MITIGATING THE URBAN HEAT ISLAND THROUGH A TARGETED LOOK AT REFORESATION AND PRESERVATION NEAR VULNERABLEPOPULATIONS: AN APPLIED SUITABILITY MODEL

by

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Abstract

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The urban heat island (UHI) is a pervasive phenomenon that affects city dwellers. There are certain populations who are especially vulnerable to its affects. Studies have shown that the urban tree canopy helps to mitigate and alleviate the negative effects of the UHI. The research was conducted for the City of Dallas, Texas. The objective of this research is twofold: one to employ an assessment to determine who is vulnerable to the UHI affects, based on the Center for Disease Control's BRACE Framework. Next, a suitability overlay model is used to analyze the optimal places where planting trees or reserving existing trees will most benefit the selected vulnerable populations. Results show the overall suitability for the study region at a block level. Further processing depicts the top most suitable sites for both reforestation and preservation. . The results

provide a roadmap for the City of Dallas decision makers to focus on these identified areas. The methodology lends itself to an outline for other regions to implement when planning for UHI and urban tree canopy management.

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Chapter 1

Introduction

1.1 Climate Change and the Urban Heat Island

There has been growing concern for climate change, and in recent years this concern has been brought to the world's attention through scientific findings and reports from agencies such as the United Nations (UN, 2014) U.S. Whitehouse (US White House, 2014), and the Intergovernmental Panel on Climate Change IPCC (IPCC, 2014). Not only is climate change impacting our planet on a global scale, but at in microclimates at the city-level; this impact tends to manifest itself and is perpetuated through the urban heat island effect (Stone, 2012).

The term "heat island" describes built up areas where the annual mean air temperature of a city that is dense and highly populated can be significantly warmer than the surrounding suburb and rural regions (Oke 1982; EPA, 2014). The rapid urbanization of cities in the western world during the past century has created massive changes in the character of the built environment. With more infrastructure like paved roads and rooftops that are low reflective surfaces, and the elimination of native vegetation, the development of cities has become a significant source of climate change through the urban heat island (Oke, 1982).

The urban heat island is a challenging aspect of urban life as it prevents people from comfortably enjoying outdoor activities and exacerbates extreme heat events. The Houston Advanced Research Center (HARC, 2009) was commissioned by the Environmental Protection Agency discovered that Dallas had an average summertime temperature that was 4 degrees warmer than rural temperatures.

Extreme heat events such as high temperatures and heat waves have been increasing across the globe (Luber, 2008). These periods of record-breaking temperatures that often last for long stretches of time in heat-waves have been harmful for people in more ways than one. When experiencing high temperatures we choose to stay indoors and rely on central air conditioning to alleviate the discomfort of the extreme heat. This air conditioning gives comfort and regulates the body-temperature so that the individual will not become ill from the extreme heat. During these heat events most people across the affected region will choose to rely on the air conditioning, which places immense stress on the power grid supplying energy to homes. This often leads to brownouts and sometimes blackouts, leaving individuals in tough situation where they not only are without air conditioning, but without electricity, sometimes for long periods of time (Miller et al, 2008). The central air conditioning climate control can provide sufficient relief from the elements when in use, but if it is not available, the results can be deadly.

Higher temperatures also produce an increased level of ozone. The correlation between higher temperatures and higher levels of pollution is evident in studies that compare the two factors across long periods of time in various geographic locations and climates (Stone, 2005). The health of the population is directly affected by these higher levels of ambient pollutants. Respiratory illnesses emerge or can be exacerbated by these increased levels of pollutants in the air (Nowak, 2014).

As understood in the scientific community, many of the undesired consequences of climate change are expected to arise in future years to come. However, many of these impacts at the smaller regional level are occurring in the present-day, and these impacts range from inconvenient, uncomfortable, or sometimes fatal. What should be of utmost concern to regional and municipal officials, is that empirical findings show that increased temperatures are primarily localized and caused by the UHI, rather than the global warming pattern (Stone, 2012). This being the case, decision-makers at the local level who have the agency to enact policy are given the responsibility of supporting these strategies in order to protect their communities.

1.2 Vulnerable Populations

It was estimated that extreme heat from weather conditions is, on average, responsible for 182 deaths in the United States annually (Center for Disease Control 2002). Extreme heat events will be potentially harmful for any individual if exposed, and there are individuals who are especially vulnerable to the physical effects of the heat, and there are individuals who are disadvantaged and are have less means to have climate control such as air conditioning. In the study of environmental justice, minority groups and those of low socioeconomic status are often disproportionately exposed to environmental harm (EPA, 2014). The Center for Disease Control (CDC) and Prevention Climate and Health Program has proclaimed in its mission statement that a primary goal is to "lead efforts to identify vulnerable populations to climate change" (CDC, 2014). These climate-sensitive health impacts will vary across geography, climate, socioeconomic and demographic backgrounds. The health impacts themselves will range in severity, intensity and category.

When creating public policy, there must be an awareness and attention paid to those who are vulnerable to disparity based on historical trends or societal tendencies. These may be minorities, the poor, the ill, or others who are disadvantaged in the public realm. These demographic sects work and live in all urban environments, and it is often a challenge for decision-makers to reduce the inequity when providing public services.

1.3 The Role of the Urban Forest

According to the book "The City and the Coming Climate" by Brian Stone, Jr., one of the leading researchers in the contemporary field of climate change and urban heat island, he argues that trees provide significant benefits to cities including shading and cooling effects, better air quality, aesthetic value, and urban heat mitigation. Trees reduce albedo reflection through the canopy of leaves , cool the air through transpiration , capture and sequester carbon pollutants, and reduce surface temperatures by providing shade which directly lowers immediate and surrounding temperatures (Stone, 2006). Balancing urban form that includes enough infrastructure to support urban life with enough vegetation and green space is challenging in the midst of rampant urban sprawl, but it is critical in planning for our future. Though there is a demand for trees in our cities and neighborhoods, we are limited by resources and funding to meet this need. At the city level these limitations include competing interests, drought conditions and budget considerations (Richards, 1992, p 64-68). With this in mind, a strategic plan to reforest an area by planting or preserving the urban tree canopy would benefit cities and residents by mitigating the UHI effects.

1.4 Study Area: Dallas, Texas

The City of Dallas was chosen based on the availability of data, and the need for urban heat island management measures. Dallas Sustainable Skylines Initiative Report (HARS, 2009) finds that trees and urban design play a key role in the urban heat island effects within the city (HARS, 2009). This report showed that in the City of Dallas heat related health impacts included at least 23 reported deaths in the 1998 event (HARC, 2009). More recently 31 deaths in Dallas County were reported in the record breaking summer of 2011 (Dallas County, 2011). A secondary factor that relates to the urban heat island is air pollution. DFW is not in compliance with federal air quality standards. The area is considered a 'non-attainment' zone, meaning there continues to be such an abundance of harmful particulates in the air shed that the region is falling below federal standards (TCEQ, 2014).

1.5 Overview of Report

This professional report aims to demonstrate that the city should manage our urban forest by strategically selecting sites to plant new trees. The report will involve a series of steps to produce a practical model. First, a vulnerability assessment is performed to identify risk factors. Next, a spatial assessment is performed to identify populations and regions that are susceptible to the risk factors. A GIS suitability analysis is then used to analyze the data and produce a geographic representation to highlight the most suitable areas for tree planting. Finally, the results will be analyzed and discussed.

A GIS driven suitability overlay analysis, a fundamental spatial operation tool, will help to determine the best location to plant trees in an urban and suburban environment by identifying sites where the presence of tree will provide the maximum benefits to the citizens, especially those of vulnerable populations. The criteria to identify these sites will be based on evidence from peer-reviewed studies and government agency reporting. This data driven model takes a systematic approach to determining optimal sites for the urban tree canopy to be so that the urban forest manager can apply these findings in their approach to reforestation and preservation.

This report is intended to not only determine ideal cites for expanding the urban tree canopy in the City of Dallas, but also it will serve as an example for city officials and urban forest managers understand how a city may maximize its tree planting and preservation benefits through urban forestry management and careful consideration of population groups, in order to combat the ill effects of the urban heat island.

Chapter 2

Literature Review

2.1 Vulnerability in the context of Environmental Justice

The concept of environmental justice was formed due to the necessity to address a history of discrimination, barriers, and disparities that certain minority groups have had to endure in the face of environmental hazards. The seminal book that illustrates these inequities is Robert Bullard's Dumping in Dixie (1990), which describes his findings of a disproportionate pattern of hazardous facilities located in areas with primarily minority and low income groups. The environmental justice movement, much like the U.S. Civil Rights movement, served to bring light to these persistent issues in our society. The influences behind these environmental injustices are broad and related to other social disparities within our institutions.

The federal government has recognized these damaging events in our history -- many that remain a systemic issue today. In an effort to curb the persistence of environmental inequities, President Clinton signed Executive Order 12898 which declared "Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations". In summary, the actions point to efforts to achieve environmental protection for all communities, and to identify disproportionately high effects of federal actions on vulnerable populations. (Executive Order No. 12,898, 1994).

All government agencies must strive to maintain environmental justice in their work.

According to the EPA, environmental justice is described as:

> the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (EPA, 2014).

Extreme heat events are an environmental injustice that disproportionately affect vulnerable populations (Ebi et al, 2006; Hansen et al, 2013). The variation across communities and climate can influence the degree of vulnerability for a region, based on a variety of factors. Vulnerability may be due to the characteristics of the individual, or the community. Due to this discrepancy in understanding of vulnerability, there have been established methods used to develop definitions among institutions who seek to define vulnerable populations. Many organizations and agencies who participate in health-risk management have a need to define this term, particularly if they make it a point to overcome the disparities in healthcare and living conditions within our current society.

The International Panel on Climate Change (IPCC) describes vulnerability in the following way

> Vulnerability to climate change is the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate variability and change
>
> (IPCC, 2007)

The World Health Organization (WHO) defines vulnerability as

> The degree to which a population, individual or organization is unable to anticipate, cope with, resist and recover from the impacts of disasters", or "the susceptibility to harm, which can be defined in terms of a population or a location. (WHO, 2012)

WHO has also developed a "Vulnerability and Adaptation Assessment," which serves as a guide to assess the degree of vulnerability within a population or region . Their recommended guidelines assess the level of vulnerability through a range of factors, including: demographic factors, health status, and culture or life condition, access to resources and services, and sociopolitical conditions (WHO, 2012).

The Center for Disease Control (CDC) is another entity responsible for reaching out to vulnerable populations, which must be assessed and categorized.

The CDC's guide for developing a vulnerability assessment is through a program called Building Resilience Against Climate Effects, or BRACE. The five steps of BRACE include:

1. Determine scope of the assessment, including area of interest, and identify health risks associated with climate exposures
2. Identify risk factors
3. Acquire information at the smallest administrative unit possible (ie. Census Block Group)
4. Assess adaptive capacity of the system's ability to cope with health issues
5. Combine information into GIS to identify areas that are vulnerable to climate-related exposure.

This paper will align closely with the BRACE (2012) method. The first two steps involve the assignment of criteria for risk factors. The criteria for vulnerability will be based on a three-prong approach addressed in BRACE (2012) and consistent with the aforementioned institutions' definitions. These criteria will be based on the population groups' level of the following conditions:

1. Sensitivity
2. Exposure
3. Adaptability

More details of each criteria will be discussed in the following sections.

2.2 Sensitivity: Age, Race, and Income

A population's degree of sensitivity to extreme heat events is based on scientific literature and case studies (Whitman, 1997; O'Neill, 2005; Hansen et al, 2013). Vulnerable are those that are not physically capable of managing the heat, this includes those who have medical conditions or are of an age group where their physicality puts them in jeopardy during extreme heat events (CDC, 2014). In a case study of the Chicago heat wave of 1995, Johnson et al (2012) developed an extreme heat vulnerability index. In the study of the mortality during the heat wave which lead to the foundation for their index, they found socioeconomic variables (sensitivity) to account for approximately 70% of vulnerability, more than physical environmental variables such as surface temperature, vegetation, and built environment (exposure). In this report, the variables that are attributed to level of sensitivity are the following: age, race, and income level (Johnson et al, 2012).

The elderly should be considered in planning because not only are they susceptible to heat-related illness due to the presence of chronic medical conditions (Whitman, 1997; Schwartz, 2005), but as the population is aging we must plan for more individuals occupying this vulnerable demographic category. This disproportionate impact on elderly individuals is staggering; an evaluation of the extreme Chicago heat-wave of 1995 found that people over 65 years old made up 72% of heat-related deaths. This appears to be a universal trend; Medina

(2006) finds in her broad study across multiple cities and climates, those who are elderly (older than 65) have been more victim to heat related illness and death. In national healthcare trends, Income is found to be moderately more impactful than race based on the following studies: The Agency for Healthcare Research and Quality (AHRQ) has reported on trends of healthcare through the nation, who have produced the National Healthcare Disparities Report (NHDR) that evaluates "prevailing disparities in health care delivery as it relates to racial factors and socioeconomic factors in priority populations. "Disparities in quality find a 6% relatively better level of healthcare for blacks, and disparity in quality of the healthcare was a difference of only 32% for blacks, 63% for Hispanics, versus a worse disparity for poor who received 89% worse relatively worse access. Age is found to be a tremendously impactful factor in regards to urban heat island effects like heat illness and respiratory disease. Older age can also allude to a higher rate of chronic or debilitating illness, which render a person medically vulnerable to heat stress (Schwartz, 2004). During the Chicago Heat Wave of 1995, the majority of deaths were linked to those over 65 years of age for both black and white individuals (Whitman et al, 1997).General healthcare trends point to adults over 65 years receiving inferior quality of care by a percentage of 39% (AHRQ, 2011).

Race has been found to be a consistent factor in risk to extreme heat illness; minority groups are especially susceptible (Whitman, 1997; O'Neill, 2005; Hansen et al, 2013). Due to a variety of intersecting socioeconomic factors that place minorities at a disadvantage; The Journal of Global Health Action found that "social and economic disparities, living conditions, language barriers, and occupational exposure are among the many factors contributing to heat-susceptibility among minority ethnic groups "(Hansen, 2013). Schwartz (2004) found nonwhites have greater risk during extreme temperatures than other factors studied, including age, gender, and gender in a case-only analysis of Wayne County, Michigan. In a study of four major metropolitan U.S. cities, O'Neil et al (2005) found the staggering disparity between the prevalence of central AC in white households, versus those in minority households. O'Neill found that as a direct result of lack of air conditioning, blacks have 5.3% higher heat-related mortality rates than that of white people (O'Neil, 2005.)

Not only are extreme heat events concentrated disproportionately in urban heat islands, but there is also a variation across certain neighborhoods. It has been found that neighborhoods with low socioeconomic status, that is lower income, lower rates of education, higher rates of poverty, and more minorities, are more susceptible to be negatively affected by extreme heat events (Harlan 2006; Chow et al, 2012). There is also a correlation to socioeconomic status; the fewer resources people may have, the less likely they are to cope with extreme heat events (Harlan, 2006; NWS, 2004).

2.3 Exposure: Land Use, Ambient Temperature, and Air Conditioning

The degree of exposure that individuals experience is dependent on the characteristics of the built environment and urban form. Regional characteristics, such as living in an urban area, will contribute to an individual's risk of heat related illness (EPA, 2006). The urban heat island (UHI) and its associated urban characteristics correlate to increases in extreme heat events within the microclimate (Stone, 2010).

The effects of the urban heat island are due in part to the land cover, land use, and general character of the built environment in the urban setting. These areas tend to have higher temperatures in general, but also experience two other effects: urban environments have shown be increasing in average temperature at a faster rate than other less urban areas (Oke, 1982), and they experience more instances of heat-waves (Taha, 1997). The magnitude of extreme heat events increases in these areas; studies have shown repeatedly that urban areas that experience heat waves result in more fatalities than other areas (Clarke, 1972; Smoyer, 1998, Tan, 2012.) Not only are dense city centers with the UHI are victim to the extreme heat events, but sprawling urban areas, as well (Stone, 2010).

Other land use characteristics work together to form the urban heat island. One is the albedo of the infrastructure. This low-reflectivity characteristic of infrastructure like paved roads and rooftops create a situation where temperatures are absorbed in the materials. These materials retain heat until they are released at night, thereby warming the air at night when the city should otherwise be experiencing a cooling of temperature (Taha, 1997). The propensity of these features to prohibit the city to cool down at night leads to higher temperatures overall (Oke, 1982.) The canyon effect created by tall buildings in dense settings also contributes to energy released as heat during the night. The canyon-like arrangement of buildings along city streets prohibit the release of heat that remain the in building materials (Oke, 1981; Loughern, 2012.) The concentration of a dense urban area with high levels of human activity will lead to higher levels of ambient heat due in part to our need for energy. These mechanisms that use energy must also dispose of residual energy, often in the form of waste heat. The elements that create the waste heat within our built environment include power generation, industrial processes, electronics, appliances, vehicle emissions and climate control devices (Block, 2004).

Exposure to extreme heat is often impacted by the individual's standard of living. Research into extreme heat events has shown that access to resources like air conditioning, which limit exposure to extreme heat, plays a significant part in decreasing risk for heat-related illness, or death (Schwartz & Zanobetti, 2001;

Kilbourne et al, 1982; McGeehin, 2001; Semenza, 1996). In an extensive study of 44 major metropolitan cities, Chestnut et al (1998) found statistically significant evidence that the higher average percentage of homes with central air conditioning in a city, is negatively related to rates of heat-related mortality.

2.4 Adaptability: Access to healthcare

Kovats et al (2003) defines adaptability as the ability of individuals to cope with the consequences of climate change, adjust to potential harm, and take advantage of opportunities. Adaptability can be attributed to a population's ability to seek medical care in times of duress (Kovats & Hajat, 2008).

2.5 The Urban Forest and the Urban Heat Island

In general, the abundance of gray infrastructure in a city that is impervious, non-reflective, and heat-retaining will harbor UHI effects. Conversely, in regions where land cover is more vegetated, the effects will be decreased, mitigated, or even reversed (Stone, 2013).

The natural characteristics of trees and the urban forest act to mitigate the negative impact of the built environment and the UHI (EPA, 2006). The Urban Heat Island is characterized by several features of the built environment, both at the surface and atmospheric levels, including properties of building materials, reduction of evapotranspiration processes, emissions of pollutants, and emissions of heat waste (Gallo et al, 1993; Oke, 1982). The presence of the urban forest works to prevent and alleviate each of these factors. The following points indicate how each contributing UHI factor is impacted by the urban forest:

Solar radiation is the primary source of heat in cities. Clearly, this solar impact is eased by the shade of the tree canopy. Trees act to lower surface temperature on buildings, driveways, streets and roads by providing shade and offsetting the surrounding radiation-absorbing materials in our grey infrastructure. The shade provided by trees has shown to be more efficient in cooling than artificial methods like mesh screens (Shashua-Bar et al, 2009). The urban forest and presence of trees in the city can affect temperatures at a variety of spatial scales due to urban form variables (Shashua-Bar et al, 2009). At the larger scale, it has been found that the temperature changes that trees create will be transferred downwind and across urban transects (Loughner et al 2012).

Shade provided by trees is a passive alternative that helps reduce need for air-conditioned climate control. A range of studies have been performed to test this theory, and quantify the results (Donovan and Butry, 2009; Ko and Radke, 2014; McPherson, 1997). Simulations that model the effect of urban design has been a way to yield useful examples (Kleerekoper et al 2012). This function of trees is an effective way of providing immediate relief from the potential harm for those in the vicinity of the tree. This is especially beneficial during the hottest summer season, when it has been found that direct shade reduces electricity consumption by almost 4% (Pandit, 2010), but the overall net reduction in consumption, as a byproduct of the indirect benefits trees provide, could be as high as 25% (Akbari, 2002). Any reduction in climate control energy production will reduce the emission of greenhouse gases from air conditioners and the electric provider (Akbari et al, 1997).

Trees lower the ambient temperature through evapotranspiration. Scientific technology has yet to create an effective anthropogenic tool that can replace the environmental function of evapotranspiration (Stone, 2010). The method in which this process mitigates the UHI involves both the roots and the leaves absorbing moisture, and releasing it in a more cool form (Taha, 1997; Zhou & Shepherd, 2010). Evapotranspiration provides indirect energy savings and climate control needs as it cools the air in a region (Rosenfeld et al, 1997; Konopacki & Akbari, 2001).

Pollution abatement is a service the urban forest provides which directly affect human health. In his 1997 study, Rosenfeld modeled that, coupled with other techniques, the presence of 11 million more trees could reduce smog in L.A. by 12% (Rosenfeld, 1997). The presence of trees in certain areas may optimize the pollution-reducing properties of trees; areas such as roadway corridors, residential areas, and industrial areas (Brack, 2000; Rowan and Nowak, 1992; Akbari, 2002). This property of trees is another critical factor in managing the urban forest to protect those who are subject to illness caused by pollution (Nowak, 2014.) Observational studies of street trees have shown there is a lower prevalence of childhood asthma for those living near higher density of trees (Lovasi et al, 2008). This indicates that the properties of trees to provide pollution abatement can directly affect the immediate area.

Chapter 3

Study Area & Data Inventory

3.1 Study Area

The DFW region is one of the fastest growing metropolitan regions in the country, placing third in the nation behind Houston and New York (US Census Bureau, 2014). The human density in Dallas is quite large – at 3,517 persons per square mile, falling below the national average (US Census, 2014). The existing infrastructure and built environment already creates ideal conditions for the urban heat island effect, and with the expectation of even more development that accompanies population growth, the city should prepare for managing the growth in a smart and sustainable manner.

In its relatively short history as an established city, Dallas has experienced all of the devastating effects of racial segregation, many effects still resonate today. In the past, minority groups resided in certain areas for various reasons, including explicit segregation, and political redlining (Graff, 2008; Phillips, 2010). These trends remain today, where most minorities reside in South Dallas. The composition of Dallas race shows only 50% makeup of white – this falls below the state numbers of 70% (US Census, 2013). The Dallas County Department of Health has performed and published reports that show these South Dallas areas as areas where there is a lack of adequate healthcare, so they should be considered when planning for healthcare needs (Dallas County, 2013). Given this fact, this study focuses on the areas that include more vulnerable population in the City of Dallas. Data

3.2 Data Inventory

The CDC's BRACE framework (2014) gives an idea for performing a vulnerability assessment based on a range of criteria. After a review of literature and data sources, a set of factors were determined to be considered the best factors when attempting to mitigate the urban heat island's effect on vulnerable populations through planting and preserving trees. The following are the data sets.

Table 3.1 Data Sets

	Factor	**Data Source**
Sensitivity	Minority (Race)	U.S. Census Bureau American Community Survey
	Level of poverty (Income)	U.S. Census Bureau American Community Survey
	Age Group	U.S. Census Bureau American Community Survey
Exposure	Condition of climate control	Dallas Central Appraisal District
	Ambient temperature	HARC, Texas Tree Foundation
	Land Cover/Land Use	City of Dallas
	Tree Canopy Cover	Texas Trees Foundation
Adaptability	Medical Professional Shortage Area	US Dept of Health and Human Services - Health Resources and Services Administration
	Medically Underserved Area	US Dept of Health and Human Services - Health Resources and Services Administration

3.3 Sensitivity

The criteria for ‘sensitivity’ factors were based on the findings in the literature review. These findings indicated various demographic categories wherein the population was vulnerable to climate related impact.

The data set to represent this factor is the U.S. Census Bureau’s American Community Survey (ACS) for 5-year estimates for the years 2008-2012 within the geographic sample of Block Groups (ACS, 2012). The ACS findings rely on the discretion of the respondent to identify themselves within a race category. These categories range from White, Hispanic, Asian, African American, Indian American, Pacific Islander, and more. The survey also presented an option for identifying oneself among a mixture of the race options. For the purpose of this report the ‘minority’ factor is extrapolated from the data for those who selected a variation of “Hispanic” or “Black.” The spatial arrangement of these groups, as seen in Figure 4.4, indicates the trending of these population to be primarily located in the Southern region of the city.

Another indicator of sensitivity was the socioeconomic factor of income level. This spatial representation of this data is found in ACS Block Group data for Median Household Income. The lower ranges of household income are concentrated in the south. See Figure 2 – Income.

Children and elderly are especially vulnerable during events of extreme heat (Stone, 2012.) This data was found in the ACS Block Group Survey. Children are classified as those under 15 years of age, and elderly are those over 65 years of age. There is not a clear trend in looking at the cite-wide scale of the age demographic.

3.4 Exposure

Within the BRACE framework, exposure can mean a variety of factors. For the purpose of this report, exposure is correlated with climate-related exposure based on land use, and living standards.

3.4.1 Existing Thermal Conditions

This map exhibits a gradient perspective of surface temperatures from low to high. This data was attained from the Houston Advanced Research Center by kinetic thermal corrected aster imaging. Areas with a higher temperature are prioritized in our model. The ambient air temperature variable is weighted by a factor of 20% of the six total variables.

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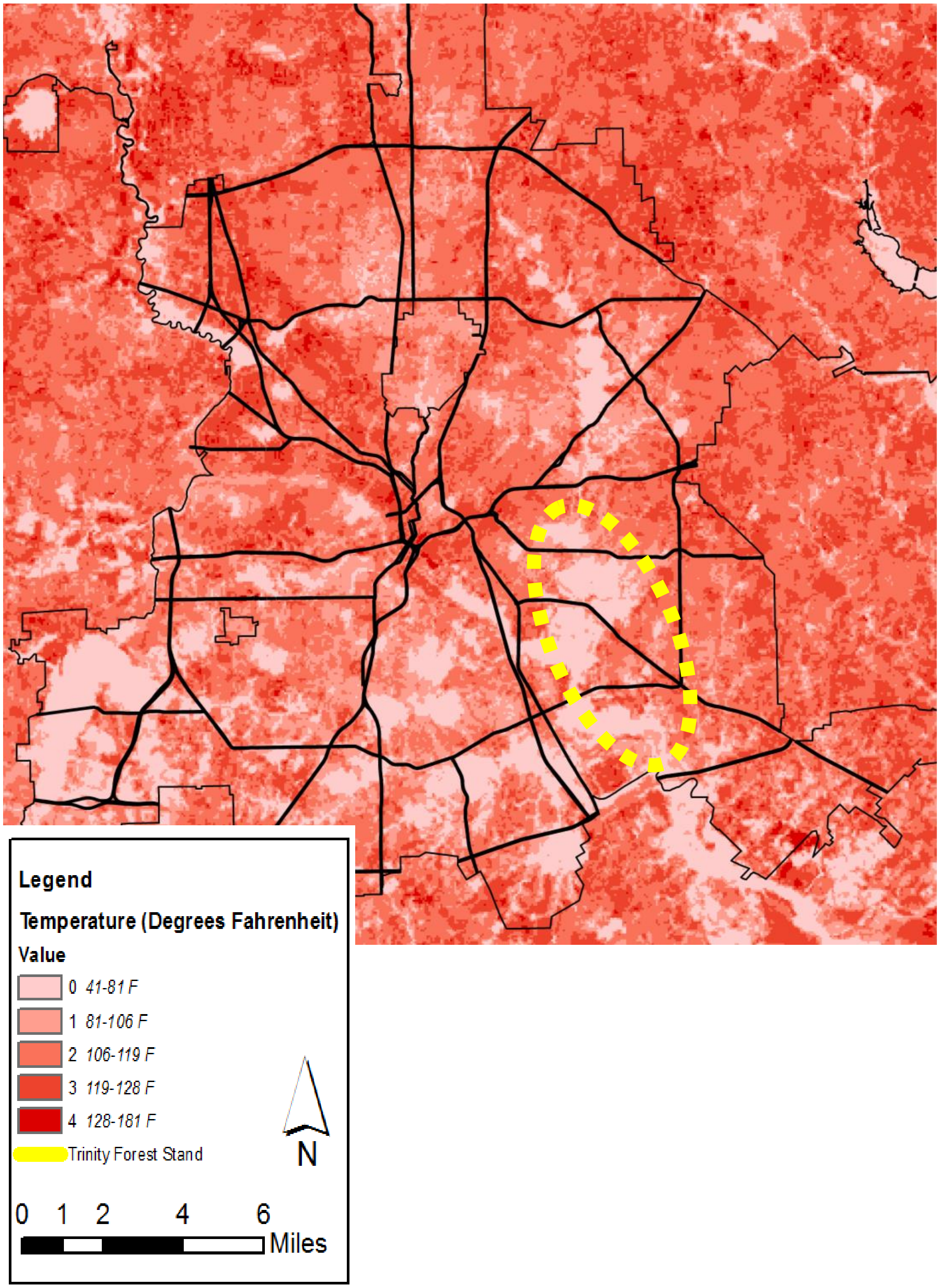


Figure 3.1 Current Temperatures

Below is the top 25% hottest areas as found through a reclassification of the surface temperature raster data. These hottest areas, or "hot spots", are displayed as a KML aerial on the image below. Note the lack of hot spots around the forested areas of the south.

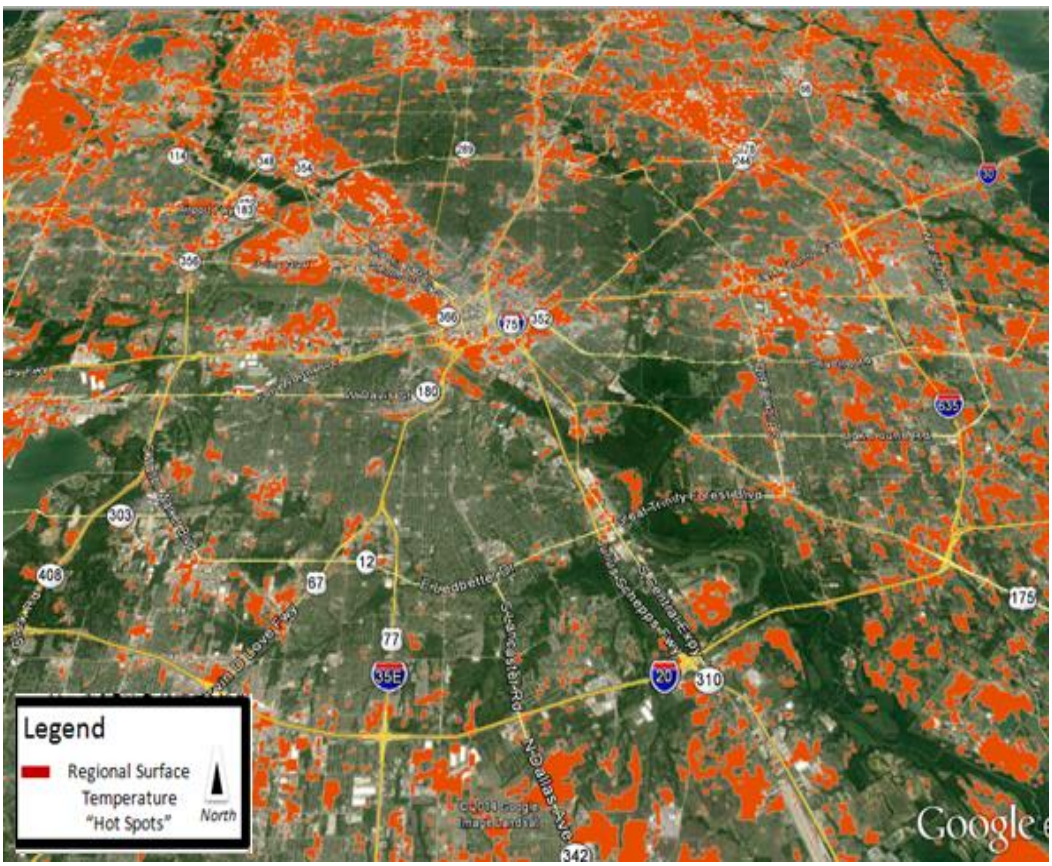


Figure 3.2 Hotspots

Land use data was extrapolated from the City of Dallas' Zoning District map (City of Dallas, 2014). Dallas has 20 categories of zoning districts, each a variation of the standard Residential to Industrial categories. I reclassified these districts into 5 basic categories.

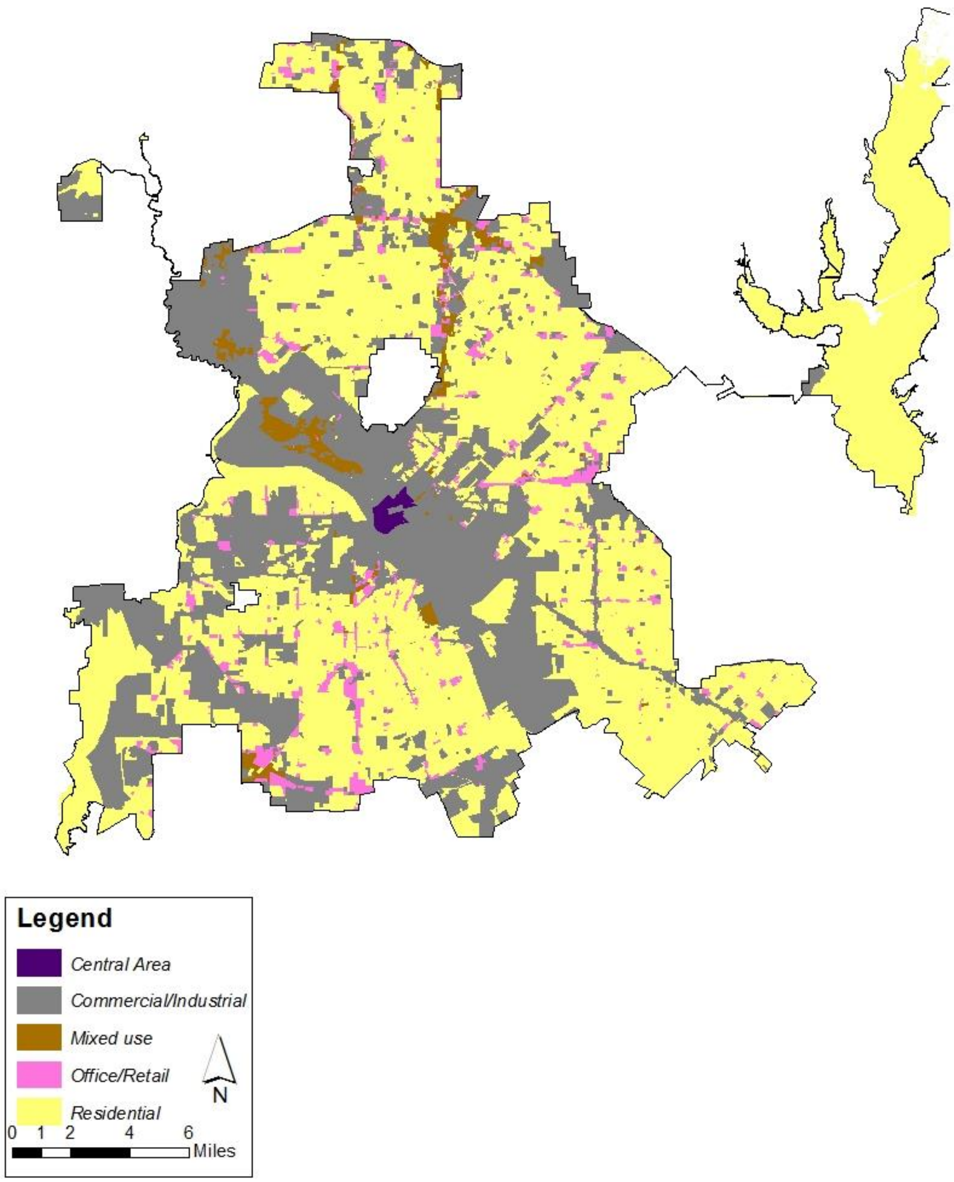


Figure 3.3 Land Use

Roadway corridors, where vehicle emissions and pollutants are concentrated, were prioritized in this study. Primary thoroughfares, such as highways, were applied to the spatial analysis. This data was found in the NCTCOG regional GIS Database.

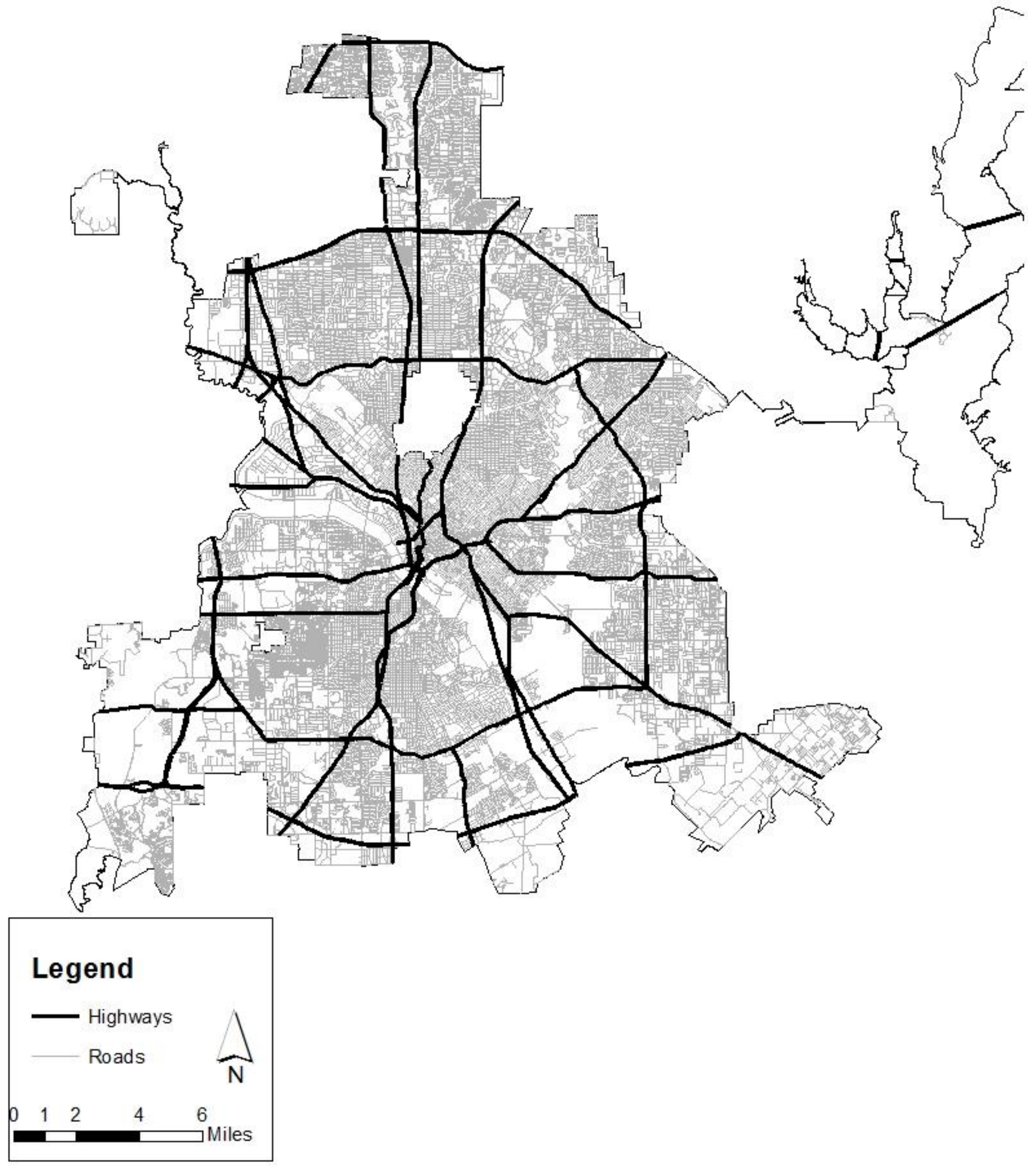


Figure 3.4 Roadways

To evaluate another element of 'exposure', the representation of living standards is based on access to climate control within the home. The Dallas Central Appraisal District (DCAD) acquires this information every year in order to maintain a database of housing conditions, as well as appropriately access taxes. In order for DCAD to accurately maintain data for properties, the information is at the parcel-level. The spatial trends indicate a higher-level of air-conditioning access in the northern portion of the city. For the purposes of this study, I extrapolated data to show which Census tracts had a significant percentage, more than 15% of properties, that indicated they had no central air conditioning. This parcel data was aggregated into larger groups of Census tracts.

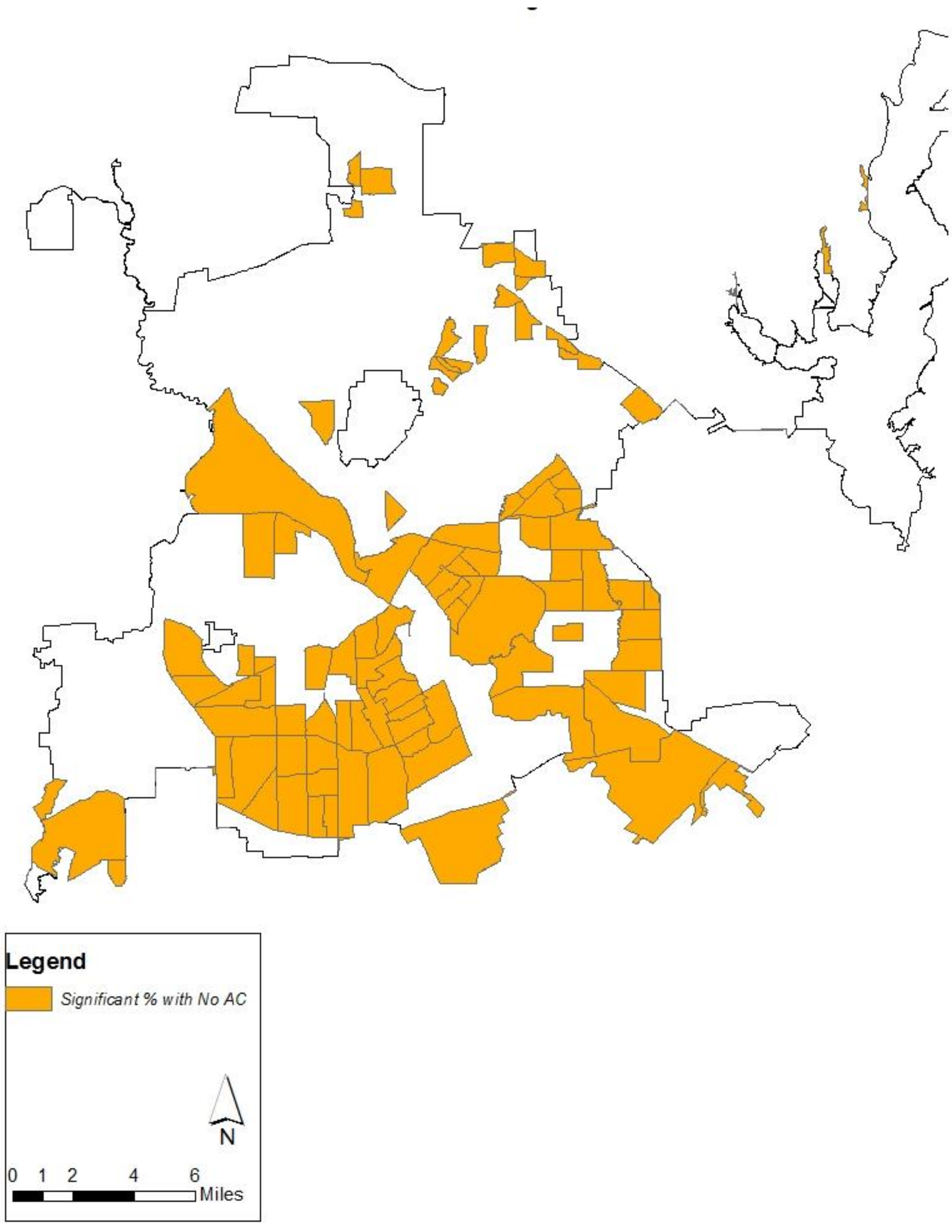


Figure 3.5 Air Conditioning

3.2.3 Adaptability

Access to health care is a factor of adaptability in the assessment of climate related vulnerability. For this study, access to health care was considered to be those within or outside of a "Health Professional Shortage Area (HSPA)" was provided by U.S. Department of Health and Human Services – Health Resources and Administration Network (HRSA). The HSPA region is found through the evaluation of criteria that includes: the demographics of population within geographic area, and the prevalence of health care resources.

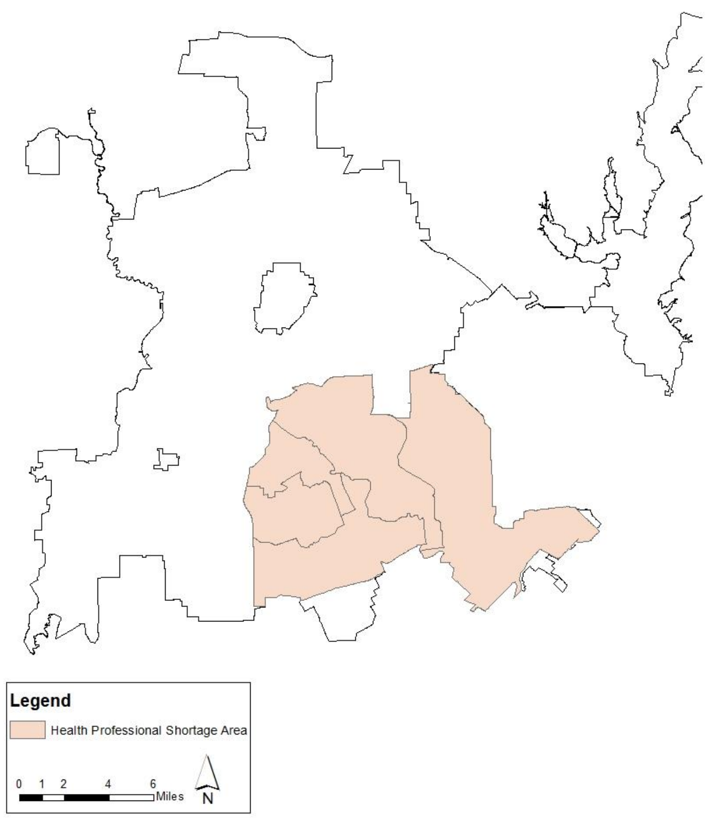


Figure 3.6 Health Professional Shortage Area

The Medically Underserved Areas (MUA) data was also provided by U.S. Department of Health and Human Services – Health Resources and Administration Network (HRSA). MUAs are areas which meet the criteria of having the lack of sufficient health resources, high infant mortality, high poverty, and high elderly population.

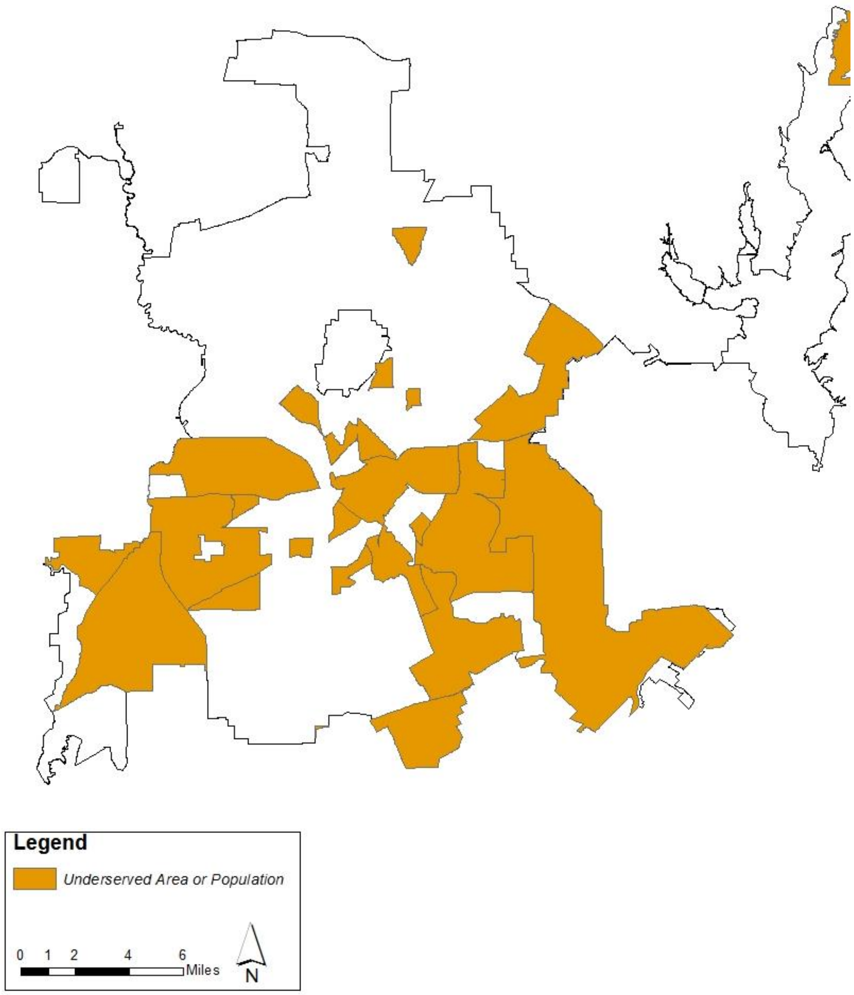


Figure 3.7 Medically Underserved Areas

This existing tree canopy coverage data was attained through the Houston Advanced Resource Center, 2009. The data was acquired through 2006 satellite imagery. As shown within the yellow call-out circle, the biggest proliferation of trees is in the Southeast portion of the city, where Great Trinity Forest Stand is situated.

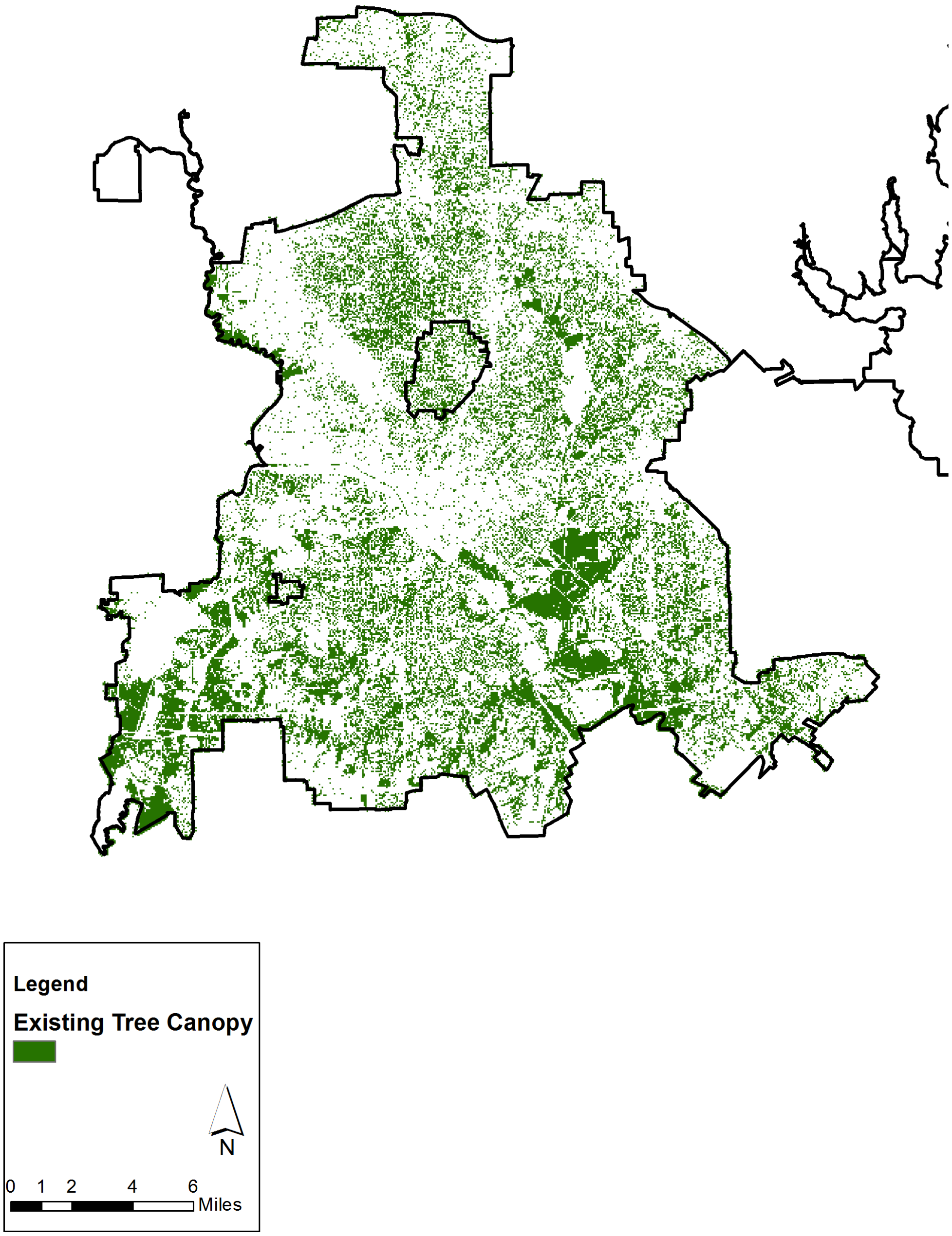


Figure 3.8 Existing Tree Canopy

Chapter 4

Methodology

The following outlines what steps are taken to follow the CDC's "BRACE" method (2012):

Step 1.
Determine scope of the assessment, including area of interest, and identify health risks associated with climate exposures

Step 2.
Identify risk factors

Step 3.
Acquire information at the smallest administrative unit possible (ie. Census Block Group)

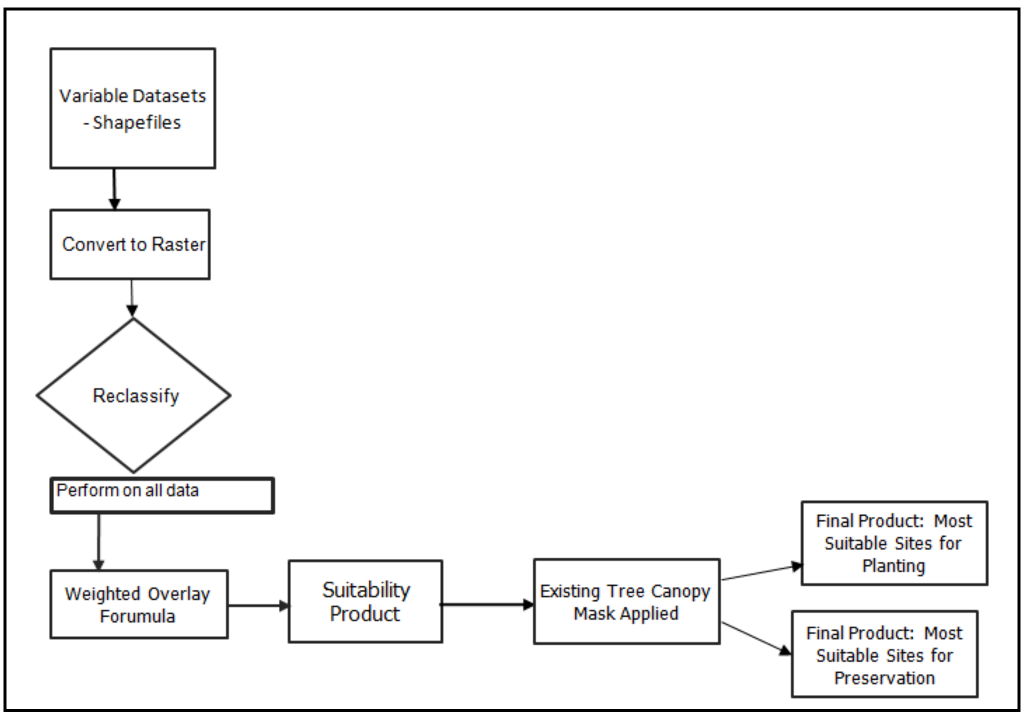
Step 4.
Assess adaptive capacity of the system's ability to cope with health issues

Step 5.
Combine information into GIS to identify areas that are vulnerable to climate-related exposure.

Steps 1-3 were completed during the first two chapters through literature review and data inventory. Steps 4 and 5 involves the application of a suitability model. Detailed processes of the suitability analysis are described in the following sections.

4.1 GIS Suitability Model

In Design with Nature (1969), Ian McHarg presents the basis of the overlaying suitability model as we know it today. McHarg's model has been critiqued as being likely to have fault in the gradient color scheme and linear ranking method (Anjomani, 1984; Malczewski, 2004) .These advanced methods are possible due to the advent of the computer-based Geographic Information Systems (GIS). This program allows a data-driven toolset to perform spatial analysis across all scopes and scales of geographic area.



Source: The author

Figure 4.1 GIS Suitability

4.2 Data Processing for Suitability Analysis

Once the appropriate data has been acquired (Chapter 3), the following step is to evaluate the GIS compatibly, and if necessary, attribute data is manipulated to reflect more appropriate spatial and categorical data as needed. This data is then converted into Raster format. The raster environment allows for more operational use of the GIS program, as it permits powerful and convenient processing, and the application of advanced programming languages, formulas, and scripts (Van Der Laan, 1991).

The cell size resolution was uniform across variables. A cell size of 250 was used, which translates into the spatial delineation of zones which are approximately 250 square feet in area. The cell size is appropriate for this study because they are large enough for the results to demonstrate a clear picture of suitable sites across the focus region, while still being small enough to define the suitable attributes of distinct areas within neighborhoods.

The raster data was reclassified based on the Suitability Index (see Figure 4.2). Data was reclassified and displayed based on the Jenks natural breaks optimization setting. This method partitions and represents the data by calculating the optimal iterations of the trends within the data, to produce a more intuitive and accurate arrangement. Once this reclassification performed on all data, the reclassified data sets were input into the suitability formula in raster calculator. The following describes the suitability assignment given to each dataset.

The original dataset of race demographics was manipulated to only show percentage of minorities versus nonminority within each block group. The reclassification shows the percentage values of the demographic makeup across the city. The majority of the southern half of the city has a high rate of minority makeup. The dataset was evaluated as continuous data for its ranges of percentage of minority composition.

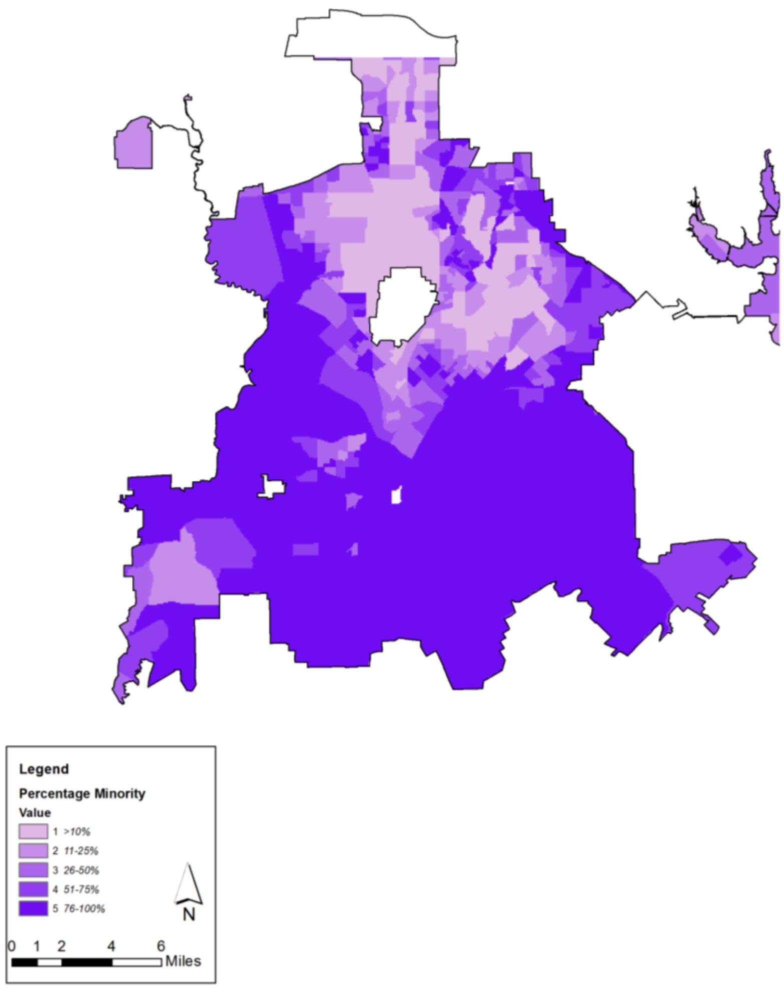


Figure 4.2 Reclass Minority

Median household income was evaluated and reclassified based on approximately $30,000 intervals. Those that fell below the average median income in Dallas were prioritized. According to the last US Census the average income is $42,436 (US Census 2010). The dataset was evaluated as continuous data for its ranges of income.

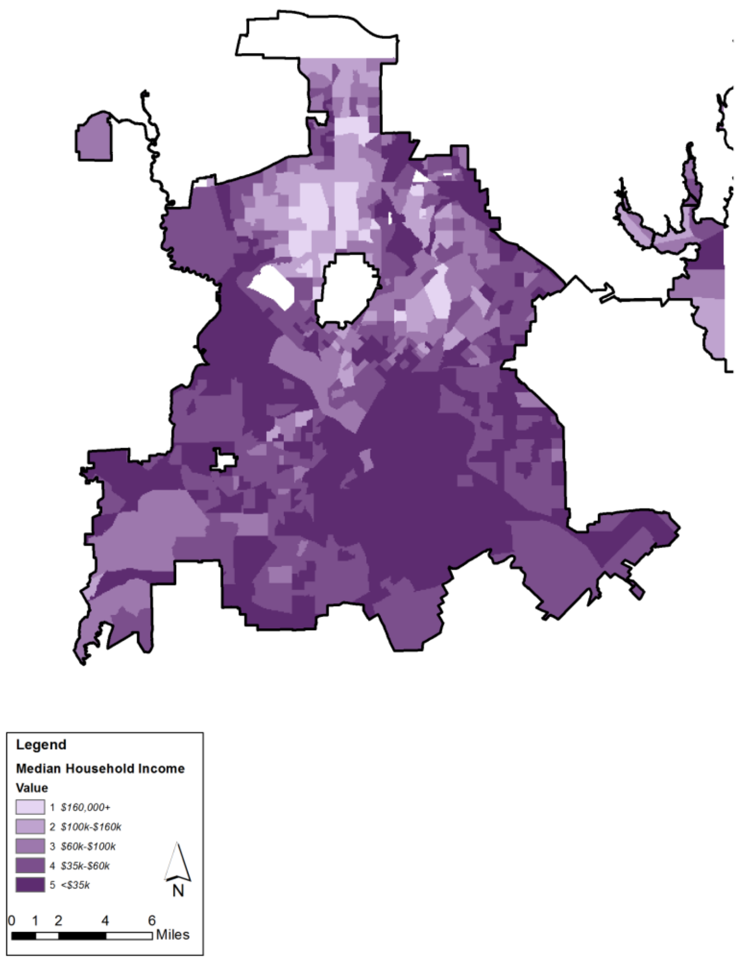


Figure 4.3 Reclass Income

The dataset for age range was manipulated to account for those under 15 and those over 65 years of age. This data is reclassified to those this new dataset as percentage of demographic makeup. The dataset was evaluated as continuous data for its ranges of percentage of children or elderly.

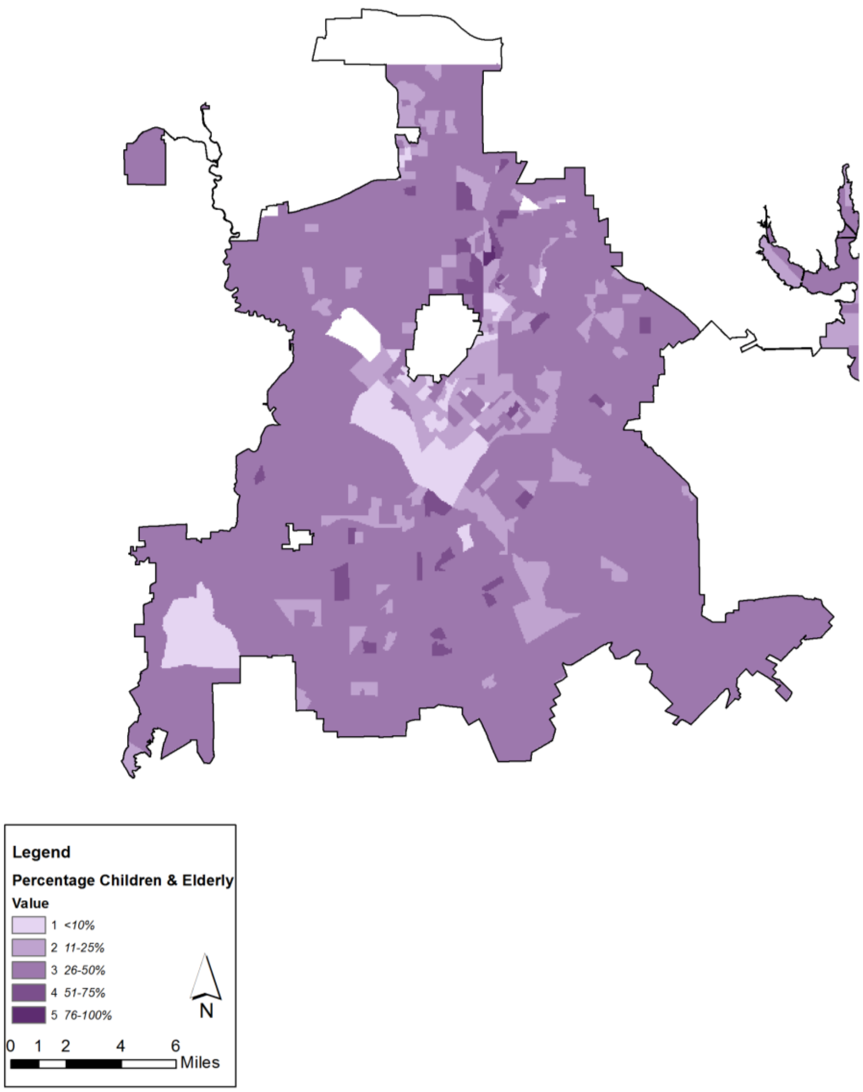


Figure 4.4 Reclass Age

This data had to be recategorized by arranging City of Dallas Zoning Districts into 5 primary Land Use types, which were then reclassified by value. Residential land uses are deemed most suitable for tree planting sites, due to residents spending a majority of their time here. Next, land uses that produce pollutants and attract vehicular traffic are prioritized, these are Commercial/Industrial Land Use sites. The dataset was evaluated as categorical data for the 5 use categories.

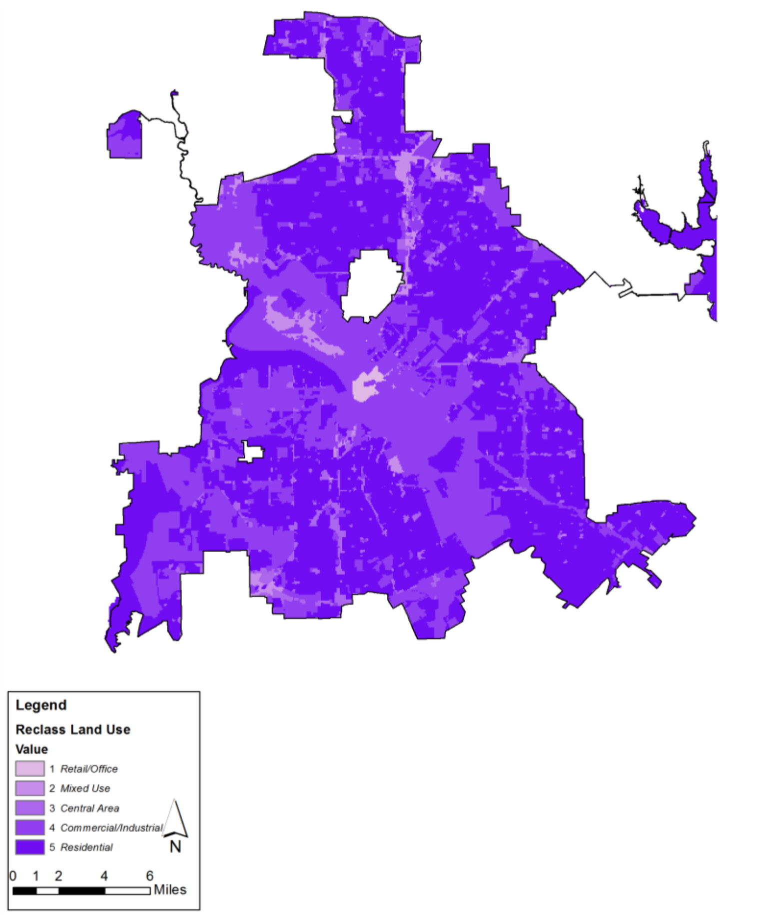


Figure 4.5 Reclass Land Use

This map Figures a gradient perspective of average temperatures from low to high. This data was attained from the Houston Advanced Research Center by kinetic thermal corrected aster imaging. Areas with a higher temperature are prioritized in our model. The dataset was evaluated as continuous data for its ranges of temperature.

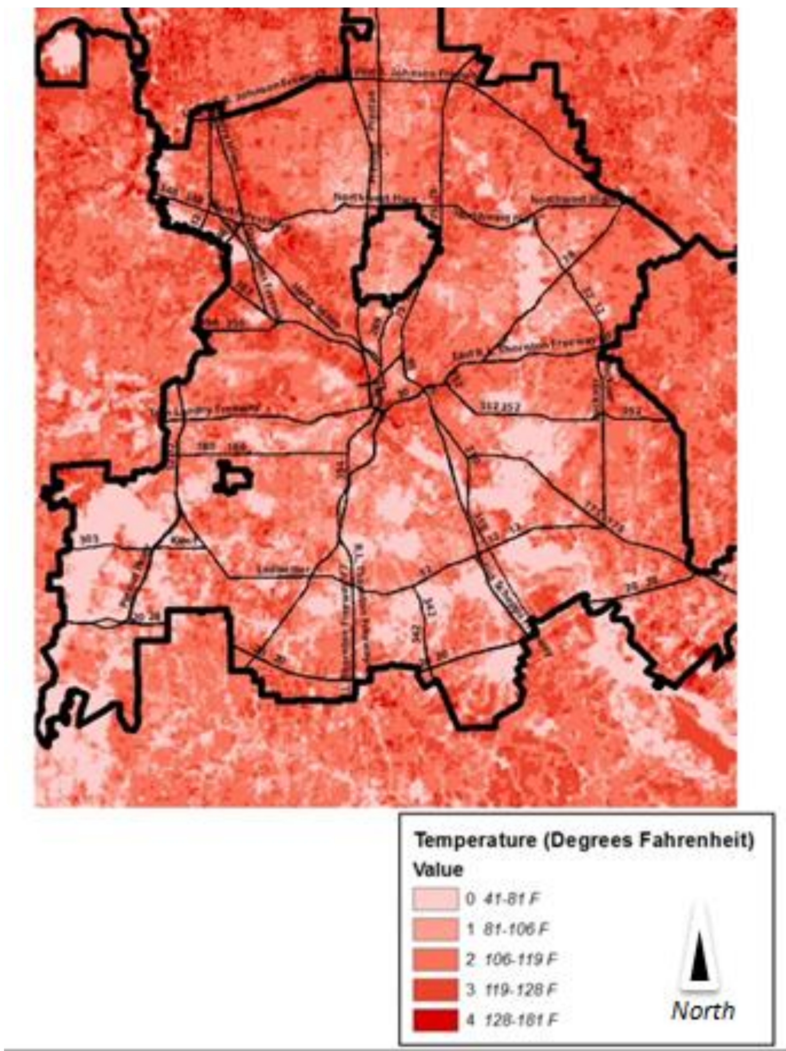


Figure 4.6 Temperatures

Euclidean distance applied once raster was complete, as shown. Roads data attained from NCTCOG GIS Clearinghouse. The abundance of pavement creates an environment of heightened temperatures, and the concentration of automobiles emitting pollutants in these regions make road corridors a key factor in planting trees for this purpose. The most suitable location for planting trees is decided as within 200 feet of the roadway. The dataset was evaluated as continuous data for its measurement intervals.

Figure 4.7 Reclass Roadway Corridors

Air conditioning data was first aggregated into Census Tracts land Block Groups l to maintain consistency. Shown is the rasterized dataset. The dataset was evaluated as discrete data for its value of either being a tract with significant percentage with no ac, and all others excluded.

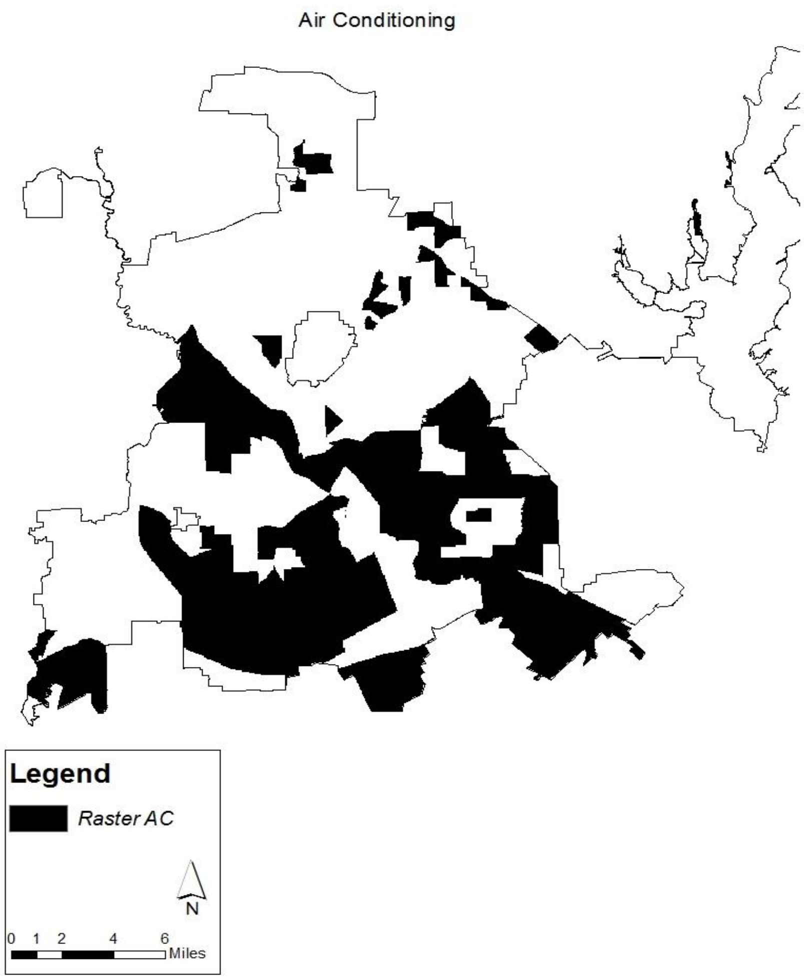


Figure 4.8 Raster Air Conditioning

The existing tree canopy data was rasterized, as seen in this inset exhibit. A mask will be applied to the analysis to eliminate potential sites for tree plantings, and will be re-applied to demonstrate ideal sites for tree preservation, based on the suitability index.

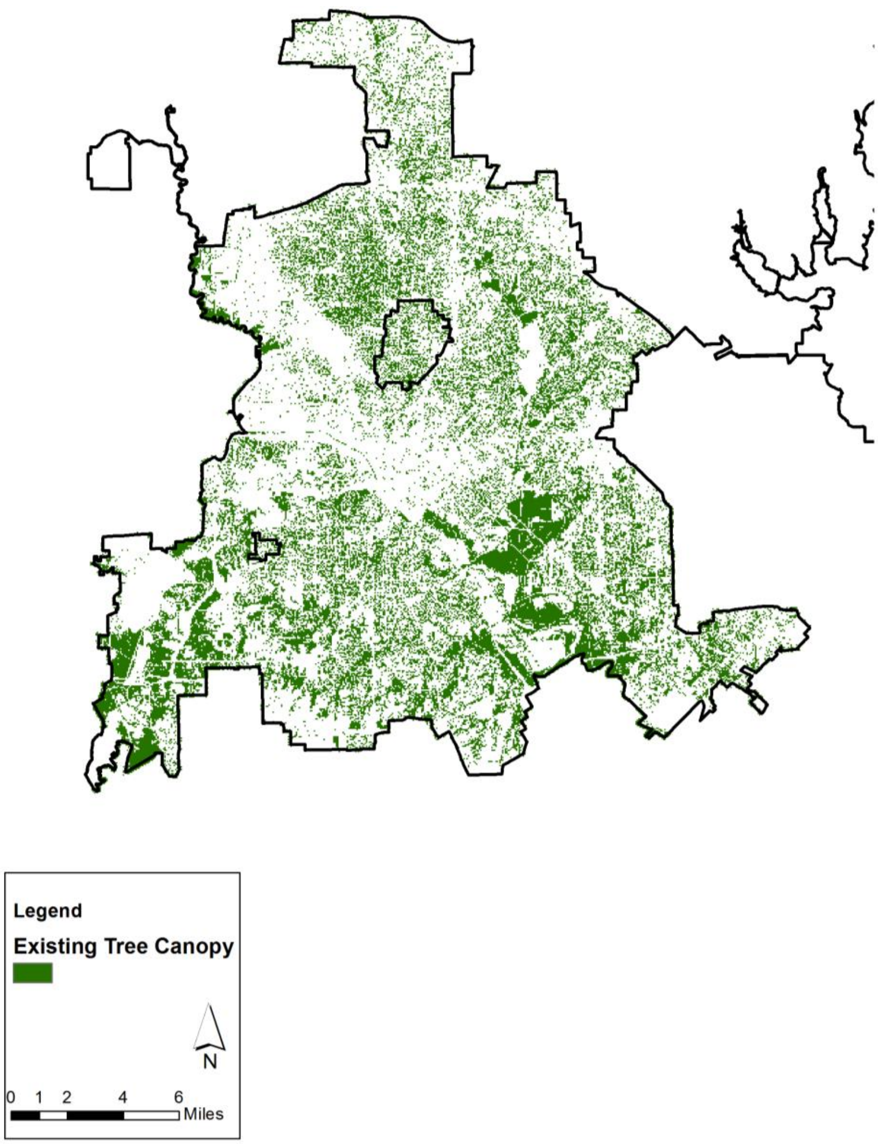


Figure 4.9 Raster Existing Tree Canopy

4.3. Analytic Hierarchy Process (AHP)

In order to determine the relative weights for the suitability model, the analytic hierarchy process (AHP) was applied through a pair-wise comparison of each factor. The AHP process has been proven to be a method during multi-criteria decision making applications, especially when dealing with large sets of data (Saaty, 1988). When acting on a multi-criteria decision making (MCDM) problem, the assignment of a hierarchy structure proves to be useful. Thoughtful prioritization of the factors is critical. Often the factors are not independent of one another, but instead are dependent on or related to a broader goal. For example, in our BRACE Framework for creating the vulnerability assessment, the factor “income level” is related to the higher level goal of assessing “sensitivity.” Our dataset contains two tiers of criteria: vulnerability assessment factors, and then a set of sub-criteria which influence the primary factors. With two sets, we will perform the suitability weighting for each set. An efficient and technical way to determine the relating weighting of the dataset is to rank the relative importance of one factor against the importance of another. This pair-wise comparison method produces a logical framework for assigning relative weighting multiplier to each attribute.

Figure 4.1 demonstrates how the pairwise results are then translated into the final composite rankings. The AHP Calculator used was developed by Klaus Goepal of Business Performance Management Singapore, and provided a simple interface for applying the research criteria(BPMSG, 2014). The pair-wise comparison depends on the judgment of the participant, thus there is a need to validate the consistency and logic within the composite pair-wise matrix. If the consistency ratio exceeds the desired level, this allows the user to reevaluate answers and modify discrepancies. The consistency ratio remained at a desirable level below 10% for each evaluation (see Appendix A for tables showing comparisons and calculations). The reasoning behind each evaluation is based on statistics gathered directly from the literature review. The following table depicts the pair-wise rankings of attributes.

Table 4.1 Final Decision Hierarchy

Level 1 – AHP%		Level 2 – AHP%		Global Priorities%
Sensitivity	0.5936	Total Percent Minority	0.184	10.90%
		Median Household Income	0.2318	13.80%
		Total Percent Children & Elderly	0.5842	34.70%
Exposure	0.2493	Land Use	0.1092	2.70%
		Ambient Temperature (Degrees F)	0.01325	3.30%
		Distance to Road (Feet)	0.0934	2.30%
		Air Conditioning	0.6649	16.60%
Adaptability	0.1571	Medically Underserved Area	0.6667	10.50%
		Health Professional Shortage Area	0.3333	5.20%

The aforementioned process within the methodology have lead us to develop the final matrix for the suitability mode. As depicted, each attribute data set has been assigned a suitability ranking based on its individual characteristics, and the relative weight of each dataset is accounted for.

Table 4.2 Suitability Index

		1 Least Suitable	**2 Mildly Suitable**	**3 Moderately Suitable**	**4 Very Suitable**	**5 Most Suitable**	**Weight %**
Sensitivity	**Total Percent Minority**	0-10%	11-25%	26-50%	51-75%	76-100%	10.9
	Median Household Income	160k+	100-160k	60-100k	35-60k	<35k	13.8
	Total Percent Children & Elderly	0-10%	11-25%	26-50%	51-75%	76-100%	34.7
Exposure	**Land Use**	Office/Retail	Mixed Use	Central Area	Commercial/ Industrial	Residential	2.7
	Ambient Temperature (Degrees F)	<81	81-106	106-119	119-128	128-181	3.3
	Distance to Road (Feet)	800-1000	600-800	400-600	200-400	0-200	2.3
	Air Conditioning	-	-	-	-	None	16.6
Adaptability	**Medically Underserved Area**	Not MUA	–	–	–	MUA	10.5
	Health Professional Shortage Area	NOT HPSA	–	–	–	HPSA	5.2

4.4. Geoprocessing

During geoprocessing the Arc Model Builder can be useful to assist in conceptualizing and implementing processes for tasks. I used Model Builder for various tasks, and the geoprocessing tool implemented to compute the weighted overlay formula. A weighted overlay formula was applied to the factor set. This weighted overlay technique was used so that the variable layers were aggregated based on spatial character, or raster cell in this scenario, and an output was produced that shows the total vulnerable-population indicator based on the variable inputs and weights.

Chapter 5

Results

The final outcome of the suitability models reveals areas within our study are that are most suitable for planting, and preserving, the urban forest. To summarize, these area locations where the population is very sensitive (based on socioeconomic factors), most exposed (based on land use, existing tree canopy, and living standards), and have the least capacity to adapt to extreme heat (based on health care accessibility). These final maps depict the 'most suitable' sites when planting for mitigating urban heat island effects around vulnerable populations. The top 20% threshold within 5 intervals of the suitability range is considered to be most suitable. This equates to approximately 150 square miles. Most prominent locations are in the south and the fringes of the city.

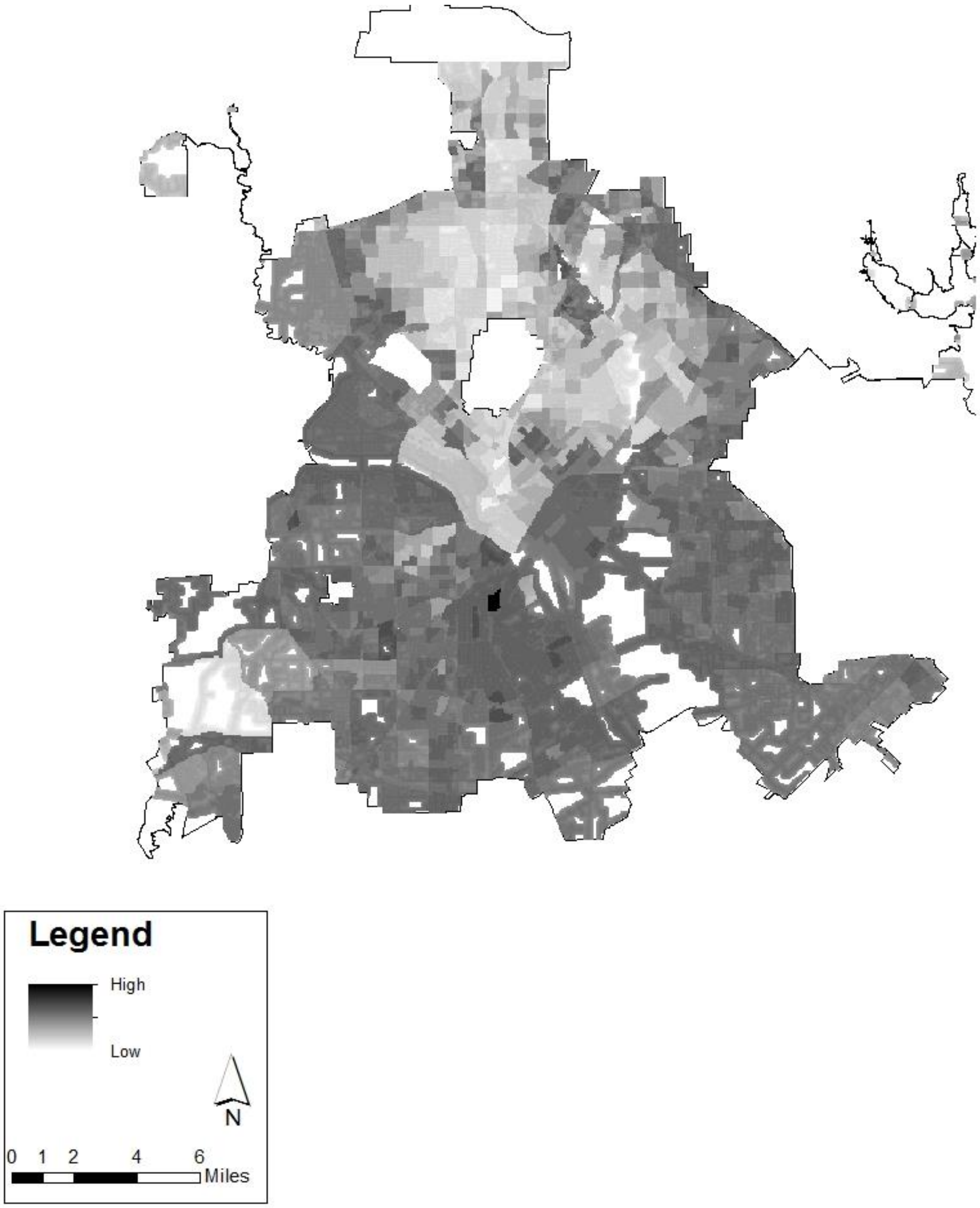


Figure 5.1 Overall Suitability

I then took these sites and applied the extract mask based on the existing tree canopy raster map, in order to just depict the locations where there is existing tree canopy. The result found the most suitable sites for preserving existing trees based on our suitability index criteria. The top 20% threshold within 5 intervals of the suitability range is considered to be most suitable. Figure 5.4 shows these sites projected against Google Earth aerials.

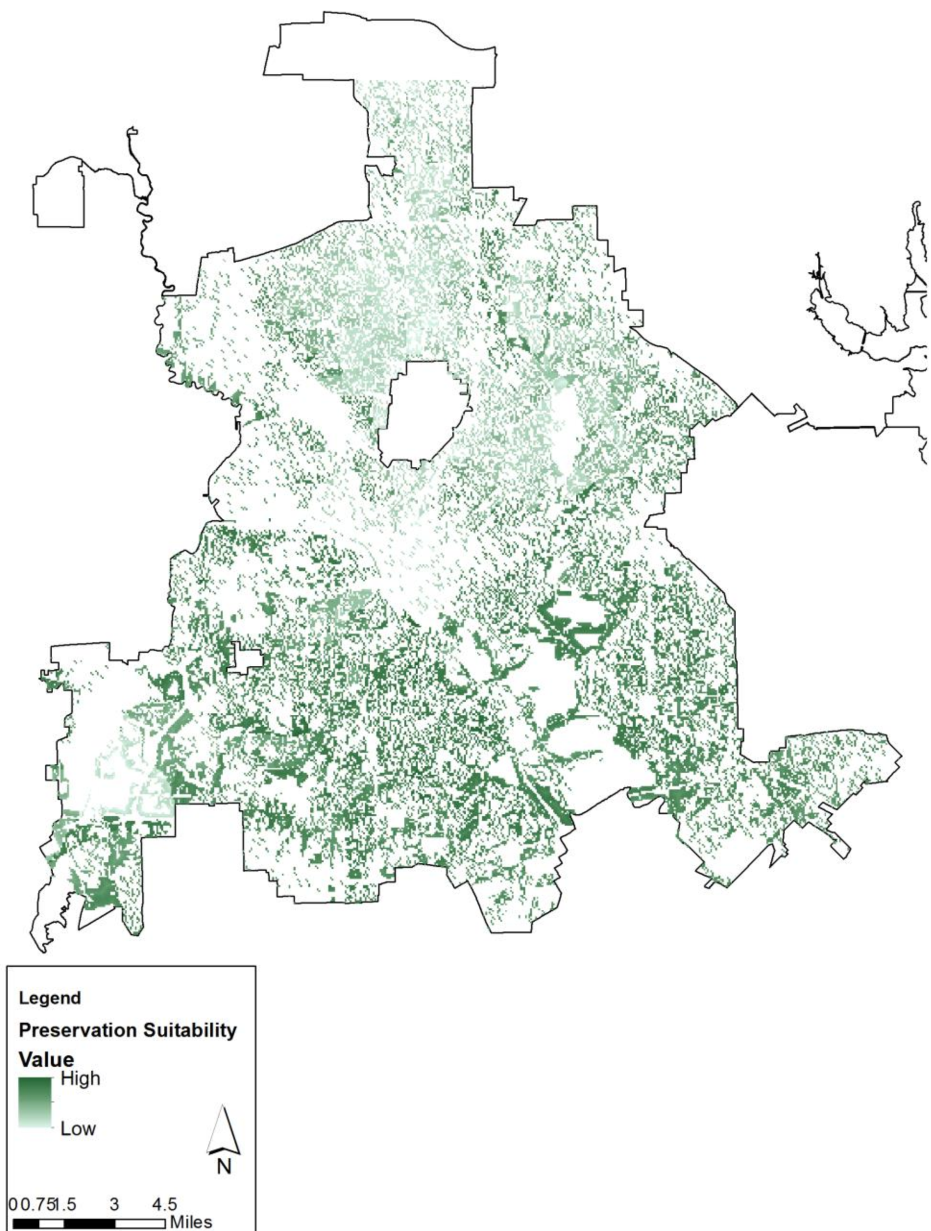


Figure 5.2 Preservation Suitability

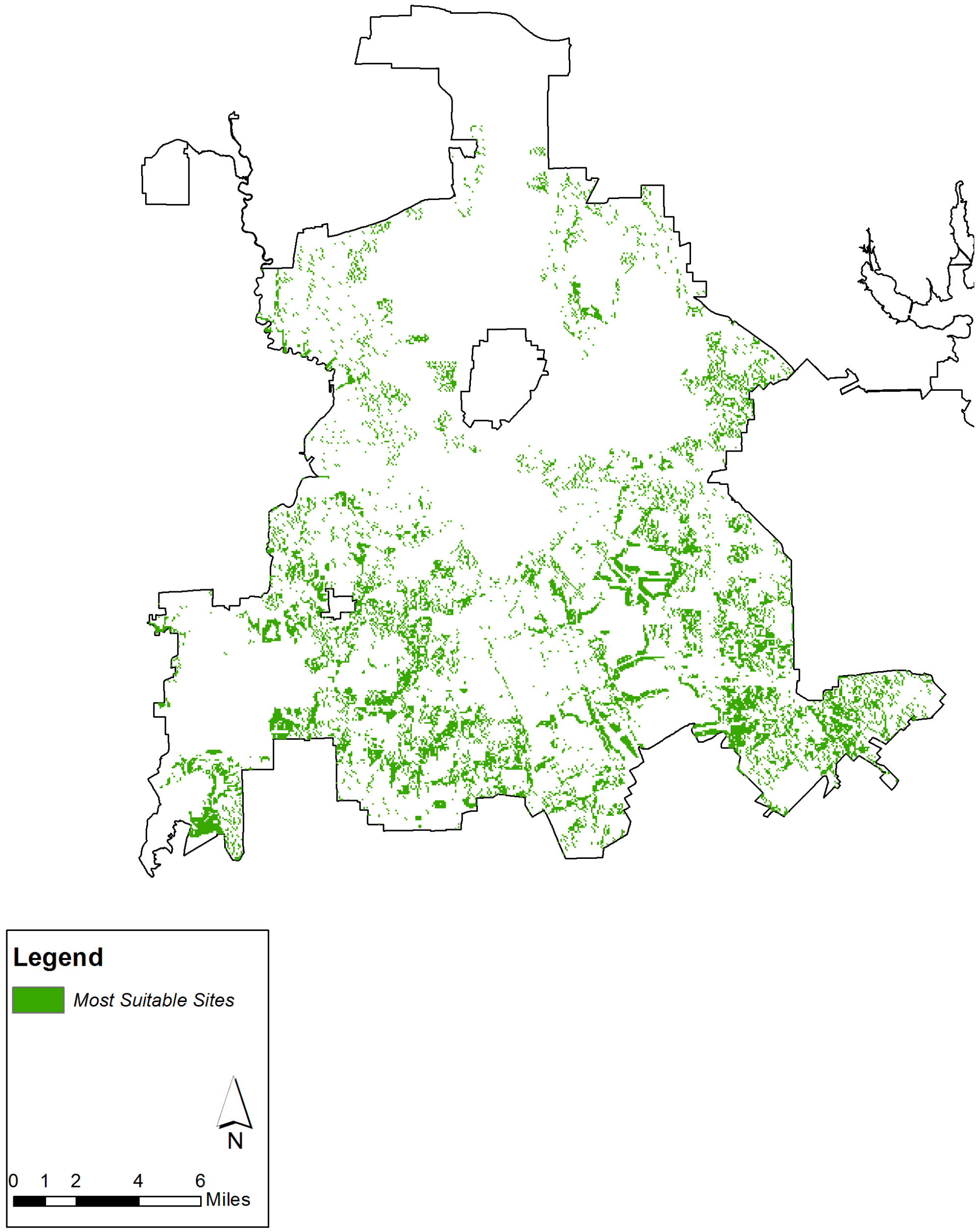


Figure 5.3 Most Suitable for Preservation

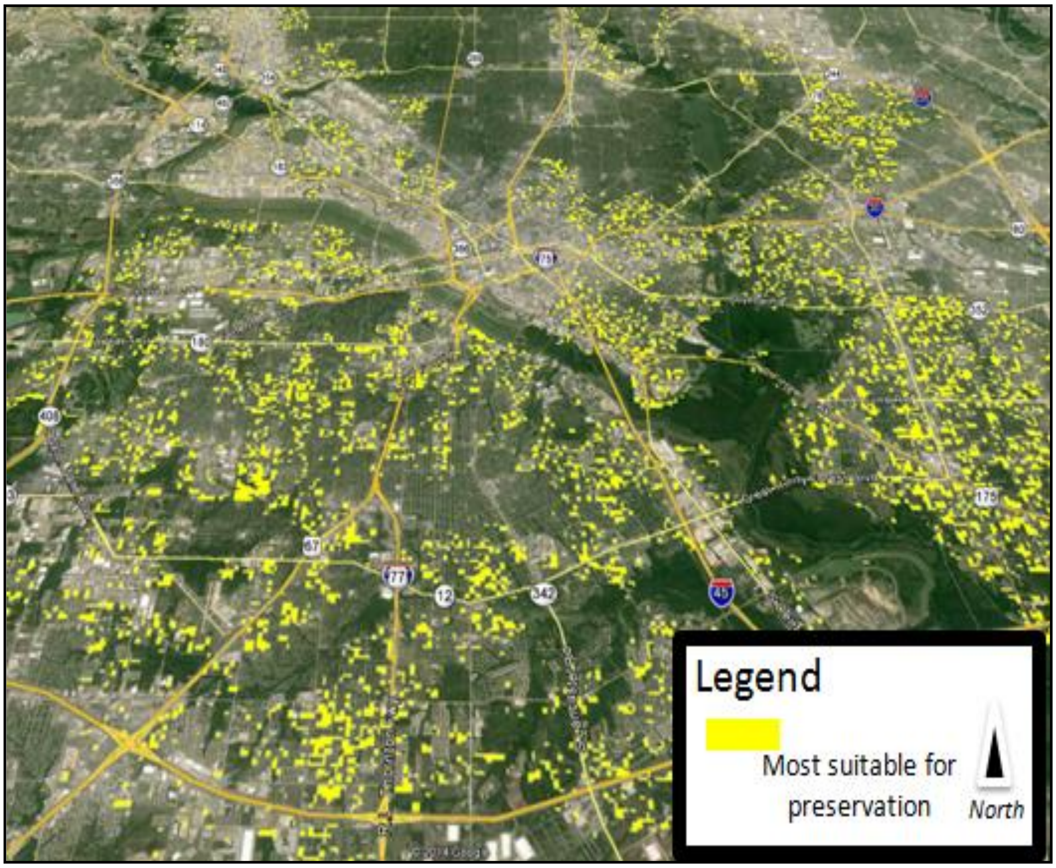


Figure 5.4 Most Suitable Preservation Sites - KML Aerial

Next, to show sites where there is a lack of trees, and therefore a need for reforestation based on our suitability protocol, I took these sites and applied the mask based on the existing tree canopy raster map,. The result found the most suitable sites for preserving existing trees based on our suitability index criteria. The top 20% threshold within 5 intervals of the suitability range is considered to be most suitable. Next, these sites are projected against a Google Earth aerial image.

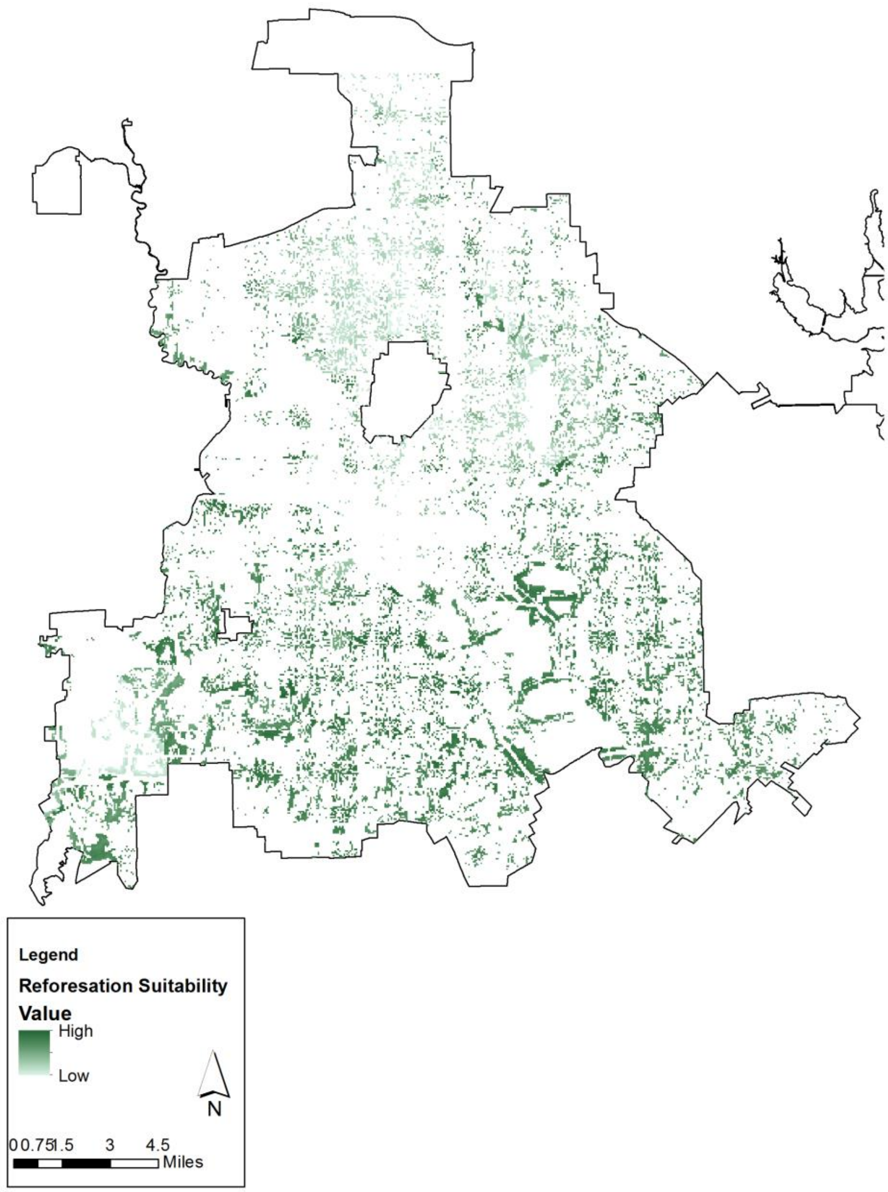


Figure 5.5 Suitability for Reforestation

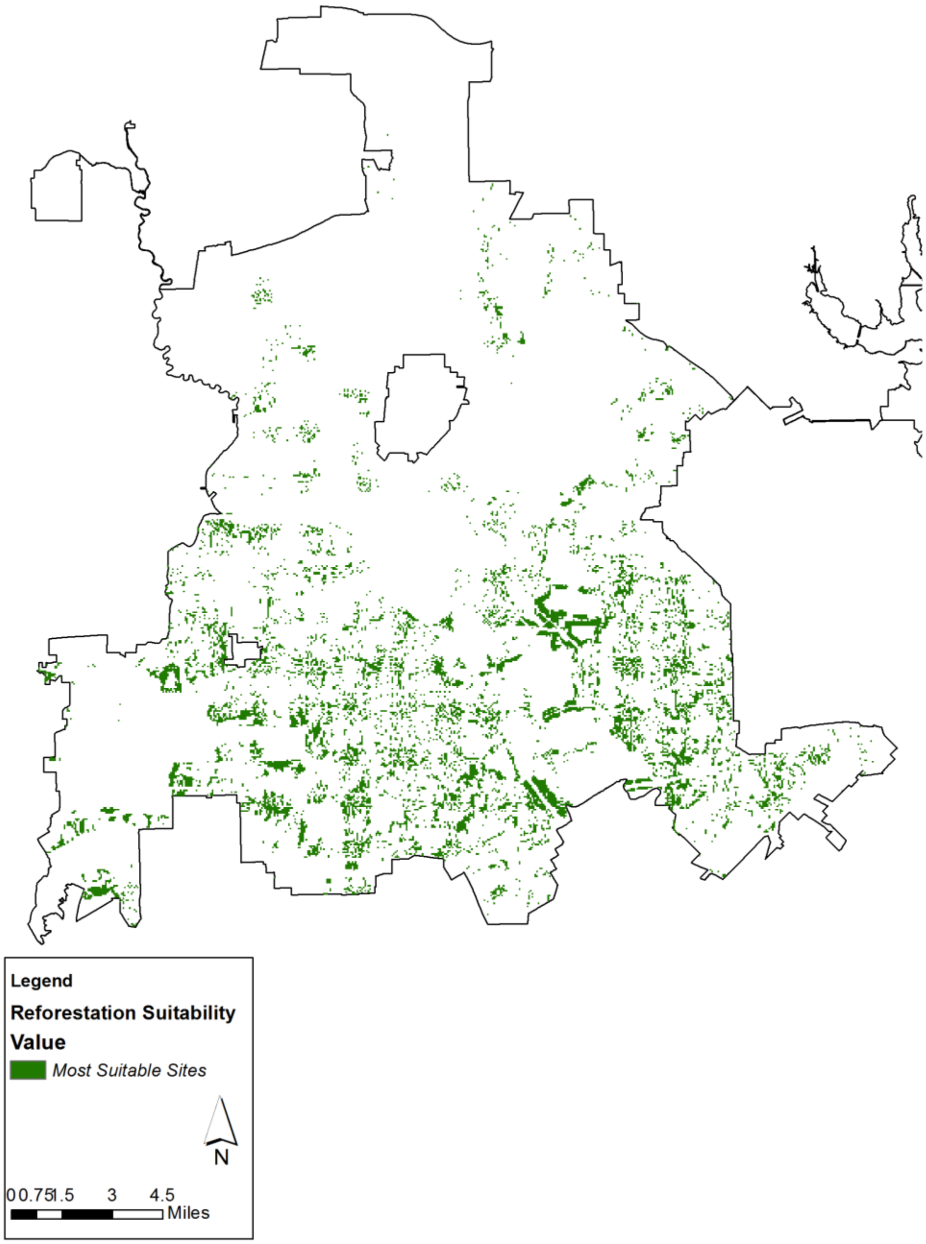


Figure 5.6 Most Suitable for Reforestation

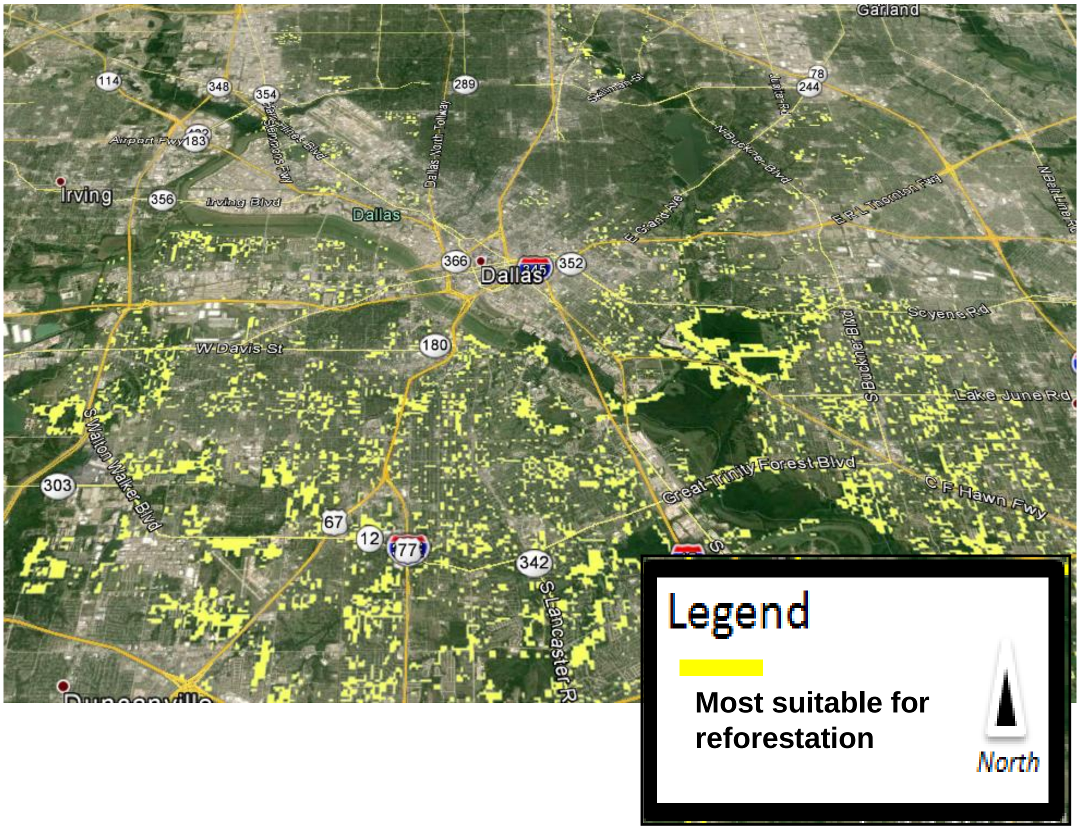


Figure 5.7 Most Suitable Reforestation Sites - KML Aerial

Chapter 6

Conclusion

6.1 Summary of the Findings / Discussion

The City of Dallas faces many challenges in heat management especially due to socioeconomic disparities. The mapping of indicators like race, income, healthcare accessibility points to distinct geographic concentrations of populations who are disadvantaged. Based on the protocol for this study, there is an overwhelming abundance of highly suitable sites in the southern region of the city, which follows the demographic and socioeconomic trends of demographics. This study follows has contributed to a comprehensive look into vulnerable population concentrations where the residents would benefit greatly from an increase in urban tree canopy, and places where the need to preserve the existence canopy is of utmost importance.

The final suitability results give a clear picture of locations throughout our study area where planting trees, or preserving existing trees, will directly benefit vulnerable populations. Whether it be a city-initiated program, or non-profit directives, the urban forest manager should consider these regional areas are in need of reforestation or preservation of urban forest.

According the studies found in the literature review, there are direct impacts on those within a vicinity of trees due to shade impact and air cooling functions. This is a targeted vulnerability analysis; it specifically identifies factors of the urban heat island that can be mitigated by the urban tree canopy. The vulnerability of extreme heat assessment is then accompanied by strategic mitigation plan, the tree planting prioritization roadmap. The geographic concentrations of socioeconomic factors, race and income, indicate problematic divisions within Dallas. Decision makers must consider these underrepresented and disadvantaged groups in order to lead the city into a sustainable future. It has been suggested that an increase in natural, green space will reduce income-related health disparities. Mitchell and Popham (2008) compared the presence of green space, socioeconomic factors, and the rate of mortality. By taking the initiative to plant trees and encourage reforestation, Dallas will be working to simultaneously reduce the negative effects of the urban heat island, and taking measures to end the continuation of the heat island.

6.2 Policy Implications and Recommendations

The City of Dallas is already well-equipped to integrate these recommendations into public policy; there are programs and regulations that already enforce some degree of reforestation and preservation guidelines. These findings can be used to implement more targeted actions and strategies. This is a viable intervention option, we already have many tools, resources and policies in place. Tree preservation is very important, that rules are codified in the Code of Ordinances. The Dallas Development Code, Chapter 51 A, Article X, a now 20 year old ordinance, which provides tree protection measures, as well as alternative off-site mitigation options. In fact, for the first time, the City of Dallas sued a developer for violating the ordinance (Dallas Morning News, 2013). In accordance with the Texas State Local Government Code, the City of Dallas has the ability to fine the responsible party for violating its Tree Preservation and Landscape Ordinances to the maximum amount allowable, being $2,000 per tree, and not less than $2,000 per day that the violation persists. (City of Dallas Ordinance sec. 51A-10.139 Fines)

The City of Dallas Comprehensive plan, "forward Dallas!" adopted in 2006, outlines the short-term and long-term vision of the city. The Vision portion explicitly asserts the urban forest as a critical component of environmental planning, where it states the goal to promote efforts to "increase the tree canopy by planting and protecting trees to reduce heat island effects and improve air quality. "In the Implementation section of the comprehensive plan, the Tree Canopy Coverage Enhancement Program serves as a framework for establishing a background, anticipated products, and measures for success, responsible departments, and stakeholders. Within this program they state the need for a meaningful ordinance to strategically protect trees in key areas. This a plan created through the input of stakeholders and interested citizens, thereby proving their understanding and desire for focused urban forest management.

Partnerships with local tree planting organizations could help the city implement a Heat Management Plan through planting. For example, Texas Trees

Foundation, a non-profit based in North Texas, has focused on Dallas. Among their research and reports is the "Roadmap Model for Urban Tree Planning & Planting." This detailed report revealed over 1.8 million potential planting sites based on a comprehensive range of selection criteria (Texas Trees Foundation, 2010). The results lend themselves to a prioritization scheme for various agencies. The assessment guidelines and resulting map of a report such as this could be memorialized in the updated of existing agency plans, and especially in the not-yet-created but inevitable 'Heat-Management Plan'. Many cities are attempting to take responsibility for climate change by initiating efforts to curtail the contributing effects of the urban area (Stone, 2012), while other cities are going even further by preparing management plans which act to prepare for the inevitable or existing effects of climate change (Bernard and McGeehin, 2004). Dallas already has a Drought Management Plan (City of Dallas, 2014), and the County has a hazard mitigation plan (Dallas County, 2014.) The results of this report, replicated to be refined or broader to suit the agency's needs, could be memorialized in any number of these plans across regions and political boundaries.

6.3 Limitations and Further Research

Going forward, it is important to recognize both the limitations to this research, and the potential to expand upon the analysis performed. There are more variables that can applied to the study criteria, for example the average age of homes in a block group, rate of vehicle ownership, use of public transportation, and site specific feasibility such as available plantable area and development pressures.

This study is based on a general overview of vulnerability determinants and assessments. While the proposed suitable areas give direction for prime locations where the benefits of the trees will be maximized based on heat and demographic factors, there is the possible to further refine the study. The vulnerable determinants can be applied include occupational status, detailed medical statistics, and more. Furthermore, the feasibility of the suitable sites could be accounted for through a more site-specific evaluation. This may include environmental and built characteristics of the planting space, land ownership status, development pressures in the area, and more.

The method used to assign priorities to the factors, the Analytic Hierarchy Method, was performed with limitations. The priorities were based on the discretion of one individual, the author, whereas there is potential and opportunity for a broad and far-reaching range of input from experts and stakeholders. The results would yield a more diverse but insightful priority matrix. The nature of the factors and the varying characteristics within renders the dataset to be subject to variance, based on the opinion of decision makers and priority setters. To illustrate this flexibility of the priority framework, a brief sensitive analysis can be applied. For example, if the results of the pairwise comparison between the sensitivity factors favored the income variable to be five times more important than race, then the resulting priorities for all three related factors would be skewed to be less or more prioritized (see Appendix B for table showing comparisons and calculations).

The scope of this study did not seek to quantify the potential effects of the suggested sites. However, there exist proven tools that use a robust suite of indicators and multipliers in order quantify the concerted effects of the urban tree canopy. The calculations provided by these tools yield figures and estimates of both applicable units, and monetary value (Nowak, 2000).

As demographic shift occurs, the vulnerability assessment will have to be first, reevaluated, and then reapplied. This may be beneficial at the next census data is released. By doing so over time, a temporal model can be developed to demonstrate shift in trends over time.

Appendix A

Analytic Hierarchy Process – Suitability Analysis

Scale: 1 - Equal Importance, 3 - Moderate importance, 5 - Strong importance, 7 - Very strong importance, 9 - Extreme importance (2,4,6,8 values in-between).

	A - wrt *Sensitivity* - or B?		**Equal**	**How much more?**
1	○ Race	or ◉ Income	**1** ◉	2 ○ **3** ○ 4 ○ **5** ○ 6 ○ **7** ○ 8 ○ **9** ○
2	○ Race	or ◉ Age	**1** ○	2 ○ **3** ○ 4 ◉ **5** ○ 6 ○ **7** ○ 8 ○ **9** ○
3	○ Income	or ◉ Age	**1** ○	2 ◉ **3** ○ 4 ○ **5** ○ 6 ○ **7** ○ 8 ○ **9** ○

CR = 5.6% OK

Calculate Result ◉ AHP ○ Balanced scale Submit_Priorities

Resulting Priorities

	Category	**Priority**	**Rank**
1	Race	18.4%	3
2	Income	23.2%	2
3	Age	58.4%	1

	A - wrt *Exposure* - or B?			Equal	How much more?
1	Land Use	or	Temperature	1	2 3 4 5 6 7 8 9
2	Land Use	or	Roadway	1	2 3 4 5 6 7 8 9
3	Land Use	or	Air conditioning	1	2 3 4 5 6 7 8 9
4	Temperature	or	Roadway	1	2 3 4 5 6 7 8 9
5	Temperature	or	Air conditioning	1	2 3 4 5 6 7 8 9
6	Roadway	or	Air conditioning	1	2 3 4 5 6 7 8 9

CR = 6.9% OK

Calculate Result   AHP   Balanced scale   Submit_Priorities

Resulting Priorities

Category		Priority	Rank
1	Land Use	10.9%	3
2	Temperature	13.3%	2
3	Roadway	9.3%	4
4	Air conditioning	66.5%	1

A - wrt *Adaptability* - or B?			Equal	How much more?
1	MUA	or HPSA	1	2 3 4 5 6 7 8 9

CR = 0% OK

Calculate Result | AHP | Balanced scale | Submit_Priorities

Resulting Priorities

Category		Priority	Rank
1	MUA	66.7%	1
2	HPSA	33.3%	2

A - wrt *Vulnerability* - or B?			Equal	How much more?
1	Sensitivity	or Exposure	1	2 3 4 5 6 7 8 9
2	Sensitivity	or Adaptibility	1	2 3 4 5 6 7 8 9
3	Exposure	or Adaptibility	1	2 3 4 5 6 7 8 9

CR = 5.6% OK

Calculate Result | AHP | Balanced scale | Submit_Priorities

Resulting Priorities

Category		Priority	Rank
1	Sensitivity	58.4%	1
2	Exposure	18.4%	3
3	Adaptibility	23.2%	2

Appendix B

Analytic Hierarchy Process – Sensitivity Analysis

A - wrt *Sensitivity* - or B?			Equal	How much more?
1	Race	or Income	1	2 3 4 5 6 7 8 9
2	Race	or Age	1	2 3 4 5 6 7 8 9
3	Income	or Age	1	2 3 4 5 6 7 8 9

CR = 5.6% OK

Calculate Result | AHP | Balanced scale | Submit_Priorities

Resulting Priorities

Category		Priority	Rank
1	Race	10.9%	3
2	Income	34.5%	2
3	Age	54.7%	1

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Derica Peters graduated from the University of North Texas with a Bachelor's of Arts in International Studies. In 2014, she graduated from the University of Texas at Arlington with a Master's of Arts in City and Regional Planning. Her academic accomplishments have included a wide-range of both applied and theoretical projects related to city planning. Research interests include ecosystem processes and low-impact development practices. She is currently the Planning & Development Coordinator the City of Waxahachie, where she hopes to continue to grow her portfolio and learn from a developing community.