



Climate Vulnerability and Risk Assessment

A wide-angle photograph of a river, likely the James River in Richmond, Virginia. The river is brown and flows towards a large stone arch bridge in the distance. The banks are lined with trees showing autumn foliage in shades of yellow, orange, and red. The sky is a clear, pale blue.

*Equitable climate action for a
healthy and resilient Richmond*

Acknowledgements

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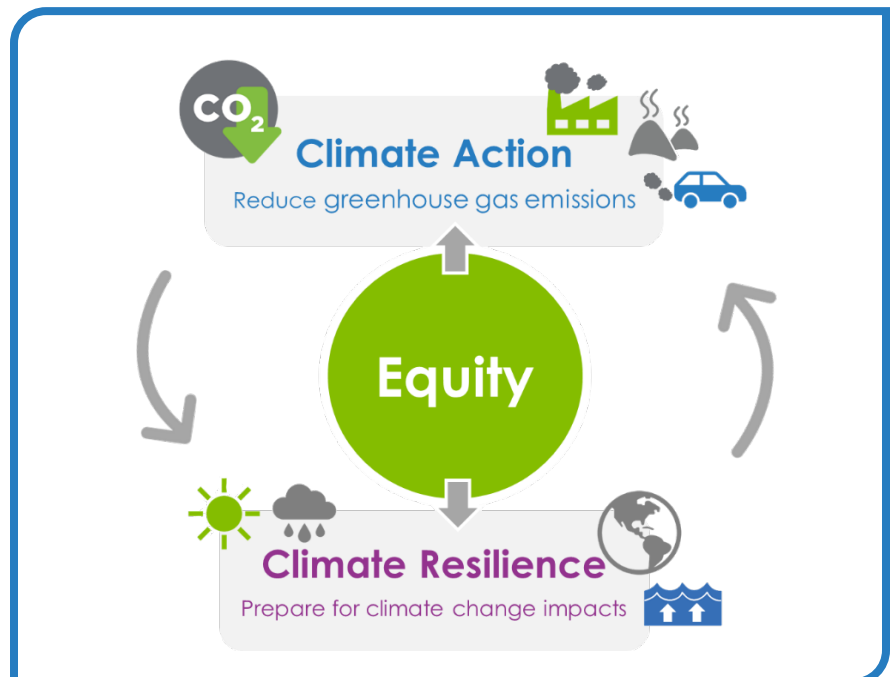
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1. Introduction

RVAgreen 2050 is the City of Richmond's equity-centered climate action and resilience planning initiative, spearheaded by the Office of Sustainability, to reduce greenhouse gas emissions 45% by 2030, achieve net zero greenhouse gas emissions by 2050 and help the community adapt to Richmond's climate impacts of extreme heat, severe storms, and flooding.

This Climate Vulnerability and Risk Assessment was created as an iterative process and is critical to understanding the specific climate threats Richmond is currently facing and will face in the coming decades, as well as the vulnerabilities of Richmond's social, built, and natural resources to increasing climate risks. This report summarizes the threats, vulnerabilities, and risks, and attempts to identify priority areas for most immediate action. Key recommendations will be integrated into implementation of the RVAgreen 2050: Climate Equity Action Plan 2030.

The report details the methodology used to measure vulnerability to and risk from to these climate impacts within the City of Richmond and reports the results of the analysis.



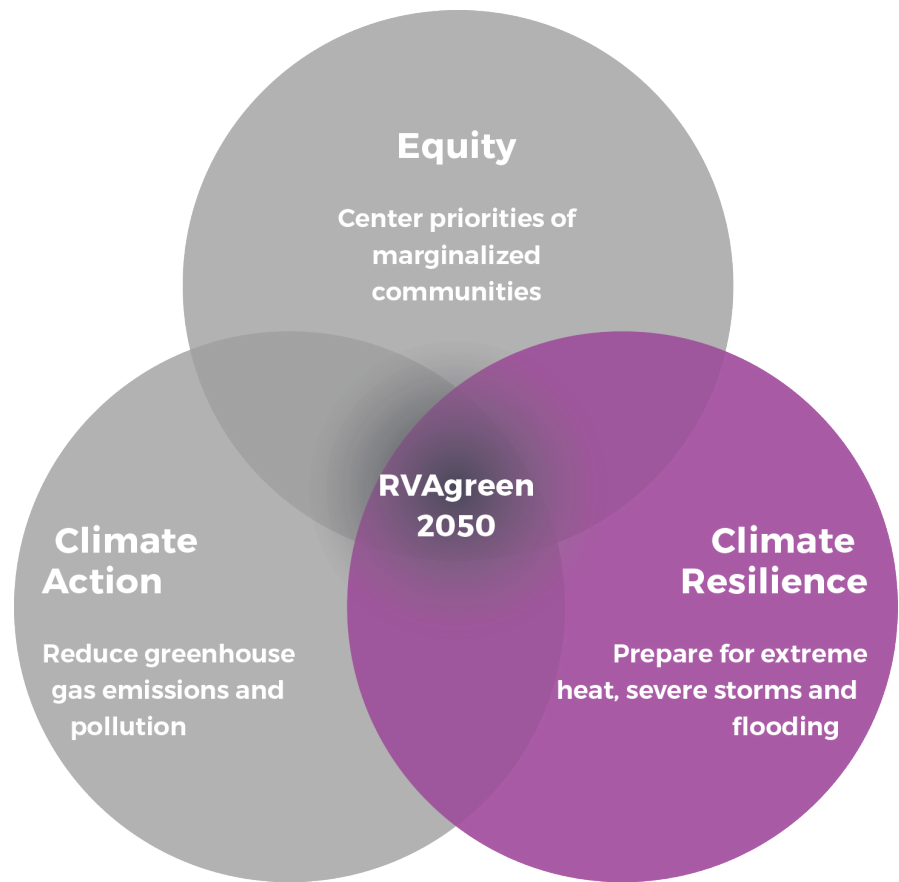
WHAT ARE GREENHOUSE GASES?

Greenhouse gases (GHGs) are gases in the earth's atmosphere that trap heat and warm the planet. GHGs include carbon dioxide, methane, nitrous oxide, and fluorinated gases. The right proportion of GHGs keep our planet warm enough to support life. When there are too many GHGs in our atmosphere, too much heat is trapped and overall temperature rises.

Human activity such as burning fossil fuels has caused a dramatic increase in these gases since around 1900, and the trend has rapidly accelerated in recent years.

REPORT PURPOSE

1. Document the data-driven and science-based collaboration with the Richmond community in the RVAgreen 2050 climate vulnerability and risk assessment process.
2. Document the process by which indicators of social and physical vulnerability and risk were selected, how the data on these indicators was acquired, and how that data was used to create the maps used in the assessment.
3. Analyze, summarize, and prioritize climate change vulnerabilities and risks to Richmond communities and natural and physical assets.
4. Integrate climate risks and vulnerabilities into the RVAgreen 2050 initiative and implementation of the Climate Equity Action Plan 2030. Provide information on the methodology employed for use in future updates by the City of Richmond or peer cities using this as a guide for their own assessments.



Climate Emergency Resolution

Richmond City Council unanimously adopted Resolution No. 2021- R049 in September 2021 to "declare the existence of a climate and ecological emergency that threatens the City of Richmond, the surrounding region, the Commonwealth of Virginia, civilization, humanity, and the natural world." City Council also acknowledged during this process the inequitable impacts on communities at the frontline of climate change and called for climate resilience measures that would dismantle the systemic structures that undermine the health of minority communities.

2. Assessment Process

The City of Richmond completed a comprehensive process for identifying climate impacts, vulnerabilities, and risks to the community's built, social, and environmental assets, as well as for prioritizing actions for those assets with the highest vulnerability and facing the highest risk.

The assessment process (process graphic shown on page 6) includes five main components:

1. a description of the latest scientific information available on climate impacts to Richmond
2. an evaluation of the vulnerabilities present
3. an assessment of the risks that climate impacts create for Richmond's population and built and natural assets
4. an analysis of the populations and built and natural assets at highest risk from climate impacts
5. a determination of planning areas that can inform prioritization and recommendations for climate resilience actions

The Climate Vulnerability and Risk Assessment methodology is based on best practice guidance from organizations such as the Urban Sustainability Directors Network, ICLEI – Local Governments for Sustainability, and the National Association of Climate Resilience Planners

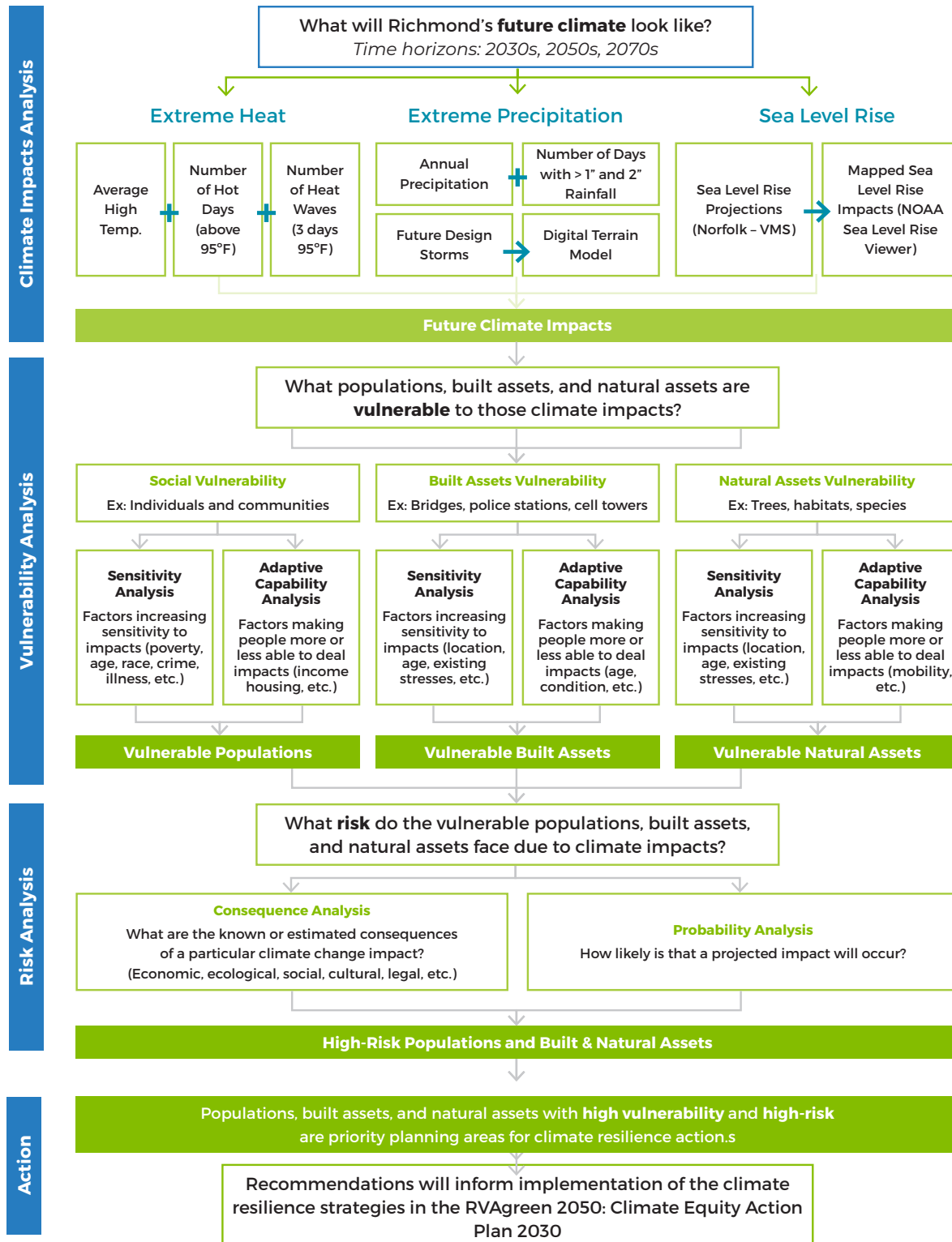
In addition, similar assessments and advice from peer cities were immensely valuable in this process. These include: Asheville, NC; Boston, MA; Cambridge, MA; Cleveland, OH; Minneapolis, MN; Portland, OR; Sarasota, FL; Somerville, MA; and, Washington, DC.

Finally, numerous local, state, and national experts assisted with identifying and gathering data, advising on best practices and the latest scientific information, and translating complex concepts for practical use by practitioners and the

community. These include representatives from the City of Richmond, Conservation Management Institute at Virginia Tech, James River Association, Mid-Atlantic Regional Integrated Sciences and Assessments, Science Museum of Virginia, and Virginia Department of Game and Inland Fisheries, among other organizations.

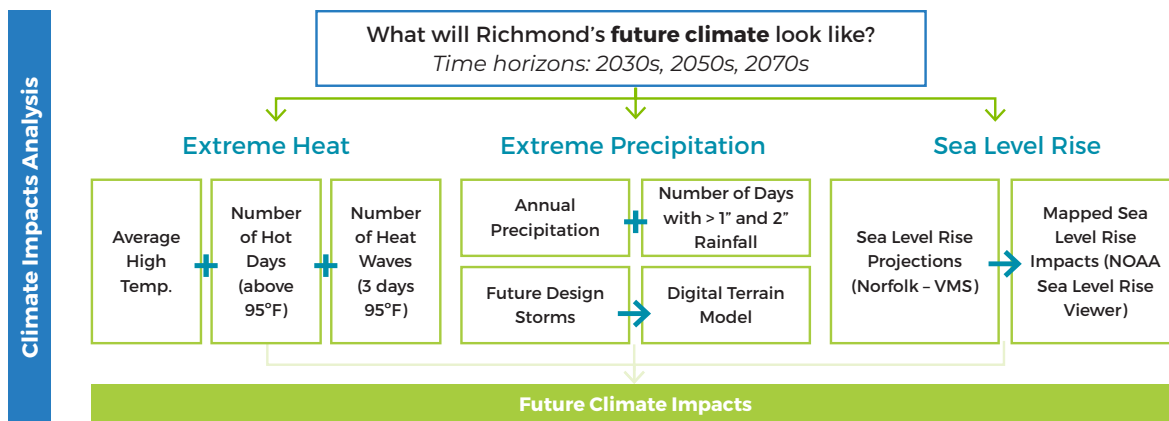
Climate Vulnerability and Risk Assessment Process

What action is needed for Richmond to prepare for or adapt to climate change?



3. Climate Impacts

Climate is defined as the long-term weather pattern in a region, and it is increasingly changing throughout the world. Research and the associated data show that global land-surface temperature, sea-surface temperature, and sea level have dramatically increased while snow cover and sea ice extent have decreased over the past 100 years.



The currently changing climate is linked to rising concentrations of greenhouse gases such as carbon dioxide, methane, nitrous oxide, and hydrofluorocarbons in the atmosphere, which insulate the planet and cause it to warm. Greenhouse gases have been released through both natural processes and human activities such as livestock raising, changing land uses and landcover, and burning fossil fuels, especially for energy and transportation.

Due to decades of burning fossil fuels and other activities, dangerous amounts of greenhouse gases are now in the atmosphere and are disrupting Earth's climate.

The impacts of climate change vary by location. Some areas of the country experience more droughts and forest fires. Richmond is already experiencing hotter average temperatures, more heat waves, and more severe storms. These impacts are projected to increase in the

future. The City completed a number of steps to identify the climate risks Richmond is facing now and is expected to experience in the coming decades. Data for the region, state, and Richmond was collected from the U.S. Climate Resilience Toolkit - Climate Explorer, National Oceanic and Atmospheric Administration (NOAA), and in partnership with Drexel University. The City also partnered with the Science Museum of Virginia and other partner organizations to conduct an

urban heat island study. For planning and prioritization purposes, climate impacts associated with increased temperatures, precipitation, and sea level rise were examined for three time horizons: 2030s, 2050s, and 2070s – sometimes described as near-term, mid-century, and late-century.

3.1 Virginia's Climate Impacts

The National Oceanic and Atmospheric Administration (NOAA) works to understand and predict changes in climate and weather and provides state-level summaries of these changes through its National Environmental Satellite, Data, and Information Service. The key climate impacts for Virginia are described to the right. As shown in Figure 3.1 Virginia's average temperatures have increased and will continue to do so, and future heat waves will be more intense. This will pose human health risks, particularly in metropolitan areas like Richmond. Cities have lower proportions of tree canopy, increased impervious surfaces, urban heat islands, and greater numbers of days of poor air quality. These conditions compound potential health effects of

Climate Impacts in Virginia

Warmer Average Temperatures	More Intense Droughts	More Extreme Heat and Precipitation
<ul style="list-style-type: none"> • Average annual temperature in Virginia has increased by about 1.5°F since the beginning of the 20th century. • Under a higher emissions pathway, historically unprecedented warming is projected by the end of the 21st century. 	<ul style="list-style-type: none"> • Naturally occurring droughts are projected to be more intense because higher temperatures will increase evaporation rates, depleting soil moisture more rapidly and adversely affecting agriculture. 	<ul style="list-style-type: none"> • The number and intensity of extreme heat and extreme precipitation events are projected to increase. • Cold waves are projected to be less intense.

Source: Virginia State Climate Summary 2022

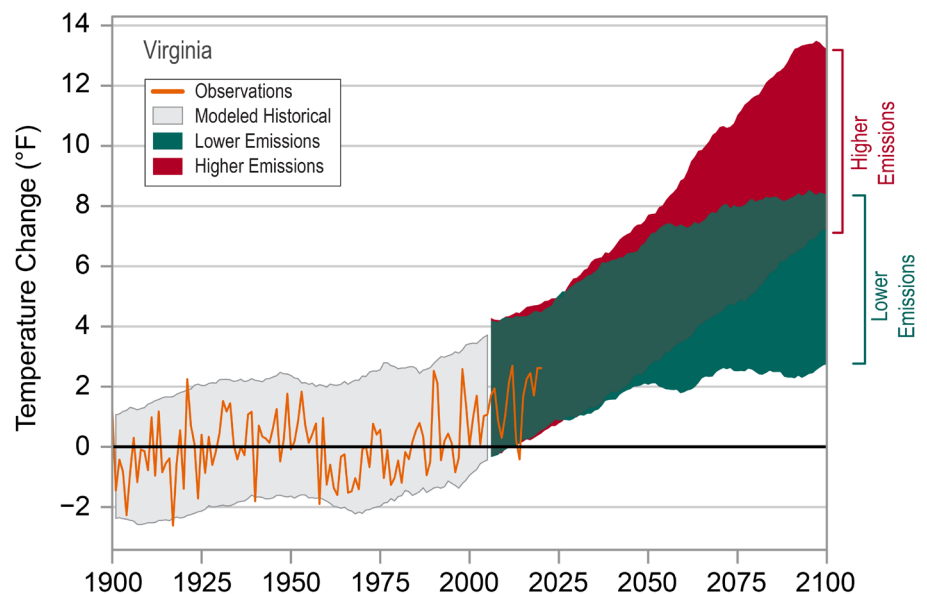


Figure 3.1. Observed and projected changes in near-surface air temperature for Virginia (Source: Virginia State Climate Summary 2022)

Observed and Projected Annual Number of Tidal Floods for Sewells Point, VA

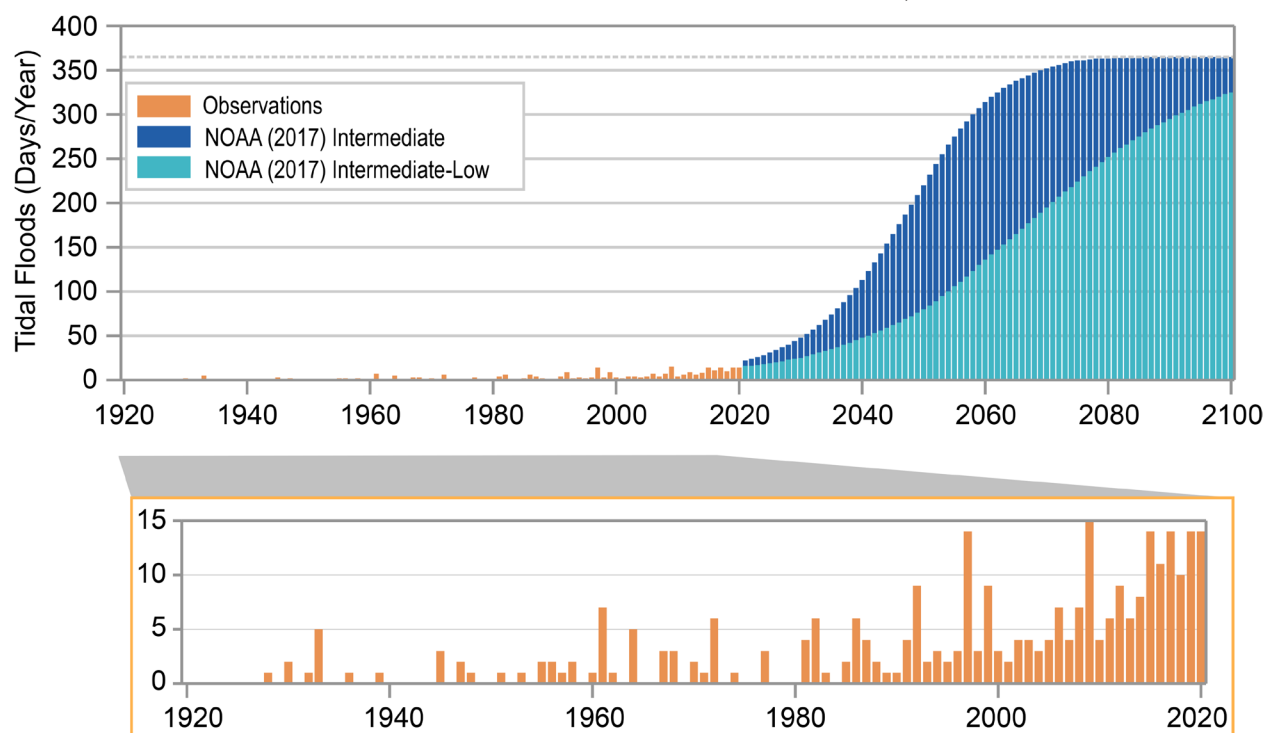


Figure 3.2. Number of tidal flood days per year for the observed record (orange bars) and projections for two possible futures: lower emissions (light blue) and higher emissions (dark blue) per calendar year for Sewell Point, VA. (Source: Virginia State Climate Summary 2022)

climate impacts for health and age-vulnerable community members.

Annual precipitation is projected to increase as well, in addition to the number and intensity of heavy precipitation events. Even as overall precipitation increases, naturally occurring droughts are projected to be more intense because precipitation will increasingly fall in high volumes for shorter periods, allowing for more extended periods with drier conditions,

and higher temperatures will increase the rate of loss of soil moisture during dry spells.

During such periods, decreased water availability will likely have important implications for the state's agricultural economy.

Finally, Virginia is facing the impacts of sea level rise – at a greater rate than the rest of the world. Since 1880, global average sea level has risen by 7-8 inches. It has risen even more along the Virginia coast

with a rise of 17 inches between 1930 and 2020 at Sewell's Point in Norfolk. Global sea level is projected to rise another 1 to 4 feet by 2100 as a result of both past and future emissions due to human activities, with greater rises possible along the Virginia coast following historical trends. This has caused and will continue to cause an increase in tidal floods and exacerbation of coastal storm surge, which damage infrastructure, cause road closures, and overwhelm storm drains.

3.2 Richmond's Climate Impacts

Like the state as whole, Richmond locally faces changing climate conditions including increasing temperatures, changing precipitation patterns, and rising sea level. These climate conditions cause climate impacts by creating more extreme precipitation and flooding events, extended heat waves, and extreme storm events. These impacts are already beginning to be felt in Richmond and are projected to increase in the future. All of these climate threats pose risks to Richmond's community members, infrastructure, and natural resources.

The following sections contain information on these climate impacts based on the latest science available. This information on historic climate trends, current climate conditions, and climate change projections helps in understanding what Richmond's future climate will look like and the climate risks and vulnerabilities that are evaluated in later portions of the assessment.

Modeling Climate Projections

Many of the climate projections included within this technical report utilize data from the World Climate Research Programme's Coupled Model Intercomparison Project Phase 5 (CMIP5) which helps to understand past and future climate changes (WCRP, 2021). The model includes different pathways or assumptions for future global greenhouse gas concentrations. In this assessment, many of the figures show future potential climate changes for both lower (RCP 4.5) and higher (RCP 8.5) emissions pathways modeled under CMIP5.

Emissions Scenario	2030	2050	2070
RCP8.5 (high)	72°F	75°F	77°F
RCP4.5 (low)	72°F	73°F	74°F

Table 3.2. Historic and projected annual average daily maximum temperature - Richmond (Source: Virginia State Climate Summary 2022)

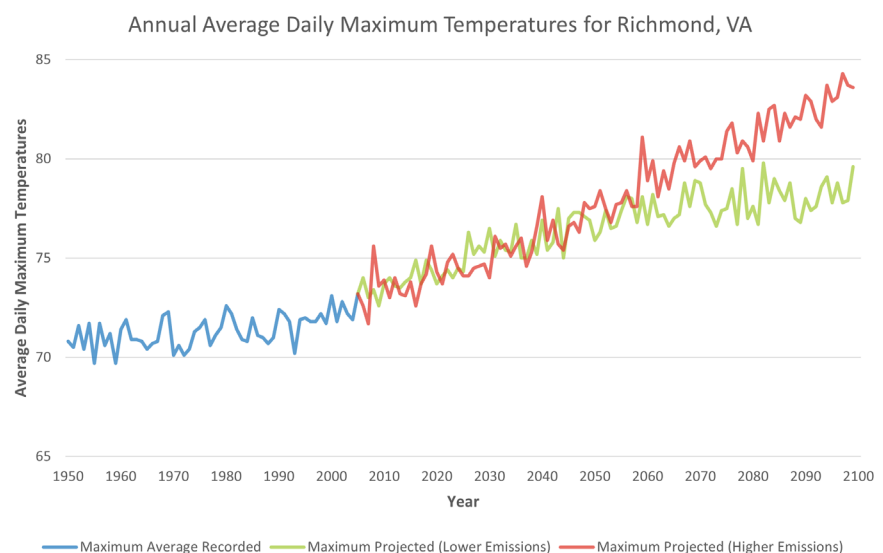


Figure 3.3 Annual average daily maximum temperature in Richmond – historical (blue) and projections under a lower (4.5) global emissions scenario (green) and a higher (8.5) global emissions scenario (red) (Source: U.S. Climate Resilience Toolkit)

3.2.1 Heat

Annual Average High Temperature

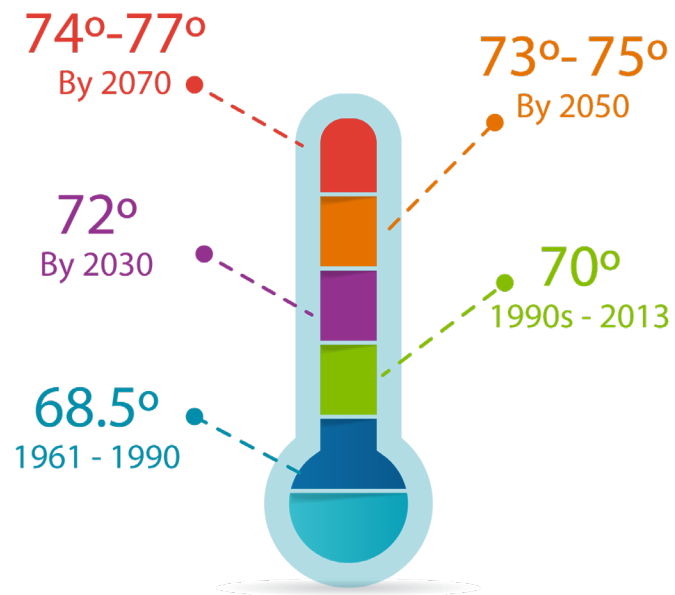
The City of Richmond has already seen an increase in the annual average high temperature.

The observed average daily maximum temperature from 1961-1990 was 68.5°F. The observed average in the 1990s was 69.8°F and from 2000 to 2013, the observed average was 70.1°F. Figure 3.3 provides projections for continued increases in average daily maximum temperature.

Days Above 95°F

In addition to an overall upward trend in average temperature, there has also been an upward trend in the number of days above 95°F.

Annual Average High Temperature Increase



Future temperature ranges reflect lower and higher global emissions scenarios. (Source data for the graphic: U.S. Climate Resilience Toolkit)

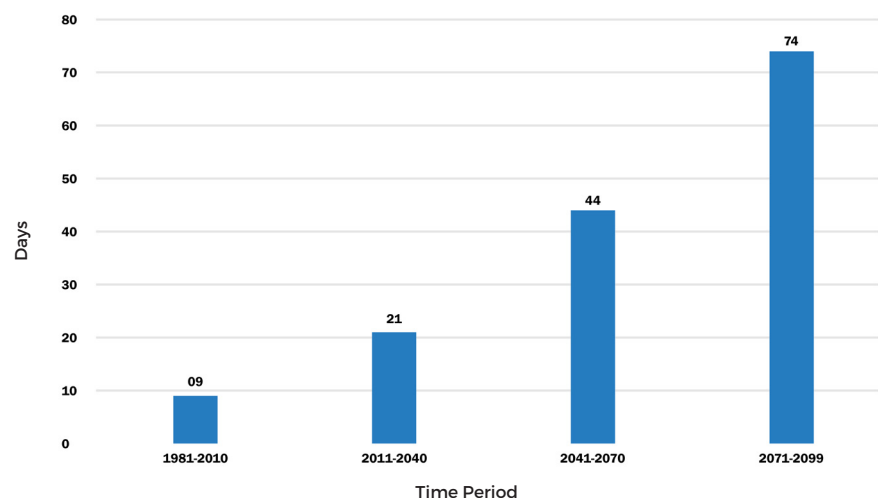


Figure 3.4 Historic and Projected Average Annual Number of Days with Temperatures over 95 degrees F for a High Emissions Future - Richmond, VA (Source: Mid-Atlantic Regional Integrated Sciences and Assessments)

Figure 3.4 provides projections for continued increases in the number of days above 95°F. Figure 3.4 shows historic information for the City on streaks of consecutive days above 90°F from 1970 to 2020.

Richmond is experiencing these high temperatures earlier in the spring and they are lasting later into the fall leading to longer summers, exacerbated drought conditions, and earlier and later, as well as more, heat waves. Higher temperatures are also leading to warmer nights on average as shown in Figure 3.5 for the period from 1970 to 2018, which becomes dangerous for public health when people, particularly in urban settings are not able to cool overnight. The City opens cooling stations during daytime hours when temperatures and/or heat indexes reach 95 degrees.

As reflected on the Daytime Warming Map, the impacts of hotter weather are not distributed evenly across Richmond. While the City as a whole is getting hotter, specific neighborhoods are experiencing greater temperature increases and urban heat island effects. Daytime warming is the difference between the morning temperature (6-7 am) and afternoon temperature (3-4

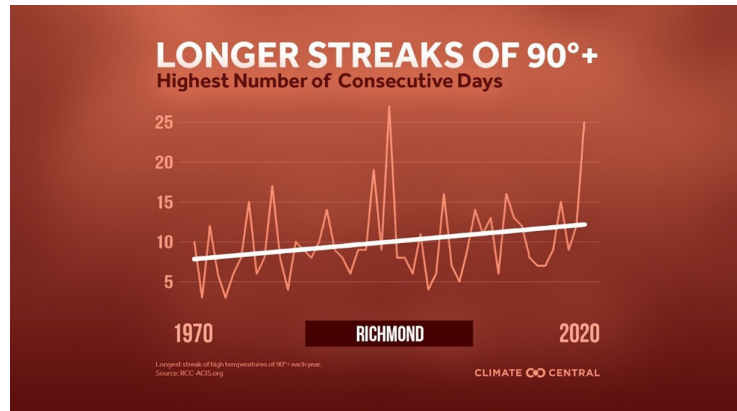


Figure 3.5 Annual days with maximum temperature above 90°F in Richmond (Source: Climate Central)

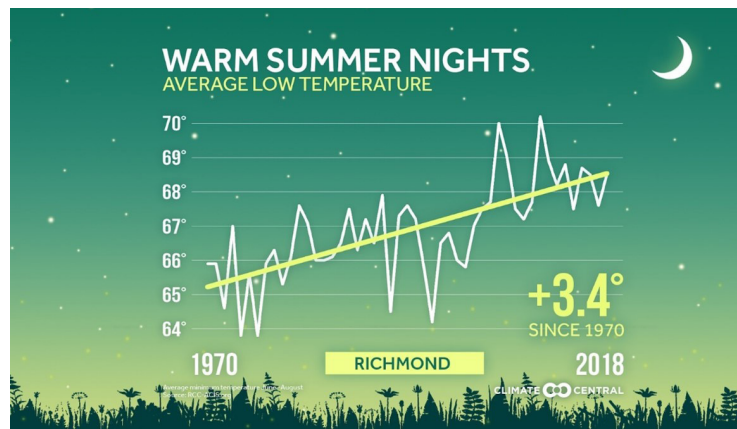
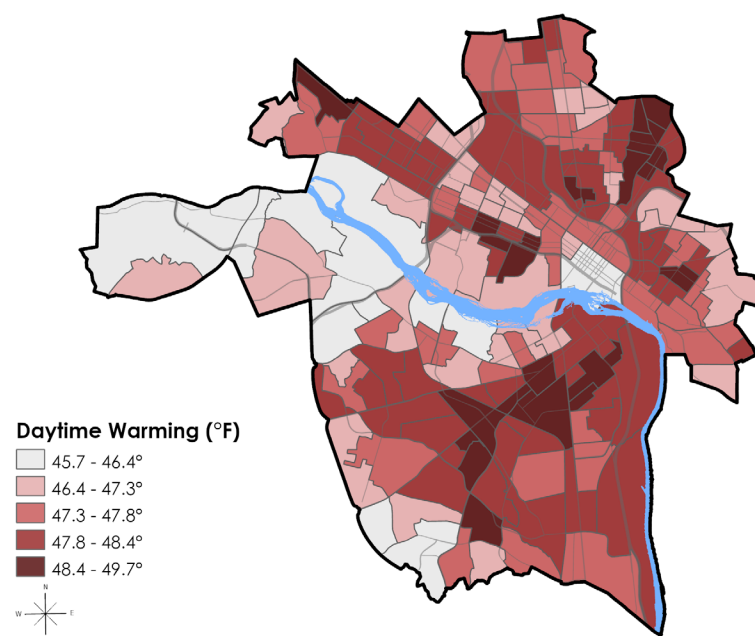


Figure 3.6 Annual Average Summer Night Low Temperature (Source: Climate Central)



Source: City of Richmond, US Census Bureau

pm) during the 2017 urban heat island study led by the Science Museum of Virginia. This is shaped by the amount of impervious surface, tree canopy, and green space present in various locations throughout the City. In Richmond, as in many other cities, climate heat effects are disproportionately impacting Black, Indigenous, and other communities of color, as explained in the Climate Equity Action Plan 2030 - Equity chapter.

Cooling Degree Days

Cooling degree days measure how much (in degrees), and for how long (in days), outside air temperature is higher than 65°F based on the average temperature each day. On a day when the average outdoor temperature is 85°F, reducing the indoor temperature to 65°F would require 20 degrees of cooling multiplied by 1 day, or 20 cooling degree days. The number of cooling degree days at any location reflects the amount of energy people use to cool a building when it is warm outside. Higher numbers of cooling degree days indicate a higher demand for energy.

The number of cooling degree days has also been increasing and is projected to continue to increase in Richmond as illustrated in Figure 3.6 as high

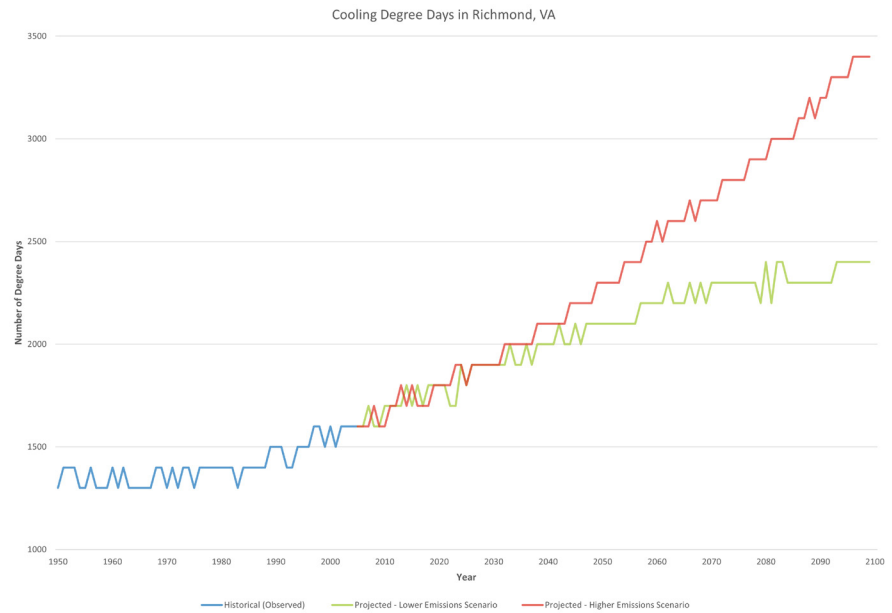
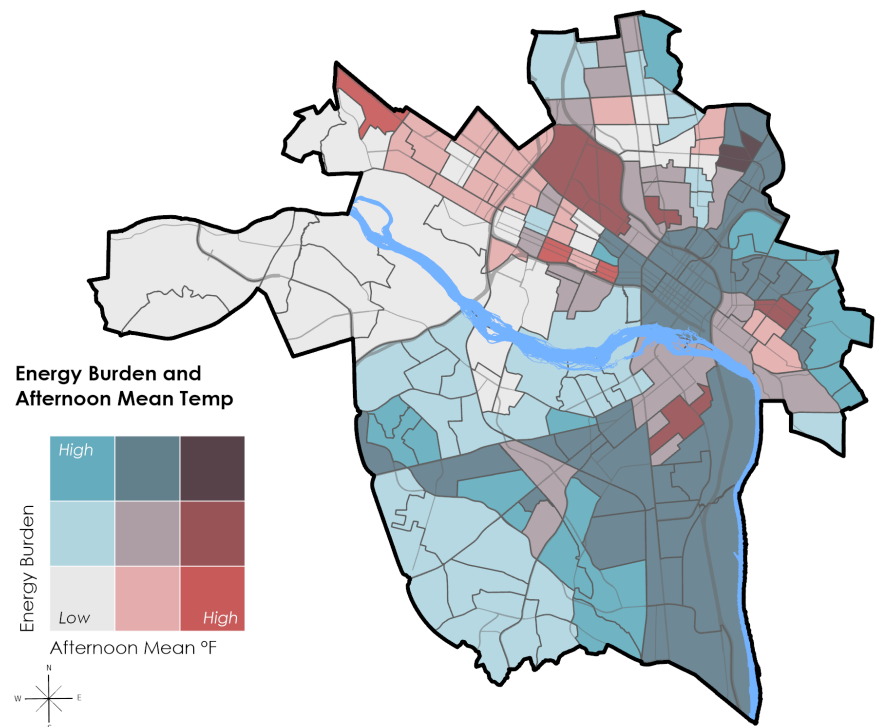


Figure 3.7 Annual cooling degree days in Richmond - historical (blue) and projections under a lower global emissions scenario (green) and a higher global emissions scenario (red) (Source: U.S. Climate Resilience Toolkit)



Source: City of Richmond, U.S. Census Bureau

temperatures continue to rise annually. Richmond's increasing temperatures and energy demand creates disproportionate burdens for the City's lower income residents as reflected on the Energy Burden and Afternoon Mean Temp Map. Energy burden represents the percentage of annual income that a household or individual pays towards their energy. A household is considered in "high burden" if they spend more than 6% of their annual income on energy bills - Richmond's average energy burden is 8.47%.

3.2.2 Precipitation

The City of Richmond has seen some historic increase in total annual precipitation and continued modest increases are anticipated.

Similar to the state of Virginia overall, Richmond has seen a somewhat greater increase in the amount of precipitation falling in heavy precipitation events compared with annual total precipitation trends. Figure 3.7 illustrates these historic trends and provide projections for continued increases in days per year with more than 1", 2", and 3" of precipitation in the City.

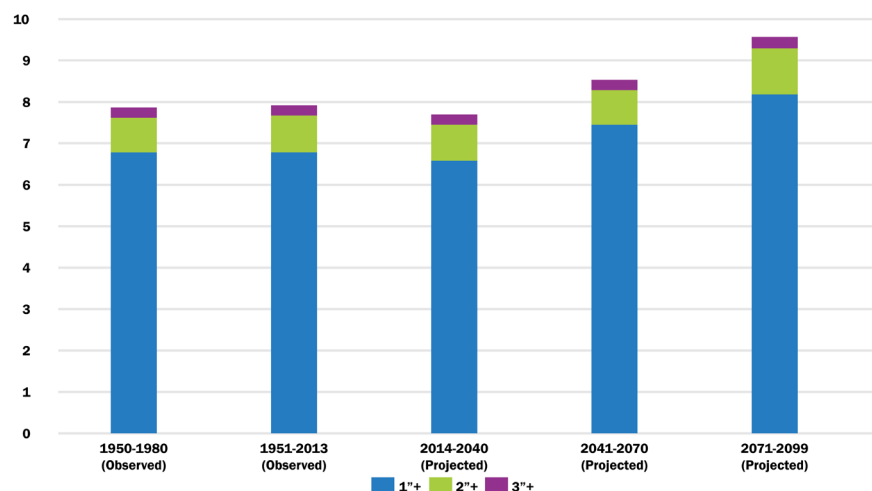


Figure 3.8 Historic and Projected Annual Days with >1, >2,>3 inches of Precipitation in Richmond (Source: U.S. Climate Resilience Toolkit)

Seasonal Precipitation

Figure 3.8 illustrates historic average seasonal precipitation from 1976 to 2005 and forecast seasonal precipitation in the near-, mid-, and long-term under lower (RCP4.5) and

higher (RCP8.5) global emissions scenarios for Richmond as forecast under the Mid-Atlantic Regional Integrated Sciences and Assessments. Precipitation is anticipated to increase the

most in winter and spring. A slight increase or decrease is anticipated in fall precipitation and little to no change in precipitation is anticipated during the summer.

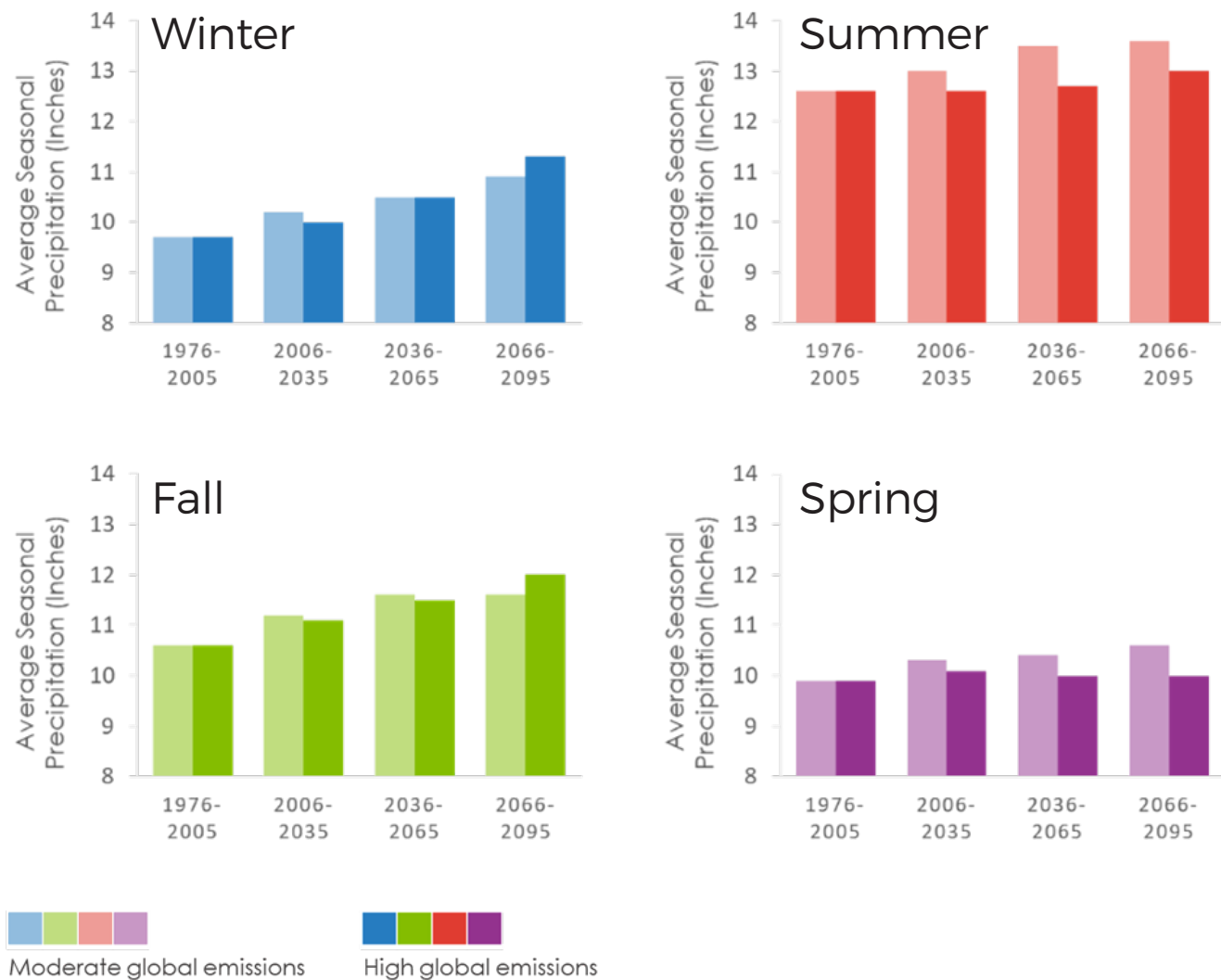


Figure 3.9 Historic and Projected Seasonal Precipitation by Emissions Scenario - Richmond, VA
(Source: Mid-Atlantic Regional Integrated Sciences and Assessments)

The City worked with Drexel University to create a more refined model for changes in seasonal precipitation for Richmond. Figure 3.9 shows the percent change in seasonal precipitation in the 2050s and 2080s under a blended scenario between the moderate and high emissions scenarios. Under this analysis, a greater increase in summer precipitation was identified when compared with the Mid-Atlantic Regional Integrated Sciences Assessments forecasts. Figures 3.10 and 3.11 illustrate these anticipated changes in rainfall depth for the 2050s and 2080s for the winter

(highest change), spring (lowest change), and fall (average change) scenarios. As a baseline, the charts also illustrate projections from NOAA Atlas 14, which provides the official estimate of precipitation frequency for the United States. Climate models are complex and entail some level of uncertainty, thus there are some variations. However, all of the forecasts show that storms affecting the Richmond area are expected to become more intense in the future, with higher rates of runoff and increased flooding.

Season	2050s	2080s
Winter (Dec-Feb)	11.3%	15.2%
Spring (Mar-May)	3.8%	5.9%
Summer (Jun-Aug)	4.6%	5.1%
Fall (Sep-Nov)	0.7%	0.8%

Figure 3.10 Delta Change Factors (increases over historical conditions) in seasonal precipitation for Richmond – projections under a blended (moderate and higher) global emissions scenario

Source: City of Richmond, Drexel University

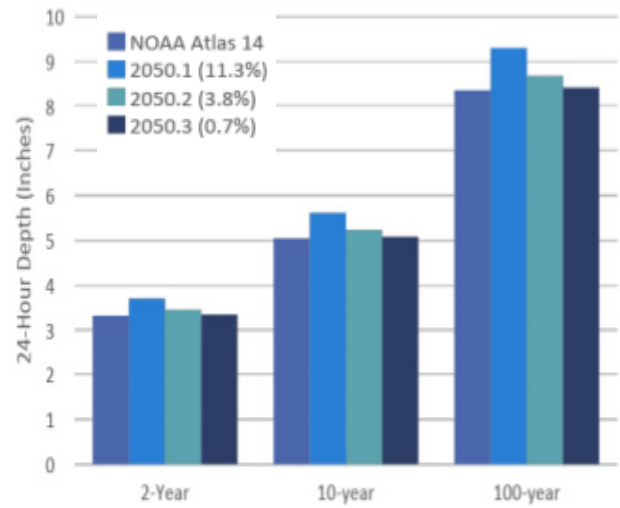


Figure 3.11 2050 Rainfall Projections for 2-, 10-, and 100-year (50%, 10%, 1%) Design Storms Under NOAA Atlas 14 Compared to Various Global Climate Models (Source: City of Richmond, Drexel University)

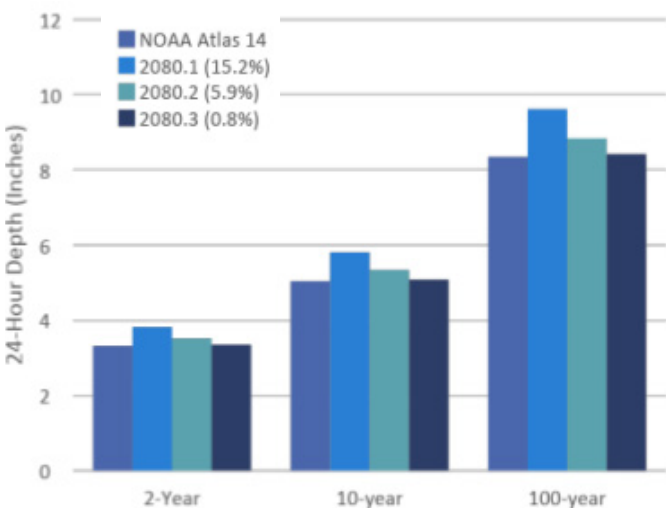
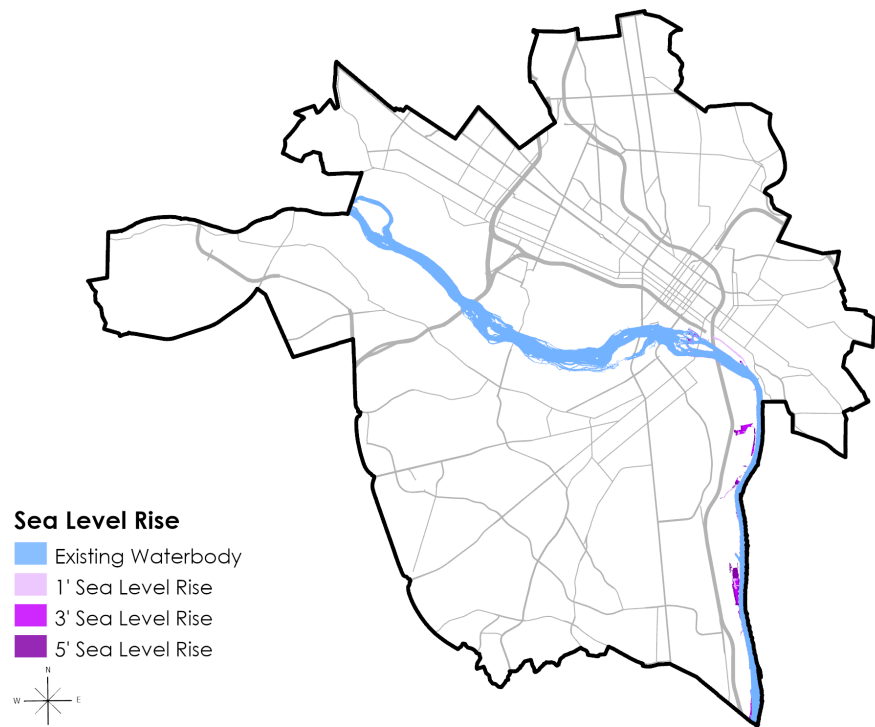


Figure 3.12 2080 Rainfall Projections for 2-, 10-, and 100-year (50%, 10%, 1%) Design Storms Under NOAA Atlas 14 Compared to Various Global Climate Models (Source: City of Richmond, Drexel University)

3.2.3 Sea Level Rise

As described earlier, Virginia is facing the impacts of sea level rise at a greater rate than the rest of the world. Over the last century, the sea level has risen nearly twice as much along the Virginia coast than the global average. Richmond will be impacted by sea level rise as it causes rising river levels upstream to the James River fall line at the 14th Street/Mayo Bridge. (Virginia Department of Game and Inland Fisheries) The exact amount of sea and river level rise depends on global emissions, but guidance from the Hampton Roads Planning District Commission's Sea Level Rise Planning Policy and Approach provided a starting point for the City for planning purposes. The Hampton Roads policy recommends using three sea level rise scenarios associated with future planning timeframes. For City of Richmond, the following sea level rise scenarios were identified:

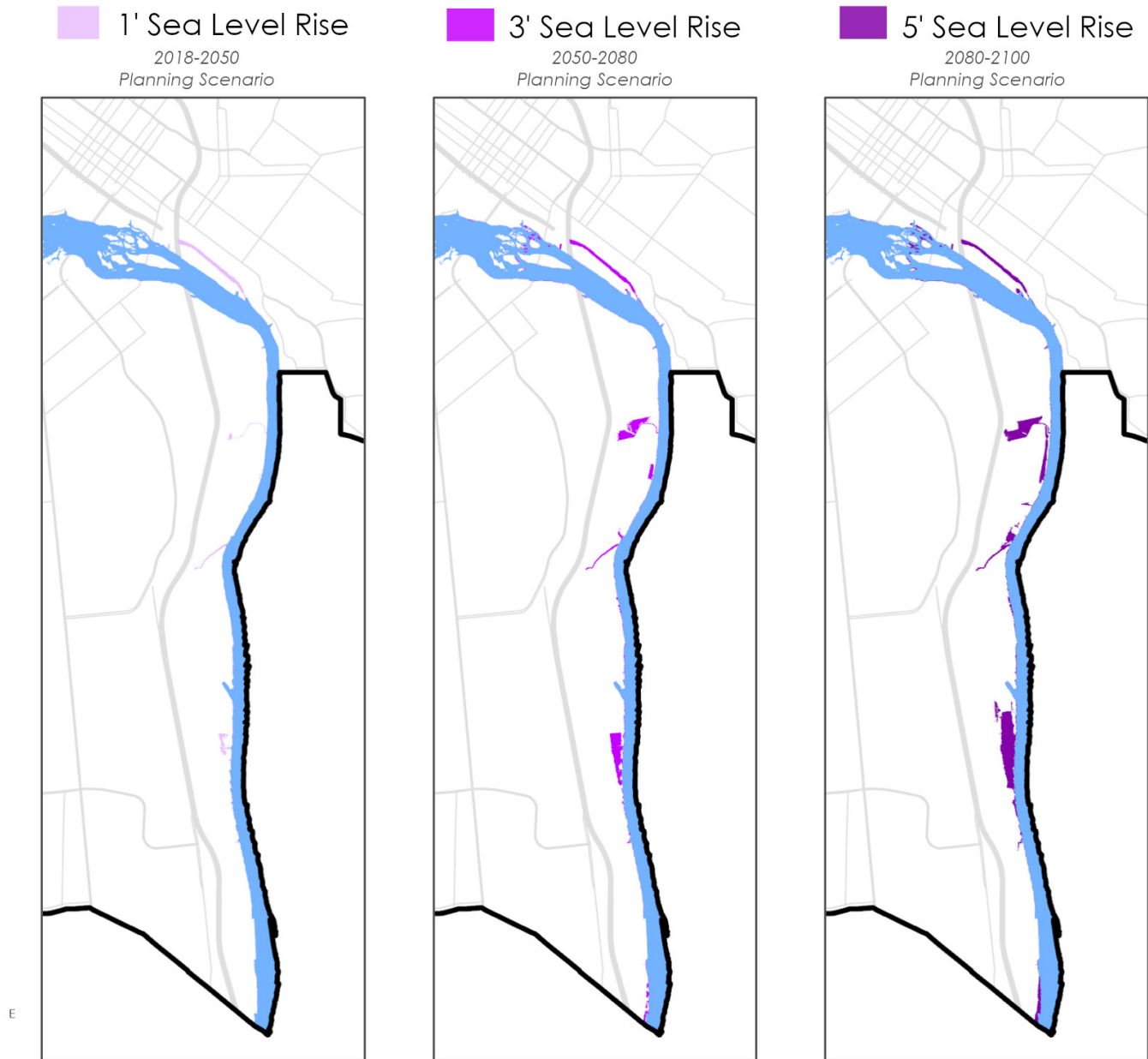
- 1' above current mean higher high water (MHHW) for near-term (2018-2050)
- 3' above current mean higher high water (MHHW) for mid-term (2050-2080)
- 5' above current mean higher high water (MHHW) for long-term (2080-2100)



Source: City of Richmond, NOAA

These sea level rise scenarios have been applied to the James River using the National Oceanic and Atmospheric Administration (NOAA) Sea Level Rise Viewer tool. The data used to create the maps below includes areas that have a high degree of confidence, or low uncertainty, representing locations that will be correctly mapped (either as inundated or dry) more than 8 out of 10 times, or in other words there is an 80 percent degree of confidence that these areas are correctly mapped. Areas mapped by NOAA as dry or wet with a low confidence or high uncertainty were removed from

these maps. Sea level rise will have a relatively minor impact on Richmond for the next century, especially when compared to the potential impacts of heat and precipitation. However, it is important to consider the impact of sea level rise for various industrial uses located in impacted areas – this is discussed further in the vulnerability and risk sections. In addition, sea level rise projections may change over the coming years or increase in future centuries and should be monitored closely.

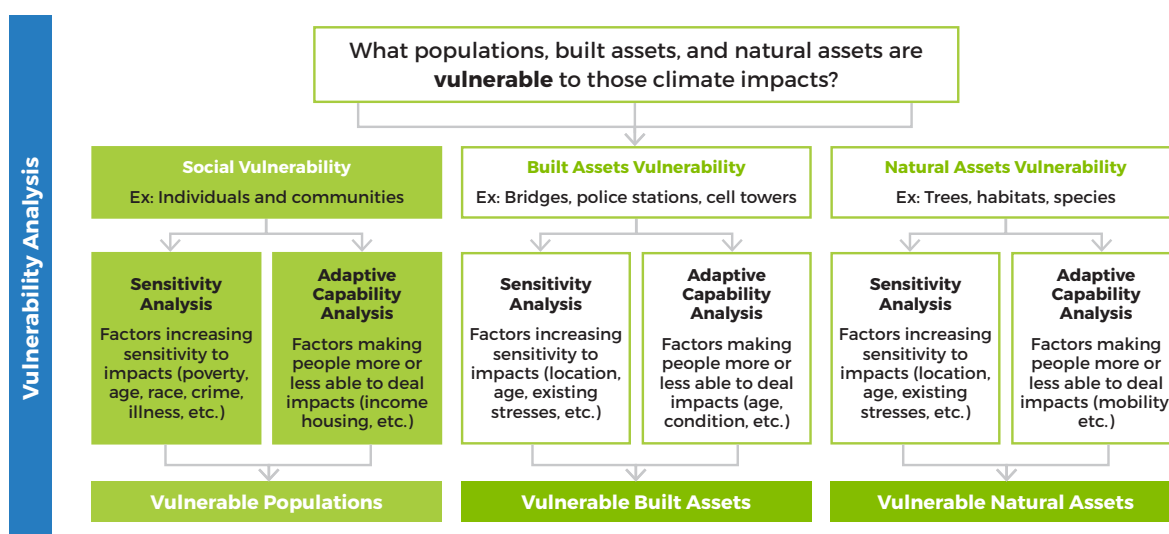


Source: City of Richmond, NOAA



4. Social Vulnerability

Once future climate impacts have been identified, the next step in the assessment process is to identify the populations, built assets, and natural assets that may be vulnerable to these climate impacts.



The first element in this step is determining social vulnerability. Social vulnerability is focused on people and their ability to withstand and respond to stressors like the impacts of climate change. The approach to social vulnerability analysis is described in the sections that follow. The results of this

analysis will be integrated with the analysis of vulnerabilities of built and natural assets in Section 5 to understand how impacts to those resources may affect communities and inform prioritization of vulnerabilities to address through climate resilience strategies. For example, if a building is

vulnerable to flooding, this analysis helps to understand how people who live in or work in, or otherwise use the building, are likely to be affected by that flooding, with a particular focus on potential impacts to socially vulnerable populations.

4.1 Variable Selection

The Social Vulnerability Index (SVI) developed by the U.S. Centers for Disease Control (CDC) uses 15 census variables to identify communities that may need support in preparing for hazards (CDC, 2015). The SVI serves as the foundation for the variables

used in this vulnerability assessment. Additional variables were added based on best practices research and examples of similar assessments in peer cities. Each of the resulting 39 factors may increase an individual's or community's vulnerability to the impacts of climate change

in Richmond – heat, precipitation, and sea level rise – as explained below. More detailed descriptions and information sources for each factor are included in Appendix A.

Population Factors

Elderly (65+)	For individuals 65 years of age or older, climate change impacts worsen the risks of certain diseases and disorders, and can increase susceptibility to heat, pollutants, and vector-borne diseases. Climate impacts can also cause changes in various social factors such as income loss and social isolation.
Children (under 18)	Having little or no direct control over the environment they live in, children under 18 have an increased vulnerability to the impacts of climate change, and can require additional care and protection from harm. Children under 18 are also more susceptible to traumatic events that can result in long-term negative effects on health, social, and behavioral outcomes
Minorities (race & ethnicity)	Minority groups tend to live in more marginal and exposed areas that have an increased susceptibility to climate impacts, as well as higher morbidity and mortality rates associated with impacts such as extreme heat.
Female	Women exposed to climate change impacts, such as poor air quality, have higher risks than men for increased cases of air particulate matter in lung tissue and anemia. Poor air quality is also associated with negative birth outcomes, and poses a risk for maternal and child health associated with stillbirth, intrauterine growth restriction, and congenital defects.
Limited English Proficiency	Individuals with limited English proficiency (LEP) have high poverty rates, various language and cultural barriers such as accessing and affording mental health care, and limited counseling in native languages, which reduces their climate change adaptability and resilience.

Health & Safety Factors

Health Opportunity Index	The Health Opportunity Index (HOI) is a measurement based on 13 indicators that reflect a wide variety of social determinants of health in order for individuals to live a long and healthy life. A low health opportunity index can indicate poor air quality, income inequality, low education levels, limited access to care, and poor food accessibility, which are all factors that increase vulnerability to the impacts of climate change.
Disabilities	With greater susceptibility to invasive diseases, and the complex disability-related challenges of evacuation and relocation, individuals with physical and mental disabilities have an increased vulnerability during storms, floods, and extreme heat. Persons with mobility or cognitive impairments are likely to experience greater vulnerability to health risks due to difficulty responding to, evacuating, and recovering from extreme events.
Obesity	Climate change impacts such as extreme heat events can increase the risk of heat exhaustion and mortality for those who are obese. In a climate-related emergency situation, individuals with severe or morbid obesity may face challenges in regards to rescue, evacuation, transport, and suitable equipment.
Diabetes	Higher ambient temperature can negatively impact glucose metabolism, increasing the incidence of diabetes as temperatures rise due to climate change. In addition, people with diabetes experience increased complications in hotter temperatures, including dehydration, heatstroke, and cardiovascular events.
Asthma	Climate change causes an increase in ozone pollution; coupled with greater concentrations of carbon dioxide and higher temperatures, pollen quantity may increase and induce longer pollen seasons. Ozone and pollen can worsen existing respiratory allergies and asthma, and serve as triggers for asthma attacks.
Chronic Obstructive Pulmonary Disease (COPD)	Individuals with COPD face increased mortality, higher rates of hospitalization and exacerbation of COPD symptoms, and a worse quality of life. The air pollutants that cause climate change exacerbate existing and cause new cases of respiratory diseases. Individuals with COPD face increased respiratory symptoms, increased rescue inhaler use, and decreased lung function.

Health & Safety Factors	
Coronary Heart Disease	Large day-to-day variations in temperature can cause individuals with coronary heart disease to have significantly more heart attacks. For every 5-degrees Celsius jump in temperature, the risk of a heart attack increases by roughly 5 percent.
High Blood Pressure	Variations in temperature can cause changes in blood pressure, and may lead to severe drops in blood pressure, increasing the risk of collapsing in older adults. Blood pressure medication can interfere with an individual's ability to self-regulate body temperatures, increasing their risk of vulnerability to climate change impacts like excessive heat.
Kidney Disease	During heat waves there is an increase in hospital admissions for acute kidney injury, and kidney failure becomes a leading cause of premature death. Dialysis patients are among the most vulnerable during natural disasters due to the potentially life-threatening impact of missed dialysis.
Mental Health (Self-Assessed)	For those with mental health issues and stress, the impacts of climate change pose significant risks for factors such as PTSD, depression, general anxiety, suicidal thoughts, and increased substance abuse. Also, excessive heat serves as a risk for individuals taking medication for mental health, due to the medication's ability to interfere with self-regulating body temperatures.
Physical Health (Self-Assessed)	Self-assessed health is increasingly being considered as a valid measure for predicting future health outcomes among elderly individuals. Older people who assess their physical health less favorably, have shown a significant correlation with functional decline and mortality. Individuals with poor physical health have difficulty responding to, evacuating, and recovering from extreme events.
Uninsured	Those who are uninsured have lower rates of health care use and experience worse health outcomes, including increased rates of mortality, and may require extra resources to prepare, evacuate, and recover from emergency situations and the impacts of climate change.
Food Access	In most cities neighborhoods are not equally served by the same number of food retail stores, which increases food security vulnerability. Individuals with low food access may have to settle for inadequate options as prices increase due to declining crop yields, livestock, and fish production, and affordable food options become limited. This map identifies the low-income census tracts within Richmond where more than 100 housing units do not have a vehicle and are more than a ½ mile from the nearest supermarket

Health & Safety Factors

Crime

There is a strong relationship between temperature and both violent and property crime. With extreme heat, the likelihood of physical aggression and violence rises due to an increase in perceived hostility, anger, and irritability. Disadvantaged neighborhoods will experience higher levels of such violence.

Household Factors

Single Parent Households

Single parent households are more likely to be in poorer neighborhoods and have fewer economic resources. With the sole responsibility for caregiving as well as providing family income, this increases their vulnerability to the impacts of climate change.

Custodial Grandparents

Custodial grandparents have been shown to have higher levels of obesity, hypertension, heart disease, limited physical functioning, and dissatisfaction with one's physical health. Additionally, custodial grandparents have reported emotional stress from financial constraints, and inadequate social support which make them vulnerable to the impacts of climate change.

Renters

Renters have a low climate change adaptability and resilience, given the low quality and short supply of available housing, as well as the renter's limited ability to retrofit their place of residence to prepare for climate change. Additionally, renters new to an area have less knowledge of local environmental hazards, such as floods, which reduce their ability to adapt to climate impacts.

Elderly Isolation

Individuals who are 65-years of age or older and alone are more likely to have limited ability to evacuate due to a disability, limited income, lack of transportation, or lack of social support from family and friends. Older Americans living alone may be more susceptible to risks such as frauds or scams, regarding home improvements or repairs before or after extreme weather events.

Income & Education Factors

Poverty	Individuals below the poverty level are more likely to depend on climate sensitive forms of employment, such as agriculture, or on low-income informal or hourly jobs. The impacts of climate change can cause a rise in risks such as physical and mental illnesses, job loss, and decreased food security. Additionally, those below the poverty level have fewer resources and receive less support, which reduces their ability to prevent, cope, and adapt to climate change impacts.
Work Outdoors	Climate change impacts serve as risks to outdoor workers through increases in temperature, poor air quality, extreme weather, diseases transmitted by ticks and mosquitoes, industrial exposures, and damage to infrastructure. Extreme heat may result in more heat-related illnesses such as heat stroke, heat exhaustion, and fatigue for outdoor workers
SNAP/Food Stamps	Individuals who receive SNAP/food stamps in areas of low food security have limited adaptability and resilience to the impacts of climate change. Disruptions in government functions during climate disasters may impact distribution of SNAP/food stamp benefits, and individuals may have to opt for non-nutritious food options.
Public Assistance Income	Climate change induced natural disasters may disrupt communication systems and pose risks to the distribution of governmental benefits. For climate resilience, public assistance income must be able to change as the demand changes, while facing the challenge of slower economic growth.
Housing Cost Burden (>30% of HH income)	Households with housing expenditures that exceed 30 percent of household income are considered financially burdened, which can limit household consumption, reduce economic mobility, and reduce climate adaptability and resilience.
No High School Diploma	Education levels are highly correlated with access to weather forecasts and warnings, as well as the types of technologies used to access weather information. Without adequate access to information, individuals cannot respond and prepare for hazards effectively.
Unemployment	Individuals who are unemployed will have a harder time relocating from areas impacted by climate change, and may lack resources to repair or rebuild their home in the event of a natural disaster.

Income & Education Factors

Housing Choice Voucher Program

The Housing Choice Voucher Program provides rental assistance to qualified low-income individuals and families to afford decent, safe, and sanitary housing. However, the largest concentration of renters using Housing Choice Vouchers is located in subsidized housing projects, which intensifies poverty to those locations. Residences with low economic standing are associated with poorer health care access, being uninsured, and higher hospitalization rates, which limits climate adaptability and resilience.

Housing & Transportation Factors

Multi-Unit Structures

Multi-Unit Structures: Multi-unit structures are buildings containing 10 or more housing units. Individuals living in multi-unit housing have limited access and limited ability to leave the building to obtain food, medicine, and other needed services. In multi-unit structures where residents rely on elevators, electricity loss makes it difficult if not impossible for some residents to evacuate, especially the elderly and those with disabilities.

Mobile Homes

Mobile Homes: Mobile homes are often isolated with limited or no access to public transportation or highways, limiting their ability to evacuate. The impacts of climate change may result in many of the mobile home parks experiencing a significant destruction of personal property and displacement of their residents.

Crowding

Crowding: Crowding, where there are more people than rooms in a household, increases psychological distress, and can contribute to the spread of communicable diseases among residents. Children are especially vulnerable, as the lack of a comfortable, quiet space can lead to difficulties studying and reading, affecting school performance and increasing social withdrawal. All of these factors can increase the vulnerability of members of a crowded household to climate impacts.

Vehicle Access

Transportation Access: Individuals in a household without a vehicle have a limited ability to evacuate or move to an area of refuge during a climate change impact, such as an air-conditioned cooling center during extreme heat, or a shelter during severe flooding.

Housing & Transportation Factors

Air Conditioning	<p>Air Conditioning: Climate change impacts, such as extreme heat, are associated with an increased risk of mortality from respiratory, cerebrovascular, and some specific cardiovascular diseases such as ischemic heart disease, congestive heart failure, and myocardial infarction. Extreme heat can also increase the risk of heat exhaustion and heat stroke, therefore without a central AC have a low climate change adaptability and resilience.</p>
Homelessness	<p>Homelessness: Homelessness is associated with both racial and ethnic disparities, and children experiencing homelessness have a 25% greater risk of poor health and higher mortality rates in adulthood, increasing vulnerability to climate impacts. Climate-related disasters lead to displacement, which increases the need for emergency and transitional shelters, and causes greater exposure to health risks.</p>
Adult Group Homes	<p>Adult Group Homes: Group homes and residential treatment centers are facilities that may offer housing, and provide personal care and medical services for adults. Group homes often service the elderly and individuals with disabilities, which increases their vulnerability. A climate-related disaster may result in power outages that can limit communication for emergency services, and severely impact those who rely on refrigerated medications, or use life-sustaining equipment.</p>
Internet Access	<p>Internet Access: Access to the internet is a crucial resource for connecting people to the information they need in areas such as emergency services, education, employment, and health. Without access to internet, through either a home-based or cellular data subscription, households may be limited in their access to this information and be more vulnerable to sudden and dangerous increases in temperature or flooding.</p>

A review of peer cities' climate vulnerability assessments revealed that this is a greater number of variables than is typically used to measure social vulnerability to climate change. The aim of this approach is to provide a more comprehensive picture of vulnerability. In addition, the intention is that by gathering this data as part of this project, it can serve multiple purposes for both internal City of Richmond as well as external community audiences. A certain factor, while possibly having a small impact on a neighborhood's aggregate vulnerability score,

could help with implementation of climate resilience strategies in the future. For example, the City and partner organizations could see where to prioritize air conditioning assistance programs based on the economic and central air conditioning data, or the data on outdoor workers could be used to target populations for education on heat-related illness prevention.

The table below lists the data sources and attributes for analysis for each of the social vulnerability factors. The factors are divided into two groups: sensitivity factors,

which affect the degree to which a person, household, or community is directly or indirectly affected by changes in climate conditions or climate change impacts; and, adaptive capacity factors, which affect the ability of a person, household, or community to accommodate changes in climate with minimal potential harm or cost. Poverty is the only factor that was used in both the sensitivity and the adaptive capacity analyses because it has such a significant impact on a person's ability to withstand and deal with shocks.

Social Vulnerability Sensitivity and Adaptive Capacity Factors

Sensitivity Factors		
Factor	Source	Attribute for Analysis
Poverty	2012-16 ACS ¹	Percent of individuals below poverty level in the past 12 months
Public Assistance	2012-16 ACS	Percent of households receiving public assistance income in past 12 months
Food Stamps	2012-16 ACS	Percent of households receiving food stamps/SNAP
Non-White	2012-16 ACS	Percent of individuals that are not white
Elderly	2012-16 ACS	Percent of individuals 65 or older
Children	2012-16 ACS	Percent of individuals under 18
Female	2012-16 ACS	Percent of individuals that are female
Disabilities	2009-13 ACS	Percent of individuals with a disability (hearing, vision, cognitive, ambulatory, self-care, or independent living difficulty)
Obesity	CDC (2015)	Percent of adults with obesity
Asthma	CDC (2015)	Percent of adults with asthma
COPD	CDC (2015)	Percent of adults with COPD
Heart Disease	CDC (2015)	Percent of adults with coronary heart disease

High Blood Pressure	CDC (2015)	Percent of adults with high blood pressure
Kidney Disease	CDC (2015)	Percent of adults with chronic kidney disease
Mental Health	CDC (2015)	Percent of adults self-reporting mental health not good for more than 13 days
Physical Health	CDC (2015)	Percent of adults self-reporting physical health not good for more than 13 days
Food Access	USDA ²	Percent of population beyond 1 mile from a “supermarket,” as defined by USDA
Grandparent Householder	2012-16 ACS	Percent of population under 18 living with grandparent householder
Single Parent Household	2012-16 ACS	Percent of population under 18 living with one parent
Work Outdoors	2012-16 ACS	Percent of population in workforce working in sectors: Natural resources, construction, and maintenance occupations; Farming, fishing, and forestry occupations; Construction and extraction
Housing Costs	2012-16 ACS	Percent of households where monthly housing costs are 30% or more of household income
Multi-Unit Structure	2012-16 ACS	Percent of housing units in a structure with 10 or more total units
Mobile Home	2012-16 ACS	Percent of housing units that are mobile homes, boats, or RVs
Crowding	2012-16 ACS	Percent of housing units with more than 1 occupant per room
Crime	RPD ³	Crime rate per person for all crimes between 11/20/2013-11/20/2018
Adaptive Capacity Factors		
Factor	Source	Attribute for Analysis
Poverty	2012-16 ACS	Percent of individuals below poverty level in the past 12 months
Unemployment	2012-16 ACS	Percent of population 16 and over unemployed
High School Diploma	2012-16 ACS	Percent of population over 25 without a high school diploma
Limited English Proficiency	2012-16 ACS	Percent of households with limited English proficiency (speaking English Less than Very Well)
Elderly Living Alone	2012-16 ACS	Percent of population 65 and over living alone
Renters	2012-16 ACS	Percent of housing units occupied by renters
Vehicle Access	2012-16 ACS	Percent of households with no vehicle available

Internet Access	2013-17 ACS	Percent of households without an internet subscription (includes dial up, satellite, broadband, cellular data plan)
Central Air Conditioning	City of Richmond Assessor (2018)	Percent of households without central air conditioning
Housing Choice Vouchers	HUD ⁴	Percent of renter-occupied housing units with Housing Choice Vouchers
Shelters/ Emergency Housing	2010 Census	Percent of individuals in emergency and transitional shelters (with sleeping facilities) for people experiencing homelessness
Group Homes	2010 Census	Percent of individuals in group homes intended for adults or residential treatment centers for adults
Uninsured	2012-16 ACS	Percent of population without health insurance coverage
Health Opportunity Index	Richmond 300	Overall Health Opportunity Index as designated by Virginia Department of Health's Office of Minority Health and Health Equity

¹ American Community Survey

² USDA Food Access Research Atlas

³ City of Richmond Police Department

⁴ U.S. Department of Housing and Urban Development

4.2 Analysis of Social Vulnerability

Based on social vulnerability assessment methodologies from several peer cities, the 39 factors described above were used in two different ways to determine which census tracts in Richmond are the most vulnerable to climate change.

4.2.1 Analysis Methods Quartile Method

Following the methodology described in several peer city vulnerability assessments, including Somerville and Washington, DC, Census tracts were ranked for each of the 38 factors and then divided into quartiles. The tracts were assigned a score between 1 and 4 based on their quartile. Then these scores were added across all 38 factors for each tract to create an aggregate vulnerability score.

Standard Deviation Method:

Following the methodology described in the Minneapolis vulnerability assessment, Census tract values were converted to z-scores using the average and standard deviation of all tracts for each of the 38 social vulnerability factors. A standard deviation classification number, or score, was assigned based on the categories below. Within this

scoring system, a score of 1 indicates the lowest relative vulnerability and 6 indicates the highest. These scores were added across all 38 factors, then the total scores were converted to z-scores and assigned an aggregate score of 1 to 6 using the same system below.

The final vulnerability map contained in this report depicts the results of the standard deviation method described above. There were minimal differences between results of the two methods, and standard deviation is generally thought of as a more robust measure of dispersion among multiple variables.

4.2.2 Additional Analysis Methods

Two additional steps were taken to assess the validity of the methodology described above: a reduced-factor analysis and a principal component analysis. In the reduced-factor analysis, a set of 12 factors was taken from the 38 described above and put into both the quartile and standard deviation methods of ranking vulnerability. The 12 factors were identified as those commonly used by peer cities and best practices guides for vulnerability assessments.

This analysis revealed only minor differences in the final vulnerability ranking of census tracts from the results of the use of 38 factors.

In addition, a correlation matrix and principal component analysis were created using the statistics software R.

The purpose of this step was to attempt to identify potential correlations between the 38 factors that may skew the results of the scoring method. This step identified a few cases where some of the 38 variables may be so interrelated as to not have significant impact on the analysis, though no perfect positive correlations were revealed. However, as noted in the Minneapolis vulnerability assessment methodology, this process is overly complicated to perform and explain to the public, and therefore was not used to alter the final method and map. Online tutorials and information from the Minneapolis vulnerability assessment report were used to complete these steps.

Appendix B contains tables and charts with the results of the correlation matrix and principal component analysis.

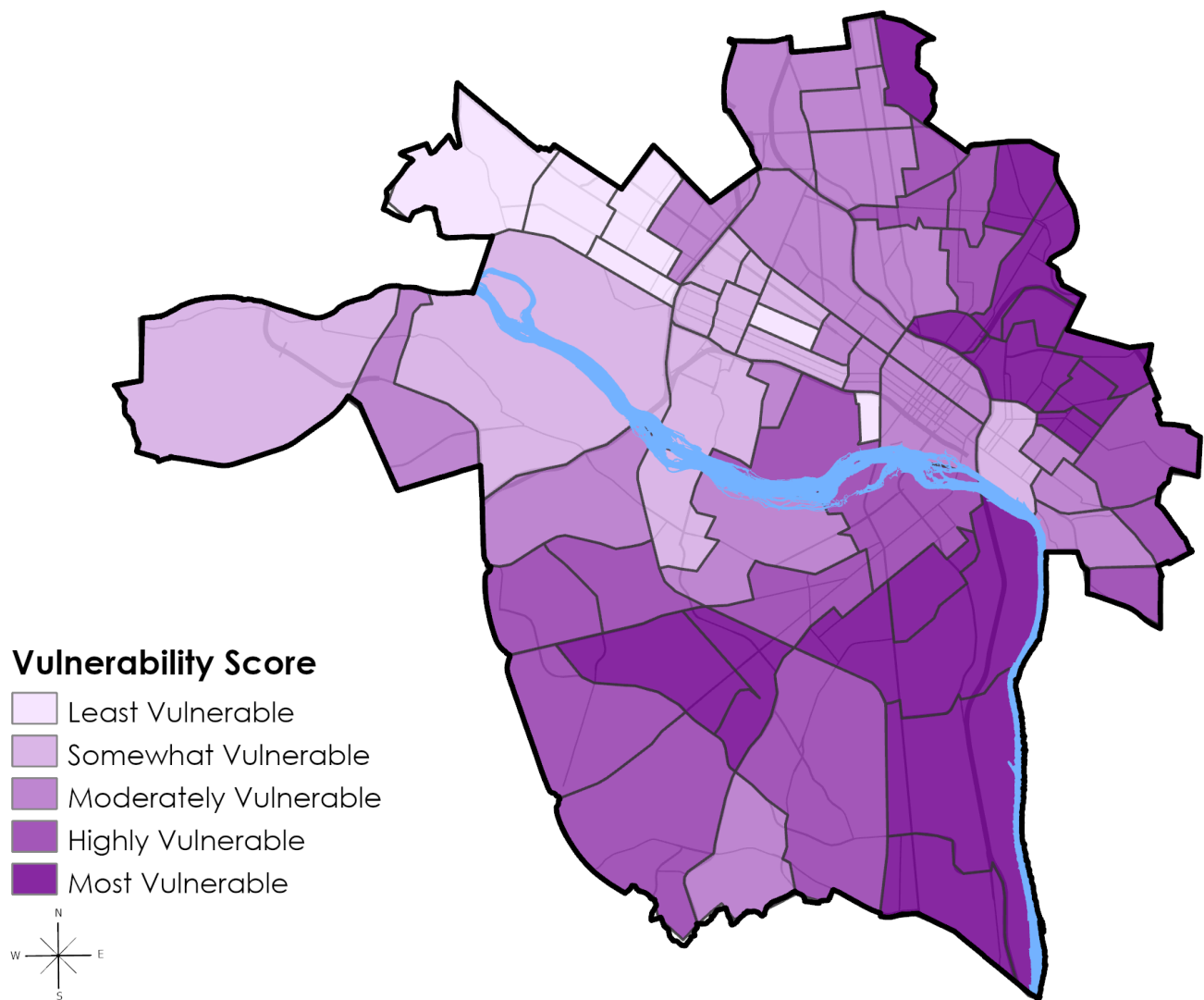
4.3 Composite Social Vulnerability Mapping

Maps were created for each of the 39 factors based on their actual values as described below.

The final vulnerability score map was created using the results of the standard deviation scoring methodology, to compare

relative overall vulnerability across Richmond's census tracts. This map shows the areas with the most social vulnerability in the darkest color, while lighter shades indicate lower levels of vulnerability. In subsequent sections, social vulnerability will be overlaid with the vulnerability ratings of built and natural assets to show the connections between people

and environment and to inform prioritization of climate vulnerabilities. For example, the map below shows that some of the more vulnerable areas are adjacent to the river, which are also areas that will be at greater risk from flooding and sea level rise.

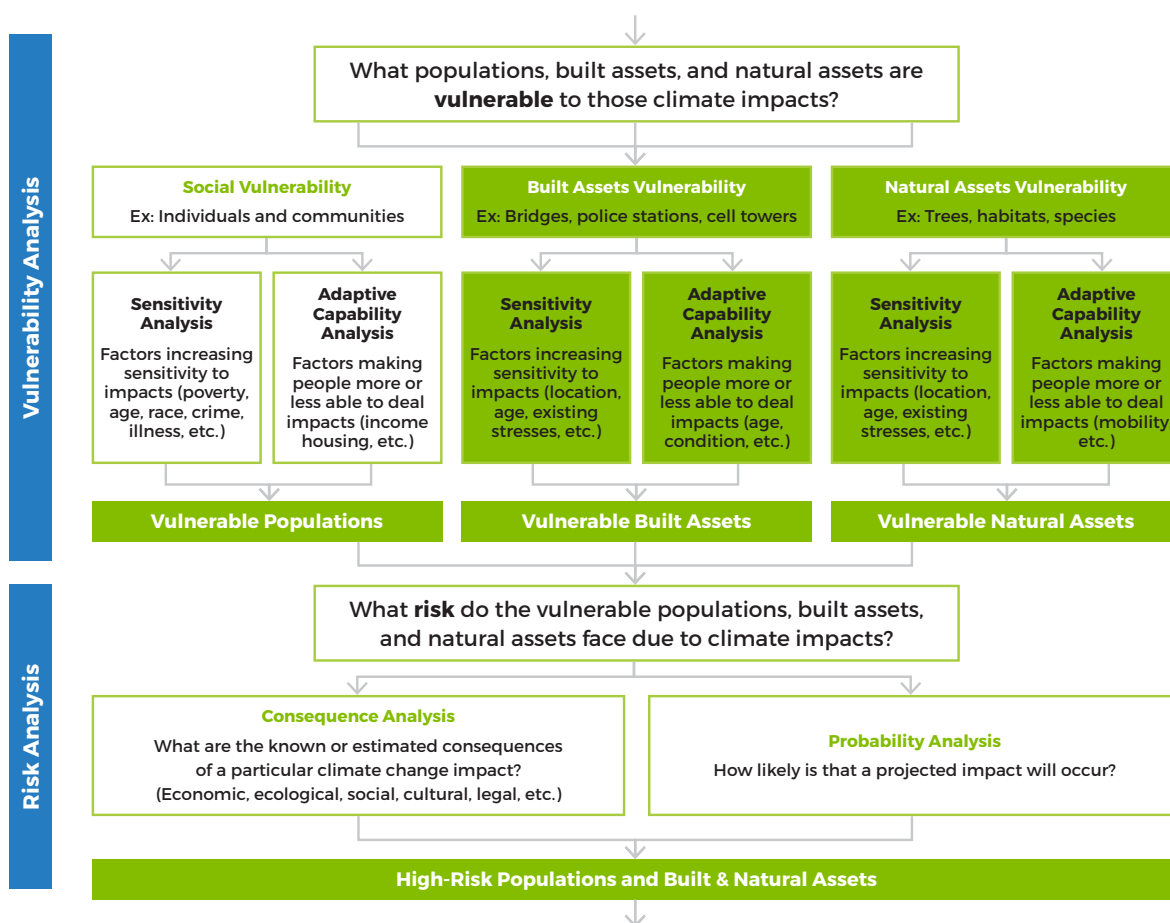


Source: City of Richmond, Climate Equity Index



5. Built and Natural Assets Vulnerability and Risk

This section addresses the vulnerability and risk analyses for built and natural assets for key climate impacts. Information on social vulnerability is incorporated through mapping analysis in these steps to understand where and how people and assets are being affected, especially for Richmond's most vulnerable communities



5.1 Analysis Methodologies

5.1.1 Vulnerability Analysis Methodology

Vulnerability to climate change encompasses physical, ecological, and social aspects that stem from increased extreme weather events, rising temperatures, changing precipitation patterns, sea level rise, and other aspects of climate on which the environment and human systems depend. Vulnerability is typically defined as a function of climate impact, sensitivity, and adaptive capacity.

In addition to creating the RVAgreen 2050 Climate Equity Index to assess social vulnerability of the Richmond community (discussed in Section 4), the City also engaged the RVAgreen 2050 technical working groups to assess vulnerability across categories of the City’s built and natural assets. The working groups scored each asset type for sensitivity and adaptive capacity and discussed details on the potential consequences and implications of impacts to each.

The scoring classifications used with the working groups are shown in Figure 5.1. If a

system or asset has both a high sensitivity to a climate impact as well as a low adaptive capacity, it is considered highly vulnerable. Results of the vulnerability assessment scoring for sensitivity, Adaptive capacity, and overall vulnerability for heat and water threats for built and natural Assets are presented in Appendix C. Built and natural asset vulnerabilities to flooding and heat were also mapped in order to understand where assets may be most vulnerable and where there may be concentrations of vulnerable assets, as well as allowing for overlays of social vulnerability with these asset vulnerabilities to understand how these potential impacts and any concentrations of impacts may affect Richmond’s frontline communities.

Sensitivity
Degree to which a system, asset, or population may be affected when exposed to climate impacts.

Adaptive Capacity
Ability of a system, asset, or population to adjust to potential damage, take advantage of opportunities, or respond to consequences.

		Adaptive Capacity Classification		
		High	Medium	Low
Sensitivity Classification	Low	1	2	3
	Medium	2	3	4
	High	3	4	5

Figure 5.1 Vulnerability Assessment Scoring Matrix (Source: City of Richmond)

5.1.2 Risk Analysis Methodology

In concert with assessing the vulnerability of Richmond's systems and assets, measures of risk were also assessed across the city's populations, built assets, and natural resources. Risk was considered as a measure of both consequence and probability.

Consequences were rated by technical working group members and City staff based on a scale of low, moderate, and high for Richmond's systems and assets across eight dimensions or criteria. The following table outlines the scoring criteria, which attempt to, at a high level, measure the repercussions or implications of a specific climate impact. Consequences were assessed across all criteria for all asset groups and compiled to create a final "consequence score" for each

asset group. Results of the Consequence scoring for Built and Natural Assets are presented in Appendix D.

Built and natural asset exposure to flooding and heat were also mapped in order to better understand where assets may be most vulnerable to climate impacts and where there may be concentrations of these vulnerable assets, and where socially vulnerable areas may intersect with these asset vulnerabilities to understand how these potential impacts and any concentrations of impacts may affect Richmond's frontline communities.

Probability was measured by mapping built and natural assets and identifying which of them lie within Richmond's hotter areas and potential areas for flooding. This mapping helps to understand

where assets currently experience climate impacts and where they may be likely to experience future or increasing climate impacts, as well as where they may be concentrations of assets with risk exposure.

Consequence: Measure of the magnitude of repercussions associated with system/asset failure in the event of a climate impact

Probability: Likelihood of an asset or system to be impacted by a particular climate change shock or stressor

Consequence Score	Area of Service Loss	Duration of Service Loss	Cost of Damage	Impacts of Public Safety Services	Impacts of Economic Activities	Impacts to Public Health	Impacts to Vulnerable Populations	Impacts to Natural Environment
3 - High	2 or more council districts	> 7 days	> \$1M	High	High	High	High	High
2 - Medium	1 council district	1-7 days	\$100k-\$1M	Moderate	Moderate	Moderate	Moderate	Moderate
1 - Low	Neighborhood	< 1 day	< \$100k	Low	Low	Low	Low	Low

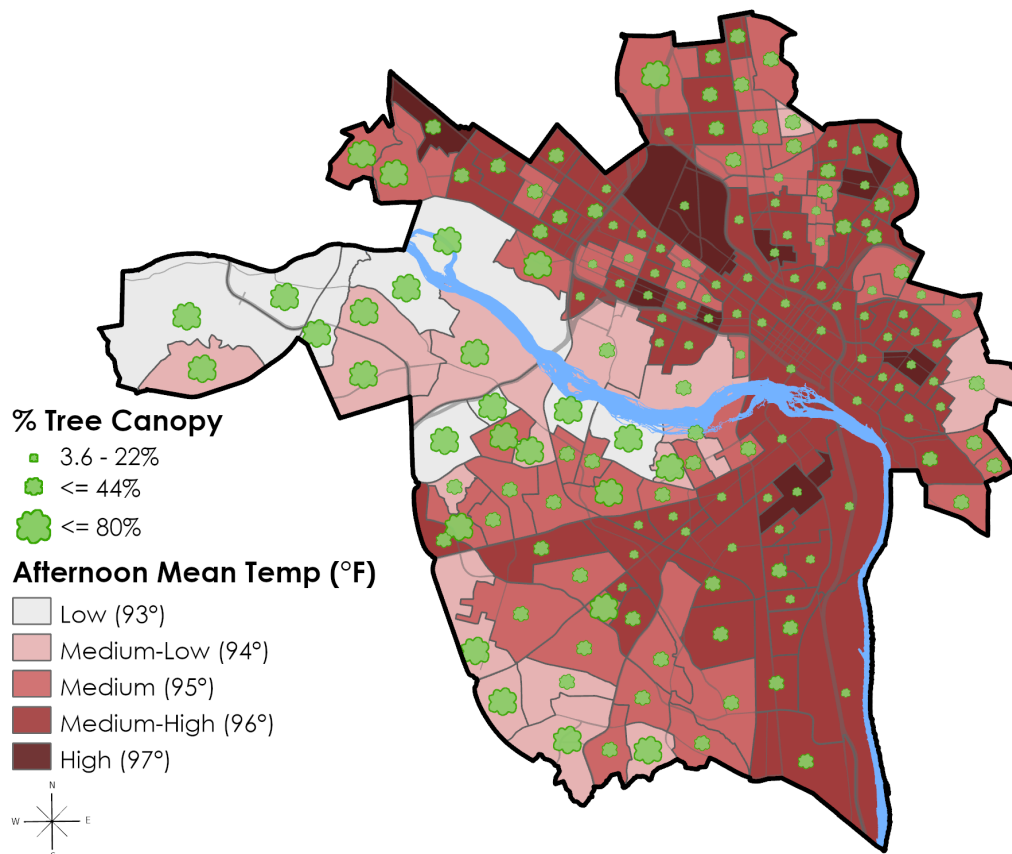
Figure 5.2 Consequence Scoring Matrix (Source: City of Richmond)

Much of Richmond's infrastructure will be resilient to future extreme heat events and increasing temperatures. The primary effects of future heat waves and increasing temperatures will be to the health and wellbeing of community members and natural resources. Increasing energy demand may impact power supply reliability, air quality, and utility costs, which will have the greatest impact on frontline communities.

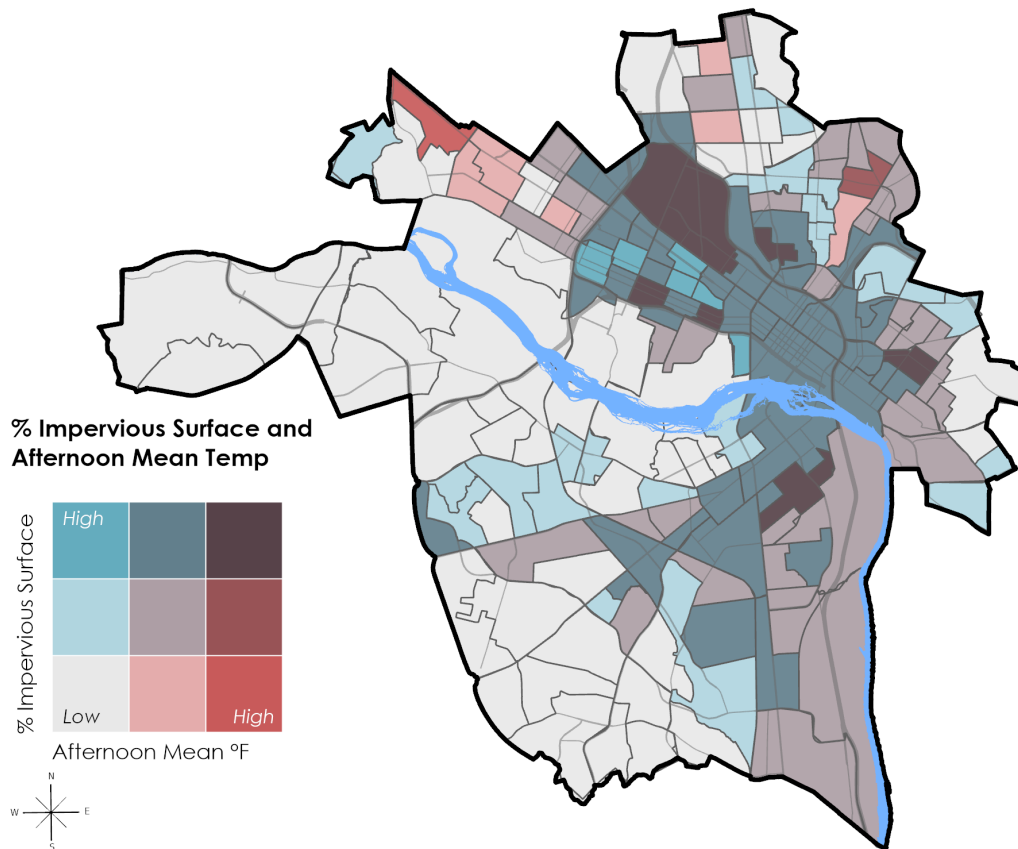
Richmond's Future Heat Risks

- Cooling demand / electric supply demand
- Power outages and supply drops (brownout)
- Urban Heat Islands
- Poor air quality
- Community health and public safety
- Limits to operating speed on rail lines
- Vegetation and native plant impacts, affecting runoff and combined sewer overflows

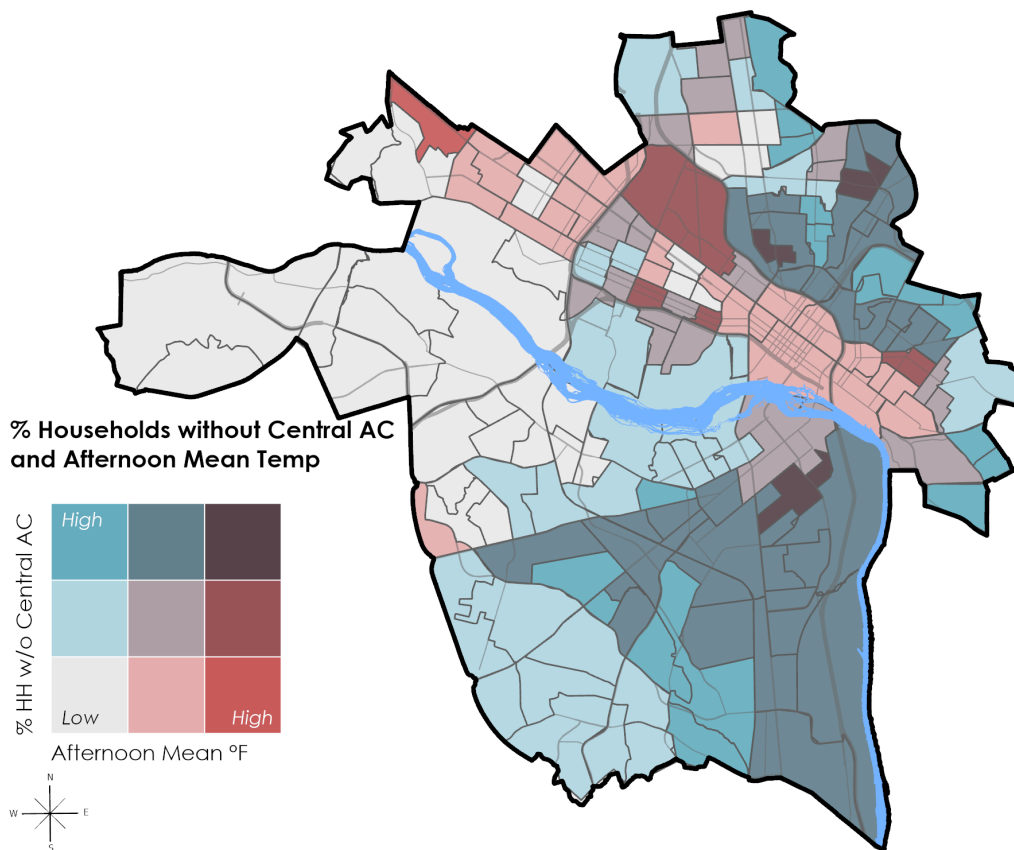
Heat Risk: Areas more at risk due to extreme heat and heat waves include those with higher temperatures shown below from the 2017 urban heat island study. Social factors - such as age, poverty, and race/ethnicity - also play an important role in evaluating overall risks to our community due to heat.



Source: City of Richmond, Esri, US Census Bureau



Source: City of Richmond, Esri, US Census Bureau



Source: City of Richmond, Esri, US Census Bureau

Approach to Assessing Flood Risk

The identification of flooding risk incorporates both changes over time to the City's floodplain areas as they are anticipated to expand and determination of those areas that are subject to localized flooding, inundation, and standing water, and thus will experience greater impacts as climate change causes more frequent extreme precipitation events.

As discussed in Section 3, the FEMA floodplains for storms with a 1% annual chance of occurring were identified as the City's 2030/2050 planning scenario and represent future flood risk in this assessment with respect to floodplains. It is important to note that federal floodplain designations are currently based on historic data and do not take into account projections for increased flooding due to climate change. Following an example from Washington DC's climate vulnerability and risk assessment, the map uses the present 100-year (1-percent annual chance) and 500-year (0.2 percent annual chance) floodplains as determined by FEMA as a proxy for future flooding. This flood risk was augmented by detailed flood risk mapping that reflects Richmond's terrain.

[ArcGIS-based flooding inundation model](#) was applied

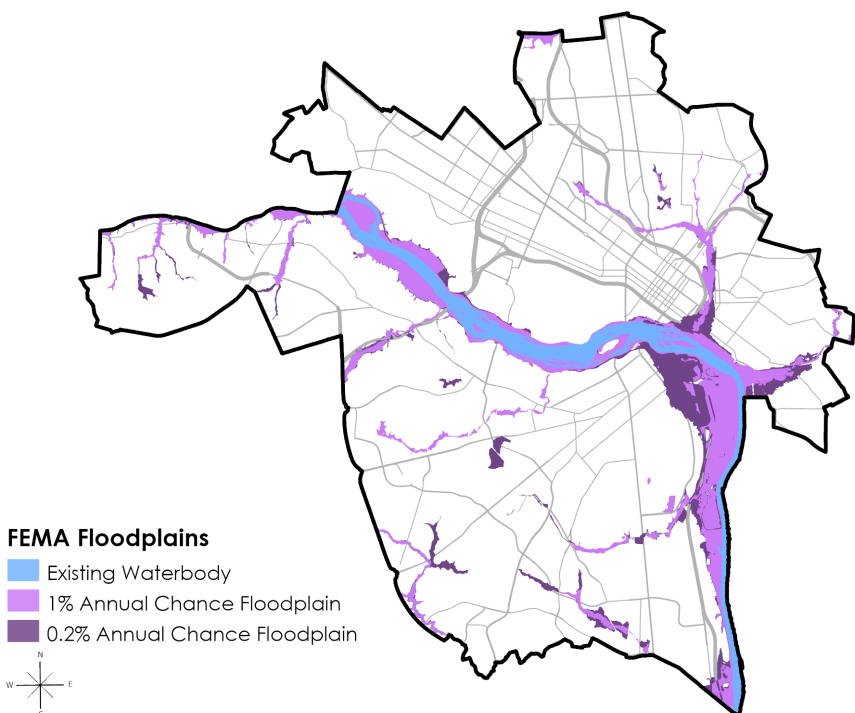
to assess potential localized flood risks using detailed data on Richmond's terrain features and building locations to identify low-lying areas and depressions where water may collect during heavy precipitation and storm events. Depressions that would allow more than two inches of floodwater to collect and deeper areas that would allow flooding of more than five inches were both mapped. The analysis calculates the spillover from each depression to the next downstream depression to predict the overall consequences of stormwater.

Finally, the areas with inundation of more than five inches were added to the 2030/2050 floodplain scenario to define the critical flood risk for

Flooding Risk: Areas at higher risk for future flooding or inundation, either located in the 100-year floodplain or in areas where water may pool more deeply after storms (5 inches or greater)

Richmond for this assessment.

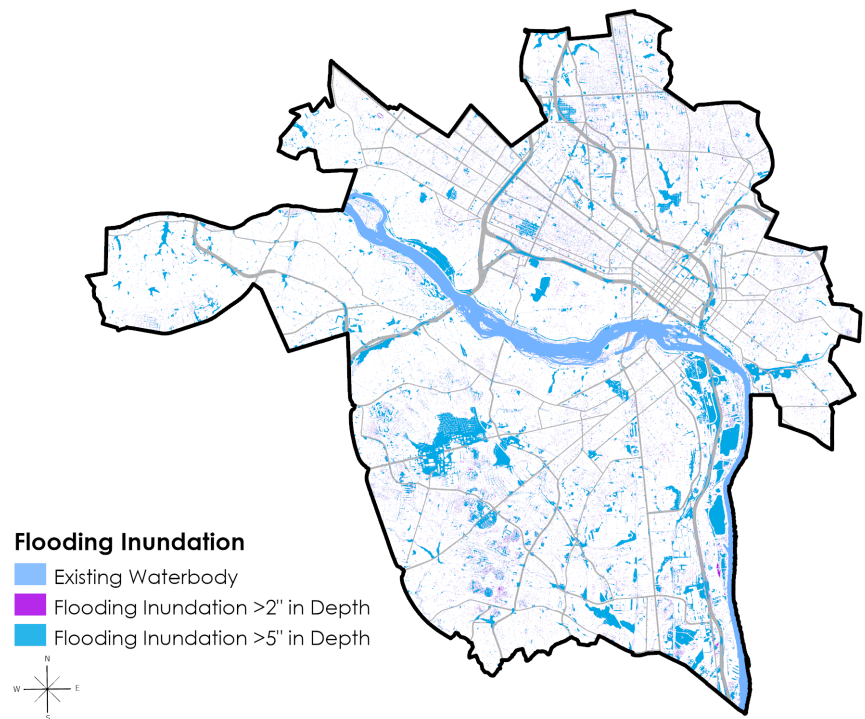
As storm and precipitation events continue to intensify, future flooding impacts will increase to communities, physical infrastructure, and natural resources throughout Richmond. Sea level rise will not impact as many areas of Richmond directly, but will impact natural, historic, energy, stormwater management, recreation, transportation, and other resources in and along the James River.



Source: City of Richmond, FEMA

Richmond's Future Flooding and Storm Risks

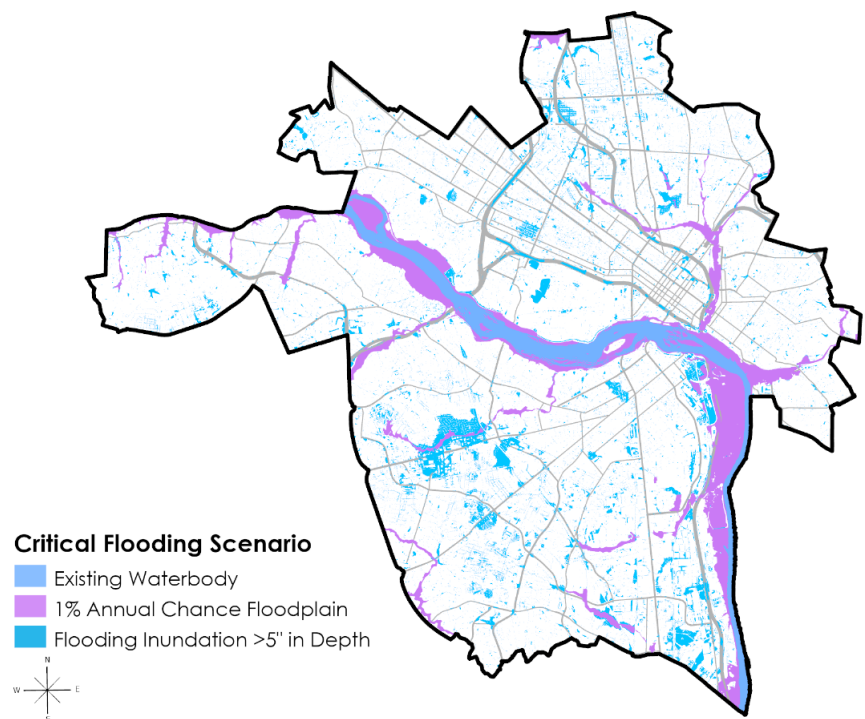
- Flood damage to properties, buildings, and equipment
- Flooding of area roadways
- Storm power outages
- Disruptions to public safety operations and emergency response
- Combined sewer system backups and wastewater overflow into local waters
- Sea level rise along the James River and tributaries
- Habitat impacts from permanent water level or quality changes



Source: City of Richmond, FEMA

5.2 Vulnerability and Risk Results

The figure below summarizes the results of RVAgreen 2050 technical working group scoring of Vulnerability and Consequence for Richmond's Built and Natural Assets. More detailed information on climate vulnerabilities, resilience factors, equity considerations, and assets at risk is presented along with the scoring results for each asset category in the sections that follow. For some asset categories Vulnerability and Consequence scoring ranged across the assets within the category and a range of scores rather than single score is indicated.

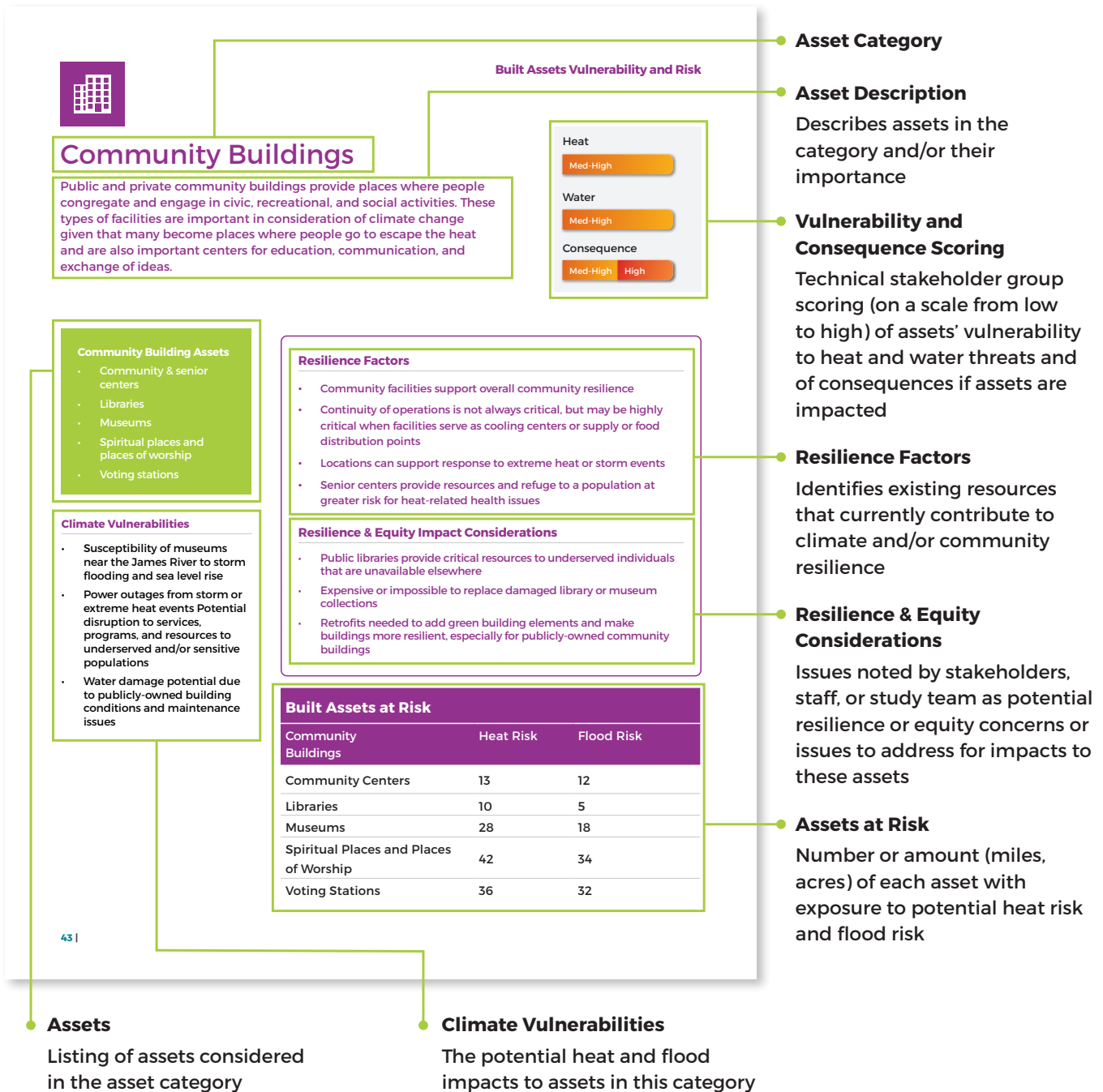


Source: City of Richmond, Esri, FEMA

Vulnerability and Consequence Scoring Summary

	Heat Risk	Flood Risk	Consequence
Communications Infrastructure	Medium	Medium	Medium
Community Buildings	Med-High	Med-High	Med-High High
Education	Medium High	Medium Med-High	Medium Med-High
Health and Social Services	Medium Med-High	Med-High	Med-High
Historic	Med-High High	Med-High High	Medium Med-High
Economic Development and Planning	Medium Med-High	Med-High High	Medium Med-High
Energy Infrastructure	Med-Low High	Low High	Low Med-High
Food System Assets and Resources	Med-High	Med-High	Med-High
Government Facilities	Med-High	Med-High	Med-High
Parks and Open Spaces	Med-High High	Med-High High	High
Public Housing Resources	High	High	High
Public Safety and Emergency Response	Medium Med-High	Med-High	Med-High
Stormwater and Sewer Infrastructure	Medium	High	High
Waste Management Infrastructure	Medium	Med-High High	Med-High High
Water Supply Infrastructure	Medium Med-High	Med-High High	High
Transportation Infrastructure			
Roads and Bridges	Medium	Med-High	Med-High
Bike/Ped	Med-High	Med-High	Med-High
Rail and Transit	Medium	Med-High	Med-High
Marine	Med-Low	Med-High	Med-High
Airport	Med-High	Med-High	Med-High
Natural Assets			
Parks and Open Spaces	Med-High	Med-High	High
Terrestrial Habitat	Med-High	Med-High	High
Trees & Vegetation	Med-High	Med-High	High
Water Bodies	Med-High	Med-High	High

Guide to Vulnerability and Risk Asset Sheets



Built Assets Vulnerability and Risk

Built assets were identified by considering the people, resources, and infrastructure in the City of Richmond, as well as the services those resources and infrastructure provide. These include assets both internal and external to the City's operational control.





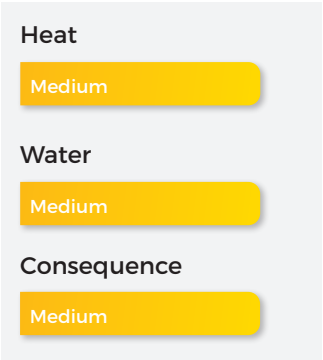
Communications Infrastructure

Richmond’s communications infrastructure is critical for the community’s ability to communicate, and becomes particularly important during extreme weather events when people need to report or respond to power outages or health/safety emergencies.

Communications Assets

- Radio transmission towers
- Cellular towers
- Other transmission towers

- Climate Vulnerabilities**
 - Temperature effects to communications infrastructure during power outages
 - Damage to towers and lines of cable from extreme storms, high winds, ice, or heavy precipitation
 - Flooding at communication or data centers
 - Service disruption



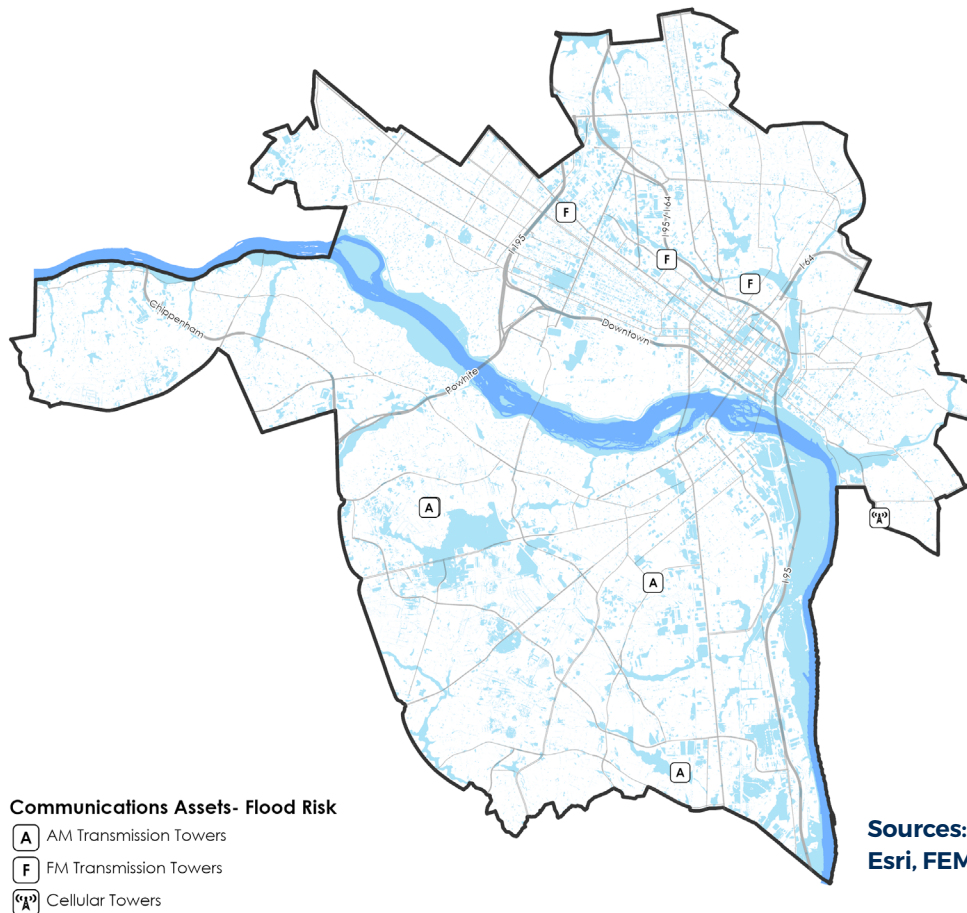
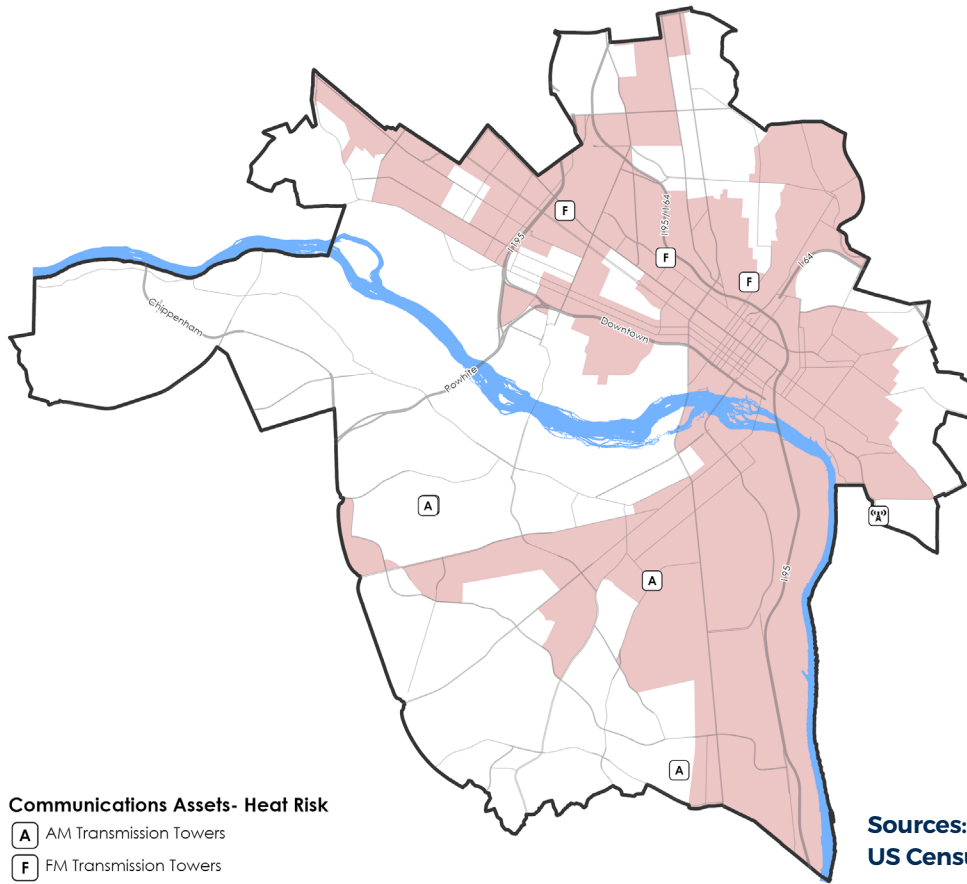
Resilience Factors

- Many emergency response and public safety facilities and operations have backup power supplies to ensure continuity of communications.

Resilience & Equity Impact Considerations

- Communications infrastructure service outages
- Cell service interruptions
- Public safety impacts
- Emergency response impacts

Built Assets at Risk		
Communications Infrastructure	Heat Risk	Flood Risk
AM Transmission Towers	1	1
FM Transmission	4	0





Community Buildings

Public and private community buildings provide places where people congregate and engage in civic, recreational, and social activities. These types of facilities are important in consideration of climate change given that many become places where people go to escape the heat and are also important centers for education, communication, and exchange of ideas.

Heat

Med-High

Water

Med-High

Consequence

Med-High High

Community Building Assets

- Community & senior centers
- Libraries
- Museums
- Spiritual places and places of worship
- Voting stations

Climate Vulnerabilities

- Susceptibility of museums near the James River to storm flooding and sea level rise
- Power outages from storm or extreme heat events Potential disruption to services, programs, and resources to underserved and/or sensitive populations
- Water damage potential due to publicly-owned building conditions and maintenance issues

Resilience Factors

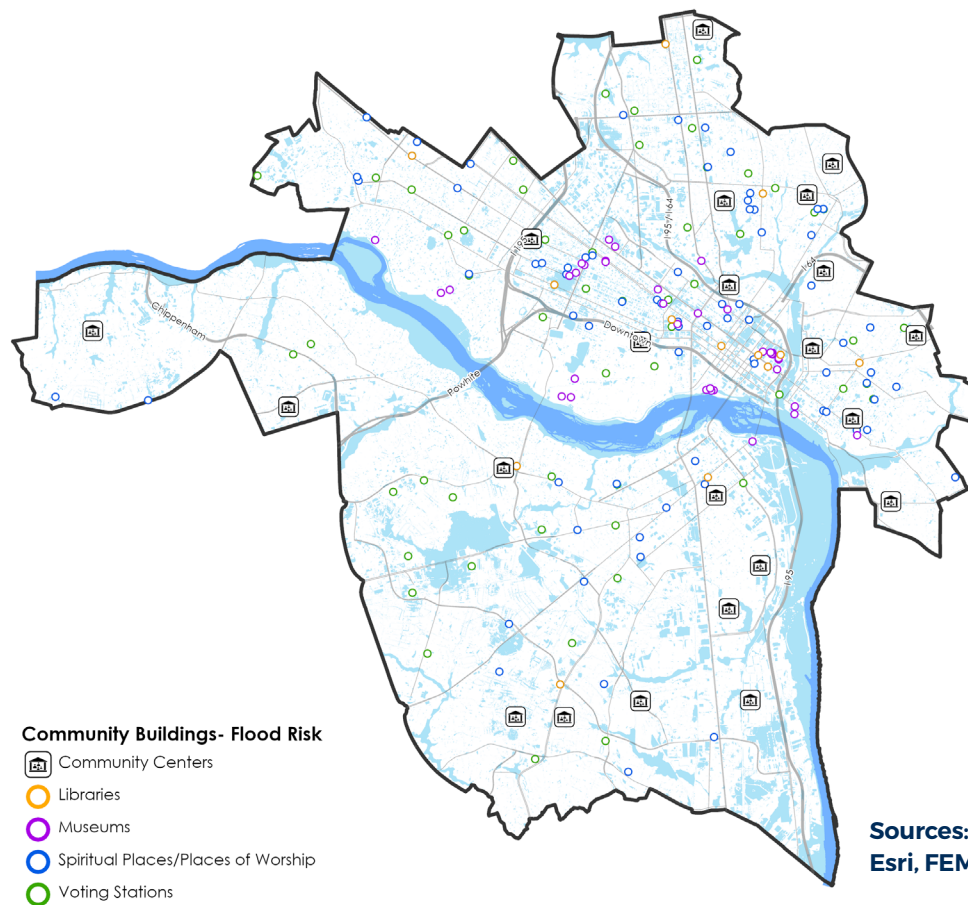
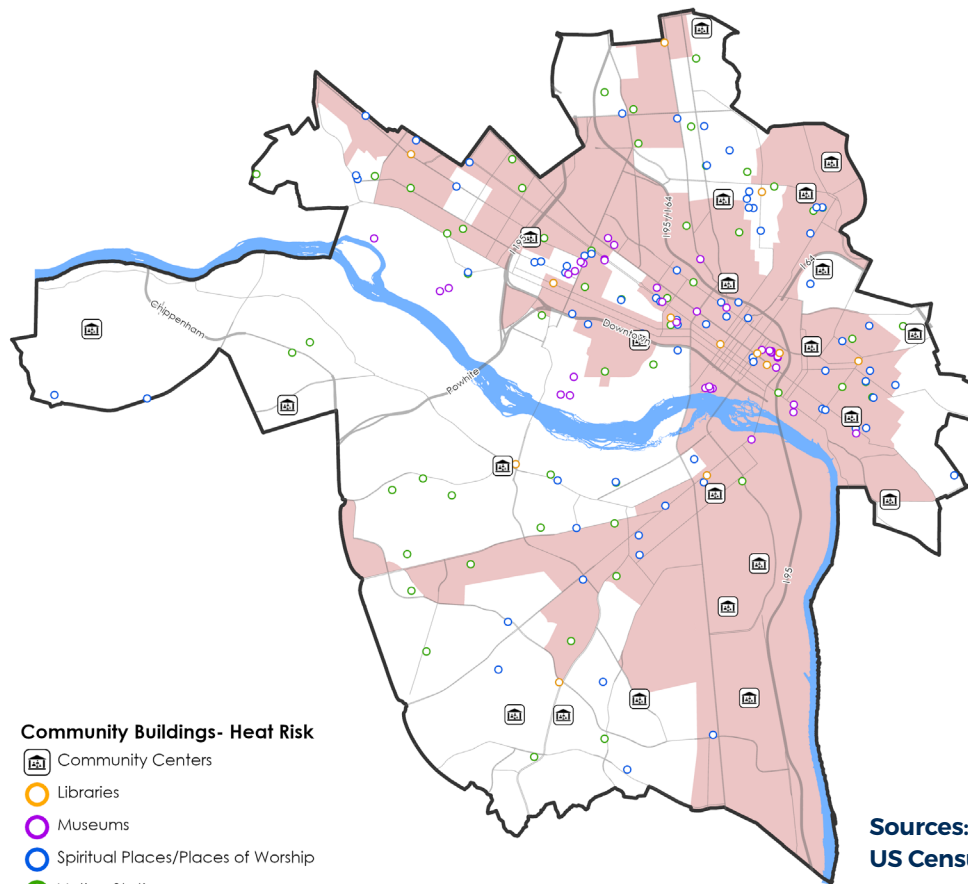
- Community facilities support overall community resilience
- Continuity of operations is not always critical, but may be highly critical when facilities serve as cooling centers or supply or food distribution points
- Locations can support response to extreme heat or storm events
- Senior centers provide resources and refuge to a population at greater risk for heat-related health issues

Resilience & Equity Impact Considerations

- Public libraries provide critical resources to underserved individuals that are unavailable elsewhere
- Expensive or impossible to replace damaged library or museum collections
- Retrofits needed to add green building elements and make buildings more resilient, especially for publicly-owned community buildings

Built Assets at Risk

Community Buildings	Heat Risk	Flood Risk
Community Centers	13	12
Libraries	10	5
Museums	28	18
Spiritual Places and Places of Worship	42	34
Voting Stations	36	32





Economic Development & Planning

Richmond's centers of economic activity as well as those planned for increased economic development are critical to the city's economic well-being. These are sources of employment and income for many residents and business owners and provide important tax revenue to the city. Community members also rely on many businesses to provide goods and services.

Economic development zones and districts

- Community unit and development plans
- Corporate headquarters
- Greater Richmond Convention Center

Climate Vulnerabilities

- Flooding, especially for small businesses
- Power outages from storm or extreme heat events
- Temporary and permanent business closures; according to FEMA, 25% of businesses do not reopen following a disaster, and many others will fail in the following year

Heat

Medium Med-High

Water

Med-High High

Consequence

Medium Med-High

Resilience Factors

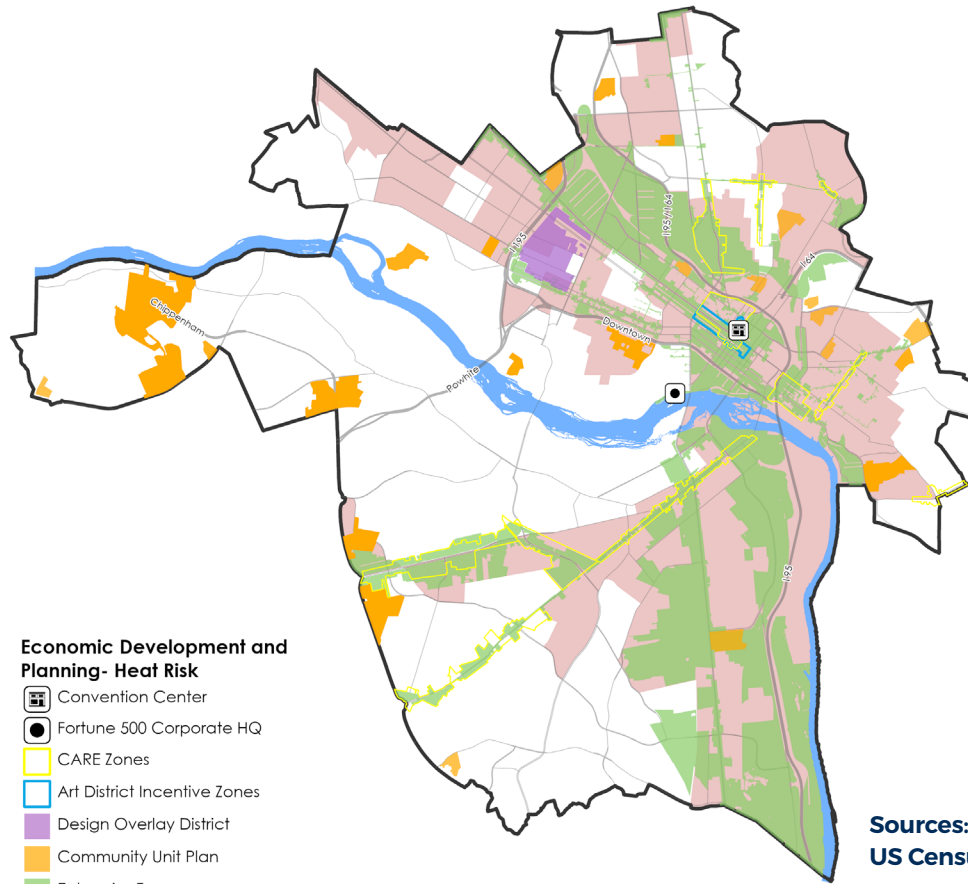
- Local, neighborhood businesses support overall community resilience and may provide support through resource distribution, coordination, or communication during or following extreme weather events and emergencies

Resilience & Equity Impact Considerations

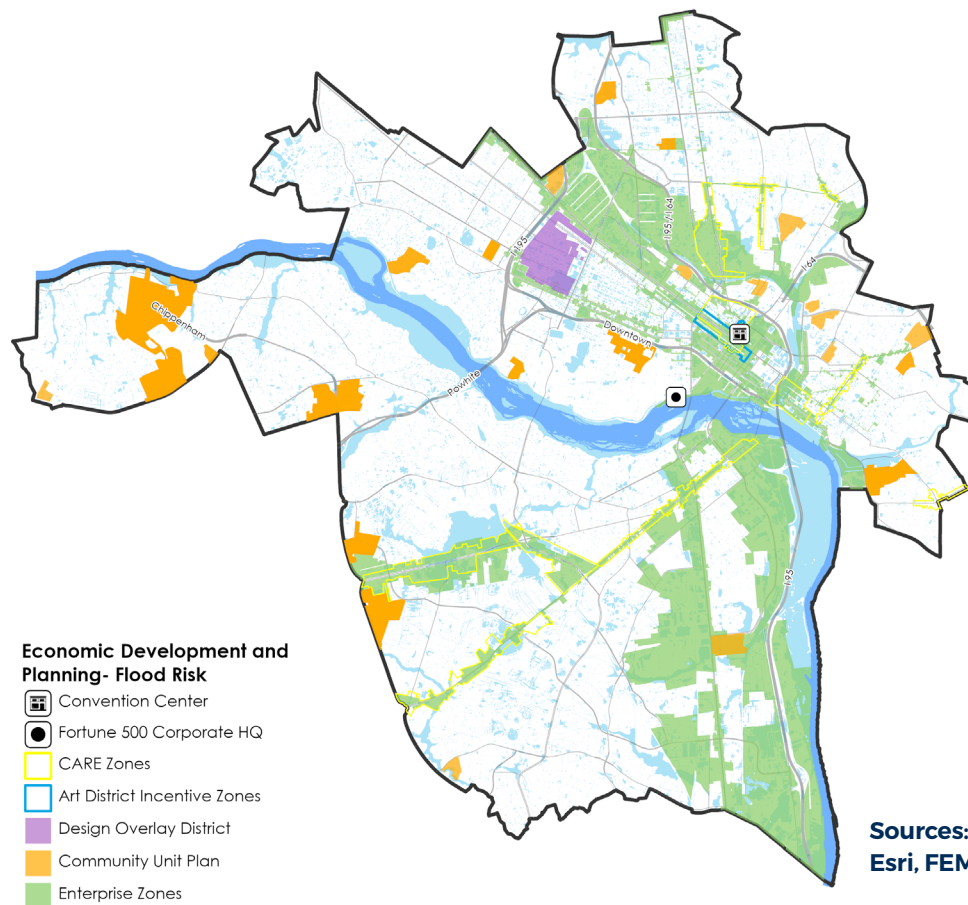
- Resilience may vary across individual businesses, economic areas, and neighborhoods and resources available
- Include climate resilience language in financial incentives for development zones
- Opportunities to make City attractive and economically resilient for those displaced by climate migration from other areas

Built Assets at Risk

Economic Resources	Heat Risk	Flood Risk
CARE Zones	12	13
Convention Center	1	0
Enterprise Zones	4	4



Sources: City of Richmond,
US Census Bureau



Sources: City of Richmond,
Esri, FEMA



Education

Access to education is foundational for individuals to achieve their potential and is a critical element of community social infrastructure. Primary and secondary educational facilities serve youth, young children, and families through education and wellbeing support services. Richmond's local colleges and universities offer opportunities for youth and adult learning, and programs that serve the wider Richmond community.

Heat

Medium High

Water

Medium Med-High

Consequence

Medium Med-High

Education Assets

- Colleges and universities
- Daycare
- K-12 public schools
- Private schools

Climate Vulnerabilities

- Storm flooding impacting roadway and sidewalk access to schools
- Power outages from storms or extreme heat events
- School closures/service loss following climate-related weather events
- Disruption to school-based programs (nutrition, outreach, support services)
- Property damage costs, especially for public schools
- Impacts to vulnerable populations including youth and frontline communities
- Private schools and higher education facilities that have residential operations may experience unique impacts during extreme weather events

Resilience Factors

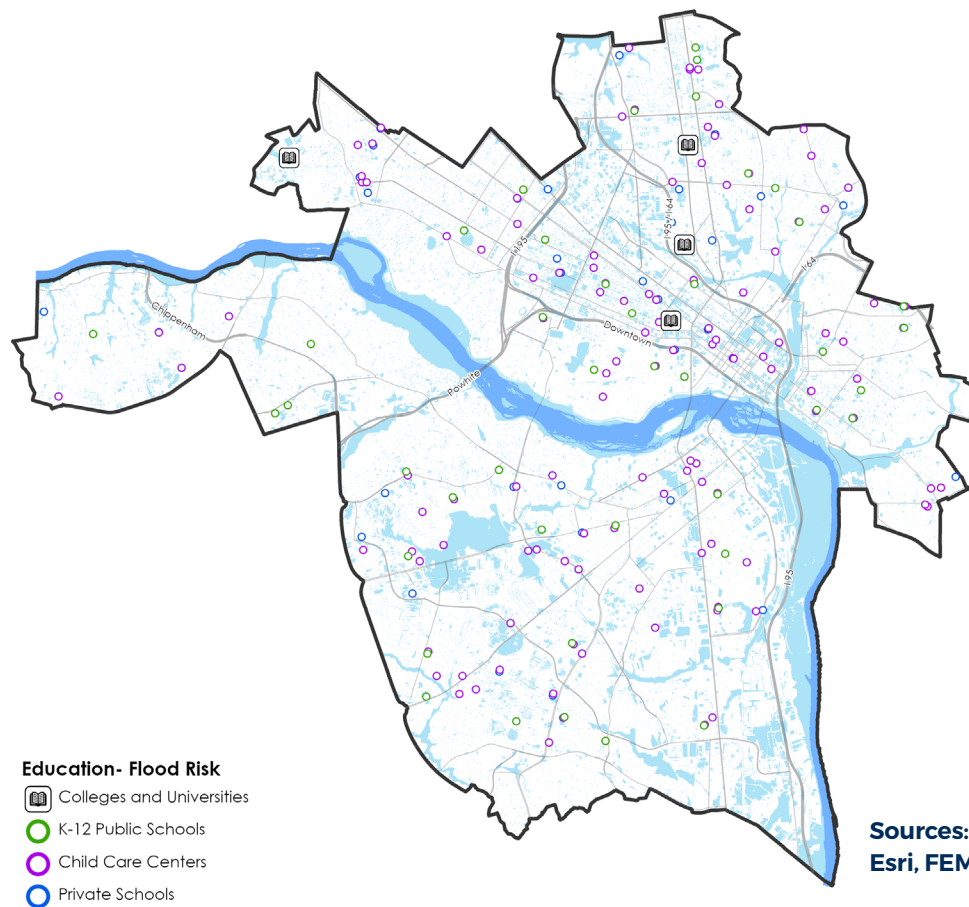
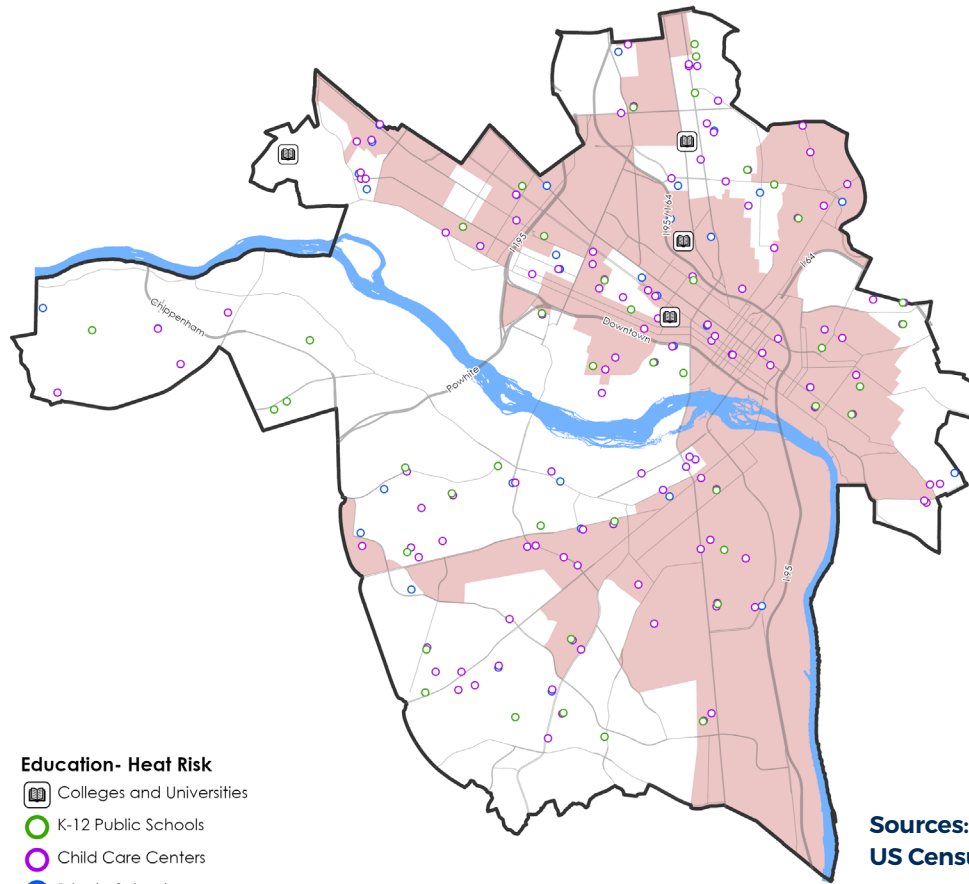
- Public schools serve as a key health resource for underserved youth through free and reduced lunch, breakfast, and other supplemental food services such as backpack buddies programs
- Schools are often key community hubs, forming a part of a community's response efforts during and following climate events or disasters
- Public schools can serve as cooling centers or shelters in extreme heat events

Resilience & Equity Impact Considerations

- Public school budgets and planning processes may limit adaptive responses
- Large universities serve as major community employers
- Higher education institutions offer resources such as residence halls, food preparation equipment, and safety personnel that could be leveraged for emergency response support
- University partnerships with agencies and non-profits are vital to climate action and response

Built Assets at Risk

Education Assets	Heat Risk	Flood Risk
Childcare Centers	61	43
K-12 Public schools	19	19
Private Schools	13	13
Colleges and Universities	2	4





Energy

Energy assets in Richmond include traditional and alternative energy sources. As the supply of clean, renewable energy continues to grow, this supports climate action by reducing GHGs and making Richmond’s energy infrastructure more resilient. Continued growth and diversification of the energy portfolio, and efforts to assure integrity of the energy grid, will offer further community-wide economic, health, and other benefits.

Energy Assets

- Alternative fueling stations
- Biodiesel plants
- Electric transmission lines and substations
- EV charging stations
- Natural gas
- Petroleum ports and terminals
- Potential renewable energy Sites

Climate Vulnerabilities

- Increased demands on the grid due to cooling needs
- Heat related sagging of power lines
- Reduced thermal efficiency of power generation due to extreme heat
- Thermal limits to the ability for transmission lines to transport power
- Storm damage to power lines
- Flooding damage to power plants, substations, and equipment
- Power outages

Resilience & Equity Impact Considerations

- The likelihood of flood damage is increased for facilities located in or near the floodplain
- Risks of leaks, hazardous material contamination, explosions, or chemical releases
- Grid transformation and security requires upgrades to make the grid more resilient

Heat

Low

High

Water

Low

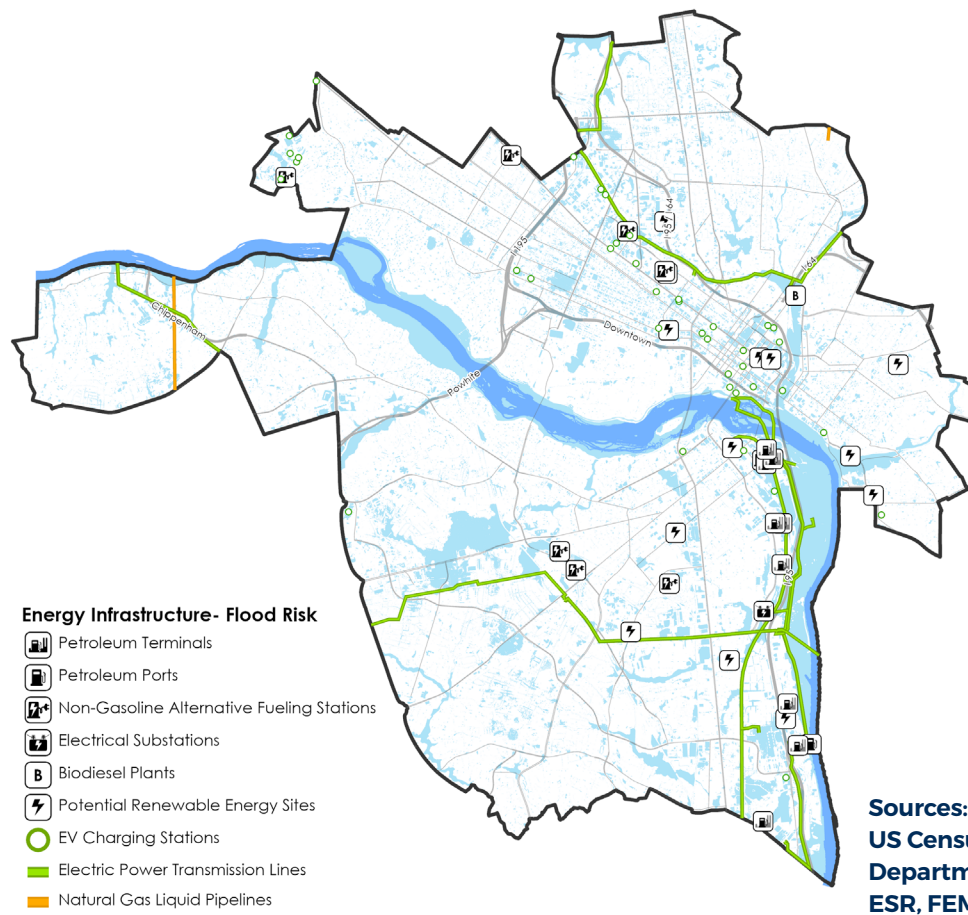
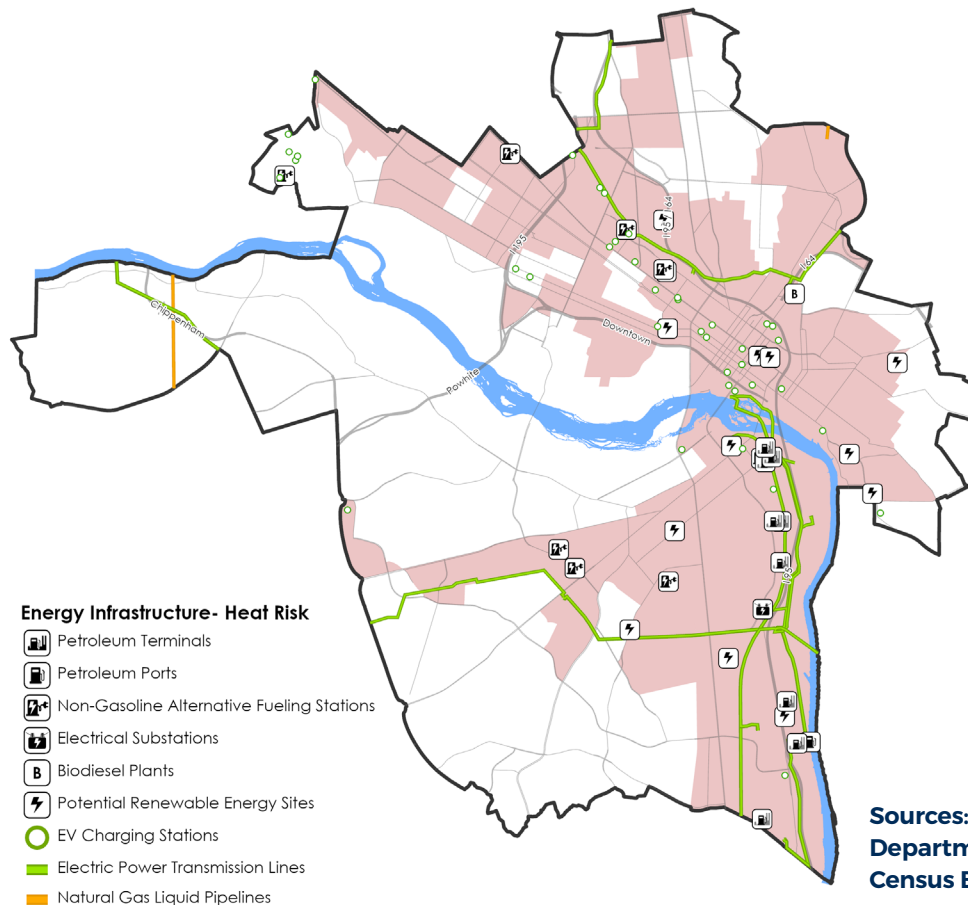
High

Consequence

Low

Med-High

Built Assets at Risk		
Energy	Heat Risk	Flood Risk
Biodiesel Plants	1	1
Electric Power Transmission Lines	45.2 miles	25.2 miles
EV Charging Stations	60	24
Petroleum Ports	1	1
Petroleum Terminals	9	8
Potential Renewable Energy Sites	12	3





Food

Food systems are complex and include many different assets and resources at varying scales – from food production on farms and in urban agricultural settings, to food processing and distribution sites, grocery stores and food storage facilities, and the resources that help get food to Richmond’s most vulnerable populations, such as food pantries and Supplemental Nutrition Assistance Program (SNAP) businesses.

Heat

Med-High

Water

Med-High

Consequence

Med-High

Food Assets

- Food pantries
- Public refrigerated warehouses
- SNAP businesses

Climate Vulnerabilities

- Changes to growing season duration
- Crop damage from periods of drought or extreme precipitation
- Extreme heat stressing livestock and farm workers
- Increased prevalence of new and/or more persistent forms of pests
- Soil erosion from floods
- Storm-related power outages affecting food distribution locations
- Impacts to food access due to transportation disruptions

Resilience Factors

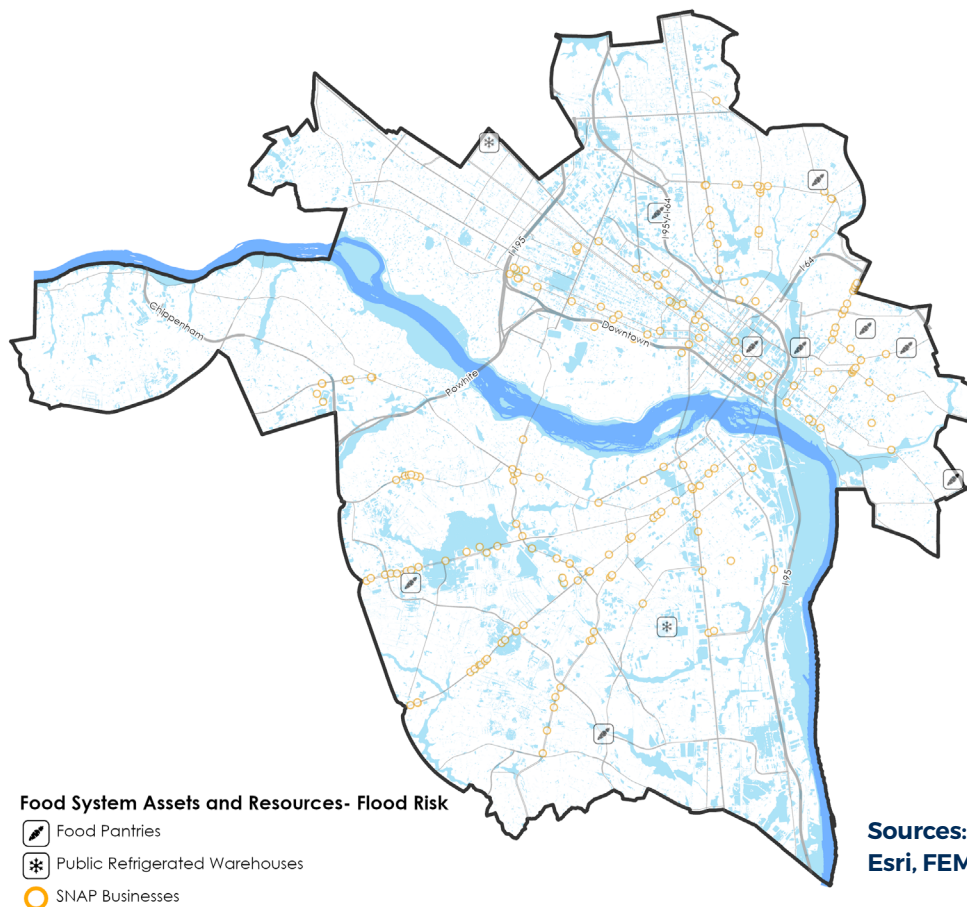
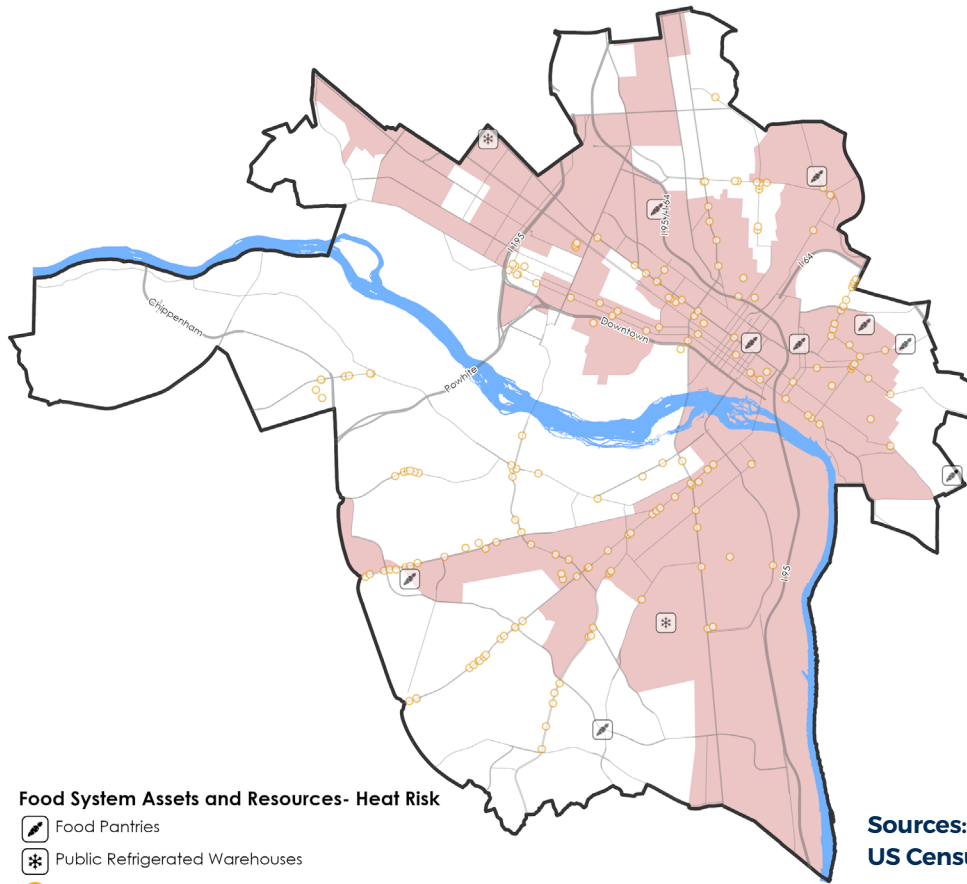
- Some community gardens are supporting community food system resilience

Resilience & Equity Impact Considerations

- Challenges to transporting food to people who need or getting people to where food supplies are if transportation is limited due to flooding
- Food pantries and storage facilities relying on power for refrigeration may be at risk when the grid is strained or during extreme weather events

Built Assets at Risk

Food System Assets and Resources	Heat Risk	Flood Risk
Food Pantries	5	0
Public Refrigerated Warehouses	2	0
SNAP Businesses	110	11





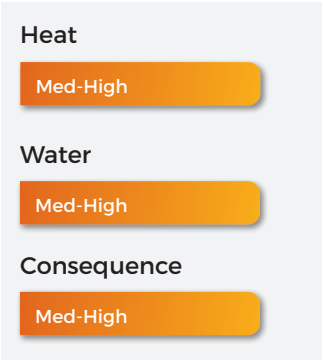
Government Facilities

As the capital of Virginia, Richmond is home to numerous State buildings as well as City government buildings. While short-term impacts to government facilities may be overcome, residents rely on the work happening in these facilities to keep the city and the Commonwealth operating normally.

Government Facility Assets

- City properties
- Courthouse and court systems
- Major state government buildings
- State capitol buildings

- Climate Vulnerabilities**
 - Susceptibility of government buildings and properties near the James River or in other low-lying or flood prone areas to storm flooding and sea level rise
 - Power outages from storm or extreme heat events
 - Potential disruption of City or State services
 - Water damage potential in older City or State buildings



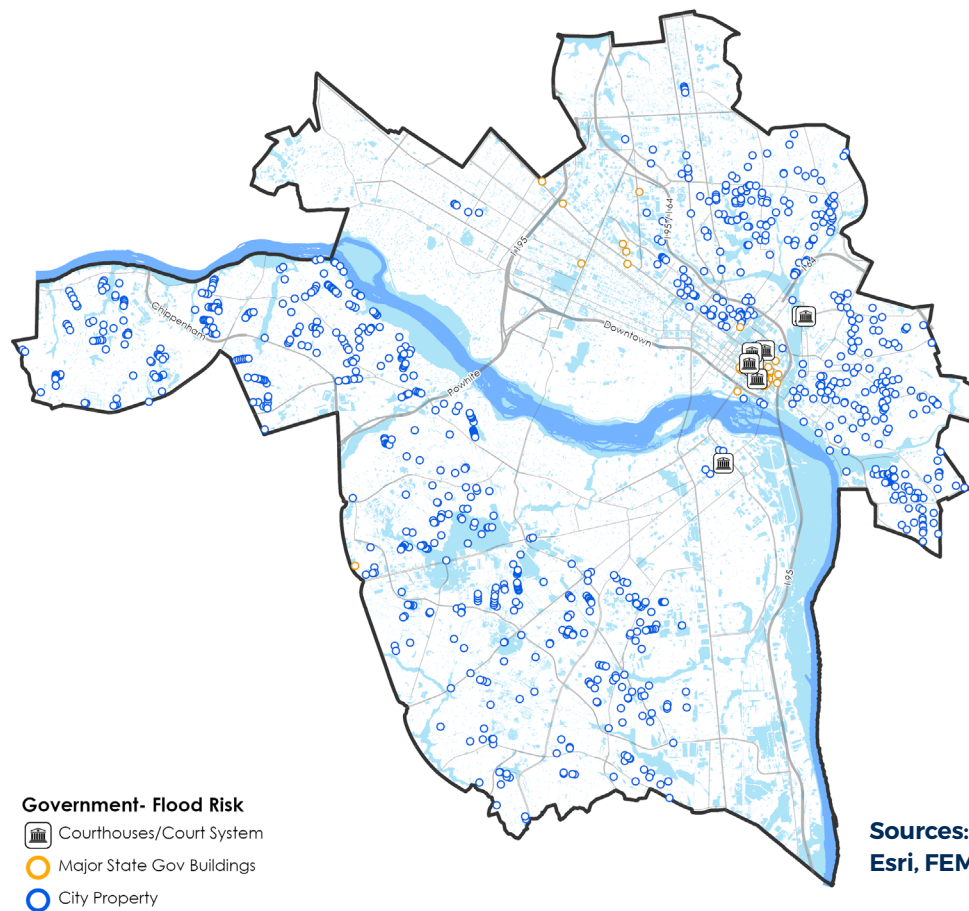
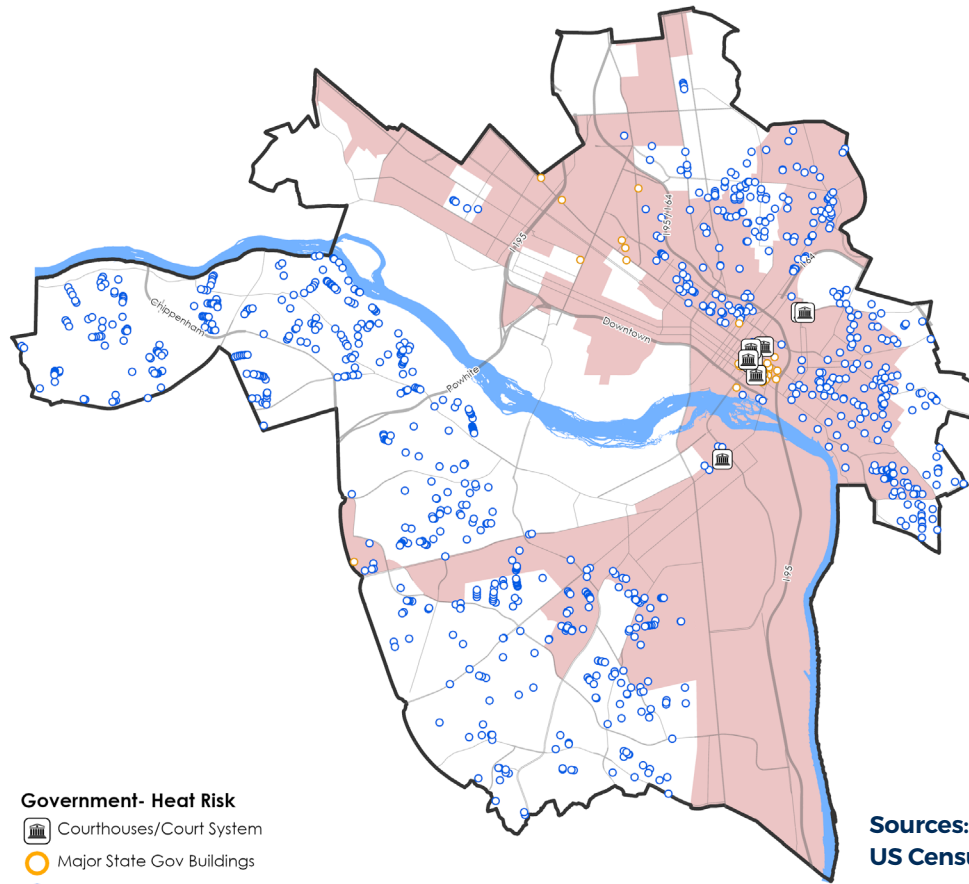
Resilience Factors

- Federal, state, and city agencies have established policies, procedures, and coordination plans in place for emergency response for disaster, storm, and other events
- City of Richmond has developed the Climate Equity Action Plan 2030 to address climate change through an equity-centered approach; this Vulnerability and Risk Assessment will expand on the plan’s resilience strategies and prioritize action through an equity lens

Resilience & Equity Impact Considerations

- City and State agencies and the buildings housing them are significant centers of employment
- Ensuring the safety of government employees, visitors, and continuity of operations is critical to Richmond’s resilience

Built Assets at Risk		
Government Facilities	Heat Risk	Flood Risk
City Property	369	118
Courthouses and Court Systems	9	1
Major State Government Buildings	36	18





Health & Social Services

Health and social services facilities serve the most basic needs of Richmond's frontline communities, often on a daily or weekly basis. These are some of the most critical facilities that need to maintain continuity of their operations in order to serve some of our community's most vulnerable members, including seniors, low-income residents, and those with chronic or acute health issues.

Heat

Medium

Med-High

Water

Med-High

Consequence

Med-High

Health & Social Services Assets

- American Red Cross chapter facilities
- Dialysis clinics
- Homeless facilities
- Hospitals
- Nursing homes
- Social services
- Urgent care facilities
- VA health/medical facilities

Resilience Factors

- Health and social services facilities support overall community resilience
- Larger hospital, nursing, and other facilities often have back-up power and system redundancy (e.g. for water lines)

Resilience & Equity Impact Considerations

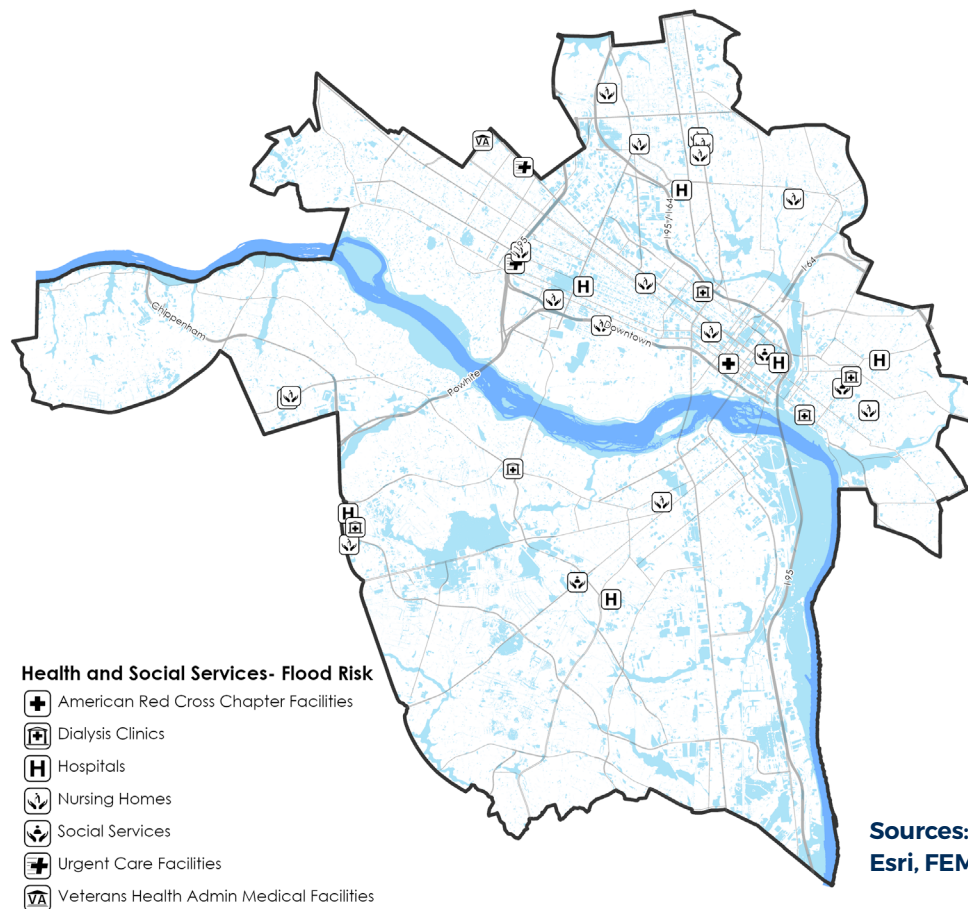
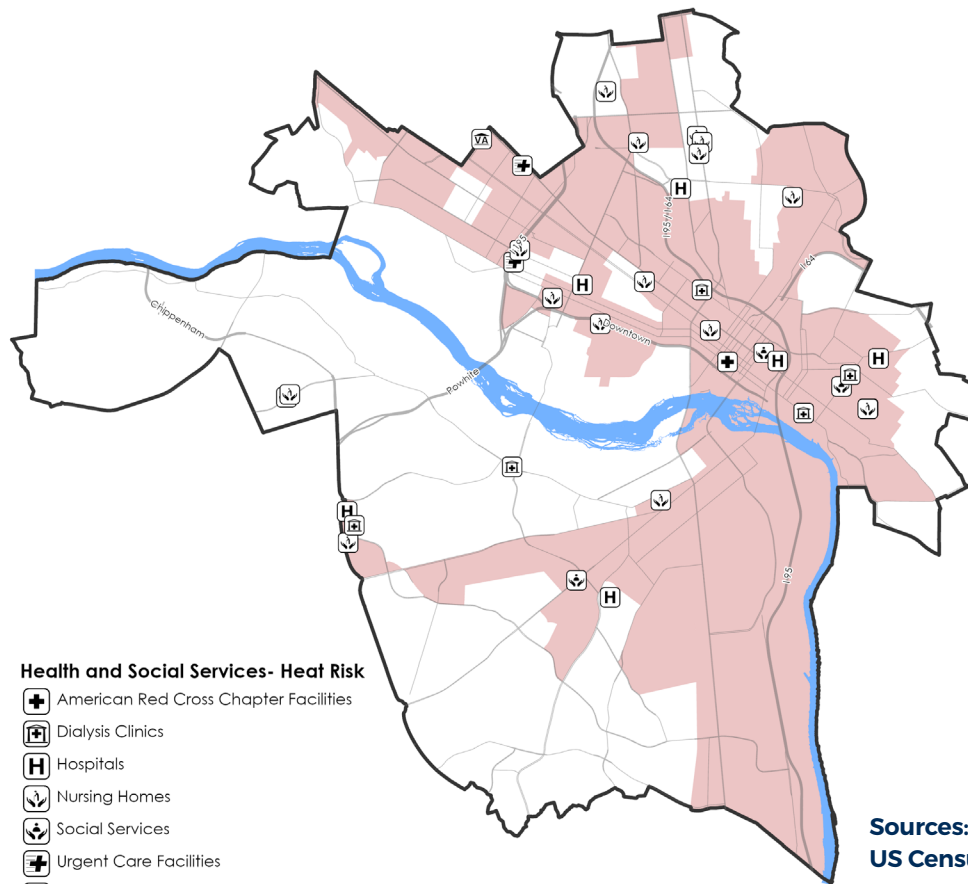
- Assess state of facilities in Richmond; ensure facilities have backup power sources
- Smaller facilities and clinics may not have sufficient adaptive resources
- The COVID-19 pandemic reinforced the need to look at consequences from multiple threats or stressors; Richmond has been seeing additional stress on its health assets; in the future these threats from events such as disease outbreaks would compound heat and water threats and diminish the adaptive capacity of health assets.

Climate Vulnerabilities

- Power or even water outages from storm or extreme heat events
- Flooding of health and social services assets in low-lying areas or future floodplains
- Potential disruption to health services, programs, and resources to underserved and/or sensitive populations
- Loss of access to emergency services and care for frontline communities due to flooding
- Health impacts from extreme heat

Highly Vulnerable Assets

Health and Social Service Facilities	Heat Risk	Flood Risk
Dialysis Clinics	3	0
Homeless Facilities	5	1
Nursing Homes	11	10
Social Services	3	1
Urgent Care Facilities	1	2
VA Health/Medical Facilities	1	0





Historic Resources

A significant part of Richmond's character is tied to various historic assets that are maintained within the area. When impacted by a flood or storm event, sometimes damage to an historic asset may not be able to be repaired, or at least not while maintaining its historic character. Historic assets are not only culturally significant, they are also a source of economic activity for the city and the region.

Heat

Med-High High

Water

Med-High High

Consequence

Medium Med-High

Historic Resources Assets

- City historic districts
- City historic sites
- National Register Historic Districts
- State and federal historic sites

Resilience & Equity Impact Considerations

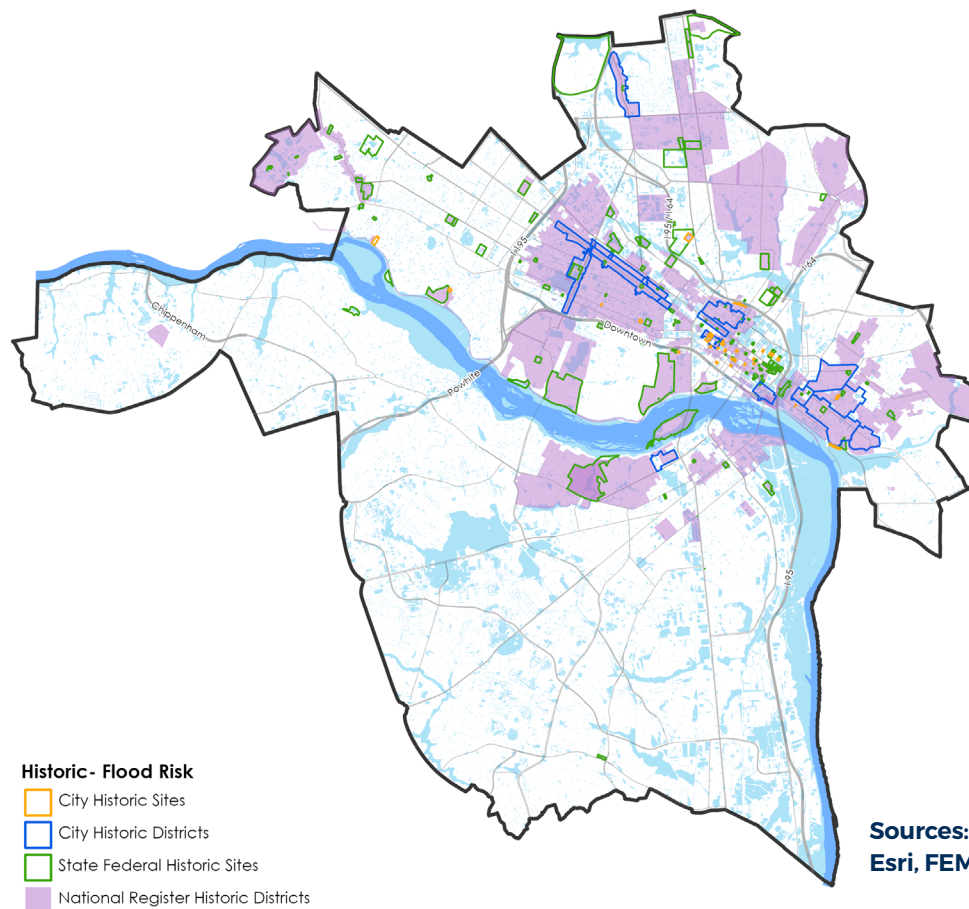
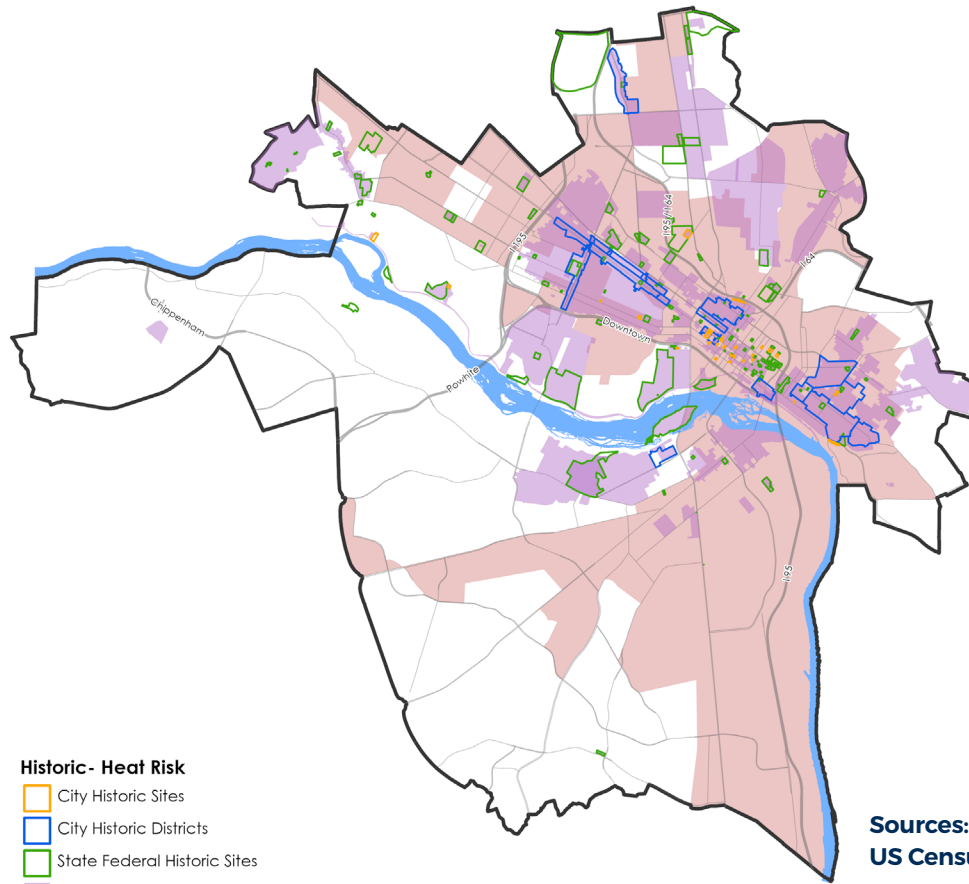
- Vulnerable to flooding damage due to age and condition of resources
- Possible retrofitting of structures to prevent lightning damages, increase heat resistance, and avoid flooding.
- Potential for engagement of cultural and historic resource organizations in climate action and resilience planning

Climate Vulnerabilities

- Flooding damage from storms and extreme precipitation events
- Other storm impacts (lightning, wind, etc.)
- Possible interior damage during power outages due to heat and humidity levels
- Potential for irreparable impacts

Highly Vulnerable Assets

Historic Resources	Heat Risk	Flood Risk
City Historic Districts	41	41
City Historic Sites	26	25
National Register Historic Districts	108	122
State Federal Historic Sites	124	119





Public Housing

Those living in public housing are among Richmond's most vulnerable populations. These communities often have lower average incomes, more limited resources, and experience more chronic stressors such as poor housing conditions, crime, and health conditions. Climate impacts intersect with existing social, health, and economic vulnerabilities for these residents.

Heat

High

Water

High

Consequence

High

Public Housing Assets

- Department of Housing and Urban Development (HUD) Multifamily Properties
- Richmond Redevelopment & Housing Authority (RRHA) Housing

Resilience & Equity Impact Considerations

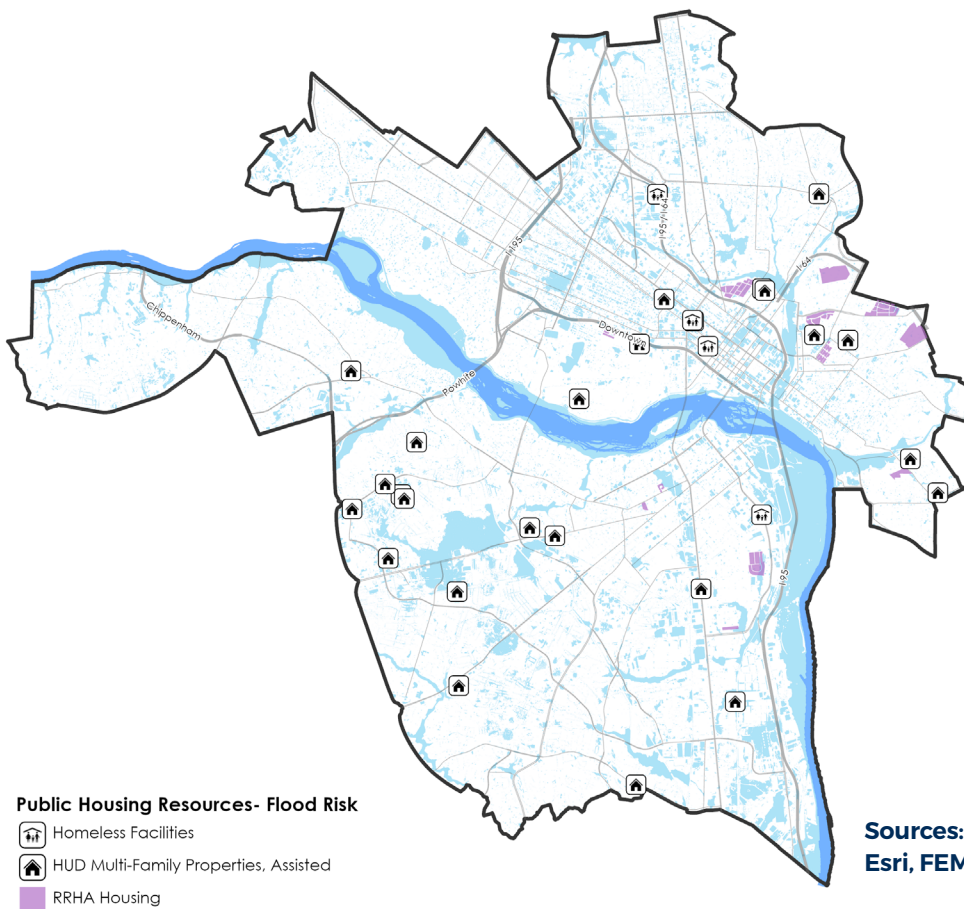
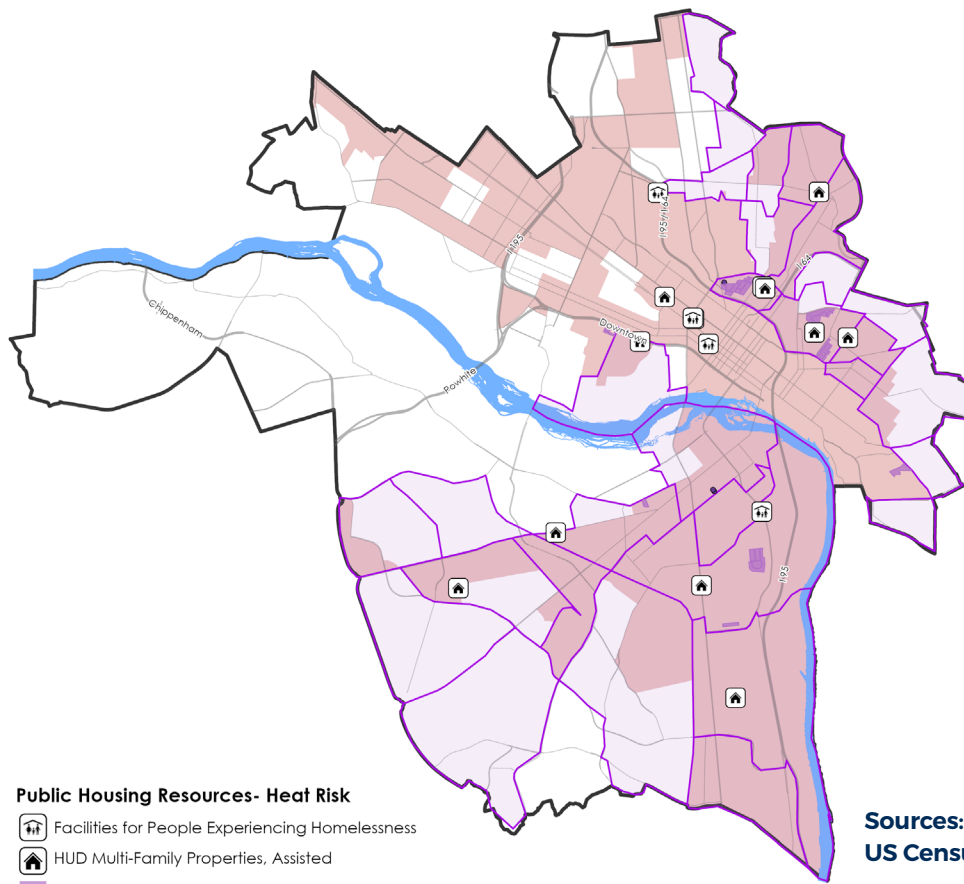
- Older housing properties have poor insulation and are more susceptible to extreme heat events, increasing utilities costs and potential health impacts for vulnerable residents
- Substantial retrofit and upgrade needs, which will require significant investment

Climate Vulnerabilities

- Structural damage from flooding or extreme storms
- Development of mold and associated health risks following flooding
- Increased demand for cooling during extreme heat events
- Heat impacts resulting in increased energy burden and/or health effects
- Thermal stress on building materials over time increasing maintenance or reducing useful life
- Power outages from storm or extreme heat events

Built Assets at Risk

Public Housing Resources	Heat Risk	Flood Risk
HUD Multifamily Properties	13	2
RRHA Housing	36	42





Public Safety and Emergency Response

Public safety facilities and emergency response operations are among the most critical assets within any community. Given the high level of importance of these facilities to public health and safety, the consequences are high if there are failures in the system.

Heat

Medium

Med-High

Water

Med-High

Consequence

Med-High

Public Safety and Emergency Response Assets

- Cooling centers
- Correctional facilities
- EMS, fire and police Stations
- Local emergency operations centers
- National shelter system facilities
- Seawall (data not available)
- Sheriff facilities

Climate Vulnerabilities

- Power outages from storm or extreme heat events
- Flooding affecting emergency response routes
- Potential disruption to public safety operations and response

Resilience Factors

- Many emergency response and public safety facilities and operations have backup/redundant power supplies to ensure continuity of communications during emergencies
- Federal, state, and city agencies have established policies, procedures, and coordination plans in place for emergency response for disaster, storm, and other events
- The City's seawall provides flood protection and is regularly tested to ensure it is in good working condition.

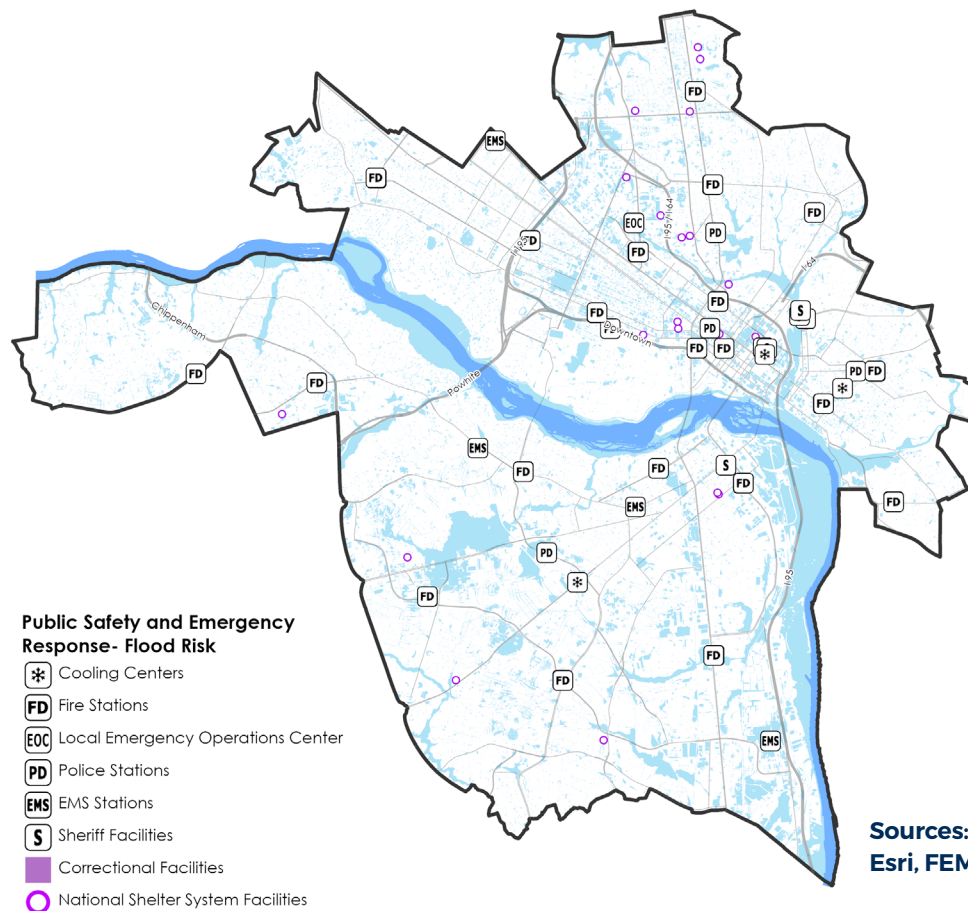
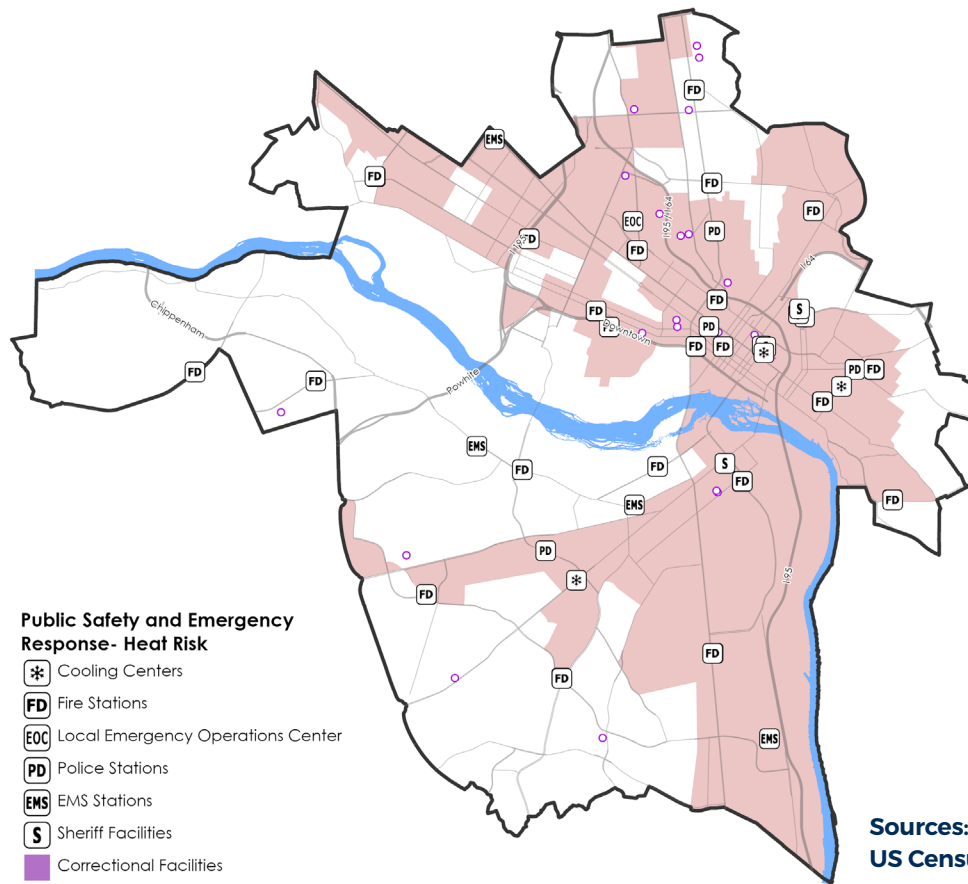
Resilience & Equity Impact Considerations

- In the past, public safety facilities and operations have been protected from heat and flood risks
- Emergency responders must be able to access areas that may be cut off during an extreme event
- Response plans need to address populations in correctional facilities during emergencies (e.g. during power outages, potential for situations requiring evacuation)

Built Assets at Risk

Public Safety and Emergency Response	Heat Risk	Flood Risk
--------------------------------------	-----------	------------

Cooling Centers	3	1
Correctional Facilities	3	3
EMS Stations	16	11
Fire Stations	14	10
Local Emergency Operations	1	1
National Shelter System	13	11
Police Stations	5	1
Sheriff Facilities	7	5





Stormwater & Sewer Infrastructure

Stormwater runoff is expected to increase through more frequent and more intense precipitation events. Richmond, like many older cities across the country, has an older stormwater system that was not built to handle today's storms or the storms of the future. In addition, a significant portion of the city's stormwater infrastructure is combined with sewer infrastructure, causing sewage overflows into the James River during extreme storms. Climate change will also stress Richmond's trees, vegetation, and greenspaces that help manage and absorb stormwater.

Heat

Medium

Water

High

Consequence

High

Stormwater and Sewer Infrastructure Assets

- Stormwater outfalls
- Stormwater & sewer Infrastructure (other)
- Sewer treatment plant

Climate Vulnerabilities

- Sea level rise inundation of stormwater outfalls near/along the James River
- Intense precipitation events causing sewer backups and wastewater overflow into local water bodies via the combined sewer system
- Flooding impacts to treatment plant and operations
- Heat impacts to the health of soils and vegetation (esp. urban and sensitive species) increasing rates at which water runs off of natural areas (overland flow) and decreasing the amount of stormwater that is naturally absorbed into the ground

Resilience Factors

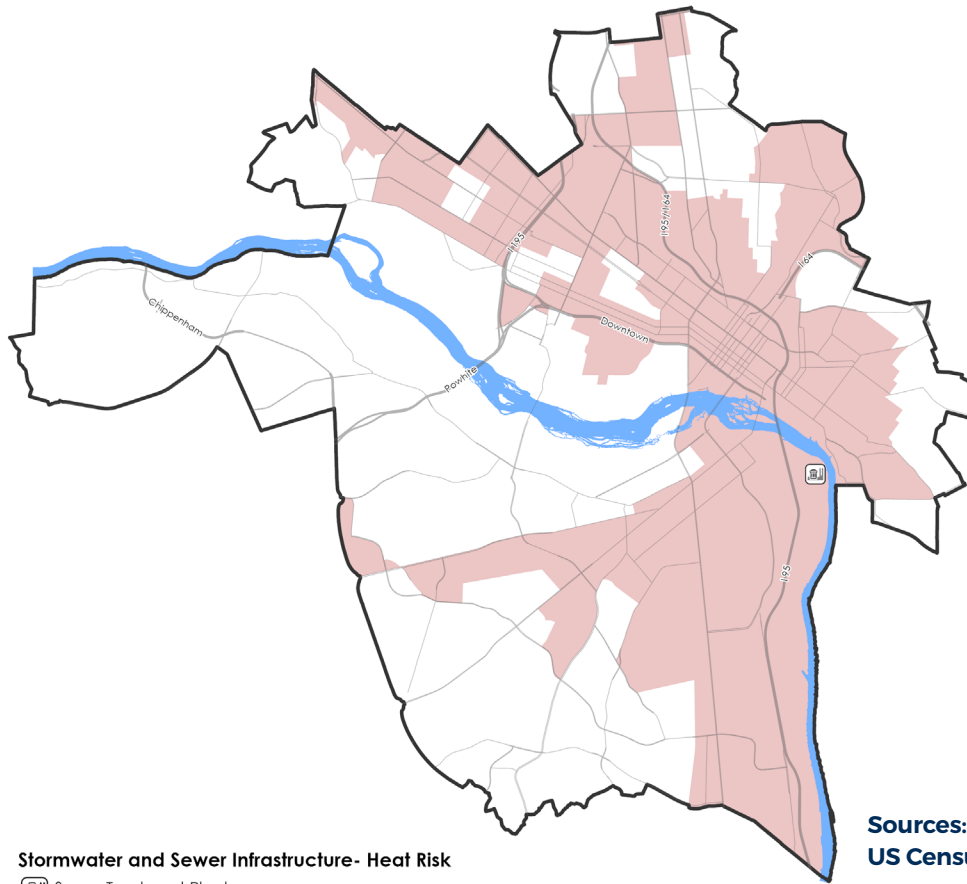
- The City is actively working to increase the capacity of the stormwater system and replace older infrastructure

Resilience & Equity Impact Considerations

- How to sustainably address need for increased watering to maintain heat-strained vegetation and enhance capacity to slow and absorb runoff
- Ensuring the wastewater treatment plant functions under greater threat and strain will require substantial investment
- As floodplains and flooding levels rise, buildings and equipment will need to be raised
- Stormwater facilities and features may need to be resized for future events
- Need to retrofit the combined sewer system

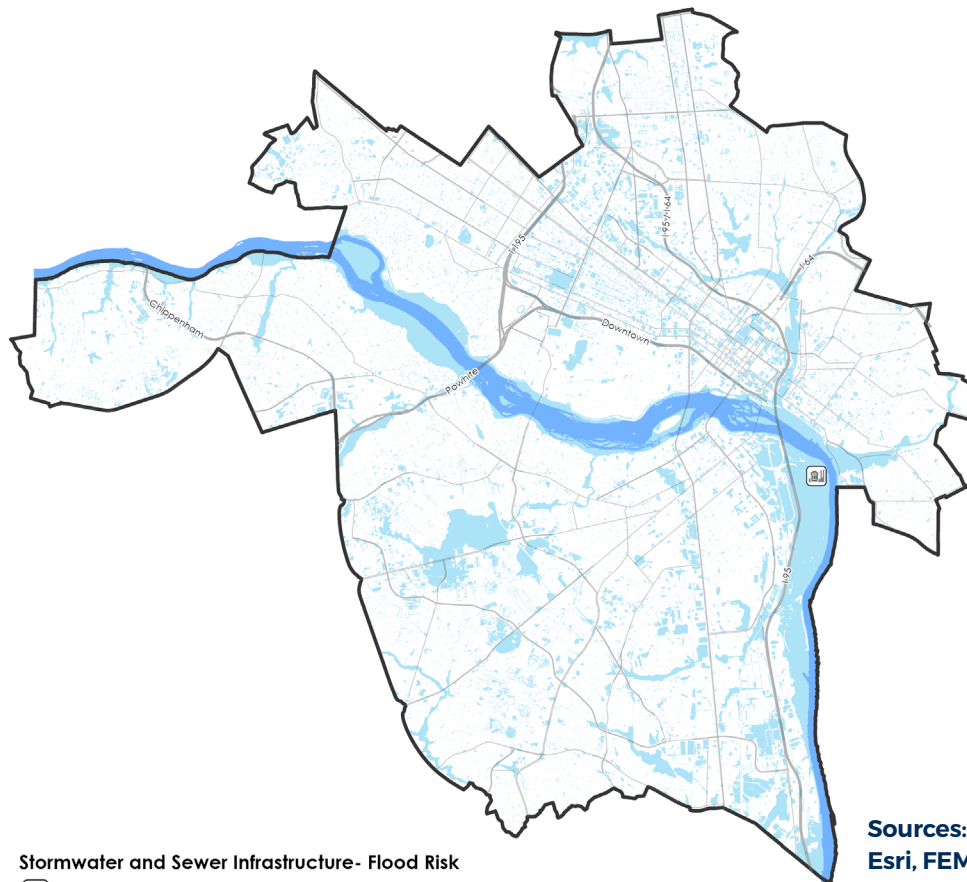
Built Assets at Risk

Stormwater and Sewer Infrastructure	Heat Risk	Flood Risk
Stormwater Outfall	468	1064
Sewer Treatment Plant	1	1



Sources: City of Richmond,
US Census Bureau

Stormwater and Sewer Infrastructure- Heat Risk
Sewer Treatment Plant



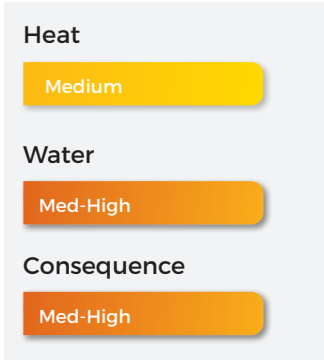
Sources: City of Richmond,
Esri, FEMA

Stormwater and Sewer Infrastructure- Flood Risk
Sewer Treatment Plant



Transportation: Roads & Bridges

Richmond’s roadway network supports vehicular mobility for residents, workers, and visitors through 1,200 miles of roadways and 177 bridges. The City is bisected by two interstates (I-64 and I-95) and surrounded by I-295. Each of these facilities carries significant traffic, with Average Daily Traffic (ADT) ranging between 50,000 and over 100,000 vehicles daily, according to Virginia Department of Transportation (VDOT).



Transportation Assets

- Roads
- Bridges

Climate Vulnerabilities

- Flooding on roadways and bridges, washing out sections of road, or undercutting roadbeds
- Increased stormwater runoff
- Storms causing downed trees or powerlines blocking roadways
- Difficulty accessing areas of the community due to roadway blockages and signal outages
- Emergency response impacts
- Extreme heat impacts damaging roadway and bridge asphalt and concrete surfaces
- Increased surface temperatures, ambient heating of the surrounding environment, and contribution to urban heat islands

Resilience Factors

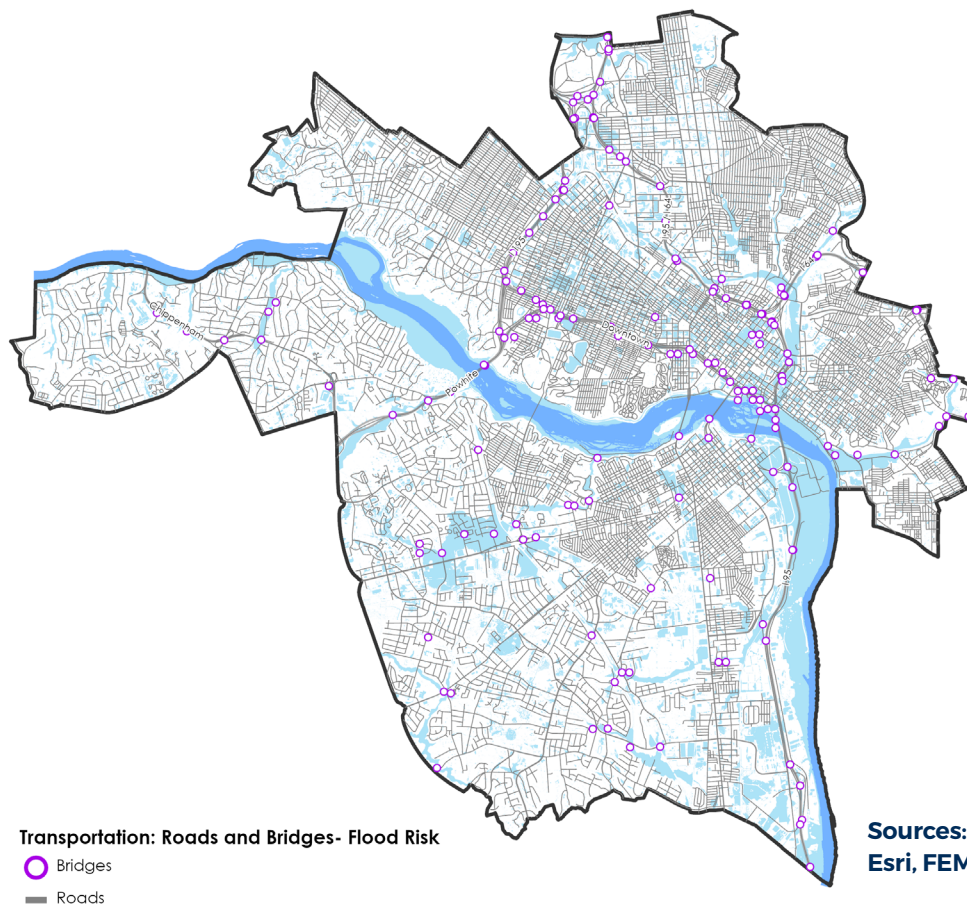
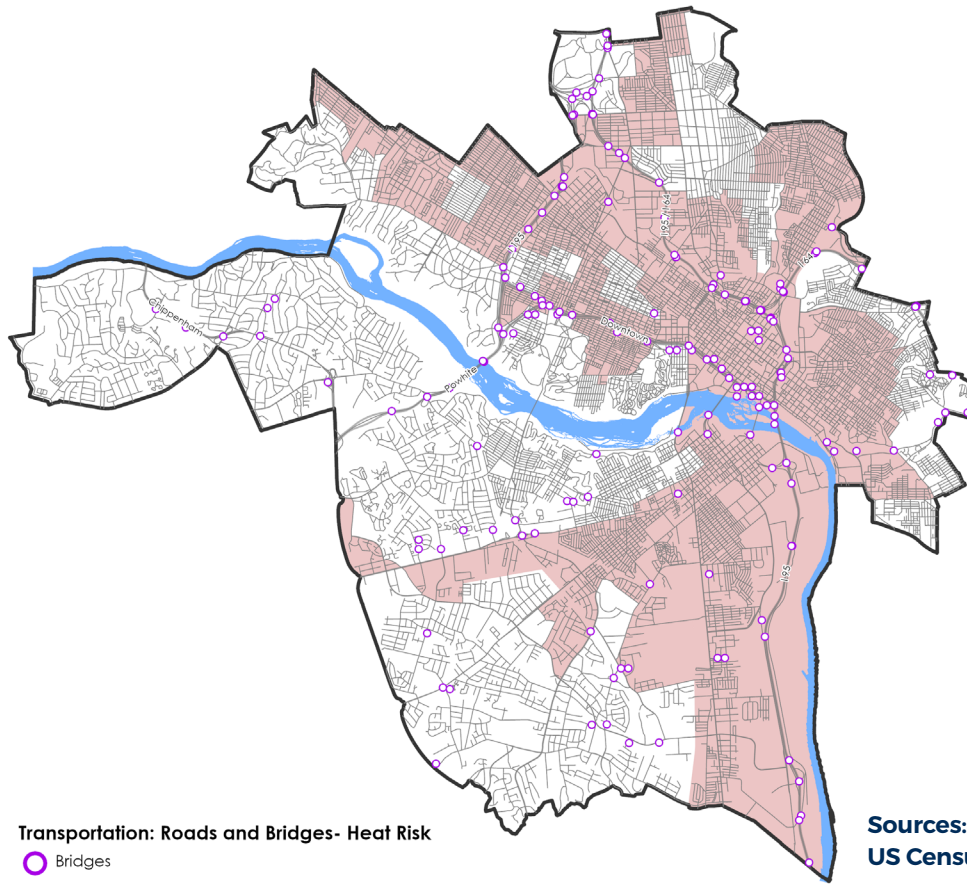
- Emergency response plans and coordination agreements are in place between State and local agencies for response
- Efforts by the Richmond Regional Transportation Planning Organization (Plan RVA) are developing road/bridge resiliency mapping that is assessing available alternative routes to more regularly inundated roadways

Resilience & Equity Impact Considerations

- The Capitol District running north-northeast to Rosedale and Bellevue has greater road density, and experiences more intense heating effects
- Recent storms have overwhelmed traditional mechanisms for managing roadway stormwater; areas of Southside experience substantial impacts
- In addition to roadway hazards, increased runoff contributes to combined sewer overflows
- Increased maintenance and replacement will be needed for miles of road

Built Assets at Risk		
Roads and Bridges	Heat Risk	Flood Risk
Roads	640.3 miles	94.3 miles
Bridges*	107	62

*All bridges within areas of Flood Risk are identified. Note: bridge elevation data was not analyzed, therefore it is unknown which bridges may be inundated under the flood risk scenario.





Transportation: Bicycle and Pedestrian Facilities

The City of Richmond maintains more than 830 miles of sidewalks and has more than 71 miles of bicycle infrastructure primarily in the form of shared lane markings (sharrows) and bike lanes, along with nearly 16 miles of trails.. This network links to the East Coast Greenway, providing interregional connections. Richmond's temperate climate and rich natural amenities such as forests, rivers, and wetlands support interest in and development of walkable and bikeable communities.

Transportation Assets

- Bike infrastructure
- Bikeshare stations
- Pedestrian infrastructure
- Trails

Climate Vulnerabilities

- Flooding of trails, bike lanes, and sidewalks from storms and extreme precipitation events
- Potential inundation of low-lying trails near the James River from sea level rise
- Debris and mud over trails following storm and flooding events disrupting travel
- Extreme heat impacts to health, safety, and mobility for bicyclists and pedestrians, especially in urban heat island areas and locations with limited tree canopy

Heat

Med-High

Water

Med-High

Consequence

Med-High

Resilience Factors

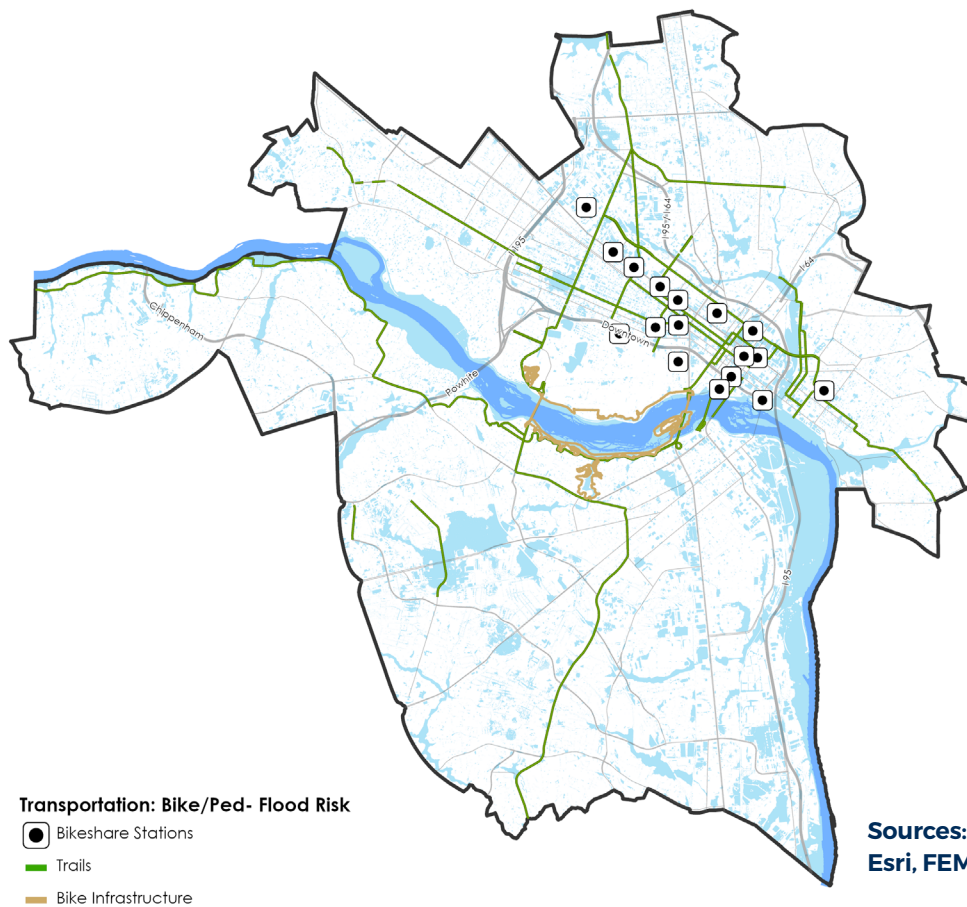
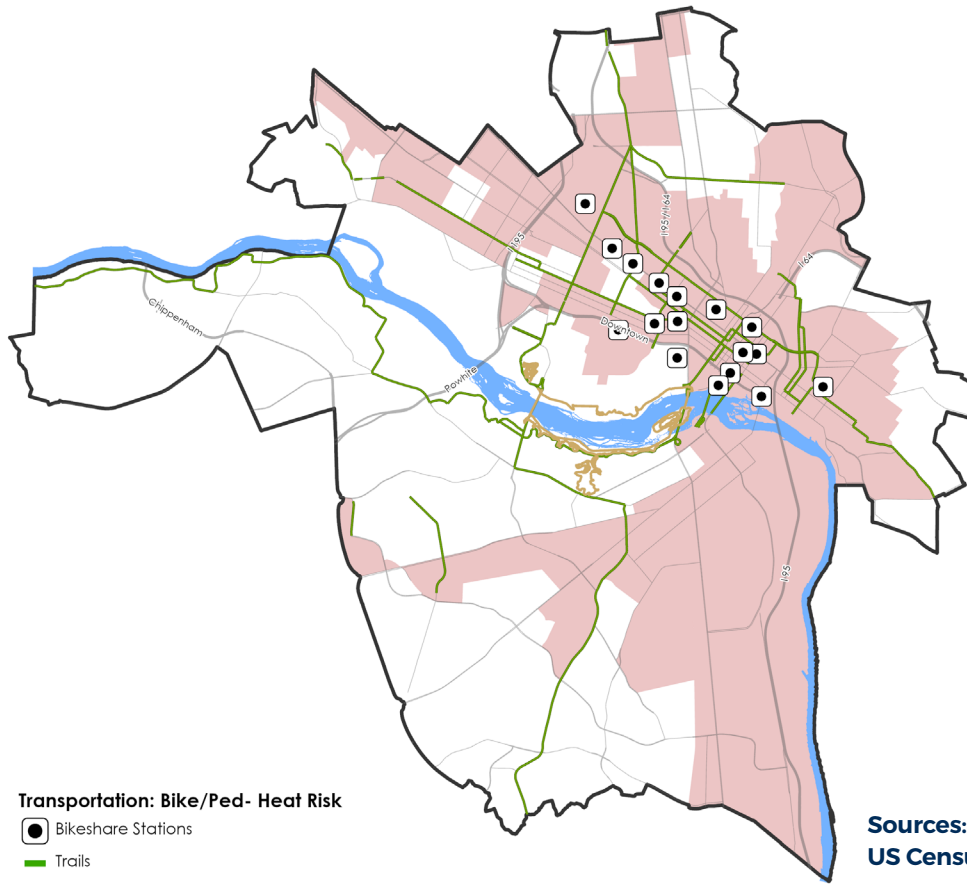
- Walkable, bikeable areas have greater community economic, health, mobility, and overall resilience

Resilience & Equity Impact Considerations

- Residents who rely on public transit, biking, and walking for transportation face increasing exposure to extreme weather conditions may have to forego trips for health or other essential purposes
- Richmond's trails and multi-use paths often lie in flat, low-lying areas prone to flooding

Built Assets at Risk

Transportation Assets	Heat Risk	Flood Risk
Bike Infrastructure	35.7 miles	11.3 miles
Bikeshare Stations	16	0
Trails	0.5 miles	4.7 miles





Transportation: Rail and Transit

Richmond serves as a significant transportation hub for the Mid-Atlantic and entire East Coast. An Amtrak passenger train line and station intersects with the CSX freight rail line in Richmond. The Greater Richmond Transit Company provides fixed route bus service, Bus Rapid Transit along 7.6 miles of Broad and Main Street, paratransit services, and vanpool and carpool options.

Transportation Assets

- Major transit stations - Amtrak/Greyhound
- Rail bridges
- Railroads

Climate Vulnerabilities

- Flooding from storms and extreme precipitation events
- Service disruptions due to increased rain or prolonged flooding
- Extreme heat impacts to riders accessing transit, affecting health, safety, and mobility
- Higher demands for on-board air conditioning use during hotter days, increasing operating emissions and costs, and impacting any electrified transit resources
- Trains must reduce speeds during periods of high temperatures

Heat

Medium

Water

Med-High

Consequence

Med-High

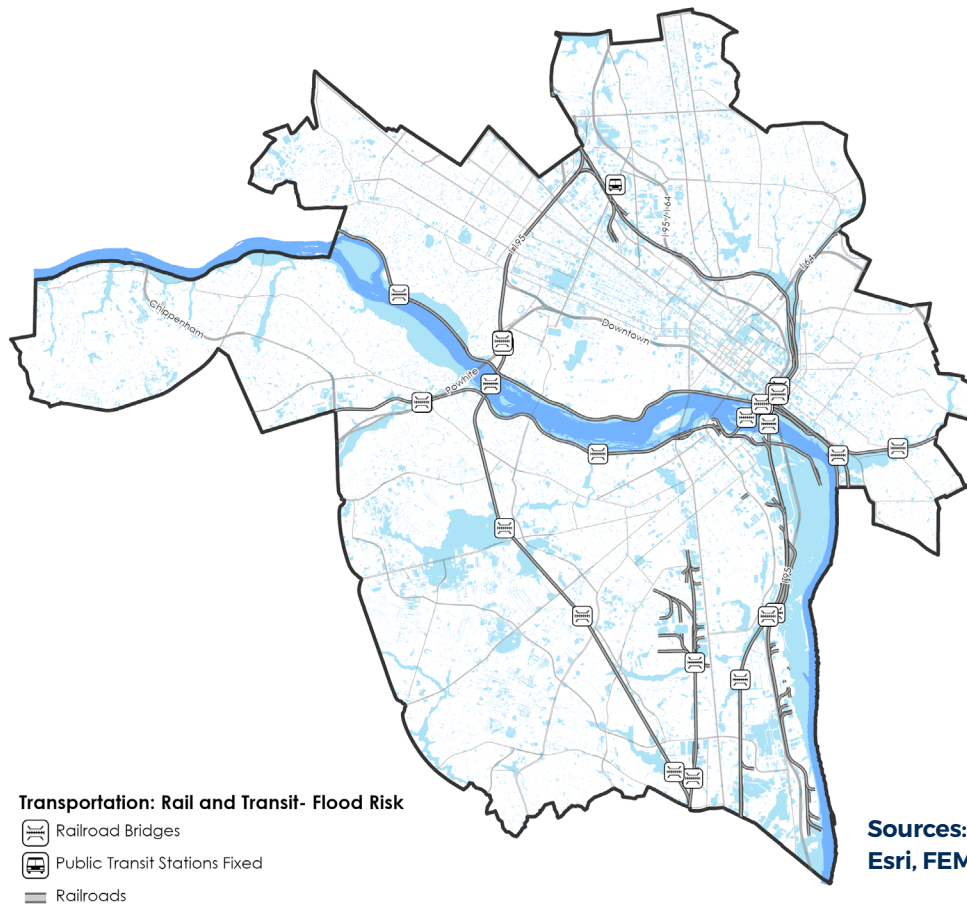
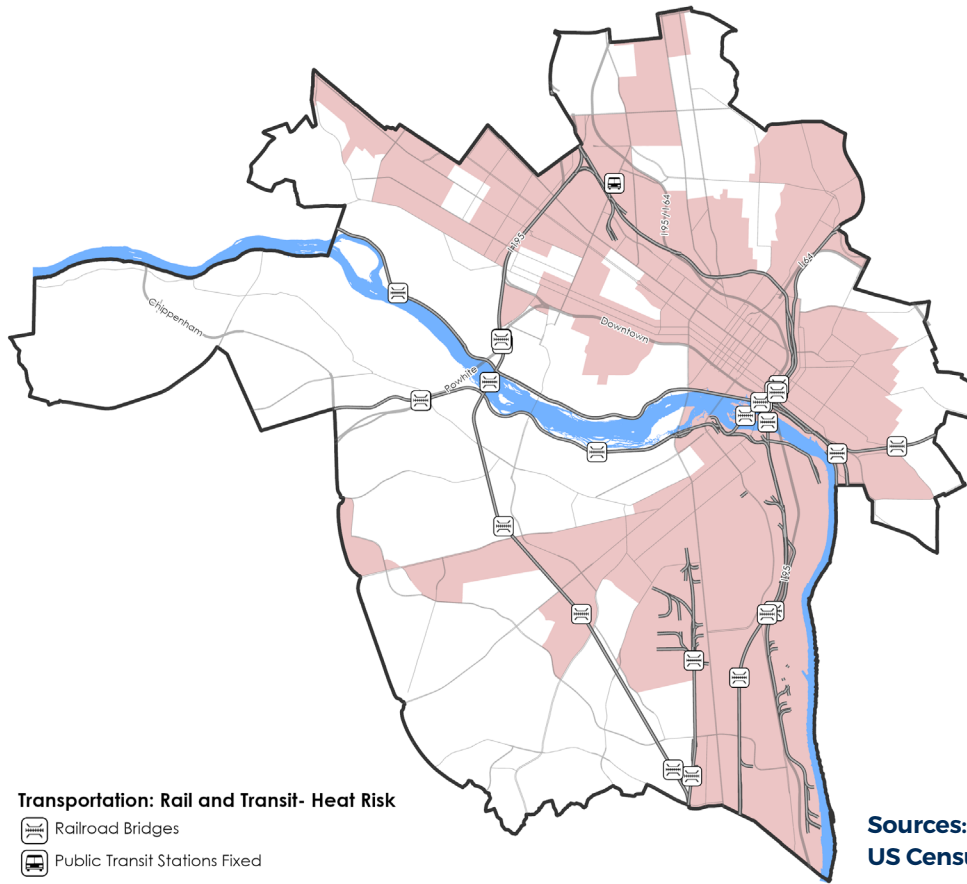
Resilience Factors

- Transit vehicles can be reallocated during emergencies to support evacuation efforts

Resilience & Equity Impact Considerations

- Transit and rail, especially bus and paratransit, serve a higher proportion of frontline populations and these riders experience a greater burden when service is disrupted
- Vulnerable riders are more exposed to high heat and extreme weather impacts in accessing transit
- Shelter installation is a priority citywide, with focused funding for installations in the underserved neighborhoods
- Continued efforts are needed to install shelters, enhance shelter designs, and plant trees at transit stops and access pathways

Built Assets at Risk		
Rail and Transit	Heat Risk	Flood Risk
Major Transit Stations - Amtrak/Greyhound	2	2
Railroad Bridges	14	15
Rail lines	112.5 miles	57.7 miles





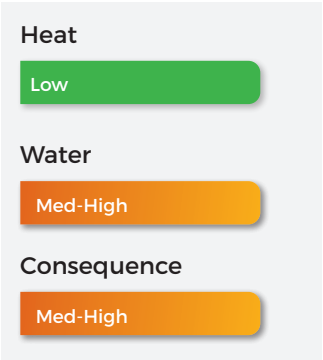
Transportation: Marine

The Richmond Marine Terminal (RMT) is a uniquely important asset to Richmond and the region. It is “the western terminus for commercial navigation on the James River and is the westernmost commercial maritime port on the North Atlantic coast” (City of Richmond, 2022) and has the quickest access to I-95 of any port.

Transportation Assets

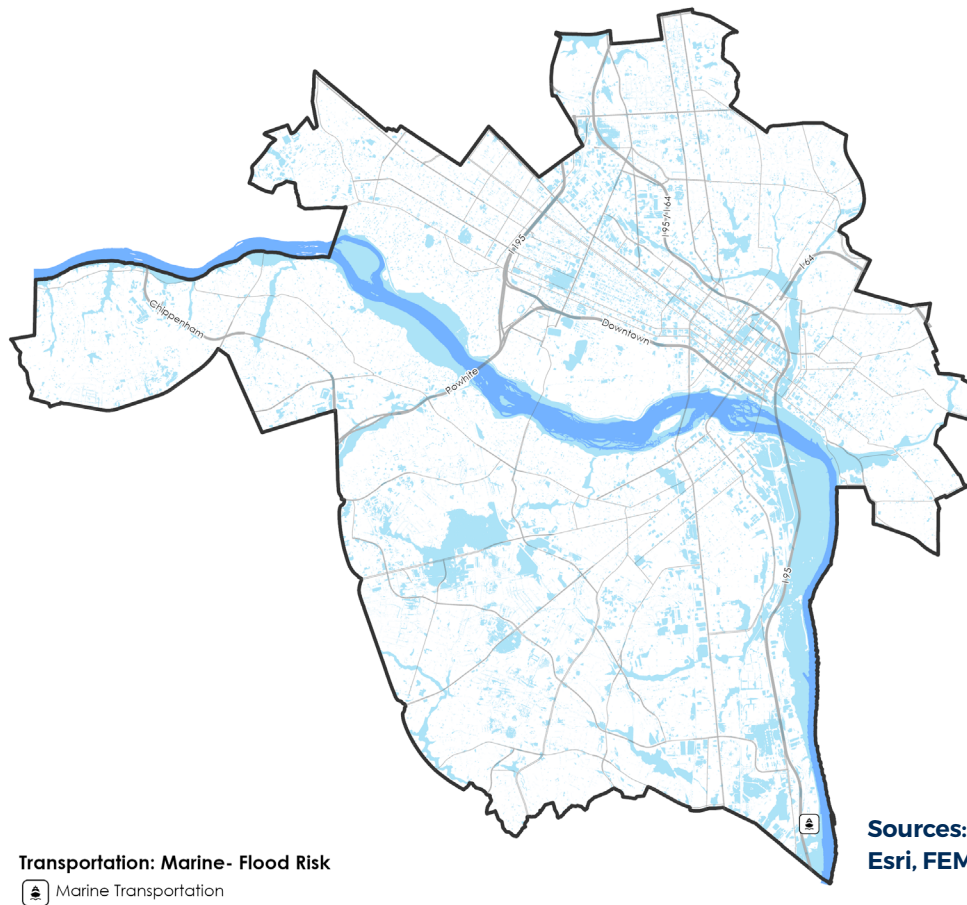
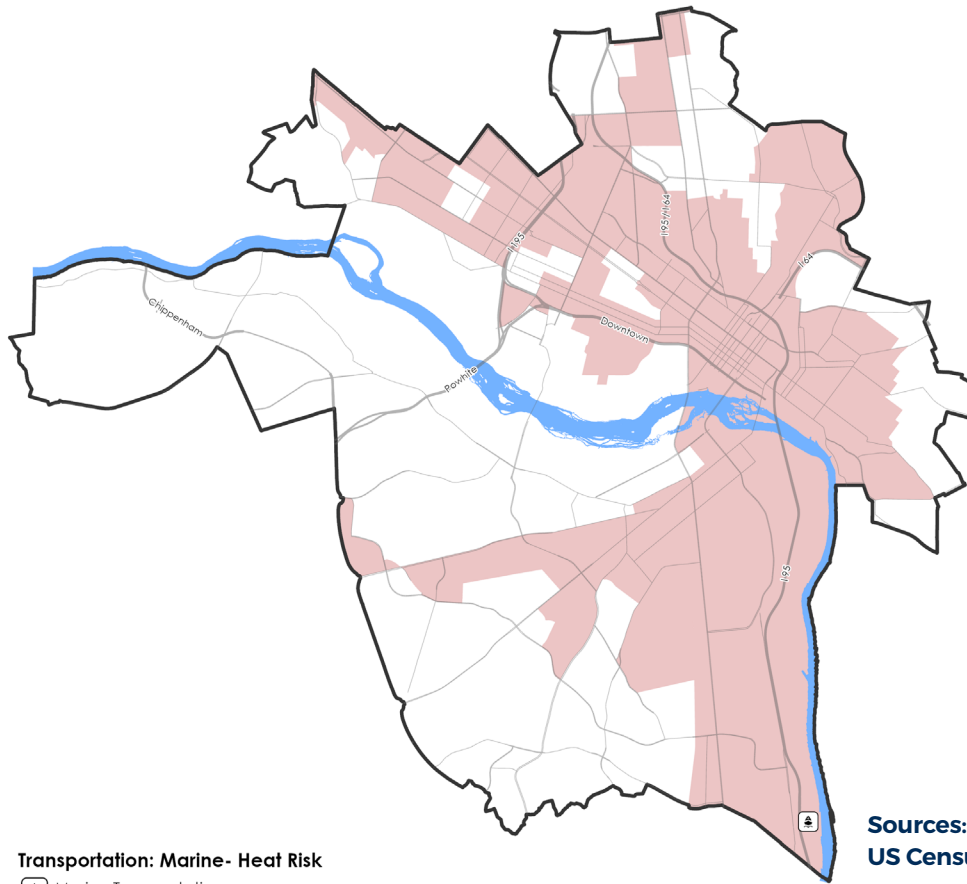
- Richmond Marine Terminal

- Climate Vulnerabilities**
- Flooding from extreme precipitation events
 - Sea level rise will impact flooding vulnerability, RMT facilities, and port operations
 - Flooding on roadway network and rail lines accessing the port
 - Debris from extreme storms and flooding events



- Resilience & Equity Impact Considerations**
- RMT is susceptible to increased flooding given its location along the tidal James River
 - Landing facilities and access to docks where cargo and passengers are transferred are at risk
 - Many goods are shipped through this port, making it a key employment center and community economic resource

Built Assets at Risk		
Marine Transportation	Heat Risk	Flood Risk
Marine	1	1





Transportation: Richmond International Airport

Richmond International Airport is located outside the City of Richmond boundary, but is a key resource for passenger travel and movement of goods in and out of the area. Aircraft operations are particularly susceptible to changes in temperature and humidity. The changing climate will have persistent effects on operations and planning.

Heat

Med-High

Water

Med-High

Consequence

Med-High

Transportation Assets

- Richmond International Airport

Resilience & Equity Impact Considerations

- Flight disruptions can have significant economic effects
- Impacts to air travel affect mail and goods
- Runways will require additional maintenance

Climate Vulnerabilities

- Extreme heat impacts to runways (warping and buckling), affecting take-off and landing capabilities at the airport
- Length of runway needed to take off and weight planes can carry affected by heat
- Increasing storm frequency and severity pose risks to air travel
- Microburst storms are a major concern for airport operations

Built Assets at Risk

Transportation Assets

Richmond International Airport

Heat Risk

Not included in city boundaries

Flood Risk

Not included in city boundaries



Waste Management

Richmond’s waste management system includes municipal and private solid waste services, recycling, and composting. Maintaining effective waste management systems helps promote public health. Also considered in this category are facilities regulated by the Environmental Protection Agency (EPA) due to the handling or storage of toxic substances. A recent report links climate change to toxic chemical spills specifically in the James River watershed as a significant threat to the region.

Waste Management Assets

- Composting, recycling and municipal solid waste facilities
- EPA emergency response facilities
- Solid waste landfill facilities

Climate Vulnerabilities

- Flooding and runoff impacts to solid waste facilities, especially East Richmond landfill, and waste collection routes
- Littering and unregulated dumping in ravines increases debris during storm events, which can overwhelm the waste management system and contribute to contamination of water supply and sensitive habitats
- Sea level rise impacts to facilities next to the James River
- Increased heat and humidity impacts to bacteria and nutrient loads, which can seep into the environment
- Extreme heat impacts to workers at waste facilities and on collection trucks

Heat

Medium

Water

Med-High

High

Consequence

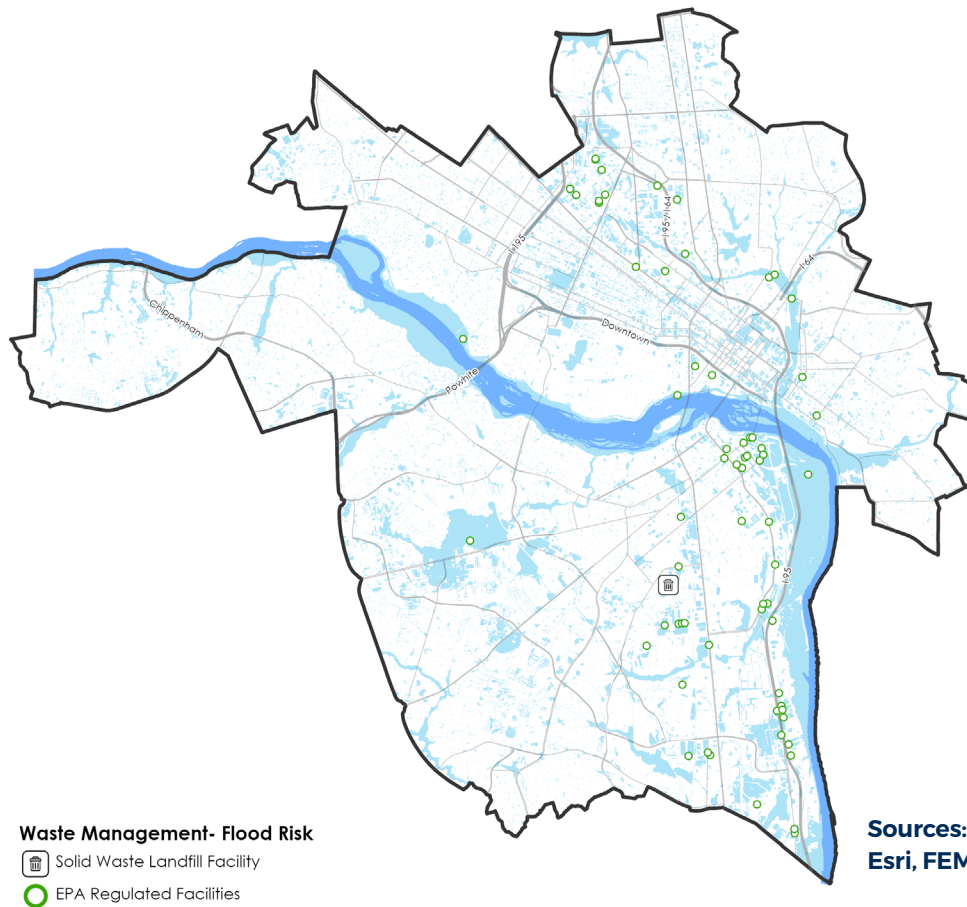
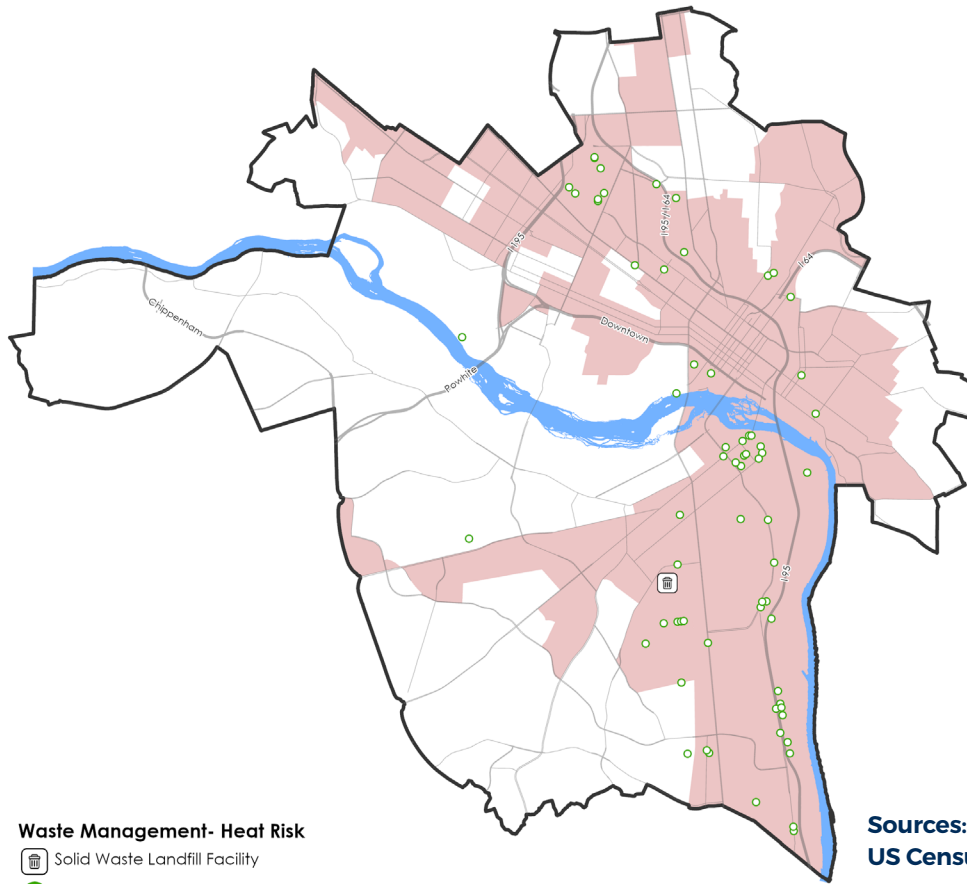
Med-High

High

Resilience & Equity Impact Considerations

- Potential for flooding and stormwater runoff from landfills to contaminate surrounding areas; the environment should be monitored for bacteria leaks and mitigation could be performed
- Future need to update waste facilities sizing
- Address alley trash collection issues, including that they can’t be served by automated trucks
- Explore and better understand medical waste from hospitals and universities
- Implement work practices for waste management crews such as shifted hours and staggered crews to manage increased heat and intense storm

Built Assets at Risk		
Waste Management Assets	Heat Risk	Flood Risk
EPA Emergency Response	75	14
Solid Waste Landfills	1	0





Water Supply

Water supply infrastructure ensures that Richmond residents have a reliable, clean source of water. The James River is the primary water source for the City.

Heat

Medium

Med-High

Water

Med-High

High

Consequence

High

Water Supply Assets

- Dams
- Water pipes
- Water treatment facilities

Climate Vulnerabilities

- Increasing heat and periods of drought
- Growth of biota, algal blooms, bacteria and viruses, eutrophication, water quality issues, and treatment facility maintenance risks
- Periods of water demand exceeding supply
- Severe storm and flooding impacts to water treatment capacity, temporary potable water impacts

Resilience Factors

- Through initiatives like smart sensors, RVAH2O, the City of Richmond's collaborative, long-term clean water effort, is improving adaptive capacity, but the system is still largely a hard infrastructure with minimal flexibility.

Resilience & Equity Impact Considerations

- Meeting water demands for maintaining and growing vegetation and tree canopy
- Potential for development of improved technologies to utilize stormwater runoff
- Green infrastructure needed, some planning initiatives underway

Built Assets at Risk

Water Supply Assets

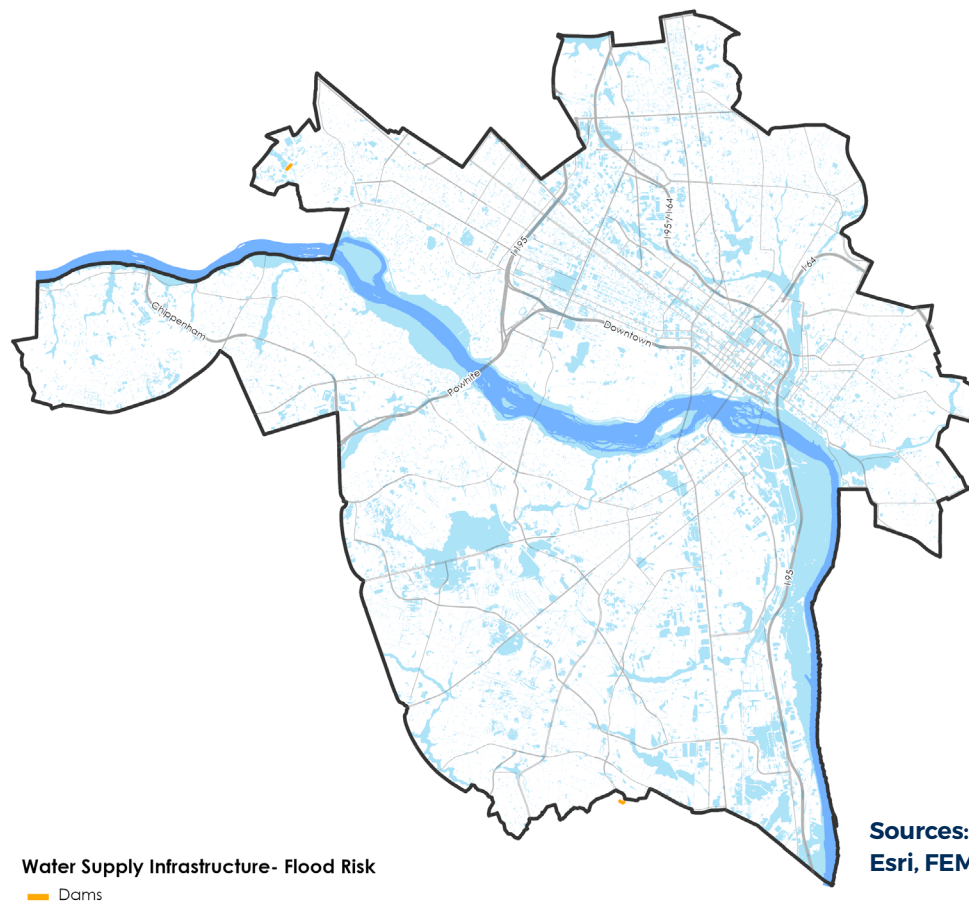
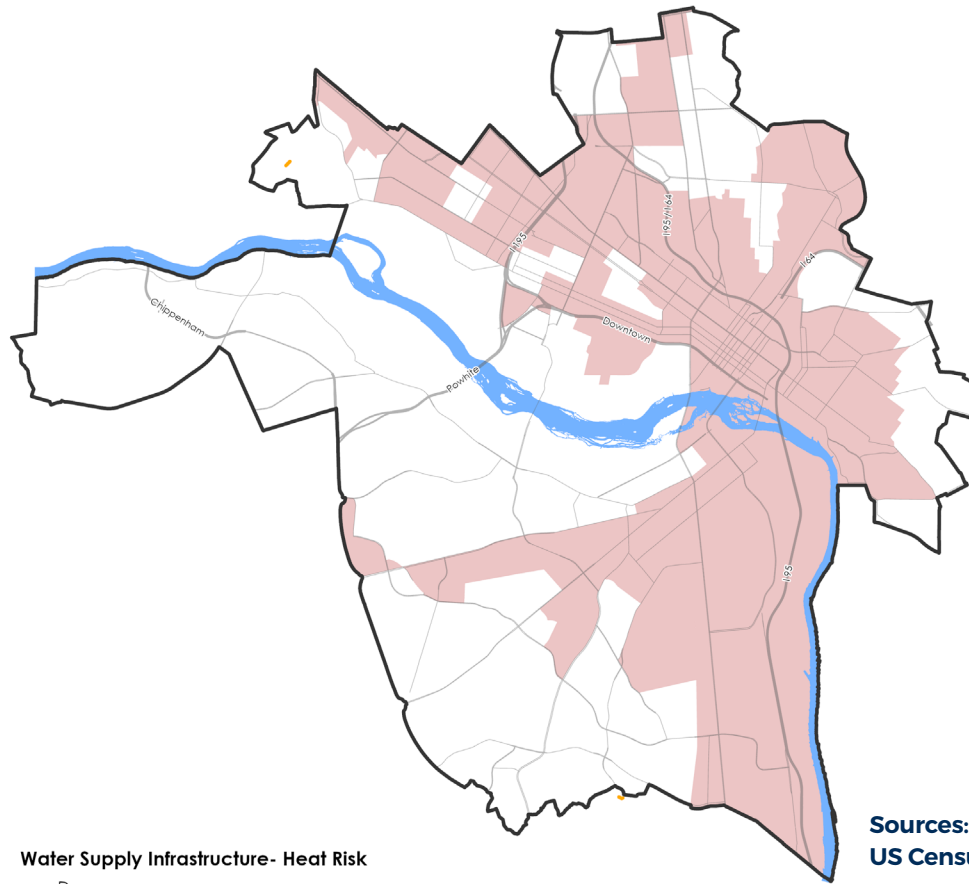
Heat Risk

Flood Risk

Dams

Water Pipes

Water Treatment Facilities



Natural Assets Vulnerability and Risk

Natural assets were identified by considering the landscape, habitats, and water features present in Richmond. These include assets both internal and external to the City’s operational control.



Parks & Open
Space



Terrestrial
Habitat



Trees and
Vegetation



Water Bodies



Parks & Open Space

Parks and open spaces play an essential role in supporting health and well-being for Richmond residents. Parks offer opportunities for residents to spend time outdoors and engage in an active, healthy lifestyle.

Heat

Medium

Med-High

Water

Medium

Med-High

Consequence

High

Parks and Open Spaces Assets

- Cemeteries
- Community gardens
- Parks and playgrounds

Climate Vulnerabilities

- Extreme heat, storms, and flooding can limit people's ability to use parks
- Plants and trees in parks and open spaces filter
- Increased invasive species
- Soil destabilization due to vegetation impacts and extreme precipitation events
- Impacts to carbon cycle and decrease in carbon sequestration due to soil impacts
- Decreases or changes to biodiversity patterns
- Park land and open space along the James River in areas impacted by river flooding

Resilience Factors

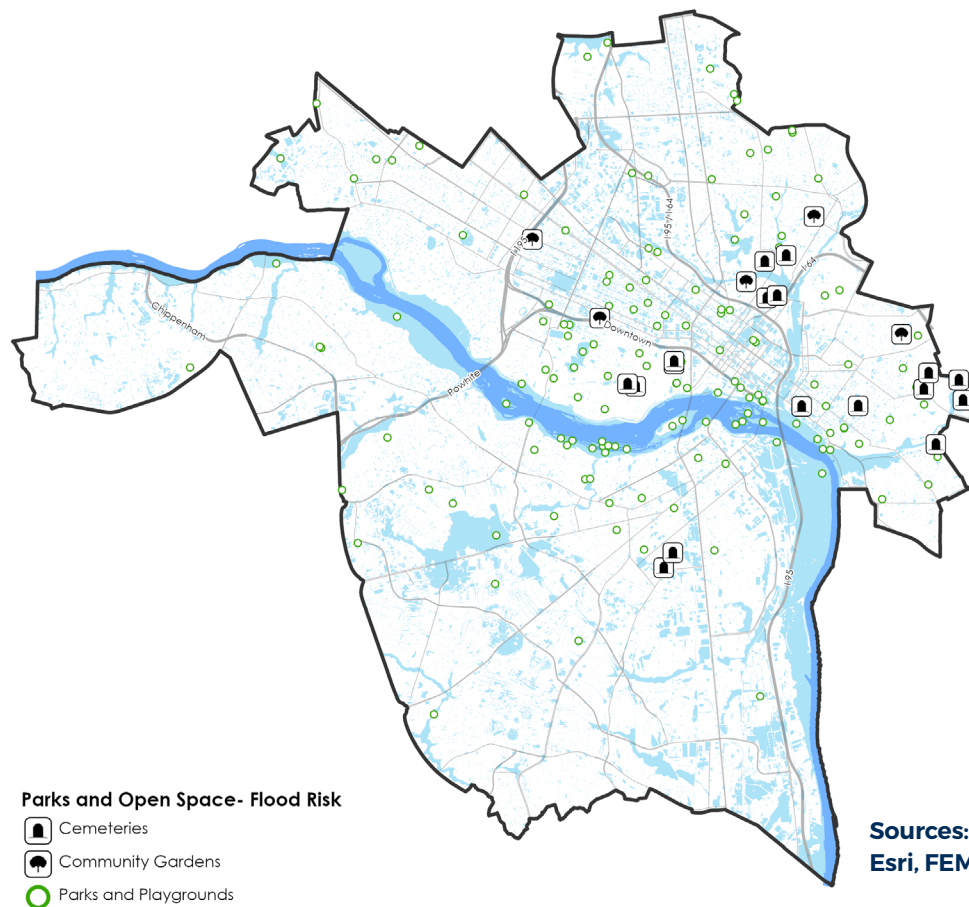
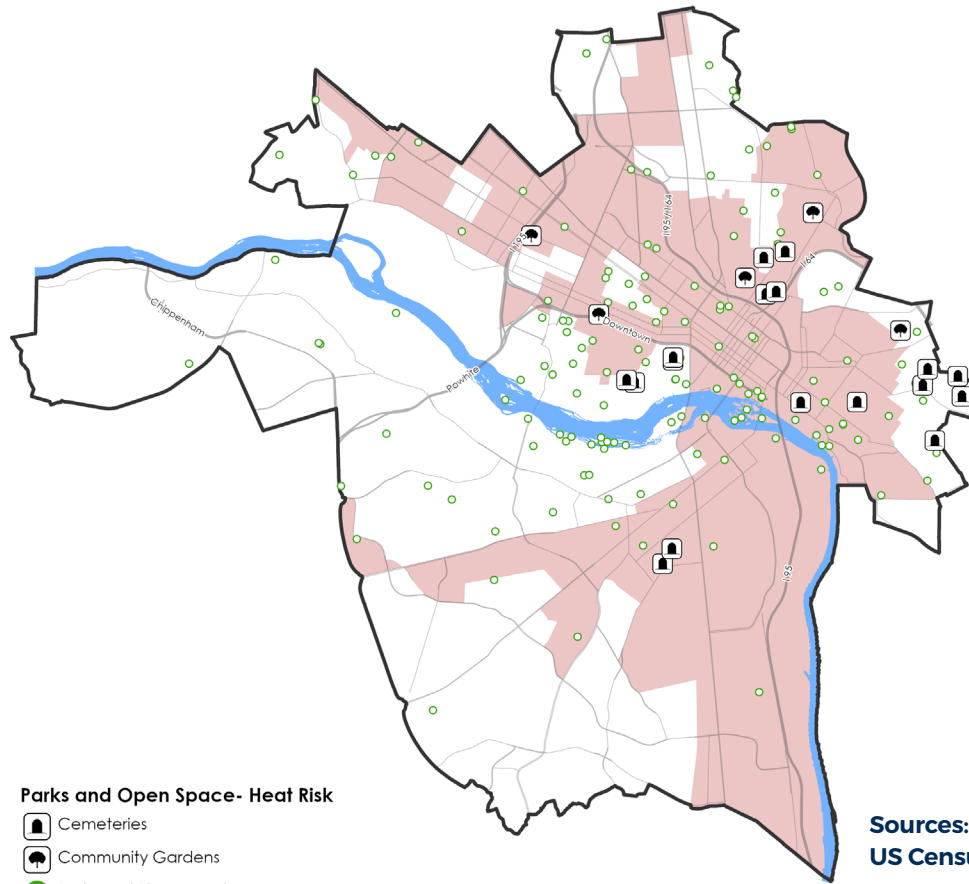
- Parks may provide tree canopy for cooling relief during heat waves
- Plants and trees in parks and open spaces filter stormwater runoff and provide capacity for accommodating excess rainfall from extreme precipitation events

Resilience & Equity Impact Considerations

- Address equity considerations and mitigation needs to redress past harms based on historic approaches to cemeteries, burial grounds, and sacred sites for minority communities
- Prioritize cemeteries as green infrastructure within the City
- Interest in increasing green spaces and resilience, including urban gardens
- Water usage impacted by periods of drought
- Increased maintenance costs
- Loss of land with potential to support local food systems

Natural Assets at Risk

Parks and Open Spaces	Heat Risk	Flood Risk
Cemeteries	7	2
Community Gardens	4	0
Parks and Playgrounds	72	47





Terrestrial Habitat

Terrestrial, or land-based, habitats support native plants and wildlife species. Like other open spaces, they also provide refuge from urban heat and support stormwater management. Key habitats include protected natural areas and James River islands. The maps on the following page show terrestrial habitats designated by the Northeast Climate Science Center and North Atlantic Landscape Conservation Cooperative, as mapped by the Natural Conservancy Eastern Conservation Science team.

Heat

Med-High

Water

Med-High

Consequence

High

Habitat Assets

- Terrestrial habitat features
- James River islands

Climate Vulnerabilities

- Most areas are located in flood zones and sensitive to flooding
- Rising water levels along James River and tributaries because of rising sea levels
- Disappearance or shrinking of islands
- Inundation of protected and sensitive lands
- Sensitivity to heat changes
- Migration of species
- Threats from invasive species

Resilience Factors

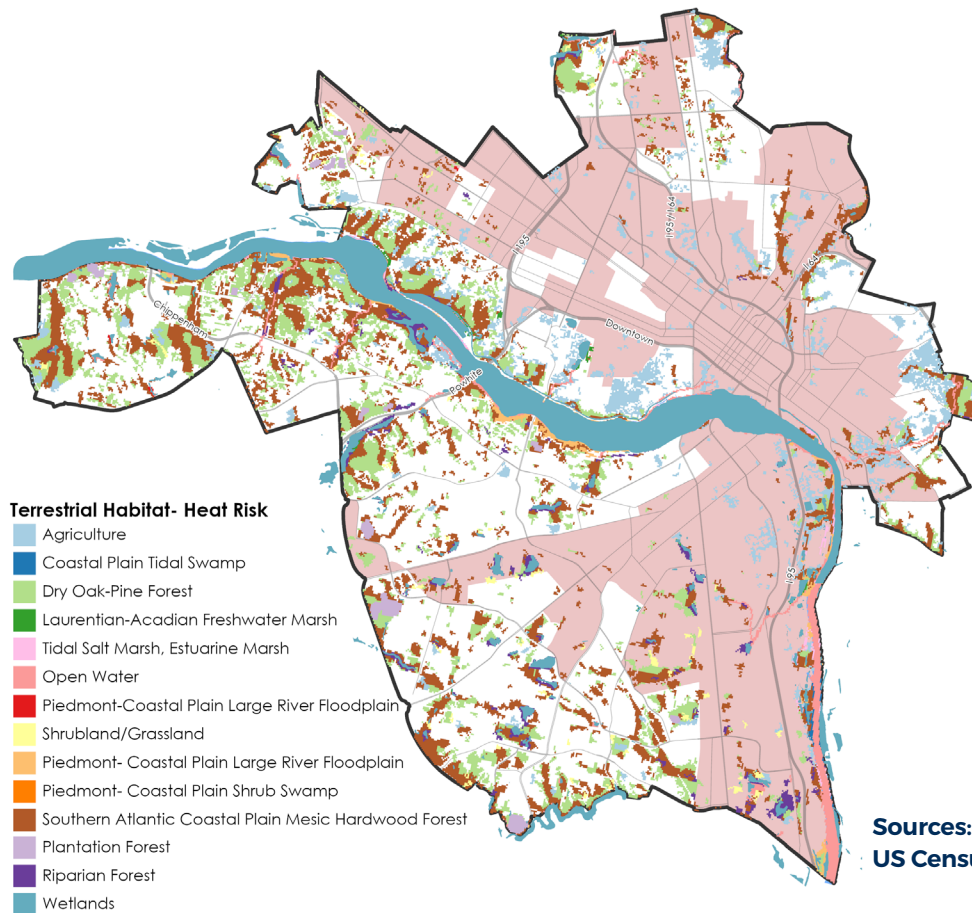
- Easement and impervious surface limitations provide protection for some areas
- Protected and natural areas currently provide relief from heat waves and help accommodate storm runoff

Resilience & Equity Impact Considerations

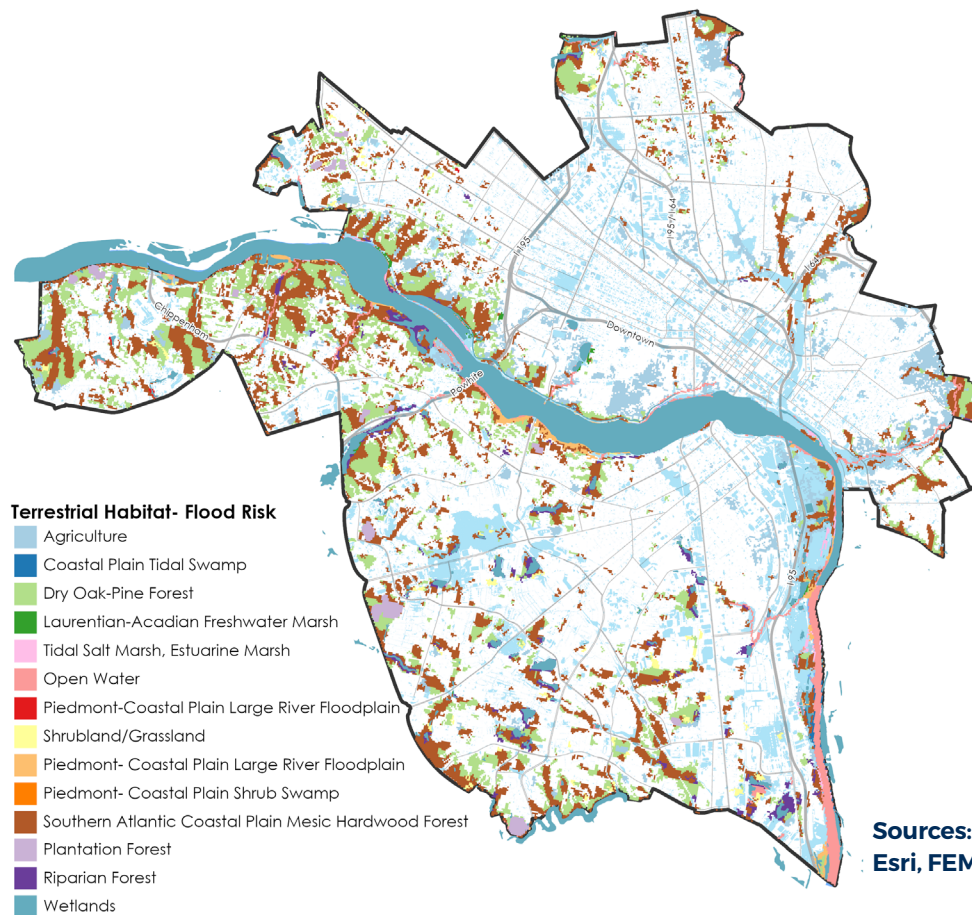
- Impacts will be substantial to James River islands and habitats along the James River due to sea level rise
- Planning for major impacts to James River Islands should be prioritized
- Land use and development pressures reduce space for climate resilience
- Increase green spaces to support natural world and human communities

Natural Assets at Risk

Habitat Assets	Heat Risk	Flood Risk
Habitat features	13	14
James River Islands	7	15



Sources: City of Richmond,
US Census Bureau



Sources: City of Richmond,
Esri, FEMA



Trees & Vegetation

Trees and vegetation include those found in open spaces and those integrated into the urban fabric. They provide valuable carbon sequestration, shading and refuge from the heat, and support for better air quality. Trees and vegetation also provide refuge and safe passage for wildlife and pollinators. Isolated trees and tiny pockets of vegetation can be just as critical as larger tracts of undisturbed land.

Heat

Med-High

Water

Med-High

Consequence

High

Trees & Vegetation Assets

- Tree canopy
- Vegetation and other pervious surface cover

Climate Vulnerabilities

- Flooding and inundation of vegetation along the river
- Storm damage to tree limbs
- Heat and/or water stress during periods of drought
- Changing native ranges of plant species
- New pests moving into the area as winter freeze line moves northward
- Effects on native species can increase opportunities for invasive species

Resilience Factors

- Past efforts have focused on planting trees and increasing vegetation
- Plants have some adaptive capacity, but generally with new species replacing species that do not survive changes
- Areas of tree plantings and vegetation provide relief from heat waves and help accommodate storm runoff

Resilience & Equity Impact Considerations

- Tree limbs broken off in storms may cause power outages and property damage
- Loss of trees may lead to worsening heat effects, decrease in air quality, soil erosion, and public health impacts
- Trees and vegetation should be replaced with more heat and drought tolerant native species.
- Adding trees can increase the City's tree canopy and moderate climate impacts
- Equity should be considered for areas with low tree cover

Natural Assets at Risk

Trees and Vegetation

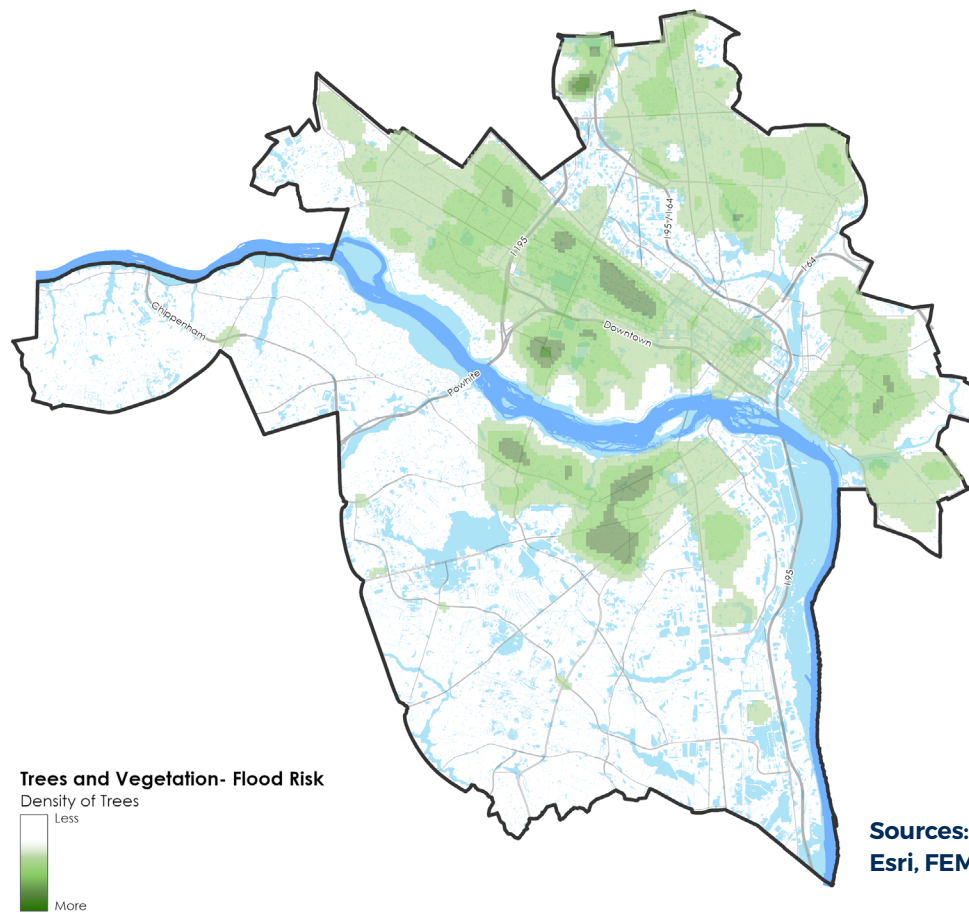
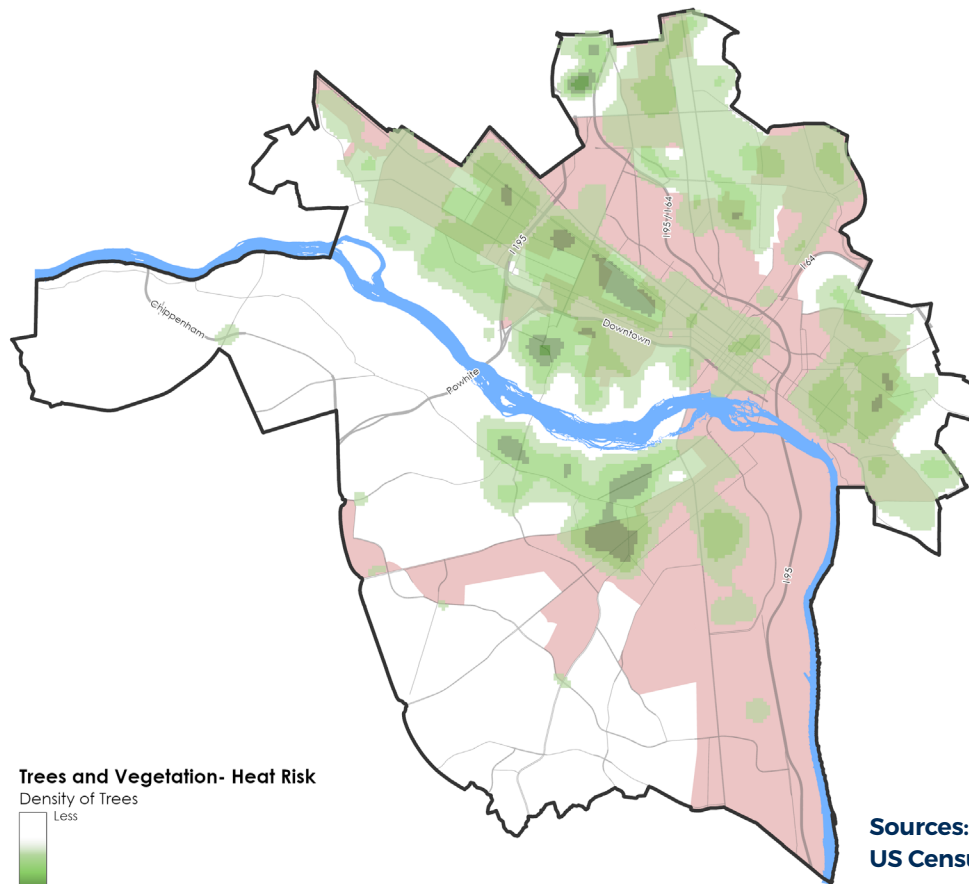
Heat Risk

Flood Risk

Trees

61396

9597





Water Bodies

Rivers, lakes, and streams are among the most sensitive resources to climate threats. They provide water storage, pathways for floodwaters, support aquatic habitats, and support human activities. Water bodies are also important for food supply and economic activity.



Water Bodies/Assets

- Chesapeake Bay Protection Area
- Creeks
- Lakes

- Climate Vulnerabilities**
 - Permanent changes to the average water level
 - Flooding of water bodies and resources that surround them
 - Fundamental changes to aquatic habitats because of rising temperatures
 - Decreased dissolved oxygen, changes to the nutrient balance, increased pollution effects, and increased algal blooms

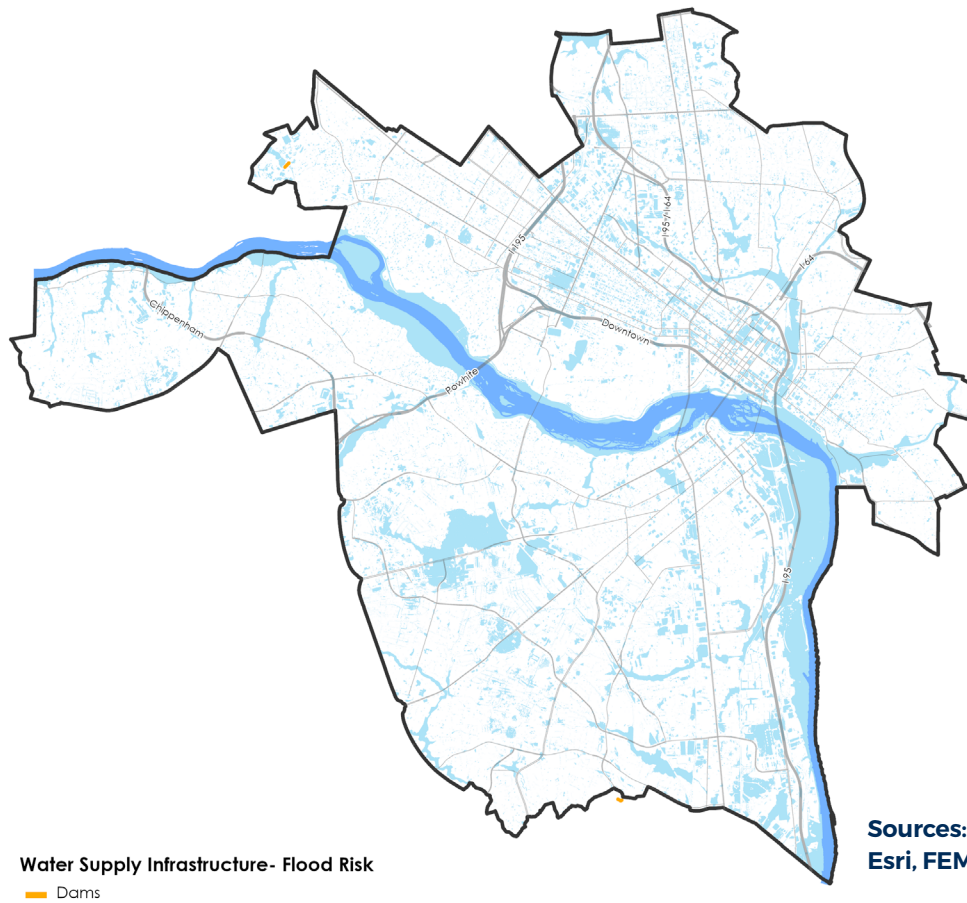
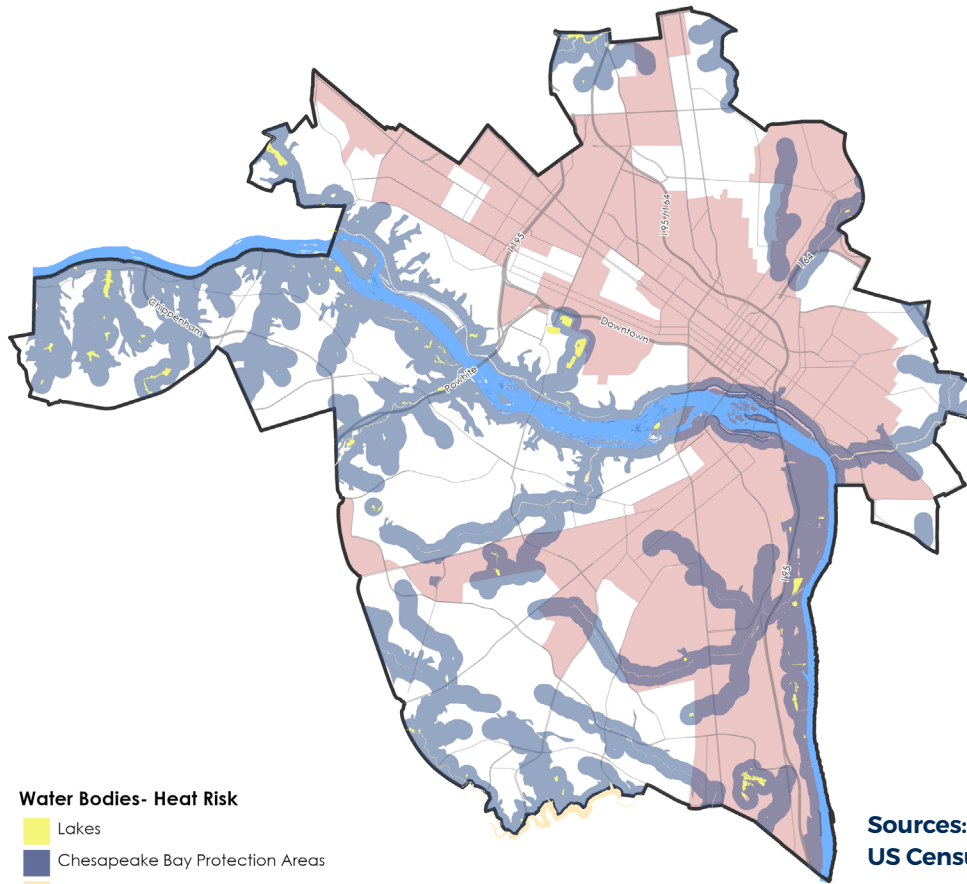
Resilience Factors

- Water bodies provide some relief to natural and human communities during heat waves
- Water resources have some adaptive capacity to accommodate extreme precipitation and runoff, but impacts over time can result in permanent changes to aquatic habitats and biotic systems

Resilience & Equity Impact Considerations

- Dependence by natural communities and humans on food from the river
- Distributional equity in access to water bodies and higher quality water resources

Natural Assets at Risk		
Water Bodies	Heat Risk	Flood Risk
Chesapeake Bay Protection Area	3782.3 acres	3410 acres
Creeks	10	31
Lakes	28	92





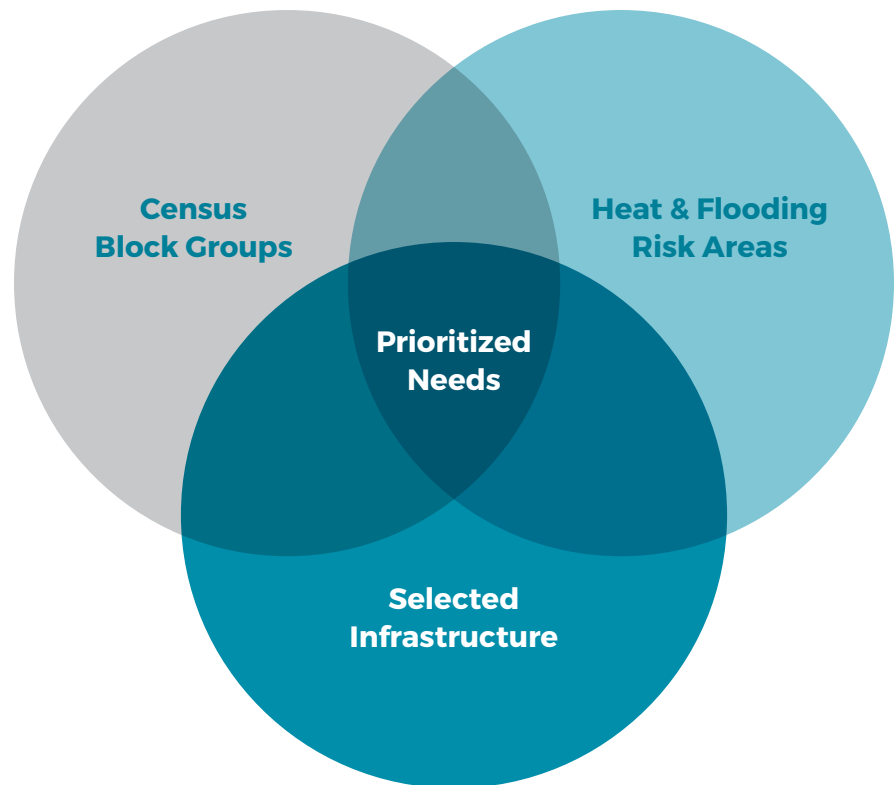
6. Priority Planning Areas

Heat and flooding risks to Richmond’s built and natural assets (Section 5) are overlaid with social vulnerability (Section 4) in order to determine priority areas for actions and interventions for enhanced climate resilience.

6.1 Prioritization Methodology

The previous section described the built and natural assets and infrastructure that are vulnerable to climate risks. This section applies the social vulnerability information from the City’s Climate Equity Index to prioritize climate and resilience actions based on risks to assets that will have the greatest impact to Richmond’s frontline communities. Mapping analysis is used to focus on assets in socially vulnerable areas or serving socially vulnerable groups.

Priority Planning Areas / Prioritized Needs – Highly Vulnerable populations, including populations identified as “Highly”

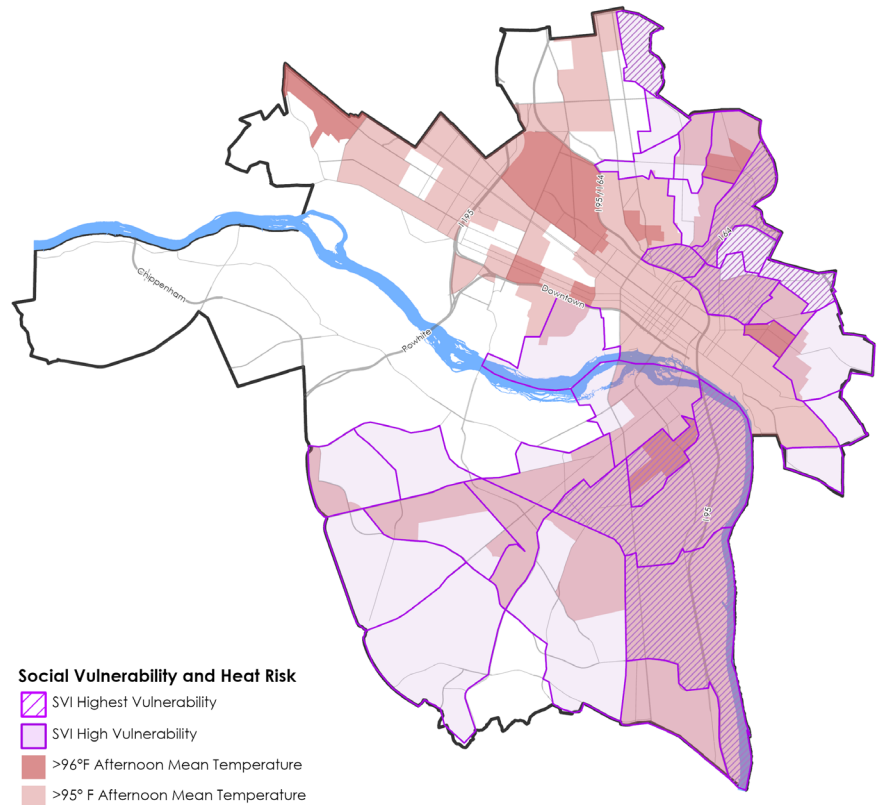


Vulnerable and “Most” Vulnerable from the Climate Equity Index were overlaid with areas facing heat and flooding risk. Assets specifically serving socially vulnerable groups subject to

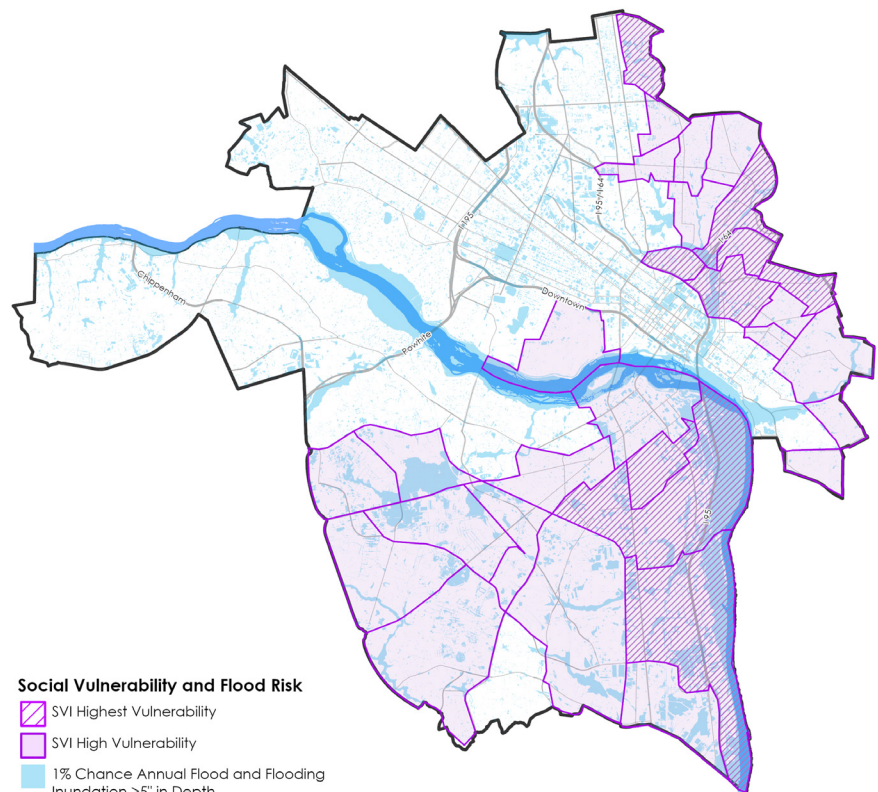
these risks were also included, such as homeless facilities, public housing, and food pantries. These broad planning areas should be considered for prioritization through mid and long term solutions.

Critical Prioritized Needs / Planning Areas – after identifying the priority planning areas for highly vulnerable populations and assets, those assets falling within census areas containing populations identified as the “Most” Vulnerable from the Climate Equity Index were identified, including the names of these assets. These critical prioritized needs can help in determining the most impactful climate and resilience actions for short term and mid-term solutions, especially in consideration of resource or funding constraints. Consequence scores which indicate the magnitude of repercussions for the community if climate impacts occur, are presented alongside the critical vulnerable assets to further support City prioritization of strategies and action.

Information on heat and flood priority planning areas and critical prioritized needs are summarized in the following sections with supporting detail presented in more detail in Appendices E and F.



Sources: City of Richmond, Esri, US Census Bureau



Sources: City of Richmond, Esri, FEMA, US Census Bureau

6.2 Prioritized Needs – Heat Vulnerability

Table 6.1 summarizes the assets in socially vulnerable areas or that predominantly or

exclusively serve socially vulnerable groups regardless of location that have exposure to heat risk from climate change (Census block groups with afternoon mean high temperatures above 95°F). The

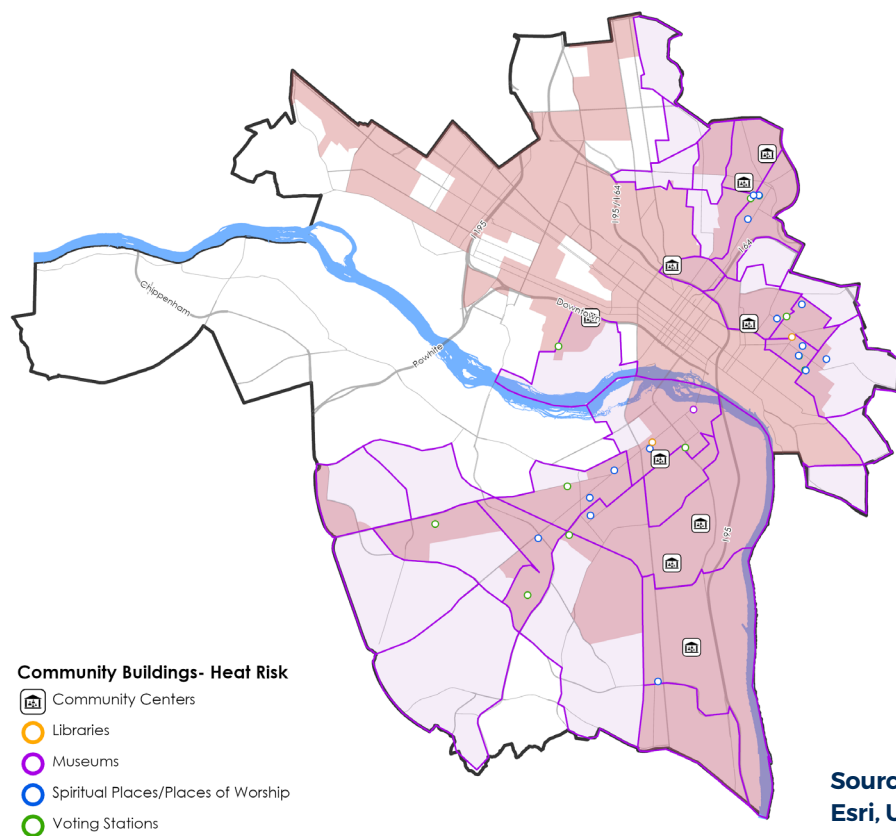
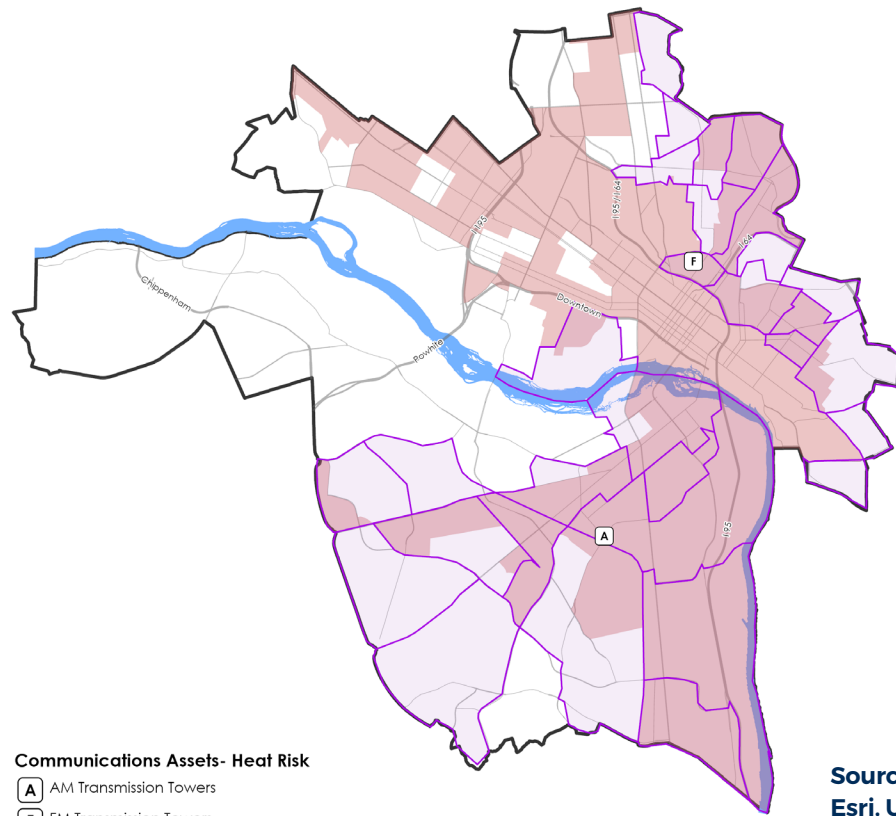
map figures on the pages that follow illustrate the location of assets with exposure to heat risk for each category or grouping of assets of similar types.

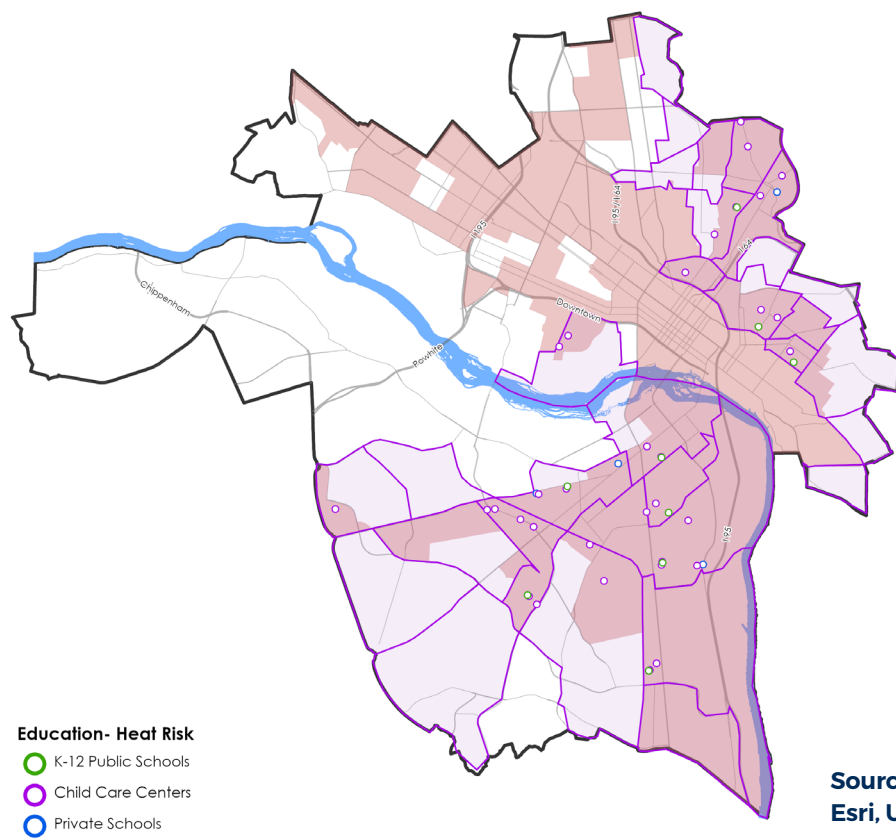
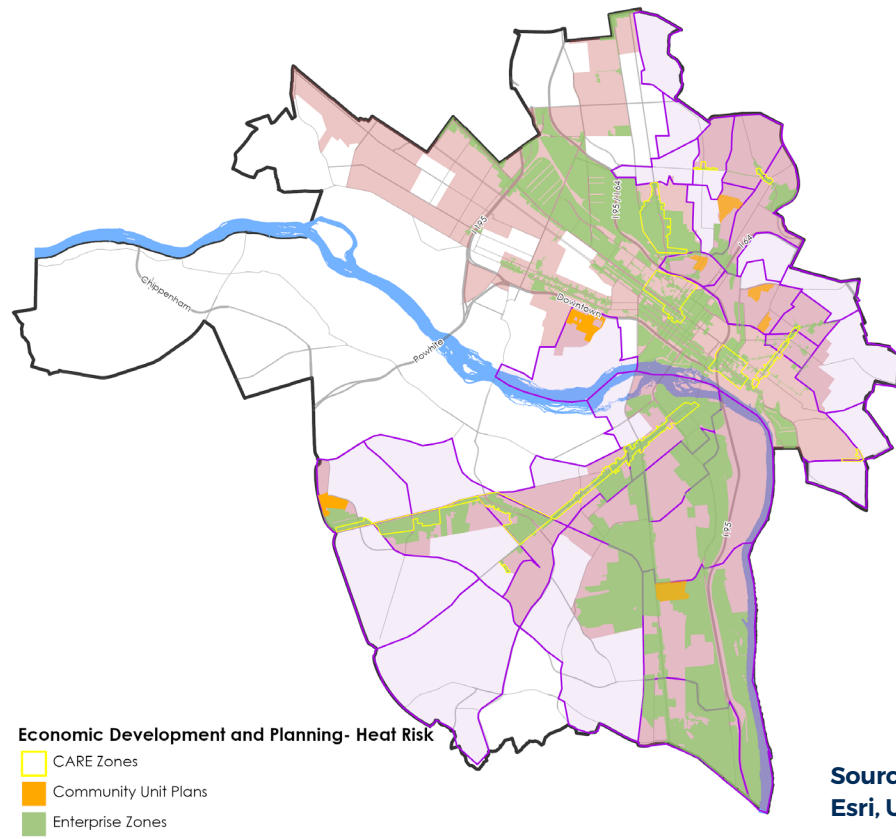
Table 6.1 - Priority Planning Areas - Heat Risk

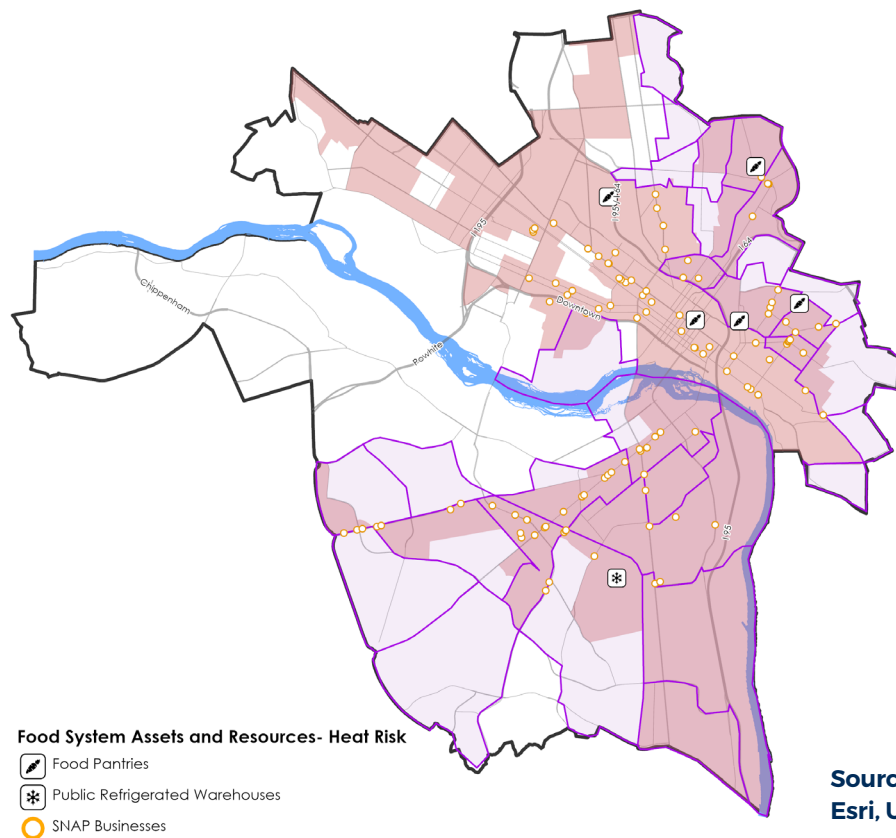
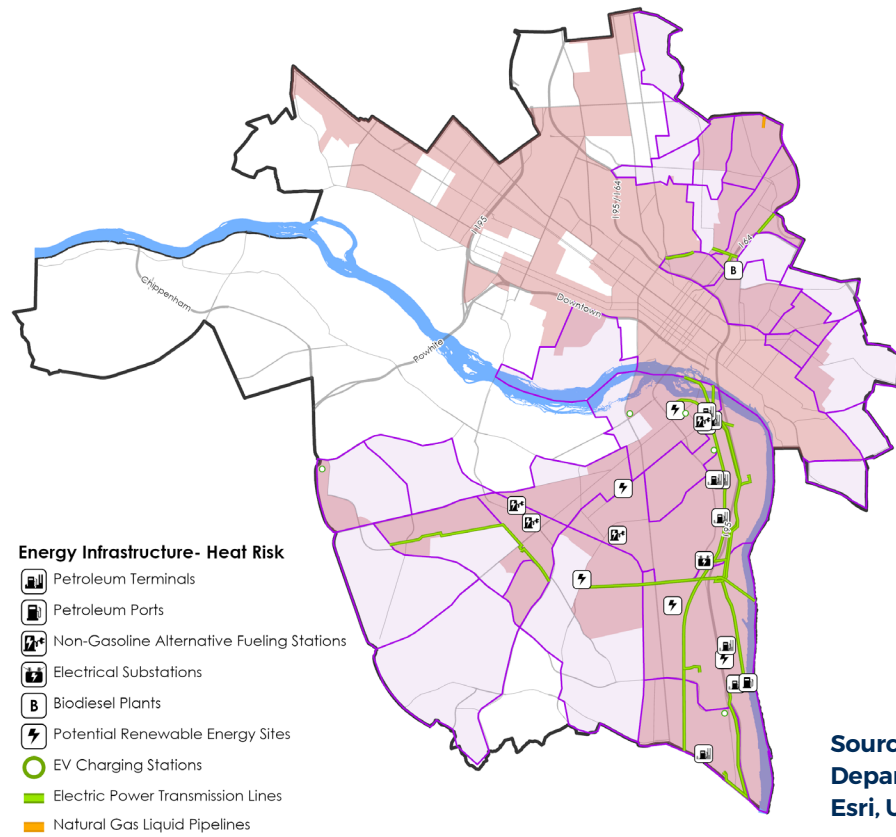
Asset Category	Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*	
				Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas
Communications Infrastructure	AM Transmission Towers	3	towers	1	0
	FM Transmission Towers	5	towers	1	0
Community Buildings	Community Centers	22	centers	9	0
	Libraries	13	libraries	2	0
	Museums	37	buildings	1	0
	Religious Centers	74	Centers	16	0
	Voting Stations	67	stations	16	0
Education	Childcare Centers	118	centers	33	0
	K12 Public Schools	44	schools	9	0
	Private Schools	34	schools	4	0
Health and Social Services	Dialysis Clinics	5	clinics	1	2
	Homeless Facilities	5	facilities	1	4
	Hospitals	6	hospitals	2	0
	Nursing Homes	17	homes	5	6
	Social Services	3	services	1	0
Historic	City Historic Districts	45	districts	2	0
	National Register Historic Districts	133	Districts	22	0
	State Federal Historic Sites	156	sites	16	0
Economic Development and Planning	CARE Zones	13	zones	10	2
	Enterprise Zones	4	zones	3	1
	Enterprise Zones Community Unit Plans	110	zones	28	0

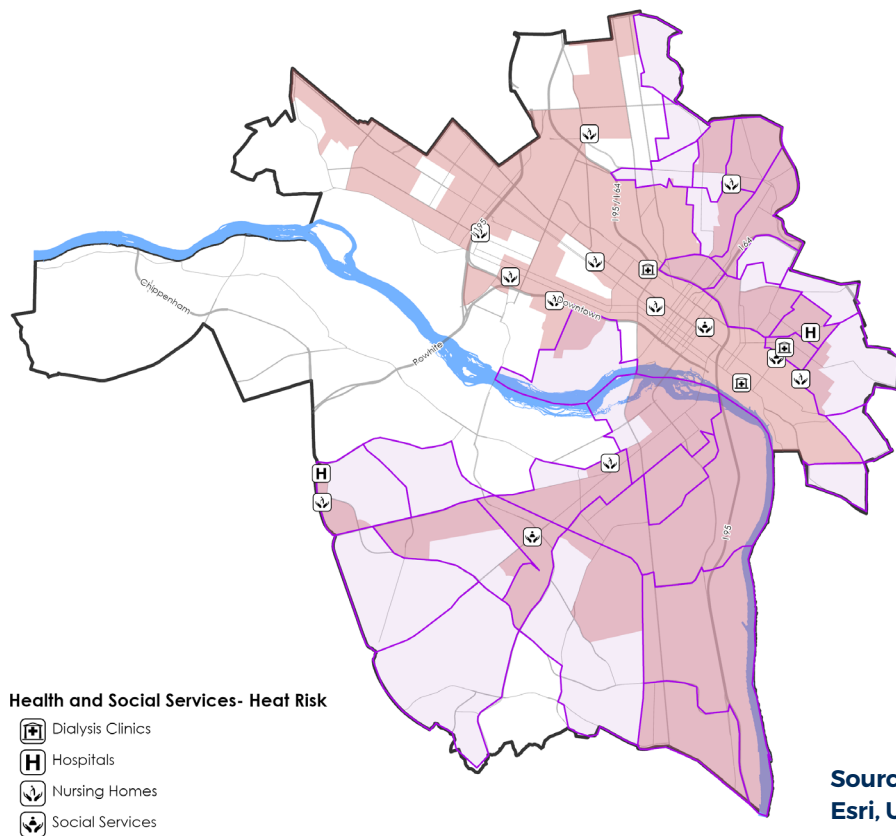
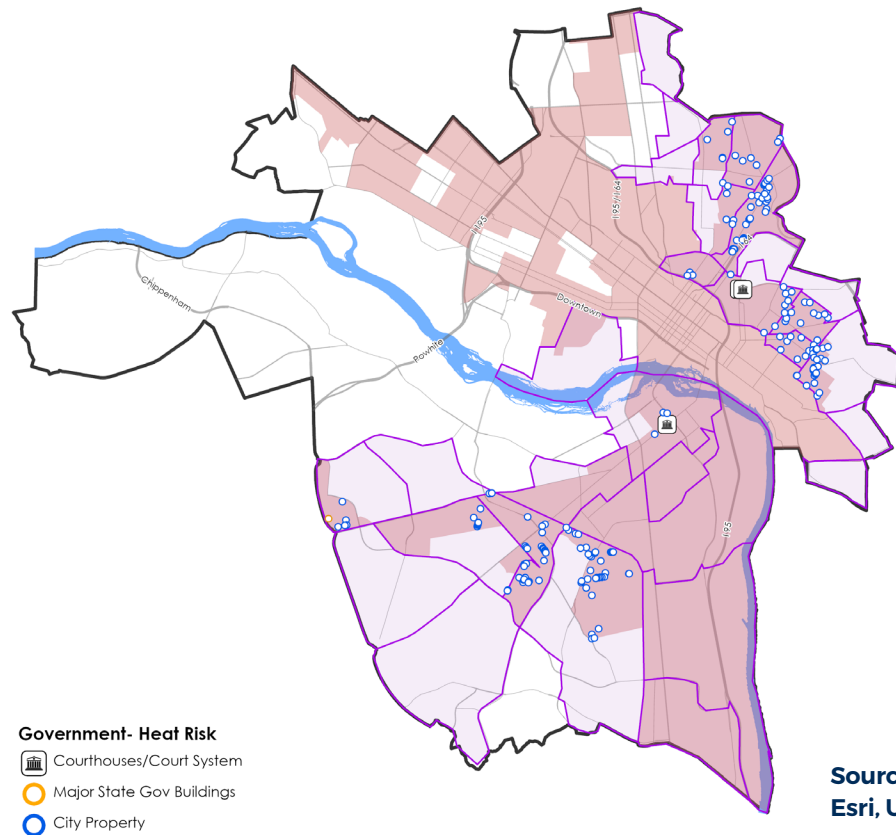
Asset Category	Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*	
				Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas
Energy Infrastructure	Biodiesel Plants	1	facilities	1	0
	Electrical Substations	1	substations	37.7	0
	Electric Vehicle Charging Stations	134	stations	16	0
	NaturalGas Pipeline	1.6	miles	0.2	0
	Non Gasoline Alternative Fueling Stations	13	stations	4	0
	Petroleum Ports	1	ports	1	0
	Petroleum Terminals	9	terminals	9	0
	Potential Renewable Energy Sites	13	sites	5	0
Food System Assets and Resources	Food Pantries	9	pantries	3	2
	Public Refrigerated Warehouses	2	sites	1	0
	SNAP Businesses	193	businesses	67	43
Government Facilities	City Property	966	properties	196	0
	Courthouses and Court Systems	9	facilities	3	0
	Major State Government Buildings	38	buildings	1	0
Parks and Open Spaces	Cemeteries	17	cemeteries	5	0
	Community Gardens	5	sites	2	0
	Parks and Playgrounds	143	parks	25	0
Public Housing Resources	HUD Multifamily Properties	27	properties	12	1
	RRHA Housing	60	locations/parcels	31	0
Public Safety and Emergency Response	Cooling Centers	3	centers	1	0
	Correctional Facilities	3	facilities	2	0
	EMS Stations	24	stations	7	0
	Fire Stations	21	stations	6	0
	National Shelter System Facilities	20	facilities	3	0
	Police Stations	5	Stations	2	0
	Sheriff Facilities	7	facilities	5	0
Stormwater and Sewer Infrastructure	Sewer Treatment Plant	1	plants	1	0
Terrestrial Habitat	James River Features Islands (Islands)	15	islands	5	0
	Terrestrial Habitat	14	habitats/locations	12	0
Transportation Infrastructure - Bike/Ped	Bike Infrastructure	71.2	miles	6.8	0
	Bikeshare Stations	17	stations	1	0
	Trails	15.94	miles	0.5	0
Transportation Infrastructure - Marine	Marine Transportation	1	unit	1	0
Transportation Infrastructure - Rail and Transit	Public Transit Stations	2	stations	0	2
	Railroad Bridges	27	bridges	7	0
	Rail Lines	159.6	miles	73.7	0

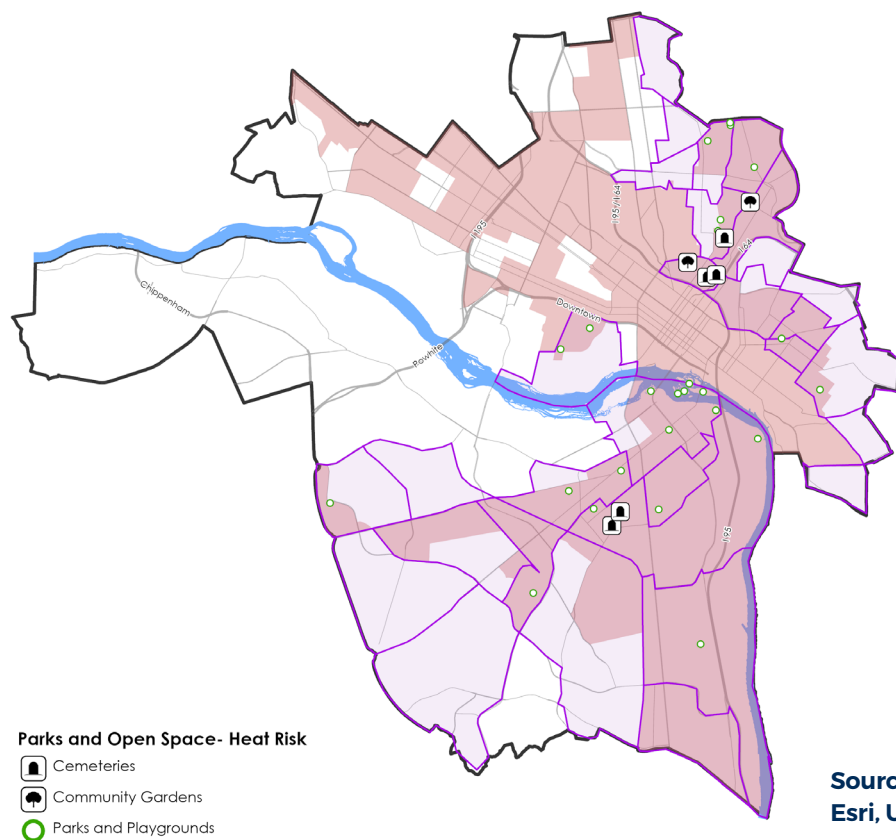
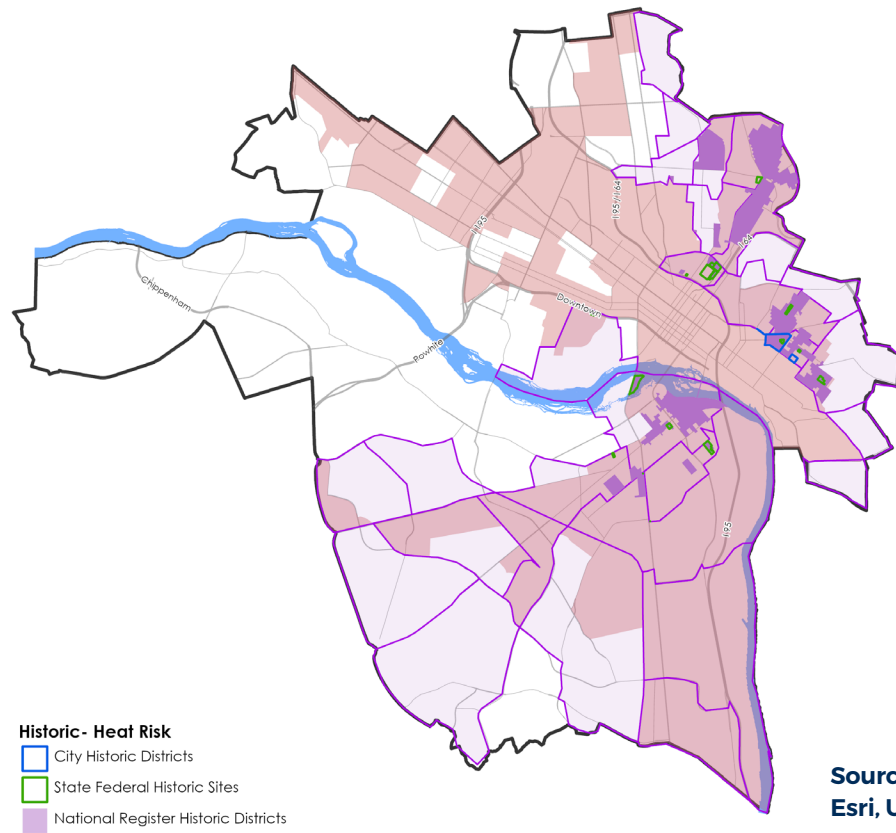
Asset Category	Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95°	
				Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas
Transportation Infrastructure - Roads and Bridges	Bridges	177	bridges	46	0
	Roads	1,206.7	miles	314.0	0
Trees and Vegetation	Tree canopy (Street Trees and Trees Other)	120,356	trees	25,696	0
Waste Management Infrastructure	EPA Regulated Facilities	79	facilities	52	0
	Solid Waste Landfill Facilities	1	facilities	1	0
Water bodies	Chesapeake Bay Protection Area	13,038.3	acres	3,193.3	0
	Creeks	31	creeks	10	0
	Lakes	100	lakes	28	0

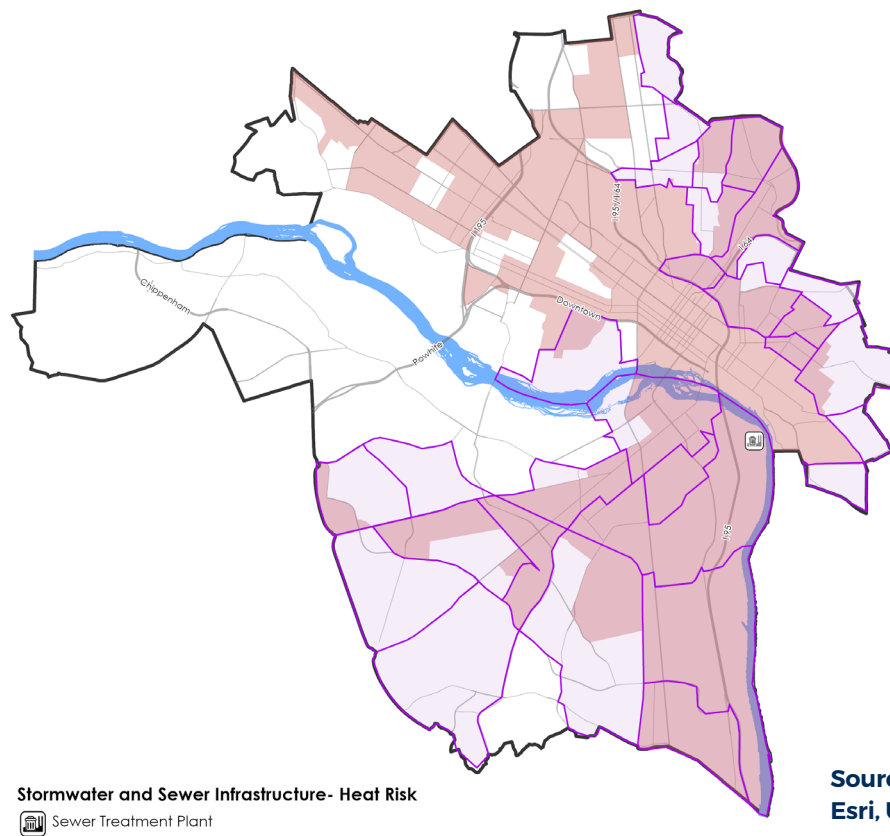
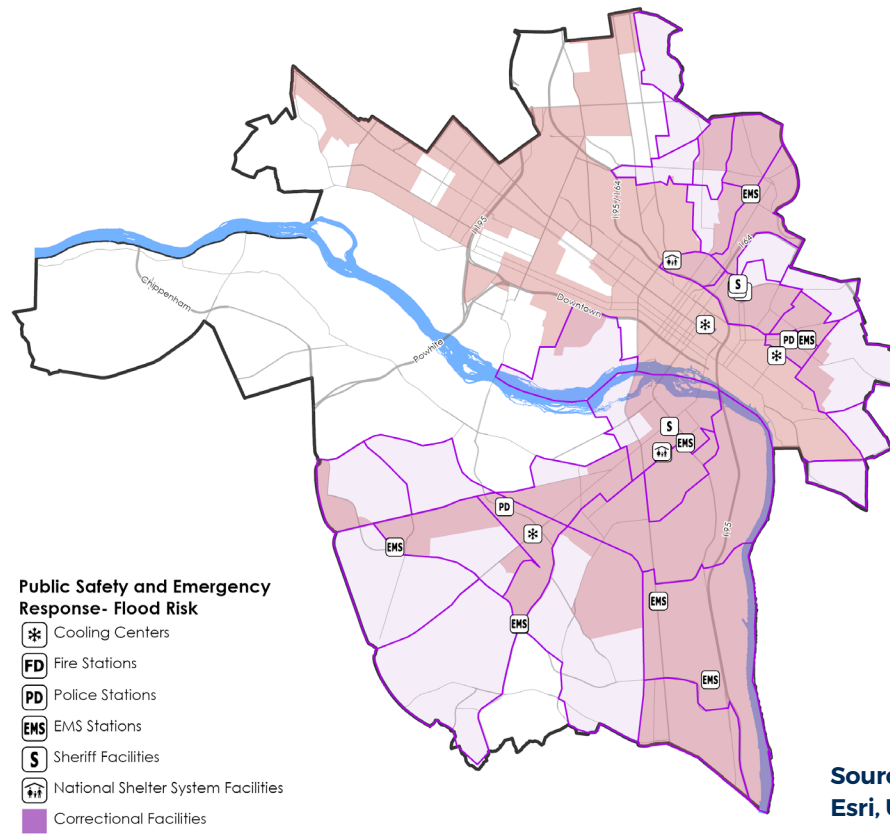


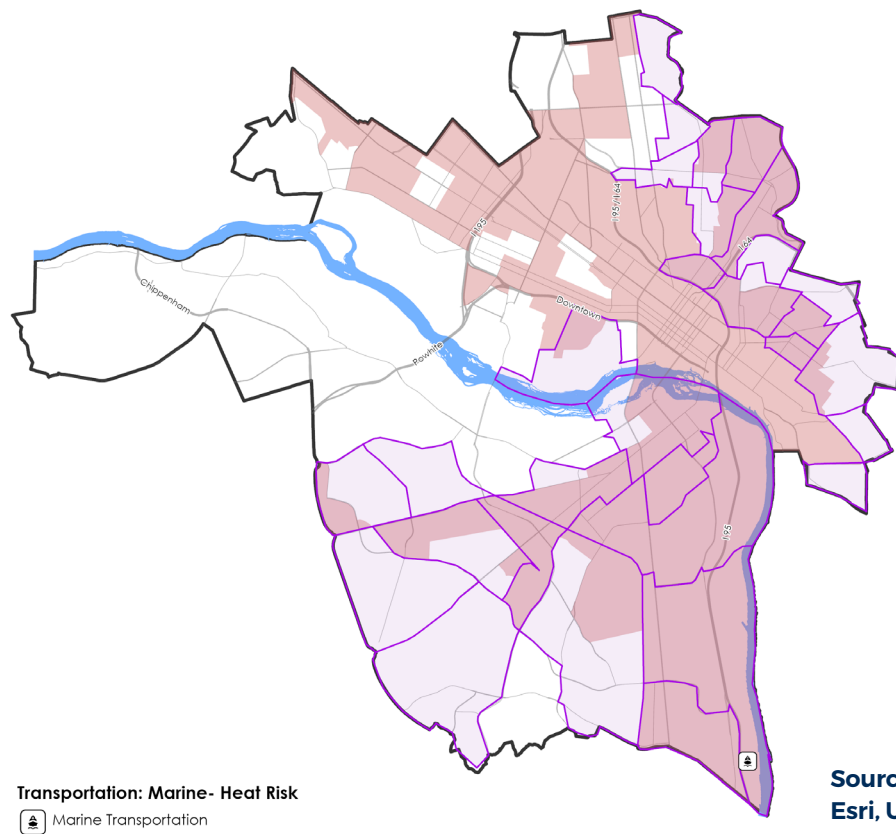
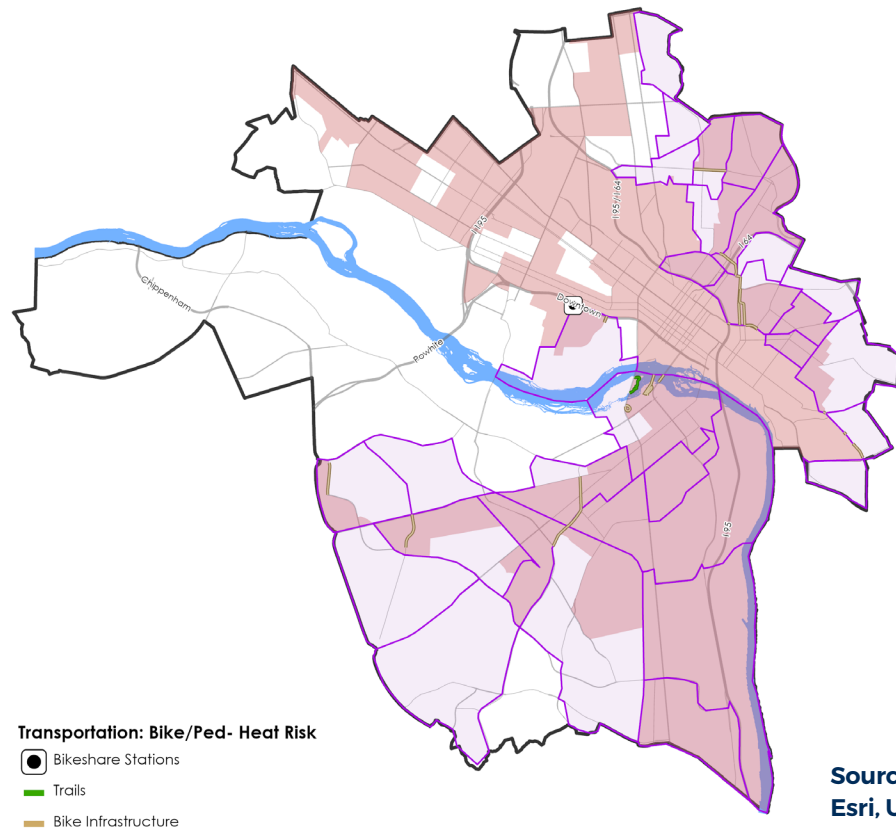


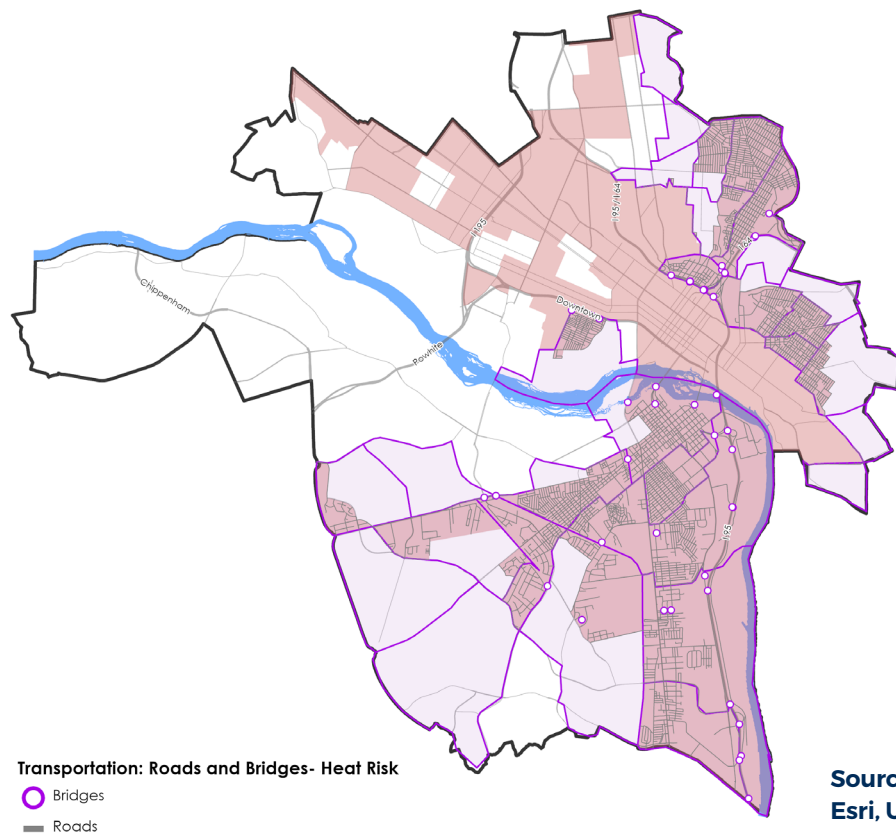
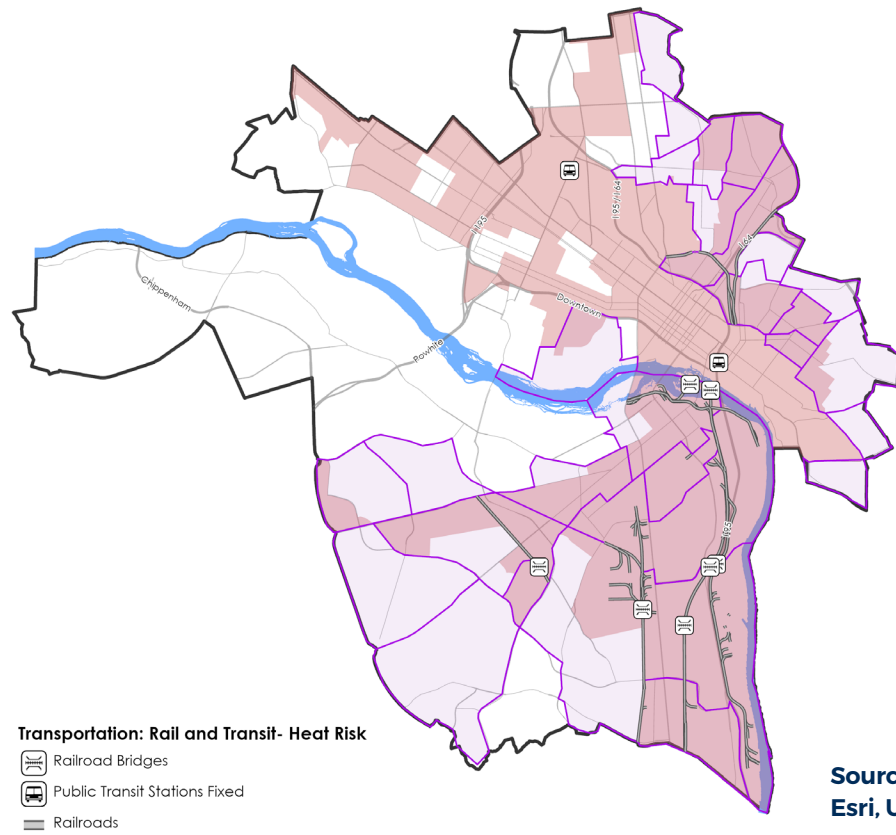


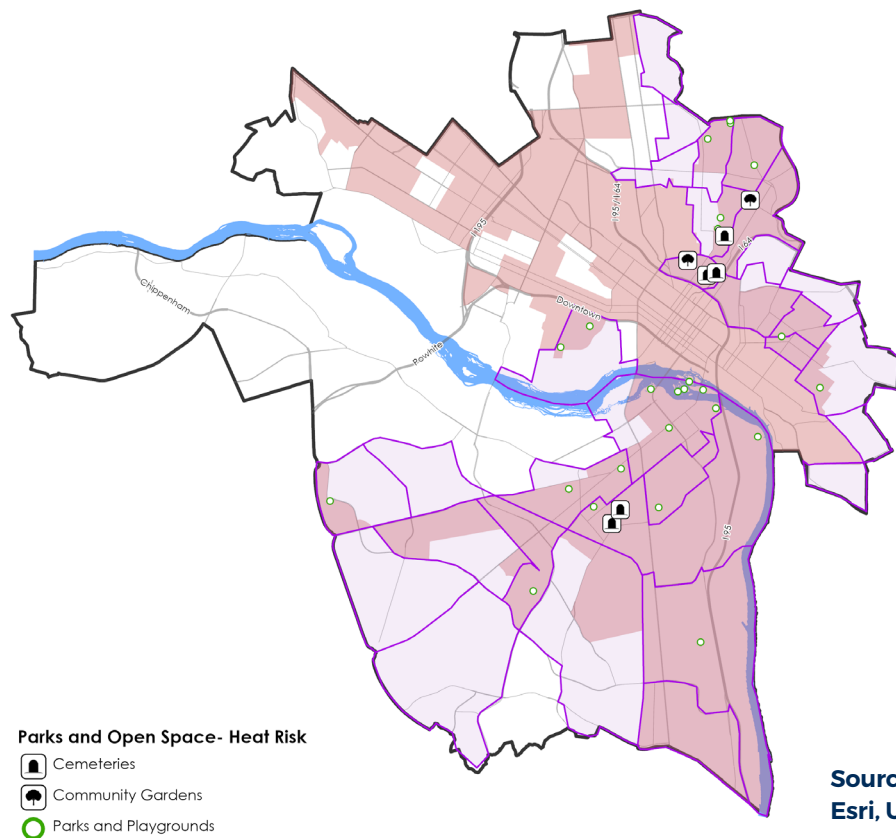
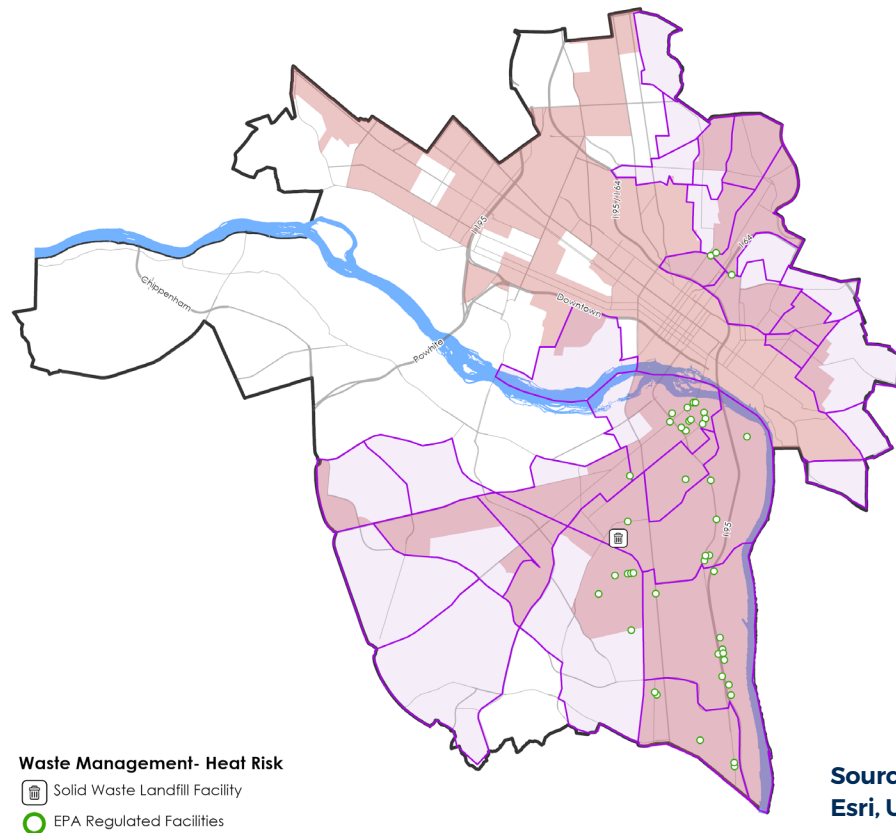


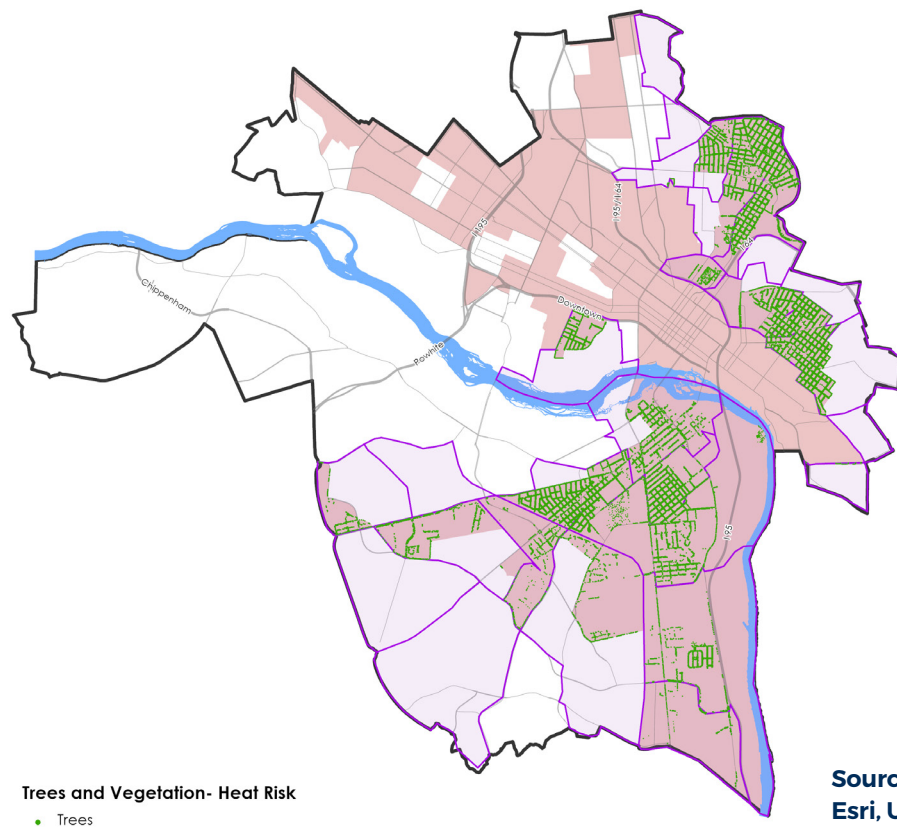
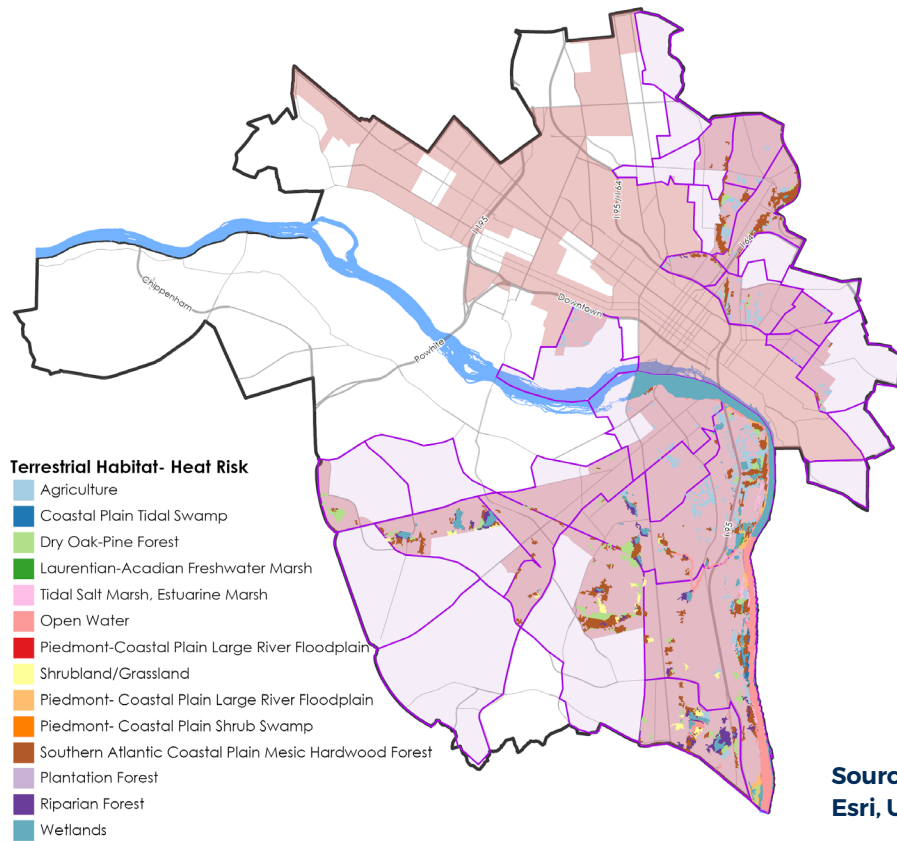


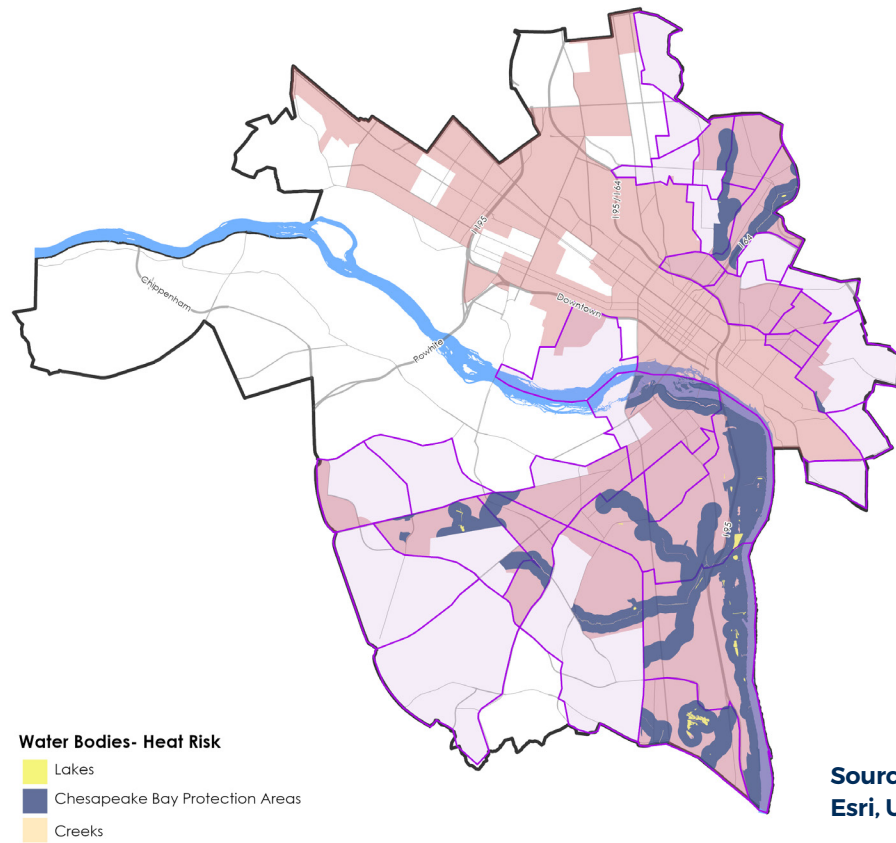












6.2 Prioritized Needs – Critical Heat Risk

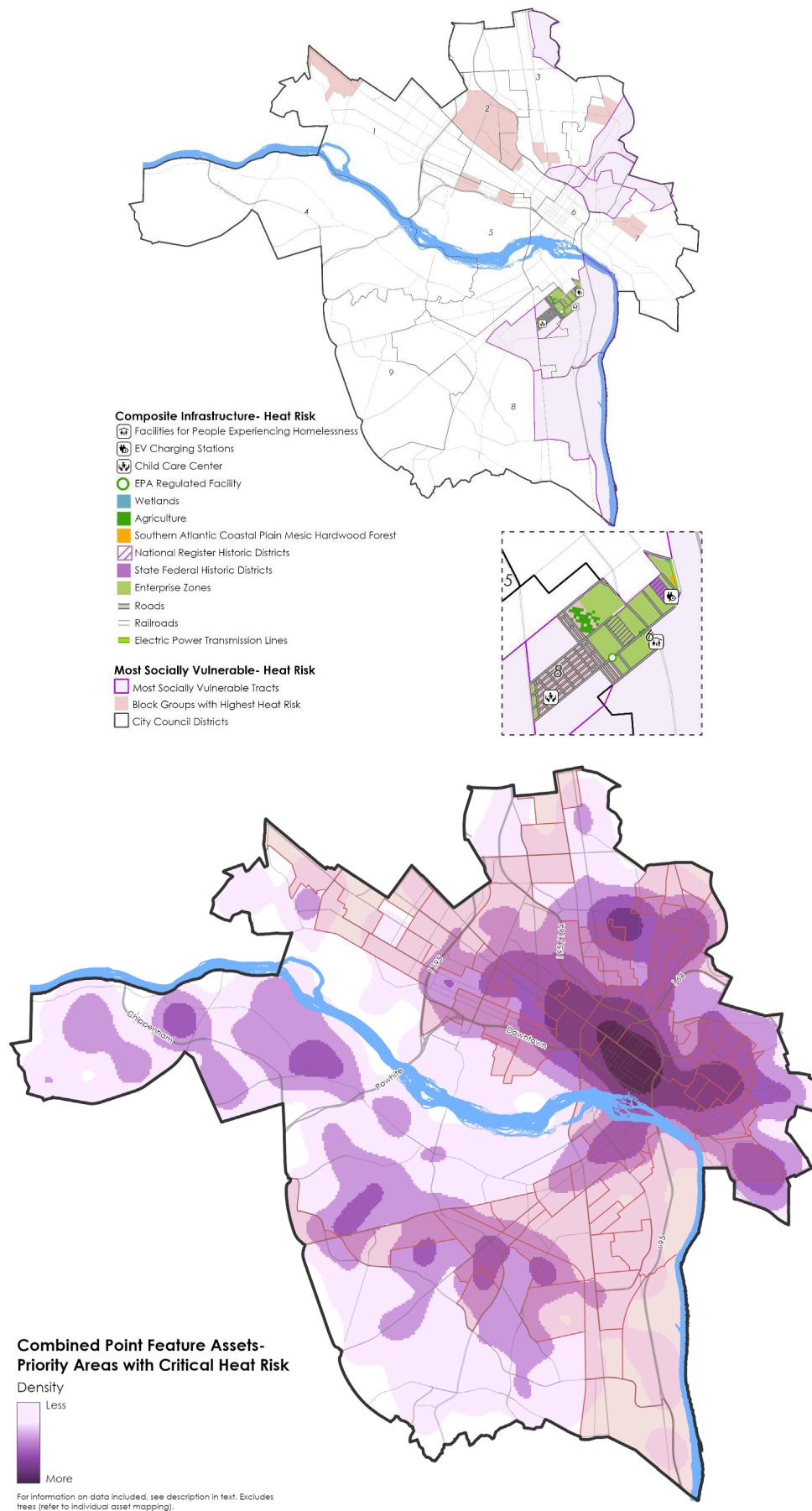
Table 6.2 and the map figure that follows summarize the assets in the “most” socially vulnerable areas or that predominantly or exclusively serve socially vulnerable groups that have exposure to the highest heat risk from climate change (areas with current afternoon mean high temperatures above 96°F). The name or address of these assets is included along with the stakeholder consequence ranking to support City prioritization of equity-centered climate resilience strategies and action for these critical resources and areas.

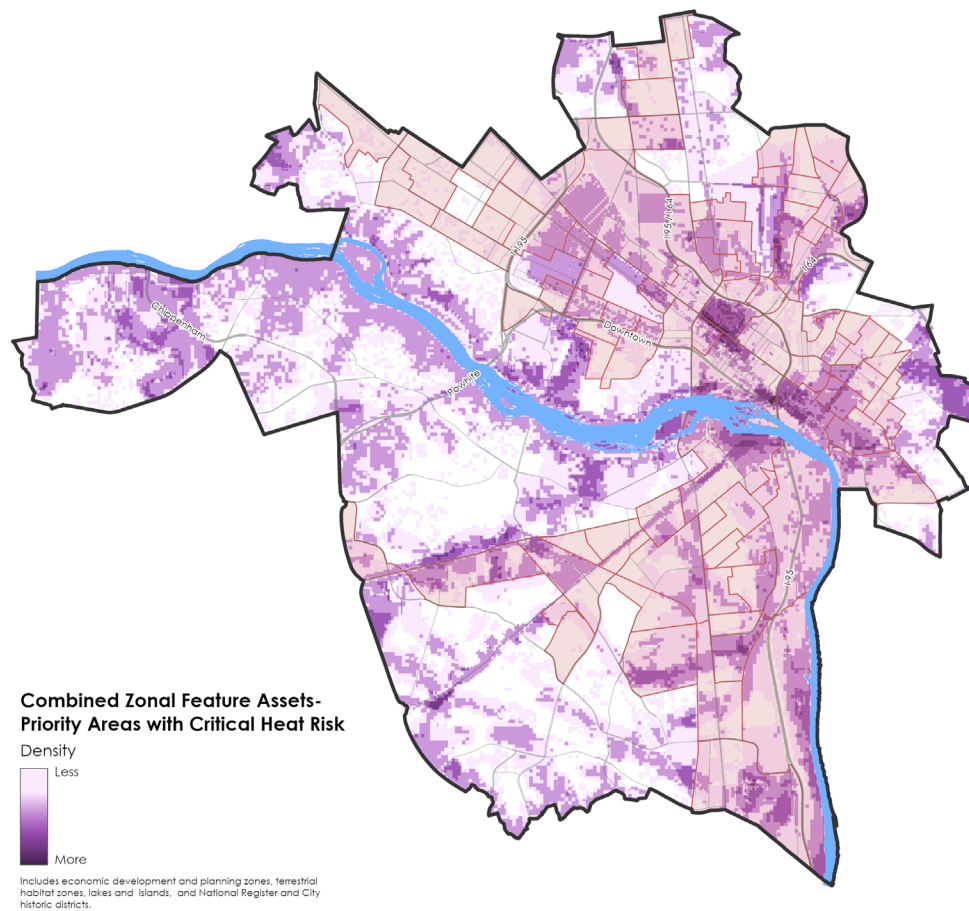
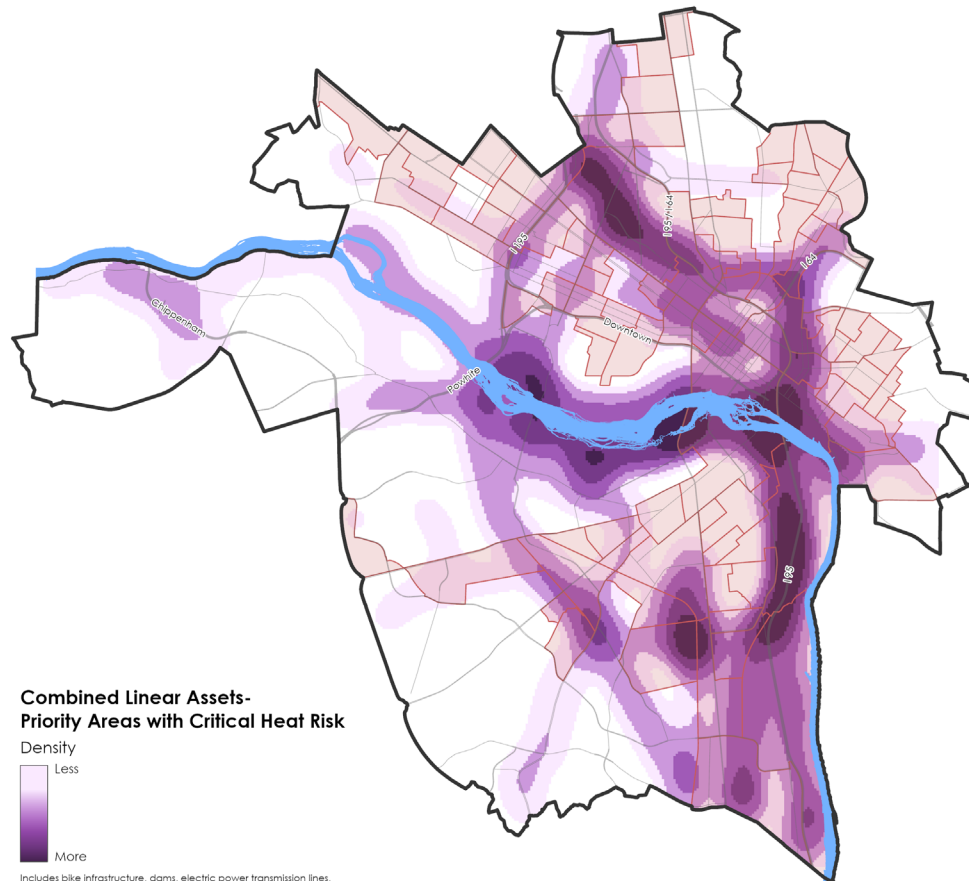
Areas with concentrations of potentially impacted assets independent of social vulnerability are shown in the final map series of heat risk. Density maps are presented for potentially impacted assets represented as: point features (such as various types of community, education, government, health, and safety facilities and buildings, housing, communications towers, bridges, and other infrastructure); linear features (such as bike infrastructure, power transmission lines, railroads, and trails); and zonal or area features (such as economic development zones, historic districts, and natural habitats and preservation areas).

Table 6.2 Prioritized Needs - Critical Heat Risk

Asset Category	Asset Name	Assets at Highest Heat Risk in Most Socially Vulnerable Areas	Assets Serving SV Groups at Highest Heat Risk Outside Most SV Areas	Units	Critical Heat Risk - Afternoon Mean High Temp >96*	
					Assets/locations exposed to Critical Heat Risk (Above 96*)	Consequence
Education	Childcare Centers	1	0	centers	Oak Grove Child Care Center - 2200 Fairfax Avenue Richmond VA 23224	
Health and Social Services	Dialysis Clinics	0	1	clinics	*DaVita Richmond Community Dialysis - 913 North 25th Street Richmond VA 23233	
	Homeless Facilities	1	1	facilities	Caritas - 1125 Commerce Road Richmond VA 23224, *Pilgrims Passage - 1500 Sherwood Road Richmond VA 23220	
	Nursing Homes	0	1	homes	*Brook Haven Rest Home - 610 Fourquaren Lane	
Historic	National Register Historic Districts	4	0	Districts	Union Hill; Southern Stove Works; Chesapeake Warehouses; Highland Park Plaza	
	State Federal Historic Sites	1	0	sites	Southern Stove Works Manchester	
Economic Development and Planning	CARE Zones	1	2	zones	*Lombardy/Chamberlayne, *North 25th Street, Meadowbridge	
	Enterprise Zones	2	0	zones	III (2746.8 acre), 1(3611.2 acre)	
Energy Infrastructure	Electric Power Transmission Lines	0.4		miles	See map for locations	
	Electric Vehicle Charging Stations	2	0.0	stations	See map for locations	Not Rated
Food System Assets and Resources	Food Pantries	0	2	pantries	*Northside Outreach Center - 3096 Meadowbridge Road Richmond VA 23222, *Sara and Steve Bayard Community Kitchen - 1415 Rhoadmiller Street Richmond VA 23220	
	SNAP Businesses	0	19	businesses	See map for locations	
Public Housing Resources	HUD Multifamily Properties	0	1	properties	*Highland Park Senior Apartments - 1221 E Brookland Park Blvd, Richmond, VA 23222	
Terrestrial Habitat	Terrestrial Habitat	2	0	habitats/locations	Agriculture; Southern Atlantic Coastal Plain Mesic Hardwood Forest	
Transportation Infrastructure - Rail and Transit	Public Transit Stations	0	1	stations	*Greyhound Bus Station - 2910 N Boulevard Richmond VA 23230	
	Rail Lines	0.6	0.0	miles	See map for locations	
Transportation Infrastructure - Roads and Bridges	Roads	9.9	0.0	miles	See map for locations	
Trees and Vegetation	Tree canopy (Street Trees and Trees Other)	1,022	0	trees	See map for areas	
Waste Management Infrastructure	EPA Regulated Facilities	1	0	facilities	Southern Printing Ink	

Consequence Scale				
Low	Medium-Low	Medium	Medium-High	Low





6.3 Prioritized Needs – Flooding Risk

Table 6.3 summarizes the assets in socially vulnerable areas or that predominantly or exclusively serve socially

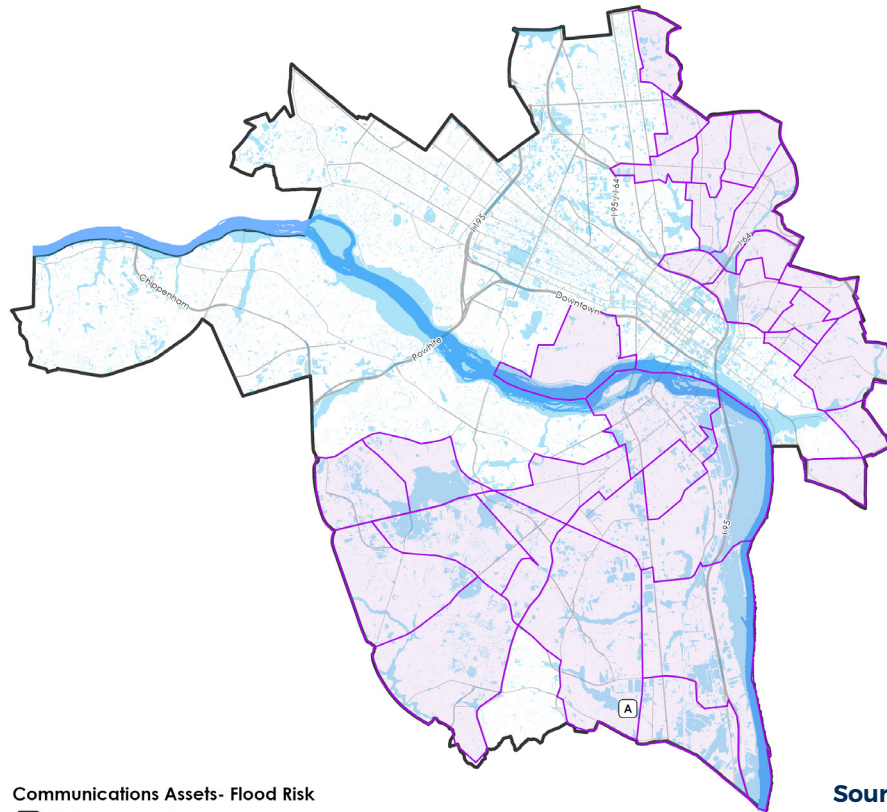
vulnerable groups regardless of location that have exposure to flooding risk from climate change (in the 100-year floodplain and/or in locations that may experience greater than 5 inches of flooding

inundation from precipitation events). The map figures on the pages that follow illustrate the location of assets with exposure to flooding risk for each category or grouping of assets of similar types.

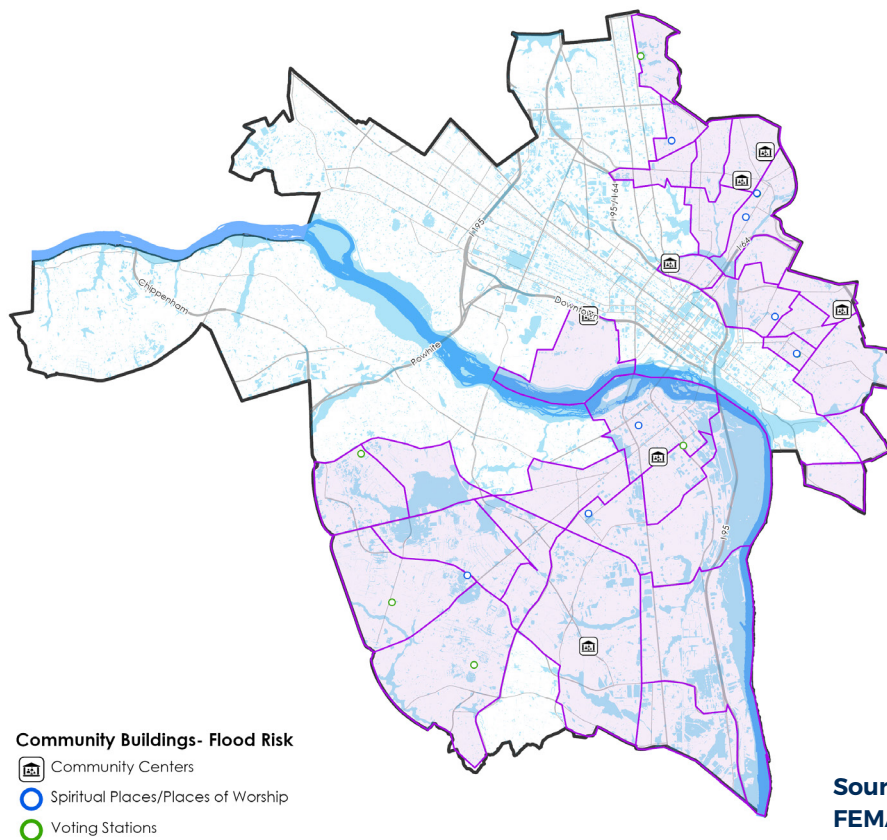
Table 6.3 - Priority Planning Areas - Flood Risk

Asset Category	Asset Name	Total City	Units	Critical Flood Risk	
				Assets at Risk	Resources
Communications Infrastructure	AM Transmission Towers	3	towers	1	0
Community Buildings	Community Centers	22	centers	7	0
	Religious Centers	74	Centers	9	0
	Voting Stations	67	stations	12	0
Economic Development and Planning	CARE Zones	13	zones	11	2
	Community Unit Plans	110	plans	30	0
	Enterprise Zones	4	zones	4	0
	Fortune 500 Corporate Headquarters	1	sites	1	0
Education	Childcare Centers	118	centers	15	0
	K12 Public Schools	44	schools	7	0
	Private Schools	34	schools	3	0
Energy Infrastructure	Biodiesel Plants	1	facilities	1	0
	Electric Power Transmission Lines	53.7	miles	21.8	0.0
	Electric Vehicle Charging Stations	134	stations	5	
	Non Gasoline Alternative Fueling Stations	13	stations	2	0
	Petroleum Ports	1	ports	1	0
	Petroleum Terminals	9	terminals	8	0
	Potential Renewable Energy Sites	13	sites	1	0
Food System Assets and Resources	SNAP Businesses	193	businesses	8	3
Government Facilities	City Property	966	properties	62	0
Health and Social Services	Homeless Facilities	5	facilities	0	1
	Hospitals	6	hospitals	3	0
	Nursing Homes	17	homes	2	8
	Social Services	3	services	0	1
Historic	City Historic Districts	45	districts	3	0
	National Register Historic Districts	133	Districts	32	0
	State Federal Historic Sites	156	sites	17	0
Parks and Open Spaces	Parks and Playgrounds	143	parks	14	0
Public Housing Resources	HUD Multifamily Properties	27	properties	1	1
	RRHA Housing	60	locations/ parcels	40	2
Public Safety and Emergency Response	Cooling Centers	3	centers	0	1
	Correctional Facilities	3	facilities	2	1
	EMS Stations	24	stations	4	0
	Fire Stations	21	stations	3	0
	National Shelter System Facilities	20	facilities	5	0
	Police Stations	5	Stations	1	0
	Sheriff Facilities	7	facilities	4	0

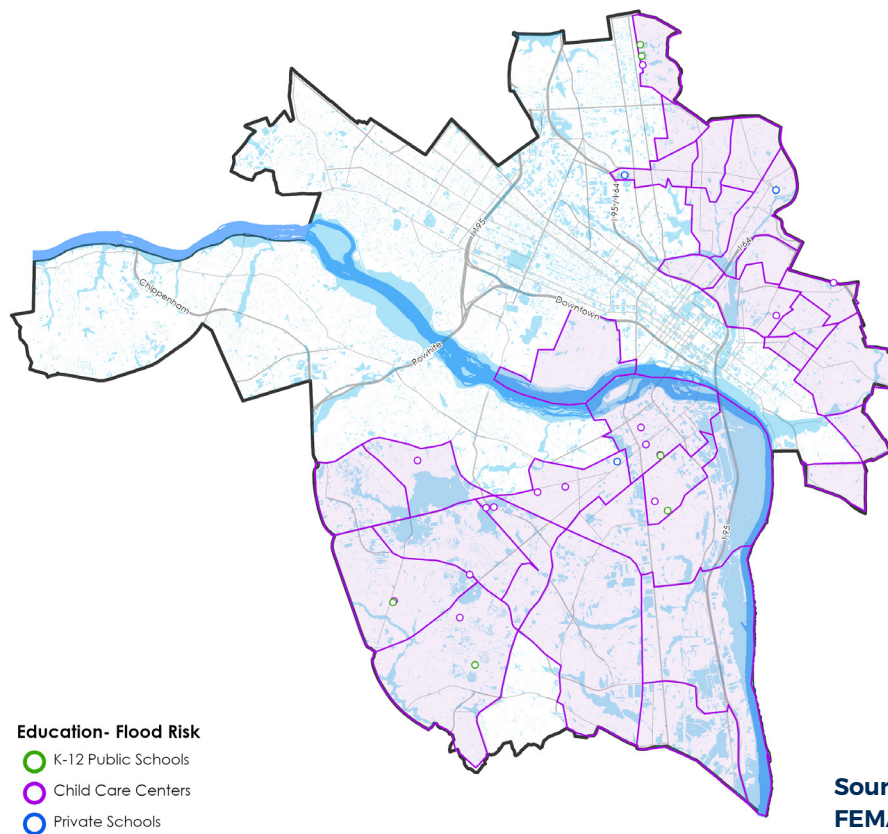
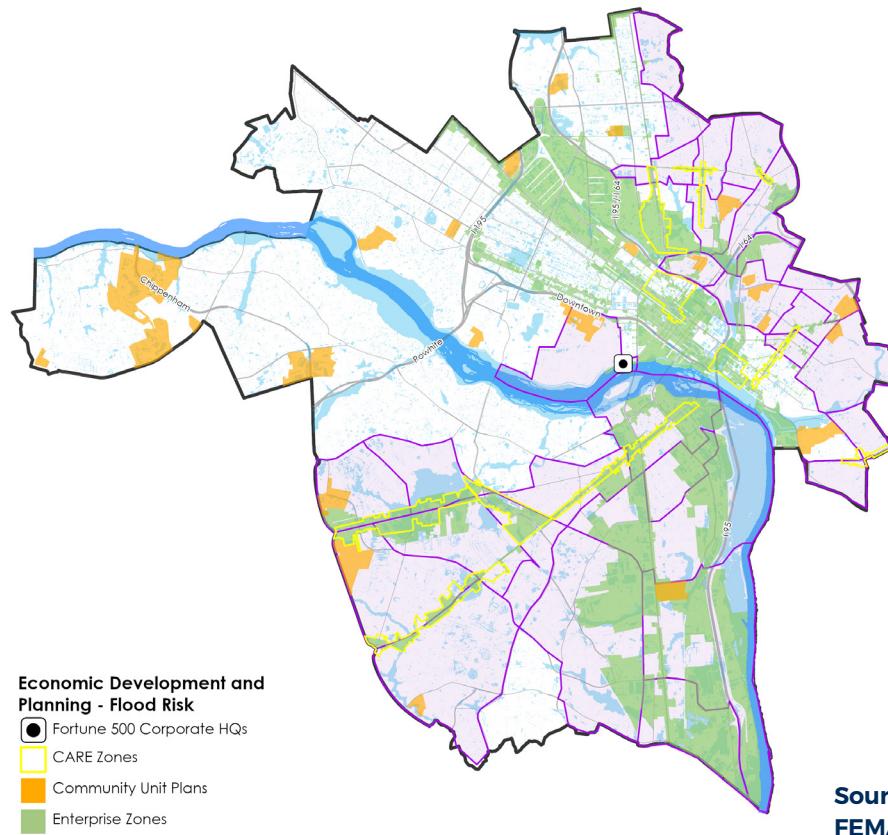
Asset Category	Asset Name	Total City	Units	Critical Flood Risk	
				Assets at Risk	Resources
Stormwater and Sewer Infrastructure	Active StormwaterOutfall	1,658	units	492	0
	Sewer Treatment Plant	1	plants	1	0
Terrestrial Habitat	James River Features Islands (Islands)	15	islands	8	0
	Terrestrial Habitat	14	habitats/ locations	13	0
Transportation Infrastructure - Bike/ Ped	Bike Infrastructure	71.2	miles	3.1	0.0
	Trails	15.94	miles	2.1	0.0
Transportation Infrastructure - Marine	Marine Transportation	1	unit	1	0
Transportation Infrastructure - Rail and Transit	Public Transit Stations	2	stations	0	2
	Railroad Bridges	27	bridges	7	0
	Rail Lines	159.6	miles	18.7	0.0
Transportation Infrastructure - Roads and Bridges	Bridges	177	bridges	27	0
	Roads	1,206.7	miles	43.8	0.0
Trees and Vegetation	Tree canopy (Street Trees and Trees Other)	120,356	trees	3,556	0
Waste Management Infrastructure	EPA Regulated Facilities	79	facilities	10	0
Water bodies	Chesapeake Bay Protection Area	13,038.3	acres	1,964.8	0.0
	Creeks	31	creeks	17	0
	Lakes	100	lakes	39	0

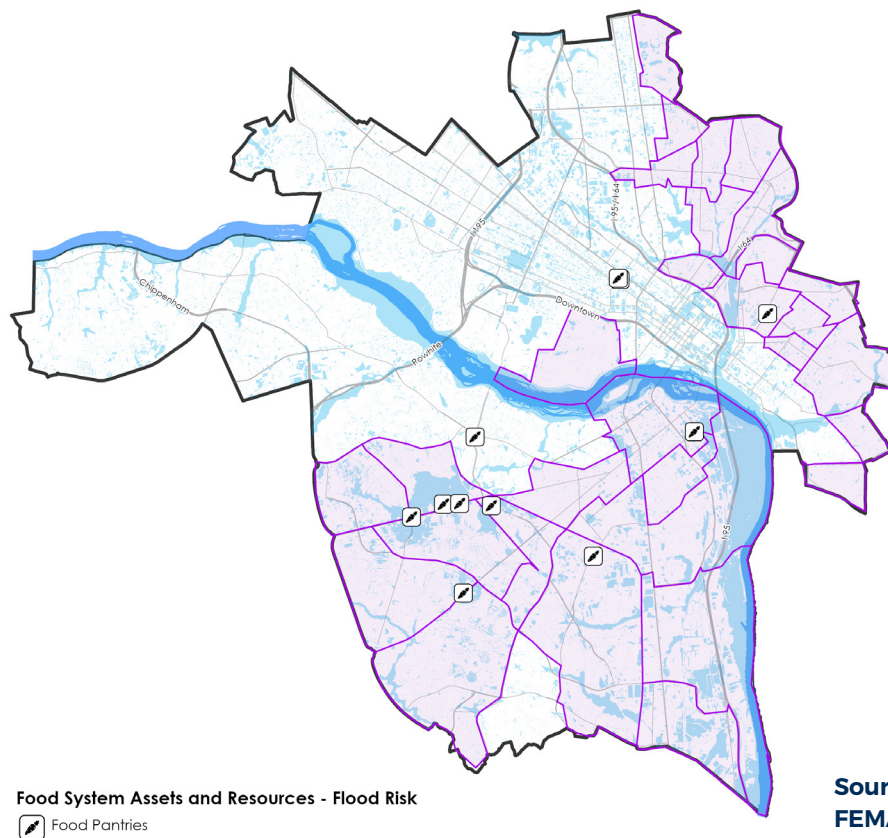
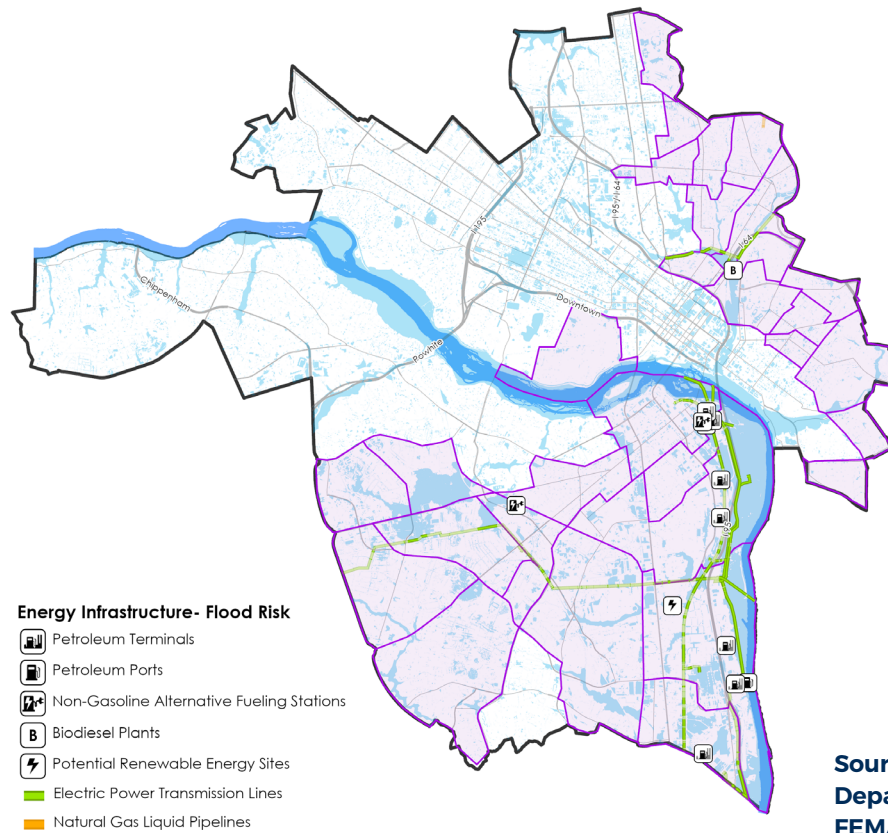


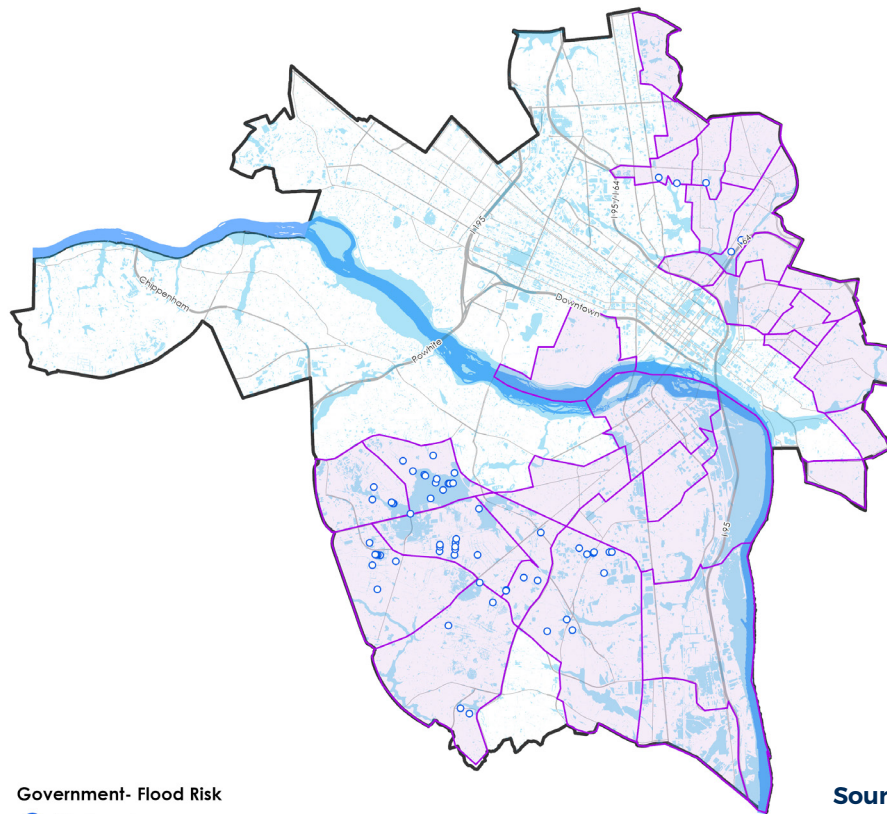
Sources: City of Richmond, Esri, FEMA, US Census Bureau



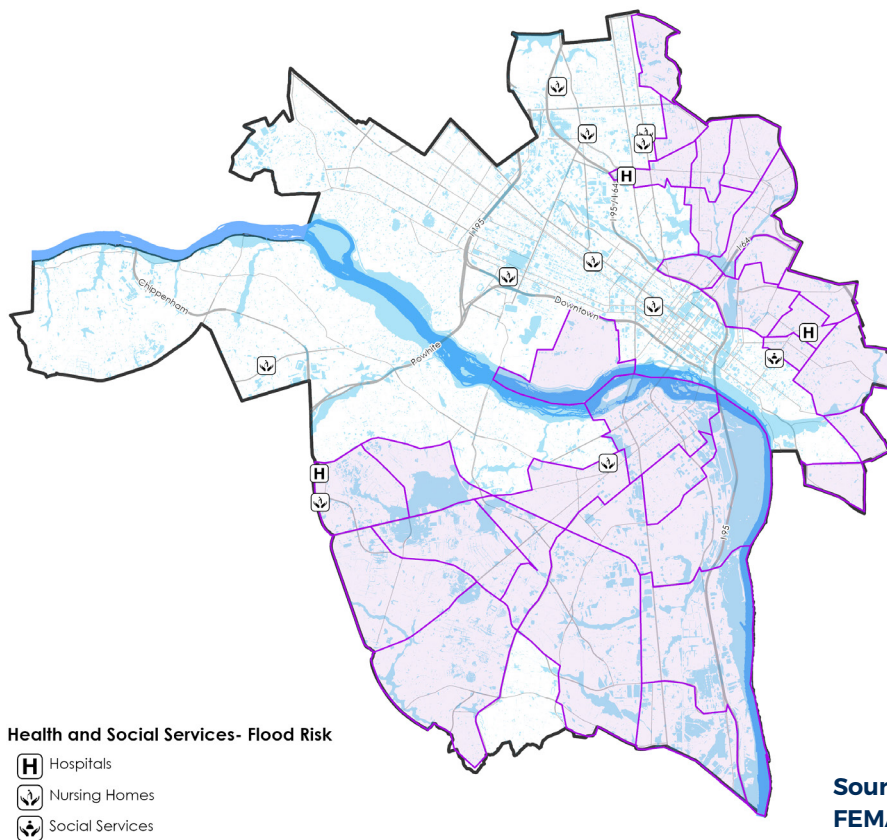
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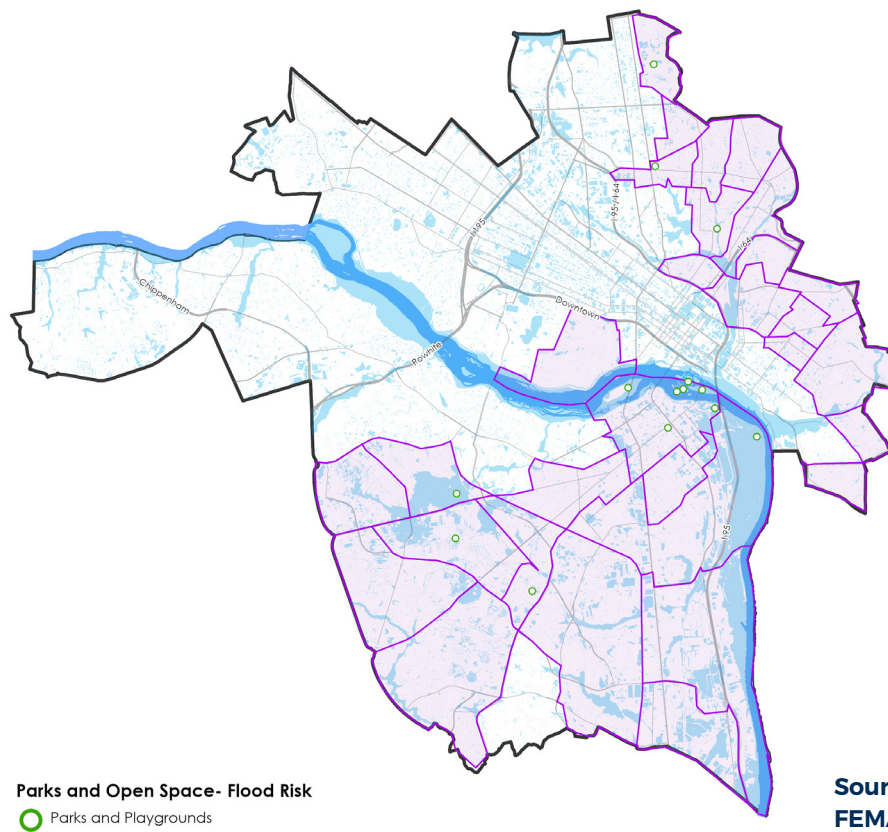
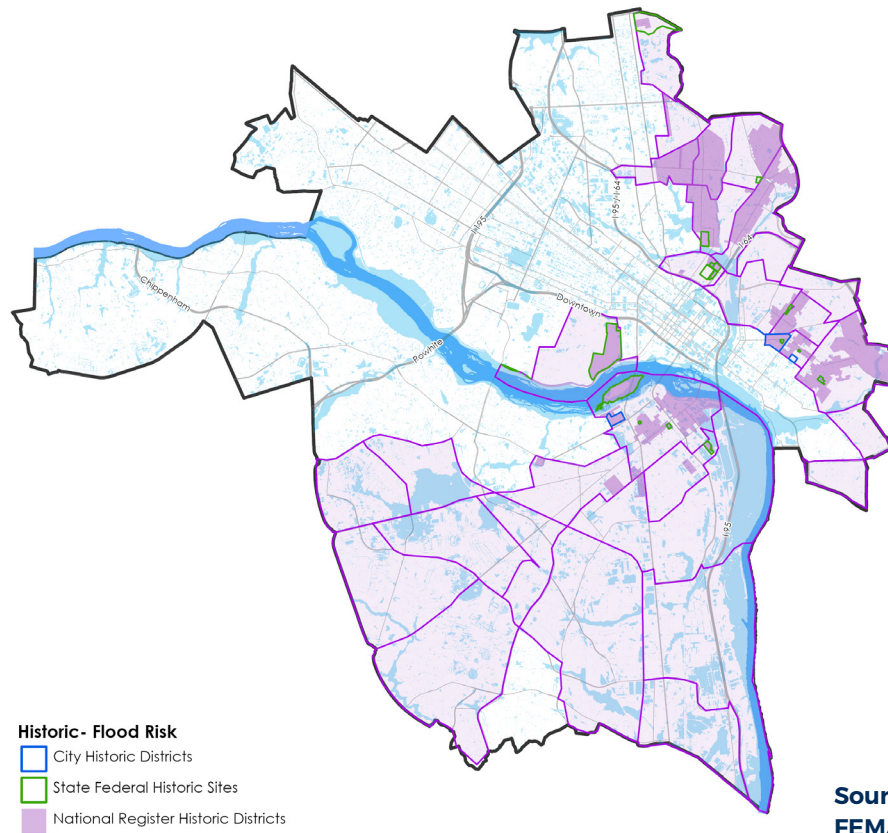


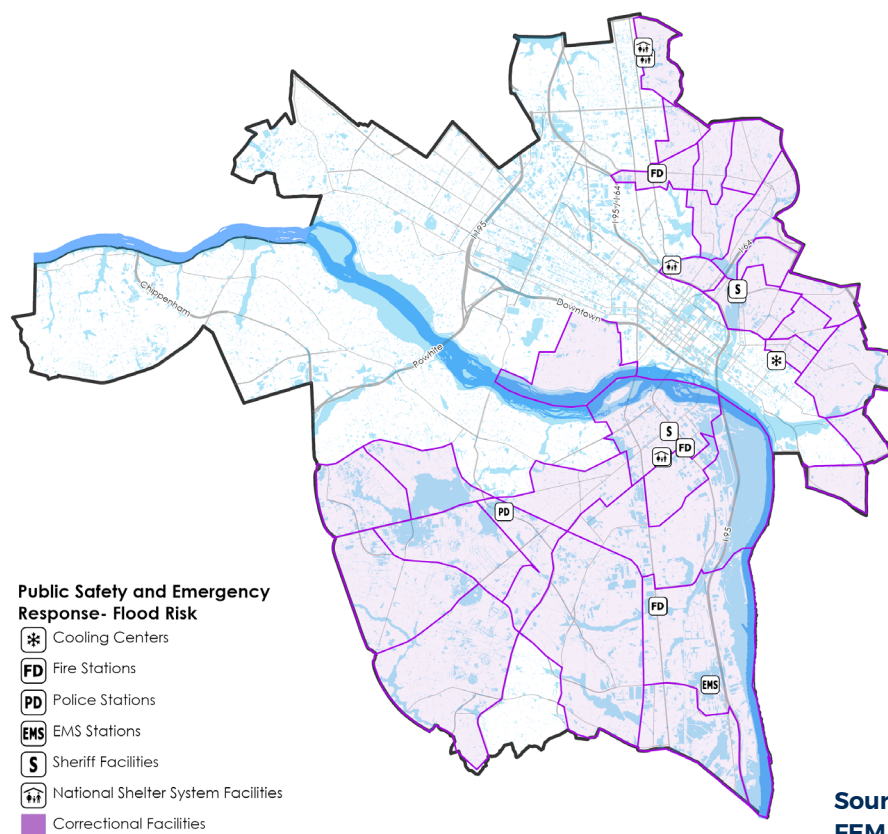


Sources: City of Richmond, Esri, FEMA, US Census Bureau

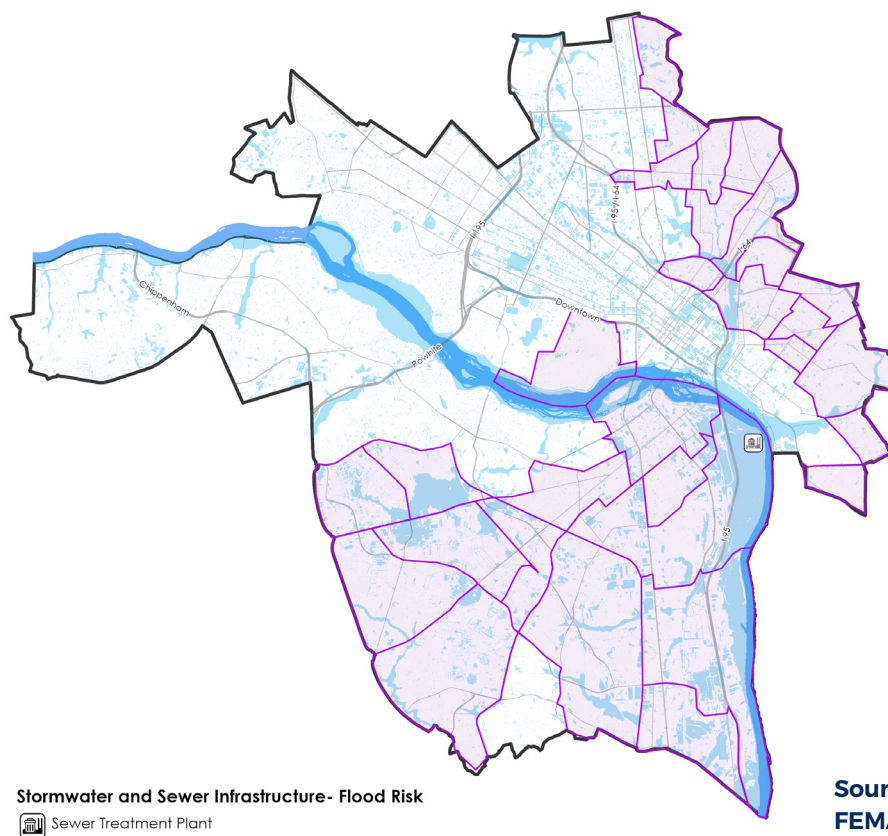


Sources: City of Richmond, Esri, FEMA, US Census Bureau

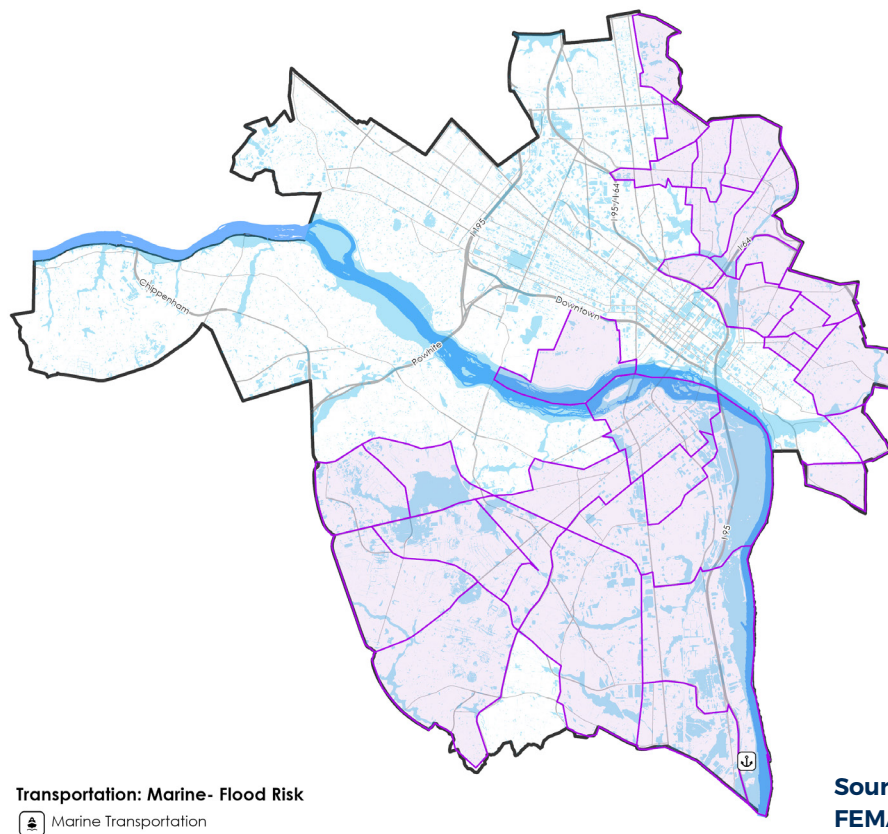
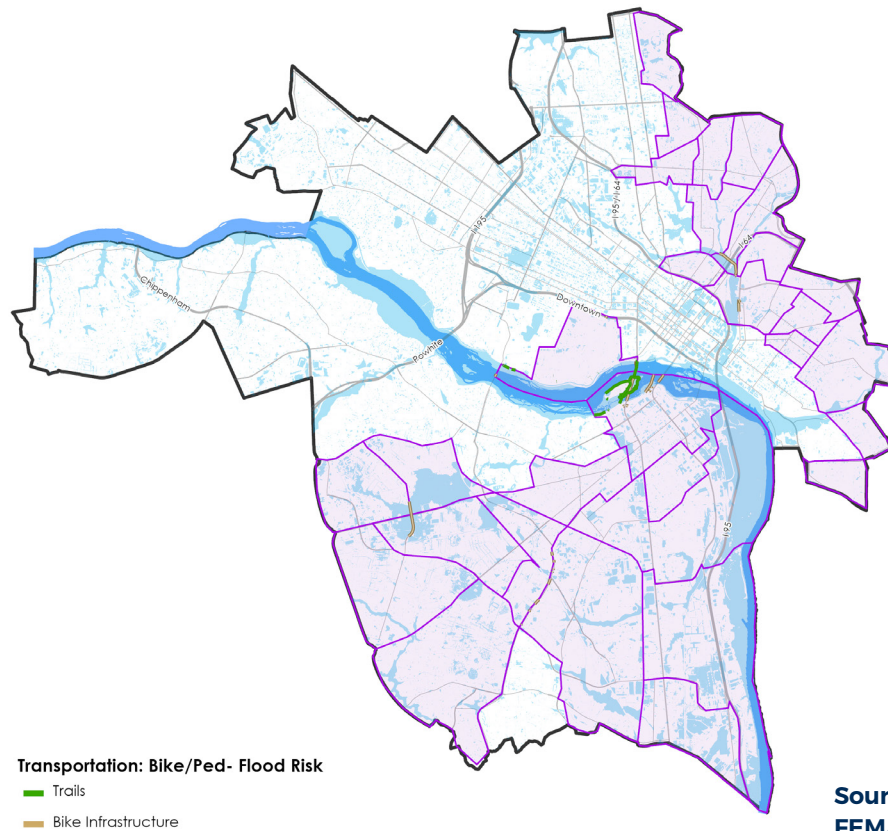


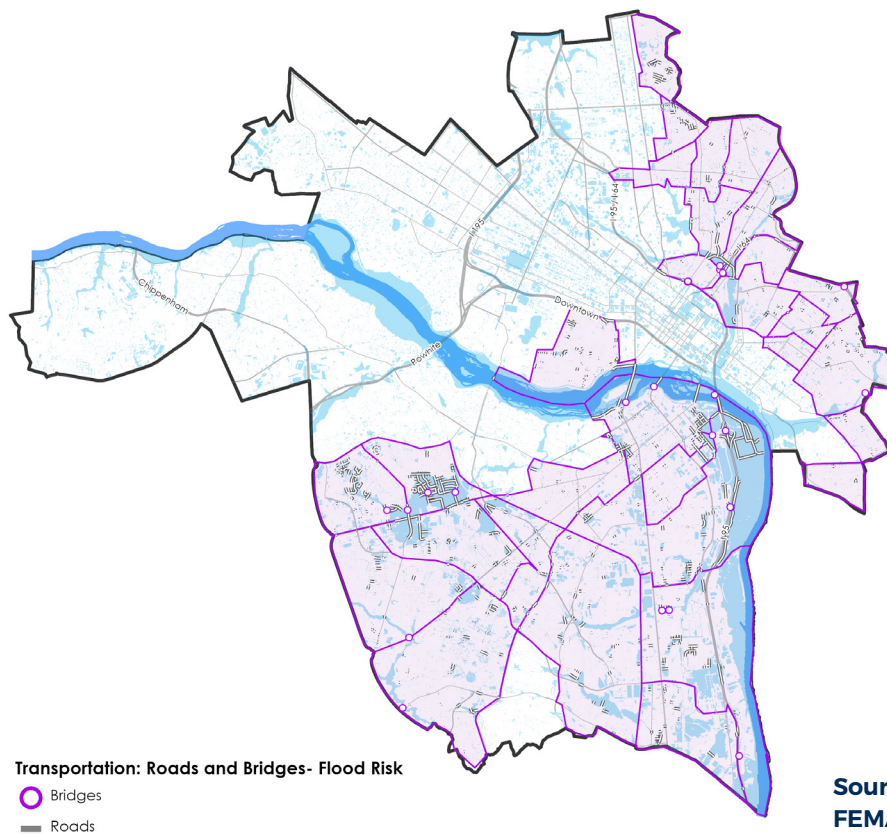
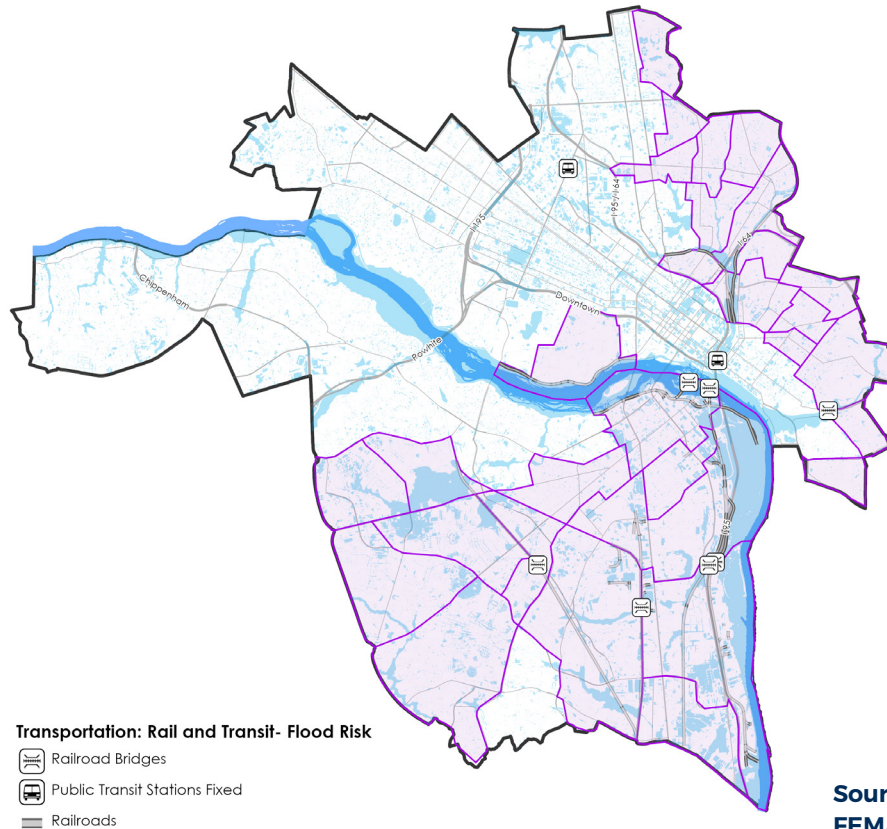


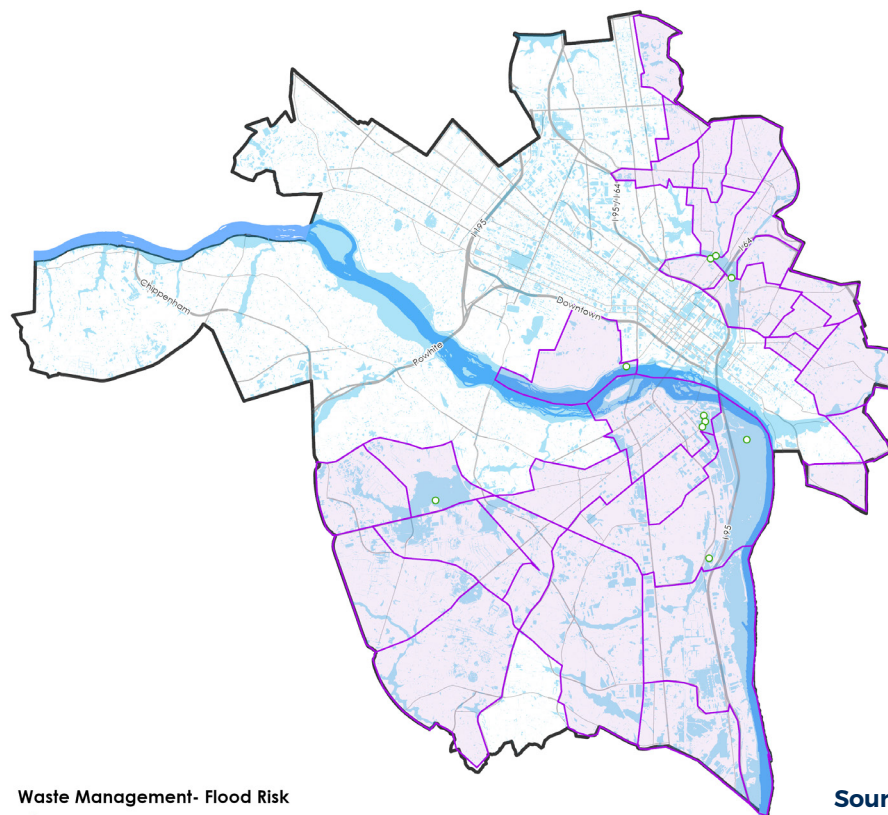
Sources: City of Richmond, Esri, FEMA, US Census Bureau



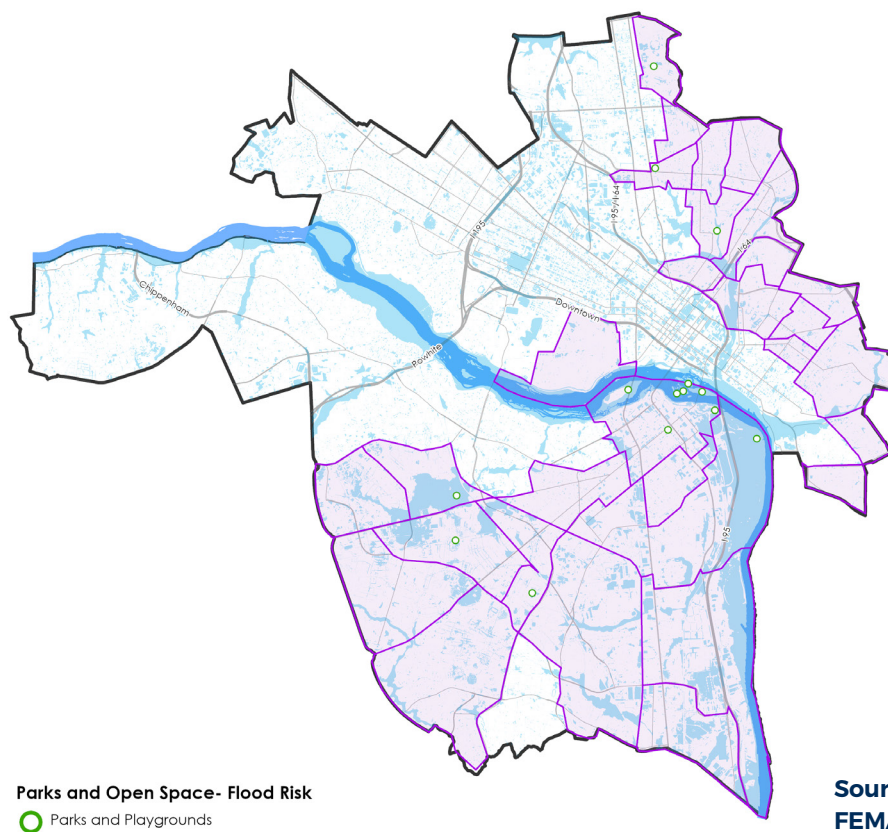
Sources: City of Richmond, Esri, FEMA, US Census Bureau



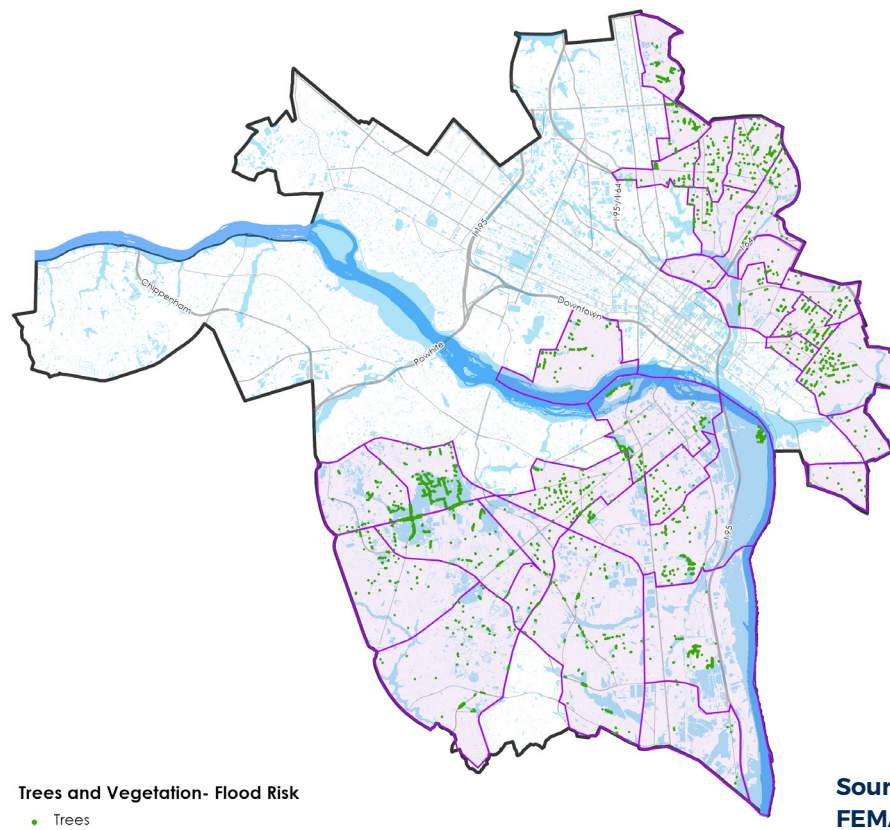
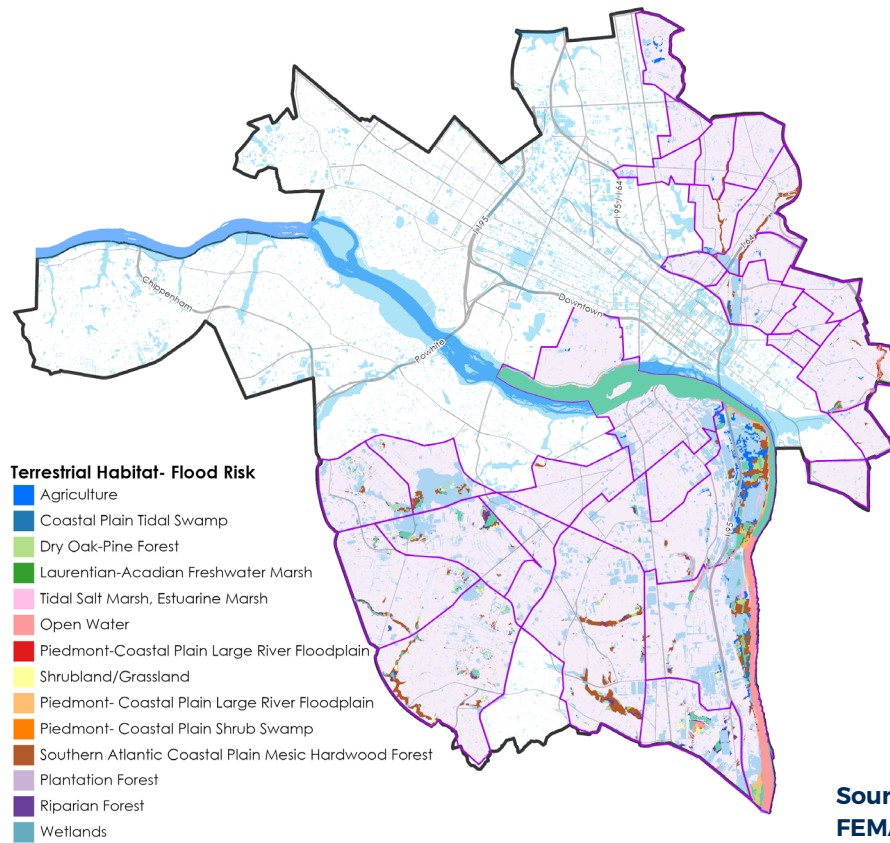


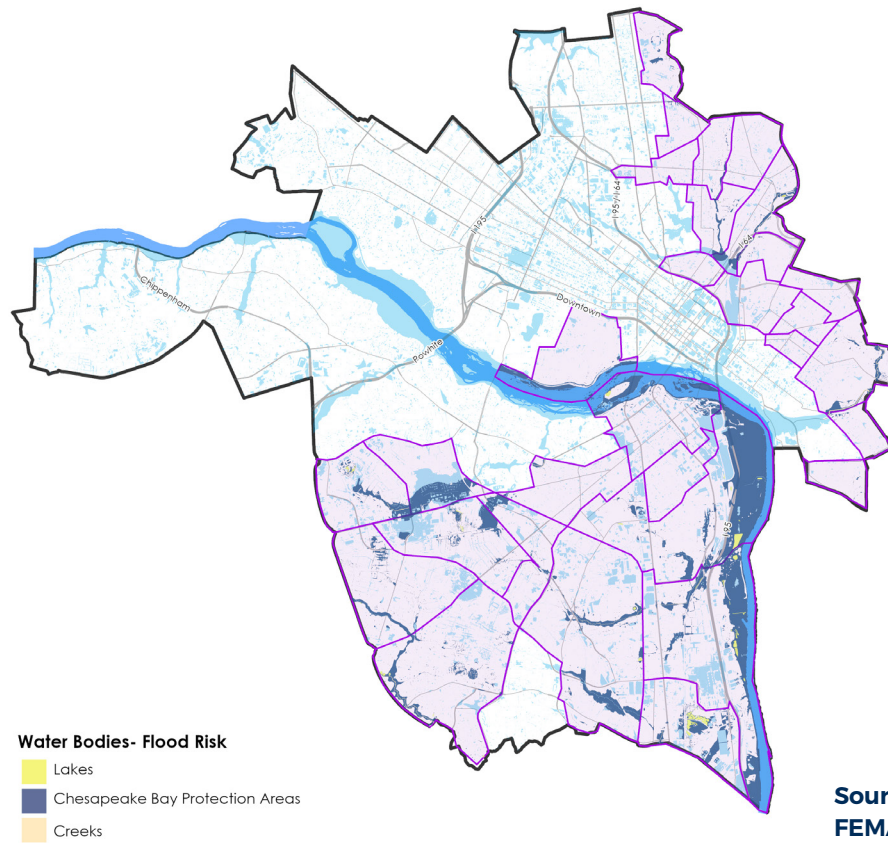


Sources: City of Richmond, Esri,
FEMA, US Census Bureau



Sources: City of Richmond, Esri,
FEMA, US Census Bureau





6.3 Prioritized Needs – Critical Flood Risk

Table 6.4 and the map figure that follows summarize the assets in the “most” socially vulnerable areas or that

predominantly or exclusively serve socially vulnerable groups that have exposure to flooding risk from climate change. The name or address of these assets is included along with the stakeholder

consequence ranking to support City prioritization of equity-centered climate resilience strategies and action for these critical resources and areas.

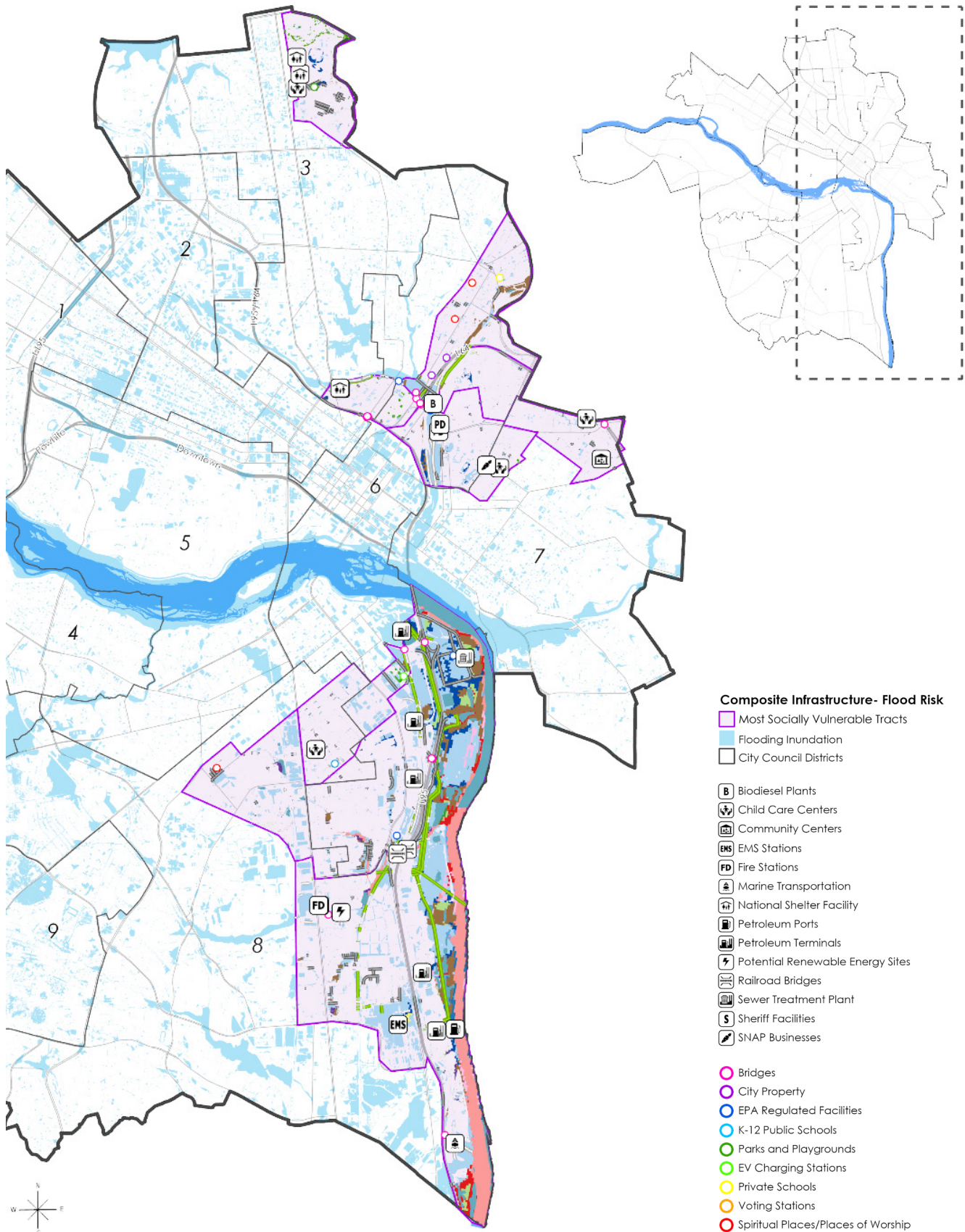
Table 6.4 – Prioritized Needs – Critical Flood Risk

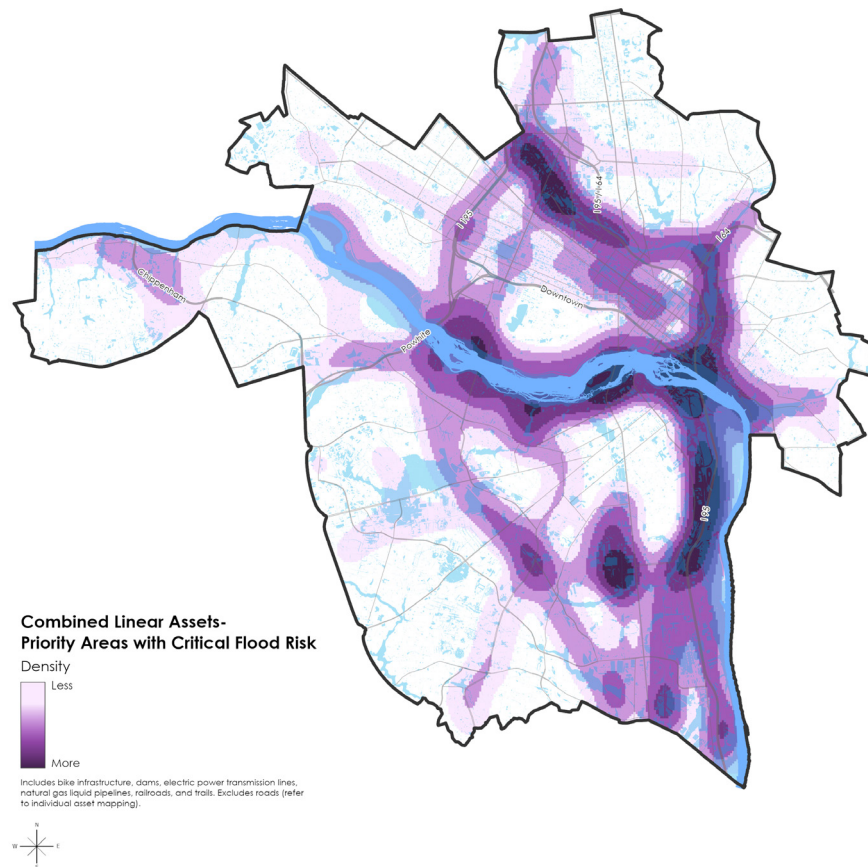
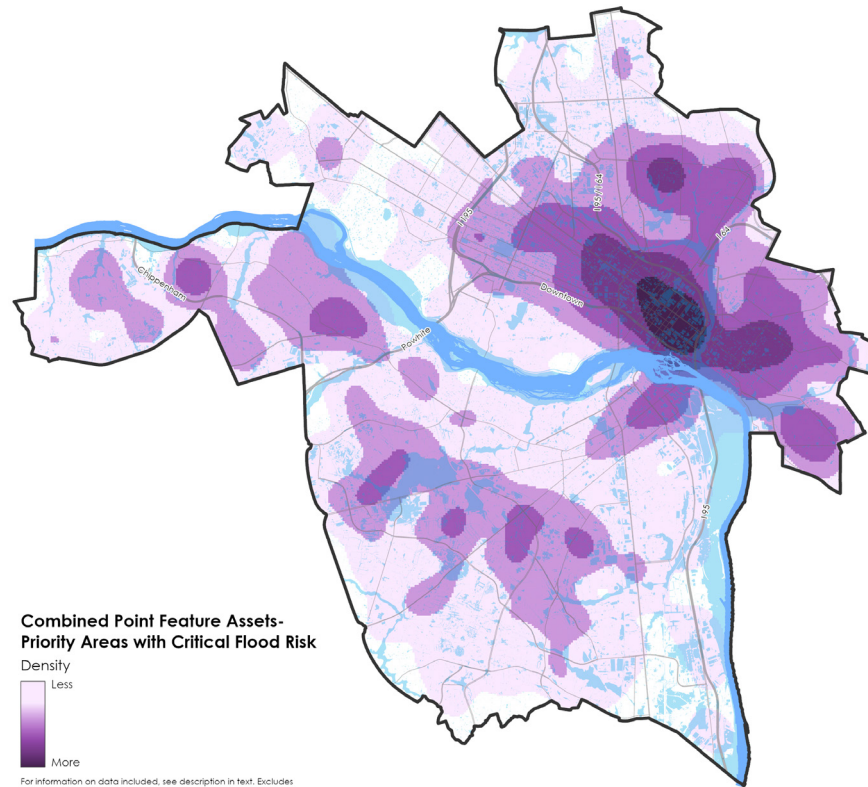
Asset Category	Asset Name	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Units	Critical Flood Risk	
					Most Vulnerable Assets with exposure to Critical Flood Risk (located within or serving socially vulnerable groups)	Consequence
Community Buildings	Community Centers	2	0	centers	Creighton Court Community Center; Calhoun Community Center and Playground	
	Religious Centers	4	0	Centers	Saint Kim Taegon Catholic Church; Fifth Street Baptist Church; Bethlehem Baptist Church; Grayland Baptist Church	
	Voting Stations	3	0	stations	Calhoun Center; John Marshall High School; 5th Street Baptist Church	
Economic Development and Planning	CARE Zones	2	11	zones	*Belt Boulevard, *Brookland Park Boulevard, *Fulton Hill, *Hull Street, *Jackson Ward, *Midlothian Turnpike, *North Avenue, *North 25th Street, *Shockoe Bottom, *Swansboro, *Upper Hull Street, Lombardy/Chamberlayne, Meadowbridge,	
	Community Unit Plans	4	0	plans	See map for locations	
	Enterprise Zones	3	0	zones	III (2746.8 acre), III (47.1 acre), 1 (3611.2 acre)	
Education	Childcare Centers	4	0	centers	North Richmond Branch YMCA; Fairfield Elementary School; Oak Grove Child Care Center; Bethlehem Baptist Church Child Development Center	
	K12 Public Schools	4	0	schools	Oak Grove Elementary School; John Marshall High School; REAL School; Thomas H Henderson Middle School	
	Private Schools	1	0	schools	Geara Group/Educational Developmental Center	
Energy Infrastructure	Biodiesel Plants	1	0	facilities	Reco Biodiesel Inc	
	Electric Power Transmission Lines	16.2	0.0	miles	See map for locations	
	Electric Vehicle Charging Stations	2		stations	1001 E 4th St (ID: 187899), 1001 E 4th St (ID: 188105)	
	Petroleum Ports	1	0	ports	Port of Richmond	
	Petroleum Terminals	5	0	terminals	Bukeye Terminals, LLC; Chevron Richmond Terminal; First Energy Corporation; Kinder Morgan Southeast Terminals- Richmond; Kinder Morgan Southeast Terminals- Richmond 2	
	Potential Renewable Energy Sites	1	0	sites	Madison Arms I and II	
Food System Assets and Resources	SNAP Businesses	1	10	businesses	See map for locations	
Government Facilities	City Property	2	0	properties	Highland Park Southern Tip: 1509 Court St; Highland Park Southern Tip: 1806 5th Ave	
Health and Social Services	Social Services	0	1	services	*DSS East District Center - 701 North 25th Street Richmond VA 23223	

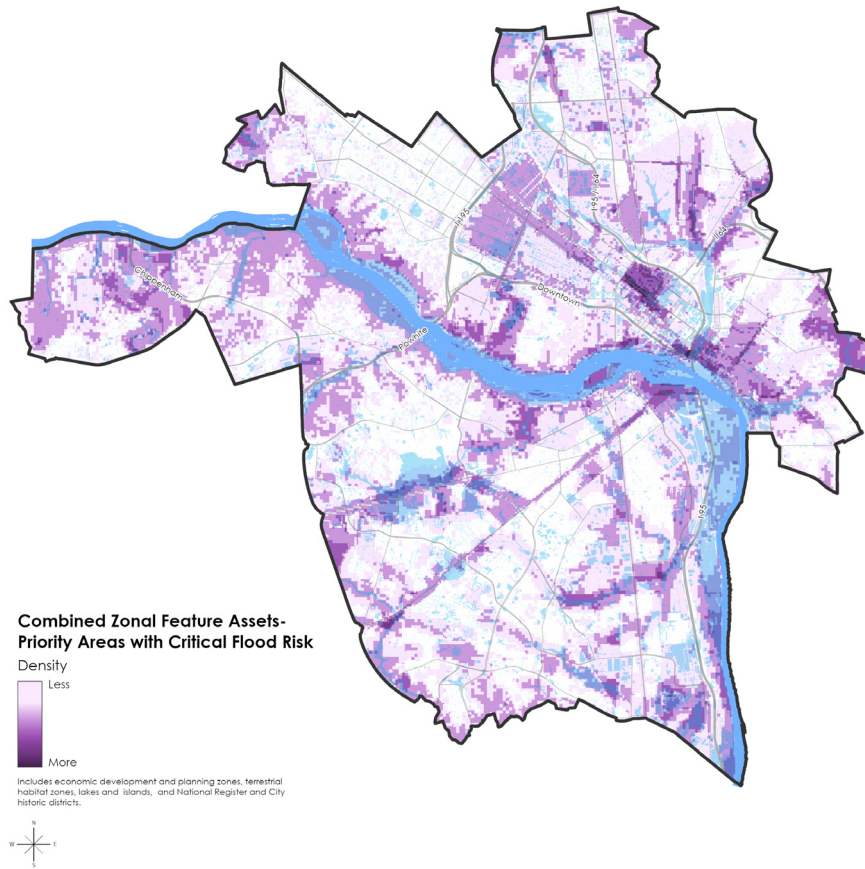
Consequence Scale				
Low	Medium-Low	Medium	Medium-High	Low

Asset Category	Asset Name	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Units	Critical Flood Risk	
					Most Vulnerable Assets with exposure to Critical Flood Risk (located within or serving socially vulnerable groups)	Consequence
Historic	National Register Historic Districts	12	0	Districts	Union Hill; Southern Stove Works; Chesapeake Warehouses; Hebrew Cemetery; Pine Camp Tuberculosis Hospital; Richmond Nursing Home; Chesnut Hill-Plateau; Fairmount; Highland Park Plaza; Manchester Industrial; Baker School; American Tobacco Company	
	State Federal Historic Sites	6	0	sites	The Almshouse; Shockoe Hill Cemetery; Pine Camp Tuberculosis Hospital; Southern Stove Works Manchester; Fairmount School; Hebrew Cemetery	
Parks and Open Spaces	Parks and Playgrounds	2	0	parks	James River Park-Ancarrows Landing; Roy West Park (Washington Park)	
Public Housing Resources	HUD Multifamily Properties	0	2	properties	*Charnwood Forest 4325 Crutchfield St Richmond VA 23225, Blue Ridge Estates - 6507 Sugar Maple Dr. Richmond VA 23225	
	RRHA Housing	39	3	locations/parcels	See map for locations	
Public Safety and Emergency Response	Cooling Centers	0	1	centers	*East District Center - 701 North 25th Street Richmond VA 23223	
	Correctional Facilities	2	1	facilities	*Medical College Of Virginia Security Ward - 401 North 12th Street Richmond VA 23219, Richmond City Jail - 1701 Fairfield Way Richmond VA 23223, Richmond Juvenile Detention Center - 1700 Oliver Hill Way Richmond VA 23219	
	EMS Stations	2	0	stations	Richmond Fire Department Company 21; Phillip Morris Fire Brigade	
	Fire Stations	1	0	stations	Richmond Fire Station 21	
	National Shelter System Facilities	3	0	facilities	John Marshall High School; The Calhoun Center; Henderson Middle School	
	Sheriff Facilities	3	0	facilities	Juvenile Detention Center; Oliver Hill Courts Building; Richmond Detention Center	
Stormwater and Sewer Infrastructure	Active StormwaterOutfall	154	0	units	See map for locations	
	Sewer Treatment Plant	1	0	plants	Anacarows Landing	
Terrestrial Habitat	Terrestrial Habitat	10	0	habitats/locations	Open water; Riparian Forest; Agriculture; Southern Atlantic Coastal Plain Mesic Hardwood Forest; Coastal Plain Tidal Swamp; Piedmont-Coastal Plain Large River Floodplain; Dry Oak-Pine Forest; Tidal Salt Marsh- Estuarine Marsh; Shrubland/Grassland; Laurentian-Arcadian Freshwater Marsh	
Transportation Infrastructure - Bike/ Ped	Bike Infrastructure	0.59	0.0	miles	See map for locations	
Transportation Infrastructure - Marine	Marine Transportation	1	0	unit	5001 Deepwater Terminal Rd	
Transportation Infrastructure - Rail and Transit	Railroad Bridges	2	0	bridges	CSX Transportation, Goode Creek; CSX Transportation, Goode Creek	
	Rail Lines	13.7	0.0	miles	miles	
Transportation Infrastructure - Roads and Bridges	Bridges	15	0	bridges	See map for locations	
	Roads	14.9	0.0	miles	See map for locations	
Trees and Vegetation	Tree canopy (Street Trees and Trees Other)	929	0	trees	See map for locations	
Waste Management Infrastructure	EPA Regulated Facilities	4	0	facilities	City of Richmond Wastewater Treatment Plant; Bellemeade Power Station; Industrial Alloy Fabricators Inc; Reco Biodiesel, LLC	
Water bodies	Chesapeake Bay Protection Area	991.4	0.0	acres	See map for locations	
	Lakes	18	0	lakes	See map for locations	
	Creeks	4	0	creeks	See map for locations	

Consequence Scale				
Low	Medium-Low	Medium	Medium-High	Low







7. Recommendations















7.1 Resilience Recommendations



































The RVAgreen 2050 Climate Equity Action Plan 2030 has identified key strategies and actions for reducing greenhouse gas emissions and increasing climate resilience,






































many of which address a number of the climate vulnerabilities and risks described in this report. Figure 7.1 presents additional or in some instances more detailed

actions recommended to more fully address the key vulnerabilities and risks that have been analyzed and the priorities that have been identified in the full Climate Vulnerability and Risk Assessment.

Figure 7.1 - Recommended Actions to Address Vulnerability and Risk

Recommended Action	Vulnerability/ Risk Addressed	Time	Resilience Benefits	Equity Benefits	Related 2030 Action Plan Strategies
Design new homes for flood risk, for extreme storm events	Flood	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Community resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Resilient Design Guidelines (BE-4.2)
Retrofit existing homes for flood risk, extreme storms	Flood	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Community resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Climate-Ready Affordable Housing (C-1.1)

Recommended Action	Vulnerability/ Risk Addressed	Time	Resilience Benefits	Equity Benefits	Related 2030 Action Plan Strategies
Incentivize relocation of housing in areas of flood risk	Flood, Sea Level Rise	2026-2030	 Flooding and sea level rise resilience  Extreme weather events resilience  Community resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Resilient Design Guidelines (BE-4.2)
Ensure public housing and community facilities have air conditioning (retrofit or new construction)	Heat	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Community resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Climate-Ready Affordable Housing (C-1.1)
Establish backup power systems for critical facilities	Flood, Heat	2026-2030	 Flooding and sea level rise resilience  Extreme weather events resilience  Community resilience	 Government accountability  Health and well-being	Municipal Resilient Infrastructure Assessment (BE-1.4) Resilient Design Guidelines (BE-4.2)
Consider a holistic review of the multiple threats/stressors health care facilities experienced across the system during COVID - develop an improvement plan that incorporates climate risks as well	Flood, Heat	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience  Community resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Climate-Ready Community Fund (C-2.1) Organizational Collaboration (C-2.3)
Climate vulnerability assessment of the tree canopy specifically	Flood, Heat	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience	 Racial equity and environmental justice  Neighborhoods  Health and well-being  Engagement and communications	Urban Heat Island Reduction (ENV-2.1) Urban Forest and Green Space Planning (ENV-2.2)

Recommended Action	Vulnerability/ Risk Addressed	Time	Resilience Benefits	Equity Benefits	Related 2030 Action Plan Strategies
Establish historic resources protection programs, such as “keeping history above water” resources, green historic preservation, etc	Flood, Sea Level Rise, Heat	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience	 Racial equity and environmental justice  Affordable housing  Neighborhoods  Health and well-being	Community Partnerships Program (C-1.5) Organizational Collaboration (C-2.3)
Create business preparedness programs (not just insurance)	Flood, Sea Level Rise, Heat	2022-2025	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience  Community resilience	 Racial equity and environmental justice  Government accountability  Engagement and communications  Community wealth	Climate Action and Resilience Information Navigator (C-1.3) Organizational Collaboration (C-2.3)
Install microgrids at critical facilities	Flood, Heat	2026-2030	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience  Community resilience	 Racial equity and environmental justice  Government accountability  Health and well-being	Municipal Resilient Infrastructure Assessment (BE-1.4) Solar Installation Incentives and Access (BE-3.2)
Modernize the grid	Flood, Heat	2022-2030	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience  Community resilience	 Racial equity and environmental justice  Government accountability  Health and well-being	Solar Installation Incentives and Access (BE-3.2)
Develop distributed energy, renewables, energy storage	Flood, Sea Level Rise, Heat	2022-2030	 Flooding and sea level rise resilience  Extreme weather events resilience  Extreme heat resilience  Community resilience	 Racial equity and environmental justice  Government accountability  Health and well-being  Community wealth	Solar Energy Education & Outreach (BE-3.1) Solar Installation Incentives and Access (BE-3.2)

7.2 Relevant strategies in the Draft RVAgreen Climate Equity Action Plan 2030:

Buildings and Energy Pathway

BE-1.4: Municipal Resilient Infrastructure Assessment:

Conduct a climate vulnerability and risk assessment of all city property (including buildings and parcels). Identify and prioritize properties for specific resilience projects.

BE-2.1: Residential Energy Burden: Implement measures to reduce the energy burden of Richmond's most vulnerable communities and improve residential resilience to climate change.

BE-3.1: Solar Energy Education & Outreach: Provide equitable education and outreach to make homes and small businesses healthy, safe, and affordable through solar installations, focusing on frontline communities and reducing disproportionately high energy burden in these neighborhoods.

BE-3.2: Solar Installation Incentives and Access: Encourage solar installations through the removal of zoning restrictions, incentivizing opportunities, and increasing funding for microgrids.

BE-4.2: Resilient Design

Guidelines: Develop Resilient Design Guidelines and require builders to incorporate design measures to reflect a changing climate, increased precipitation and flooding in concert with a public education campaign to convey the benefits of adaptive and resilient buildings.

Community Pathway

C-1.1: Climate-Ready Affordable Housing: Develop and implement climate mitigation and resilience requirements for the Affordable Housing Trust Fund.

C-1.3: Climate Action and Resilience Information Navigator: Help small businesses, homeowners, and renters navigate programs and incentives for reducing emissions and increasing climate resilience.

C-1.4: Community Benefits Scorecard and Agreements: Develop tools with frontline communities to evaluate City development projects and ensure they address

community priorities for climate action and resilience, and encourage use by private developers as well.

C-1.5: Community Partnerships Program: Develop a climate action and resilience neighborhood partnerships program.

C-2.1: Climate-Ready Community Fund: Establish a Climate-Ready Community grant program to provide funding to neighborhood-focused organizations to work with residents on climate action and resilience projects.

C-2.3: Organizational Collaboration: Partner with community leaders, organizations, and businesses to build community capacity for climate resilience.

C-2.4: Resilience Hubs: Create neighborhood resilience hubs in frontline communities.

Environment Pathway

ENV-1.3: Urban & Community Agriculture: Develop, fund, and implement an urban and community agriculture program.

ENV-2.1: Urban Heat Island

Reduction: Develop, fund, and implement an urban heat island reduction plan and program.

ENV-2.2: Urban Forest and Green Space Planning: Use urban forest and green space planning to increase climate resilience.

ENV-3.1: Neighborhood Prioritization: Identify and prioritize extreme precipitation and flooding projects using community engagement and data.

ENV-3.2: Extreme Precipitation Resilience Planning and Operations: Increase planning and capacity for green infrastructure management and flood resilience measures.

ENV-3.3: Land Management Practices: Enhance land management practices to increase capacity for flood resilience measures.

Transportation and Mobility

TM-1.4: Climate Resilient

Infrastructure: Develop a climate resiliency plan for transportation infrastructure that prioritizes projects using Envision and the Climate Equity Index.

TM-2.3: Residential Mobility and Complete Streets:

Promote safely walkable and bikeable neighborhoods that connect Richmonders to jobs, necessities, and amenities throughout the city in alignment with the Richmond Connects Plan.

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9. Appendix A: Social Vulnerability Factors

Population Factors

Elderly: Old age is generally accompanied by an increased risk of certain diseases and disorders, along with changes in various social factors such as income loss and social isolation. The impacts of climate change worsen these risks, and can increase susceptibility to heat, pollutants, and vectorborne

diseases for individuals 65 years and older. Conditions that limit mobility, and reduced physical ability make movement to avoid disasters challenging. In a study conducted to assess temperature variability and elderly mortality, research found that each 1-degree Celsius increase in summer temperature variability increased the death rate for elderly people with chronic

conditions between 2.8 and 4.0 percent, depending on the condition. The mortality risk was 1 to 2 percent greater for those living in poverty and for African-Americans. The risks of these climate impacts, such as extreme heat, can further burden elderly populations given that older adults who own air-conditioning units may not utilize them during heat waves due to high operating costs. Additionally,

² Filiberto, D., Wethington, E., Pillemer, K., Wells, N., Wysocki, M., & Parise, J. (2010). Older People and Climate Change: Vulnerability and Health Effects. Retrieved from <https://www.asaging.org/blog/older-people-and-climate-change-vulnerability-and-health-effects>

³ Zanolotti, A., O'Neill, M., Gronlund, C., & Schwartz, J. (2012). Central Authentication Service. Retrieved from <https://www.ncbi.nlm.nih.gov.proxy.library.vcu.edu/pmc/articles/PMC3340087/>

⁴ Lamontagne, N. (2012). Environmental Factor - May 2012: Extramural papers of the month. Retrieved from <https://factor.niehs.nih.gov/2012/5/dert/index.htm>

⁵ Gamble, J. L., Hurley, B. J., Schultz, P. A., Jaglom, W. S., Krishnan, N., & Harris, M. (2012). Climate change and older Americans: state of the science. *Environmental health perspectives*, 121(1), 15–22. doi:10.1289/ehp.1205223

⁶ Kakkad, K., Barzaga, M. L., Wallenstein, S., Azhar, G. S., & Sheffield, P. E. (2014). Neonates in Ahmedabad, India, during the 2010 Heat Wave: A Climate Change Adaptation Study. *Journal of Environmental and Public Health*, 2014, 1–8. doi:10.1155/2014/946875

⁷ Stanberry, L. R., Thomson, M. C., & James, W. (2018). Prioritizing the needs of children in a changing climate. *PLoS medicine*, 15(7), e1002627. doi:10.1371/journal.pmed.1002627

⁸ Majeed, H., & Lee, J. (2017). The impact of climate change on youth depression and mental health. *The Lancet Planetary Health*, 1(3), e94–e95.

⁹ Hansen, A., Bi, L., Saniotis, A., & Nitschke, M. (2013). Vulnerability to extreme heat and climate change: is ethnicity a factor?. *Global health action*, 6, 21364. doi:10.3402/gha.v6i0.21364

studies have found associations between acute exposure to ambient ozone and increased risk of death, as well as an increased number of emergency room visits and hospital admissions among older adults.

Children: Children under 18 have an increased vulnerability to the impacts of climate change, having no or little direct control over the environment they live in. This increases their risks from climate-related disasters, and can require additional care and protection from harm. Furthermore, infants and children under 5 have substantial vulnerability to dehydration and heat stress, and there are more heat-related deaths among infants during heat waves. Children under 18 are also more susceptible to traumatic events that can result in long-term negative effects on

health, social, and behavioral outcomes. Additionally, climate change impacts can expose pre-existing psychological vulnerabilities in children under 18.

Minorities: Minorities are more vulnerable to the impacts of climate change. Due to historic and institutional racism, they tend to live in more marginal and exposed areas that are more susceptible to climate impacts. For instance, minorities have a higher morbidity and mortality rate associated with extreme heat. In a heatwave study conducted in Los Angeles during 1989-1998, the African American mortality rate was double the city's average. Additionally, Hispanic or Latinx individuals are heavily represented in construction and crop and livestock production, and are three times more likely to die on the

job from excessive heat than non-Hispanic/Latinx individuals. Latinx and Hispanics have the lowest rate of health insurance of any racial or ethnic group in the U.S., which limits their access to care. Native Americans tend to be among the most vulnerable, often living close to nature, in relatively natural environments rather than in cities, and growing and making much of the food and other products that they need to survive.

Female: The impacts of climate change on health, including increased exposures to heat, poor air quality, and extreme weather events, pose different risks for men and women. Exposure to climate change impacts such as poor air quality has a worse impact on women, due to increased rates of cases of air particulate matter in lung tissue and higher rates of anemia. Poor

¹⁰ Shonkoff, S. B., Morello-Frosch, R., Pastor, M., & Sadd, J. (2009). Environmental health and equity impacts from climate change and mitigation policies in California: a review of the literature. California Climate Change Center

¹¹ Halberg, S. (2017). Hispanics more likely to be affected by climate change. Retrieved from <http://thenationshealth.aphapublications.org/content/46/10/E56>

¹² Baird, R. (2008). The impact of climate change on minorities and indigenous peoples. Briefing). Minority Rights Group International: London.

¹³ Sorensen, C., Murray, V., Lemery, J., & Balbus, J. (2018). Climate change and women's health: Impacts and policy directions. PLoS medicine, 15(7), e1002603. doi:10.1371/journal.pmed.1002603 Retrieved from <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6038986/>

¹⁴ Chen, L. H., Knutsen, S. F., Shavlik, D., Beeson, W. L., Petersen, F., Ghamsary, M., & Abbey, D. (2005). The association between fatal coronary heart disease and ambient particulate air pollution: are females at greater risk?. Environmental health perspectives, 113(12), 1723-1729.

¹⁵ Šrám, R. J., Binková, B., Dejmek, J., & Bobak, M. (2005). Ambient air pollution and pregnancy outcomes: a review of the literature. Environmental health perspectives, 113(4), 375-382

¹⁶ World Health Organization. (2010). Gender, Climate Change, and Health. Retrieved from <https://www.who.int/globalchange/GenderClimateChangeHealthfinal.pdf>

¹⁷ Maldonado, C. Z., Rodriguez, R. M., Torres, J. R., Flores, Y. S., & Lovato, L. M. (2013). Fear of Discovery Among Latino Immigrants Presenting to the Emergency Department. Academic Emergency Medicine, 20(2), 155-161. doi:10.1111/acem.12079

¹⁸ Boston.gov. (2019). Climate Vulnerability Assessment. Retrieved from https://www.boston.gov/sites/default/files/imce-uploads/2017-01/crb_-_focus_area_va.pdf

¹⁹ U.S. Global Change. (2019). Populations of Concern. Retrieved from <https://health2016.globalchange.gov/populations-concern/content/populations-concern>

air quality is also associated with negative birth outcomes, and poses a risk for maternal and child health associated with stillbirth, intrauterine growth restriction, and congenital defects. Additionally, women can have a more difficult time recovering from a climate-related disaster due to having lower income than men.

Limited English Proficiency:

Many implications of limited English proficiency (LEP) increase vulnerability to climate change. Individuals with LEP have high poverty rates and various language and cultural barriers. Additionally, those with LEP may have citizen status challenges, which make them more hesitant to seek out help. Furthermore, barriers such as accessing and affording mental health care,

and limited counseling in native languages, limits their climate change adaptability and resilience. For example, during a flooding event, residents may face the challenge of communicating with emergency response personnel. Likewise, if residents are more socially isolated, they may be less likely to hear about upcoming events.

Health and Safety Factors

Health Opportunity Index:

The Health Opportunity Index (HOI) is a measurement based on 13 indicators that reflect a wide variety of social determinants of health. The 13 indicators are categorized into four profiles: community environmental, consumer opportunity, economic opportunity, and wellness

disparity. Each indicator, the profiles, and the HOI itself, provide implications of the opportunity for individuals to live a long and healthy life in each area. Additionally, the HOI explains approximately 60 percent of variation in Disability Free Life Expectancy in Virginia Census Tracts. A low health opportunity index can indicate poor air quality, income inequality, low education levels, limited access to care, and poor food accessibility, which are all factors that increase vulnerability to the impacts of climate change.

Disabilities: Persons with physical and mental disabilities have an increased vulnerability to the impacts of climate change. A disability is defined as “a person who has a physical or mental impairment that substantially limits one or more major life

²⁰ Virginia Department of Health. (2019). Virginia Health Opportunity index (HOI). Retrieved from <http://www.vdh.virginia.gov/health-equity/virginia-health-opportunity-index-hoi/>

²¹ Virginia Department of Health. (2019). Methodology. Retrieved from <https://www.vdh.virginia.gov/omhhe/hoi/what-is-the-hoi/methodology>

²² Virginia Department of Health. (2019). What is the HOI. Retrieved from <https://www.vdh.virginia.gov/omhhe/hoi/what-is-the-hoi>

²³ Americans with Disabilities Act. (2019). What is the definition of disability under the ADA? Retrieved from <https://adata.org/faq/what-definition-disability-under-ada>

²⁴ Gamble, J. L., Balbus, J., Berger, M., Bouye, K., Campbell, V., Chief, K., & Hallisey, E. (2016). Ch. 9: Populations of concern (pp. 247-286). US Global Change Research Program, Washington, DC

²⁵ Wolbring, G., & Leopatra, V. (2012). Climate Change, Water, Sanitation and Energy Insecurity: Invisibility Of People With Disabilities. Canadian Journal of Disability Studies, 1(3), 66. doi:10.15353/cjds.v1i3.58

²⁶ Balbus, J. M., & Malina, C. (2009). Identifying Vulnerable Subpopulations for Climate Change Health Effects in the United States. Journal of Occupational and Environmental Medicine, 51(1), 33-37. doi:10.1097/jom.0b013e318193e12e

²⁷ Saxton, M., & Ghenis, A. (2018). Commentary: Disability and climate change-impact on health and survival. Retrieved from <https://www.ehn.org/cli-mate-change-and-disability-2569643231.html>

²⁸ Harvard School of Public Health. (2014). Obesity has doubled since 1980, major global analysis of risk factors reveals. Retrieved from <https://www.hsph.harvard.edu/news/press-releases/worldwide-obesity/>

²⁹ Gray L. (2017). Social Determinants of Health, Disaster Vulnerability, Severe and Morbid Obesity in Adults: Triple Jeopardy?. International Journal of Environmental Research and Public Health, 14(12), 1452. doi:10.3390/ijerph14121452

activity.” Factors that contribute to that vulnerability can include bodily impairments, such as cognitive or hearing impairments, and activity and participation limitations that increase difficulties with evacuations. There is greater vulnerability during storms, floods and extreme heat; susceptibility to invasive disease; and the complex disability-related challenges of relocation and forced migration (i.e. finding new housing or support networks). Furthermore, individuals with disabilities have a lower survival rate than those without disabilities. Additionally, those with disabilities are vulnerable largely due to inequalities and exclusion from resilience and mitigation efforts. Older adults with mobility or cognitive impairments are likely to

experience greater vulnerability to health risks due to difficulty responding to, evacuating, and recovering from extreme events. Systems designed to assist people in times of emergencies are often inaccessible to individuals with disabilities. Adaptive efforts such as ramps to enter shelters, accessible bathrooms, feasible evacuation transportation, and effective communication technologies on evacuation planning for those with impairments, are essential for reducing vulnerability.

Obesity: Since 1980, worldwide obesity has more than doubled, and obesity can be associated with highly elevated risks of adverse health outcomes. In a climate-related disaster, individuals with severe or morbid obesity may present challenges in

emergency situations with regards to rescue, evacuation, transport, and suitable equipment, which increases their vulnerability. Obesity is a leading risk factor for morbidity and premature mortality, and climate impacts such as an extreme heat event, can increase the risk of heat exhaustion and mortality. Climate change impacts also increase exposure to obesity risk factors, since climatic extremes damage agricultural production and threaten food security.

Diabetes: Individuals with diabetes have an increased vulnerability to the impacts of climate change. Higher ambient temperature can negatively impact glucose metabolism, due to a reduction in body fat that is used to turn food into body heat. Research has found that

³⁰ An, R., & Xiang, X. (2015). Social Vulnerability and Obesity among U.S. Adults. *International Journal of Health Sciences (IJHS)*, 3(3). doi:10.15640/ijhs.v3n3a2

³¹ Blauw, L. L., Aziz, N. A., Tannemaat, M. R., Blauw, C. A., Craen, A. J., Pijl, H., & Rensen, P. C. (2017). Diabetes incidence and glucose intolerance prevalence increase with higher outdoor temperature. *BMJ Open Diabetes Research & Care*, 5(1). doi:10.1136/bmjdr-2016-000317

³² See Footnote 30 Above

³³ Dain, K., & Hadley, L. (2012). Diabetes and climate change—Two interconnected global challenges. *Diabetes Research and Clinical Practice*, 97(2), 337-339. doi:10.1016/j.diabres.2012.07.002

³⁴ International Diabetes Federation. (2012). Diabetes and Climate Change. Retrieved from <https://ncdalliance.org/sites/default/files/rfiles/IDF%20Diabetes%20and%20Climate%20Change%20Policy%20Report.pdf>

³⁵ Lieberman, B. (2018). More asthma attacks expected in warmer climate » Yale Climate Connections. Retrieved from <https://www.yaleclimateconnections.org/2017/07/more-asthma-attacks-expected-in-a-warming-climate/>

³⁶ CDC.gov. (2018). CDC - Asthma - Data and Surveillance - Asthma Surveillance Data. Retrieved from: <http://www.cdc.gov/asthma/asthma-data.htm>

³⁷ Stocks, J., & Sonnappa, S. (2013). Early life influences on the development of chronic obstructive pulmonary disease. *Therapeutic advances in respiratory disease*, 7(3), 161-173. doi:10.1177/1753465813479428

³⁸ Götschke, J., Mertsch, P., Bischof, M., Kneidinger, N., Matthes, S., Renner, E. D., ... Milger, K. (2017). Perception of climate change in patients with chronic lung disease. *PloS one*, 12(10), e0186632. doi:10.1371/journal.pone.0186632

³⁹ Donaldson, G. C., Goldring, J. J., & Wedzicha, J. A. (2012). Influence of Season on Exacerbation Characteristics in Patients With COPD. *Chest*, 141(1), 94-100. doi:10.1378/chest.11-0281

for every 1-degree Celsius increase in outdoor temperature, there has been an approximate 4% increase of the total diabetes incidence in the United States per year between 1996 and 2009. Additionally, a 1-degree Celsius rise in environmental temperature could account for more than 100,000 new diabetes cases per year in the US. In hotter temperatures, dehydration and heatstroke increases morbidity and mortality in people with diabetes. People with diabetes are predisposed to cardiovascular events during heat waves and higher mortality from heart attack on days of high air pollution.

Adult Asthma: Adults with asthma are more vulnerable to the impacts of climate change. Climate change causes an increase in ozone pollution; coupled with greater concentrations of carbon dioxide and higher

temperatures, pollen quantity may increase and induce longer pollen seasons. Ozone and pollen can worsen existing respiratory allergies and asthma, and serve as triggers for asthma attacks. More than twenty-six million Americans suffer from asthma, and each day ten people die from asthma related deaths. Although this map only shows adult asthma rates, it is important to note that inflammation in the lungs in children can impair lung development and lead to an increased risk of lung disease in adulthood.

COPD: Individuals with respiratory diseases are particularly vulnerable to the impacts of climate change. Air pollution from climate change-causing emissions sources does not only exacerbate existing respiratory disease, but can cause respiratory diseases as well. Individuals with COPD face

increased mortality, higher rates of hospitalization, and exacerbation of COPD symptoms, and worse quality of life in cold weather seasons. Additionally, heat-wave-related mortality has been found to be higher among those with chronic respiratory disease, even when hospitalized. The risks associated with climate change impacts also include increased respiratory symptoms, increased rescue inhaler use, and decreased lung function in former smokers with COPD.

Coronary Heart Disease: With large day-to-day variations in temperature, individuals with coronary heart disease have significantly more heart attacks. Research has shown that outdoor temperature affects the rate of heart attacks, the rate of heart attacks increases on warm days following sudden temperature swings. The study

⁴⁰ McCormack, M. C., Paulin, L. M., Gummerson, C. E., Peng, R. D., Diette, G. B., & Hansel, N. N. (2017). Colder temperature is associated with increased COPD morbidity. *The European respiratory journal*, 49(6), 1601501. doi:10.1183/13993003.01501-2016 Retrieved From: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5817981/>

⁴¹ Napoli, N. (2018). Heart Attacks Often Follow Dramatic Changes in Outdoor Temperature. Retrieved from <https://www.acc.org/about-acc/press-releases/2018/02/27/11/19/heart-attacks-often-follow-dramatic-changes-in-outdoor-temperature>

⁴² Stotz, A., Rapp, K., Oksa, J., Skelton, D. A., Beyer, N., Klenk, J., ... Lindemann, U. (2014). Effect of a brief heat exposure on blood pressure and physical performance of older women living in the community—a pilot-study. *International journal of environmental research and public health*, 11(12), 12623–12631. doi:10.3390/ijerph111212623

⁴³ Kim, Y. M., Kim, S., Cheong, H. K., Ahn, B., & Choi, K. (2012). Effects of heat wave on body temperature and blood pressure in the poor and elderly. *Environmental health and toxicology*, 27, e2012013. doi:10.5620/eht.2012.27.e2012013

⁴⁴ Barraclough, K. A., Blashki, G. A., Holt, S. G., & Agar, J. W. (2017). Climate change and kidney disease—threats and opportunities. *Kidney International*, 92(3), 526–530. doi:10.1016/j.kint.2017.03.047

⁴⁵ Tasian, G. E., Pulido, J. E., Gasparrini, A., Saigal, C. S., Horton, B. P., Landis, J. R., ... Keren, R. (2014). Daily Mean Temperature and Clinical Kidney Stone Presentation in Five U.S. Metropolitan Areas: A Time-Series Analysis. *Environmental Health Perspectives*, 122(10), 1081–1087. doi:10.1289/ehp.1307703

results indicated that the risk of a heart attack increases by about 5 percent for every five-degree jump in temperature in degrees Celsius (9 degrees Fahrenheit). Swings of more than 25 degrees Celsius (45 degrees Fahrenheit) were associated with a greater increase in heart attack rates compared to a smaller increase with temperature swings of 10 to 25 degrees Celsius (18-45 degrees Fahrenheit). While the body generally has effective systems to respond to changes in temperature, rapid fluctuations can create more stress on those systems, which is a risk for those with coronary heart disease.

High Blood Pressure: Those with high blood pressure are vulnerable to the impacts of climate change. Variations in temperature can cause

fluctuation in blood pressure, and may lead to severe drops in blood pressure, increasing the risk of falls in older adults. Furthermore, excessive heat serves as a risk for individuals taking medication for high blood pressure, since the medication can interfere with self-regulating body temperatures.

Kidney Disease: Individuals with kidney disease are vulnerable to the impacts of climate change, especially during extreme heat events. Studies have shown that during heat waves there is an increase in hospital admissions for acute kidney injury, and kidney failure becomes a leading cause of premature death, or death before life expectancy. Additionally, increased ambient temperature and sunlight have been recognized

as prominent risk factors for the formation of kidney stones, to which those with kidney disease are already more susceptible. Researchers state this is caused by heat-associated sweating, which results in a reduction in urine volume, and leads to urinary supersaturation with stone-forming salts. Furthermore, the impacts of climate change also pose significant risk to chronic medical patients dependent on access to functioning health services. Dialysis patients are among the most vulnerable because of the potentially life-threatening impact of missed dialysis.

Self-Assessed Mental Health/Stress: Self-assessed national public health surveys are used by the CDC to ensure their research includes a wide variety of demographics and socioeconomic characteristics. For those with mental health

⁴⁶ Centers for Disease Control and Prevention. (2019). About Mental Health. Retrieved from <https://www.cdc.gov/mentalhealth/about/index.htm>

⁴⁷ Dodgen, D., D. Donato, N. Kelly, A. La Greca, J. Morganstein, J. Reser, J. Ruzek, S. Schweitzer, M.M. Shimamoto, K. Thigpen Tart, and R. Ursano, 2016: Ch. 8: Mental Health and Well-Being. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 217-246. <http://dx.doi.org/10.7930/J0TX3C9H>

⁴⁸ Bouchama, A., M. Dehbi, G. Mohamed, F. Matthies, M. Shoukri, and B. Menne, 2007: Prognostic factors in heat wave-related deaths: A meta-analysis. Archives of Internal Medicine, 167, 2170-2176. <http://dx.doi.org/10.1001/archinte.167.20.ira70009>

⁴⁹ Hansen, A., P. Bi, M. Nitschke, P. Ryan, D. Pisaniello, and G. Tucker, 2008: The effect of heat waves on mental health in a temperate Australian city. Environmental Health Perspectives, 116, 1369-1375. <http://dx.doi.org/10.1289/ehp.1133>

⁵⁰ Lee, Y. (2000). The predictive value of self assessed general, physical, and mental health on functional decline and mortality in older adults. Journal of Epidemiology & Community Health, 54(2), 123-129. doi:10.1136/jech.54.2.123

⁵¹ Centers for Disease Control and Prevention. (2018). Populations and Vulnerabilities. Retrieved from <https://ephtracking.cdc.gov/showPcMain.action>

⁵² Lewin, M. E., & Altman, S. H. (2000). America's health care safety net intact but endangered. Washington, D.C.: Institute of Medicine. Retrieved from: <https://www.ncbi.nlm.nih.gov/books/NBK224530/>

⁵³ Zeuli, K., & Nijhuis, A. (2017). The resilience of America's Urban Food Systems: Evidence from Five Cities. Retrieved from http://icic.org/wp-content/uploads/2017/01/Rockefeller_ResilientFoodSystems_FINAL_post.pdf?x96880

and stress, the impacts of climate change pose significant risks for factors such as PTSD, depression, general anxiety, suicidal thoughts, and increased substance abuse. Furthermore, excessive heat serves as a risk for individuals taking medication for mental health, since the medication can interfere with self-regulating body temperatures. Studies have shown that due to heat wave exposure, pre-existing mental illness was found to triple the risk of death, and there are increases in aggressive behavior, violence, and suicides. Likewise, there is an increase in hospital admissions and emergency room visits during heat waves for people with psychiatric illnesses.

Physical Health (Self-Assessed): Self-assessed health is increasingly being considered as a valid measure

for predicting future health outcomes among elderly individuals. Older people who assess their physical health less favorably, have shown a significant correlation with functional decline and mortality. Individuals with poor physical health have difficulty responding to, evacuating, and recovering from extreme events.

Uninsured: Uninsured individuals may require extra resources to prepare, evacuate, and recover from emergency situations and the impacts of climate change. They are much more likely to have unmet health care needs, and are less likely to have a primary source of care. Furthermore, those who are uninsured have lower rates of health care use, and experience worse health outcomes, including increased rates of mortality. This significantly reduces climate

change adaptability and resiliency for those who are uninsured.

Food Security (Low Food Access): Food insecurity and/or living in a food desert makes individuals vulnerable to the impacts of climate change. Research has shown that in major cities a very small share of total food consumed is processed and packaged locally. During an extreme weather event, such as flooding, the locations of food distributors impose a great risk for distribution and access. In most cities, neighborhoods are not equally served by the same number of food retail stores, creating local food availability vulnerabilities. Likewise, most food distributed to retail is delivered by truck, making roads a critical point of vulnerability. Furthermore, food prices will continue to rise as crop yields, livestock,

⁵⁴ Zeuli, K., Nijhuis, A., & Gerson-Nieder, Z. (2018). Resilient Food Systems, Resilient Cities: A High-Level Vulnerability Assessment of Toronto's Food System. Retrieved from <https://www.toronto.ca/legdocs/mmis/2018/hl/bgrd/backgroundfile-118076.pdf>

⁵⁵ Food and Agriculture. Organization of the United Nations. (2017). The Future of Food and Agriculture - Trends and Challenges. Retrieved from <http://www.fao.org/3/a-i6583e.pdf>

⁵⁶ Dodge N. (2013). Effect of climate change and food insecurity on low-income households. American journal of public health, 103(1), e4.

⁵⁷ Harp, R. D., & Karnauskas, K. B. (2018). The Influence of Interannual Climate Variability on Regional Violent Crime Rates in the United States. GeoHealth, 2(11), 356-369. doi:10.1029/2018gh000152

⁵⁸ Plante, C., & Anderson, C. (2017). Global Warming and Violent Behavior. Retrieved from <https://www.psychologicalscience.org/observer/global-warming-and-violent-behavior>

⁵⁹ Ranson, M. (2014). Crime, weather, and climate change. Journal of environmental economics and management, 67(3), 274-302.

⁶⁰ Mares D. (2013). Climate change and levels of violence in socially disadvantaged neighborhood groups. Journal of urban health : bulletin of the New York Academy of Medicine, 90(4), 768-783. doi:10.1007/s11524-013-9791-1 Retrieved from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3732690/>

⁶¹ Steinbruner, J. D. (2013). Chapter 1, Climate Change as a National Security Concern. In Climate and social stress: Implications for security analysis (pp. 15-34). Washington, D.C: National Academies Press.

⁶² Phillips, B. D. & Morrow, B. H. (2007) Social Science Research Needs: Focus on Vulnerable Populations, Forecasting and Warnings Natural Hazards Review, 8 (3), pp. 61-68.

and fish production are projected to decline due to climate change. Individuals with specific dietary needs may confront shortages of key foods, and depending on access may have to settle for inadequate options. Low-income individuals intersect with food security as well. As prices increase, affordable food options become limited; if there is not an adequate number of food retail stores, food banks, and other sources within reach of a certain area, this makes residents more vulnerable. This map identifies the low-income census tracts within Richmond where more than 100 housing units do not have a vehicle and are more than a ½ mile from the nearest supermarket, or a significant number of share residents are more than 20 miles from the nearest supermarket. Additionally, even with a vehicle there are low-income census tracts where a significant number or share of residents is more than 1 mile

(urban) or 10 miles (rural) from the nearest supermarket.

Crime: Research has shown a strong relationship between temperature and both violent and property crime. With extreme heat, the likelihood of physical aggression and violence rises due to an increase in perceived hostility, anger, and irritability. The increase in number of interactions between individuals in warmer weather may be the primary driving force between the relationship of climate and crime. A study that conducted a 30-year assessment of monthly crime and weather data, has suggested that “between 2010 and 2099, climate change will cause an additional 22,000 murders, 180,000 cases of rape, 1.2 million aggravated assaults, 2.3 million simple assaults, 260,000 robberies, 1.3 million burglaries, 2.2 million cases of larceny, and 580,000 cases of vehicle theft in the United States.” Additionally, neighborhoods with higher

“social disadvantage” such as more female-headed households and unemployment are very likely to experience higher levels of violence as a result of abnormally warm temperatures. Climate change may also accelerate existing social instabilities or conflicts.

Household Factors

Single Parent Households:

Single parent households are more likely to be in poorer neighborhoods and have fewer economic resources. Preschool children living with one parent, for example, can be more socially isolated, and this can have an impact on how they cope and respond to environmental hazards. Single parents are responsible for caregiving as well as providing family income, and therefore increase their vulnerability to the impacts of climate change.

⁶³ Zakour, M. J., Harrell, G. S., & Harrell, E. B. (2008) Access to Disaster Services. *Journal of Social Service Research*. *Journal of Social Service Research*, pp. 27-54

⁶⁴ Penn State College of Earth and Mineral Sciences. (2018). Human Vulnerability to Climate Impacts. Retrieved from <https://www.e-education.psu.edu/geog438w/node/252>

⁶⁵ Whitley, D. M., Fuller-Thomson, E., & Brennenstuhl, S. (2015). Health Characteristics of Solo Grandparent Caregivers and Single Parents: A Comparative Profile Using the Behavior Risk Factor Surveillance Survey. *Current gerontology and geriatrics research*, 2015, 630717. doi:10.1155/2015/630717

⁶⁶ Butler F. R., Zakari N. (2005) Grandparents parenting grandchildren: assessing health status, parental stress, and social supports. *Journal of Gerontological Nursing*;31(3):43-54.

⁶⁷ Conway F., Jones S., Speakes-Lewis A. (2011). Emotional strain in caregiving among African American grandmothers raising their Grandchildren. *Journal of Women and Aging*. 23(2):113-128. doi: 10.1080/08952841.2011.561142.

Custodial Grandparents:

Compared to single parents, grandparents have a higher prevalence of physical health problems which make them vulnerable to the impacts of climate change. Studies have shown higher levels of obesity, hypertension, heart disease, limited physical functioning, and dissatisfaction with one's physical health in custodial grandparents. Additionally, custodial grandparents have reported emotional stress from financial constraints, and inadequate social support. Without adequate knowledge of the availability of specialized services, and many having limited transportation to available health service sites, the impacts of climate change pose a great risk to grandparents responsible for grandchildren under 18.

Renters: Renters, especially low-income tenants, are often neglected when it comes to strategies that seek to lessen the impact of climate change on households. Renters have a low climate change adaptability and resilience, given the limited and sometimes low-quality of housing stock, as well as the renter's limited ability to

retrofit their place of residence to prepare for climate change. Additionally, renters, who may be more transient than homeowners, new to an area have less knowledge of local environmental hazards, such as floods, which reduce their ability to adapt to climate impacts.

65+ years living alone: Many elderly people who live alone are on a fixed income, which reduces their climate change adaptability and resilience. Additionally, individuals who are 65-years of age or older are more likely to be disadvantaged in terms of their ability to evacuate because of a disability, limited income, or lack of transportation. For example, 43 percent of single Social Security recipients aged 65 years or older depend on Social Security for 90% or more of their income. Research has shown that older Americans living alone may be at a higher risk for abuse from frauds or scams, regarding home improvements or repairs before or after extreme weather events. Likewise, staying with friends or family is not a viable option

for isolated elderly lacking social support, and therefore increases their vulnerability to the impacts of climate change.

Income and Education Factors

Poverty: Individuals below the federal poverty level have fewer resources and receive less support, which reduces their ability to prevent, cope with, and adapt to climate change impacts. Climate change impacts increase the vulnerability of individuals below the poverty level, causing a rise in risks such as physical and mental illnesses, job loss, and decreased food security. Furthermore, individuals below the poverty level are more likely to depend a on climate sensitive employment, such as agriculture, or on low-income informal or hourly jobs. These methods of employment often have little job security and protection against climate-related risks and disruptions. Additionally, low-income households generally spend a larger portion of their budgets on necessities like energy than other consumers.

Related to adaptive capacity:

Poverty reduction is largely driven by asset growth. With reduced income and asset losses due to natural disasters, asset growth slows down, and diminishes poverty reduction. For climate resilience for individuals below the poverty level, strategies should be designed in a way that includes those below the poverty level, and should aim overall to reduce poverty.

Working Outdoors: Individuals who work outdoors are among the first to be exposed to the impacts of climate change. Outdoor workers include farmers and other agricultural workers, construction workers, transportation workers, paramedics, firefighters, police, and other first responders. According to the EPA, the risks of climate change impact outdoor workers through “increases in temperature, poor air quality, extreme weather, diseases transmitted by ticks and mosquitoes, industrial exposures, and damage to infrastructure.” Extreme heat may result in more heat-related illnesses such as heat stroke, heat exhaustion, and fatigue for outdoor workers. Higher temperatures can also increase the risk of respiratory

illness among workers. Additionally, the impacts of climate change generate risky conditions for workers involved in disaster response, rescue, and cleanup.

SNAP/Food stamps:

Disruptions in government functions during climate disasters may impact distribution of SNAP/food stamp benefits. Additionally, individuals who receive SNAP/food stamps in areas of low food security may have low adaptability and resilience to climate impacts. By releasing benefits early in anticipation of an extreme weather event such as a hurricane, individuals are able to prepare for closures and other obstacles that occur following a storm. Studies have shown an increase in the number of unemployment claims following a natural disaster. Therefore, ensuring proper outreach for individuals to apply for benefits, and potentially increasing benefits for those already enrolled, can enhance their climate resilience abilities. Additionally, the impacts of climate change pose risks to the distribution of benefits when communication systems are disrupted.

Public Assistance Income:

According to the U.S. Census Bureau, public assistance income refers to “assistance programs that provide either cash assistance or in-kind benefits to individuals and families from any governmental entity.” For example, social security public assistance income is designed to provide benefits and services in retirement, on death, during the birth and childhood of infants, for disability, unemployment and for sickness and long-term illness. For climate resilience, public assistance income must be able to change as the demand changes, while facing the challenge of slower economic growth. This includes demands such as unemployment coverage, which may increase after a natural disaster. Additionally, the impacts of climate change pose risks to the distribution of benefits when communication systems are disrupted after a natural disaster. The number of households receiving public assistance significantly correlate with households living in poverty or with insufficient resources.

Housing Cost Burden: Housing

expenditures that exceed 30 percent of household income have historically been viewed as an indicator of a housing affordability problem. If a household exceeds 30 percent of its income for housing costs it is considered burdened, and burdened households have less ability to deal with the impacts of climate change such as rising energy and food costs, natural disasters, and property damage from floods. Younger adults are spending approximately 45 percent of their income on rent in their first decade in the workforce. Additionally, the share of renter households that spent 50 percent or more of monthly income on rent, has increased by 42 percent between 2001 and 2015, to a total of 17 percent. This can limit household consumption and reduce economic mobility, which limits climate adaptability and resilience.

Limited Education: Education can play an important role in reducing the negative impacts of extreme climate events in various ways. Formal education is considered as a direct way in which individuals obtain knowledge, skills, and competencies that can influence their adaptive capacity. Furthermore, studies

have shown that education improves socio-economic status, since a higher education generally increases earnings. Individuals without a high school degree are more than twice as likely to live in inadequate housing compared to those with some college education. Additionally, 38 percent of Americans without a high school degree do not have health insurance, compared to 10 percent with a college degree. Furthermore, the level of education is highly correlated with access to weather forecasts and warnings as well as the types of technologies used to access weather information. Without adequate access to information, individuals cannot respond and prepare for hazards appropriately.

Unemployment: Individuals who are unemployed will have a harder time relocating from areas impacted by climate change, and would require substantial aid to repair or rebuild their home in the event of a natural disaster. Furthermore, those who are unemployed cannot economically contribute to recovery from a disaster within a community, which results in a slower recovery process.

Housing Choice Voucher:

The Housing Choice Voucher Program provides rental assistance to qualified low-income individuals and families to afford decent, safe, and sanitary housing. Housing can include single-family homes, townhouses, and apartments, and is not limited to units located in subsidized housing projects. However, the largest concentration of Housing Choice Vouchers is within the inner city in subsidized housing projects, which further contains poverty to those locations. A prolonged concentration of poverty can exacerbate adverse health outcomes such as diabetes, asthma, and lung disease, and lead to an increase in mortality rates. Additionally, residences with low economic standing are associated with poorer health care access, being uninsured, and higher hospitalization rates, which increase vulnerability to the impacts of climate change.

Housing and Transportation Factors

Multi-Unit Structures: Multi-unit structures, defined in this data set as buildings containing 10 or more housing units, are vulnerable to the impacts of climate change. During a climate event such as a natural disaster, individuals living in multi-unit housing have limited access and limited ability to evacuate due to their dense population. In multi-unit structures where residents rely on elevators, electricity loss makes it difficult, if not impossible, for elderly residents and those with disabilities to leave the building to obtain food, medicine, and other needed services.

Mobile Homes: Mobile homes are often isolated with limited or no access to public transportation or highways, limiting food access, first responders' access, and evacuation ability. The structure of mobile homes often have no strong foundation or basement, which increases their vulnerability to climate change risks such as extreme flooding. In the event of a climate-related natural

disaster, mobile home parks could see significant destruction of personal property and displacement of their residents.

Crowding: Crowding, where there are more people than rooms in a household, increases psychological distress, and can contribute to the spread of communicable diseases among residents. While a lack of privacy can result in stress, difficult social interactions, and an increase in behavioral problems for all household members, children appear to be the most vulnerable. Research has found that an increase in crowded conditions is positively associated with social withdrawal among children. Furthermore, parents in overcrowded homes often show less responsive parenting. Children are socialized within the home to learn roles and relate to others, and their degree of crowding can correlate with differences in child wellbeing across socioeconomic statuses. The lack of a comfortable, quiet space can lead children to have difficulties studying and reading, affecting their school performance. All of these factors can increase the

vulnerability of members of a crowded household to climate impacts.

No vehicle access: Individuals in a household without a vehicle lack mobility certainty, and are less able to move to an area of refuge during a climate change impact, such as an air-conditioned cooling center during extreme heat, or a shelter during severe flooding. By having a lack of mobility certainty during a natural disaster, individuals without vehicle access have a reduced climate change adaptability and resilience.

No Central AC: Individuals with no central AC have low climate change adaptability and resilience. Climate change impacts such as extreme heat, are associated with increased risk for those dying from cardiovascular, respiratory, cerebrovascular, and some specific cardiovascular diseases, such as ischemic heart disease, congestive heart failure, and myocardial infarction. Additionally, extreme heat can cause risks such as heat exhaustion and heat stroke.

Emergency and transitional shelters (with sleeping facilities) for people experiencing homelessness: In 2017, over 553,000 Americans were homeless. Emergency and transitional shelters serve as a safety net and important alternative to living on the streets for a number of children, youth, individuals, and families experiencing homelessness. Climate-related disasters lead to displacement, which increases the need for emergency and transitional shelters, and causes greater exposure to health risks. Homelessness is associated with both racial and ethnic disparities, and children experiencing homelessness have a 25% greater risk of poor health and higher mortality rates in adulthood.

Group homes intended for adults: Residential treatment centers for adults: Group homes and residential treatment centers are facilities that may offer housing, and provide personal care and medical services for adults. Group homes often service the elderly and individuals with disabilities, which

increases their vulnerability. A climate-related disaster may result in power outages that can limit communication for emergency services, and severely impact those who rely on refrigerated medications, or use life-sustaining equipment.

Internet Access: Access to computers and internet technology is a crucial resource for connecting people to the information and skills they need in areas such as education, employment, and health. Many individuals in low- and middle-income communities especially, depend on public computer and internet access for information. Additionally, the internet can provide almost instantaneous communication, and therefore many emergency services use it as a method of distributing important information. Without access to internet, through either a home-based or cellular data subscription, households may be limited in their access to this information.

9. Appendix B:

Statistical Outputs – Social Vulnerability Sensitivity & Adaptive Capacity

Sensitivity Variables	poverty	65+	<18	disability	obesity	asthma	COPD	heart disease	high blood press	kidney disease	poor mental health	poor physical health	grandparent/grandchild	work outdoors	SNAP	public assistance	nonwhite	single parent	multiunit	mobile homes	crowding	crime	housing cost
poverty																							
65+	-0.49																						
<18	0.37	0.04																					
disability	0.45	0.09	0.6																				
obesity	0.6	-0.11	0.76	0.84																			
asthma	0.83	-0.32	0.65	0.74	0.9																		
COPD	0.65	0	0.78	0.8	0.96	0.9																	
heart disease	0.33	0.35	0.72	0.78	0.86	0.67	0.91																
high blood press	0.3	0.29	0.73	0.82	0.9	0.69	0.88	0.97															
kidney disease	0.45	0.24	0.73	0.82	0.91	0.76	0.93	0.98	0.97														
poor mental health	0.88	-0.44	0.6	0.64	0.84	0.96	0.85	0.56	0.56	0.64													
poor physical health	0.67	-0.07	0.78	0.81	0.98	0.92	0.99	0.88	0.87	0.91	0.88												
grandparent/grandchild	-0.06	0.07	-0.06	0.11	0.17	0.14	0.12	0.17	0.22	0.19	0.08	0.13											
work outdoors	0.11	-0.05	0.32	0.23	0.4	0.25	0.35	0.32	0.32	0.26	0.34	0.4	0.01										
SNAP	0.75	-0.23	0.79	0.69	0.85	0.89	0.87	0.67	0.67	0.75	0.86	0.88	0.06	0.3									
public assistance	0.6	-0.23	0.57	0.57	0.7	0.74	0.72	0.55	0.55	0.63	0.71	0.72	0.24	0.09	0.82								
nonwhite	0.6	-0.16	0.61	0.83	0.94	0.9	0.86	0.76	0.84	0.84	0.8	0.89	0.26	0.28	0.77	0.65							
single parent	0.56	-0.26	0.58	0.66	0.83	0.8	0.75	0.6	0.66	0.67	0.76	0.78	0.33	0.29	0.73	0.63	0.81						
multiunit	0.33	-0.27	-0.35	-0.22	-0.23	-0.02	-0.21	-0.34	-0.37	-0.28	0.04	-0.2	-0.2	-0.18	-0.06	-0.05	-0.1	-0.11					
mobile homes	0.15	-0.08	0.1	-0.06	0.06	0.09	0.12	0.03	-0.02	-0.04	0.22	0.14	-0.05	0.47	0.04	-0.06	-0.02	0	-0.02				
crowding	0.41	-0.26	0.54	0.28	0.51	0.48	0.49	0.33	0.33	0.32	0.57	0.54	-0.02	0.67	0.54	0.28	0.38	0.43	-0.09	0.5			
crime	0.55	-0.29	0.14	0.38	0.48	0.54	0.46	0.31	0.31	0.36	0.56	0.48	0.06	0.22	0.47	0.34	0.49	0.48	0.28	0.07	0.23		
housing cost	0.7	-0.36	0.11	0.48	0.51	0.65	0.48	0.29	0.31	0.36	0.68	0.51	0.02	0.18	0.39	0.36	0.6	0.47	0.33	0.28	0.27	0.53	
female	0.01	0.17	0.27	0.1	0.04	0.1	0.08	0.09	0.1	0.13	0.01	0.05	-0.07	-0.25	0.17	0.12	0.06	0.08	0.03	-0.25	-0.1	-0.18	-0.14

Principal Component Analysis

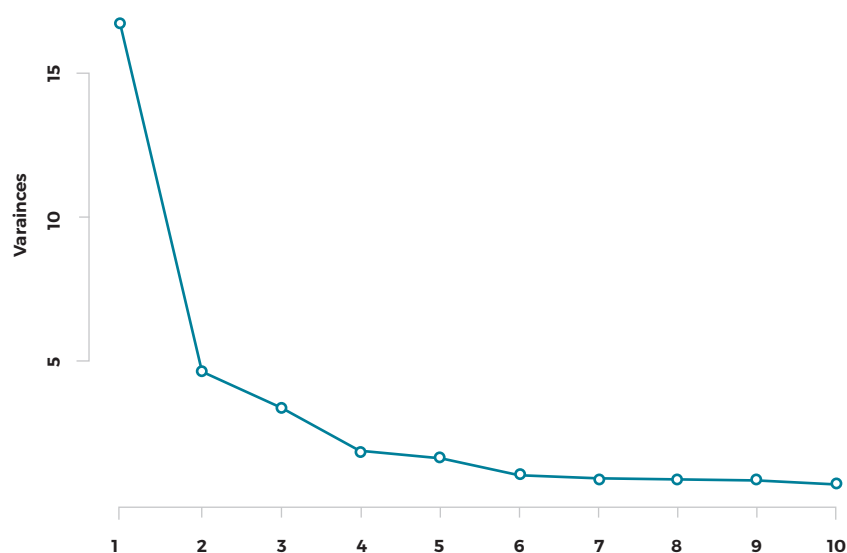
There are several “rules of thumb” for determining a cutoff point for the number of variables that explain the variance in data, including using the variables (or principal components) that explain 70% or 90% of the variance.¹ As shown in the table below, 90% of the variance in the social vulnerability scoring can be explained using just 10 of the 36 variables in this analysis.

Another rule of thumb is to use a scree graph like the one below where the variables are plotted along the x-axis and variance associated with each component is on the y-axis. The “elbow” in the graph represents a potential cut-off point for principal components of variation – a sometimes subjective test.

Adaptive Capacity Variables	poverty	no HS diploma	limited English	65+ living alone	unemployment	no vehicle	renter	uninsured	no central AC	HOI	HCV	shelters
poverty												
no HS diploma	0.59											
limited English	0.12	0.5										
65+ living alone	-0.27	-0.19	-0.19									
unemployment	0.66	0.53	0.1	-0.08								
no vehicle	0.82	0.59	-0.01	0	0.59							
renter	0.69	0.25	0.12	-0.25	0.33	0.56						
uninsured	0.4	0.76	0.69	-0.26	0.37	0.24	0.31					
no central AC	0.66	0.79	0.15	-0.2	0.58	0.74	0.36	0.46				
HOI	-0.53	-0.28	0.02	0.17	-0.37	-0.4	-0.53	-0.24	-0.36			
HCV	0.17	0.45	0.11	-0.02	0.33	0.15	0.04	0.51	0.37	-0.08		
shelters	0.12	-0.1	0.02	-0.1	0.05	0.06	0.17	0.05	0.04	-0.16	-0.04	
group homes	0.06	0.02	0.02	-0.03	0.02	0.07	0.1	0.2	0.06	-0.19	0.22	0.17

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Standard	4.10	2.17	1.85	1.39	1.28	1.03	0.98	0.96	0.93	0.86
Proportion	0.46	0.13	0.09	0.05	0.04	0.03	0.03	0.02	0.02	0.02
Cumulative	0.46	0.58	0.67	0.73	0.77	0.80	0.83	0.85	0.87	0.90

Figure 8.1: Scree graph produced in R



¹ “How Many Components should be Retained from a Multivariate Time Series PCA?,” Rea and Rea: <https://arxiv.org/pdf/1610.03588.pdf>.

9. Appendix C:

Asset Vulnerability Stakeholder Scoring

Communications Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Communications Infrastructure	1.5	1.75	3.25	2	1.6	3.6

Community Buildings

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Libraries and Community Centers	2.4	2.13	4.53	2.24	2.25	4.49
Museums	2.14	2.08	4.22	2.06	2.21	4.27
Religious Centers	2.5	2	4.50	2.13	2	4.13
Voting Stations	2.57	2.13	4.70	2.38	2.25	4.63

Economic Development and Planning

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Convention Center	1.78	2.17	3.95	2	2.43	4.43
Fortune 500 Companies	2.4	2.43	4.83	2.63	2.63	5.26
Planning Zones, Plan Areas and Districts*	2.25	2.13	4.38	2.25	1.86	4.11

*CARE, Art District Incentive, and Enterprise Zones; Community Unit and Development Plans; Design Overlay District

Education

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Childcare Facilities	2.5	2	4.50	2.13	2	4.13
Colleges and Universities	1.95	1.68	3.63	1.87	1.75	3.62
K12 Public Schools	2.59	2.41	5.00	2.47	2.31	4.78
Private Schools	2	1.5	3.50	1.86	1.5	3.36

Energy Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Biodiesel Plants	1.4	2	3.40	2	2.4	4.4
Electric Power Transmission Lines	3	2.4	5.40	2	2.2	4.2
Electrical Substations	2.67	2.2	4.87	2.83	2.4	5.23
Natural Gas Pipeline	1.5	2.2	3.70	1.33	2.4	3.73
Non Gasoline Alternative Fueling Stations	1.5	1.33	2.83	1.4	2	3.4
Petroleum Ports	1.67	2.5	4.17	2.83	2.6	5.43
Petroleum Terminals	1.67	2.5	4.17	2.83	2.6	5.43
Potential Renewable Energy Sites	1.17	1	2.17	1.5	1	2.5

Food System Assets and Resources

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Food Pantries and Warehouses	2.17	2	4.17	2.17	2	4.17

Government Facilities

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
City Property	2.2	2.33	4.53	2.13	2.29	4.42
Court System	2.1	2.25	4.35	2.25	2.25	4.5
State Government	2	2	4.00	2.13	2.43	4.56

Health and Social Services

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Homeless Facilities	2.5	2.17	4.67	2.17	2.33	4.5
Hospitals	2.23	1.71	3.94	2.19	2.06	4.25
Nursing Homes	2.5	2.17	4.67	2.17	2.33	4.5
Other Health	1.86	1.71	3.57	2	2	4
Social Services	2.5	2.17	4.67	2.17	2.33	4.5

Historic

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Historic Sites	2.4	2.71	5.11	2.75	3	5.75

Public Housing Resources

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
RRHA / HUD Housing	2.7	2.51	5.21	2.46	2.6	5.06

Public Safety and Emergency Response

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Emergency Operations	2.18	2.17	4.35	2.13	2.14	4.27
Fire Stations	1.95	2.23	4.18	2.13	2.33	4.46
Police / Sheriff	1.95	2.23	4.18	2.13	2.33	4.46
Social Services	2.5	2.17	4.67	2.17	2.33	4.5

Stormwater and Sewer Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Sewer Treatment Plant	1.73	1.95	3.68	3	2.44	5.44
Stormwater & Sewer Infrastructure	1.46	1.75	3.21	3	2.75	5.75

Transportation Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Airport	2.22	1.83	4.05	2.11	2	4.11
Bike and Pedestrian	2.5	2.31	4.81	2.54	2.23	4.77
Marine	1.25	1.17	2.42	2.36	2.29	4.65
Transit / Rail	2.13	1.8	3.93	2.38	2.07	4.45
Road	1.64	1.92	3.56	2.8	2.13	4.93

Waste Management Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
EPA Emergency Response Facilities	1.78	1.67	3.45	2.88	2.14	5.02
Solid Waste Landfill Facilities	1.5	1.78	3.28	2.4	2.22	4.62
Composting, Recycling, and MSW Facilities	1.91	1.8	3.71	2.45	2.2	4.65

Water Supply Infrastructure

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
Dams	1.46	1.75	3.21	3	2.75	5.75
Water Supply Infrastructure	1.91	2.11	4.02	2.33	2.5	4.83

Natural Assets

Assets	Heat Threats			Water Threats		
	Sensitivity	Adaptive Capacity	Combined Heat Vulnerability Score	Sensitivity	Adaptive Capacity	Combined Water Vulnerability Score
<i>Water Bodies</i>						
Protected Areas, Creeks and Lakes	2.62	2.25	4.87	2.85	2.08	4.93
<i>Trees and Vegetation</i>						
Trees and Vegetation	2.62	2	4.62	2.31	2.08	4.39
<i>Terrestrial Habitat</i>						
Protected Areas and Habitats	2.62	2.25	4.87	2.85	2.08	4.93
<i>Parks and Open Spaces</i>						
Cemeteries	2.55	2.25	4.80	2.5	2.1	4.6
Community Gardens	2.77	2.27	5.04	2.75	2.19	4.94
Parks and Playgrounds	3	2.29	5.29	3	2.29	5.29

9. Appendix D: Consequence Analysis

Communications Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Communications Infrastructure	15	2	2	1.5	2.5	2	2	2	1

Communications Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Libraries and Community Centers	18.4	2.29	2.43	2.64	2.14	1.85	2.39	2.73	1.94
Museums	16.8	2.1	2.43	2.71	1.81	2	1.94	2.14	1.67
Religious Centers	18.38	2	2.29	2.43	2.33	2	2.56	2.78	2
Voting Stations	20.05	2.43	2.57	2.71	2.44	2.13	2.5	2.89	2.38

Consequence Scale				
Low 8	Medium-Low 8.01-11.99	Medium 12-15.99	Medium-High 16-19.99	Low 20-24

Economic Development and Planning

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Convention Center	15.22	2.2	2.57	3	1.29	2	1.33	1.5	1.33
Fortune 500 Companies	17.4	2.67	2.5	2.67	1.67	2.57	1.83	2	1.5
Planning Zones, Plan Areas and Districts	19.13	2.25	2.2	2.43	2.43	2.71	2.38	2.88	1.86

*CARE, Art District Incentive, and Enterprise Zones; Community Unit and Development Plans; Design Overlay District

Education

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Childcare Facilities	18.38	2	2.29	2.43	2.33	2	2.56	2.78	2
Colleges and Universities	15.38	2.21	1.82	2.49	1.57	2	1.79	1.67	1.83
K-12 Public Schools	19.19	2.5	2.46	2.54	2.31	2.07	2.5	2.73	2.06
Private Schools	15.19	2.14	1.83	2.14	1.57	2.14	1.86	1.67	1.83

Economic Development and Planning

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Biodiesel Plants	12.67	1.33	1.67	1.67	2	1.33	1.33	1.33	2
Electric Power Transmission Lines	19.5	2.75	2.5	2.75	2.5	2.5	2.5	2.75	1.25
Electrical Substation	19.75	2.75	2.75	2.75	2.5	2.5	2.5	2.5	1.5
Natural Gas Pipelines	18.92	1.75	2.5	2.5	2.5	2.25	2.5	2.67	2.25
Non Gasoline Alternative Fueling Stations	13.33	1.67	2	1.67	1.33	1.67	1.33	1.67	2
Petroleum Ports	19.5	2	2.5	2.75	2.75	2.25	2.5	2	2.75
Petroleum Terminals	19.5	2	2.5	2.75	2.75	2.25	2.5	2	2.75
Potential Renewable Energy Sites	10.25	1.25	1.75	1.75	1	1.25	1	1.25	1

Food System Assets and Resources

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Food Pantries & Warehouses	17.6	2	2.4	1.8	2	2.4	2.4	2.6	2
Private Schools	15.19	2.14	1.83	2.14	1.57	2.14	1.86	1.67	1.83

Government Facilities

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
City Property	18.6	2.57	2.17	2.86	2.67	2	2.17	2.17	2
Court System	18.57	2	2	2.57	2.86	1.86	2.57	2.71	2
State Government	18.76	2.71	2.29	2.86	2.57	2.33	2	2.17	1.83

Health and Social Services

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Homeless Facilities	19.57	2.67	2.5	2.33	2.33	2.4	2.5	2.67	2.17
Hospitals	19.34	2.37	2	2.42	2.52	2.4	2.63	2.83	2.17
Nursing Homes	19.57	2.67	2.5	2.33	2.33	2.4	2.5	2.67	2.17
Other Health	19.1	2.17	2.2	2.17	2.33	2.67	2.4	2.83	2.33
Social Services	19.57	2.67	2.5	2.33	2.33	2.4	2.5	2.67	2.17

Historic Resources

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Historic Sites	15.48	2	2.67	2.71	1.29	2.14	1.43	1.57	1.67

Historic Resources

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
RRHA / HUD Housing	21	2.69	2.75	2.67	2.6	2.49	2.75	2.83	2.23

Public Safety and Emergency Response

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Emergency Operations	19.24	2.36	2.28	2.42	2.76	2.08	2.61	2.9	1.83
Fire Stations	18.8	2	2.2	2.54	2.76	2.01	2.54	2.76	2
Police / Sheriff	18.8	2	2.2	2.54	2.76	2.01	2.54	2.76	2

Stormwater and Sewer Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Sewer Treatment Plant	21.62	2.71	2.61	2.86	2.67	2.43	2.87	2.67	2.8
Stormwater & Sewer Infrastructure	22.13	2.57	2.71	3	2.71	2.57	2.86	2.85	2.86

Transportation Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Airport	17.09	2.91	2.5	2.4	1.7	2.8	1.56	1.44	1.78
Bike & Pedestrian	18.77	2.5	2.18	1.73	2.58	2.08	2.69	2.85	2.17
Marine	17.31	2.67	2.56	2.56	1.63	2.7	1.71	1.71	1.78
Transit/Rail	18.63	2.64	2.36	2.14	2.13	2.47	2.13	2.6	2.15
Road	19.35	2.47	2.36	2.57	2.54	2.29	2.27	2.53	2.33

Waste Management Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
EPA Emergency Response - regulated facilities	20.29	2.11	2.11	2.75	2.89	2	2.88	2.78	2.78
Solid Waste Landfill Facilities	19.28	2.6	2.4	2.38	2.2	2	2.4	2.4	2.9
Transfer Stations									
General Solid Waste System: (Composting, Municipal Solid Waste, Recycling)									
Composting	19.22	2.45	2.36	2.4	2.27	2	2.55	2.45	2.73
Municipal Solid Waste									
Recycling									

Water Supply Infrastructure

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
Water Supply Infrastructure	22.26	2.92	2.54	2.83	2.85	2.58	3	3	2.54

Natural Assets

Assets	Consequence Total Score	Area of service loss	Duration of service loss	Cost of damage	Public safety impacts	Economic activities impacts	Public health impacts	Vulnerable populations impacts	Environmental impacts
<i>Water Bodies</i>									
Protected Areas, Creeks and Lakes	20.17	2.69	2.64	2.62	2.09	2.42	2.42	2.3	3
<i>Trees and Vegetation</i>									
Trees and Vegetation	20.91	2.62	2.73	2.33	2.54	2.08	2.69	2.92	3
<i>Terrestrial Habitat</i>									
Protected Areas and Habitats	20.17	2.69	2.64	2.62	2.09	2.42	2.42	2.3	3
<i>Parks and Open Spaces</i>									
Community Gardens	20.83	2.62	2.44	2.4	2.37	2.39	2.8	3	2.82
Green/ Community Spaces	20.83	2.62	2.44	2.4	2.37	2.39	2.8	3	2.82
Parks and Playgrounds	21.47	2.78	2.57	2.5	2.38	2.38	2.88	3	3

9. Appendix E: Heat Risk

Richmond Built and Natural Assets

Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*			Critical Heat Risk - Afternoon Mean High Temp >96*			
			All Assets at Heat Risk	Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas	All Assets at Highest Heat Risk	Assets at Highest Heat Risk in Most Socially Vulnerable Areas	Assets Serving SV Groups at Highest Heat Risk Outside Most SV Areas	Assets/locations exposed to Critical Heat Risk (Above 96*) in Most Vulnerable SV Areas or serving SV Groups*
Active StormwaterOutfall	1,658	units	468	327	0	0	0	0	0
AM Transmission Towers	3	towers	1	1	0	0	0	0	0
		American Red Cross Chapter Facilities	1	facilities	1	0	0	0	0
		Art District Incentive Zones	0.15	acres	1	0	0	0	0
Bike Infrastructure	71.2	miles	35.7	6.8	0.0	7.4	0.0	0.0	0
		Bikeshare Stations	17	stations	16	1	0	5	0
Biodiesel Plants	1	facilities	1	1	0	0	0	0	0
		Bridges	177	bridges	107	46	0	2	0
CARE Zones	13	zones	12	10	2	3	1	2	*Meadowbridge, *North 25th Street, *Lombardy/Chamberlayne
		Cellular Towers	1	towers	0	0	0	0	0
Cemeteries	17	cemeteries	7	5	0	0	0	0	0
		Chesapeake Bay Protection Area	13,038.3	acres	3,728.30	3,193.3	0.00	31.10	0.00
Childcare Centers	118	centers	61	33	0	6	1	0	Oak Grove Child Care Center - 2200 Fairfax Avenue Richmond, VA 23224
City Historic Districts	45	districts	41	2	0	5	1	0	0
City Historic Sites	29	sites	26	0	0	2	0	0	0
		City Property	966	properties	369	196	0	26	0
Colleges and Universities	4	universities	2	0	0	0	0	0	0
Community Centers	22	centers	13	9	0	1	0	0	0
Community Gardens	5	sites	4	2	0	1	0	0	0

Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*			Critical Heat Risk - Afternoon Mean High Temp >96*			
			All Assets at Heat Risk	Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas	All Assets at Highest Heat Risk	Assets at Highest Heat Risk in Most Socially Vulnerable Areas	Assets Serving SV Groups at Highest Heat Risk Outside Most SV Areas	Assets/locations exposed to Critical Heat Risk (Above 96*) in Most Vulnerable SV Areas or serving SV Groups*
Community Unit Plans	110	plans	35	28	0	0	0	0	0
Composting, Recycling, and MSW Facilities	no data points available		0	0	0	0	0	0	0
Convention Center	1	centers	1	0	0	0	0	0	0
Cooling Centers	3	centers	3	1	2	0	0	0	0
Correctional Facilities	3	facilities	3	2	1	0	0	0	0
Courthouses and Court Systems	9	facilities	9	3	0	0	0	0	0
Creeks	31	creeks	10	9	0	0	0	0	0
Dams	2	dams	0	0	0	0	0	0	0
Design Overlay District	3	districts	3	0	0	0	0	0	0
Dialysis Clinics	5	clinics	3	1	2	1	0	1	*DaVita Richmond Community Dialysis - 913 North 25th Street Richmond VA 23233
Electric Power Transmission Lines	53.7	miles	45.2	37.7	0.0	3.9	0.4	0.0	See map for locations
Electric Vehicle Charging Stations	134	stations	60	16	0	17	2	0	
Electrical Substations	1	substations	1	1	1	0.0	0.0	0.0	0
EMS Stations	24	stations	16	7	0	4	0	0	0
Enterprise Zones	4	zones	4	3	1	2	2	0	*III (2746.8 acre), *I(3611.2 acre)
EPA Regulated Facilities	79	facilities	75	52	0	14	1	0	Southern Printing Ink
Fire Stations	21	stations	14	6	0	3	0	0	0
FM Transmission Towers	5	towers	4	1	0	1	0	0	0
Food Pantries	9	pantries	5	3	2	2	0	2	*Northside Outreach Center - 3096 Meadowbridge Road Richmond, VA 23222, *Sara and Steve Bayard Community Kitchen - 1415 Rhoadmiller Street Richmond, VA 23220
Fortune 500 Corporate Headquarters	1	sites	0	0	0	0	0	0	0
Homeless Facilities	5	facilities	5	1	4	2	1	1	Caritas - 1125 Commerce Road Richmond, VA 23224, *Pilgrims Passage - 1500 Sherwood Road Richmond, VA 23220
Hospitals	6	hospitals	4	2	0	0	0	0	0
HUD Multifamily Properties	27	properties	13	12	1	1	0	1	*Highland Park Senior Apartments - 1221 E Brookland Park Blvd, Richmond, VA, 23222
James River Features Islands (Islands)	15	islands	7	5	0	0	0	0	0

Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*			Critical Heat Risk - Afternoon Mean High Temp >96*			
			All Assets at Heat Risk	Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas	All Assets at Highest Heat Risk	Assets at Highest Heat Risk in Most Socially Vulnerable Areas	Assets Serving SV Groups at Highest Heat Risk Outside Most SV Areas	Assets/locations exposed to Critical Heat Risk (Above 96*) in Most Vulnerable SV Areas or serving SV Groups*
K12 Public Schools	44	schools	19	9	0	1	0	0	0
Lakes	100	lakes	28	28	0	0	0	0	0
Libraries	13	libraries	10	2	0	0	0	0	0
Local Emergency Operations Centers	1	center	1	0	0	1	0	0	0
Major State Government Buildings	38	buildings	36	1	0	4	0	0	0
Marine Transportation	1	unit	1	1	0	0	0	0	0
Museums	37	buildings	28	1	0	2	0	0	0
National Register Historic Districts	133	Districts	108	22	0	24	4	0	Union Hill; Southern Stove Works; Chesapeake Warehouses; Highland Park Plaza
National Shelter System Facilities	20	facilities	13	3	0	3	0	0	0
NaturalGas Pipeline	1.6	miles	0.2	0.2	0.0	0.0	0.0	0.0	0
Non Gasoline Alternative Fueling Stations	13	stations	12	4	0	3	0	0	0
Nursing Homes	17	homes	11	5	6	1	0	1	*Brook Haven Rest Home - 610 Fourquare Lane
Parks and Playgrounds	143	parks	72	25	0	7	0	0	0
Pedestrian Infrastructure	no data points available		0	0	0	0	0	0	0
Petroleum Ports	1	ports	1	1	0	0	0	0	0
Petroleum Terminals	9	terminals	9	9	0	0	0	0	0
Police Stations	5	Stations	5	2	0	1	0	0	0
Potential Renewable Energy Sites	13	sites	12	5	0	2	0	0	0
Private Schools	34	schools	13	4	0	3	0	0	0
Public Refrigerated Warehouses	2	sites	2	1	0	0	0	0	0
Public Transit Stations	2	stations	2	0	2	1	0	1	*Greyhound Bus Station - 2910 N Boulevard Richmond VA 23230
Railroad Bridges	27	bridges	14	7	0	0	0	0	0
Rail Lines	159.6	miles	112.5	73.7	0.0	13	0.6	0.0	See map for locations
Religious Centers	74	Centers	42	16	0	5	0	0	See map for locations
Richmond International Airport	0	airports		Outside city limits		0	0	0	0
Roads	1,206.7	miles	640.3	314.0	0.0	80.1	9.9	0.0	0
RRHA Housing	60	locations/parcels	36	31	5	0	0	0	0
Sewer Treatment Plant	1	plants	1	1	0	0	0	0	0
Sheriff Facilities	7	facilities	7	5	0	0	0	0	0

Asset Name	Total City-wide	Units	Heat Risk - Afternoon Mean High Temp >95*			Critical Heat Risk - Afternoon Mean High Temp >96*			
			All Assets at Heat Risk	Assets at Heat Risk in Highly Socially Vulnerable (SV) Areas	Assets Serving SV Groups at Heat Risk Outside Highly SV Areas	All Assets at Highest Heat Risk	Assets at Highest Heat Risk in Most Socially Vulnerable Areas	Assets Serving SV Groups at Highest Heat Risk Outside Most SV Areas	Assets/locations exposed to Critical Heat Risk (Above 96*) in Most Vulnerable SV Areas or serving SV Groups*
SNAP Businesses	193	businesses	110	67	43	19	0	19	See map for locations
Social Services	3	services	3	1	2	0	0	0	0
Solid Waste Landfill Facilities	1	facilities	1	1	0	0	0	0	0
State Federal Historic Sites	156	sites	124	16	0	13	1	0	Southern Stove Works Manchester
Terrestrial Habitat	14	habitats/locations	13	12	0	4	2	0	Agriculture; Southern Atlantic Coastal Plain Mesic Hardwood Forest
Trails	15.94	miles	0.50	0.5	0.00	0.00	0.00	0.00	0
Tree canopy (Street Trees and Trees Other)	120,356	trees	61,396	25,696	0	6,846	1,022	0	See map for areas
Urgent Care Facilities	2	facilities	1	0	0	0	0	0	0
Vegetation/pervious surface cover	no data points available		0	0	0	0	0	0	0
Veteran Health Administration Medical Facilities	2	facilities	1	0	0	0	0	0	0
Voting Stations	67	stations	36	16	0	2	0	0	0
Water Pipes	no data points available		0	0	0	0	0	0	0
Water Treatment Plant	no data points available		0	0	0	0	0	0	0

9. Appendix F: Flood Risk

Richmond Built and Natural Assets

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
Active StormwaterOutfall	1,658	units	731	935	672	698	1064	492	0	154	0	See map for locations
AM Transmission Towers	3	towers	1	1	1	1	1	1	0	0	0	0
		American Red Cross Chapter Facilities	1	facilities	0	0	0	1	0	0	0	0
		Art District Incentive Zones	0.15	acres	0	0	1	1	1	0	0	0
Bike Infrastructure	71.2	miles	6.8	9.0	5.0	5.5	11.3	3.1	0.0	0.59	0.0	See map for locations
		Bikeshare Stations	17	stations	0	1	0	0	0	0	0	0
Biodiesel Plants	1	facilities	1	1	1	1	1	1	0	1	0	Reco Biodiesel Inc
		Bridges	177	bridges	39	48	43	44	62	27	0	15
CARE Zones	13	zones	5	6	13	13	13	11	2	2	11	*Belt Boulevard, *Brookland Park Boulevard, *Fulton Hill, *Hull Street, *Jackson Ward, *Midlothian Turnpike, *North Avenue, *North 25th Street, *Shockoe Bottom, *Swansboro, *Upper Hull Street, Lombardy/Chamberlayne, Meadowbridge,
		Cellular Towers	1	towers	0	0	0	0	0	0	0	0

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
Cemeteries	17	cemeteries	0	0	2	2	2	0	0	0	0	0
		Chesapeake Bay Protection Area	13,038.3	acres	2,501.3	3,265.7	1,703.1	1,918.4	3409.6	1,964.8	0.0	991.4
Childcare Centers	118	centers	0	1	43	56	43	15	0	4	0	North Richmond Branch YMCA; Fairfield Elementary School; Oak Grove Child Care Center; Bethlehem Baptist Church Child Development Center
City Historic Districts	45	districts	1	5	41	43	41	3	0	0	0	0
City Historic Sites	29	sites	0	2	25	27	25	0	0	0	0	0
		City Property	966	properties	22	47	100	136	118	62	0	2
Colleges and Universities	4	universities	0	0	4	4	4	0	0	0	0	0
Community Centers	22	centers	0	0	12	15	12	7	0	2	0	Creighton Court Community Center; Calhoun Community Center and Playground
Community Gardens	5	sites	0	0	0	0	0	0	0	0	0	0
Community Unit Plans	110	plans	45	45	110	110	110	30	0	4	0	See map for locations
Composting, Recycling, and MSW Facilities	no data points available		0	0	0	0	0	0	0	0	0	0
Convention Center	1	centers	0	0	0	0	0	0	0	0	0	0
Cooling Centers	3	centers	0	0	1	1	1	0	1	0	1	*East District Center - 701 North 25th Street Richmond VA 23223
Correctional Facilities	3	facilities	1	2	3	3	3	2	1	2	1	*Medical College Of Virginia Security Ward - 401 North 12th Street Richmond VA 23219, Richmond City Jail - 1701 Fairfield Way Richmond VA 23223, Richmond Juvenile Detention Center - 1700 Oliver Hill Way Richmond VA 23219
Courthouses and Court Systems	9	facilities	0	1	0	0	1	0	0	0	0	0
Creeks	31	creeks	27	31	31	31	31	17	0	4	0	0
Dams	2	dams	0	0	0	0	0	0	0	0	0	0
Design Overlay District	3	districts	0	0	3	3	3	0	0	0	0	0
Dialysis Clinics	5	clinics	0	0	0	0	0	0	0	0	0	0
Electric Power Transmission Lines	53.7	miles	18.9	25.6	15.4	17.2	25.2	21.8	0.0	16.2	0.0	See map for locations

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
Electrical Substations	1	substations	0	0	0	0	0	0	0	0	0	0
Electric Vehicle Charging Stations	134.	stations	2	15	24	27	24	5	0	2	0	1001 E 4th St (ID: 187899), 1001 E 4th St (ID: 188105)
EMS Stations	24	stations	1	2	11	17	11	4	0	2	0	Richmond Fire Department Company 21; Phillip Morris Fire Brigade
Enterprise Zones	4	zones	3	3	4	4	4	4	0	3	0	III (2746.8 acre), III (47.1 acre), 1 (3611.2 acre)
EPA Regulated Facilities	79	facilities	5	18	10	13	14	10	0	4	0	City of Richmond Wastewater Treatment Plant; Bellemeade Power Station; Industrial Alloy Fabricators Inc; Reco Biodiesel, LLC
Fire Stations	21	stations	0	1	10	13	10	3	0	1	0	Richmond Fire Station 21
FM Transmission Towers	5	towers	0	0	0	0	0	0	0	0	0	0
Food Pantries	9	pantries	0	1	0	1	0	0	0	0	0	0
Fortune 500 Corporate Headquarters	1	sites	0	1	0	1	1	1	0	0	0	0
Homeless Facilities	5	facilities	0	1	1	1	1	0	1	0	1	*HomeAgain - 2 East Main Street Richmond VA 23219
Hospitals	6	hospitals	0	0	5	5	5	3	0	0	0	0
HUD Multifamily Properties	27	properties	0	0	2	2	2	1	1	0	2	*Charnwood Forest 4325 Crutchfield St Richmond VA 23225, Blue Ridge Estates - 6507 Sugar Maple Dr. Richmond VA 23225
James River Features Islands (Islands)	15	islands	15	15	15	15	15	8	0	0	0	0
K12 Public Schools	44	schools	0	0	19	29	19	7	0	4	0	Oak Grove Elementary School; John Marshall High School; REAL School; Thomas H Henderson Middle School
Lakes	100	lakes	42	52	88	98	92	39	0	18	0	See map for locations
Libraries	13	libraries	0	0	5	6	5	0	0	0	0	0
Local Emergency Operations Centers	1	center	1	1	1	1	1	0	0	0	0	0
Major State Government Buildings	38	buildings	0	0	18	22	18	0	0	0	0	0
Marine Transportation	1	unit	1	1	0	0	1	1	0	1	0	5001 Deepwater Terminal Rd
Museums	37	buildings	2	8	18	25	18	0	0	0	0	0

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
National Register Historic Districts	133	Districts	24	30	122	129	122	32	0	12	0	Union Hill; Southern Stove Works; Chesapeake Warehouses; Hebrew Cemetery; Pine Camp Tuberculosis Hospital; Richmond Nursing Home; Chesnut Hill-Plateau; Fairmount; Highland Park Plaza; Manchester Industrial; Baker School; American Tobacco Company
National Shelter System Facilities	20	facilities	0	0	11	17	11	5	0	3	0	John Marshall High School; The Calhoun Center; Henderson Middle School
NaturalGas Pipeline	1.6	miles	0.1	0.1	0.1	0.1	0.2	0.0	0.0	0	0	0
Non Gasoline Alternative Fueling Stations	13	stations	0	1	9	9	9	2	0	0	0	0
Nursing Homes	17	homes	0	0	10	11	10	2	8	0	10	*Brookdale Imperial Plaza - 1717 Bellevue Avenue Richmond VA 23227, *Greenfield Residences At Monument Avenue - 501 North Allen Avenue Richmond VA 23220, *Hermitage Methodist Home - 1600 Westwood Avenue Richmond VA 23227, *Humphrey's Retirement Home - 3405 Chamberlayne Avenue Richmond VA 23227, *Jones & Jones LLC - 7804 Forest Hill Avenue Richmond VA 23225, *Madison House - 3212 Chamberlayne Avenue Richmond VA 23227, *The Parkwood - 3003 Parkwood Avenue Richmond VA 23221, *Tiffanie's Manor For Young Adults - 115 North Jefferson Street Richmond VA 23220
Parks and Playgrounds	143	parks	26	33	24	31	47	14	0	2	0	James River Park-Ancarrows Landing; Roy West Park (Washington Park)
Pedestrian Infrastructure	no data points available		0	0	0	0	0	0	0	0	0	0
Petroleum Ports	1	ports	1	1	0	0	1	1	0	1	0	Port of Richmond
Petroleum Terminals	9	terminals	0	4	8	8	8	8	0	5	0	Bukeye Terminals, LLC; Chevron Richmond Terminal; First Energy Corporation; Kinder Morgan Southeast Terminals- Richmond; Kinder Morgan Southeast Terminals- Richmond 2

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
Police Stations	5	Stations	0	0	1	2	1	1	0	0	0	0
Potential Renewable Energy Sites	13	sites	2	3	2	2	3	1	0	1	0	Madison Arms I and II
Private Schools	34	schools	0	0	13	20	13	3	0	1	0	Geara Group/Educational Developmental Center
Public Refrigerated Warehouses	2	sites	0	0	0	0	0	0	0	0	0	0
Public Transit Stations	2	stations	1	1	2	2	2	0	2	0	2	*Main Street Amtrak Station - 1500 E Main St Richmond VA 23219, *Greyhound Bus Station - 2910 N Boulevard Richmond VA 23230
Railroad Bridges	27	bridges	14	19	5	5	15	7	0	2	0	CSX Transportation, Goode Creek; CSX Transportation, Goode Creek
Rail Lines	159.6	miles	48.5	0.0	17.2	21.8	57.7	18.7	0.0	13.7	0.0	See map and reference file for locations
Religious Centers	74	Centers	0	0	34	50	34	9	0	4	0	Saint Kim Taegon Catholic Church; Fifth Street Baptist Church; Bethlehem Baptist Church; Grayland Baptist Church
Richmond International Airport	0	airports		Outside city limits			0	0	0	0	0	0
Roads	1,206.7	miles	28.7	56.7	71.7	84.9	94.3	43.8	0.0	14.9	0.0	See map for locations
RRHA Housing	60	locations/parcels	1	1	42	55	42	40	2	39	3	See map for locations
Sewer Treatment Plant	1	plants	1	1	0	0	1	1	0	1	0	Anacarows Landing
Sheriff Facilities	7	facilities	0	3	5	6	5	4	0	3	0	Juvenile Detention Center; Oliver Hill Courts Building; Richmond Detention Center
SNAP Businesses	193	businesses	0	6	11	16	11	8	3	1	10	See map for locations
Social Services	3	services	0	0	1	1	1	0	1	0	1	*DSS East District Center - 701 North 25th Street Richmond VA 23223
Solid Waste Landfill Facilities	1	facilities	0	0	0	1	0	0	0	0	0	0
State Federal Historic Sites	156	sites	13	20	119	133	119	17	0	6	0	The Almshouse; Shockoe Hill Cemetery; Pine Camp Tuberculosis Hospital; Southern Stove Works Manchester; Fairmount School; Hebrew Cemetery

Asset Name	Total City-wide	Units	Flooding Risks				Critical Flood Risk					
			In 100-year Floodplain	In 500-year Floodplain	Affected by >5" Flooding Inundation	Affected by >2" Flooding Inundation	All Assets in 100-year Floodplain and/or >5" Flooding Inundation	Assets at Risk in Highly Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Highly SV areas	Assets at Risk in Most Socially Vulnerable Areas	Resources Serving SV Groups at Risk Outside Most SV areas	Assets exposed to Critical Flood Risk in Most Vulnerable SV Areas or serving SV Groups*
Terrestrial Habitat	14	habitats/ locations	13	14	14	14	14	13	0	10	0	Open water; Riparian Forest; Agriculture; Southern Atlantic Coastal Plain Mesic Hardwood Forest; Coastal Plain Tidal Swamp; Piedmont-Coastal Plain Large River Floodplain; Dry Oak-Pine Forest; Tidal Salt Marsh- Estuarine Marsh; Shrubland/Grassland; Laurentian-Arcadian Freshwater Marsh
Trails	15.94	miles	4.7	5.4	0.4	0.5	4.7	2.1	0.0	0	0.0	0
Tree canopy (Street Trees and Trees Other)	120,356	trees	1,739	3,286	8,408	12,019	9597	3,556	0	929	0	See map for locations
Urgent Care Facilities	2	facilities	0	0	2	2	2	0	0	0	0	0
Vegetation/pervious surface cover	no data points available		0	0	0	0	0	0	0	0	0	0
Veteran Health Administration Medical Facilities	2	facilities	0	0	0	0	0	0	0	0	0	0
Voting Stations	67	stations	0	2	31	45	32	12	0	3	0	Calhoun Center; John Marshall High School; 5th Street Baptist Church
Water Pipes	no data points available		0		0	0	0	0	0	0	0	
Water Treatment Plant	no data points available		0	0	0	0	0	0	0	0	0	