies provides insight into how different governance institutions (e.g., city departments) are framing climate resilience, the adaptation strategies they are pursuing, why and where they are pursuing these strategies, and possibly for whom these strategies will benefit. In addition, coding allows for quantitative analysis that can highlight city planning priorities—for example: if strategies for drought mitigation are extracted and coded most often, then drought mitigation is likely a priority for the plan's governing body.

While the Atlanta metropolitan area faces general threats brought about by climate change, there are specific regions of the city that may be more susceptible to certain climate hazards. For example, due to topography and infrastructure, there are communities that are more exposed to flooding more than others—analyses of the plans may reveal that strategies for flooding mostly address these areas. If not, it is important that flooding strategies are made a priority in these areas for future planning. Additionally, analysis may reveal that existing strategies for flooding may not consider socioeconomic conditions or underrepresented key knowledge systems, geographies, or beneficiaries. Much of the time, this lack of consideration is due to a lack of representation in public policy which can lead to a neglect of community needs—most likely an ultimate result of lower socioeconomic status.

2.8.1 Review of Governance Document Analysis

Inter-rater reliability was used for reproducibility and review purposes of initial climate resilience coding. Successful inter-rater reliability relies on multiple coders coding content similarly and without extreme variation (Milne & Adler 1999). Once the full extraction and coding of climate resilience strategies was completed, two other coders were given a random sample of ten, uncoded climate resilience strategies from the coding database. The two coders then independently code these ten strategies at their own discretion. Once all coding was complete, the three coders convened to discuss the differences and similarities between their coding, as well as interpretations of the codebook and climate resilience strategies. A minimum of 60% of all strategies being coded the same among three coders, was the minimum threshold used for the purposes of this study. Of the strategies coded for in this study, 88% were coded the same among three coders.

3 RESULTS

3.1 Heat Exposure Analysis

A large spatial variation exists in the City of Atlanta's average summer LST. The warmth of the city's urban core (on average above 30 degrees Celsius) can be largely attributed to large extents of impervious surface, such as the major highway I-85/I-75. These major roadways are visible in Figure 12, characterized by clusters or streaks of reddish color. Other types of

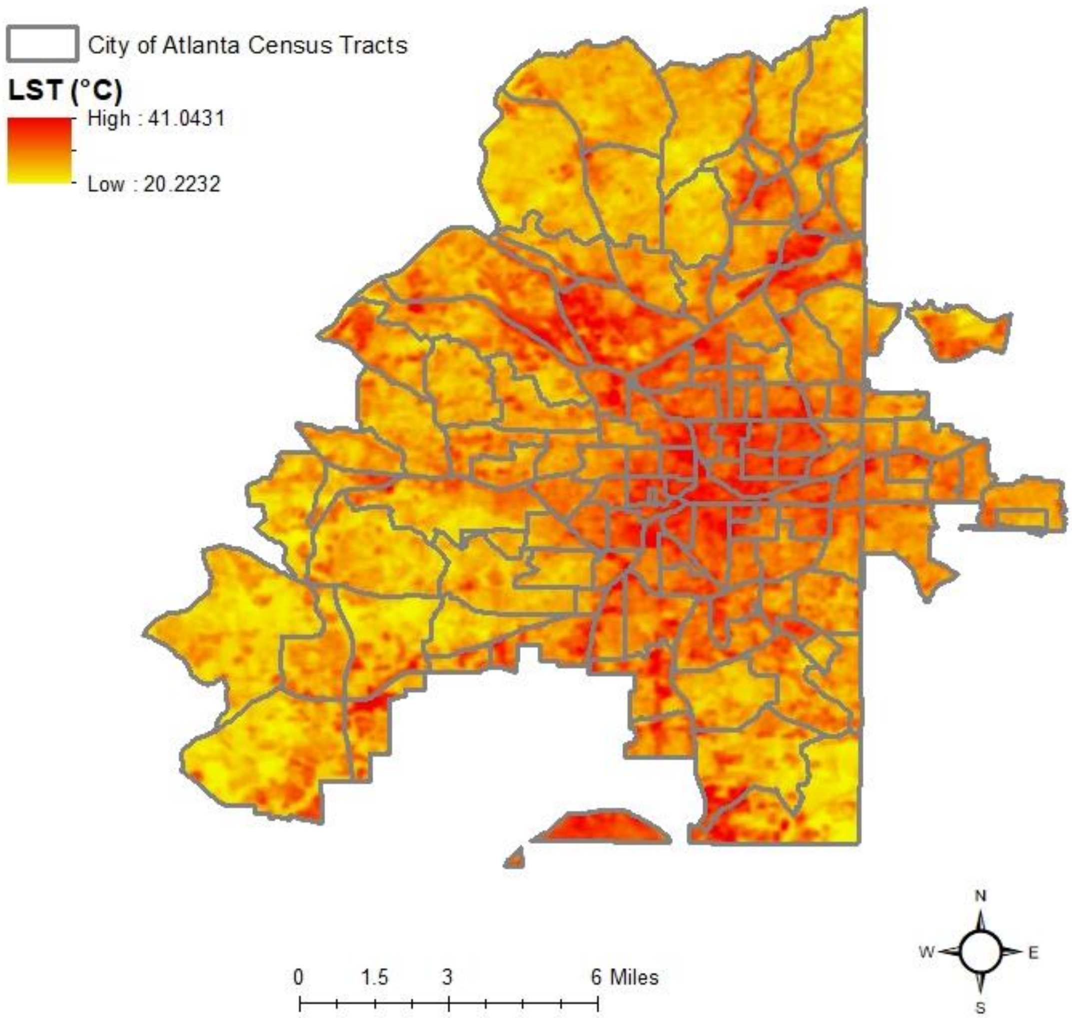


Figure 12. Average Summer LST (2013-2019).

impervious surface downtown include a high concentration of buildings and parking lots, surrounded by streets.

The City of Atlanta has a relatively large urban tree canopy, which is present in most regions with lower LST values. This canopy or vegetation can be visualized in Figure 13, where NDVI was mapped alongside average summer LST. Generally, where NDVI values are lower, LST is expected to be higher. Low NDVI values represent low amounts of vegetation, likely replaced by extensive built, anthropogenic environments. Aside from the urban core and nearby major roadways, there are large pockets of cooler, yellow colored areas, which correspond with higher amounts of NDVI (greener colors). Trees and greenspace provide environmental services beyond mitigating heat and are a prime factor as to why greener communities tend to have lower surface temperatures due to shading and the cooling qualities of evapotranspiration (Qiu et al. 2017). Other infrastructure such as blue or grey infrastructure and reflective or permeable technologies may be responsible for cooler areas, and thus higher amounts of NDVI. NDVI is lowest in the urban core where these roads and built structures exist.

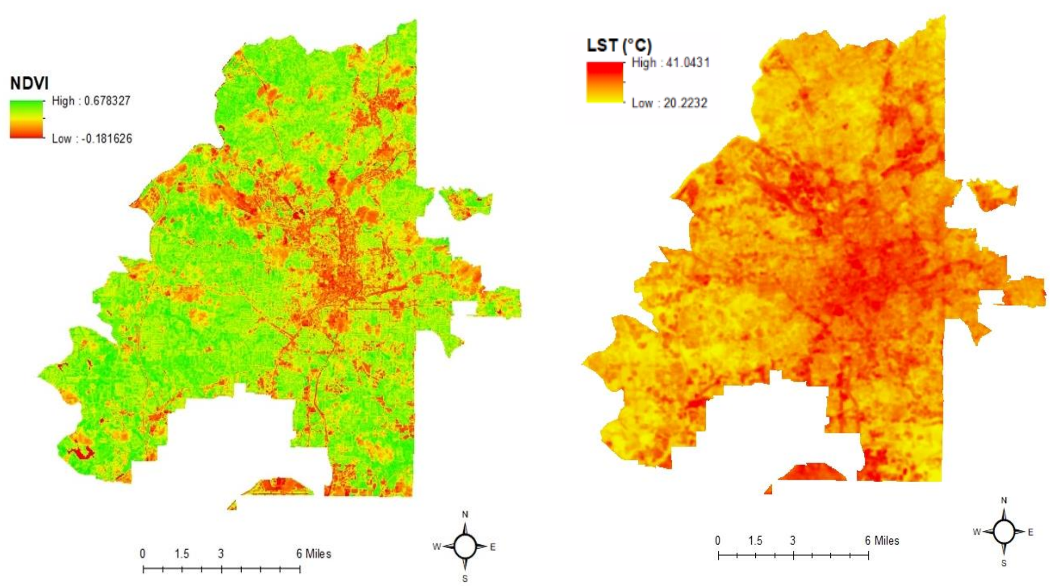


Figure 13. NDVI (2019) vs average LST.

On average, and throughout all three observed months, temperature values above 30 °C can be observed in these areas. The months of June, July, and August (Figure 14) are also shown to prove consistency with expected Atlanta summer temperature climatology (Appendix E). The month of July boasts the highest average LST for urban Atlanta (42.63 °C), followed by August (41.85 °C).

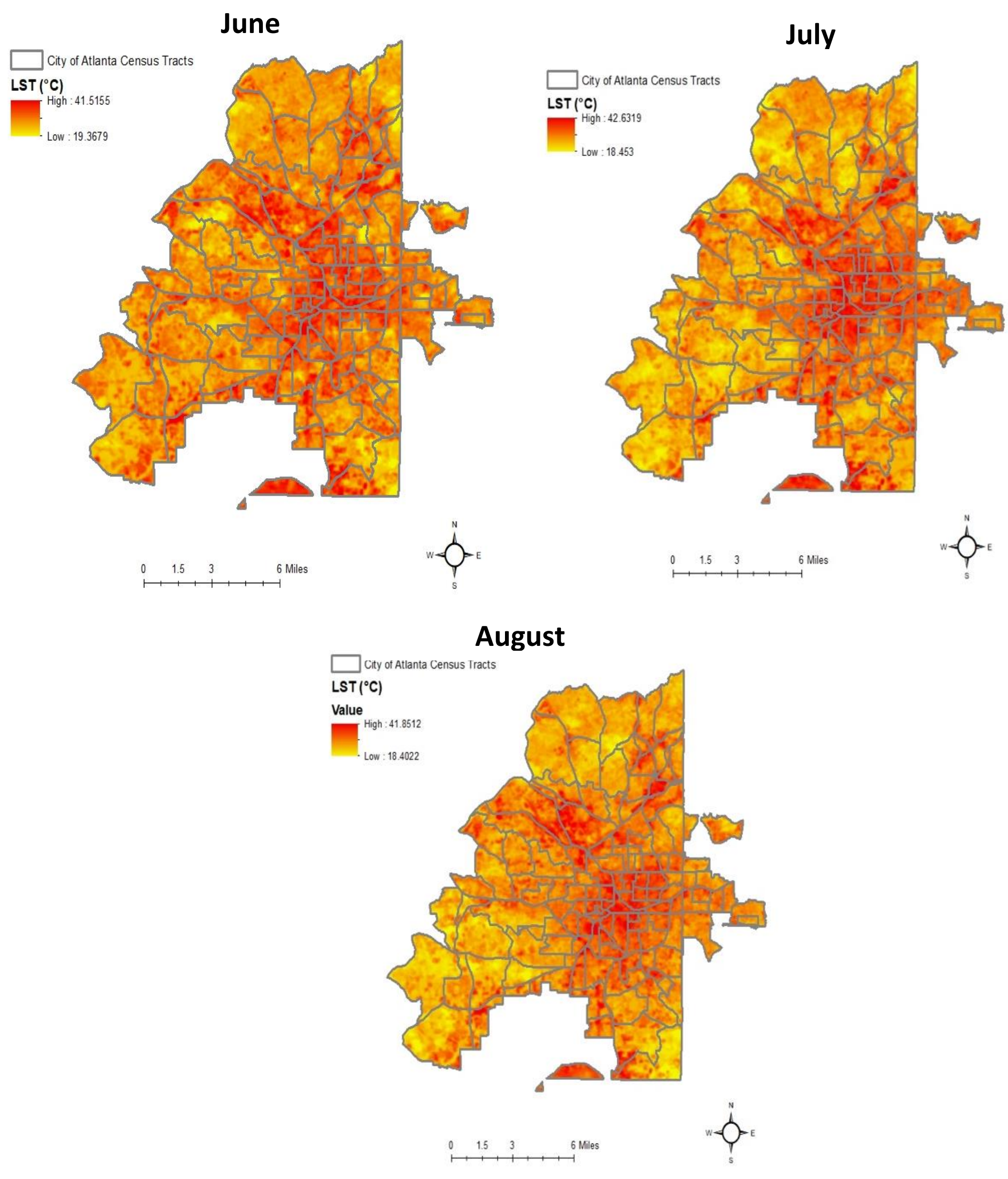


Figure 14. Average June, July, and August LST.

In exploring the relationship between socioeconomic variables and LST, a negative correlation of -0.45 was found between average census tract LST and census tracts with black populations of 70% or more of the total tract populations—suggesting that as black populations increase, temperature decreases. The medium-strength relationship is visualized in Figure 15.

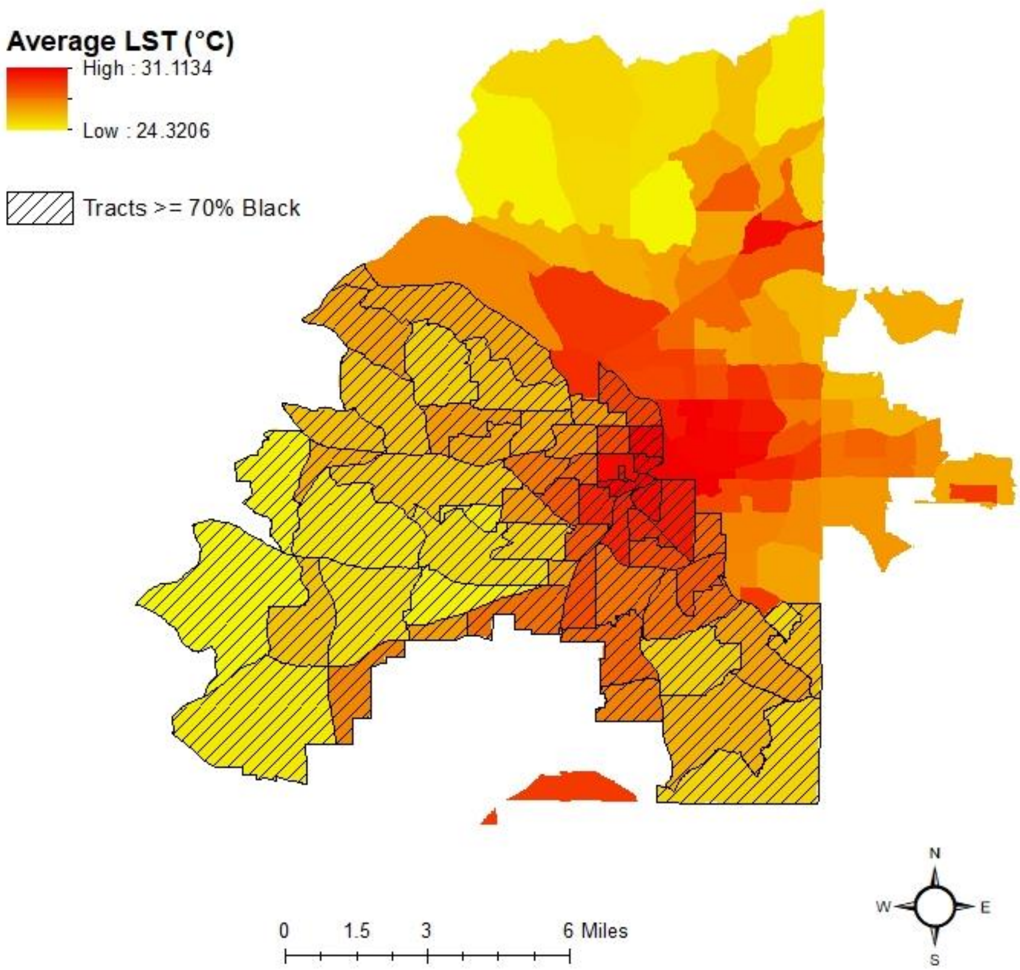


Figure 15. Average LST per census tract. Census tracts that are equal to or over 70% black are overlaid.

The southwestern region of Atlanta is largely populated by black residents. It is also widely vegetated or without intensive development, with the exception for some patches of infill (Figure 15). Black populations in the city's inner core, however, may experience higher temperatures due to minimal vegetation and expansive urban development without proper heat mitigating measures. Table 3 displays the correlation output, where Column 1 is the percentage of black residents per census tract, and Column 2 is average LST per census tract.

Table 3: Correlation results for majority black census tracts (≥ 70% black) vs average LST per census tract. The negative correlation (~-0.45) indicates that as the percentage of the black population increases, temperature decreases.

	Column 1	*Column 2*
Column 1	1	
Column 2	-0.4451368	1

Poverty versus LST (Figure 16) displayed a positive, but weak correlation of ~0.13, despite the urban core being heavily concentrated with regions where at least 20% of the population lives below poverty. Table 4 displays the correlation output, where Column 1 represents the percentage of the population within the census tract that lives below poverty. Column 2 is average LST per census tract.

Table 4: Correlation results for census tracts with at least 20% of population below poverty level vs average LST per census tract. A weak correlation between the two variables was found—temperature slightly increasing as the percentage of poverty increases.

	Column 1	*Column 2*
Column 1	1	
Column 2	0.12621808	1

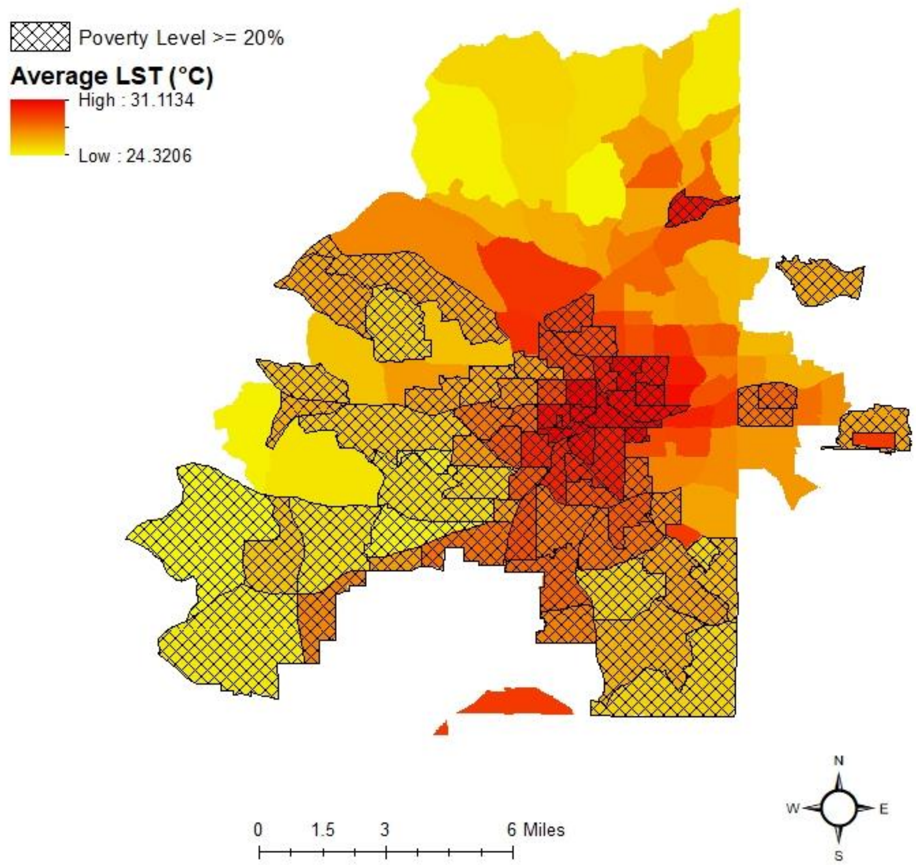


Figure 16. Average LST with census tracts where at least 20% of the population lives below the poverty level overlaid.

3.2 Flood Map Analysis

Flooding in the City of Atlanta's urban communities is mostly localized and non-life threatening, but chronic and repetitive due to lack of proper infrastructure or development within a floodplain. Unlike heat, flooding is at its smallest risk within the center of Atlanta where urban development is at its greatest, with the exception of FIRM Panels 13121C0241F, 13121C0242F, and 13121C0243F (FEMA's National Flood Hazard Layer Viewer 2019)—which have Woodall, Tanyard, and Proctor Creek flowing through them, respectively. Areas along these creeks are diagnosed with having a 1% annual chance flood hazard. The FIRM panel most urbanized and most central to the city of Atlanta (FIRM panel 13121C0244F), has been designated an “Area of Minimal Flood Hazard” with scattered areas of a 0.2% annual flood chance hazard within its boundaries.

Several other notable bodies of water have designated flood risk hazards. South River possess a regulatory floodway, or “reserved” space for flooding in the event the water level rises. Along South River’s banks and its tributaries, just northeast of Hartsfield-Jackson International Airport, is a 1% annual chance flood hazard. Cautious 0.2% annual chance flood hazards extend beyond the 1% flood hazards in these areas (FIRM Panels 13121C0359F, 13121C0386F, 13121C0367F, 13121C0378F). Utoy Creek in West Atlanta (FIRM Panel 13121C0351F), possesses a regulatory floodway similar to South River, surrounded by a 1% annual chance flood hazard. Nancy River and its tributaries flow through northern Atlanta (FIRM Panels 13121C0231F and 13121C0232F). This body of water also has a designated regulatory floodway and a 1% annual chance flood hazard.

A segment of the Chattahoochee River passes along the western border of the city (FIRM Panels 13121C0228F, 13121C0229F, and 13121C0227F) and has the largest regulatory floodway in the City of Atlanta, accompanied by a 1% annual chance flood hazard. This segment of the major river is also responsible for multiple bodies of water that flow through and around the City of Atlanta. Previously mentioned was Proctor Creek, as it extends from the Chattahoochee River into center city Atlanta from Western Atlanta, carrying with it a 1% annual chance flood hazard along a regulatory floodway (FIRM panels 13121C0236F and 13121C0237F). Proctor Creek also feeds the Center Hill Tributary, that flows southeast with a 1% annual chance flood hazard and isolated 0.2% annual chance flood hazards (FIRM Panels

13121C0236F, 13121C0237F, and 13121C0239F). Peachtree Creek has a 1% annual chance flood hazard along a regulatory floodway that extends to the east from this Chattahoochee River segment, across the City of Atlanta and into the City of Decatur (FIRM panels 13121C0233F, 13121C0234F, and 13121C0253F). Peachtree Creek also feeds Woodall Creek on the western side of the city and Clear Creek on the eastern side of the city. Woodall Creek possesses a very narrow regulatory floodway surrounded by a 1% annual chance flood hazard. Clear Creek begins as a wide regulatory floodway with a 1% annual chance flood hazard but becomes more narrow as it flows south (FIRM panels 13121C0242F and 13121C0261G). In the southwestern region of the City of Atlanta is Sandy Creek, also with a narrow regulatory floodway and 1% annual chance flood hazard (FIRM panels 13121C0217F and 13121C0238F).

3.3 Climate Resilience Governance Document Analysis

A preliminary identification of documents identified 78 potential documents to analyze. Plans selected for analysis will contain strategies/actions or targets that explicitly address a climate resilience external driver (e.g., heat, flood, drought). Of the 78 governance documents identified, including the City of Atlanta’s Code of Ordinances, 14 documents had 58 strategies that explicitly addressed an external driver and fell within the study’s time period of 2013-2019.

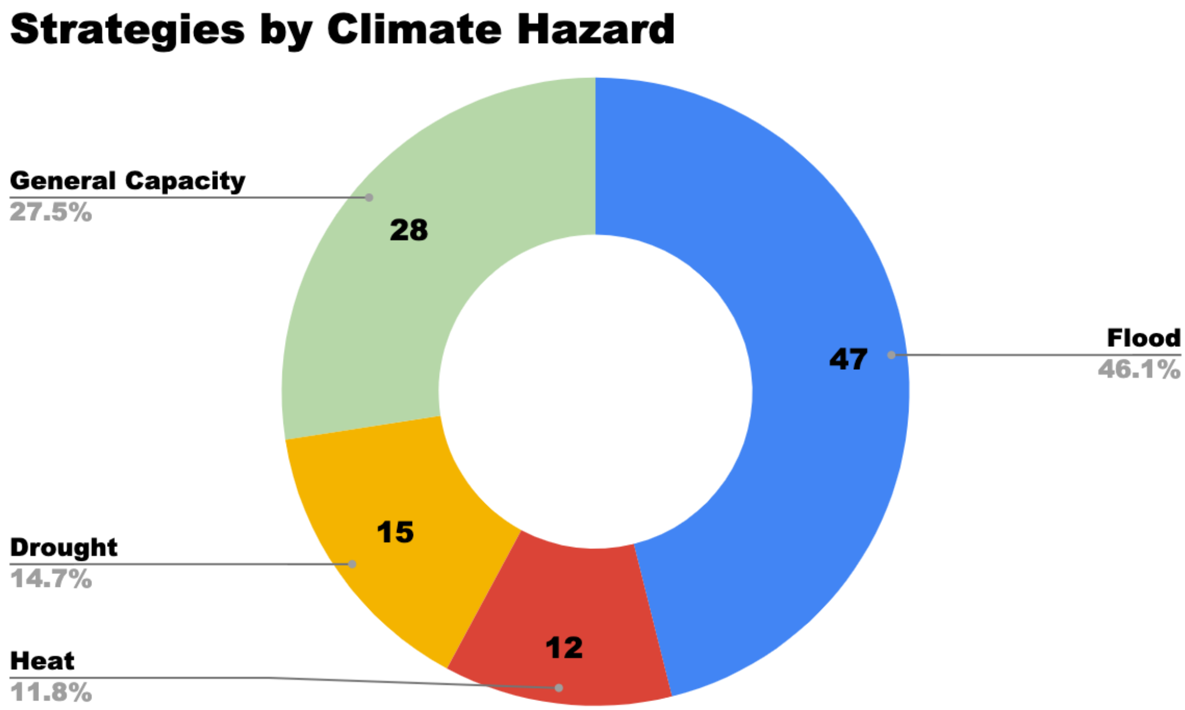


Figure 17. Breakdown of number of strategies per climate hazard (note that some strategies can address more than one climate hazard).

Flooding (whether urban, non-specific, riverine, or all) accounts for the most strategies coded among plans that were analyzed. Although not a climate hazard included for the purposes of this study, drought was the next climate hazard identified most, followed by heat. A breakdown of the number of strategies coded for climate hazards is displayed in Figure 17. About half of the coded strategies were intended to be implemented city wide—the other half of strategies applying to specific neighborhoods, with the exception of the strategies within the *North Georgia Water Resource Management Plan*, where strategies were coded as sub-national/regional. All flood strategies were coded as beneficial for the general public. As expected for a naturally motivated climate hazard, the knowledge base for all flood and heat strategies came from the natural sciences. Local knowledge systems, in addition to institutional knowledge systems, were also coded often for flooding strategies as they are important for addressing many of the climate threats that plague urban communities. Implementing programs or activities that address climate resilience encompassed most strategies, as well as changes in (or from) the "norm" (or normal way of doing things), and changes in policies/laws to enforce strategies.

3.3.1 Flood in Climate Governance Documents

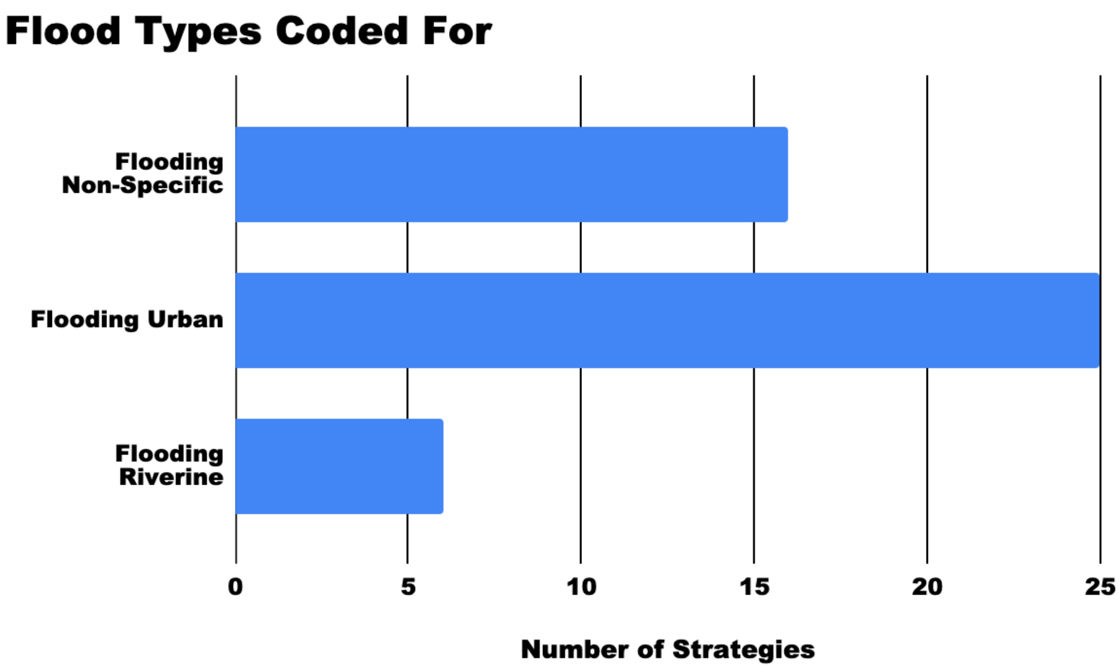


Figure 18. Types of flooding coded for.

Three types of flooding were coded for in this study: "non-specific", urban flooding, and riverine. Non-specific flooding refers to a mention of flooding in a strategy, without referencing an urban or riverine setting. Some plans included strategies for the City of Atlanta and for regions outside of the city's political boundaries—thus flooding strategies that were not clearly urban or riverine within the City of Atlanta were coded as non-specific. Urban flooding in this study refers to a strategy that applies to flooding within the downtown region of the City of Atlanta. Riverine flooding refers to a strategy that mentions a river, creek, or stream. Of the three, urban flooding was coded for most, followed by non-specific flooding, and then riverine flooding.

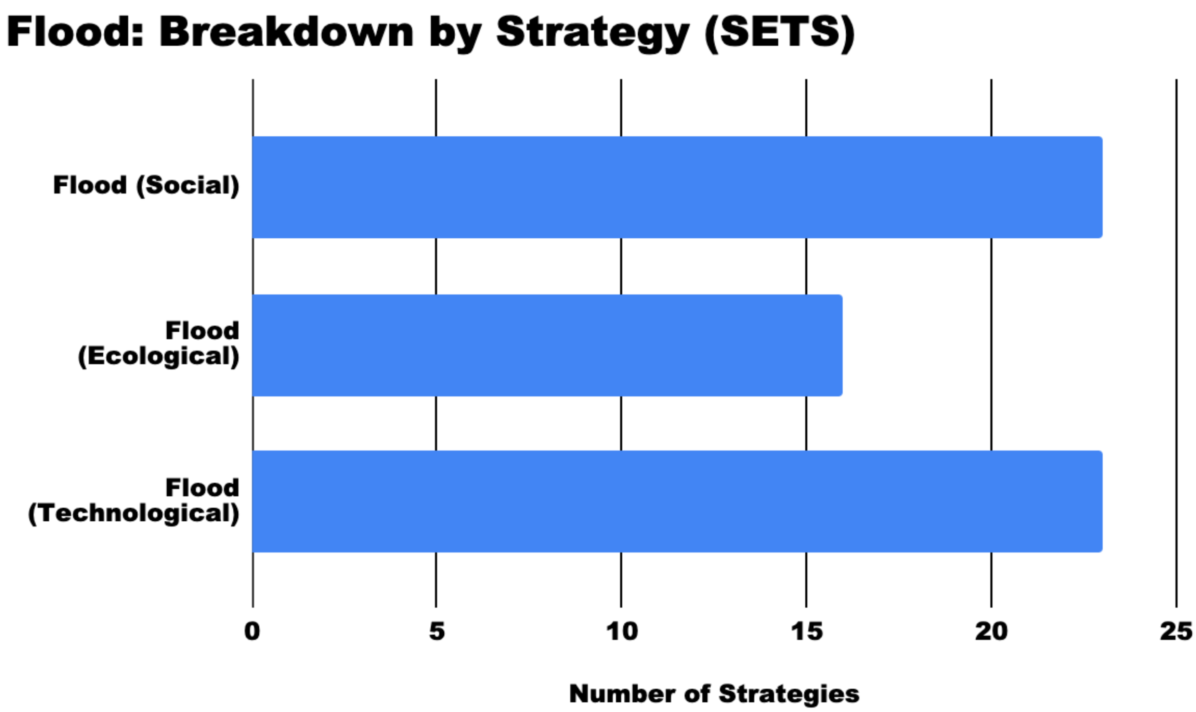


Figure 19. Breakdown of flooding strategies coded as implementing social, ecological, or technological solutions.

Utilizing a SETS framework revealed that coded strategies for flooding had a large amount of social influence, tied for the most with technological solutions (Figure 18). Ecological solution-based strategies followed with several fewer strategies. This coding indicated that climate resilience planning in Atlanta is depending largely on technological solutions to solve flooding issues, mainly from institutional and governance parties (Figure 19). Twelve flood strategies also had legal implications, involving ordinances and environmental justice concerns. The *Historic Atlanta Master Plan* (Plan ID: ATL20) details one of these legal strategies:

"Address the absence of enforcement of tree regulations; raise the financial penalties for illicit tree cutting to address watershed flooding." Social safety nets or social support, educational, informational, behavioral, and economic strategies were coded for least among social strategies for flooding.

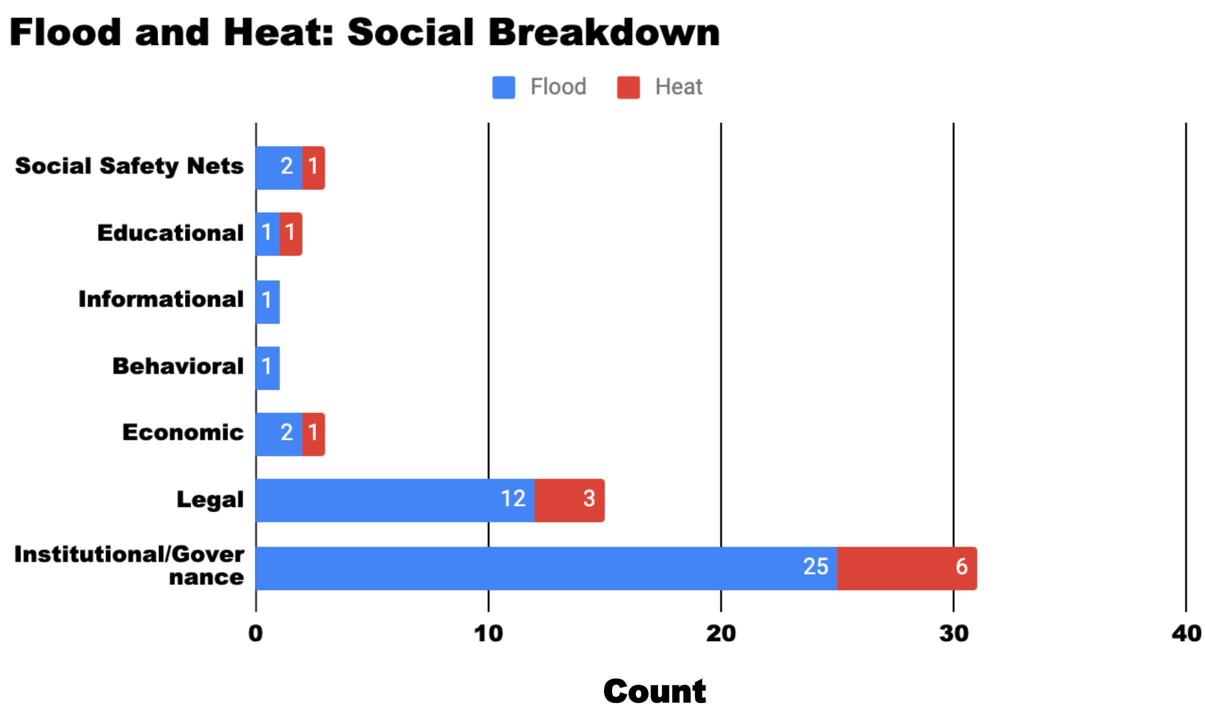


Figure 20. Breakdown of social strategies coded for heat and flood.

Ecologically based flood strategies (Figure 20) largely involved green infrastructure as a tool to mitigate flooding in urban Atlanta. For example, Action 3.4.1 from the *Resilient Atlanta: Actions to Build an Equitable Future* plan (Plan ID: ATL01 in the codebook) involved creating 500 acres of greenspace to address "frequent flooding" along Proctor Creek, an area that was previously identified as having a 1% annual chance flood hazard (Figure 21). Communities along Proctor Creek have been identified as "environmental justice hot zones", as these areas have frequently flooded. Construction of the Proctor Creek Greenway is intended to mitigate flood issues in these areas and will likely have general capacity implications as well. Typically paired with green infrastructure strategies are ecosystem-based strategies, which involve restoration of the natural environment or the addition of infrastructure to a natural environment, such as a watershed. "Management practices" strategies were also coded as ecological flooding strategies, which included implementing the regular maintenance or improvement of drainage systems.

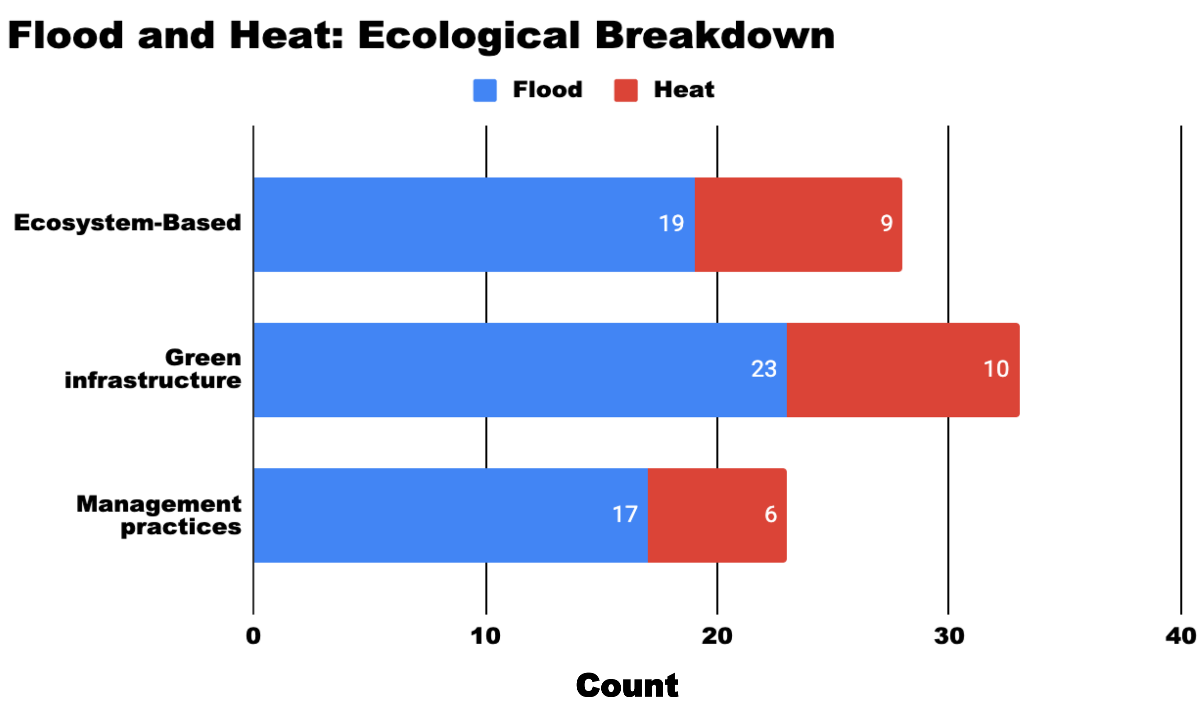


Figure 21. Breakdown of ecological strategies coded for heat and flood.

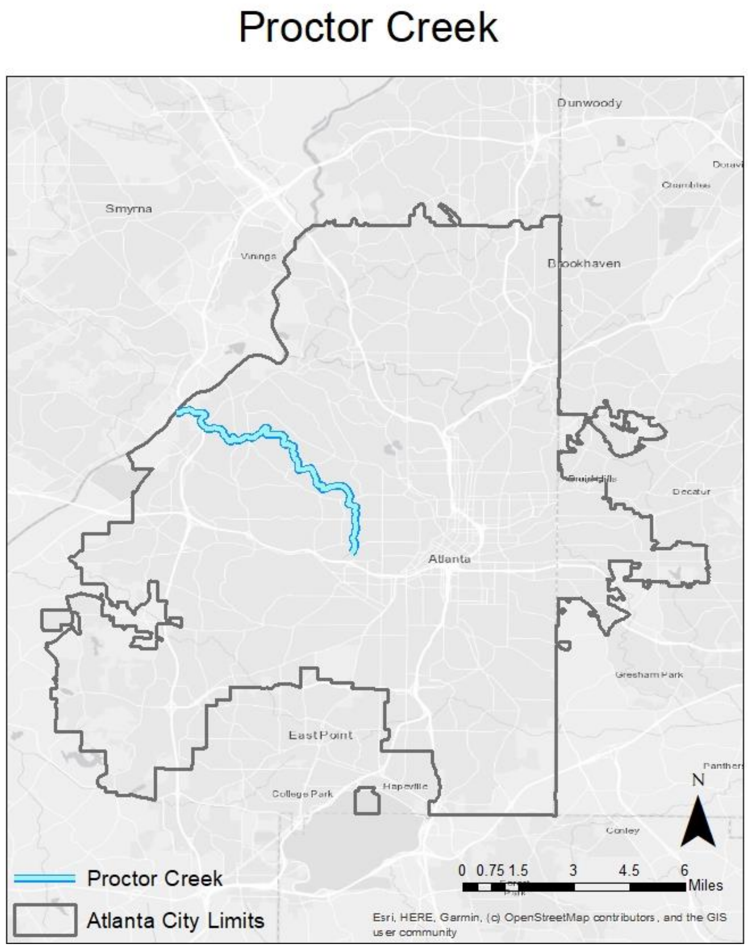


Figure 22. Proctor Creek.

Technological flood strategies included built environment planning and design, which was coded for most (Figure 22). Twenty-three flood strategies were coded as built environment planning and design, including the expansion of green infrastructure connectivity around the city (e.g., greenways, beltlines) and the introduction of new technologies or urban designs to manage urban flooding. Engineered infrastructure (coded second most) included strategies that looked to implement man-made materials such as permeable pavements and grey infrastructure. An example of an infrastructure operation and maintenance strategy (coded third most) was coded for in *The Atlanta Capital Improvements Plan* (Plan ID: ATL22): “Remove overgrown vegetation surrounding Avery Park creeks and streams and day-light them for better water management systems". South River, a water body assigned a 1% annual chance flood hazard, flows through a portion of Avery Park in southern Atlanta (Figure 23). While this strategy can be interpreted as an ecological strategy as well, it also involves the maintenance and improvement of technological, anthropogenic infrastructure to better manage water flows. "Technological development and improvement" was coded for least, but included strategies for technological flood modeling software to improve responsiveness to flooding events.

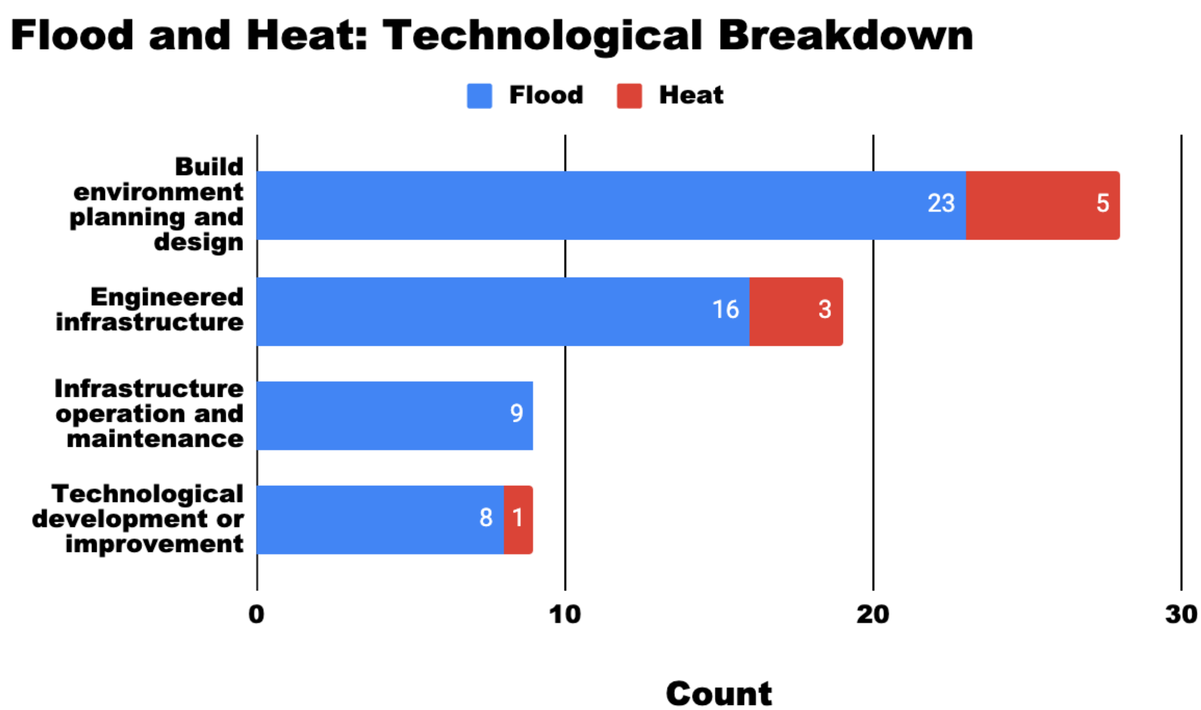


Figure 23. Breakdown of technological strategies for heat and flood.

Many plans and strategies generally address stormwater flooding in the city of Atlanta, not highlighted by the NFHL. Several other notable bodies of water that have designated flood risk hazards go unmentioned in recent planning, including Nancy River that flows through northern Atlanta and the segment of the Chattahoochee River along the western border of Atlanta. However, urban neighborhoods south of the I-20/I-75/85 corridor border many of the streams, tributaries, and creeks that flow from the Chattahoochee River and bring flooding issues. One of these bodies of water is Utoy Creek, which has a coded strategy to restore and restabilize the stream's banks (Figure 24).

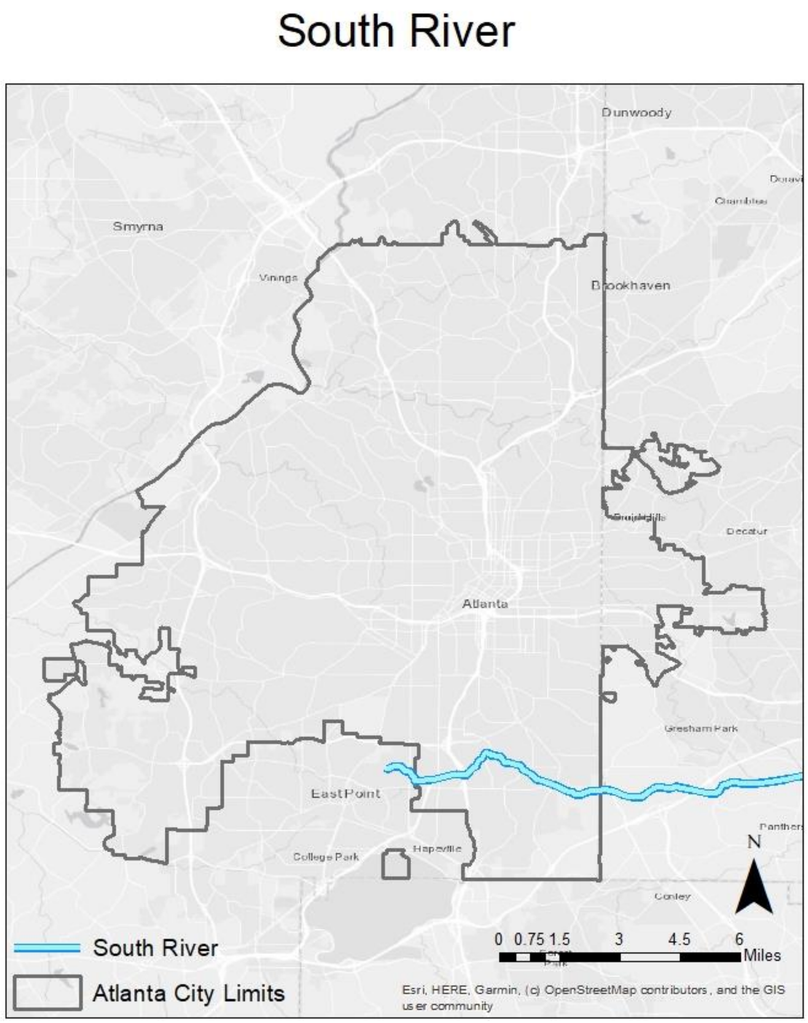


Figure 24. South River.

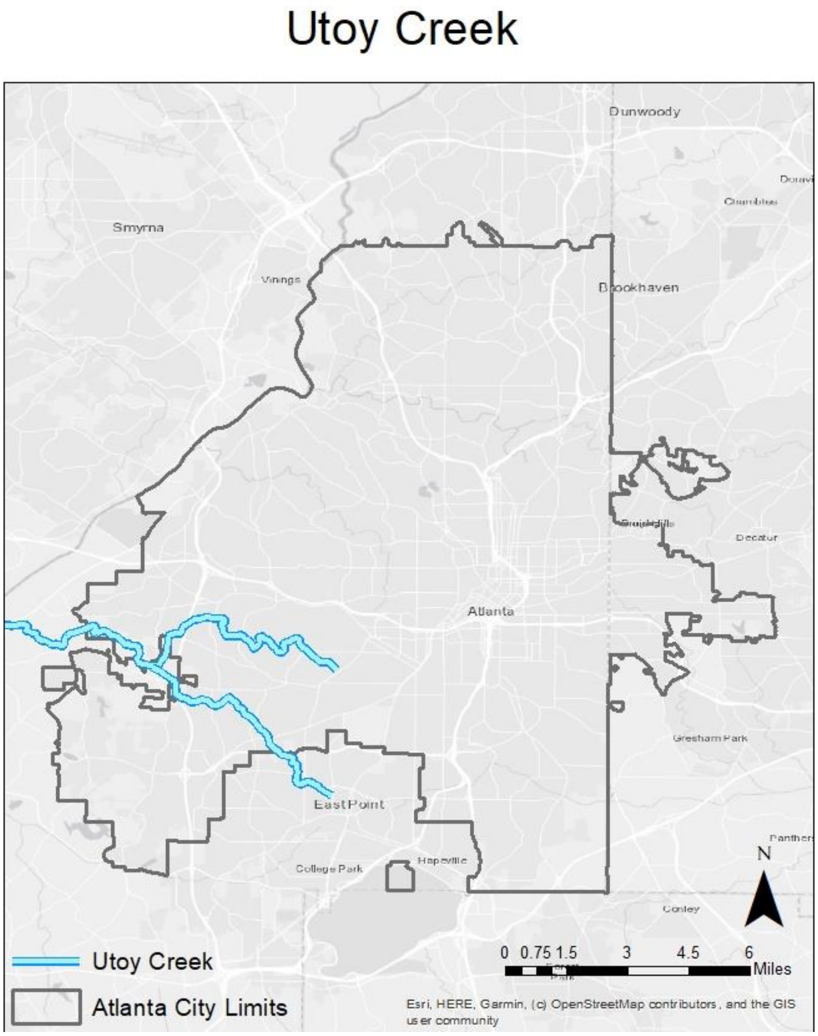


Figure 25. Utoy Creek.

3.3.2 Heat in Climate Governance Documents

Although the largest threat to Atlanta residents, heat was the external climate hazard least explicitly planned for. Social strategies for heat were similar to flood, in that its strategies for both were focused mostly on institutional/governance planning, followed by legal changes (Figure 19). City governance placed a large emphasis on the expansion or maintenance of the urban tree canopy and green infrastructure, especially in the urban core or downtown Atlanta where the highest temperatures are the most concentrated (Figure 25). Action 3.4.3: from the

Resilient Atlanta: Actions to Build an Equitable Future plan outlined "Protecting and expanding Atlanta's tree canopy".

Heat was also similar to ecological strategies for flooding, especially being that green infrastructure strategies intended to mitigate flooding also possess ecosystem services that provide heat relief. For example, the *Downtown Atlanta Master Plan* explicitly addressed planting more trees in the downtown area to "help mitigate the 'urban heat island' effect". Management practices included expanding and permanently protecting greenspace in the downtown area, also in the *Resilient Atlanta: Actions to Build an Equitable Future* plan.

Of the few technological strategies for heat, one strategy was coded from the City of Atlanta's *Climate Action Plan*, outlining the introduction of "cool roofs" to buildings downtown. This technological development or improvement strategy utilizes cool roof technology that reflects more heat energy than it absorbs, reducing the heat transfer to surrounding areas and within the building, also decreasing energy consumption.

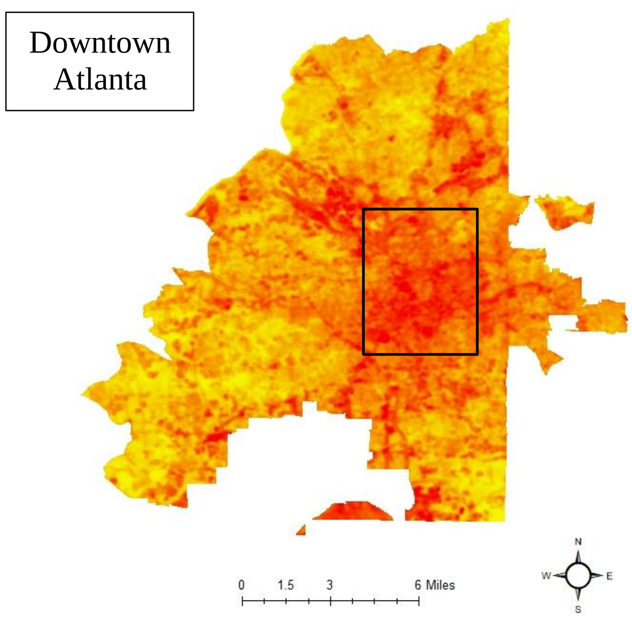


Figure 26. City of Atlanta average summer LST, with downtown region highlighted. Note the cluster of higher temperatures.

4 DISCUSSION AND CONCLUSION

Atlanta is an urban area that is continuing to grow in size and population, and as a result needs to plan for climate threats of the future. As climate change threatens some areas of the United States more than others, the urban population landscape will change, and the City of Atlanta is one of these urban areas that will see an in-migration of people escaping various climate threats (Hauer 2017), especially sea level rise. The City of Atlanta's climate resilience planning should reflect lessons learned from past events and necessary preparations based on future projections. In addition, planning should address inequalities in climate resilience that expose themselves in a number of forms, including communities that are chronically flooded in extreme rain events, and potential elevated extreme heat exposure in certain areas. This study was able to identify how the City of Atlanta and its internal planning entities are planning for climate resilience in the future, concerning heat and flood. It was also able to generally identify, to an extent, the level of exposure to heat and flood threats certain areas of the city may endure.

For the climate hazard of flooding, the NFHL revealed areas that are most likely to flood throughout the City of Atlanta, which tended to be areas and communities that surround rivers, creeks, streams, and their tributaries. Atlanta's climate resilience planning mostly addressed flooding, among other climate hazards. Citywide, larger scale plans typically did not include localized flooding and focused on urban stormwater flood issues, with the majority flood strategies intended to be implemented downtown areas. The NFHL listed most of these downtown areas as "Areas of Minimal Flood Hazard", indicating that the NFHL does not incorporate intensive storm water flooding hazards into its flood analysis. Citywide plans were largely institutional or governance based with legal implications, and focused on green infrastructure construction to mitigate urban flooding. Neighborhood or community plans tended to focus on localized flooding attributed to local bodies of water and the lack of proper stormwater infrastructure. Local plans that fell within the 2013-2019 time of this study mostly looked to implement strategies that addressed flooding in south central Atlanta communities below the I-20/I-75/85 corridor, which tended to have higher African American populations and higher rates of poverty. Although not explicitly stated, this has implications for equity concerns in climate resilience planning, as chronic flooding in these neighborhoods (e.g., Peoplestown, Mechanicsville) has gone unattended or has been ineffectively addressed (Kinney 2016) (Figure 26). In local plans that addressed hazards in these neighborhoods, flooding strategies were technological and ecological, and tended to discuss infrastructure repair and maintenance, as well as the introduction of newer technologies such as “permeable pavers” to mitigate flooding. Environmental justice was explicitly addressed once in a citywide plan, for flooding concerns near Proctor Creek, however the extent to which environmental injustice exists in Atlanta is not limited to this one area. Larger, citywide plans backed by governance institutions should address more equity concerns in these additional areas.

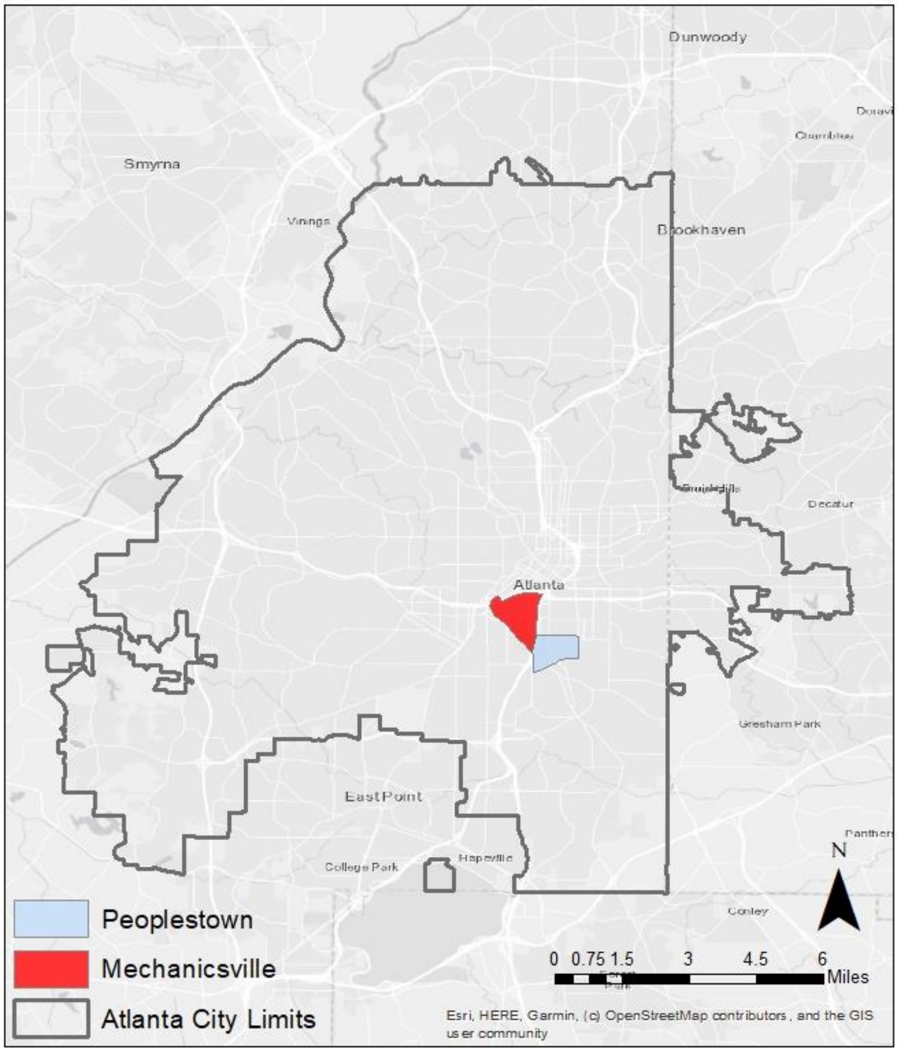


Figure 27. Peoplestown and Mechanicsville neighborhoods.

Heat planning was not extensive and was mostly limited to the downtown region of Atlanta. The mapping of LST allowed for the identification of spatial heat variation in areas around the city—the hottest of which should also be addressed in climate resilience planning, especially with impending rising temperatures (Climate Central 2019). Because air temperature is measured meters above the surface, noticeable differences in temperature were expected. Differences in air temperature and LST values up to 5 degrees Celsius have also been observed in related studies (Avdan & Jovanovska 2016; Srivastava et al. 2009). LST was shown to be highest in these downtown areas where urbanization was at its highest and vegetation (via NDVI) was at its lowest. Thus, heat strategies were most focused in these areas and largely governance based, involving the introduction of additional green infrastructure (that can also mitigate flooding) and trees to expand tree canopy cover. Most heat strategies doubled as general capacity strategies, especially when implementing green infrastructure solutions. Expanding legal regulations to protect existing tree canopy cover from developers was also mentioned. Legal regulations for the protection of tree canopy cover should be citywide rather than solely focused on downtown, in order to avoid future heat issues in highly vegetated areas of the city. NDVI was shown to be higher in these areas where black populations and poverty rates were highest and LST was lowest, indicating that vegetation and tree canopy cover is not a problem for predominately black regions within the City of Atlanta. As a result, the relationship between high black populations and high LST, and between relationship between higher poverty rates and high LST, was not strong. However, as the threat most dangerous to city residents, a plan solely for heat mitigation could also increase public safety and increase heat mitigation effort or awareness, especially downtown. With the exception of heat waves, heat threats are not always punctual events like flooding, but requires the same attention in climate resilience planning.

Land use/land cover maps may be more accurate for assessing vegetation cover in an urban region, being that higher values of NDVI may not always indicate heavy vegetation, but another heat mitigating material or reflective surface such as blue infrastructure. In the future, this study could be expanded to later years as average temperatures continue to increase and amplify the urban heat island. Such a future study could also assess the efficiency of city governance achieving planning goals that were previously set in these governance documents. Additional summer months and Landsat 8 satellite passes over the region will also provide more

LST data to be analyzed, potentially unobscured by cloud cover as well, which limited the selection of summer days used for this study. Due to limited access to weather station data in the city of Atlanta, the Hartsfield-Jackson International Airport was used for temperature validation. The airport is not within City of Atlanta limits, and may not always accurately reflect temperatures that are a result of the urban heat island in the city's urban core. This may have led to larger differences in observed LST and historical temperatures. Creating a network of temperature sensors within the city of Atlanta's political boundaries that have public historical, hourly temperature data could provide better data for temperature analysis.

It is also important to note that this study did not evaluate the effectiveness of climate planning strategies. It is common for written strategies to never be implemented due to inaction, funding, or circumstantial adjustment to plans. Strategies that are implemented are not all equally effective and do not guaranteed the intended results. This study also only evaluated formal planning down to the neighborhood scale, whereas informal planning that may be underway or not publicly available was not included for analysis.

The results of this study also revealed that recent climate resilience planning does not cover all regions within the City of Atlanta. Not only does this present an equity concern, but legal risk as well, as those who reside in areas that are unaddressed in climate resilience planning may seek legal compensation for damages, health concerns, and other complications due to unmitigated climate hazards. To combat this and increase productivity, equity, and inclusiveness in future climate resilience planning, it is recommended that the City of Atlanta utilize its Neighborhood Unit Planning (NPU) system be utilized for localized resilience planning. The *Atlanta Capital Improvements Plan* incorporated NPUs into their strategies for location purposes; however, not all NPUs were addressed within this plan. Allowing NPU communities to organize their climate resilience concerns into localized plans can raise community and citywide governance awareness on issues of climate resilience. Having updated and relevant NPU plans can create a framework in which NPUs can present planning documents to larger scale governance bodies for assistance with funding and strategy implementation. Many NPUs hold monthly meetings for planning concerns and discussions. NPU climate resilience planning can boost inclusiveness in strategies and targets to mitigate local climate hazards. Thus, climate threats can be addressed more specifically using local knowledge, likely from those who know local climate hazards best from firsthand experience.

REFERENCES

Adapt NY. *Case Study: Deadly Chicago Heat Wave of 1995* |. (2016). Retrieved March 10, 2020, from https://www.adaptny.org/2016/07/21/case-study-deadly-chicago-heat-wave-of-1995/

Ali, S., Patnaik, S., & Madguni, O. (2017). Microclimate land surface temperatures across urban land use/ land cover forms. *Global Journal of Environmental Science and Management*, *3*(3), 231–242. https://doi.org/10.22034/gjesm.2017.03.03.001

Allen, D. (2014). Learning from Atlanta. In Etienne, H.F. (Ed.) and Faga, B. (Ed.)., *Planning Atlanta* (pp. 14-26). Chicago, IL: APA Planner's Press.

Atlanta Regional Commission. (2018, January 20). *Vulnerability and Resiliency Framework for the Atlanta Region*. Retrieved from https://cdn.atlantaregional.org/wp-content/uploads/arc-vulnerability-and-resiliency-framework.pdf

Adams, L. (2006). "Headed for Louisville:" Rethinking Rural to Urban Migration in the South, 1930-1950. *Journal of Social History*, *40*(2), 407–430. JSTOR.

Avdan, U., & Jovanovska, G. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. *Journal of Sensors*, *2016*, 1–8. https://doi.org/10.1155/2016/1480307

Bernard, H. R., & Ryan, G. W. (2010). Analyzing qualitative data: Systematic approaches. Thousand Oaks, CA, US: Sage Publications, Inc.

Bierbaum, R., Smith, J. B., Lee, A., Blair, M., Carter, L., Chapin, F. S., … Verduzco, L. (2013). A comprehensive review of climate adaptation in the United States: more than before, but less than needed. *Mitigation and Adaptation Strategies for Global Change*, *18*(3), 361–406. https://doi.org/10.1007/s11027-012-9423-1

Blackmon, D. A. (2009), *Slavery by Another Name: The Re-Enslavement of Black Americans from the Civil War to World War II*. New York, NY: Knopf Doubleday Publishing Group.

Buyantuyev, A., & Wu, J. (2010). Urban heat islands and landscape heterogeneity: Linking spatiotemporal variations in surface temperatures to land-cover and socioeconomic patterns. *Landscape Ecology*, *25*(1), 17–33. https://doi.org/10.1007/s10980-009-9402-4

Caradot, N., Granger, D., Chapgier, J., Cherqui, F., & Chocat, B. (2011). Urban flood risk assessment using sewer flooding databases. *Water Science and Technology*, *64*(4), 832–840. https://doi.org/10.2166/wst.2011.611

Carrie Teegardin, T. A. J.-C. (n.d.). Damage exceeds flood map boundaries. Retrieved October 16, 2019, from Ajc website: https://www.ajc.com/news/local/damage-exceeds-flood-map-boundaries/gNKk95E96BMgu9aFyZY0IL/

City of Atlanta. (n.d.). *Historical Markers by County*. Georgia Info - An Online Georgia Almanac. Retrieved January 30, 2020, from https://georgiainfo.galileo.usg.edu/topics/historical_markers/county/fulton/thrasherville

Climate Change | Topics | EESI. (n.d.). Retrieved March 5, 2019, from https://www.eesi.org/topics/climate-change

Damsø, T., Kjær, T., & Christensen, T. B. (2016). Local climate action plans in climate change mitigation – examining the case of Denmark. *Energy Policy*, *89*, 74–83. https://doi.org/10.1016/j.enpol.2015.11.013

Iwaniec, D.M., Cook, E. M., Berbés-Blázquez, M., Davidson, M. J., & Grimm, N. B. (in review). Integrating existing climate adaptation planning into future: A strategic scenario for the central Arizona-Phoenix region.

Debbage, N. (2019). Multiscalar spatial analysis of urban flood risk and environmental justice in the Charlanta megaregion, USA. *Anthropocene*, *28*, 100226. https://doi.org/10.1016/j.ancene.2019.100226

de Blasio, M. B., & Shorris, A. (2017). *Cool Neighborhoods NYC*. Retrieved from https://www1.nyc.gov/assets/orr/pdf/Cool_Neighborhoods_NYC_Report_FINAL.pdf

Dixon, P. G., & Mote, T. L. (2003). Patterns and Causes of Atlanta's Urban Heat Island–Initiated Precipitation. *Journal of Applied Meteorology*, *42*(9), 1273–1284. https://doi.org/10.1175/1520-0450(2003)042<1273:PACOAU>2.0.CO;2

Drought Status. (n.d.). Retrieved April 26, 2019, from Metropolitan North Georgia Water Planning District website: https://northgeorgiawater.org/current-water-stats/drought-status/

Etienne, H.F. (Ed.) and Faga, B. (Ed.). (2014), *Planning Atlanta*. Chicago, IL: APA Planner's Press.

Ferguson, A. P., & Ashley, W. S. (2017). Spatiotemporal analysis of residential flood exposure in the Atlanta, Georgia metropolitan area. *Natural Hazards*, *87*(2), 989–1016. https://doi.org/10.1007/s11069-017-2806-6

Frey, W. H. (1980). Black In-Migration, White Flight, and the Changing Economic Base of the Central City. *American Journal of Sociology*, *85*(6), 1396–1417. JSTOR.

Fu, Y., & Zhang, X. (2017). Planning for sustainable cities? A comparative content analysis of the master plans of eco, low-carbon and conventional new towns in China. *Habitat International*, *63*, 55–66. https://doi.org/10.1016/j.habitatint.2017.03.008

Hauer, M. (2017). Migration induced by sea-level rise could reshape the US population landscape. *Nature Climate Change*, *7*. https://doi.org/10.1038/nclimate3271

Hauer, M. E., Evans, J. M., & Mishra, D. R. (2016). Millions projected to be at risk from sea-level rise in the continental United States. *Nature Climate Change*, *6*, 691.

Heat Waves and Climate Change | Center for Climate and Energy Solutions. (n.d.). Retrieved August 12, 2019, from https://www.c2es.org/content/heat-waves-and-climate-change/

Heath, E., & Heath, J. (2014). Changing Demographics and Unprecedented Growth. In Etienne, H.F. (Ed.) and Faga, B. (Ed.)., *Planning Atlanta* (pp. 27-39). Chicago, IL: APA Planner's Press.

Imhoff, M. L., Zhang, P., Wolfe, R. E., & Bounoua, L. (2010). Remote sensing of the urban heat island effect across biomes in the continental USA. *Remote Sensing of Environment*, *114*(3), 504–513. https://doi.org/10.1016/j.rse.2009.10.008

Jesdale Bill M., Morello-Frosch Rachel, & Cushing Lara. (2013). The Racial/Ethnic Distribution of Heat Risk–Related Land Cover in Relation to Residential Segregation. *Environmental Health Perspectives*, *121*(7), 811–817. https://doi.org/10.1289/ehp.1205919

Hotchkiss, J. L., Moore, R. E., & Zobay, S. M. (2003). Impact of the 1996 Summer Olympic Games on Employment and Wages in Georgia. *Southern Economic Journal*, *69*(3), 691–704. JSTOR.

Impervious surfaces and urban flooding: USGS Water-Science School. (n.d.). Retrieved April 2, 2019, from https://water.usgs.gov/edu/impervious.html

Jiang, F. (2017). Evaluation of Stray Light Correction for the Thermal Infrared Sensor (TIRS) from Landsat 8. *Rochester Institute of Technology*, 145.

Kim, Y., Mannetti, L., Iwaniec, D. M., Grimm, N. B. Berbés-Blázquez, M., Markolf, S. (in review) Social, ecological and technological strategies for climate adaptation. In Resilient Urban Futures. Editors Zoé Hamstead et al., Springer.

Kruse, K. M. (2013). White flight: Atlanta and the making of modern conservatism (Vol. 89). Princeton University Press.

Kamel, M. (2003) Ecotone Classification According to its Origin - SciAlert Responsive Version. (n.d.). https://doi.org/10.3923/pjbs.2003.1553.1563

KC, B., Shepherd, J. M., & Gaither, C. J. (2015). Climate change vulnerability assessment in Georgia. *Applied Geography*, *62*, 62–74. https://doi.org/10.1016/j.apgeog.2015.04.007

Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Prado, K. A. M., … Wood, S. A. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability*, *2*(1), 29–38. https://doi.org/10.1038/s41893-018-0202-1

Kim, J.-P., & Guldmann, J.-M. (2014). Land-Use Planning and the Urban Heat Island: *Environment and Planning B: Planning and Design*. https://doi.org/10.1068/b130091p

Kim, Y., Mannetti, L., Iwaniec, D. M., Grimm, N. B., Berbés-Blázquez, M., Markolf, S. (in review) Chapter 3. Social, ecological and technological strategies for climate adaptation. In Resilient Urban Futures (Editors: Zoé Hamstead and David Iwaniec), Springer

Kinney, J. (2016, November 23). *Stormwater Rethink Aimed at Flooding in Atlanta Neighborhoods*. Next City. https://nextcity.org/daily/entry/atlanta-manages-stormwater-by-not-fighting

Knox, P. (n.d.). *CLIMATE OF GEORGIA*. 6.

Kromm, C. (2011, September 28). *Black Belt Power: African-Americans come back South, change political landscape*. Facing South. https://www.facingsouth.org/2011/09/black-power-african-americans-come-back-south-shake-up-southern-politics.html

Kruse, K. M. (2013). *White flight: Atlanta and the making of modern conservatism* (Vol. 89). Princeton University Press.

Kunkel K. 2019. Scenarios of Climate Extremes: Atlanta, GA. Urban Resilience to Extreme Events (internal report)

Liu, T., & Yang, X. (2015). Monitoring land changes in an urban area using satellite imagery, GIS and landscape metrics. *Applied Geography*, *56*, 42–54. https://doi.org/10.1016/j.apgeog.2014.10.002

Lloyd, R. (2012). Urbanization and the Southern United States. *Annual Review of Sociology*, *38*(1), 483–506. https://doi.org/10.1146/annurev-soc-071811-145540

Logan, J. R., Zhang, W., & Chunyu, M. (2015). Emergent Ghettos: Black Neighborhoods in New York and Chicago, 1880–1940. *AJS; American Journal of Sociology*, *120*(4), 1055–1094.

Massachusetts Office of Coastal Zone Management. (n.d.). 1% Annual Chance Flood. Retrieved December 17, 2019, from Mass.gov website: https://www.mass.gov/service-details/1-annual-chance-flood

NASA - Ecosystem, Vegetation Affect Intensity of Urban Heat Island Effect [Feature]. (n.d.). Retrieved April 26, 2019, from https://www.nasa.gov/mission_pages/terra/news/heat-islands.html

NASA. (2000, August 30). *Measuring Vegetation (NDVI & EVI)* [Text.Article]. https://earthobservatory.nasa.gov/features/MeasuringVegetation/measuring_vegetation_2.php

National Park Service - Atlanta. (n.d.). *African-American Experience*. Atlanta: A National Register of Historic Places Travel Itinerary. Retrieved January 30, 2020, from https://www.nps.gov/nr/travel/atlanta/africanamerican.htm

National Weather Service: US Department of Commerce, N. (n.d.). Catastrophic Atlanta Flood of 2009. Retrieved January 2, 2020, from https://www.weather.gov/ffc/atlanta_floods_anniv

National Weather Service: US Department of Commerce, N. (n.d.). Irma Causes Widespread Damage in Georgia (9/11/17). Retrieved January 2, 2020, from https://www.weather.gov/ffc/2017_Irma

Noor, K. B. M. (2012). Using Content Analysis to Investigate Sustainable Development Planning and Management in Malaysian Local Plans. *International Social Science Journal*. Retrieved from https://www.academia.edu/26098554/Using_Content_Analysis_to_Investigate_Sustainable_Development_Planning_and_Management_in_Malaysian_Local_Plans

Ogunjobi, K. O., Adamu, Y., Akinsanola, A. A., & Orimoloye, I. R. (2018). Spatio-temporal analysis of land use dynamics and its potential indications on land surface temperature in Sokoto Metropolis, Nigeria. Royal Society Open Science, 5(12). https://doi.org/10.1098/rsos.180661

Pollock, D. A. (2014, May 30). The Battle of Atlanta: History and Remembrance. Retrieved December 12, 2019, from https://southernspaces.org/2014/battle-atlanta-history-and-remembrance/

Pooley, K. (n.d.). Segregation's New Geography: The Atlanta Metro Region, Race, and the Declining Prospects for Upward Mobility [April 15, 2015]. Retrieved December 15, 2019, from Southern Spaces website: https://southernspaces.org/2015/segregations-new-geography-atlanta-metro-region-race-and-declining-prospects-upward-mobility/

Qiu, G. Y., Zou, Z., Li, X., Li, H., Guo, Q., Yan, C., & Tan, S. (2017). Experimental studies on the effects of green space and evapotranspiration on urban heat island in a subtropical megacity in China. *Habitat International*, *68*, 30–42. https://doi.org/10.1016/j.habitatint.2017.07.009

Quattrochi, D. A., & Luvall, J. C. (1997, July 8). High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks in EOS IDS Project ATLANTA. Retrieved December 15, 2019, from Project ATLANTA - Urban Heat Island Study website: https://weather.msfc.nasa.gov/atlanta/

Rhodes, J. (2017, September 7). Geographies of Privilege and Exclusion: The 1938 Home Owners Loan Corporation "Residential Security Map" of Atlanta. *Atlanta Studies*. https://www.atlantastudies.org/2017/09/07/jason-rhodes-geographies-of-privilege-and-exclusion-the-1938-home-owners-loan-corporation-residential-security-map-of-atlanta/

Rothstein, R. (2017). *The color of law: A forgotten history of how our government segregated America*. Liveright Publishing.

Runfola, D. M., & Hankins, K. B. (2010). *Urban Dereliction as Environmental Injustice*. *9*(3). https://acme-journal.org/index.php/acme/article/view/874

Sastry, N., & Gregory, J. (2014). The Location of Displaced New Orleans Residents in the Year After Hurricane Katrina. *Demography*, *51*(3), 753–775. https://doi.org/10.1007/s13524-014-0284-y

Sheng, L., Tang, X., You, H., Gu, Q., & Hu, H. (2017). Comparison of the urban heat island intensity quantified by using air temperature and Landsat land surface temperature in Hangzhou, China. *Ecological Indicators*, *72*, 738–746. https://doi.org/10.1016/j.ecolind.2016.09.009

Silver, C., & Moeser JV. (1995). The Separate City: Black Communities in the Urban South, 1940–1968. Lexington: Univ. Press Ky.

Spikes, T. M. (2019). Diversifying Environmental Advocacy in Atlanta: A Case Study of Atlanta's African American-Led Community-Based Groups Working Against Environmental Injustices. *Georgia State Master's Thesis*, 81.

Srivastava, P. K., Majumdar, T. J., & Bhattacharya, A. K. (2009). Surface temperature estimation in Singhbhum Shear Zone of India using Landsat-7 ETM+ thermal infrared data. *Advances in Space Research*, *43*(10), 1563–1574. https://doi.org/10.1016/j.asr.2009.01.023

Stone Brian, Hess, Jeremy J., & Frumkin Howard. (2010). Urban Form and Extreme Heat Events: Are Sprawling Cities More Vulnerable to Climate Change Than Compact Cities? *Environmental Health Perspectives*, *118*(10), 1425–1428. https://doi.org/10.1289/ehp.0901879

USGS. (2019, October). USGS EROS Archive—Landsat Archives—Landsat 8 OLI (Operational Land Imager) and TIRS (Thermal Infrared Sensor) Level-1 Data Products. Retrieved from Earth Resources Observation and Science (EROS) Center website:

https://www.usgs.gov/centers/eros/science/usgs-eros-archive-landsat-archives-landsat-8-oli-operational-land-imager-and?qt-science_center_objects=0#qt-science_center_objects

Vincent, E. A. *Vincent's subdivision map of the city of Atlanta, Dekalb County, state of Georgia: showing all the lots, blocks, sections, &c*. [Savannah, Ga.: Edward A. Vincent, 185] [Map] Retrieved from the Library of Congress, https://www.loc.gov/item/2006635244/.

Yao, R., Luo, Q., & Li, B. (2011). A simplified mathematical model for urban microclimate simulation. *Building and Environment*, *46*(1), 253–265. https://doi.org/10.1016/j.buildenv.2010.07.019

Zhou, Y., & Shepherd, J. M. (2010). Atlanta's urban heat island under extreme heat conditions and potential mitigation strategies. *Natural Hazards*, *52*(3), 639–668. https://doi.org/10.1007/s11069-009-9406-z

Zou, K. H., Tuncali, K., & Silverman, S. G. (2003). Correlation and Simple Linear Regression. *Radiology*. https://doi.org/10.1148/radiol.2273011499

APPENDIX A

List of governance documents used for the study:

1. Resilient Atlanta: Actions to Build an Equitable Future:
   http://www.100resilientcities.org/wp-content/uploads/2017/11/Atlanta-Resilience-Strategy-PDF-v2.pdf
2. North Georgia Water Resource Management Plan:
   http://northgeorgiawater.org/wp-content/uploads/2018/03/Water-Resource-Management-Plan_REVISED.pdf
3. City of Atlanta Climate Action Plan:
   https://atlantaclimateactionplan.files.wordpress.com/2016/02/atlanta-climate-action-plan-07-23-2015.pdf
4. City of Atlanta Code of Ordinances:
   https://library.municode.com/ga/atlanta/codes/code_of_ordinances?nodeId=10376
5. North Buckhead Neighborhood Master Plan:
   http://www.nbca.org/Plan/Final/NorthBuckhead_Report_05.15.2015.pdf
6. Lakewood Livable Centers Plan:
   http://www.atlantaga.gov/Home/ShowDocument?id=19143
7. Downtown Atlanta Master Plan:
   https://www.atlantaga.gov/home/showdocument?id=40541
8. Turner Field Stadium Neighborhoods Plan:
   https://www.atlantaga.gov/home/showdocument?id=24209
9. Midtown Garden District Neighborhood Plan:
   https://www.atlantaga.gov/home/showdocument?id=39873

10. West Side Land Use Framework Plan:

https://www.atlantaga.gov/home/showdocument?id=39877

11. Morningside Lenox Park Master Plan:

https://www.atlantaga.gov/home/showdocument?id=40555

12. Historic Atlanta Master Plan:

https://www.atlantaga.gov/home/showdocument?id=39879

13. Washington Park Visioning Plan:

https://www.atlantaga.gov/home/showdocument?id=21661

14. Atlanta Capital Improvements Plan:

https://www.atlantaga.gov/home/showdocument?id=40523

APPENDIX B

Coding Manual for Content Analysis

Assigning S, E, T (with additional categories from IPCC)

Social	S1	Social safety nets	social safety nets and social protection, food banks and distribution of food surplus, municipal services including water and sanitation, vaccination programs, essential public health services including reproductive health services, enhanced emergency medical services, international trade
	S2	Educational	awareness raising and integrating into education, gender equity in education, extension services, sharing local and traditional knowledge, integration of local and traditional knowledge into adaptation planning, participatory action research and social learning, community surveys, knowledge-sharing and learning platforms, international conferences and research networks, communication through media, operations training
	S3	Informational	hazard and vulnerability mapping, early warning and response systems, systematic monitoring and remote sensing, climate services (including improved forecasts), downscaling climate scenarios, longitudinal datasets, integrating indigenous climate observations, community-based adaptation plans (including community-driven slum upgrading and participatory scenario development). **<u>*data driven</u>**
	S4	Behavioural	Accommodation, household preparation and evacuation planning, retreat and migration, soil and water conservation, storm drain clearance, livelihood diversification, changing livestock and aquaculture practices, crop-switching, changing cropping practices, patterns and planting dates, silvicultural options, reliance on social networks.
	S5	Economic	financial incentives including taxes and subsidies, insurance (including index-based weather insurance schemes), catastrophe bonds, revolving funds, payments for ecosystem services (PES), water tariffs, savings groups, microfinance, disaster contingency funds, cash transfers
	S6	Legal, regulations,	land zoning laws, building standard, easements, water regulations and agreements, laws to support disaster risk reduction, laws to encourage insurance purchasing, defining property rights and land tenure security, protected areas, marine protected areas (MPAs), fishing quotas, patent pools and technology transfer.

	S7	Institutional/governance	New research / information, evaluate effectiveness of …, develop a plan for…, explore…, coordination, partnerships
Ecological	E1	Ecosystem-based	ecological restoration, wetland and floodplain conservation and restoration, increasing biological diversity, afforestation and reforestation, conservation and replanting mangrove forest, bushfire reduction and prescribed fire, assisted migration or managed translocation, ecological corridors, ex situ conservation and seed banks, green and open space
	E2	Green infrastructure	green infrastructure (e.g. shade trees, green roofs), urban gardens, rain gardens
	E3	Management practices	community-based natural resource management (CBNRM), adaptive land-use management, controlling overfishing, fisheries co-management, ecosystem focused plan?

Technological	T1	Built environment planning and design	urban planning and design, design storm, building codes
	T2	Engineered infrastructure	seawalls and coastal protection structures, flood levees, sewage works, improved drainage, beach nourishment, pavement, physical buildings, solar shade, flood and cyclone shelters
	T3	Infrastructure operation and maintenance	system inspection and monitoring, operator training program, facility and equipment maintenance/repair, drainage cleaning, best management practices (BMPs)
	T4	Technological solution development and improvement	new crop and animal varieties, genetic techniques, traditional technologies, efficient irrigation, water saving technologies, conservation agriculture, food storage and preservation facilities, hazard mapping and monitoring technology, early warning systems, building insulation, mechanical and passive cooling, renewable energy technologies, second generation biofuels

Knowledge system
What form of knowledge system is relevant to this adaptation strategy?

K1	Local knowledge (not necessarily Indigenous)
K2	Academic knowledge from natural & applied sciences (e.g. climatologists, hydrologists, engineers, urban designers/planners)
K3	Academic knowledge from social sciences (e.g. anthropologists)
K4	Academic knowledge from health sciences (e.g. epidemiologists)

K5	Artistic knowledge (e.g. actors, photographers)
K6	Institutional knowledge (e.g. institutional memory, governance)

Geographical/spatial scale (Adaptation Spatial Scale)
If relevant, what is the geographical/spatial scale of the proposed adaptation option?

G1	Neighborhood specific
G2	City-wide
G3	Sub-national (province, state)
G4	National
G5	Another administrative scale (e.g. a health unit, Indigenous territory)
G6	Watershed/basin/catchment
G7	Ecosystem feature (e.g. wetland, delta, mangrove)
G8	Unknown/undefined
G9	City-owned properties

Beneficiaries
Who are the intended beneficiaries of the proposed adaptation option? Check as many as apply.

B1	Private business
B2	Collectives (i.e. specific group of people such as women, elderly, marginalized, etc.)
B3	General public (including residents)

Scope (Point of Intervention)
What's the intended scope of the adaptation strategy?

S1	Change in norms or ways of doing things
S2	Continue, change or implementation of a program
S3	Change in policy, laws or regulation
S4	Change in economic instruments (e.g. subsidies, taxes)
S5	Punctual event or activity (e.g. recommendation, short-term pilot program)

External Driver

D1	Flooding Non-specific
D2	Flooding Urban

D3	Flooding Riverine
D4	Flooding Coastal
D5	Heat
D6	Drought
D7	Non-Specific Hazards

APPENDIX C

Codebook: https://docs.google.com/spreadsheets/d/1QFrKUtuHhaBIVEf4KK_--kn1lrFGaxLbDgFf9v44kuM/edit#gid=0

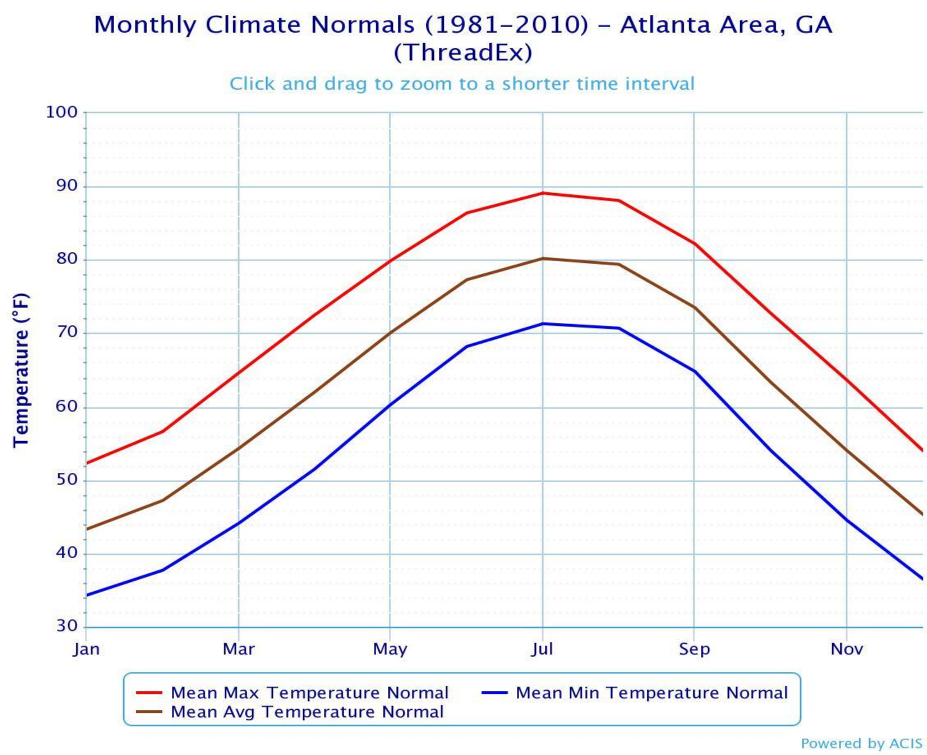
APPENDIX D

Landsat 8 bands and observation parameters (USGS 2019).

	Bands	Wavelength (micrometers)	Resolution (meters)
Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) Launched February 11, 2013	Band 1 - Coastal aerosol	0.43 - 0.45	30
	Band 2 - Blue	0.45 - 0.51	30
	Band 3 - Green	0.53 - 0.59	30
	Band 4 - Red	0.64 - 0.67	30
	Band 5 - Near Infrared (NIR)	0.85 - 0.88	30
	Band 6 - SWIR 1	1.57 - 1.65	30
	Band 7 - SWIR 2	2.11 - 2.29	30
	Band 8 - Panchromatic	0.50 - 0.68	15
	Band 9 - Cirrus	1.36 - 1.38	30
	Band 10 - Thermal Infrared (TIRS) 1	10.60 - 11.19	100
	Band 11 - Thermal Infrared (TIRS) 2	11.50 - 12.51	100

APPENDIX E

Average temperatures for Atlanta, GA (weather.gov).



APPENDIX F

Temperature data for validation.

Dates	Air temperature at Hartsfield-Jackson Airport (°C) at 11 AM	LST (°C)	Difference
August 23, 2013	23.88	27.66	-3.78
August 26, 2014	26.68	30.38	-3.7
July 28, 2015	30.56	32.25	-1.69
June 12, 2016	30	31.88	-1.88
July 14, 2016	28.89	34.97	-6.08
August 15, 2016	28.89	N/A - Clouds	N/A
August 31, 2016	28.89	31.88	-2.99
July 17, 2017	26.67	28.31	-1.64
June 18, 2018	28.89	31.98	-3.09
July 4, 2018	30.56	31.02	-0.46
August 5, 2018	30	N/A - Clouds	N/A
June 21, 2019	27.78	34.13	-6.35
August 8, 2019	29.44	31.94	-2.5