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ANALYZING THE URBAN HEAT ISLAND EFFECT IN THE CITY OF WESTMINSTER, MARYLAND, WITH ATTENTION TO MITIGATIVE AND ADAPTIVE MEASURES

by

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Abstract

ANALYSING THE URBAN HEAT ISLAND EFFECT IN THE CITY OF WESTMINSTER, MARYLAND, WITH ATTENTION TO MITIGATIVE AND ADAPTIVE MEASURES

Andrew Raymond Gray

Urban Heat Islands (UHI) have many negative health effects on vulnerable populations in urban areas. This research investigates the UHI hazard in the City of Westminster, Maryland by documenting the UHI effect and social vulnerability of the City of Westminster.

312 near surface air temperature measurements for 17 measurement locations were analyzed to determine if there is a UHI in Westminster. Additionally, land surface temperature maps and demographic information were collected to visually determine where the highly vulnerable populations are located, in relation to the heat hazard locations in Westminster. This information indicates where UHI mitigative measures should be located to help those that are most vulnerable in Westminster.

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Chapter One: Introduction

1.1 Background

The Urban Heat Island (UHI) is the difference in temperature between more urbanized locations compared to their rural surroundings (Voogt, 2004; Memon et al., 2008; Dannenberg et al., 2011). Cities of various sizes are warmer than their rural surrounding, but the UHI is most often associated with large cities due to the dominance of urbanized, impervious surfaces compared to vegetated surfaces. Urbanized surfaces have lower albedos and lower specific heat characteristics which produce hotter surfaces. Additionally, urbanized impervious surfaces cannot regulate temperature through evapotranspiration because of the alteration to soil moisture, material heat capacity, albedo, emissivity, and higher conductivity (Deng and Wu, 2013).

Voogt (2004) identifies and discusses three categories of heat islands: surface heat island, canopy layer heat island, and boundary layer heat island (Figure 1). A surface heat island refers to the temperature of a surface. A canopy layer heat island refers to the layer of air closest to the surface. Its thickness corresponds to the mean surrounding building height. The boundary layer heat island refers to the area that extends from the canopy layer heat island to a height of 1 kilometer or more by day, shrinking to two hundred meters or less at night (Voogt, 2004).

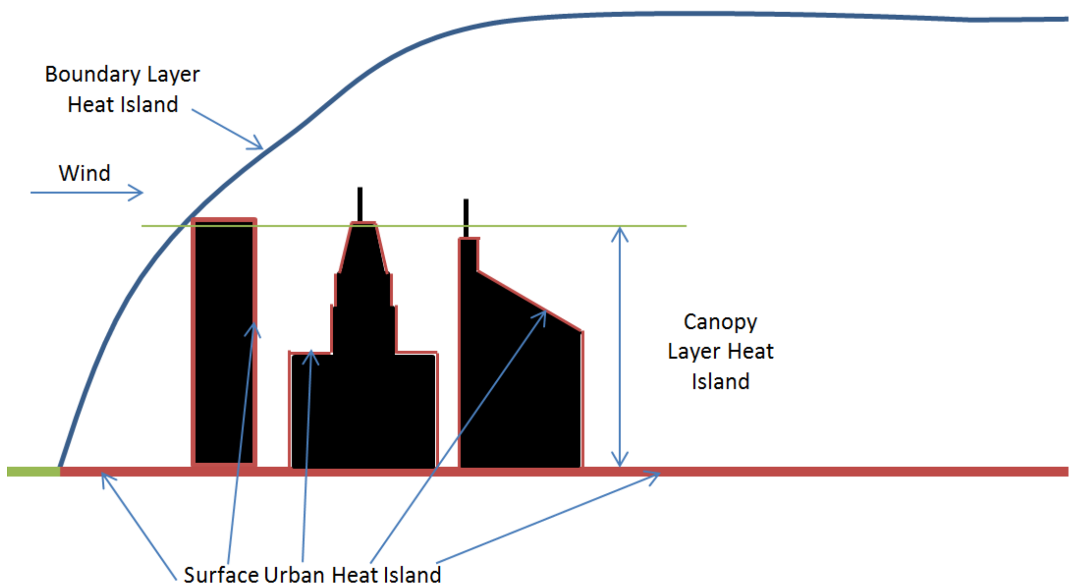


Figure 1. Locations of the Surface, Canopy, and Boundary UHI (Figure is modified from Srivanit and Hokao (2012)

Numerous studies document the UHI effect (Oke, 1976; Klysik and Fortuniak, 1999; Magee et al., 1999; Hinkel et al., 2003; Doyle and Hawkins, 2008; Yokobori and Ohta, 2009; Hart and Sailor, 2009; Grathwohl et al., 2009; and Huang et al., 2011), but most of this research focuses on large cities with more pronounced heat islands. Less attention has been given to the heat island effects of medium and smaller sized cities. Moreover, much of the research on the UHI effect utilizes only land surface temperature (LST) or air temperature measurements (Eliasson and Svensson, 2003; Weng et al., 2004; Doyle and Hawkins, 2008; Yokobori and Ohta, 2009; Huang et al., 2011; Connors et al., 2012; Ivajnsic et al., 2014; Yan et al., 2014; and Linden et al., 2015), but not both measures. Further research is needed using both LST and air temperature measurements (e.g. Unger et al. 2009); Such efforts are preferable because they provide more of a comprehensive description of the UHI by capturing how near-surface air temperature varies over different land use/cover characteristics (i.e. vegetation, grassland, and asphalt).

The UHI effect has been documented in smaller cities. Hutcheon et al. (1967) documented a heat island of up to 13° Fahrenheit in Corvallis, Oregon, a city of 21,000 in the month of January. Research conducted by Torok et al. (2001), concluded that small cities under 10,000 people exhibit a smaller UHI effect then larger cities, but such an effect is still significant. For instance, temperature in the center of Hamilton, Victoria, Australia was around 5.4° Celsius higher than the temperature in its rural surroundings; temperature in the Center of Camperdown, Victoria, Australia was 2.7° Celsius higher than the temperature in its surroundings; and the temperature in the center of Colac, Victoria, Australia was 2.8° Celsius higher than its surroundings (Torok et al.,2001). Elevated summer temperatures in the center of cities can increase the risk of heat related health effects upon exposed vulnerable populations. More research is needed to determine the health risk posed by UHIs upon highly vulnerable populations in smaller communities.

1.2 Research purpose and questions

The purposes of this study are to evaluate the UHI of Westminster, Maryland using air temperature and LST measurements and to identify where in Westminster mitigative and adaptive planning measures should be implemented to reduce extreme heat hazard upon the city’s most vulnerable residents. The results of this research will be used to inform citizens, elected officials, and planners of Westminster about the UHI and its potentially adverse effects, and possible mitigation measures.

To achieve its purposes, this thesis will address the following questions:

1. Is there a surface and canopy layer heat island present in the City of Westminster?
2. Where in Westminster are its most highly vulnerable residents located?
3. Where are highly vulnerable residents located in relation to potential extreme heat hazard locations?

Chapter Two: Literature Review

2.1 City of Westminster

The City of Westminster has a population of around 19,200 people with another 19,000 people in its immediate surroundings and is the county seat of Carroll County, located in north central Maryland (Carroll County Planning, 2018). Westminster is also the commercial hub of north and central Carroll County. As the county seat and the commercial hub of the surrounding area, many government, social, health care, entertainment, educational, hospitality, and other professional services are located throughout Westminster. Westminster also has a historic downtown and Main Street which has played a role in the Civil War. Although most studies tend to focus on the UHI of large cities, some have noted that smaller cities, such as Westminster, can have notable heat islands (Torok et al., 2001; Hinkel et al., 2003; Doyle and Hawkins, 2008). To date, no studies have documented the heat island of Westminster or evaluated the vulnerability of Westminster citizens to it.

2.2 Definition and causes of the UHI

Many studies (e.g., Klysik and Fortuniak, 1999; Gallo and Owen, 1999; Hart and Sailor, 2009; Yokobori and Ohta, 2009; Nichol et al., 2009; Huang et al., 2011) conclude that the UHI results from the alteration of natural surface characteristics. More specifically, according to Memon et al. (2008) the UHI is caused by surface energy balance changes that result from increased storage and absorption of solar radiation, decreased vegetation coverage, latent heating, and other uncontrollable variables such as synoptic weather conditions, seasons, diurnal conditions, wind speed, and cloud cover.

Memon et al. (2008) also notes that much of the UHI effect results from anthropogenic heat generated by vehicles, power plants, air conditioners, and other heat sources.

Smaller, isolated areas within cities, often located around a building, parking lot, roadway, or other urbanized surface, can create a localized area with higher temperatures referred to as micro UHI's, or hot spots (Aniello et al., 1995; Smargiassi et al., 2009). Such areas can exhibit surface temperatures as much as 10º Celsius warmer than the surrounding urban area (Smargiassi et al., 2009, 659). The causes and negative effects of hot spots are similar to the causes and negative effects of the UHI. As such, similar methods can be used for mitigation (i.e. increase vegetation and lighter colored surfaces).

2.2.1 Surface energy balance

The most obvious source of land surface and air temperature warming is from the sun. The suns energy is absorbed and transformed into sensible heat by all surfaces at different levels of intensity from sunrise to sunset (Memon et al., 2008). Urbanized impervious surfaces absorb solar radiation and generate higher temperatures due to reduced evapotranspiration, material heat capacity, soil moisture content, albedo, conductivity, and emissivity (Deng and Wu, 2013). The level of solar energy absorption depends on many factors which include cloud cover, sky view factor, and construction materials (Memon et al., 2008).

In cities, impervious surfaces dominate landscapes. According to Kalkstein et al. (2013), roofs and pavements account for up to 70 percent of all urbanized surfaces found in an average United States city. These surfaces are typically darker than the natural surfaces that they replace. The darker the surface, typically, the more energy it will absorb (i.e. lower albedo) (Kalkstein et al., 2013). Increased levels of energy absorption, coupled with other factors, such as higher conductivity, result in a higher amount of heat storage in urban surfaces (Memon et al., 2008). Additionally, for materials to remain cool and store less heat, they need to have properties that have a high visible and infrared reflectance since these two wavelengths represent 89 percent of the solar spectrum (Prado and Ferreira, 2004). Once the sun goes below the horizon, stored energy in urban surfaces is radiated into the atmosphere, warming the adjacent air (Memon et al., 2008).

Different surfaces have different specific heat properties that affect their temperature. For instance, a water surface has a specific heat of 4.18 (Cp) (kJ kg−1 K−1); asphalt has a specific heat of 0.90 (Cp) (kJ kg−1 K−1); and a rooftop has a specific heat of 1.01 (Cp) (kJ kg−1 K−1) (Nakayama and Fujita, 2010). Water has a higher specific heat capacity as compared to that of dry soil, meaning that it takes more solar energy to increase the temperature of water (Thomas and Zachariah, 2010). Determining the specific heat of soil is complicated because the specific heat is determined by soil moisture content (Sellers et al. 1996). Dry soil has a lower specific heat capacity than wet soil.

The effect of soil moisture content in an urbanized area is important in reducing surface and air temperature. In the Kajang-Cheras-Dengkil area of Malaysia, urbanized surfaces substantially increased by 135 percent from 1988 to 1999, however, due to a wet season in 1999, the UHI effect was greatly reduced because of the rainwater soaking into the ground; causing the soil to cool (Ahmad and Md Hashim, 2007). Ahmad and Md Hashim, (2007) 137, also determined that “90 percent of the heat pixels disappeared” on the LST map of the Kajang-Cheras-Dengkil area of Malaysia because of the increased soil moisture content in 1999.

Albedo refers to the solar reflectance of an object (Akbari et al., 2009). Research conducted by Morini et al. (2016), simulated increasing the albedo of walls, roofs, and roads, for an entire urban area, from an albedo of 0.2 to 0.8, which resulted in a decrease in the "urban temperature by up to 2.5º Celsius."

Emissivity "is a measure of the inherent efficiency of the surface in converting heat energy into radiant energy (Sobrino et al., 2001, 256)." Factors that determine surface emissivity include, soil moisture content, roughness and material composition and the "observation conditions (i.e., wavelength, pixel resolution, and observation angle)" (Sobrino et al., 2001, 256)." Different surfaces have different emissivity, which influences the surface energy balance.

Additionally, the amount of solar radiation that is absorbed by a surface is calculated by Wang et al. (2015) 140, as Rn = G + H + LE, where Rn "represents the arithmetic difference between the received solar radiation and the outgoing terrestrial radiation"; G represents the soil heat flux; H represents the sensible heat flux; and LE represents the latent heat flux. After the surface absorbs the solar radiation, it is radiated into the surrounding environment. The thermal radiative power is used to "assess the impact of the solar reflectance of a surface on the UHI effect (Wang et al., 2015, 140)."

Lastly, evapotranspiration influences the surface energy balance by cooling the surrounding air temperature. Evapotranspiration is the process when vegetation releases water vapor (Akbari et al., 2009). Evapotranspiration can reduce the adjacent air temperature by up to 2 to 8º Celsius (Taha, 1997). A reduction in air temperature is caused when the latent heat flux becomes very strong. Not only does the water vapor on vegetation keep its surface from heating, it can actually lower its temperature.

2.2.2 Anthropogenic heat

Anthropogenic heat, as compared to the influence of solar radiation heating, may seem small or even non-existent in the context of community-wide temperature data. Hamilton et al. (2009) concluded that "total heat emissions from buildings (anthropogenic)…during a summer day are between 0.04 and 0.4 times that of incident solar radiation, depending on built form density (Hamilton et al., 2009, 807)." However, during the winter months, anthropogenic heat can be up to 25 times greater than that of the effects of incident solar radiation (Hamilton et al., 2009). Examples of the intensity of anthropogenic heat are documented by Magee et al. (1999) and Hinkel et al. (2003), who identified UHIs in Fairbanks and Barrow, Alaska, respectively, in the winter months when solar influence would have less of an effect on temperature due to the shorter length or total absence of solar influence. This can be compared to areas located in the conterminous United States, which are closer to the equator and have longer lengths of solar influence per day in the winter. Shorter periods of solar influence enable researchers to isolate the UHI effect to anthropogenic heating.

2.2.3 Urban form and the UHI

A city's urban form is important in the creation of the UHI and the Micro UHI because a city's urban form refers to the physical land uses that are the city itself (streets, buildings, forest land, parks, and streams). A study by Stone et al. (2010), discussed how urban form has contributed to the increased number of heat events in sprawling metropolitan areas as compared to more compact metropolitan areas. The main reason for increased heat events is the loss of vegetation. When the urban form changes from more vegetative to more urbanized, the physical surface cannot regulate temperature as well, causing the temperature to rise.

Larger city centers, in addition to having vast amounts of urbanized surfaces at ground level, typically have urbanized surfaces extending upwards several hundred feet in the air. Taller buildings, in conjunction with urbanized surfaces at ground level, absorb and store more solar energy. These tall buildings grouped together create what is known as “urban canyons” which take even longer to cool (Akbari et al., 2009, 7). Such urban canyons further increase the UHI effect by reducing the flow of air that removes hot air from between these large vertical urban surfaces (Akbari et al., 2009).

2.3 Ways to identify the UHI

According to the U.S. Environmental Protection Agency (USEPA, 2018), there are two ways to identify the existence of a UHI: (1) measuring air temperature; and (2) measuring land surface temperature. Measuring the air temperature of the urban canopy layer is a better way to identify areas that may cause risks to human health and safety because it identifies the temperature that is experienced by people (USEPA, 2018). To capture the spatial variability of a UHI, however, air temperature measurements must be scattered throughout an urban area and/or a considerable amount of time must be spent to consistently transect the study area by vehicle. Doyle and Hawkins (2008) used fixed temperature sensors to collect hourly air temperature measurements from May to September. This temperature collection technique provides many accurate samples but would be expensive and require permission to locate the thermometers on private and/or public property. Another method would be collecting temperature measurements at different sites by commuting to each measurement location. For example, Oke, (1976), used automobile traverses to collect temperature measurements; Brandsma and Wolters (2012) used bicycles to collect temperature measurements; and Yokobori and Ohta, (2009) used a motorbike.

Measuring the land surface temperature better captures the spatial variability of the UHI. Land surface temperature refers to the temperature of a surface and is measured by special thermal imaging instruments fixed to satellites and airplanes (USEPA, 2018). Land surface temperature measurements are ideal for mapping large geographic areas but sometimes cannot accurately map details such as hot spots within neighborhoods if the spatial resolution is too coarse. Huang et al. (2011) studied the LST in the Gwynns Falls watershed, in the State of Maryland, which included 298 census block groups, to determine correlations between social variables and the UHI effect. Johnson and Wilson (2009) examined the UHI of Philadelphia, Pennsylvania to study where vulnerable populations were located in relation to the increased estimated LST and heat related fatalities in 1993.

2.4 Where have UHI's been reported

Past studies have observed the UHI effect in numerous cities in various biomes and climate types (Imhoff et al., 2010). The following is a sample of cities in which the UHI has been reported: Vancouver, Canada (Oke, 1976), Lodz, Poland (Klysik and Fortuniak, 1999), Fairbanks, Alaska (Magee et al., 1999), Barrow, Alaska (Hinkel et al., 2003), Shippensburg, Pennsylvania (Doyle and Hawkins, 2008) Tokyo, Japan (Yokobori and Ohta, 2009), Portland, Oregon (Hart and Sailor, 2009), Boonville, Missouri (Grathwohl et al., 2009), and Baltimore, Maryland (Huang et al., 2011). The body of studies that documents UHIs illustrates that they vary geographically with such factors as latitude, population, and regional climate.

Latitude has a major effect on the location and intensity of the UHI. Urban areas located in lower latitudes have a UHI influenced by both solar and anthropogenic sources. Urban areas located in higher latitudes have a larger influence from anthropogenic heating sources in the winter as compared to the summer, due to the shorter amount of solar influence and increased space-heating needs (Hinkel et al., 2003). The UHI effect is relatively weak in the summer months in higher latitudes, as compared to lower latitudes (Hinkel et al., 2003). Overall, the UHI effect tends to have a greater impact on higher latitudes than lower latitudes (Wienert and Kuttler, 2001).

Areas with higher population density generally exhibit a higher UHI, however, industrial areas within the city that typically have fewer residents are some of the hottest areas because they contain more urbanized land surfaces. Lu and Weng (2006) mentioned that impervious surfaces were highest in commercial areas and decreased as land became more residential. Imhoff et al. (2010), mentions that locations with larger impervious surface areas are correlated to higher surface temperatures. Combining the information gathered from Lu and Weng (2006) and Imhoff et al. (2010), would suggest commercial areas would consist of some of the hottest temperatures in an urban area.

Smaller cities can also be affected by the UHI effect, sometimes more than larger cities. Oke (1973) mentioned that the UHI effect associated with an individual heat source has a smaller affect in larger cities than smaller ones. It should be noted that the amount of total heat energy that urban surfaces can physically absorb, store, and re-radiate, and the potential for pressure gradient forces that would occur with differences in air temperature, increase the circulation of air thereby minimizing the urban/rural temperature difference (Oke, 1973).

The UHI has been observed in many cities smaller than Westminster. For example, Torok et al. (2001), observed the UHI effect in the Australian cities of Hamilton, Camperdown, and Colac with populations below 10,000. Doyle and Hawkins (2008) observed a UHI effect in Shippensburg, Pennsylvania, a small city with a population of about 5,600. Hinkel et al. (2003) observed the UHI effect in Barrow, Alaska, with a population of about 4,600. All five of these cities are less than half the size of Westminster.

The intensity of the UHI effect can be drastic between an urban core and surrounding rural areas in different climates. When an urban area is surrounded by mostly forest, the surrounding rural area will be much cooler than the urban core (Imhoff et al., 2010). However, in an arid climate, the UHI intensity between the surrounding rural area and the urban core is not as extreme due to lack of vegetation in the rural surroundings (Imhoff et al., 2010). For example, Baltimore has an urban core much warmer than its surroundings as compared to Las Vegas which has an urban core cooler than some of its rural surroundings (Imhoff et al., 2010). Baltimore would exhibit a UHI as compared to a possible Urban Heat Sink exhibited in Las Vegas (Imhoff et al.,2010). An Urban heat sink occurs when the urban core is cooler than the surrounding rural area (Imhoff et al.,2010). In summary, urban areas that experience the greatest UHI intensity between their rural surroundings and their urban core are influenced by what type of biome they are located in. Urban areas located in biomes with less vegetation will have less temperature difference between their rural surroundings and their urban core (Imhoff et al., 2010).

2.5 Negative effects of the UHI

The UHI has many negative effects on both the natural and human world. In Austin, Texas, the hotter temperatures in the months from April to October increase ground-level ozone, leading to higher levels of air pollution (City of Austin Heat Island Risks, 2016). Higher temperatures coupled with air pollution can cause assorted medical problems, such as respiratory problems, exhaustion, heat stroke, and even death (Dannenberg et al., 2011; Kenward, 2014; City of Austin Heat Island Risks, 2016).

On average, 1,000 people die every year in the U.S. from extreme heat (Reyes and Rosen, 2007). UHIs intensify and lengthen heat waves during summer months (Reyes and Rosen, 2007) contributing to increased morbidity and mortality among vulnerable groups. Kenward et al. (2014) 2, studied 60 cities since 2004 and concluded that there were, "12 cities that have averaged at least 20 more days a year above 90º Fahrenheit" than their nearby rural surroundings. This is important because "days over 90º Fahrenheit, are associated with dangerous ozone pollution levels that can trigger asthma attacks, heart attacks, and other serious health impacts (Kenward et al., 2014, 1)." Moreover, Kenward et al. notes that "single-day urban temperatures in some metro areas were as much as 27º Fahrenheit higher than their surrounding rural areas (2014, 1)." Extreme heat increases the burden on human health and public services and can lead to an increase in the number of unhealthy days.

An example of a serious health and social breakdown caused by extreme heat is highlighted in *Heat Wave* by Eric Klinenberg (2002). Klinenberg explores the heat wave of July 1995 in Chicago, IL that lasted over a week and caused over 700 fatalities (Klinenberg, 2002). Heat waves can affect sizeable areas and large numbers of people, for example, a heat wave in Europe during the summer of 2003 is linked to the death of 50,000 people (Mirzaei and Haghighat, 2010).

In addition to the negative consequences to human life, the UHI can be harmful to aquatic life as a result of warmer storm water runoff flowing from warm, urbanized surfaces that ultimately flow into bodies of water that aquatic life rely on. The negative effects on the aquatic life in these bodies of water includes affecting their metabolism and reproduction rates, indicating increased stress, which will ultimately lead to death of such aquatic life (USEPA, 2016).

Indirectly, the UHI effect increases electric demand due to increased use of air conditioning, which leads to more air pollution (City of Austin Heat Island Risks, 2018). As a result of more air pollution and anthropogenic heat released into the atmosphere, even more electricity continues to be used for air conditioning, which exacerbates this unsustainable cycle. Akbari et al. (2009) mentioned that the estimated increase in yearly energy costs caused by the UHI effect in Washington D.C. alone approaches nearly $50 million.

2.5.1 Social vulnerability to extreme heat

Not all people are as susceptible to harm from heat stress associated with UHIs. The elderly has a harder time coping with temperature extremes than younger people. A study by D'Ippoliti et al. (2010) discovered that there is a measurable increase in the morality rate in a city’s population that is over 65 years of age during heat wave events. The study revealed that the percentage of the increased mortality during such events can be up to 33.6 % higher than average daily mortality rates (D'Ippoliti et al., 2010). Garssen et al. (2005) also observed an increase in the morality rate in the population over 65 years of age during periods with hotter average temperatures. Older adults are more susceptible to extreme heat due to physiological, socio-economic status, illness, and disability (Morabito et al., 2015).

According to the Centers for Disease Control and Prevention, children under four years old are also susceptible to heat related negative health effects. Children's capacity to perspire is more limited than adults, and are therefore less efficient in regulating their body temperatures. This leads to greater risk of dehydration (Anderson et al., 2000; Kovats and Hajat, 2008). Anderson et al. (2000) found that children's bodies heat up and cool down quicker due to their smaller body mass.

The homeless population tends to live in areas where public services are more readily available and the UHI is more intense as a result of the surrounding urbanized land uses. During the 2006 Phoenix, Arizona heat wave, 11 of the 13 heat stroke deaths were attributed to the homeless (Kovats and Hajat, 2008). The homeless are extremely vulnerable to extreme heat because the risk factors for heat related mortality "correlate closely with the characteristics of homeless individuals (Ramin and Svoboda, 2009, 655)." These risk factors include older age, living alone, social isolation, absence of air conditioning, and alcoholism, (Ramin and Svoboda, 2009).

Strong heat/mortality relationships were associated with the population that had less than a high school education level (Harlan et al., 2013). The lack of air conditioning was strongly linked with lower educational attainment and vulnerability to heat effects (Harlan et al., 2013). Additionally, Harlan et al. (2006) concluded that neighborhoods with lower educational attainment were more susceptible to heat stress. Heat stress on the human body can be mitigated by access to proper climate control.

People with lower incomes have a harder time affording amenities such as reliable central air conditioning which can lead to an increase in heat related mortality rates in the summer. A study conducted by Smoyer et al. (2000), concluded that the cost of living was a factor influencing mortality rates among elderly people since people who have more disposable income are able to afford conveniences, such as air conditioning, to avoid negative health risks associated with higher temperatures. Additionally, the lower income population is indirectly affected by heat waves due to heath factors such as mental illness, obesity, and/or inferior housing which all affect the mortality rate (Kovats and Hajat, 2008).

2.6 Ways to mitigate the UHI

Several studies have proposed ways to mitigate the UHI effect. The two most popular ways to mitigate the UHI effect are to (1) increase the surface albedo and (2) increase urban vegetation (Taha, 1997; Rosenfeld et al., 1997; Solecki et al., 2005; Akbari, 2009).

The albedo of structures can be increased by painting them white. This cultural adaptation to extreme heat has been practiced for centuries in hot climate regions to keep outdoor and indoor temperatures as low as possible (Akbari et al., 2009). In fact, simulations predict that a typical home air conditioning bill could be reduced by over 20% if the albedo of a home’s exterior increased from 0.2 to 0.6 (Akbari et al., 2009, xxiii). This represents a substantial increase in energy savings.

Increasing the amount of vegetation in urban areas helps reduce UHI effects. For example, shading reduces surface temperatures by up to 45° Fahrenheit over unshaded surfaces (USEPA, 2016A). Ca et al. (1988) concluded that air temperature in a 0.6 km^2 park surrounded by commercial and urban land uses was more than 2° Celsius cooler, at noon, than surrounding urban land uses. In fact, such a park reduces the air temperature as much as 1.5° Celsius in a commercial area located 1 km downwind. This example demonstrates the cooling power of an urban park and how effective its associated vegetation is on the surrounding urban environment.

Chapter Three: Data and Methods

3.1 Introduction

The following data and methods section will be organized by each of the three research questions:

1. Is there a surface and canopy layer heat island present in the City of Westminster?
2. Where in Westminster are its most highly vulnerable residents located?
3. Where are highly vulnerable residents located in relation to potential extreme heat hazard locations?

3.2 Question #1 - Is there a surface and canopy layer heat island present in the City of Westminster?

3.2.1 Data

To answer this question, air temperature measurements were obtained through field measurements and land surface temperature was derived from satellite imagery. Air temperature measurements of the canopy layer heat island were taken and recorded at 17 locations in and around the City of Westminster, roughly seven and one-half feet off the surface (figure 2, and figure 3). Data were collected between June 1, 2016 and August 28, 2016, roughly twice a week, over 19 days. These locations were determined by approximating certain locations with diverse land use and land cover characteristics along an easily accessible route throughout Westminster. This route is identified in (figure 4). Sampling locations were assessed for accessibility and safety. Table 1 summarizes the land use/land cover classification for each measurement site and Appendix A contains pictures and detailed descriptions of the 17 sample sites.

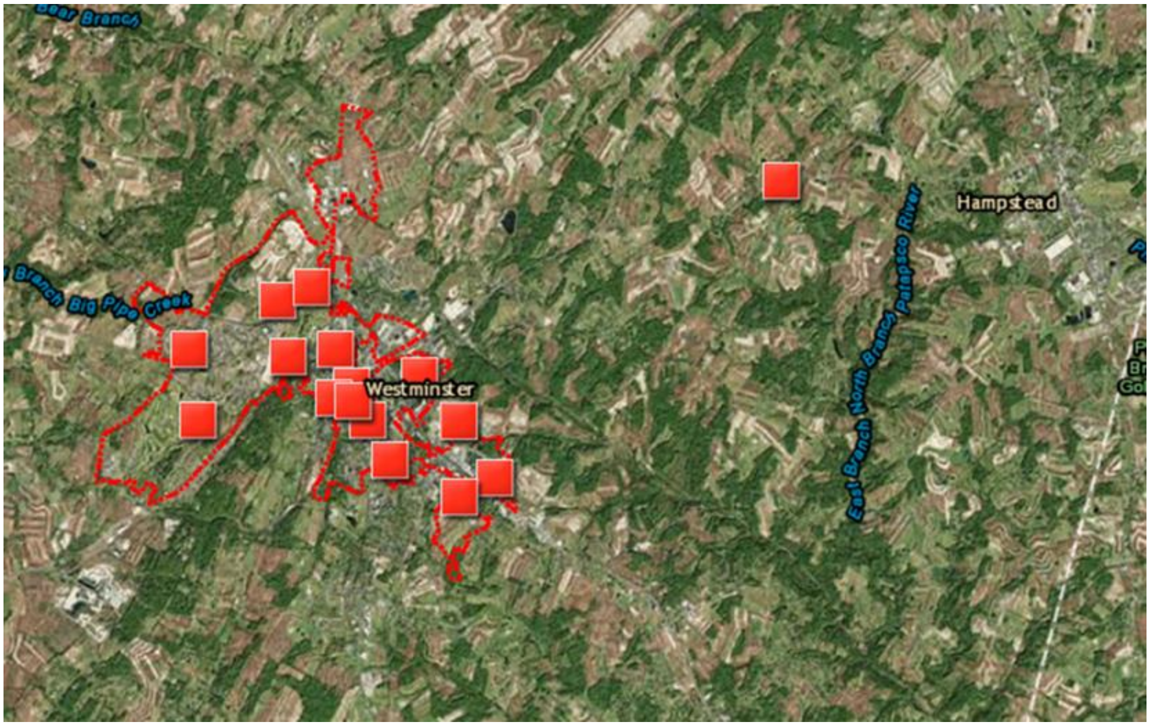


Figure 2. All temperature Measurement Locations

Figure 3. Temperature Measurement Locations in the Westminster Area

Figure 4. Temperature Measurement Collection Route

Table 1. Land Use/Land Cover Classification for each Measurement Site

Measurement Locations by Levels of Development		
Less Developed	Medium Developed	More Developed
Tohoma Farm Road	Wyndtryst Drive and Lower Field	City Parking Lot
Center Street at High Acre Drive	Meadow Creek Drive	Dutterer Way and PA Ave
Maryland 482	Royer Road	Pleasanton Road
	Willow Street	Belle Grove Square
	Market Street	Longwell Lot
		Locust and Main
		Main West of Center
		Green Street
		Town Mall Lot

The air temperature data were collected using a SM-28 SKYMASTER Manual V 4.05, WeatherHawk hand-held thermometer. At each location, the temperature was not recorded until the reading on the thermometer stabilized, in order to determine the average temperature to the tenth of a degree. Each date, location, and temperature were recorded and organized in tables in Appendix B.

Land surface temperature maps of Westminster and the surrounding area were obtained from Maryland View (Figure 5). Maps of the Normalized Difference Vegetation Index (NDVI) were also obtained to represent urban and natural land cover (Figure 6). Please refer to Appendix C for more information on how these maps were generated.

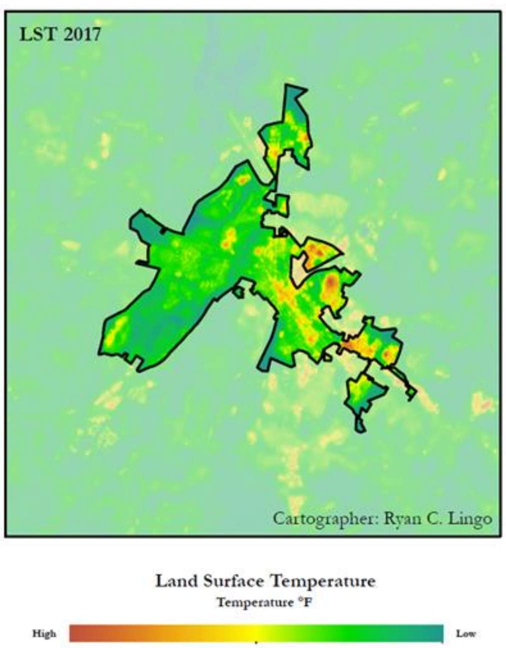


Figure 5. LST Map of the City

Figure 6. NDVI Map of the City

3.2.2 Methods

312 air temperature measurements were collected from June 1, 2016, to August 28, 2016, at 17 measurement locations in and around Westminster. Air temperature measurements were collected roughly twice a week (19 days) and each measurement location was classified by its land use. Land use classifications were assigned a number in order to run statistical analysis. Less developed land uses locations were assigned a value of one; medium developed land uses locations were assigned a value of two; and more developed land uses locations were assigned a value of three. These locations were assigned their value by analyzing the surrounding impervious vs. pervious land uses. Locations that are dominated by impervious land uses were assigned a value of three (High). Locations that are more suburban (i.e. single-family dwellings) were assigned a value of two (Medium). The Market Street location was assigned a value of two and not a three because there is a large farm field located directly adjacent to the Kohl's parking lot. Lastly, largely pervious locations were assigned a value of one (Low).

Descriptive statistics were used to describe the central tendency, variability, skewness, and kurtosis of air temperature measurements within each of the land use/land cover groups. Furthermore, the Kruskal-Wallis test was used to determine if differences between air temperatures are statistically significant at the 0.05 significance level (α) (McGrew et al., 2014). Choice of test was determined by the normality of the data, which was assessed with the Shapiro Wilk test. Given the relatively small sample of air temperature measurements used, bootstrapping was also used (10,000 resamples) when estimating the *p*-value of the Kruskal-Wallis test.

Land surface temperature maps were used to visually identify where the hottest locations are in and around Westminster. Areas that exhibit hotter LST will be identified along with several sample locations of cooler LST for comparison.

3.3 Question #2 - Where in Westminster are its most highly vulnerable residents located?

3.3.1 Data

The potential highly vulnerable locations were assessed by collecting data from the 2017 American Community Survey (ACS), at the block group level. These data were collected for the 22 block groups located in and adjacent to Westminster. All .CSV files obtained from the Census Bureau, American Fact Finder, were converted into Excel files. All final data were imported into one Excel document and converted by ArcMap into one table. This table was joined with the block group shapefile, for *2017*, *State of Maryland*.

The demographic information reviewed at each block group included population over 65, population under five years old, poverty status of individuals in the past year by living arrangement, educational attainment for the population over 25 years old, and per capita income in the past year.

3.3.2 Methods

Demographic block group data were analyzed using GIS software to determine the locations with the highest percentage of the population over 65 years old, the highest percentage of the population under five years old, the highest percentage of the population below poverty level, the lowest percentage of educational attainment, and the lowest income level. This information was used to determine where the most highly vulnerable block groups are located in and around Westminster. The block groups were not only labeled with the raw data number; they were also assigned a color based on the vulnerability. Red block groups contain the most vulnerable populations and the green block groups contain the least vulnerable populations. This makes it easier to visually analyze the vulnerability data. (United States Census, 2019)

3.4 Question #3 - Where are highly vulnerable residents located in relation to potential extreme heat hazard locations?

3.4.1 Data

This question will be evaluated by comparing data obtained from the land surface temperature map from question #1 with the GIS maps of the locations maps of social vulnerability based on the demographic variables selected to address question #2.

3.4.2 Methods

Data are used to explore the LST and social vulnerability landscape in Westminster by identifying locations that have the hottest LST and the highest social vulnerability. Locations are grouped into four categories: 1. Higher Temperatures and Low Social Vulnerability, 2. Higher Temperatures and High Social Vulnerability, 3. Lower Temperatures and Low Social Vulnerability, and 4. Lower Temperatures and High Social Vulnerability. Such information will provide a basic understating of the priority locations in Westminster to implement best planning UHI mitigation measures. Please note that “Social-vulnerability” is the product of social inequalities (i.e. income, education, age) and geographic inequalities such as the level of development (Cutter et al. 2003; Brooks, 2003).

Chapter Four: Results

4.1 Question #1 - Is there a surface and canopy layer heat island present in the City of Westminster?

4.1.1 Canopy Layer Heat Island

Table 2 presents the descriptive statistics of air temperature for each of the land use classes. The less developed land uses, exhibit the lowest mean, median, and maximum air temperatures. The less developed land uses, and the more developed land uses on average are tied having the lowest interquartile range. The medium developed land uses, on average, exhibit the highest mean, median, standard deviation, and minimum air temperatures. They also exhibit the highest interquartile range, the lowest skewness, and lowest kurtosis. The more developed land uses, on average, exhibit the lowest standard deviation, minimum air temperature and are tied with the less developed land uses with the lowest interquartile range. The highest maximum air temperature, skewness, and kurtosis are also present in the more developed land uses.

Table 2. Descriptive Statistics Results

Descriptive Statistic Test Results			
	Less Developed	Medium Developed	More Developed
Mean	88.093	89.403	88.094
Median	87.750	88.800	88.200
Standard Deviation	6.5822	7.1715	6.5564
Minimum	68.5	69.4	67.6
Maximum	100.2	102.2	104.0
Interquartile Range	8.6	10.9	8.6
Skewness	-0.483	-0.383	-0.569
Kurtosis	0.752	-0.022	1.081

Table 3 presents the results of the Kruskal-Wallis test. The *p*-value is greater than 0.05, meaning that the null hypothesis is not rejected, and that there is not a significant difference in air temperature between the three land-use classes.

Table 3. Kruskal-Wallis Test Results

Kruskal-Wallis Test Results		
Land Use Classification	Number of Measurements	Mean Rank
Less Developed (LOW)	46	150.17
Medium Developed (MEDIUM	95	168.05
More Developed (HIGH)	171	151.78
Total	312	
Kruskal-Wallis: $X^2 = 2.25$, $df = 2$, $p = 0.32$		

4.1.2 Surface heat island

The surface heat island in Westminster is evident in the more intense commercial and industrial land uses. According to the City of Westminster 2009 Comprehensive Plan, many land use designations are provided for in Westminster. There are three main locations in Westminster that mainly consist of business and commercial land uses (City of Westminster, 2009). These three locations are: Downtown Westminster, along Maryland State Route 140 (Baltimore Boulevard), and along Maryland State Route 97 (Littlestown Pike) (City of Westminster, 2009). Several other business and commercial locations with high LST are located outside these areas and are discussed below.

The land surface temperature maps visually indicate an increased LST in defined locations mainly in Downtown Westminster, and in certain commercial and industrial locations along Maryland Route 140 and Maryland Route 97. Please see Appendix D and E indicating the hottest and coolest LST areas in and around Westminster and their corresponding number identified in figure 7 and figure 8. Several locations with lower surface temperature are identified in Appendix D and E.

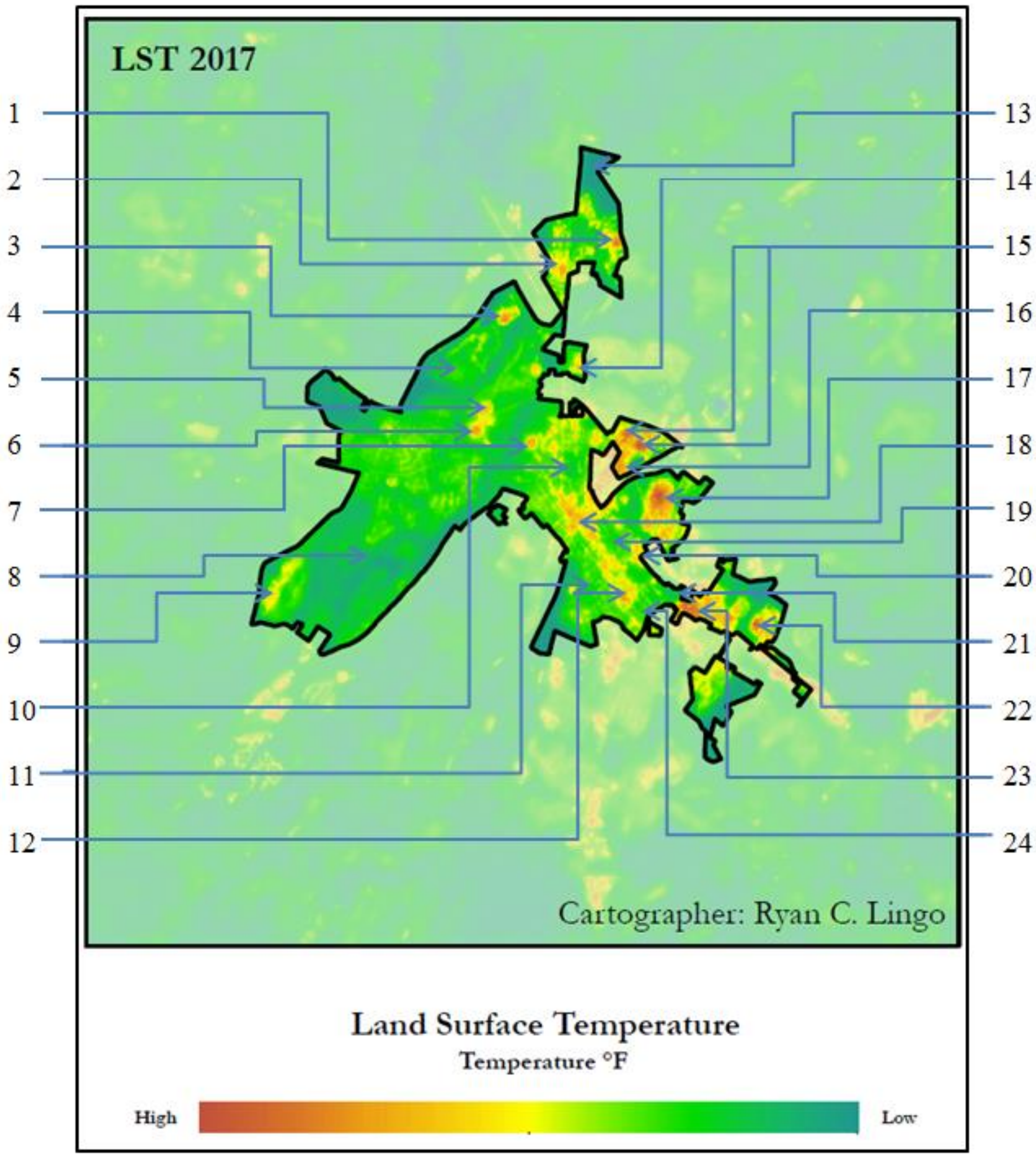


Figure 7. Map of Select LST Locations Inside City Limits. The lowest LST temperature has been identified as 80.35º Fahrenheit and the highest LST temperature has been identified as 111.55º Fahrenheit on this map.

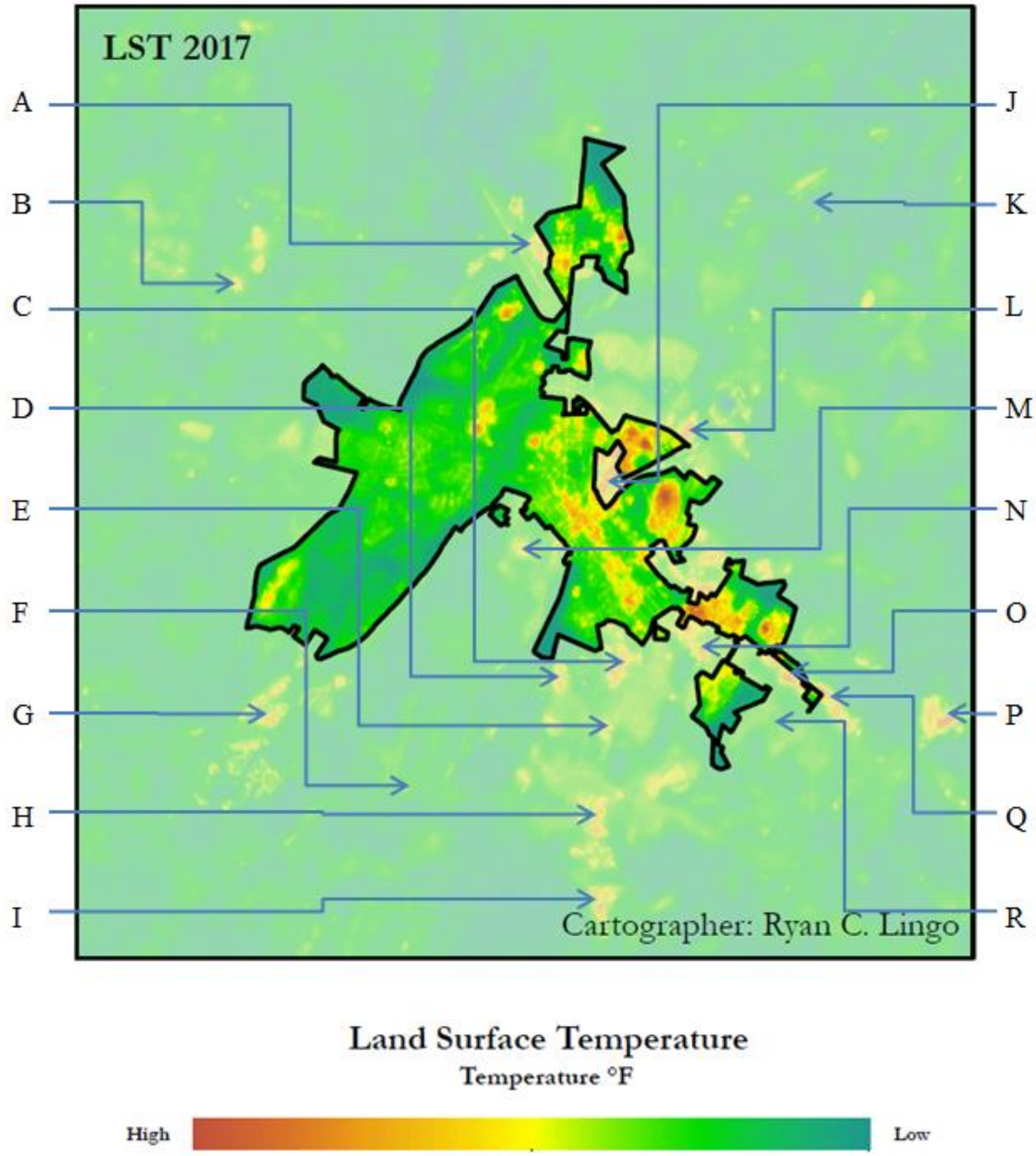


Figure 8. Map of Select LST Locations Outside Westminster City Limits.

The lowest LST temperature has been identified as 80.35° Fahrenheit and the highest LST temperature has been identified as 111.55° Fahrenheit on this map.

4.2 Question #2 - where in Westminster are its most highly vulnerable residents located?

Figure 9 illustrates the GEOID numbers for each of the block groups analyzed in and around Westminster. Select demographic data was collected at the block group level from the 2017 ACS for the State of Maryland in order to analyze where the most highly vulnerable locations are in Westminster for the following: highest percentage of children under five years old; highest percentage of the population over 65 years old; highest percentage of the population below poverty; income (per capita income in past 12 months); and highest percentage of the population with less than a high school diploma (Appendix F).

4.2.1 Highest percentage of children under five years old

The area in and around Westminster with the highest percentage (14%) of children under the age of five years old is located in the downtown area of Westminster. This area is bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27. The second highest area in and around Westminster with the highest percentage (11%) of children under age five is located outside Westminster to the northeast. The third highest percentage (10%) of children under age five is located south of the central core of downtown, extending out to include the Carroll County Agricultural Center. Please see figure 10 for more information.

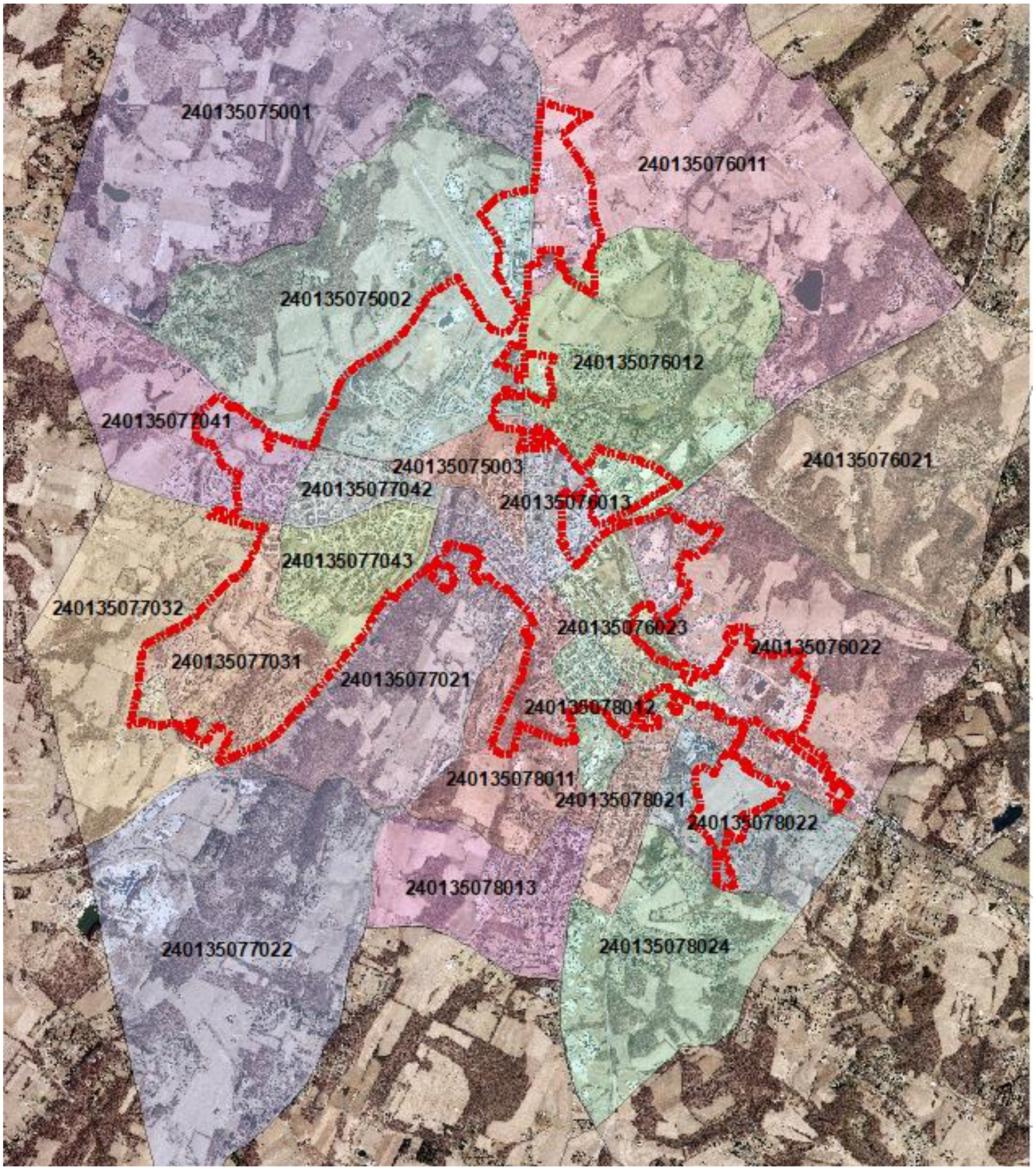


Figure 9. Map of Block Groups in and Around the City

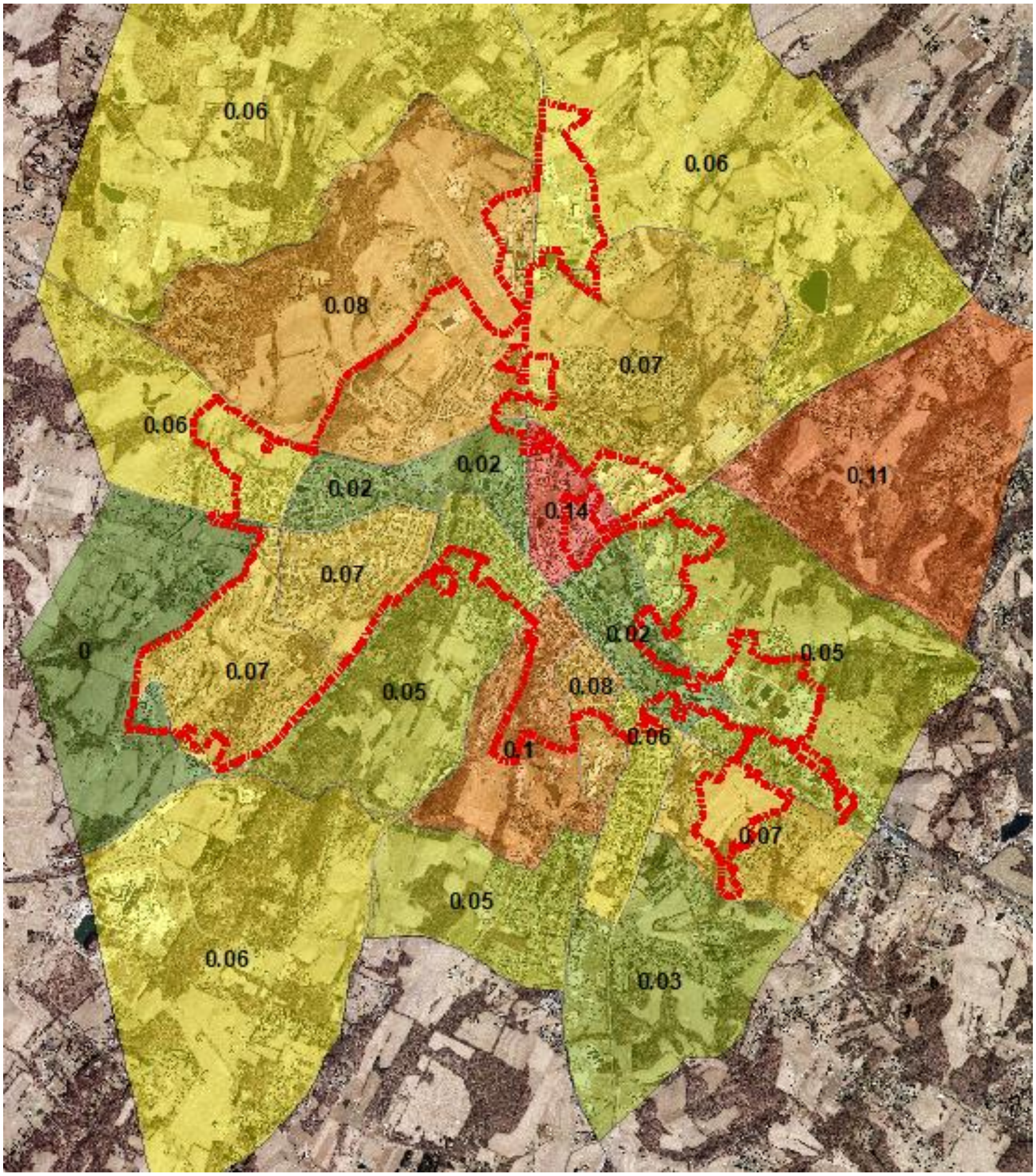


Figure 10. Percent of Population Under Five Years Old. Block Groups labeled in Percentage (i.e. 0.14 is 14% of the population under five years old)

4.2.2 Highest percentage of the population over 65 years old

The highest percentage (57%) of the population over 65 years of age is located outside of Westminster. However, there is a small area in Westminster which includes Carroll Lutheran Village, a retirement community. The second highest percentage (25%) of the population over 65 years old is located outside Westminster, southeast of downtown to Little Pike Creek. This area is bordered by New Windsor Road, Little Pike Creek, Maryland 27, and West Main Street. This block group includes Sunnybrook Senior Apartments. The block groups bordered by Gist Road, Washington Road, East Main Street and Center Street and encompasses the campus of Carroll Hospital Center and the Westminster Senior Center also have a sizable percentage of elderly (23%). This area encompasses the campuses of Carroll Community College, Westminster Senior High School, and Carroll County Career and Technology Center. Please see figure 11 for more information.

4.2.3 Highest percentage of the population below poverty

The highest concentration of individuals living below the poverty level percentage (58%) is in the downtown area of Westminster. This area is bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27. Another poverty cluster (33%) is located downtown, bordered by West Main Street, Maryland 140, and Pennsylvania Avenue. A smaller poverty cluster (12%) is located in downtown, bordered by East Main Street, Maryland 27, Maryland 140, and Maryland 97.

Please see figure 12 for more information.

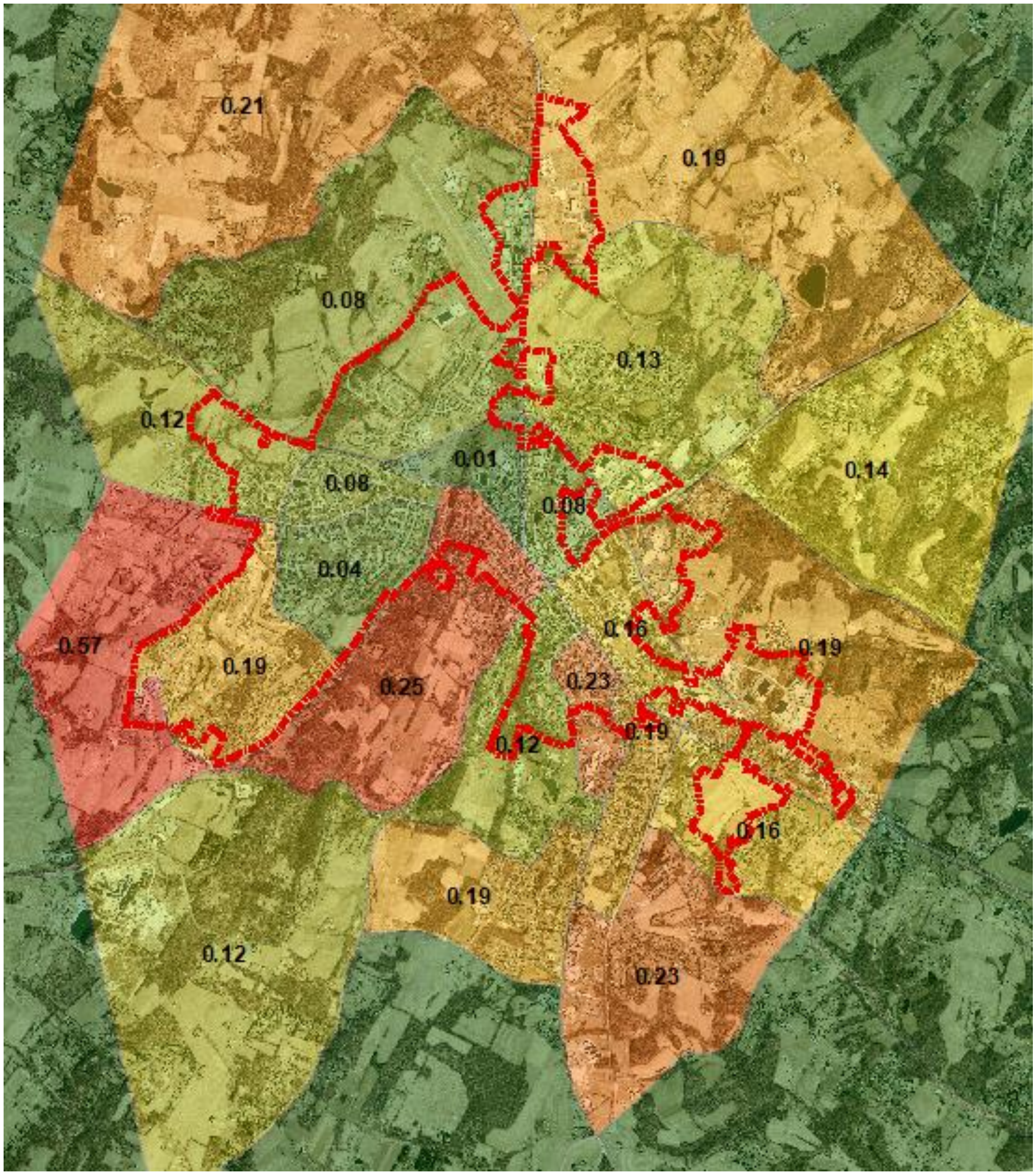


Figure 11. Percent of Population Over 65 Years Old. Block Groups labeled in Percentage (i.e. 0.57 is 57% of the population over 65 years old)

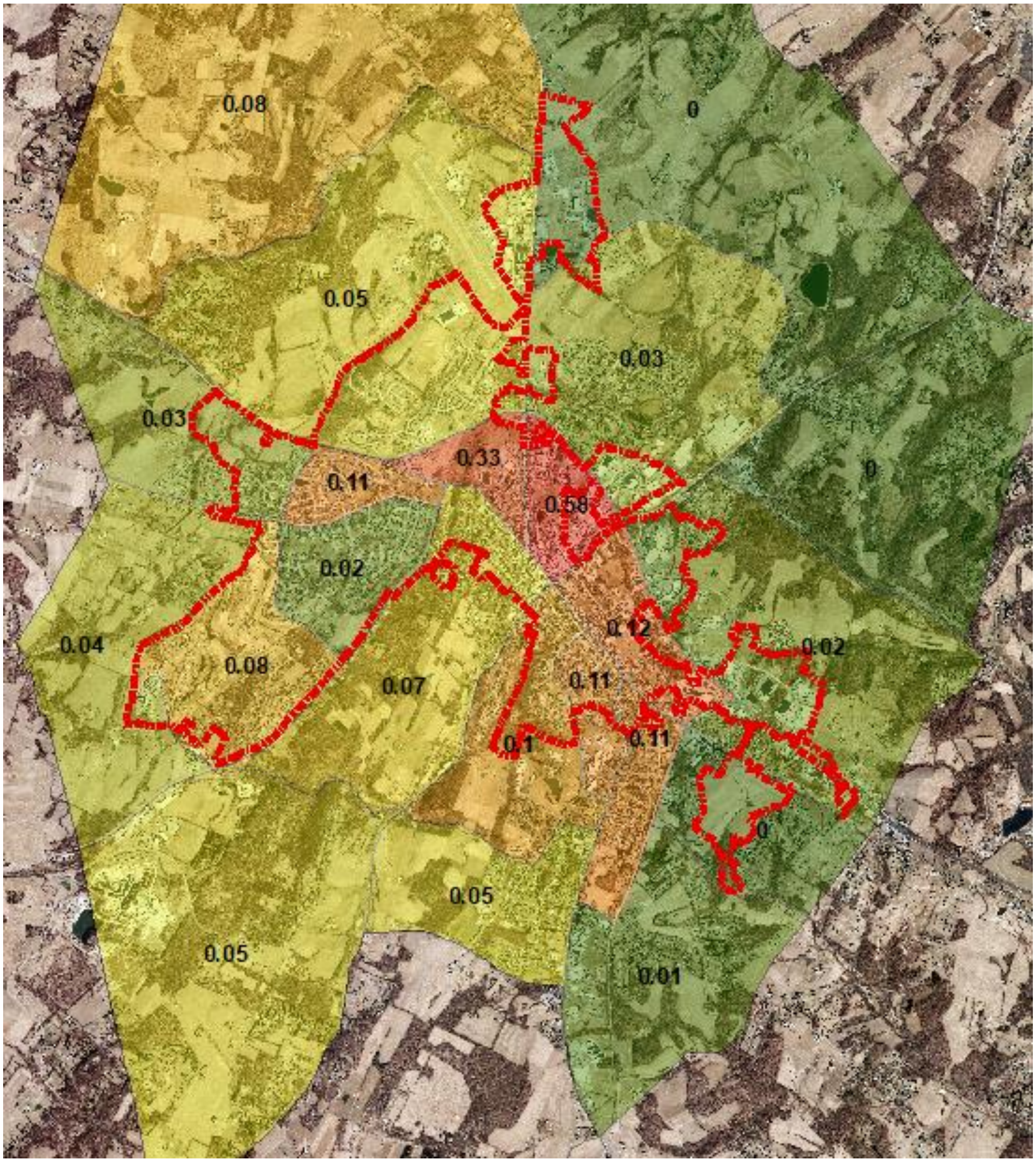


Figure 12. Percent of Population Below Poverty Level. Block Groups labeled in Percentage (i.e. 0.58 is 58% of the population below the poverty level)

4.2.4 Income (per capita income in past 12 months)

The lowest income ($5,637) block group is located downtown. This area is bordered by West Main Street, Maryland 140, and Pennsylvania Avenue. Other lower income block groups, ($11,923) and $16,460 respectively, are located downtown. Please see figure 13 for more information.

4.2.5 Highest percentage of the population with less than a high school diploma

The block group the highest percentage (33%) of the population over 25 years old without a high school diploma is located downtown, in an area bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27. The next two block groups with a significant percentage of persons over 25 without high school diplomas, 30% and 28%, are located downtown, and are spatially contiguous to the block group with the highest percentage. Please see figure 14 for more information.

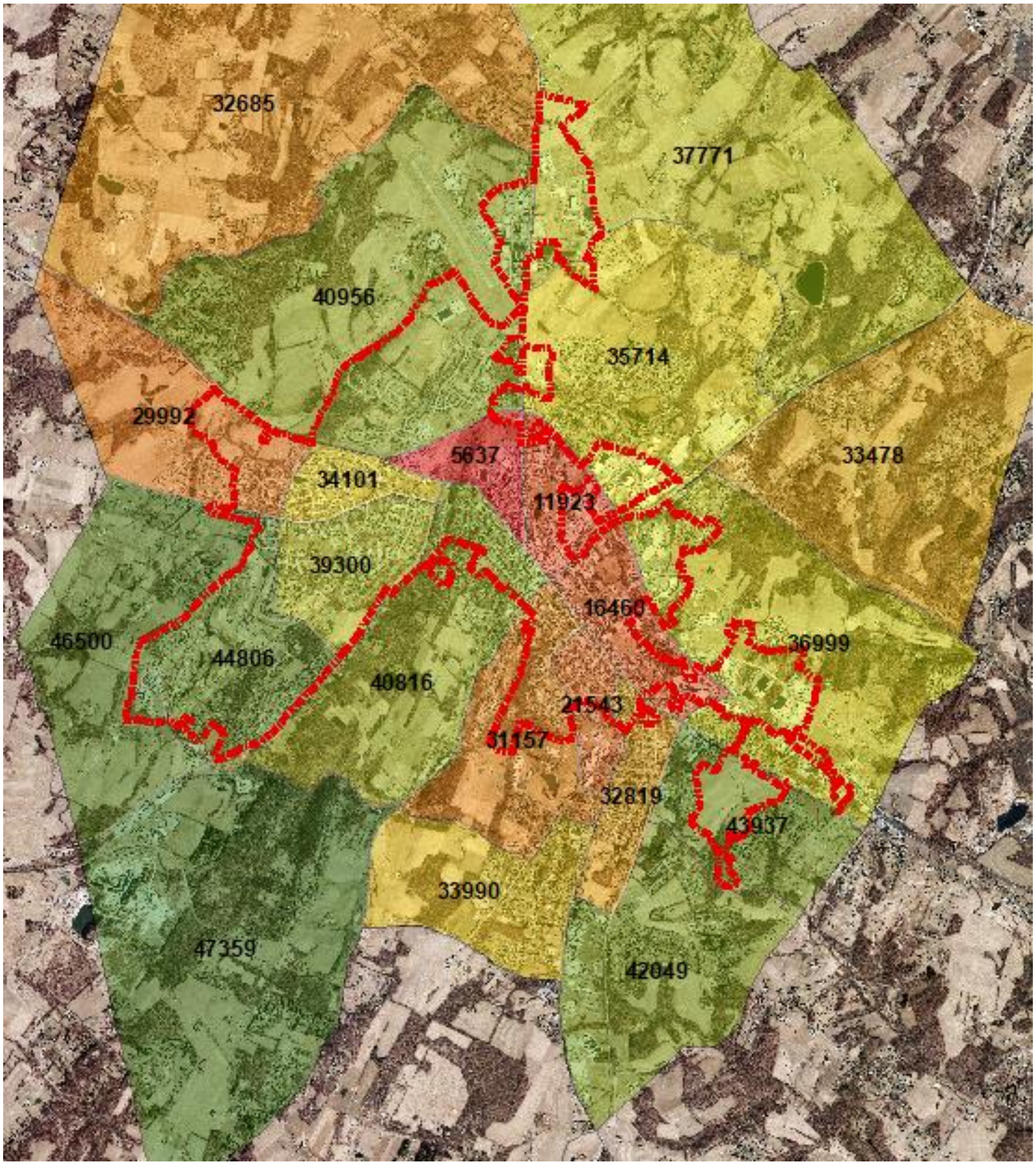


Figure 13. Per Capita Income in Past 12 Months

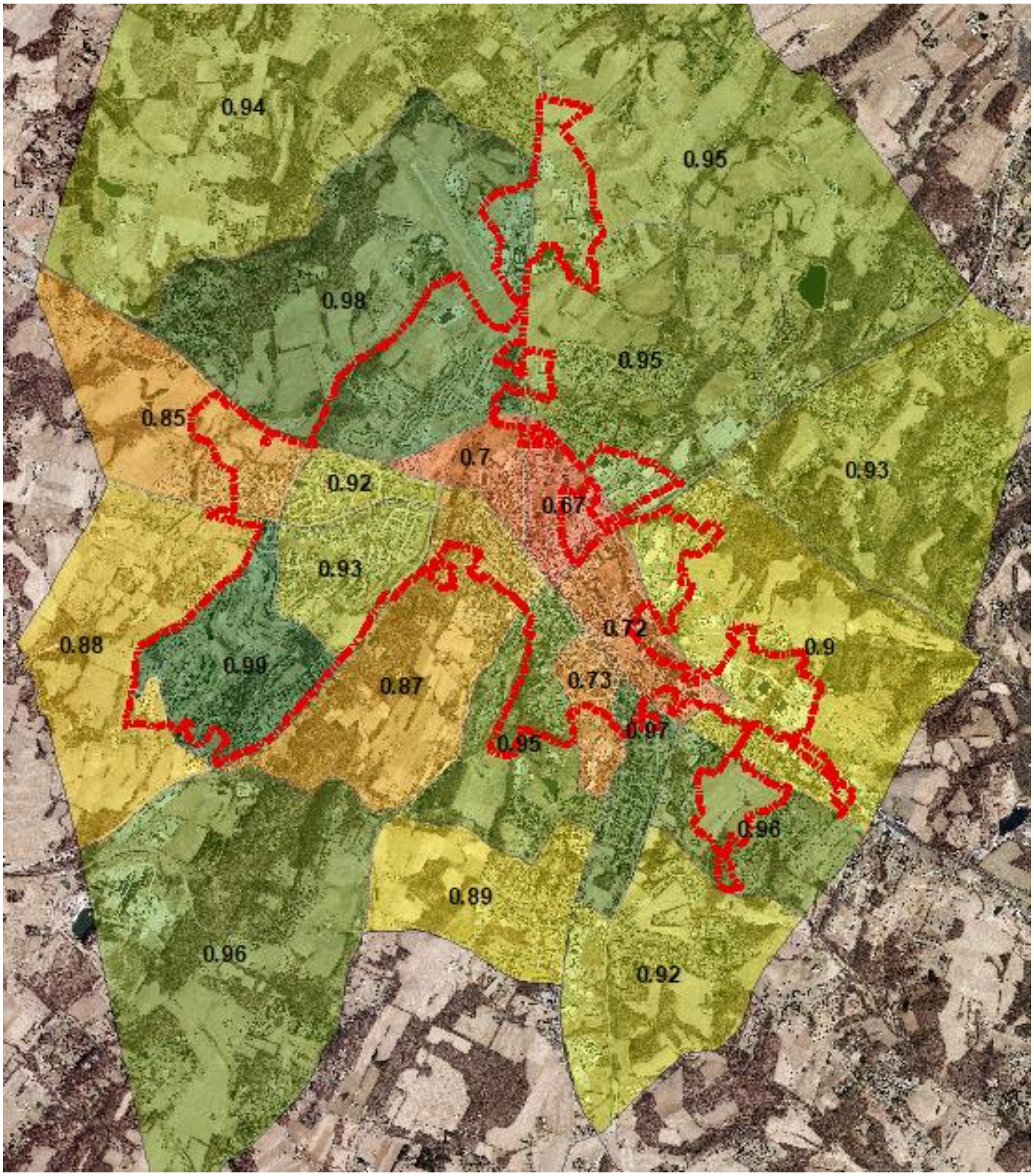


Figure 14. Percent of Population with at least a High School Diploma. Block Groups labeled in Percentage (i.e. 0.67 is 67% of the population with at least a high school diploma)

4.3 Question #3 - Where are the highly vulnerable residents located in relation to the potential extreme heat hazard locations?

Figures 15 and 16 are risk matrices which conceptualize and classify the relationship between social vulnerability and exposure to extreme heat hazard for areas within and adjacent to the City of Westminster, Maryland. Figure 15 addresses the locations inside Westminster and Figure 16 addresses locations surrounding Westminster.

In order to determine the vulnerability of select areas in Westminster, the following maps were visually analyzed: percent of population under five years old; percent of population over 65 years old; percent of population below poverty level; percent of population with at least a high school diploma; per capita income in past 12 months; and the LST map. The LST map was visually analyzed to determine select areas distributed around Westminster that were easily identifiable due to their cooler or hotter LST temperature. The location of these select areas were then identified within the five social-vulnerability maps to visually determine their social-vulnerable status. The block groups identified in red, in each of the maps, had the highest social-vulnerability status for each vulnerability group, and block groups identified in green had the least. There was some discretion used to determine whether a block group fell into the high-social vulnerable category or low social-vulnerable category while visually averaging the data from all five maps. These locations were then grouped into one of the two figures below: Heat and Vulnerability Categories for Westminster, Maryland, and Heat and Vulnerability Categories for areas surrounding Westminster, Maryland. The matrices should be used in the identification of the priority locations where recommended UHI mitigation measures should be implemented. These mitigation measures will be discussed in section 5.8.

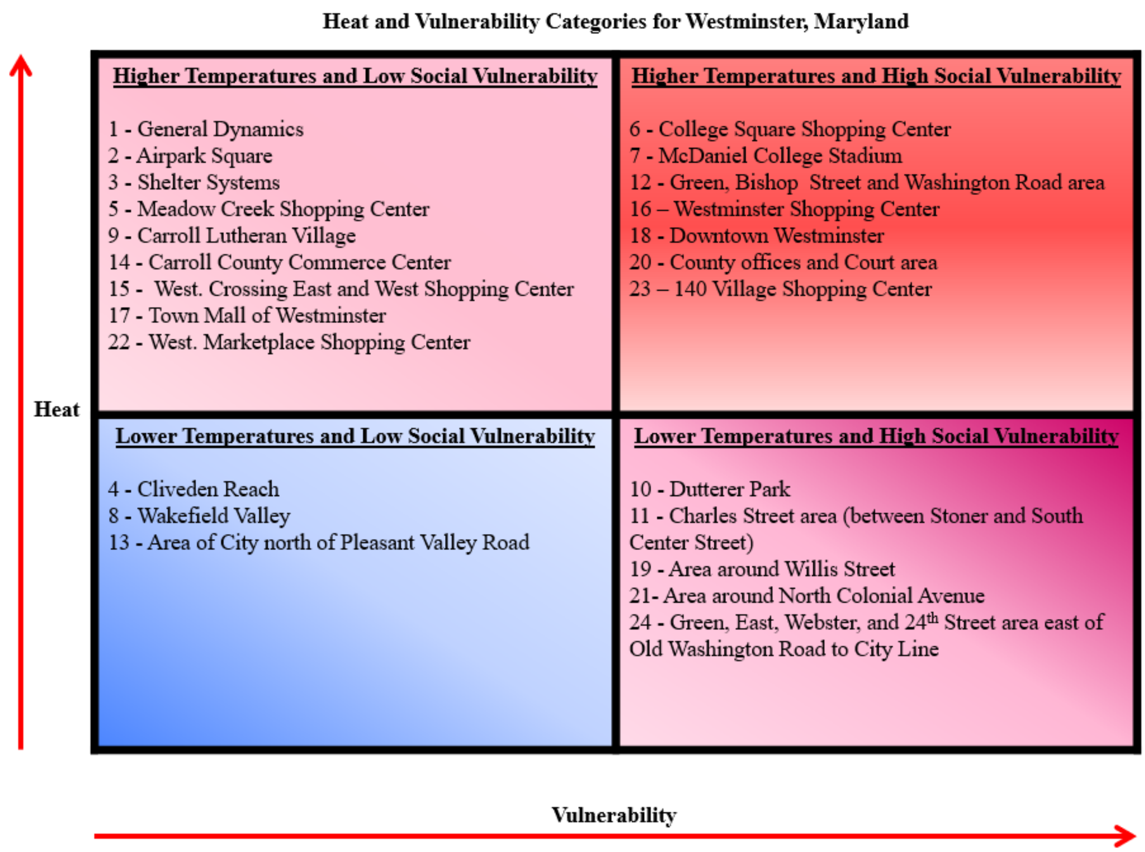


Figure 15. Risk Matrix of Heat and Vulnerability Categories for Westminster, Maryland

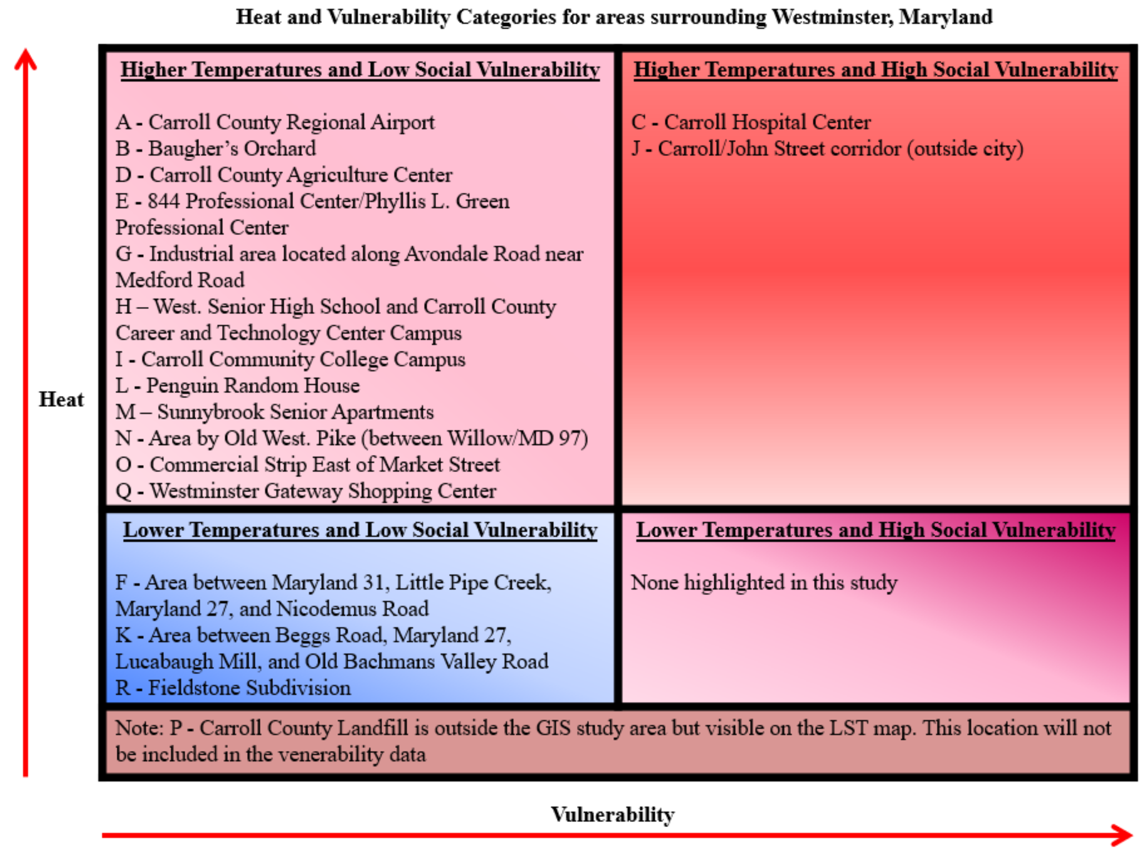


Figure 16. Risk Matrix of Heat and Vulnerability Categories for areas surrounding Westminster, Maryland

Chapter Five: Discussion

5.1 Introduction

The following chapter will (1) discuss the results for each research question and discuss factors that may have influenced the accuracy of the data; (2) provide a content review of comprehensive plans from other municipalities to understand best practices for UHI mitigation; (3) provide a review of current Westminster law and policy; and (4) report on what best practices from the content review Westminster can incorporate into current law and policy to help mitigate the UHI effect.

5.2 Question #1 - Is there a surface and canopy layer heat island present in the city of Westminster?

After review of the data and results, there would appear to be a surface heat island located in the commercial and industrial areas of Westminster, but not a canopy layer heat island. The hotter LST near the commercial and industrial land uses create more of a micro heat island effect as discussed in section 2.1.3. Such micro heat islands are clearly identifiable with commercial and industrial properties or groups of commercial and industrial properties, as seen in figures 7 and 8.

5.2.1 Canopy layer heat island

The statistical analysis of the air temperature measurements did not conclude that there was a canopy layer heat island present in Westminster, even though, as expected, the less developed land uses on average exhibited the lower mean, median, and maximum air temperature measurements. The medium developed land uses, on average, exhibited the highest mean, median, standard deviation, and minimum air temperature. One would expect that the more developed land uses would exhibit the highest mean, median, maximum, and highest standard deviation. A higher standard deviation should be exhibited in the more developed land use category since shade and damp conditions in such areas, on some days, would be expected to create an urban oasis effect reducing the surrounding air temperature. The more developed land uses do exhibit the lower minimum and highest maximum air temperatures but the least standard deviation in temperature. This may point to only a couple extreme temperature deviations.

It should be noted that for both the mean and median air temperature for all three land use classes there is only a slight variation in temperature. The mean air temperature for the less developed land use is 88.093 and for the more developed land use is 88.094. This is a difference of only 0.001º F. However, the difference from the more developed to the medium developed is 1.309º F. The median air temperature for the medium developed land use is 88.800 and for the more developed land use is 88.200. This is a difference of 0.6º F. The difference in air temperature from the less developed land use to the more developed land use is 0.45º F.

The lowest temperature was recorded in the more developed land use category not the less developed land use category. This lower temperature (67.6º F) was recorded at Locust and Main Street, in Downtown, on June 8, 2016, while the weather conditions were cloudy with rain. However, temperature measurements recorded during this day consistently exhibited a lower than average air temperature across all measurement locations, this low temperature may be due to the urban oasis effect where the more urbanized land uses are cooler than their surrounding non-urbanized land uses possibly due to more water laying on impervious surfaces reducing surface temperature.

The hottest temperature recorded (104° F) was located at the Town Mall of Westminster parking lot on August 17, 2016. The weather conditions for this day were also cloudy with rain. This day exhibited measurements that varied considerably with the high of 104° F to a low of 85.9° F, recorded at Locust and Main Street. It is hard to say why there is such a large temperature difference between the two locations which are both classified as a more developed land use. After further review of the temperature measurements recorded that day, the temperature consistently increases from the Locust and Main Street location, to the Town Mall location: 85.9°, 89.4°, 91.2°, 93.1°, 95.5°, 98.7°, and 104° F. This could be due to the cloud cover diminishing and the LST and canopy layer consistently warming over this roughly thirty-minute period.

It should be noted that the following factors may have influenced the accuracy of the temperature measurements. First, the thermometer constantly measured air temperature, therefore registered temperatures fluctuated every few seconds. This required an estimate of the average air temperature to a tenth of a degree Fahrenheit based on visual analysis. Such estimates may have affected the accuracy of the data slightly. Second, external influences, such as the thermometer taking several minutes to heat-up from the air-conditioned car to the outside air temperature, measurement locations temporarily blocked, varying traffic conditions, and personal commitments, all affected the ability to consistently measure the air temperature at the exact location and time each day.

5.2.2 Surface heat island

The surface heat island will be discussed initially for locations north of Maryland route 140 and then south of Maryland route 140. Since Maryland route 140 is the main route through Westminster, this would be a logical place to segment Westminster from north and south.

5.2.2.1 North of Maryland route 140

There are four hot spots identified around the Carroll County Regional Airport. These locations include Shelter Systems, airport tarmac, Airpark Square Business Park, and the General Dynamics Building located on Tech Court. Adjacent buildings on Tech Court do not indicate a high LST as exhibited at the General Dynamics Building. This may be due to lighter color roofing surfaces on the Knorr Brake, Advanced Thermal Battery, and the Strouse Buildings.

Locations of buildings on the West side of Maryland 97 with darker roofing surfaces are clearly identifiable on the LST maps. These buildings are located immediately south of Airport Drive and immediately west of Aileron Court in the Airpark Square Business Park. The Shelter Systems Building is clearly identifiable because it is isolated from other commercial and industrial land uses and the building clearly has a darker roofing surface. The airport tarmac also consists of higher LST. The tarmac is clearly identifiable given its proximity to the Carroll County Regional Airport runway which has a higher LST as well.

There are numerous hot spots along the northern part of Maryland 140. The Carroll County Landfill is identified as a hot spot. This may be due to the dark tarp covering part of the landfill and the corresponding reduction of vegetation. The Westminster Gateway Shopping Center is identified as a hot spot due to its dark roofing surface and surrounding parking lot. The Westminster Marketplace shopping Center also registers as a hot spot due to the large parking surfaces and lower albedo roofing surfaces.

The differences in surface temperature for surfaces with different levels of surface albedo are also evident in Westminster. The Westminster Marketplace shopping center, especially the Home Depot Building registers as a hot spot on the LST map to the right in figure 17. In contrast, it would appear from the LST map that the adjacent Lowes Building has a lower LST than its surrounding parking lot mainly due to its high albedo roofing surface. The adjacent Home Depot Building has a darker roofing surface and a corresponding higher LST (Figure 17).

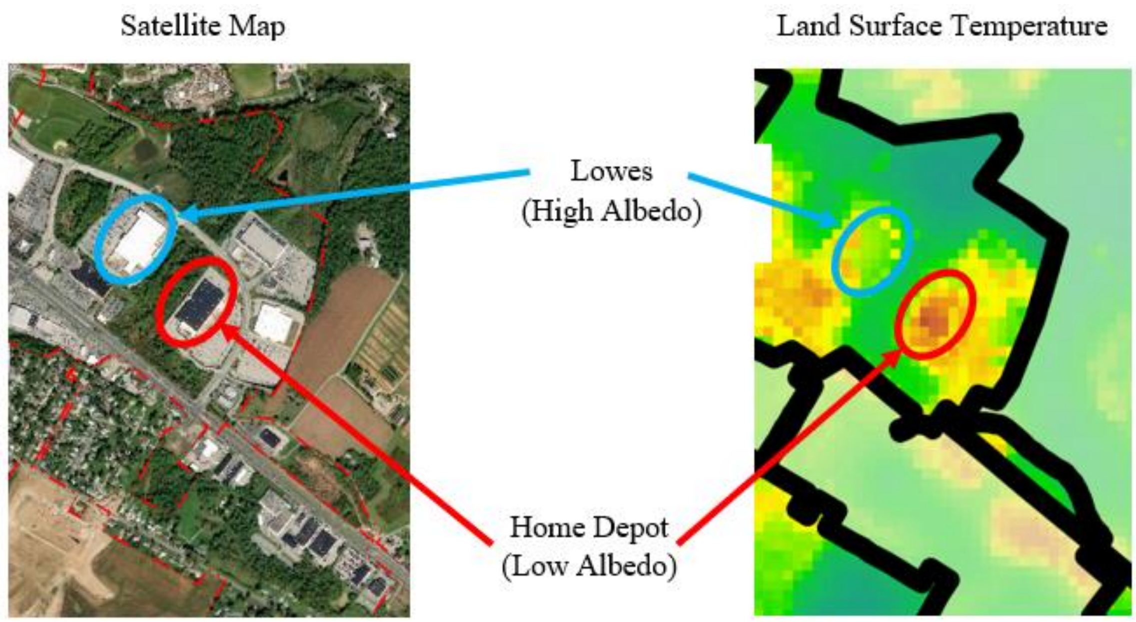


Figure 17. LST Comparisons Between Lowes and Home Depot

Other locations such as the Town Mall of Westminster, Westminster Crossing East and West Shopping Centers, Carroll County Commerce Center, Meadow Creek Shopping Center, and Baugher's Orchard are all identified as hot spots possibly due to their large parking lots, even though Baugher's Orchard and most of the buildings at Meadow Creek Shopping Center have high albedo roofs. Regarding surface temperature and albedo, the Penguin Random House Building located along Hahn Road has a higher albedo roof than the Penguin Random House building located on Bennet Cerf Drive. The LST of the building roof on Hahn Road should have a lower LST, yet it has a higher LST. Other surface properties must have a higher influence on the LST of this particular roofing surface than what would be typical of a high albedo roof.

5.2.2.2 South of Maryland route 140

Many locations south of Maryland 140 exhibit increased LST. The entire historic downtown area is densly populated with many urbanized surfaces. In the downtown area, Main Street and Pennsylvania Avenue are both cooled by over 300 street trees (City of Westminster Comprehensive Tree Plan, 2018). Such trees help to reduce the UHI effect and reduce cooling costs for the adjacent buildings while providing an appearance that makes Downtown Westminster unique. The street trees may be why downtown has a lower LST then other shopping areas along Maryland 140 (Figure 18).

The commercial strip east of Market Street, the 140 Village Shopping Center, Westminster Shopping Center, the area around Carroll and John Streets, and the College Square Shopping Center all have large parking lots and urbanized surfaces and all exhibit a high LST. The College Square Shopping Cneter is located in close proxcility to a highly forested land use. Figure 19 provides an example of the LST difference between the College Square Shopping Center, a commercial land use, and a highly vegetated land use both located on the west side of the City. The vegetated land use indicated in the satellite map on the left has a lower surface temperature as indicated on the LST map to the right. To the contrary, the commercial land use indicated in the satellite map on the left has a higher surface temperature as indicated in the LST map to the right.

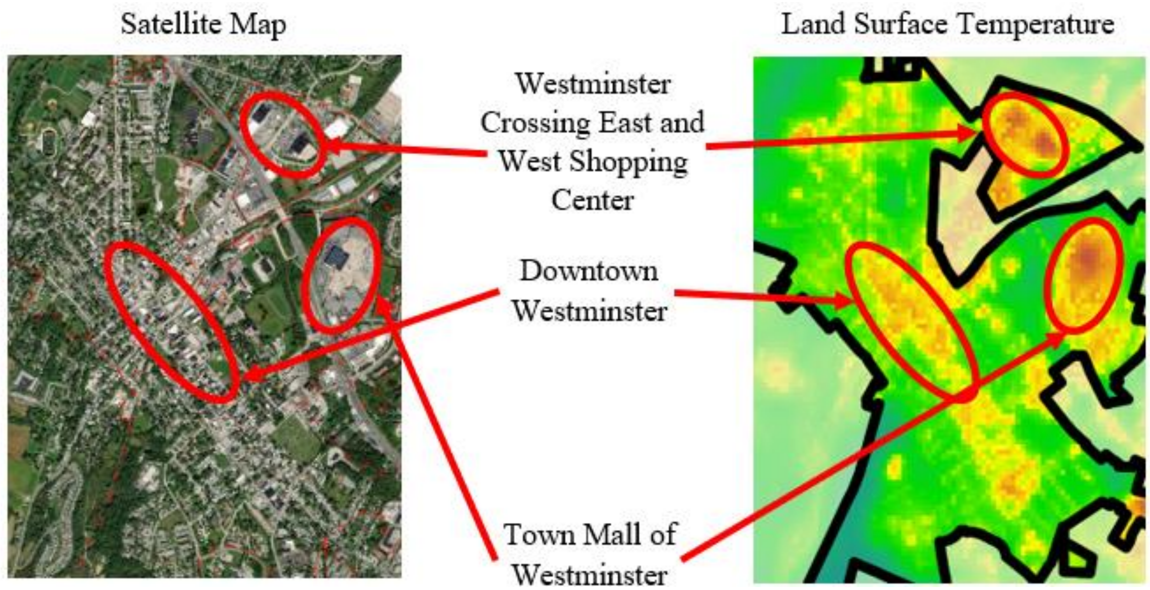


Figure 18. LST Comparisons Between Downtown and Commercial Strip

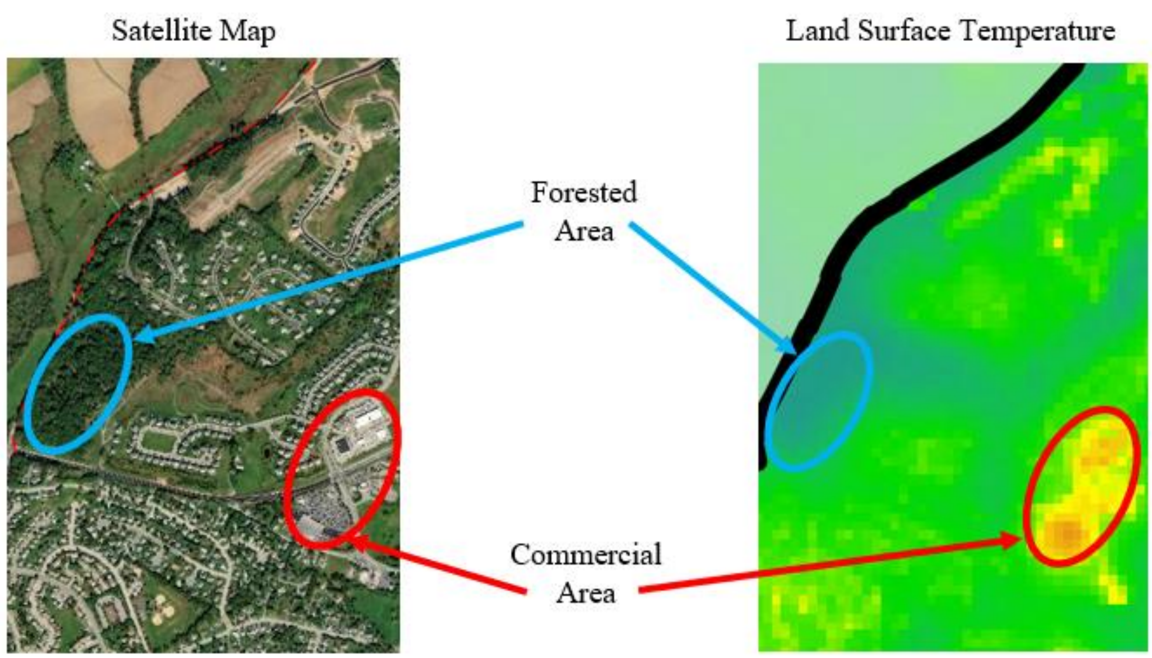


Figure 19. LST Comparison Between Commercial and Forest

Figure 20 clearly shows that hotter LST exists in proxcimity to the darker roofing surfaces at the 140 Village Shopping Center and the area around Green Street, Bishop Street and Washington Road. These locations also exhibit large impervious parking surfaces that further increase the LST.

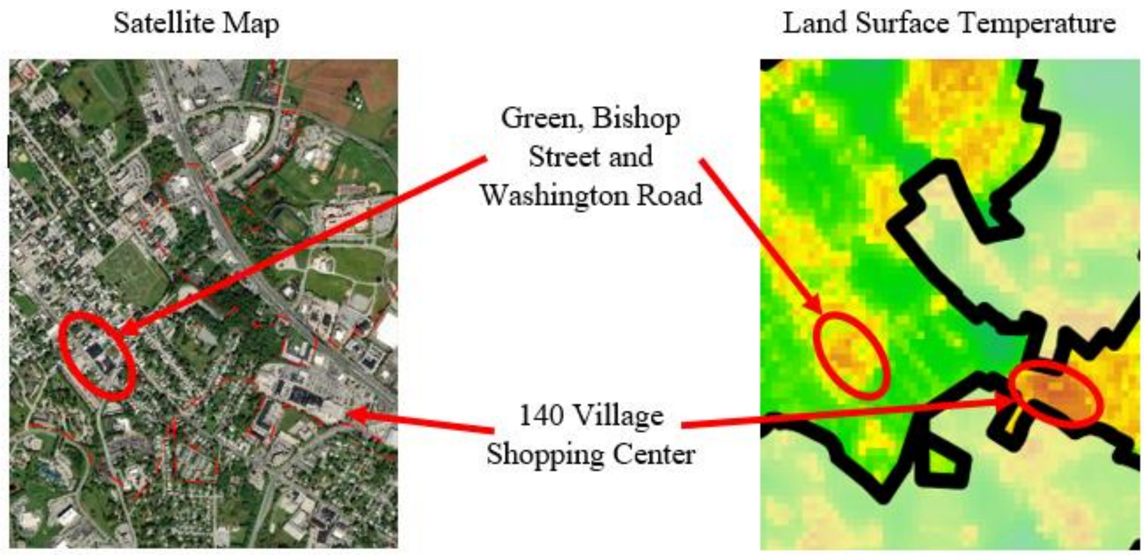


Figure 20. LST Comparisons Between Industrial and Commercial

The McDaniel College stadium field is identified as a hot spot. This surface must be artificial, which may be more conducive to storing heat. The Carroll Hospital Center complex and the Carroll County Agricultural Center complex also have a high LST. The satellite imagery clearly depicts a highly reflective roofing surface for both facilites, however, the surrounding parking lots have an effect on the LST. The Agricultural Center complex has limited paved parking spaces but a large low cut grass field accomodates parking. Such a low cut field has a higher LST resulting from the lower soil moisture conetent and evaportranspiration. The 844 Professional Center and the Phyllis L. Green

Professional Center also have a high LST. Once again, darker roofing surfaces and large parking areas are the reason.

The campuses of Carroll Community College, Westminster Senior High School, and the Carroll County Career and Technology Center also exhibit a high LST. These buildings have roofing surfaceses that are more of a grayish color and are surrounded by large parking lots, especially Carroll Community College.

Other locations that exhibit a high LST are Carroll Luthern Village and the commercial area located around Avondale Road. These roofing surfaces are grayish and are surrounded by large parking lots. The area along Old Westminster Pike (between Willow and Maryland 97) is also identifed as a hot spot mainly due to the low albedo roofings surfaces and paved parking areas.

The 2017 LST map clearly indicates that there is a micro surface heat island effect present in Westminster, particularly at commercial and industrial locations. Such locations have higher amounts of urban land use cover and lower surface albedo as seen in figures 7 and 8.

5.3 Question #2 - Where in Westminster are its most highly vulnerable residents located?

After review of the data, the highest vulnerable populations are located in the downtown area of Westminster. More specifically, the block group bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27. This block group contains the highest percentage of children under the age of 5; the highest percentage of people below poverty level; the highest percentage of people without a high school diploma; and the second lowest per capita income. It should be noted that the block group with the lowest per capita income is located immediately to the west of this block group and contains McDaniel College. If college students living on campus are counted, they would add to the lower income of the block group that is bordered by West Main Street, Maryland 140, and Pennsylvania Avenue. If the incomes for college students are counted, removing them from the count would possibly raise the income for this block group, possibly bringing this block group out of last place for lowest per capita income. A map indicating the three most vulnerable block groups is indicated in figure 21.

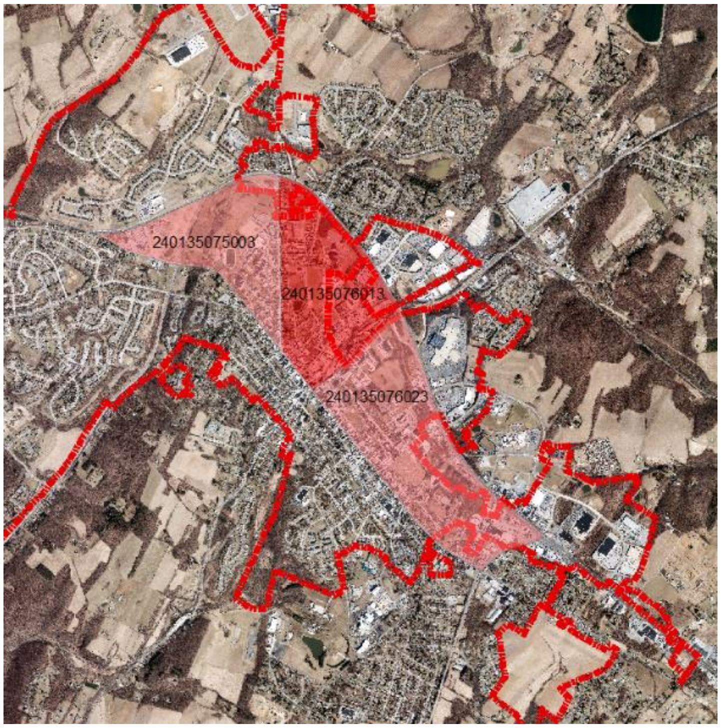


Figure 21. Most Social Vulnerable Block Groups

5.4 Question #3 - Where are the most highly vulnerable residents located in relation to the potential heat hazard locations?

The location with the highest LST and the highest social-vulnerable population resides in an area located just outside the City of Westminster under the zoning and development authority of Carroll County. This area is mostly commercial; however, there are some residents located on the outskirts of this area. Advective heating caused by a summer-time breeze would move the higher temperatures from the commercial land uses into adjacent residential neighborhoods. Best UHI mitigation practices should be incorporated into the existing urban form of this neighborhood and adjacent neighborhoods located between East/West Main Streets and Baltimore Boulevard, located both inside and outside Westminster, in order to reduce the heat stress in these social-vulnerable areas. It should be noted that any policy enacted for the City of Westminster would not affect areas outside Westminster City limits and is why cooperation with Carroll County Government is essential in implementing a uniform set of requirements for the entire Westminster area.

5.5 UHI mitigation in Maryland Municipal comprehensive plans

Best UHI mitigation practices discussed in 2.6 include (1) increasing the surface albedo and (2) increase urban vegetation. Select Maryland cities have started to address the UHI in their comprehensive plans using these examples. In particular, Bel Air discusses high albedo urban surfaces and green roofing material; Gaithersburg discusses how low impact development and innovative design in which vegetation is preserved reducing the UHI effect; Annapolis and Elkton both mention how increasing the tree canopy will reduce the UHI effect (City of Gaithersburg, 2004; City of Annapolis, 2009; Town of Elkton, 2010; Town of Bel Air, 2016). These cities have not only recognized the UHI effect, they have begun to lay out policy to help in mitigation. More local governments should address this problem. Once identified and accepted, local governments can effectively address UHI mitigation by adopting a more detailed development policy.

5.6 Current land use laws and policies in Westminster related to UHI mitigation

The following Westminster law and policy are relevant to the recommendation of UHI mitigation techniques: (1) The Charter and Code of the City of Westminster; (2) 1993, City of Westminster Landscape Manual; and (3) 2016, Adopted Development Design Preferences Manual. It should be noted, that the City Code is the law and no modifications can be granted, unless under certain circumstances, by variance through the Board of Zoning Appeals. The latter two documents are not as legally binding as the City Code, and the Planning and Zoning Commission may vote for alternative compliance. These documents are important for UHI mitigation because all three documents are reviewed during the development review process.

The Charter and Code of the City of Westminster discusses landscaping in several subsections. Most notable subsections include the following:

1. § 164-113 Location and landscaping, establishes the requirements for landscaping in larger off-street-parking facilities by providing requirements for adjacent landscape buffering and internal landscaping (Charter and Code of the City of Westminster Maryland, 2018, § 164-113). For the purpose of UHI mitigation this section of code is extremely important since it requires provisions for shading larger parking facilities. Internal parking lot landscaping provides the most effective shading and landscaping buffering around the parking lot also provides shading.

2. The Planned Industrial Zone and the Restricted Industrial Zone have landscaping requirements contained in § 164-57 which establishes buffer and screening requirements for uses in such zones which are adjacent to any public right-of-way or residential zone (Charter and Code of the City of Westminster Maryland, 2018, § 164-57). This provision provides for shading and a wide minimum landscape buffer from adjacent residential uses and the public-right-of-way. This 30-foot buffer will be an area with increased soil moisture content, increased shading, and increased evapotranspiration, reducing a chance of a surface heat island from occurring in such buffered area potentially next to residential land uses. This landscaped buffer will also shade immediately adjacent impervious parking areas reducing surface temperature for commercial and industrial land uses, which were identified as having the highest LST in Westminster.
3. The Planned Regional Shopping Center Zone, which includes the Town Mall of Westminster, has landscaping requirements contained in § 164-107, which provide for a buffer, landscaping, and other infrastructure around the subject property (Charter and Code of the City of Westminster Maryland, 2018, § 164-107). The mall is one of the most urbanized land uses in Westminster. Providing for proper landscaping is important in the reduction of the surface UHI for such a large urban land use. Just like the Planned Industrial Zone, the Planned Regional Shopping Center Zone requires a 30-foot landscape buffer providing an area with increased soil moisture content, increased shading, and increased evapotranspiration as compared to impervious parking surfaces. This landscape buffer will reduce the chances of a surface heat island from occurring

immediately adjacent to residential land uses and providing shade to adjacent parking areas.

4. In determining where to plant trees along city roadways, § 148-9, § 148-10, and § 148-11 should be taken into consideration. § 148-9, establishes the distance that trees must be from street corners and fire hydrants; § 148-10, establishes the type and distance from above and below ground utilities; and § 148-11, establishes regulations for maintaining roadside trees (Charter and Code of the City of Westminster Maryland, 2018, Chapter 148). These sections provide important considerations for all areas in Westminster when determining where to plant trees.
5. The Development Design Preferences Manual **(**DDPM**)** "serves as recommendations to guide the layout, alteration, or construction of buildings or improvements" within Westminster (City of Westminster Mayor and Common Council, 2016, 4). There are four main areas of focus in the DDPM. The first area of focus is the Commercial District. This manual describes new commercial development in which such development helps preserve the architectural continuity of the historic downtown and encourages a more pedestrian friendly environment. The second area of focus is residential development with preferences such as providing open space, quality site circulation, and quality architectural design. The third area of focus is the historic district with preferences such as providing pedestrian scale design, development complementing the historic atmosphere of downtown, and providing street level retail amenities. The fourth area of focus is resource conservation which describes different sustainable development techniques that could be used to reduce the

UHI effect such as low-impact-development, on site stormwater capture, energy conservation, and pervious surfaces.

6. The City of Westminster, Landscape Manual includes landscaping requirements for both residential and commercial development. Besides screening and buffering requirements, residential projects do not require an excessive amount of landscaping. Residential development typically requires the following landscaping be included:

- "All multiple family dwellings shall be required to provide 3.5 Planting Units for each dwelling proposed therein (City of Westminster, 1993, 13)."
- "Two Planting Units shall be required for every other proposed dwelling unit (City of Westminster, 1993, 13)."

Note: a Planting Unit is a unit of measure consisting of: "one major deciduous tree (minimum 2" cal.); or two minor deciduous trees (minimum 1" cal.); two evergreens (minimum 5' ht.); or five shrubs (minimum 24" ht.); or 250 square feet of groundcover, perennial flowers and/or ornamental grasses (City of Westminster, 1993, 5)." This section of the landscape manual is the main policy that sets the requirements for most of the residential landscaping in the City, especially for single family detached dwellings.

7. Landscaping for "Commercial, Office, Industrial, and Public Development" is discussed in Section V.C. of the manual (City of Westminster, 1993, 15). Such development requires a certain amount of landscaping for the total amount of adjacent and interior street frontage; frontage between off-street parking and the adjacent street; landscaping within the off-street parking area; and screening

around "loading, service, outside storage, and dumpster areas (City of Westminster, 1993, 15)." Just like the code provisions discussed above, this section of the manual set's requirements for large urban commercial and industrial land uses. Such land uses exhibit the hottest land surface temperatures in Westminster. Such section can be modified to incorporate UHI mitigation best practices.

It should be noted that other Westminster law and policy dictate development pattern including the city boundary, urban growth boundary, zoning, existing public infrastructure and the Water and Wastewater Allocations Policy. Such laws and policy dictate where new development and public infrastructure can occur on a macro level. Some locations are not permitted to develop as intensely as others (i.e. residential areas outside Westminster vs. commercial areas inside). Currently, the main policy that has the most influence on growth in and around Westminster is the adopted Water and Wastewater Allocations Policy. Most new development must have water and sewer service. This policy provides direction on how the city wants to allocate its limited water and sewer resources for all projects that require a net increase in water and sewer usage. This information is important to note; however, it would not be an appropriate place to dictate micro issues such as UHI mitigation measures in new development.

5.7 Recommended UHI mitigation practices into current Westminster law and policy

The City of Westminster can counteract some of the adverse effects of climate change and abate extreme heat hazard by amending its existing land use and building codes. What follows are recommendations based on the finding of this investigation, a survey of relevant studies, a review of community comprehensive plans for cities throughout Maryland, and a review of the current land use policy's and laws in Westminster that relate to the UHI.

The following recommendations are sustainable implementation strategies to abate extreme heat hazard that Westminster could adopt. These recommendations include:

1. The landscape manual can be amended to indicate total lot tree canopy coverage of at least 40 percent (City of Rockville, 2002; City of Gaithersburg, 2004; and City of Baltimore, 2006).
2. The zoning code should require street trees on all new residential and commercial streets. Such tree planning should meet current industry standards (City of Gaithersburg, 2004; City of Hagerstown, 2008; Town of Elkton, 2010; Town of Easton, 2010; and City of Cumberland, 2013).
3. The DDPM can be amended to include green roofs in conjunction with white roofs in order for projects to have an alternative in meeting the 40 percent tree canopy coverage threshold (City of Gaithersburg, 2004 and Town of Bel Air, 2016).
4. The zoning code should require white roofs on all large industrial and commercial buildings (Town of Bel Air, 2016). White roofs should be encouraged for residential projects but not mandatory due to unforeseen circumstances that may affect each individual residential property, such as cost. In this case, white roofs for residential projects should be included in the DDPM in order for the Planning Commission the opportunity to grant alternate compliance.

5. The DDPM should include information regarding higher albedo paving surfaces for all residential and commercial projects (Town of Bel Air, 2016). Such surfaces in conjunction with properly placed landscaping will reduce the UHI effect in a variety of locations. This information should be inserted in the DDPM so the Planning Commission may grant alternate compliance in case of unforeseen circumstances.
6. The landscape manual should be amended to specify the location of vegetation plantings that would help decrease energy consumption in both the winter and summer months, for both residential and commercial development. For instance, evergreen trees should be located to the north of buildings "to reduce the influence of cold winter winds (Akbari et al., 1992, xxi)." Deciduous trees should be placed to the south, east, and west of buildings to help block the solar energy in the summer while letting the solar energy absorb into the building during the cold winter months (City of Gaithersburg, 2004).
7. The landscape manual should require that new developments report the existing and proposed tree canopy coverage and require such new developments meet or exceed existing conditions (City of Rockville, 2002; City of Gaithersburg, 2004; City of Frederick, 2009; City of Cumberland, 2013).
8. The landscape manual should include increasing the planning unit credit for relocating existing vegetation on site and provide an even higher credit for retaining the existing mature trees on site, without relocation (City of Gaithersburg, 2004; City of Havre De Grace, 2004; Town of Elkton, 2010).

9. The DDPM should require the total area of soil disturbance and impervious surface be indicated (City of Annapolis, 2009). This would allow the Planning Commission and staff to review and possibly require a reduction of both the soil disturbance and impervious surface area if substantially higher than the total parking lot and building area.

Additionally, Westminster should implement an award program that recognizes developers who demonstrate the very best in sustainable design (City of Frederick, 2009). Such an award program may generate new ideas for inclusion into future Westminster law and policy. Additionally, the city code should provide language and means for enforcement to reduce stream temperatures and the amount of toxic chemicals from storm water runoff by managing the critical area around streams and other bodies of water (City of Gaithersburg, 2004; City of Havre De Grace, 2004; City of Frederick, 2009; Town of Easton, 2010; Town of Elkton, 2010; City of Cambridge, 2011. This will require additional staff and the effective implementation may take some time.

It should be noted, that proper landscaping policy must take into consideration how trees will affect all commercial and industrial properties. The landscaping should not only buffer such commercial and industrial land uses from surrounding properties and shade their associated urbanized surfaces; landscaping must also take into consideration proper site visibility so commercial properties are not obstructed from the public view. The landscaping should also enhance the appearance of the business, so it is more inviting to potential customers. The most restrictive landscaping requirements should be addressed in the DDPM, however, modest landscaping should be listed as a Code requirement.

Chapter Six: Conclusion

My thesis studied the presence of the UHI effect in the City of Westminster, Maryland, and involved the collection of air temperature, land surface temperature, and demographic information. The research was structured around the following three research questions and the analysis concluded the following:

1. **Is there a surface and canopy layer heat island present in the City of Westminster?**

   The typical UHI generally associated with larger urban areas was not present in Westminster. However, small micro UHI's indicated in the LST map were located at select commercial and industrial locations in and around Westminster.

2. **Where in Westminster are its most highly vulnerable residents located?**

   The downtown area of Westminster is where the most highly vulnerable population lives. More specifically, the area bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27.

3. **Where are the highly vulnerable residents located in relation to the potential heat hazard locations?**

   Areas that have higher LST in the highly vulnerable block group bordered by West Main Street, Pennsylvania Avenue, Maryland 140, and Maryland 27 are the most susceptible to the UHI effect, more specifically, the John and Carroll Street area. This hotter industrial and commercial area is located just outside Westminster under the development authority of Carroll County. Additionally, all such locations that are classified as *Hot and Vulnerable* should be given special prioritization when it comes to the implementation of best planning UHI mitigative measures.

Westminster should review the areas that are the hottest and most vulnerable to the UHI effect inside the corporate limits and propose planning measures that will hopefully lower the temperature, thereby decreasing associated negative health effects. Next steps should include, further monitoring of air temperatures at several fixed stations around the Westminster area. These measurements would provide valuable data for City of Westminster Officials to use in ongoing identification of the hottest areas. As Westminster continues to grow, planning for heat mitigation will minimize the risks of potential heat-related illness as discussed in this paper.

Appendix A: Descriptions of Sampling Locations

Sample location #1

The temperature collection route started in the center of Westminster, adjacent to the Westminster Volunteer Fire Department. This starting point was selected because this location is where my vehicle was parked and represents one of the larger parking lots in the center of Downtown Westminster. This location would consist of a more developed land use pattern due to its relatively large impervious parking surface surrounded by residential buildings to the northwest, a large 29,662 square foot fire station to the southeast, and the rear of many commercial businesses facing historic West Main Street to the south (SDAT, 2018a). It should be noted that there is a small grass plot adjacent to the parking lot located northeast of the measurement location. One could speculate that this vacant lot may be utilized for future fire station expansion due to the property tax records indicating ownership by the Westminster Fire Engine & Hose Company No 1 (SDAT, 2018a).

Sample location #2

The second measurement location is along the southern side of Dutterer Way between Pennsylvania Avenue and Winters Street. This location consists of a more developed land use pattern due to its proximity to higher density development located along historic Pennsylvania Avenue, a major route into downtown. About one-half of a block to the east of the measurement location is Dutterer Family Park. According to parcel information obtained from the Maryland Department of Assessments and Taxation, Dutterer Family Park consists of roughly 10.48 acres and contains sports fields, a playground, walking paths, and a brick plaza (City of Westminster, 2018; SDAT, 2018b; SDAT, 2018c; SDAT, 2018d; SDAT, 2018e; SDAT, 2018f). Westminster West Middle School and William Winchester Elementary School are both adjacent to the park and are located on the opposite side from the measurement location and contain recreational fields, increasing the vegetated area adjacent to the park.

Sample location #3

The third measurement location is at the corner of Lower Field Circle and Wyndtryst Drive. This area consists of a medium developed land use containing new single family detached dwellings built around 2011 (SDAT, 2018g; SDAT, 2018h; SDAT, 2018i). The corner where the measurements were recorded contain single family detached dwellings located on three sides of the intersection and a large 20,843 square foot grass open space, owned by the Village of Meadowcreek Community Association Inc (SDAT, 2018j). It should be noted that to the northeast of the measurement location sits the State of Maryland, State Highway Administration maintenance facility, located on roughly 30.22 acres and consists of woods, buildings, and large paved surfaces (SDAY, 2018k). The temperature collection location is closer to the existing buildings and paved surfaces than the wooded section of this state-owned lot.

Sample location #4

The fourth measurement location is near the corner of Wyndstar Circle and Meadow Creek Drive. This area consists of a medium type of land use containing mostly single family detached dwellings built around 2006 (SDAT, 2018l; and SDAT, 2018m). Immediately located to the south of this measurement location is 33,902 square feet of recreational open space owned by the Village of Meadowcreek Community Association Inc. (SDAT, 2018n). Located just to the south of the recreational open space is a major commercial center with shops and restaurants. Immediately to the east of the existing commercial center is vacant land that is currently zoned Neighborhood Commercial, and would appear to be vacant land for the second phase of the Village of Meadow Creek, per the Special Finance Plat, Village of Meadow Creek, dated 2014, located in Plat Book #48, Folio #41 (Plats.net, 2014).

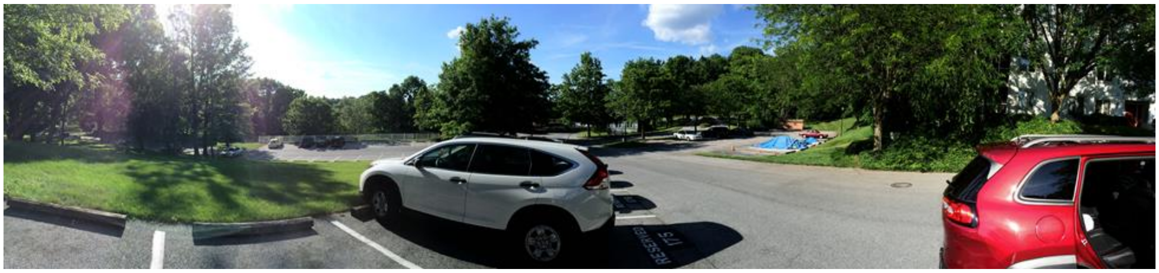
Sample location #5

The fifth measurement location is off Royer Road near Ewing Drive. This area consists of a medium developed land use pattern containing single family detached dwellings built around 1978 (SDAT, 2018o; and SDAT, 2018p). About a block to the north of this measurement location is the Westminster Municipal Pool located on 1.92 acres of land consisting of a parking lot with a capacity of well over 50 spaces, several small recreational buildings, two public pools, and playground equipment (SDAT, 2018q). Adjacent to the municipal pool is a large 3.70-acre storm water management facility mostly containing a man-made lake (SDAT, 2018r).

Sample location #6

The sixth measurement location is off Tahoma Farm Road next to the golf cart path associated with the old Wakefield Valley Golf Course. This area would be considered to have a less developed land use pattern. The Wakefield Valley Golf Course is now recreational open space with its old golf cart paths now used by residents for walking. The old golf course is currently overgrown with vegetation. Additionally, Tahoma Farm Road is lined with trees on both sides providing shade.

Sample location #7



The seventh measurement location is off Pleasanton Road and would be considered as exhibiting a more developed land use pattern. This location consists of nine multifamily condominium buildings which are three stories high, surrounded by large trees and a parking area that lines the drive aisle connecting the nine multifamily dwellings.

Sample location #8

The eighth measurement location is off Park Place immediately adjacent to historic Belle Grove Square. The surrounding neighborhood would be considered to exhibit a more developed land use pattern. In the middle of the neighborhood and immediately adjacent to the measurement location is a 32,234 square foot park (SDAT, 2018s). This urban park, Belle Grove Square, contains benches and a fountain surrounded by mostly historic homes some of which date back to 1865 (SDAT, 2018t). There are also two large churches Saint Paul's, built in 1869 and Church of the Brethren, built in 1932, which surround the park on two sides (Weeks, 1978, 155).

Sample location #9

The ninth measurement location is at the Longwell Parking lot in the center of downtown. This location would exhibit a more developed land use pattern. The surface parking lot is roughly 1.072 acres and is adjacent to the two to three story Longwell parking Garage to the south, which is in turn adjacent to the rear of the many businesses located along historic East Main Street (SDAT, 2018u). To the east, is the Sherwood parking lot. To the north sits a three-story brick restaurant and a seven story brick multifamily apartment complex. Historic City Hall is located to the northeast in the middle of a highly vegetated lot surrounding the historic mansion built in 1845 (SDAT, 2018v). Lastly, to the east across the parking lot, contains single family detached dwellings built around 1913 (SDAT, 2018w).

Sample location #10

The tenth measurement location is on East Main Street at Locust Lane. This location would exhibit a more developed land use pattern. The measurement location is surrounded by a densely built area consisting of commercial development along East Main Street. There are three story buildings built on each side of Locust Lane. Across Main Street from Locust Lane is the Westminster Branch Library which has a small front yard with grass and mature trees. It should be noted, that both East and West Main Street consists of street trees that add to the natural vegetation and in turn may reduce the UHI effect in downtown. On the other end of Locust Lane sits the Sherwood Parking Lot and the Longwell Parking Garage.

Sample location #11

The eleventh measurement location is along East Main Street, east of Center Street. This location would consist of a more developed land use pattern. As noted earlier, East and West Main Street consists of mostly mature street trees. This may provide enough shade, to reduce the possibility of increased summertime thermal heating. This section of Main Street consists of a mixture of commercial and residential land uses located along each side of the street.

Sample location #12

The twelfth measurement location is along East Green Street, east of Old Washington Road. This location would consist of a more developed land use pattern. Green Street consists of mostly residential land uses. This location is situated on a substantial incline and one can see a good way out over the entire downtown area which makes this location more susceptible to windier conditions, which may affect the temperature.

Sample location #13

The thirteenth measurement location is along Willow Avenue near its intersection with Old Westminster Pike. This location would consist of a medium developed land use pattern. It should be noted, that as of 2018, a new development has been built across Old Westminster Pike containing hundreds of single-family detached dwellings. These dwellings were not present when the data was collected in 2016. During 2016, the area across Old Westminster Pike, to the south, consisted of farmland. The area to the east consists of a business and the rest of the area contains single-family detached dwellings constructed around 1940 and contain dispersed mature landscape plantings which provide shade to the neighborhood (SDAT, 2018x; and SDAT, 2018y).

Sample location #14

The fourteenth measurement location is in the Kohl's parking lot along Market Street. This location would consist of a medium developed land use pattern. This existing commercial layout is typical of your large big box retail location. Kohl's is located on a 9.76-acre parcel that mostly consists of a large off-street parking lot and the store itself (SDAT, 2018z). To the West of Kohl's sits the Home Depot, home improvement retailer, situated on a 14.29-acre property that mostly contains a large parking lot and the commercial building (SDAT, 2018aa). To the north is BJ's Wholesale Club, the Greene Turtle Sports Bar, and a bank located on roughly 12.3 acres (SDAT, 2018bb; and SDAT, 2018cc). Land use to the east consists of farmland and is the reason why this location was considered a medium developed land use and not a more developed land use.

Sample location #15

The fifteenth measurement site is located on High Acre Drive near North Center Street. This location would consist of a less developed land use pattern and is also one of the higher elevations in the entire Westminster area. Due to this location's elevation, there is a two million gallon water tank and a one million gallon raw water storage reservoir located roughly 900 feet from this measurement location. The measurement location is also surrounded by two large embankments from where the existing one lane road was dug into the hillside. To the northeast of the measurement location consists of a less developed land use pattern. South of the measurement location consists of a senior living facility and to the West sits Winters Mill High School, located on a 56.03-acre property (SDAT, 2018dd).

Sample location #16

The sixteenth measurement location is in the parking lot of the Town Mall of Westminster. This location would consist of a more developed land use pattern. The measurement location is located to the north of the mall facility. The 55+ acre commercial property consists mostly of the mall building and the large parking lot surrounding the mall structure (SDAT, 2018ee). The mall is located to the west of the measurement location; however, to the east of the measurement location, the current land use consists of a large grass field which may help to regulate the air temperature.

Sample location #17

The last measurement location is at Calvary Bible Church located near the intersection of Gorsuch Road North and Hampstead Mexico Road (Maryland State Route 482). This measurement site was selected because it is located roughly half-way between Westminster and the Town of Hampstead. It would seem that this location is far enough removed from both urban centers to not be affected by the potential UHI from either Westminster or Hampstead. It should be noted that only eight measurements were collected from the Maryland State Route 482 location due to circumstances that involved me staying in Westminster and not immediately traveling to this location after the hour of data collection.

Appendix B: Temperature Measurements

Temperature Measurements for each Location, each day June 1 to June 22, 2016

Temperature Measurements							
	1-Jun	4-Jun	8-Jun	11-Jun	15-Jun	18-Jun	22-Jun
Parking Lot	93	84	76.2	92.1	85	81.1	89.8
Dutterer Way and PA Ave	90.2	85.8	73	94.8	85.3	82.8	88.5
Pleasanton Road	96.1	83.5	72.4	97.4	83	86.3	83
Belle Grove Square	91.6	83.8	68	95	82	82.2	84.9
Longwell Lot	89.5	84.7	68.5	95.4	84.7	88.2	86.4
Locust and Main	88.3	86	67.6	94.6	80.4	84.8	83.5
Main West of Center	90.9	83.2	70.2	93.5	81.9	84.4	84.4
Green Street	93.2	79.7	72.1	92.7	82.4	88.3	86.3
Town Mall Lot	89.7	83.5	71.1	94.2	84.4	85.8	85.2
Wyndtryst Drive and Lower Field	95.6	84.2	71.8	93.5	81.4	87.8	84.3
Meadow Creek Drive	93.4	84	74.7	93.2	87.6	87.7	84
Royer Road	96.5	83.3	74.8	98	87.8	85.9	85.5
Willow Street	88.1	81.6	69.4	92.1	83.6	87.9	83
Market Street	92.6	84	71.8	97.5	81	87.8	82.2
Tahoma Farm Road	93.9	84.3	74.7	96	84.4	87.2	81.9
Center at High Acre	91	81.9	68.5	94	82.9	87.8	81.9
Maryland 482	*	85.4	*	91.7	83.2	*	*

Temperature Measurements for each Location, each day July 2 to July 31, 2016

Temperature Measurements						
	2-Jul	6-Jul	19-Jul	25-Jul	27-Jul	31-Jul
Parking Lot	81.8	102.8	93.7	89.3	99.9	87.2
Dutterer Way and PA Ave	82.9	93.7	98	90.6	98.9	98.2
Pleasanton Road	80.6	89.3	101.4	96.7	94.7	90.1
Belle Grove Square	82.1	88.5	94.1	95.5	94.6	88.2
Longwell Lot	81.9	88	92.4	94.2	93.7	89.9
Locust and Main	80.9	93	92	95.1	91.6	88.9
Main West of Center	81.1	90.6	87.8	93.4	91.4	86.3
Green Street	79.3	88.6	90	94.6	92.8	87.7
Town Mall Lot	77.7	90.1	86.7	98.3	97.6	87.3
Wyndtryst Drive and Lower Field	81	95	97.7	97.1	99.2	92.6
Meadow Creek Drive	83.2	100.2	99.7	98.7	93	93.8
Royer Road	83.2	91.4	100.5	96.6	94.2	93.4
Willow Street	78.6	89.4	89.3	96.8	93.2	87.2
Market Street	78.3	90.1	84.7	101.2	95.7	87.8
Tahoma Farm Road	82.8	92.3	93.1	93.6	91.1	90.9
Center at High Acre	77.1	90.1	84.7	97	100.2	87.1
Maryland 482	77.4	*	*	*	*	85.5

Temperature Measurements for each Location, each day Aug.3 to Aug. 28, 2016

Temperature Measurements						
	3-Aug	7-Aug	11-Aug	15-Aug	17-Aug	28-Aug
Parking Lot	85.7	87.3	99	88.8	94.1	90.6
Dutterer Way and PA Ave	86	86.5	98.3	87.1	100.2	88.5
Pleasanton Road	83.8	88.3	93.8	87.3	94	89
Belle Grove Square	83.9	87.8	93.6	88.4	95.2	87.3
Longwell Lot	82.3	88.6	94.2	87.8	93.5	88.2
Locust and Main	80.4	85.8	97.2	87.6	85.9	90.6
Main West of Center	82	86.2	92.5	86.5	89.4	87.2
Green Street	81.4	88.2	93.2	86.2	91.2	85.8
Town Mall Lot	86.4	92.2	95.6	85.2	104	87.1
Wyndtryst Drive and Lower Field	84.1	88.8	100.3	86.6	101.7	95.8
Meadow Creek Drive	82.3	84.8	101.2	88.2	102.2	91
Royer Road	86	87.6	95.1	83.6	97.1	89.5
Willow Street	90	88.1	92.7	84.5	93.1	87.8
Market Street	90.3	92.7	98.2	86.9	95.5	87.2
Tahoma Farm Road	84.7	86.9	94.6	87.5	96.7	87.8
Center at High Acre	92.9	88.2	100.2	84.4	98.7	86.5
Maryland 482	*	87.7	*	88.4	*	91.5

Appendix C: Calculating the Normalized Difference Vegetation Index

The NDVI and LST maps were created by Ryan Lingo by using the following process. “Landsat 5 band designation for NIR is band four and for red is band three; Landsat 8 band designation for NIR is band five and for red is band four (Lingo, 2018, 17).” The next step is to calculate emissivity since “the thermal function in TerrSet calculates blackbody temperatures”, not gray bodies, which land surfaces are considered (Lingo, 2018, 17). Next, Lingo used “the thermal module in TerrSet…to calculate LST” which used thermal band ten (Lingo, 2018, 17-18). Avdan and Jovanovska, (2016) and Anandababu et al. (2018) also used the same type of process to calculate LST using Landsat 8 data. Their research provides an easy to understand flowchart that guides the reader in LST retrieval and confirms the process used by Lingo, (2018) (Avdan and Jovanovska, 2016 and Anandababu, D. et al., 2018).

Appendix D: Select LST locations Inside City limits

LST Locations Inside City Limits	
Number	Description
1	General Dynamics
2	Airpark Square
3	Shelter Systems
4	Cliveden Reach
5	Meadow Creek Shopping Center
6	College Square Shopping Center
7	McDaniel College Stadium
8	Wakefield Valley
9	Carroll Lutheran Village
10	Dutterer Park
11	Charles Street area (between Stoner and South Center Street)
12	Green, Bishop Street and Washington Road area
13	Area of Westminster north of Pleasant Valley Road
14	Carroll County Commerce Center
15	Westminster Crossing East and West Shopping Center
16	Westminster Shopping Center
17	Town Mall of Westminster
18	Downtown Westminster
19	Area around Willis Street
20	County offices and Court area
21	Area around North Colonial Avenue
22	Westminster Marketplace Shopping Center
23	140 Village Shopping Center
24	Green, East, Webster, and 24th Street area east of Old Washington Road to Westminster City Line
Key:	
Hotter locations	
Cooler locations	

Appendix E: Select LST Locations Outside City Limits

LST Locations Outside City Limits	
Number	Description
A	Carroll County Regional Airport
B	Baugher’s Orchard
C	Carroll Hospital Center
D	Carroll County Agriculture Center
E	844 Professional Center/Phyllis L. Green Professional Center
F	Area between Maryland 31, Little Pipe Creek, Maryland 27, and Nicodemus Road
G	Industrial area located along Avondale Road near Medford Road
H	Westminster Senior High School and Carroll County Career and Technology Center Campus
I	Carroll Community College Campus
J	Carroll/John Street corridor
K	Area between Beggs Road, Maryland 27, Lucabaugh Mill, and Old Bachmans Valley Road
L	Penguin Random House
M	Sunnybrook Senior Apartments
N	Area along Old Westminster Pike (between Willow and Maryland 97)
O	Commercial Strip East of Market Street
P	Carroll County Landfill
Q	Westminster Gateway Shopping Center
R	Fieldstone Subdivision
Key:	
Hotter locations	
Cooler locations	

Appendix F: Social Vulnerability

GEOID	Percentage of the Population Below Poverty	Highest Percentage of Children Under Five Years Old	Percentage of the Population with more than a High School Diploma	Income (Per Capita Income in Past 12 months	Highest Percentage of the Population over 65 Years Old
5001	0.08	0.06	0.94	$32,685	0.21
5002	0.05	0.08	0.98	$40,956	0.08
5003	0.33	0.02	0.7	$5,637	0.01
6011	0	0.06	0.95	$37,771	0.19
6012	0.03	0.07	0.95	$35,714	0.13
6013	0.58	0.14	0.67	$11,923	0.08
6021	0	0.11	0.93	$33,478	0.14
6022	0.02	0.05	0.9	$36,999	0.19
6023	0.12	0.02	0.72	$16,460	0.16
7021	0.07	0.05	0.87	$40,816	0.25
7022	0.05	0.06	0.96	$47,359	0.12
7031	0.08	0.07	0.99	$44,806	0.19
7032	0.04	0	0.88	$46,500	0.57
7041	0.03	0.06	0.85	$29,992	0.12
7042	0.11	0.02	0.92	$34,101	0.08
7043	0.02	0.07	0.93	$39,300	0.04
8011	0.1	0.1	0.95	$31,157	0.12
8012	0.11	0.08	0.73	$21,543	0.23
8013	0.05	0.05	0.89	$33,990	0.19
8021	0.11	0.06	0.97	$32,819	0.19
8022	0	0.07	0.96	$43,937	0.16
8024	0.01	0.03	0.92	$42,049	0.23

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Curriculum Vitae

Education

Towson University, Towson, Maryland, 2015 – Present (Expected Conferral May 2019)
Master of Arts in Geography and Environmental Planning

Towson University, Towson, Maryland, 2011 – 2014
Bachelor of Science in Metropolitan Studies (Cum Laude, 3.9 GPA)

Presenter at 5th Annual Towson University EnviroFest - Transportation Planning for a Sustainable Environment – May, 2013

Finalist – 1st annual Maryland State Sustainable Growth Challenge

Presenter at the 2015 Regional Meeting of the Middle Atlantic Division of the American Association of Geographers - The Effect of Emerging Demographics and Aging of the Population on Location Choice and Travel Behavior by Households

Professional Experience

Comprehensive Planner, City of Westminster – 56 West Main Street, Suite 1, Westminster, MD, 21157, 2015 – present

Responsibilities include: Planning and Zoning tasks as assigned by the Director of Community Planning and Development. Assists with hundreds of zoning relate inquiries per year related to land use, development, annexations, liquor licensing, permitting, and water and sewer allocations. Also, acts as the City's planning liaison to Carroll County Government and United States Census. Collaborates with the City Administrator, City Attorney, and Planning Director to draft ordinances and resolutions. Reviews all signage, building permits, and residential/commercial development proposals for consistency with the City Zoning Code, Landscape Manual, and Development Design Preferences Manual.

Completed the state-mandated, mid-cycle review of the City's 2009 Comprehensive Plan Currently working on a project that will accurately map the Westminster City boundaries from the 1800's. Lead Staff Member to the Board of Zoning Appeals, Planning and Zoning, Historic District, and Tree Commissions, which includes:

- Board of Zoning Appeals – assembles and presents the City staff report and coordinates legal advertising for all variance, special exception, and zoning administrator appeal cases.

- Planning and Zoning Commission - reviews and presents petitions for rezoning, proposed signage, and development proposals.

- Historic District Commission - reviews all Section 106 Filings, reviews and presents all applications for renovation or alteration in the Historic District Zone and reviews all applications and facilitating the process regarding the City Historic Tax Credit Program. Helped facilitate the Commissions update of the 1977 Standards for Renovation.

- Tree Commission – completes and monitors applications towards many urban forestry recognition programs and manages urban forestry grants. Assisted the Tree Commission in the creation of the first ever City of Westminster, Comprehensive Tree Plan. Coordinating partnership between the Commission and McDaniel College for Environmental Studies Students to become more familiar with the City's urban forestry.

CAD Designer/Information Technology Support, Reisterstown Lumber Co. – 13040 Old Hanover Road, Reisterstown, MD, 21136, 2010 – 2015

Responsibilities included: Using computer drafting software and equipment to design custom houses and home additions; assisting engineers in architectural design and engineering; and keeping all company computer and networking equipment functioning properly. Built the WI-FI network that connects computers and machinery to the server and internet in remote areas of the lumber yard. Programs and equipment used include: Auto CAD, Sketch Up, Key Beam, Key Build, I-Pro, Alpine View, Bluebeam Revu, Microsoft Office Suite and Xerox plotter/scanner.

Memberships

American Planning Association, Member # 337732
Golden Key International Honor Society –Top 15% of graduating class
Phi Sigma Alpha Honor Society – Political Science
Omicron Delta Kappa – Leadership
Gamma Theta Upsilon - Geography
Phi Theta Kappa- International Honor Society (3.5 GPA or better)