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The Relationship between Urban Heat Islands and Redline Districts

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Abstract

As climate change worsens and the world attempts to find solutions to global changes, it is important to identify how climate change will affect individual communities. Climate resilience tactics aim to protect vulnerable populations against environmental harms, such as excess heat. Historically, communities of color face forms of environmental racism. One example of structural racism includes the loans given out by the Home Owners Loan Corporation during the 1940s which "redlined" certain communities of color by refusing to give these neighborhoods loans and rated these areas undesirable for loaners. Urban heat islands occur in residential, densely populated areas with lots of impervious surfaces and little vegetation and result in extreme heat conditions. Redlined communities and urban heat island effects are strongly connected, which was the focus of the first part of this study. In the second part, data collection and patterns were analyzed in order to identify vulnerable communities within the city of Lynchburg, Virginia. This analysis helped inform what communities are most vulnerable by determining which neighborhoods experienced the most urban heat and what demographics comprise these communities. Redlined districts had close interaction with high temperatures in certain areas, but lack of full city coverage affected results. Other indicators such as Black residents and poverty rates also had a close relationship with high heat areas within the city according to Census tracts. Based on the findings, the neighborhoods of Seminary Hill, Fairview Heights, Winston Ridge, Diamond Hill, the Business District, and Tinbridge Hill were identified as areas that trended hotter than others in the city. These issues will be addressed by recommendation of collaborative action and field work to bring about policy changes within these neighborhoods, such as increased urban landscaping in certain communities and community empowerment through education.

Keywords: Redlining, urban heat island effect, urban heat islands, vulnerable populations,

climate change, environmental justice

Introduction

As global average temperatures increase, sea levels rise, and natural disasters become more frequent as a result of climate change, some communities feel the effects more than others (Bullard, 2000). This idea of disproportionate impact is the foundation of environmental justice, a social and political movement that aims to eliminate the unequal distribution of environmental harm to certain demographics (Bullard, 2000). Vulnerable communities exist for many reasons, including dynamics related to socioeconomic status and race, and, in many cases, vulnerable communities are groups of individuals that are dealing with one or more sources of oppression (Dow & Downing, 2015). High concentrations of poverty expose communities to more harm from climate change, whether that be due to pollution, urban heat, a lack of clean water resources, or at-home hazards such as lead poisoning (Dow & Downing, 2015). Individuals experiencing poverty are more likely to have limited housing options; oftentimes the low-cost options available are perceived by middle and upper-class citizens as less desirable and are located in closer physical proximity to environmental hazards (Bullard, 2000). Additionally, vulnerable communities are typically unable to access resources that might buffer seasonal health concerns that affect everyone in a city, such as air conditioning in their home or nearby air conditioning centers to prevent harm from heat waves (Eisenman et al., 2016). There is a rich history of environmental hazards and risks occurring within communities that are dealing with some form of oppression; as climate change effects worsen, vulnerable communities are going to experience more harms that will require resiliency and adaptation planning to address the effects of climate change and mitigate negative impacts. Smith (2008) provides a powerful statement on the core issues of environmental justice and vulnerable communities when stating:

"In terms of absolute burden, however, it seems clear that it [climate change] most

> threatens the poorest and most vulnerable populations in all societies, probably in close inverse proportion to income, wealth, and power. The rich will find their world to be more expensive, inconvenient, uncomfortable, disrupted, and colorless—in general, more unpleasant and unpredictable, perhaps greatly so. The poor will die." (Smith, 2008)

The insight that Smith provides informs us that these communities urgently need to be identified in order to minimize heat mortality that will occur as a result of the extreme heat events that climate change causes.

Studies to identify communities vulnerable to urban heat island effects have been conducted across the nation in areas such as Portland, Oregon and Richmond, Virginia. Drawing from nationwide studies, the Virginia Foundation for Independent Colleges undertook a larger heat watch study in the Commonwealth of Virginia to gain information on urban heat islands within cities. In studying extreme heat and its relationship with socioeconomic factors, the first step in the process is identifying the most at-risk communities to pursue fieldwork in. This study aims to identify the communities most at risk in the city of Lynchburg, Virginia, in order to inform the larger study to address the disproportionate effects of extreme heat events in large cities. In the context of this study, the foundational steps include identifying the data patterns found in a heat watch by making the technical data understandable to the average citizen, identifying key at-risk communities, identifying key indicators of high urban heat risk, and educating and uplifting voices within affected communities in order to effectively communicate with citizens and develop policy within the next steps of this collaborative project.

This study is divided into two main parts. The first part addresses the relationship between redlining, urban heat island effect, and other identifiers of vulnerable communities within the city of Lynchburg. The second part discusses the data collection from heat sensors and a summary of the results found and created from the data. Both sections aim to explain, identify and address the residential neighborhoods and vulnerable communities in Lynchburg which are most at risk to extreme heat events and urban heat island effects.

Part 1: Urban Heat and Redlining

Climate change is increasing the number of extreme heat events and therefore there is a growing number of communities at risk to high heat events in larger cities. According to the National Aeronautics and Space Administration (NASA), up to 80% of the planet's population will live in larger cities within the next 50 years (Zhang et al., 2010). In larger areas, more extreme heat events occur due to infrastructure, lack of green space and other extraneous variables resulting in urban heat islands. This means that due to a growing population, urban heat islands will affect many populations, but as with almost every other environmental concern, certain populations already experience urban heat island effects disproportionately. In most larger cities, this pattern has to do with the historical practice of redlining and racial segregation.

History plays a large role in determining vulnerability for communities with regards to multiple bio-socioeconomic and environmental justice issues. One example of a historical policy that has directly influenced the racial composition of neighborhoods in larger cities is called *redlining*. Redlining refers to the systematic refusal of loans to residents in Black neighborhoods carried out by the Home Owners Loan Corporation (HOLC) between 1934 and 1940 (Rothstein, 2017). HOLC was a United States federal agency that issued loans and mortgages to certain communities based on an assessment of security and upward mobility of a neighborhood (Rothstein, 2017). Research has shown that systematically these assessments were deeply flawed, as they assessed predominantly White neighborhoods highly, issuing loans and mortgages while rating Black neighborhoods badly and denying opportunities for loans and mortgages (Rothstein, 2017). Even a White neighborhood with proximity to a high population of Black residents was going to be rated lower than areas surrounded by primarily White neighborhoods. Regardless of the average income, if a neighborhood contained people of color despite being “middle class” at the time, then they were on a downward “Trend of Desirability” (Rothstein, 2017).

Despite redlining practices ending in 1951, the impact of the HOLC assessments can still be observed even now in the 21st century. Predominantly Black neighborhoods also were influenced and impacted by factors beyond the redlining policies of the HOLC that aimed to establish and maintain racial segregation. Other systemically racist policies included incitement of violence by intimidation and attacks on Black citizens in neighborhoods such as Louisville, Kentucky, through rallies, racist groups entering communities and committing acts of crime against Black citizens, and encouragement of White citizens to move out of neighborhoods where even a single Black citizen had moved into the area (Rothstein, 2017). Research has shown that communities with low HOLC security ratings have been associated with low homeownership rates, reduced access to credit, and a limited ability for residents to move out of these neighborhoods and into higher-income communities even today (Rothstein, 2017). Redlined neighborhoods have historically lacked the ability to gain generational wealth by lacking access to quality and reliable housing, employment, and transportation, therefore limiting the ability for redlined communities today to have escaped the cycle of poverty (Lynch et al., 2021). In many large cities, there is a continued trend of segregation that remains and affects multiple demographics such as the income gap and poverty levels (Rothstein, 2017).

Urban Heat Island Effect

Large cities also experience more of the environmental hazards associated with climate change. This is largely due to a phenomenon called “urban heat island effect”. An urban heat island is defined as an area where there are higher average temperatures within heavily populated, larger metropolitan areas compared to surrounding more rural areas due to human-created conditions (U.S. EPA, 2008a). On hot summer days, impermeable surfaces, such as roads, sidewalks, and roofs, can affect the surface temperature of the land (Bounouna et al., 2017). This is because as the sun’s solar energy shines down onto the Earth’s surface, it is either reflected or absorbed back. Certain colors and materials are better at reflecting solar energy than others, and impermeable surfaces typically do a poor job of reflecting solar energy. Therefore, darker, impermeable surfaces such as pavements and roofing reflect far less solar energy compared to trees and vegetation (U.S EPA, 2008a). Additionally, trees, water, and vegetation provide shade and aid in evapotranspiration, the process by which water evaporates out of the leaves and provides cooling effects to the land (Bounouna et al., 2017). Tall buildings in larger cities absorb massive amounts of heat and affect wind patterns in a city’s atmosphere, leading to less wind allowing cooling (U.S EPA, 2008a). Additionally, materials such as steel and stone store significantly more heat than other materials, and tend to affect the surrounding areas (U.S EPA, 2008a). Lastly, there is the added concern of anthropogenic heat, which refers to heat caused by human activity such as energy production, driving vehicles, air conditioning, and industrial facilities (U.S EPA, 2008a).

For this study, the focus is on surface heat and increased surface temperatures within heavily populated areas. Typically, surface heat is most intense during the day during the hottest days of summer (U.S. EPA, 2008a). Surface heat is measured most easily indirectly through remote sensing to give an approximate surface temperature value in a given area (U.S. EPA, 2008a). Cities in the United States have air temperatures up to 10 degrees warmer than nearby rural vegetated areas (Bounouna et al., 2017). Figure 1 is a map displaying the surface temperature of New York City in comparison to the amount of vegetation present. Therefore, more vegetation density often has a relationship with lower surface temperatures in metropolitan areas like New York City (Figure 1).

Though many indicators have a relationship with urban heat island effects, redline districts have been found to have a strong relationship with urban heat. A recent study found that 94% of 108 cities studied had a higher surface temperature in redlined areas compared to non-redlined areas (Armstrong, 2020). Some scholars have suggested that this is because more projects such as park initiatives occurred in White communities, as well as fewer roads built through the neighborhoods when compared to predominantly Black communities (Armstrong, 2020). This would cause less tree canopy cover and more impervious areas to be present in historically segregated Black communities that still exist within city infrastructure today.

Case Study of Richmond, VA

A comprehensive heat watch project was studied in Richmond, Virginia. The study allowed the examination of urban heat island effects in vulnerable populations by creating a map of the areas that were previously redlined, then sending out volunteers with mobile sensors to monitor the effects of days with heatwaves in various locations (Hoffman, 2018). The study also made note of the percentage of tree canopy cover, impervious surfaces, and poverty levels. The areas that were considered most vulnerable by the study had significant overlap with redlined districts (Figure 2). The map on the left displays the HOLC ratings made in the 1940s overlaid with the city map of Richmond. On the right are the results of Hoffman's urban heat island study, displaying areas that were found to be most vulnerable to urban heat, longer heat seasons, and more high heat events (Hoffman, 2018).

Figure 2 shows side-by-side comparison of the neighborhoods that had increased vulnerability next to the Richmond residential HOLC map, with the areas colored in for their rating, the redlined districts in red. Visually, the areas that have increased vulnerability to urban heat have a close relationship with areas that were previously redlined. If you look closely at the image, you can locate the river (blue) on the top, on the bottom, the grey area through the middle is the river (Figure 2). Almost every area with historical redline districts is vulnerable to urban heat. Furthermore, Hoffman found that the amount of tree canopy cover, land surface temperature, and impervious surfaces varied by HOLC rating, with lower ratings resulting in more environmental harm in neighborhoods (Figure 3).

Case Study in Lynchburg

In 2010, Lynchburg had a population of 70,000 and a heat island measure of 5.5 C and 9.9F, which indicates the temperature difference between the highest heat and rural areas (Zhang et al., 2010). In 2020, the population is approximately 79,000 and Lynchburg is growing steadily with a 4.6% population growth rate since the last Census and has produced a sprawl of new neighborhoods, developments, and economic growth in the area (Honosky, 2021). Due to this growth, there is a need to identify the development pattern of the city and make plans to address urban heat island effect as effects will worsen with more development and time.

There are still clear racial and economic divides within Lynchburg today, with redlined districts having the lowest income in the area according to the 2010 U.S Census. In John Abell's study (2018) about the lasting effects of redlining in parts of Lynchburg, it was found that redlined areas have been maintained by most measures. Areas that were redlined now have a low median household income that prevents homeownership and poverty rates over 40% in most C or D (low ranking) HOLC rated areas. The results show that the areas of Lynchburg that were deemed unsuitable in the 1930s during HOLC rating remain impoverished today (Abell, 2018).

Abell (2015, 2018) has done significant research in Lynchburg showing poverty is the main component of vulnerability and has suggested that areas that are below the poverty line are vulnerable to heat island effects. Lynchburg had 22.6% of the population in poverty as of 2013 (Abell, 2015). Housing patterns may change and adapt over time, but as seen in Abell's study, income still plays a large role. In addressing income inequality, it is important to note that generational poverty as a result of racist practices can exist without strictly relating to redline districts. In Lynchburg, Black poverty rates were on average above 34% (Abell, 2020). In Abell's (2015) study done on Lynchburg, the city is broken down into 12 census tracts, similar to areas split up by HOLC, which gives a contextual representation of historical poverty levels compared to today's census tracts, and it shows that there is a significant difference in poverty rates between the White and Black population, with the White poverty rate at 19.0% in Lynchburg and the Black poverty rate at 34.7% (Abell, 2015).

These studies emphasize the need for quantitative heat data within the city. As areas such as Lynchburg continue to industrialize, existing segregation and disproportionate harm will influence vulnerable communities in Lynchburg. It is vital that these communities are identified when addressing climate change mitigation within city planning so that policies can be made to address this information and find solutions. Identifying these vulnerable communities will also allow these areas to learn the issues affecting them and make decisions. We can use this information to ask the questions: what populations in the city of Lynchburg are most vulnerable to urban heat island effects, how much overlap is there with redline districts and other indicators of vulnerability, and how can this analysis be used to assist these communities in resilience planning?

In order to identify these populations, data collection and analysis is vital. A project mapping urban heat islands and temperature data did not yet exist for Lynchburg, although there are pre-existing databases and research done to examine redlined districts and their existence continuing into the modern day. By using heat sensors provided by consulting groups, heat maps of the city were produced and uploaded into geospatial software in order to analyze the patterns, identify patterns between poverty, redline districts, and high heat areas in neighborhoods. These areas are the product that will be used to inform the next steps of this project which will reach out to these communities and build policy plans.

Part 2: Data Collection and Analysis

To collect data on urban heat island effects, the Virginia Foundation for Independent Colleges (VFIC) organized a heat mapping project across the Commonwealth of Virginia, including Lynchburg. The data were collected by sensors provided by an outside consultant, CAPA Strategies, to obtain heat and humidity data across the city to identify the urban heat islands that are present within the city (CAPA Strategies, 2021). Five routes were mapped across the city of Lynchburg, specifically planned by VFIC project organizers that aimed to include potentially vulnerable communities as well as measure heat near important landmarks such as parks, schools, grocery stores, churches, family centers, and government buildings. These routes were approximately 20 miles each, and each route was assigned a designated driver and a passenger in charge of helping to navigate the pre-planned route.

A window of days for record heat was chosen by VFIC project organizers by examining historical high-temperature records. The actual data collection day was set as July 15th, 2021, based on its prediction for a high heat event and a lack of extraneous variables such as rain and cloudiness which might affect heat sensor data. A volunteer team of ten faculty and students from the University of Lynchburg and Randolph College, as well as other established sustainability and environmental specialists in the area, participated in the data collection by driving the assigned routes with the sensors provided. On the day of data collection, I acted as the navigator for driver Dr. Henry-Stone of Route 2, a 21-mile traverse. The heat sensor provided by CAPA Strategies was placed in the passenger window and turned on, and the route was driven at three different times during the day: 6-7 am, 3-4 pm, and 7-8 pm (Figure 4).

The sensors collected heat, humidity, longitude and latitude, speed, and location along the course each second. After each route was driven, Google Surveys were submitted to the coordinator of the project, Dr. Karin Warren to disclose any disruptions, wrong turns, weather conditions, or problems that occurred while volunteers were driving the routes to account for anomalies in the data. Figure 4 shows all of the routes driven during the three different time windows depicting the complete coverage of each route driven in the city. Once the routes were driven during the three different time windows, the sensor was returned to CAPA Strategies.

From there, the raw heat data collected by the sensors was downloaded by CAPA Strategies and compared with the ending survey which asked for any problems while driving the route from volunteers. The consultant, CAPA Strategies, was then responsible for downloading multi-band land cover rasters from satellite information accumulated during the driving of each route. Multi-band land cover rasters give multiple bands of pixelated raw data in the form of rasters, which are a grid of pixels that comprise an image. The multiple land cover bands make a larger, complex, and complete image about a certain area of land, in this instance, the city of Lynchburg. While the sensor travels around town during the driving route day, it sends information to satellites, then allowing many images of the heat information in that area to be analyzed. CAPA used a moving window analysis, where each area where sensors detected information is associated with landscape patterns present and then calculated statistics of the land cover bands. The data were then combined with land cover data in a Machine Learning model and a predictive raster land surface model was made of each traverse period to show the surface heat of each area driven. The data were then cross-validated by CAPA Strategies using a 70:30 holdout method for accuracy, where 70% of the data is used for training and 30% is used to test the model used.

Results were provided by CAPA Strategies as overlays and TIFF images (CAPA Strategies, 2021). These documents were downloaded and analyzed in Esri Software specifically using ArcMap to examine the heat data in relation to other indicators of vulnerable populations. Layers used include HOLC Ratings for neighborhoods in Lynchburg generated by GIS Online

Users, ACS Poverty Rates and Race from 2010 Census Data and neighborhoods all made by the Lynchburg city GIS Department.

Analysis of Data Found

It was found that in the areas where HOLC Ratings were lower, the temperatures trended higher than areas where HOLC Ratings were higher (Figures 5-7). In areas previously rated as “A” or “B”, there were no temperatures that were extremely high in any residential areas. The only exception to this was a hotspot within a “B” area, which is now Randolph College.

Some “C” and “D” rated areas, including redline districts which are “D” rated, did not have high surface temperatures when compared to “A” and “B” areas. However, all of the residential HOLC-rated areas that did have high surface temperatures were either “C” or “D” rated HOLC areas. The GIS maps (Figures 5-7) show the morning, afternoon, and evening temperatures with the HOLC rating “A” colored green, “B” colored blue, “C” colored yellow, and “D”, redline districts, colored red.

As seen in Figure 4, certain areas in the city of Lynchburg heat up to higher temperatures than others. It is important to note that only a small portion of the city contains areas that were rated by HOLC, mostly the downtown area. Furthermore, a very small amount of the city contains redlined areas. While these areas still contain vulnerable populations, certain areas contain different demographics compared to the historically redlined areas which will be examined later in the analysis.

The heat maps tell us an interesting story about high heat in Lynchburg. The first image (Figure 5) shows the highest heat reached during the morning traverse, the second (Figure 6) during the afternoon traverse, and the last (Figure 7) during the evening traverse.

The morning afternoon surface temperatures ranged from approximately 66 degrees to 73 degrees (Figure 5). The highest heat areas are along the southeast side of town, situated close to where Highway 29 runs through the city. These areas are mixed between residential and commercial areas, with impervious surfaces such as the Riverridge Mall. The coolest part of the city tends to be the northwest, much of which is more densely vegetated.

The afternoon surface temperatures are the highest among the three, as this is when heat waves occur and the areas most vulnerable to urban heat island effects are revealed by the surface temperature data (Figure 6). Temperatures ranged from 88 to 98 degrees, much higher than the morning temperatures. This data was revealing in some important ways. For example, across the city, there was an increased temperature from the morning to the afternoon, but the middle corridor had lower afternoon temperatures relative to the other areas. However, some neighborhoods got notably hotter and commercial areas remained at a high temperature.

In the evening, many areas cooled off quicker than others, such as the commercial areas that heated up quickest (Figure 7). Surprisingly, the middle corridor trended hotter relative to other areas in the city more in the evening compared to the afternoon. Neighborhoods that were yellow to blue in the afternoon heat maps are yellow and red in certain areas, particularly in the neighborhoods in the Fort Hill area.

The residential areas visually hottest in the darker red clearly contain areas that were historically rated lower. However, not all redlined areas had higher surface temperatures than previously “A” or “B” rated HOLC areas. For example, the average surface temperature in the previously redlined neighborhood now known as Fairview Heights reached approximately 96 degrees Fahrenheit while historically highest rated neighborhoods such as Riverside and Fort Hill did not exceed 93 degrees Fahrenheit.

The neighborhoods that were hottest and had been rated by HOLC were all previously either rated declining or hazardous, which is what we would call redlined. Out of the 32 HOLC-rated neighborhoods in the areas that would be considered high heat during the afternoon, approximately only 25% of the A-rated neighborhoods were in high heat areas compared to 50% of D-rated neighborhoods. The approximate temperatures of the neighborhoods previously redlined trended higher than neighborhoods previously rated best or still desirable. Clicking pixels within the GIS software produces an approximate temperature value in the area. For D-rated areas the values during the afternoon were approximately 93 compared to the A-rated temperatures of approximately 91. This information was obtained from finding the approximate highest temperature value in each HOLC-rated neighborhood and averaging the values from all A and D-rated neighborhoods to the nearest whole temperature. Time of day does influence this with the middle corridor heating up slightly more in the evening leading to a slightly higher temperature in more C rated neighborhoods, but generally not affecting A or D rated neighborhoods. In the morning, a slight hotspot occurs downtown in a D rated neighborhood of 71 degrees, which is still a comparatively cooler temperature. Although the middle corridor decreased in temperature from afternoon to evening, this area was cooler relative to other areas in the afternoon but roughly the same temperature as other areas in the evening. It is unclear why this pattern might occur. Speculatively, this area may comprise more buildings letting off residual heat in the nighttime not captured in the afternoon heat information.

However, it is clear that redlined districts or neighborhoods with lower HOLC ratings were not the only areas with the highest surface temperatures in the city of Lynchburg. More recent development has occurred in the city of Lynchburg, and not all residential areas have available HOLC ratings to compare the historical value to the current day value. Areas that had more urban heat than others but do not have HOLC ratings to compare include Boonsboro and Peakland (Figure 8). These areas also include non-residential areas that influence high heat such as Virginia Episcopal School affecting the Peakland neighborhood heat data. Other clear non-residential areas also appeared on the heat map with hotspots such as Riverridge Mall, Wards Road business areas, and Sandusky Elementary School. These areas are not residential, thus do not necessarily indicate vulnerable populations, but do indicate areas of concern for high heat areas and likely too many impermeable surfaces.

Regarding commercial zones, it is important to note that these are areas of high concern in city planning. Liberty University is one of the hottest areas in the city of Lynchburg, despite there being many other universities (Figure 8). However, the effects of this study mostly occur during summer, during which most Liberty Students are not on campus. Additionally, Liberty University is not primarily a residential area, and students have great accessibility to air conditioning centers that are not available to neighborhoods being considered. Additionally, year-round students live off-campus, and these students are being considered when acknowledging high-risk areas. Regardless, Liberty University clearly needs to limit the number of impervious surfaces they are building and consider adding more green space.

However, to understand which residential communities might be at the highest risk aside from redlined districts, it is important to examine the demographics of these areas. Using Census

Tract information uploaded by the city of Lynchburg GIS department, we can examine the overlap between race, income, and high heat areas. Figure 9 is a map showing an overlay depicting 2010 Census Tracts and the estimated percentage of families in poverty in each tract. In neighborhoods previously redlined or rated declining, there are generally higher percentages of families in poverty. Additionally, the map (Figure 9) shows that there is a connection between the percentage of those in poverty in a tract and the urban heat that an area experiences.

Tracts that are hotter tend to have higher estimated percentages of families in poverty (Figure 9). It is important to note that there are constraints to the data presented as this Census is from 2010. While there is newer Census information, these data are not available in GIS for comparison. The cooler temperature situated in the middle of Lynchburg may be due to some development in these areas not reflected in the Census data from 2010. It is unclear why higher poverty areas in the middle corridor did not have peak temperatures, were comparatively warmer in the evening, and are still relatively developed. Regardless, patterns can be seen in the data in other areas. In Census Tract 4 along the James River, there is a low poverty percentage compared to the highest heat areas residentially (Figure 9). Census Tract 19 appears to be one of the most affected areas and has an estimated 35.5% of the residents in poverty, in addition, Census Tract 14 is greatly affected with 42% of residents in poverty (Figure 9).

In addition, it's important to consider the conditions that caused these communities to be unable to access generational wealth. HOLC ratings were primarily based on how many Black residents there were in a neighborhood, therefore it is important to consider the population demographics of areas that are at risk of high heat areas (Figure 10). Furthermore, this information can tell us whether the composition of neighborhoods has changed and how much an area might be gentrified. In areas that were previously redlined, we can assume that high percentages of Black residents once lived there, and if these areas have a low percentage relative to other areas, it is likely that Black citizens were displaced from these areas.

The areas most affected by high surface temperatures include Census Blocks 14, 19, 18, and certain sections of other downtown Census Blocks. For example, no evident hotspots are seen in Census Block 3. Comparatively, Census Blocks 6, 5, 4, 7, and 11 have clear hotspots within the blocks, mostly within areas that are residential (Figure 10). These areas have a higher population of Black or African American residents compared to lower heat areas with no clear hotspots (Figure 10). Census Blocks like 2.01 contain a range of residential and commercial zones, with most of the residential zones comprising the low heat areas, and also having much lower percentages of African American citizens (Figure 10). The clear exception to this pattern is in Census Block 14, where 11.87% of the population is African American alone but is one of the hottest areas (Figure 10). Again, this area comprises a mix of residential and commercial zones, such as Liberty University and shopping centers. Regardless, the neighborhoods in this area are still at risk, especially with regard to poverty levels (Figure 9).

When setting aside commercial zones and student spaces, it becomes clear which neighborhoods are the most vulnerable within Lynchburg, Virginia. These neighborhoods include Seminary Hill, Fairview Heights, Winston Ridge, Diamond Hill, the Business District, and Tinbridge Hill; each trend higher than other areas in each time of day on the heat maps (Figure 8). Other areas comprise residential areas, factories, or commercial buildings that while impervious, do not have residents at risk to consider towards vulnerable populations. Of the neighborhoods listed, all have an area previously redlined except Winston Ridge and the

Business District which were not rated by HOLC (Figures 6, 8). To consider why certain areas downtown that had previously been redlined are now at an average risk of urban heat island effects, it is important to recognize the role that gentrification plays. Gentrification is the changing of residential areas where historically lower income neighborhoods are moved into and renovated by wealthier individuals, pushing out lower income citizens. Previously, Rivermont, Daniels Hill, and College Hill had areas that were redlined. Rivermont and Daniels Hill are within Census Tract 4, which has a poverty percentage of 18.7%, comparatively much lower than the most at risk Census Tract 19, with a poverty rate of 35.5% (Figure 9). The downtown area has been renovated heavily, especially scenic real estate that overlooks the river in this zone.

Gentrification, development, and suburban sprawl all influence the composition of neighborhoods within the city. It is important to note that the Census data used is from 2010, and the city continues to develop in significant ways perhaps not captured by the race and income statistics provided. In future studies, more recent Census data may be helpful when analyzing discrepancies.

Future Recommendations

In order to acknowledge the inequity of heat within Lynchburg, Virginia, it is important to get city officials involved. From this point forward, action groups need to acknowledge the vulnerable populations identified and reach out to leaders within these communities. The analysis of this data is meant to inform the larger project and identify communities to engage and connect with when planning. It is vital that adaptation methods and resiliency methods are community-based and led by individuals identified in the populations found to be vulnerable so that these communities are both informed and advocating for their own needs and interests

(Walker & Mason, 2015). Neighborhood centers are present within many of these communities such as Diamond Hill Center, Fairview Center, Miller Center, and Yoder Neighborhood Center. As this study has established key areas, this information should be used to inform hands-on organizational planning, using these centers as possible places to educate and engage community members with the data found.

Based on the literature around urban heat islands and resiliency planning, it is advised that community members and collaboratives should push for deliberate urban planning to eliminate impermeable surfaces within these neighborhoods, and ensure that these communities have access to cooling centers, and provide air conditioning within these housing communities (U.S EPA, 2008b). The first step in acknowledging this problem on a city level, and in the grander scheme a national level, is to empower these communities with the information they need to understand the problems at hand. Working through the data presented in this may be difficult to digest by populations not well acquainted with data and its interpretation. Teaching and simplifying the data gathered and visualized in GIS of heat sensor data is essential in the next steps of policy planning and community involvement. Understanding raw data is not essential to tackling heat equity, but helping vulnerable populations to understand the problems affecting them is an essential part of the analysis and lies on the scientists and researchers involved. In the continuing studies from this information, statistical analysis should be done to quantify the patterns examined, and information found in this study should become public, engaging, and digestible by the vulnerable populations found in this study.

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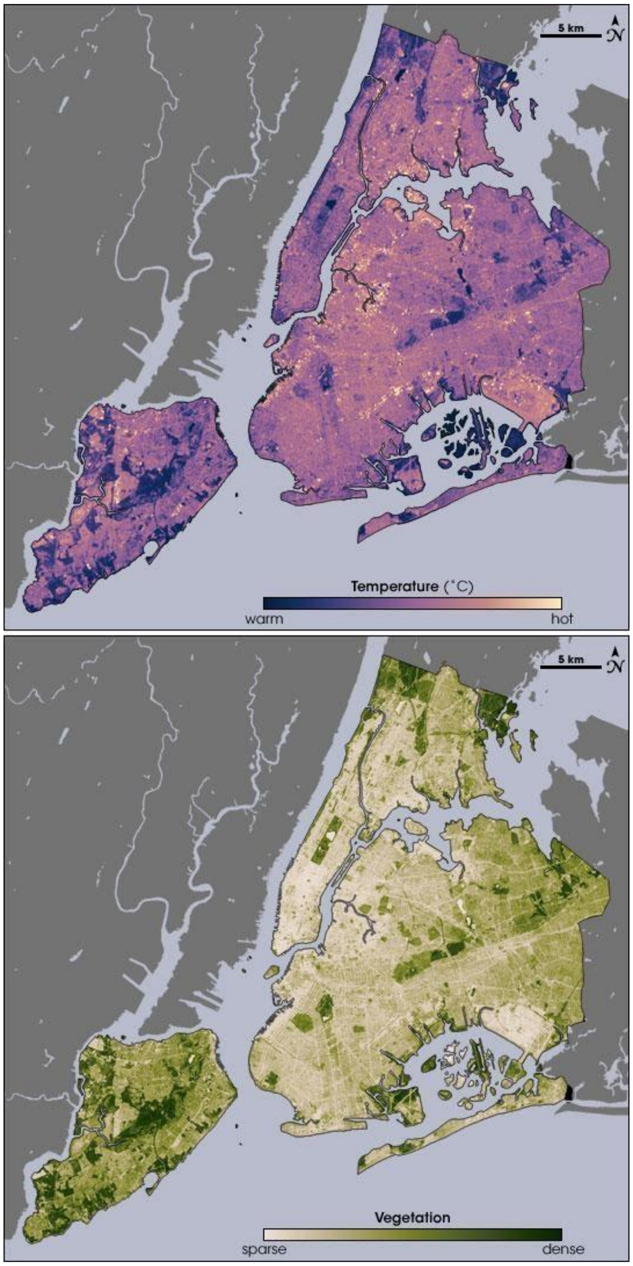


Figure 1. Comparison of surface temperature (top panel) to vegetation cover (bottom panel) in New York City. The white and lighter areas indicate higher temperatures in the top image, which correspond to areas that have sparse vegetation in light green in the bottom vegetation image Dark purple areas are lower surface temperature areas which corresponds to dense vegetation cover (Figure 1). Created by NASA (Zhang et al., 2010).

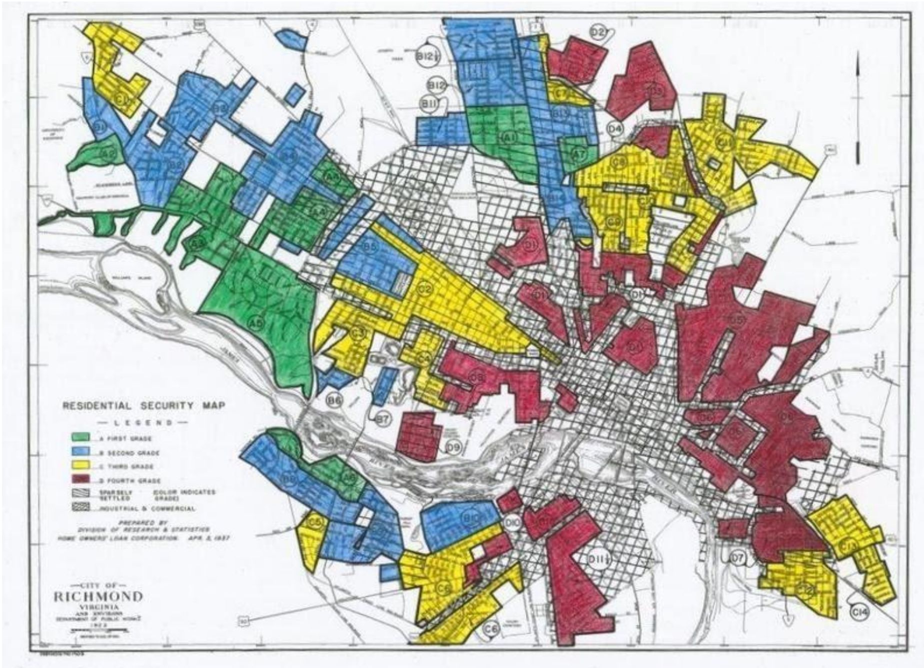
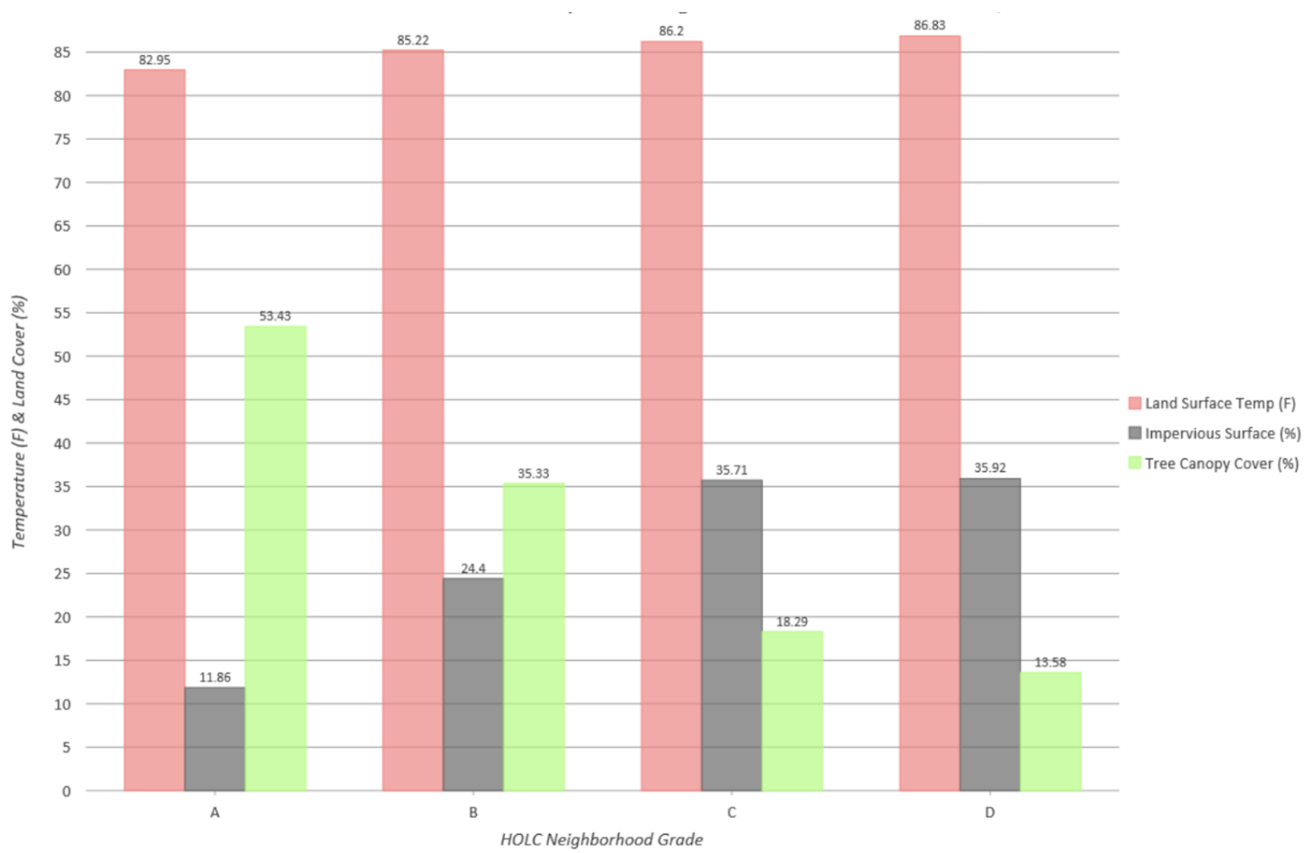


Figure 2. Comparison of urban heat vulnerability and HOLC rating map. The green areas were considered “A” rated as best, blue is “B” considered still desirable, the yellow is “C” ratings considered declining, and redlined areas are rated “D” and were considered hazardous. The areas in red outlined are the areas considered *redlined* based on their HOLC rating. Maps of

Richmond, Virginia created by Living Atlas and Hoffman et al (2020).



Land Surface Temperature and Impervious Surface increase as HOLC neighborhood grade decreases while tree canopy increases with neighborhood grade.
(*Source: NLCD & Landsat 8 data summarized by HOLC grade by Groundwork Milwaukee.*)

Figure 3. Environmental Risk factors by HOLC neighborhood grade in Richmond, Virginia. Land surface temperature, tree canopy cover, and HOLC neighborhood grade used to compare factors in different HOLC ratings. Graph made by Hoffman et al. (2020).

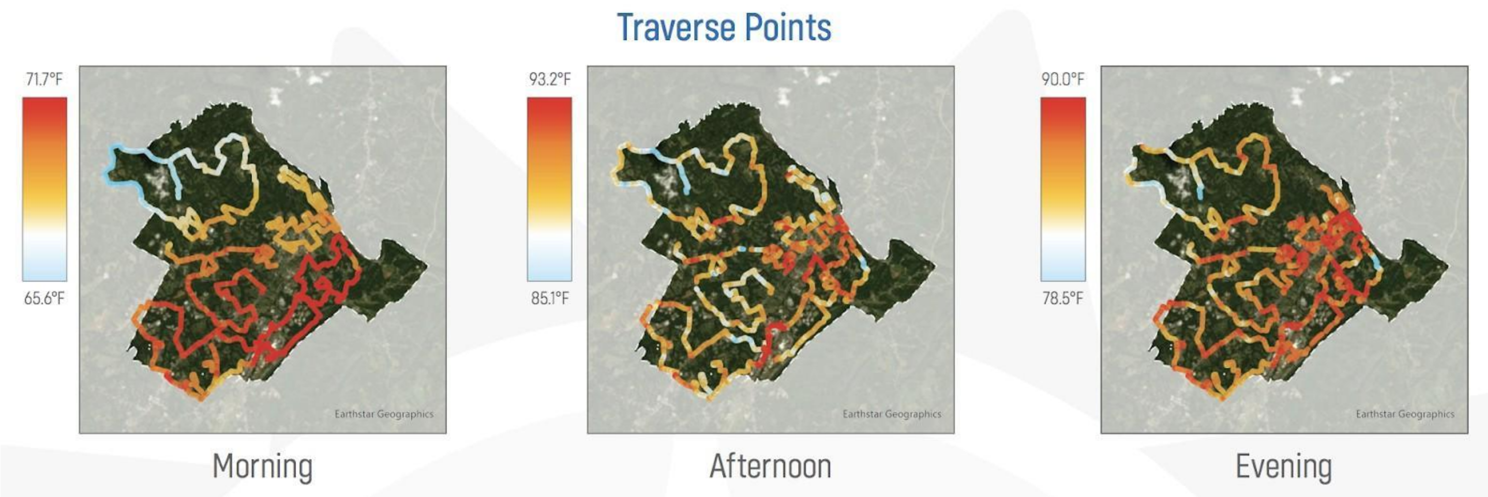


Figure 4. Traverse points and routes of Lynchburg, Virginia heat map project. Darker red colors indicate areas along the route that were a higher temperatures along traverse points and routes in the city of Lynchburg. Cooler temperatures are indicated by blue and white colors on the traverse. Depicts routes driven during the morning, afternoon, and evening on the volunteer date. Map created by CAPA Strategies (2021).

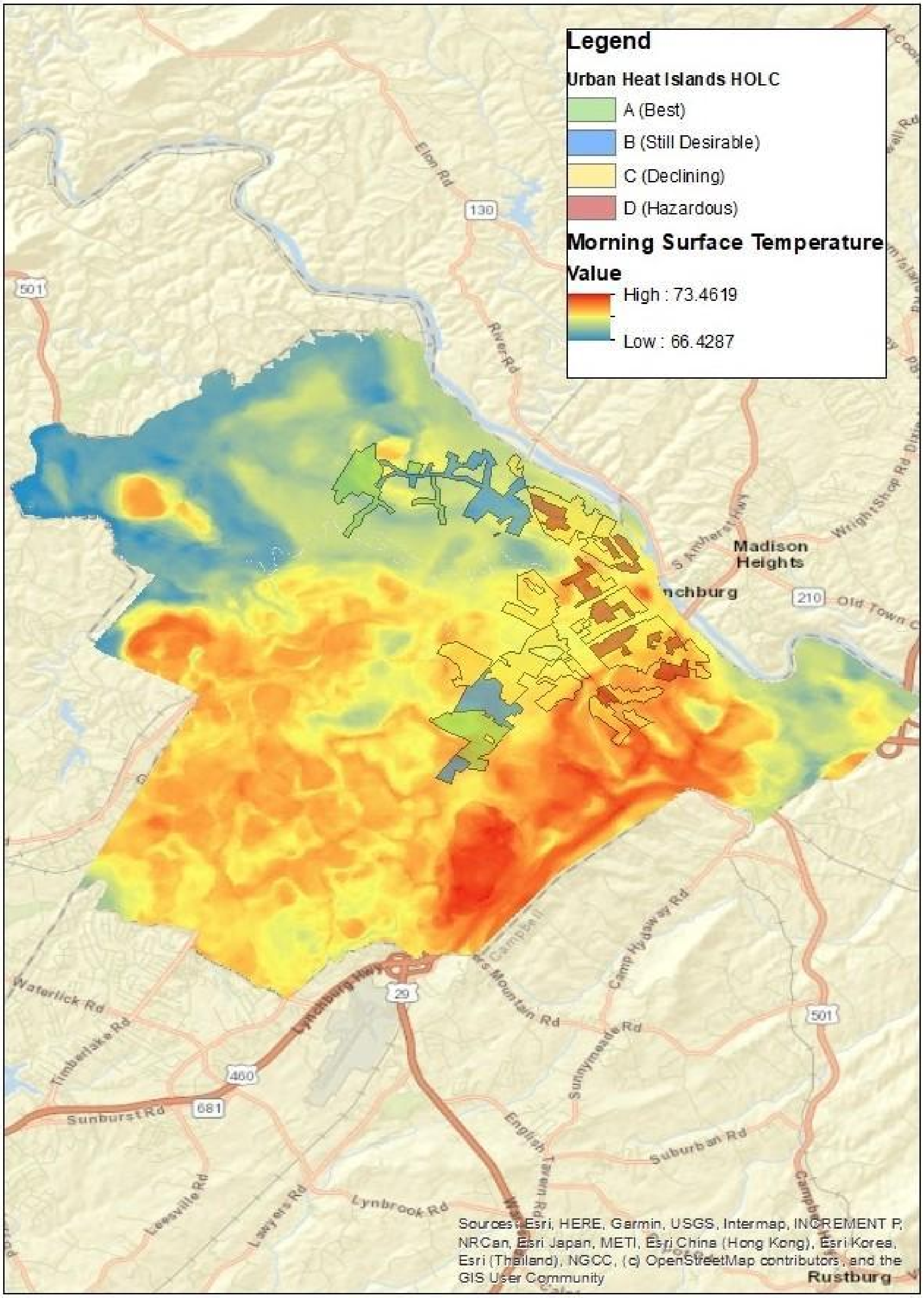


Figure 5. *Morning peak temperatures found in Lynchburg, Virginia during heat watch project* and HOLC rating overlay. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day.

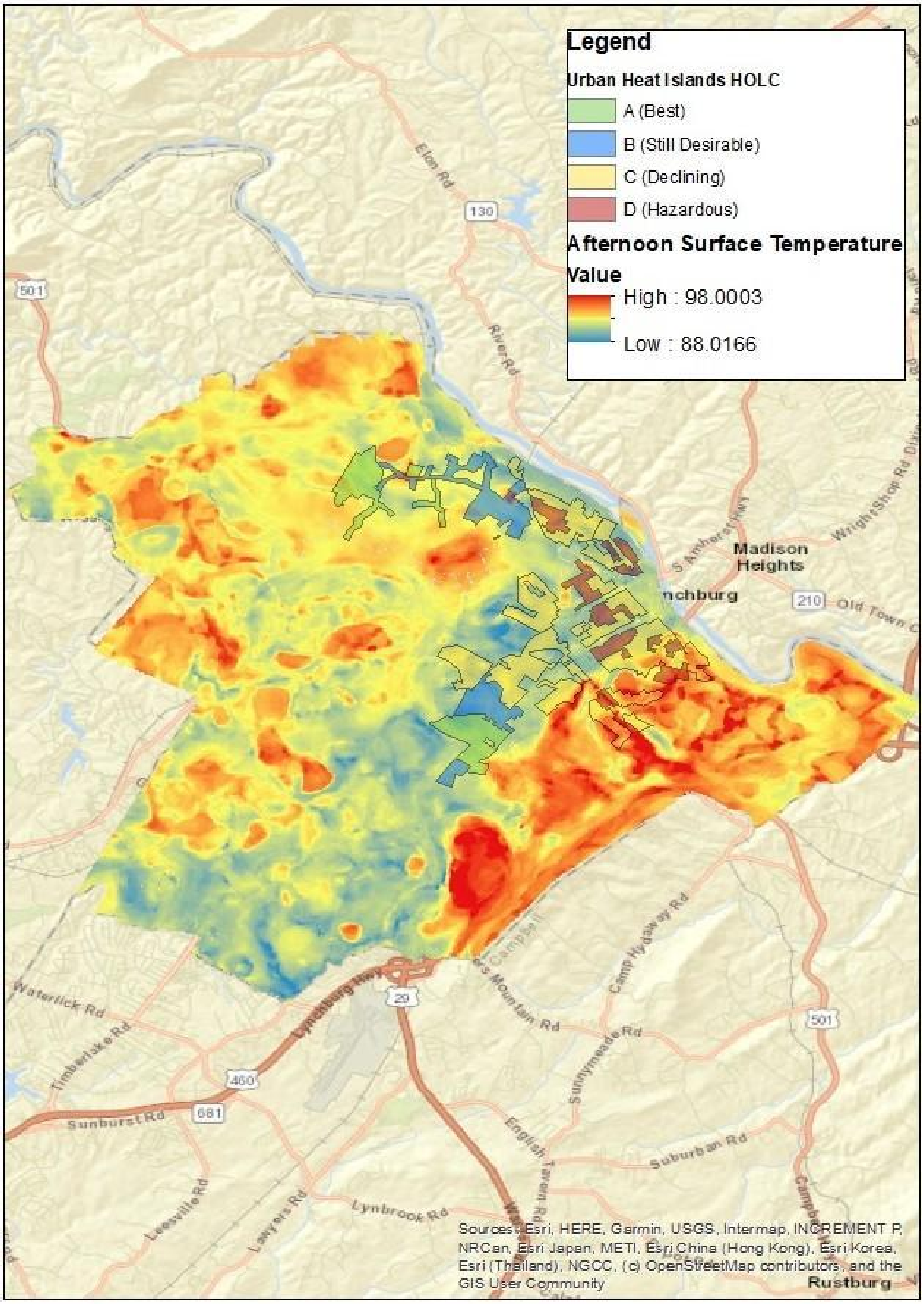


Figure 6. *Afternoon peak temperatures found in Lynchburg, Virginia during heat watch project* and HOLC rating overlay. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day.

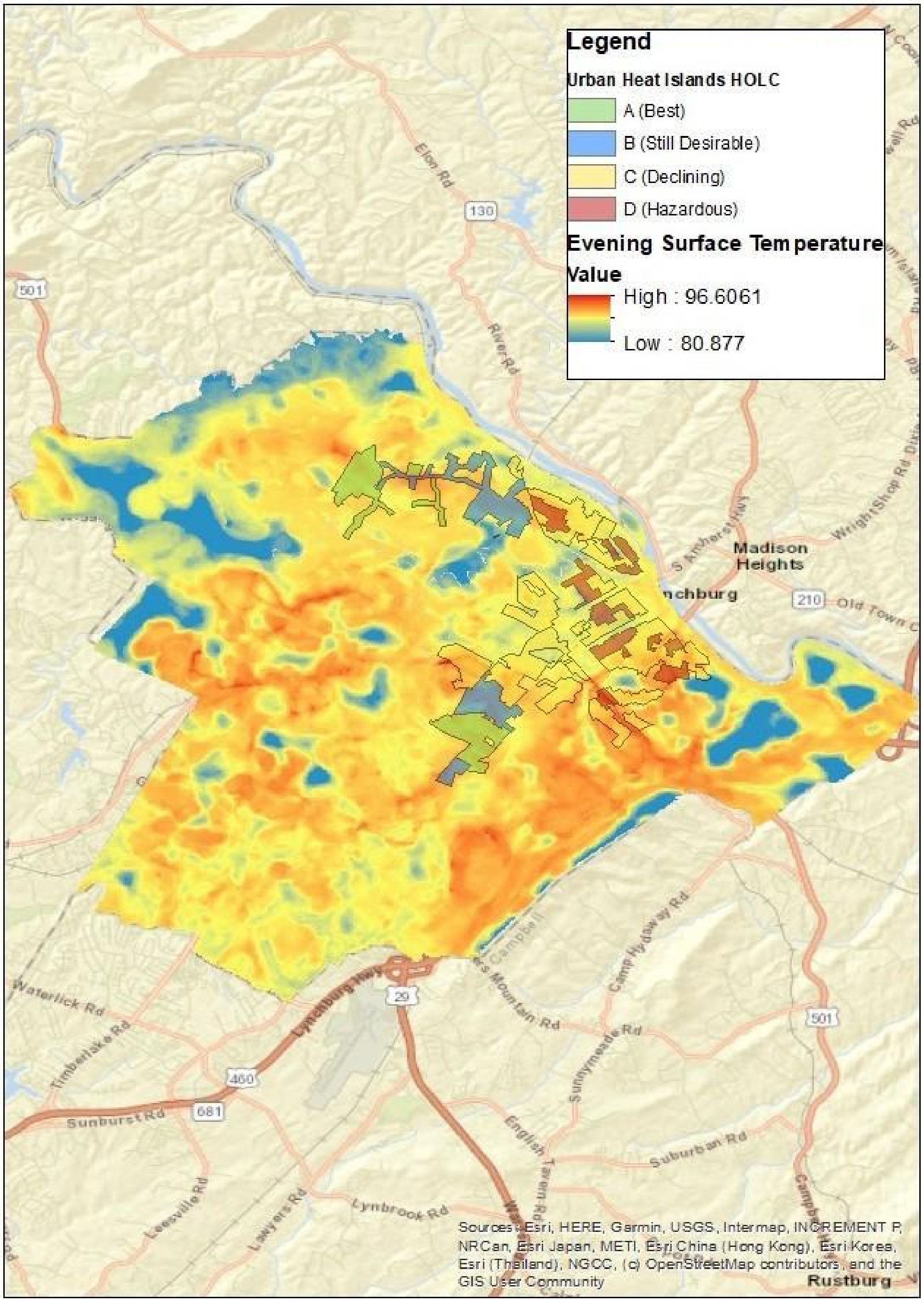


Figure 5. *Morning peak temperatures found in Lynchburg, Virginia during heat watch project* and HOLC rating overlay. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day.

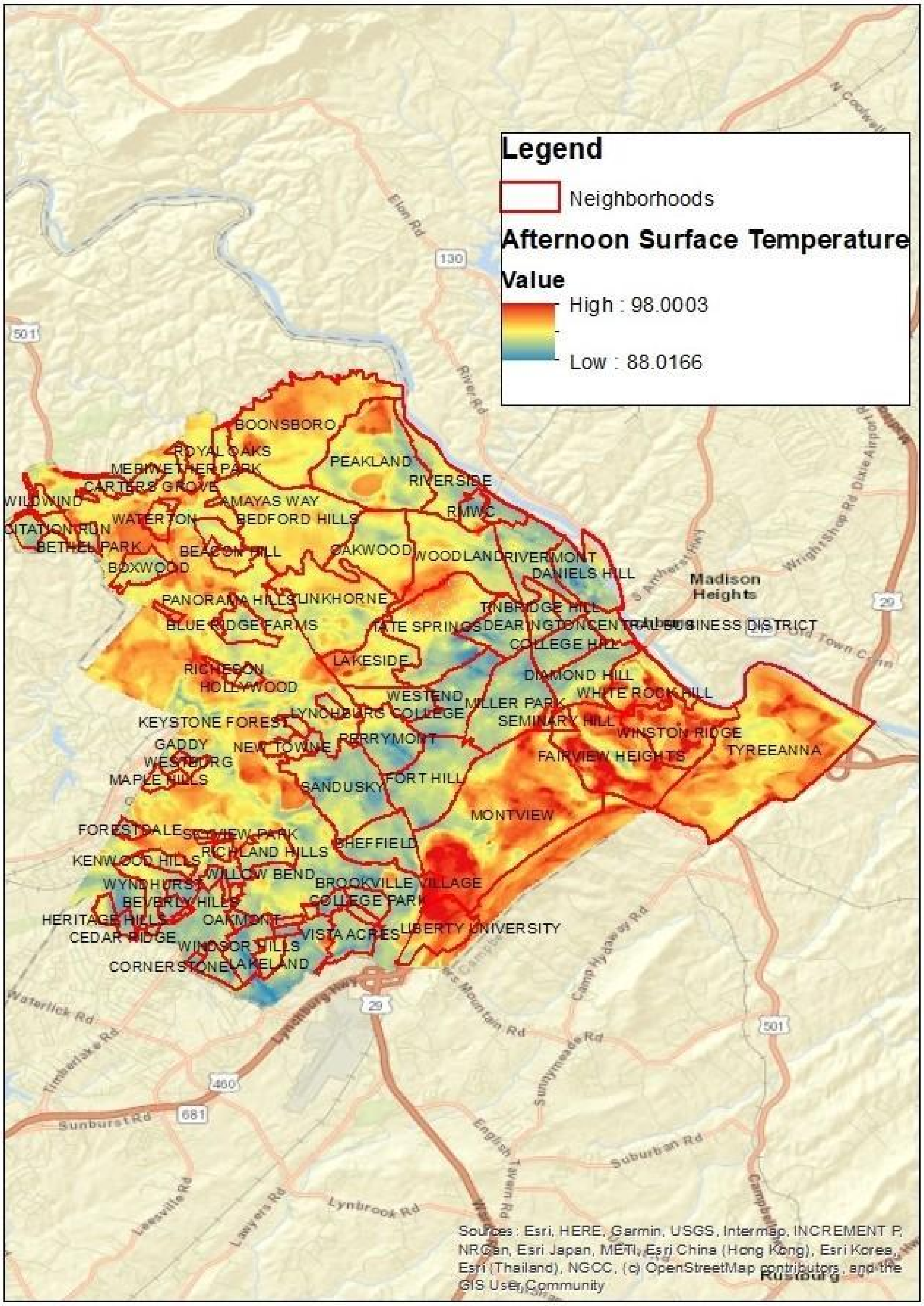


Figure 8. Neighborhoods of Lynchburg, Virginia in comparison to highest temperatures reached during the afternoon on ground surface. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day and neighborhood overlays taken from public Lynchburg GIS layers.

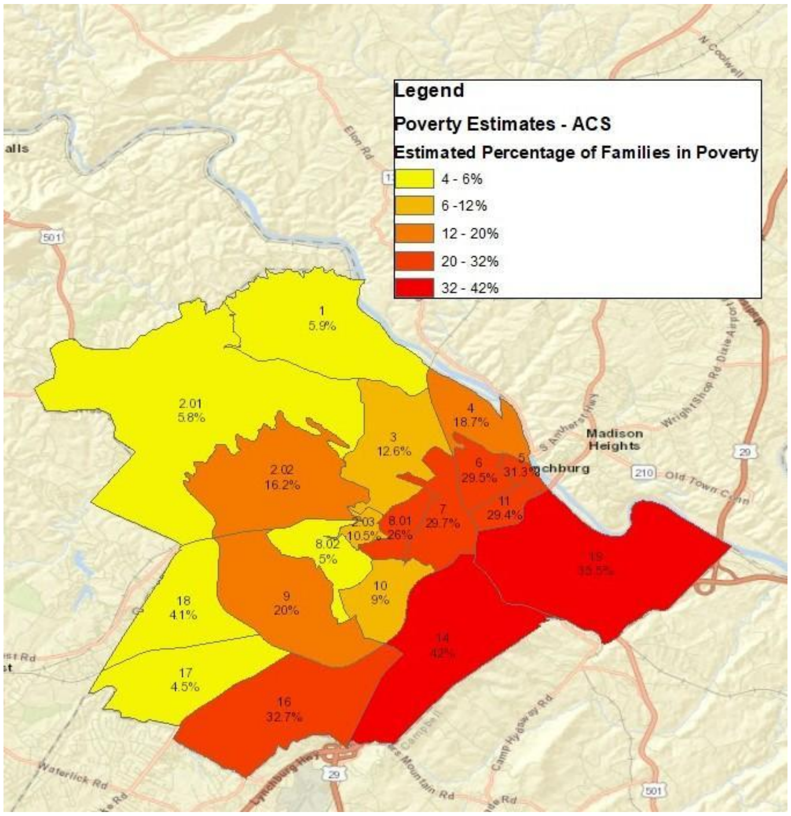


Figure 9. Highest heat areas during the afternoon in the city of Lynchburg in comparison to an overlay displaying ACS Poverty percentages according to Lynchburg 2010 Census data. Darker red areas represent areas of higher poverty rates. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day and neighborhood overlays taken from public Lynchburg GIS layers.

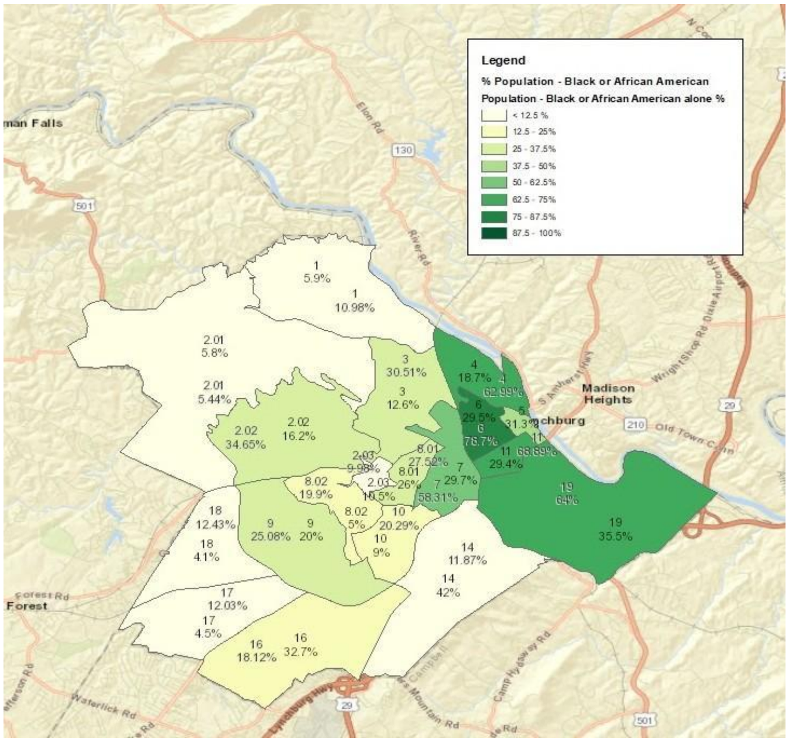


Figure 10. *Highest land surface temperatures in comparison to percentage of Black population in Census* Image depicting the highest heat areas during the evening in the city of Lynchburg from the afternoon and percentage of Black or African American residents in green. Darker green indicates a higher percentage of Black or African American residents in that Census Tract. Map created using CAPA Strategies heat sensor data and the routes taken during the volunteer day and neighborhood overlays taken from public Lynchburg GIS layers.