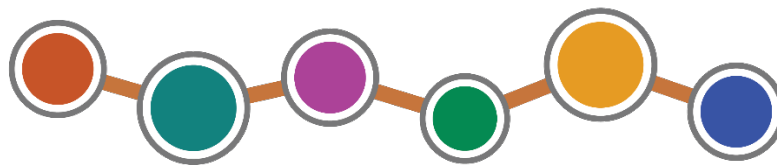


DUKE STREET LAND USE PLAN



Climate Change Vulnerability and Risk Assessment Report

September 2026

Prepared for:

City of Alexandria, Virginia

Prepared by:

Kimley»Horn

Table of Contents

Acronyms and Definitions	2
Executive Summary	3
Study Purpose and Background	3
Existing Environmental Conditions Assessment	3
Climate Change Adaptation Measures.....	4
I. Existing Environmental Conditions Assessment	6
A. Purpose and Objectives.....	6
B. Corridor Overview.....	7
C. Background Review.....	8
Flooding	8
Water Quality	9
Extreme Heat	10
D. Environmental Risk Profile.....	11
Flood Risk	11
Water Quality Risk	14
Heat Risk	17
I-Tree Canopy Tool	19
Total Environmental Risk Ranking.....	20
E. Social Vulnerability	23
F. Existing Conditions Conclusions	25
Future Risks	25
II. Climate Change Adaptation Measures	27
A. Citywide Efforts.....	27
B. ASCE 24-24 Updates	29
C. Mitigation Strategies for the Duke Street Corridor	30
Site-Specific Conceptual Recommendations.....	34
D. Conclusion.....	36
References.....	37

Acronyms and Definitions

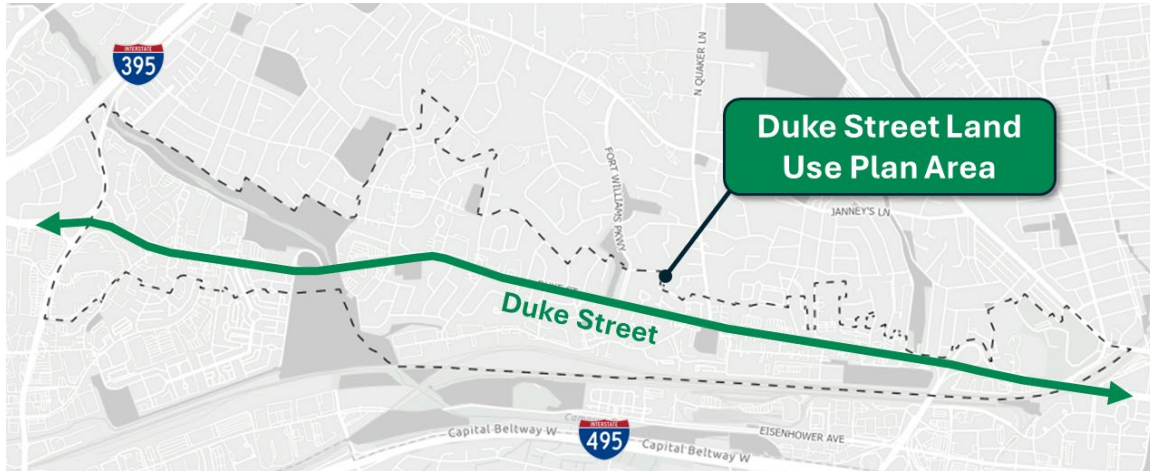
Acronym	Definition
BMP	Best Management Practice
CASSCA	City of Alexandria Storm Sewer Capacity Analysis
CDC	U.S. Center for Disease Control
CRCI	Community Resilience Challenges Index
DCR	Virginia Department of Conservation and Recreation
DEQ	Virginia Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
IDDE	Illicit Discharge Detection and Elimination
NHC	National Hurricane Center
NIHHIS	National Integrated Heat Health Information System
NOAA	National Oceanic and Atmospheric Administration
PM2.5	Air pollution particles smaller than 2.5 microns (fine particles)
PM10	Air pollution particles smaller than 10 but greater than 2.5 microns (coarse particles)
RPA	Resource Protection Area
TMDL	Total Maximum Daily Load
TPL	Trust for Public Land
UHI	Urban Heat Island
USDA	U.S. Department of Agriculture
VDOT	Virginia Department of Transportation

Executive Summary

STUDY PURPOSE AND BACKGROUND

The purpose of the overall Duke Street Land Use Plan is to update the corridor's long-term land use vision, which has not been comprehensively updated since 1992, to allow the City to proactively plan for change and prepare for challenges and opportunities.

Figure 1: Duke Street Land Use Plan Study Area



EXISTING ENVIRONMENTAL CONDITIONS ASSESSMENT

The Duke Street Land Use Plan Climate Change Vulnerability and Risk Assessment was performed to evaluate environmental risk along Duke Street and identify potential mitigation strategies that can be advanced along with future development of the corridor. The effort started with an existing environmental conditions assessment (**Section I: Existing Environmental Conditions Assessment**) to identify existing areas of increased environmental risk due to flooding, degraded water quality, and intense heat. Using publicly available data and data obtained from the City, environmental criteria were analyzed and quantified into a total environmental risk score for each parcel within the study area. The results revealed environmental “hotspots” of elevated risk which were then used to identify potential types of, and locations for, mitigation strategies.

The key takeaways from this assessment are:

- The highest environmental risks are concentrated in the western and central portions of the study area
- The strongest indicators of environmental risk are the following risk factors:
 - High impervious surface coverage (e.g., large roof areas with associated surface parking)
 - Lower tree coverage

The Landmark neighborhood on the western side of the study area has high environmental risk and has also been identified as an area of existing market rate affordable housing; therefore, this area should be a high priority for mitigation efforts. The central portion of the study area, centered

around Alexandria Commons and Alexandria City Campus, was identified as an area of high environmental risk, but it was ranked low for social vulnerability since there are fewer residents in the area. The area is primarily commercial and industrial, so although there are few residents, there is a high number of employees/staff who work in the area and are exposed to high environmental risk during working hours. Prioritizing future efforts in this hotspot can provide benefits to those working in the area, as well as the surrounding residential areas.

CLIMATE CHANGE ADAPTATION MEASURES

Based on the results of the initial environmental risk assessment, the study team conducted a detailed process to identify climate change adaptation measures to be considered as mitigation strategies. Identified measures for future consideration include a mix of policy- and infrastructure-oriented strategies, including:

- Installing floodproofing measures
- Planting additional street trees
- Encouraging green infrastructure and rooftop cooling strategies
- Reducing impervious areas

The full results of this assessment are summarized in **Section II: Climate Change Adaptation Measures** and **Table 1**.

Table 1: Proposed Mitigation Strategy Summary Table

Typology	Description	Environmental Risk(s) Mitigated	Proposed Mitigation Strategies	Cost
1	Residential Areas Adjacent to Floodplain	Flooding	- Education - Outreach - Private floodproofing - Flood mitigation	Low
2	Large Expanses of Building/Roof Area with Lack of Green Space	- Urban Heat Island - Flooding - Water Quality	- Green roofs - Cool roofs - Dual-purpose solar - Tree planting	Low to High
3	Streets with Overhead Utilities and Lack of Mature Canopy Growth	- Urban Heat Island - Flooding	- Underground utility lines - Plant street trees	High
4	Large Surface Parking Lots with Lack of Mature Canopy Growth	- Urban Heat Island - Flooding - Water Quality	- Mixed-use development - Green infrastructure - Dual-purpose solar - Tree planting	High

I. Existing Environmental Conditions Assessment

A. PURPOSE AND OBJECTIVES

As climate change increasingly impacts communities around the world, Alexandria residents are faced with environmental hazards such as increasingly severe flooding and extreme heat. The City's Energy and Climate Change Action Plan, completed in 2023, identified flooding and heat as priority vulnerabilities based on climate data analysis, previous regional climate studies, and community workshops.¹

This assessment aims to analyze the existing environmental risk along the corridor by assessing environmental factors such as floodplains, 311 flooding complaints, areas of intense heat, tree canopy, impervious surfaces, and areas treated by stormwater Best Management Practices (BMPs). This assessment forms the basis for identifying climate change mitigation opportunities along the corridor in **Section II: Climate Change Adaptation Measures**.

Three environmental risks were evaluated in this assessment:

- Flood Risk
- Water Quality Risk
- Heat Risk

Flood risk in the corridor was based on fluvial flooding, pluvial flooding, and flash flooding. Fluvial flooding occurs when rivers, lakes, or streams overflow their banks, often due to heavy rainfall or snowmelt. Pluvial flooding is any flooding not related to an overflowing body of water; for example, flooding at surcharging inlets when the storm sewer system is overwhelmed during heavy rainfall. The last category of flooding evaluated was flash flooding, which is defined as a rapid rise in water levels caused by intense rainfall or dam breaks.

Water quality risk refers to the likelihood of pollutants entering the City's waterways. During rainfall events, stormwater flows over the ground and picks up pollutants such as spilled motor oil, pet waste, fertilizers, pesticides, paint, grease, or litter. This contaminated stormwater runoff then flows into the nearest waterway, degrading the water quality for wildlife and humans who use the stream.

Heat risk was based on hotspots of high temperatures within the study area. Extreme temperatures are occurring more frequently due to climate change, and the urban heat island effect exacerbates high temperatures in urban areas. Urban heat islands are caused by high concentrations of impervious surfaces such as buildings, roads, and parking lots, which absorb and re-emit heat more than natural landscapes. This creates "islands" of higher temperatures in urban areas relative to outlying areas. These islands can cause an increase of 1 to 7 degrees Fahrenheit in the daytime and 2 to 5 degrees Fahrenheit during the nighttime.²

B. CORRIDOR OVERVIEW

The study area extends along Duke Street from S Van Dorn Street/N Van Dorn Street to the CSX-owned railroad at the King Street Metro Rail station, as shown in **Figure 1**. The southern limits of the study area are bounded by the railroad, and the northern limits follow the neighborhoods directly adjacent to Duke Street.

Duke Street is crossed by Holmes Run on the western side of the study area, Strawberry Run in the center of the study area, and Taylor Run on the eastern side of the study area. Timber Branch is adjacent to the eastern side of the study area, and Backlick Run flows adjacent to the southwestern corner of the study area. These streams flow south towards Cameron Run, which flows to the southeast, turning into Hunting Creek downstream and eventually joining the Potomac River. Approximately 35 acres of the study area are in the 100-year FEMA floodplain, which is defined as land area with a 1 percent annual chance of flooding. The built environment is highly developed and includes approximately 480 acres (50 percent of the total study area) of impervious areas, including high concentrations of impervious areas in above-ground parking lots.

Stormwater BMPs are designed to detain and filter stormwater runoff to reduce flooding and improve water quality. There are around 90 existing BMPs along the corridor, with the most common type being bioretention facilities.

As defined in the City of Alexandria Zoning Ordinance, the Resource Protection Area (RPA) is a 100-foot buffer from tidal wetlands, tidal shores, and nontidal wetlands connected by surface flow and contiguous to tidal wetlands or water bodies with perennial flow. The RPA is regulated to protect environmentally sensitive areas.³ Approximately 10 percent of the study area is designated as RPA. The vacant Virginia Passenger Rail Authority (VPRA) property (of which approximately 19 acres are within the study area) acts as a natural treatment system for surface runoff entering the Cameron Run RPA due to its undeveloped nature.⁴

Within the study area, roughly 264 acres are currently considered to be covered by tree canopy, which is approximately 27 percent of the total study area and 13 percent below the City's 40 percent canopy coverage goal set by the Environmental Action Plan 2040.⁵ Of the 264 acres of tree canopy found on both public and private properties, only 46 acres have an overlap of tree canopy with impervious surfaces (roads, buildings, parking lots, etc.). In other words, only 18 percent of the tree canopy within the study area overlaps with an existing impervious surface. This means approximately 446 acres of impervious surfaces do not have cover from existing tree canopy. See **Appendix M** for the impervious surfaces and tree canopy cover within the study area.

C. BACKGROUND REVIEW

The existing conditions assessment began with a review of relevant background materials. The list below summarizes key documents that were reviewed. For a list of comprehensive citations, see the **References** section.

City of Alexandria Documents

1. Duke Street Corridor Plan background packet
2. City of Alexandria Energy and Climate Change Action Plan
3. Northern Virginia Hazard Mitigation Plan
4. Flood Action Alexandria
5. 2016 City of Alexandria Storm Sewer Capacity Analysis
6. Phase 3 Chesapeake Bay TMDL Action Plan for 100% Compliance
7. Bacteria Total Maximum Daily Load (TMDL) Action Plan
8. Environmental Action Plan 2040

Federal and State Climate and Sustainability Databases

1. FEMA floodplain database
2. NOAA sea level rise database
3. National Hurricane Center (NHC) storm surge database
4. The Trust for Public Land heat island database
5. USDA Forest Service i-Tree Canopy Tool
6. Climate and Economic Justice Screening Tool (CEJST)
7. FEMA Resilience Analysis and Planning Tool
8. Virginia Social Vulnerability Index
9. Intergovernmental Panel on Climate Change (IPCC) Interactive Atlas

Flooding

The Northern Virginia Hazard Mitigation Plan was completed in 2022 to identify and assess hazards such as droughts, floods, winter weather, high winds, and other major disasters. An overall risk score was calculated for each hazard based on the sum of a total probability score and a total consequence score, and the hazards were rated as low, medium, or high risk based on the overall risk score.⁶ Within the City of Alexandria, flood risk was given a high hazard ranking. Between 1950 and 2021, there have been 40 flood or flash-flood events within the City, resulting in a total of \$695,000 in property damage. High wind and severe storm events were also rated as a high risk for the City, with 14 events between 1950 and 2021 resulting in approximately \$4.5 million in property damage.⁷

The City of Alexandria Energy and Climate Change Action Plan completed in 2023 studied the potential impacts of flooding throughout the City. There have been recent severe flash flooding events within the City in July of 2019, July and September of 2020, and August and September of 2021, as well as storm events associated with Hurricane Isabel in 2006, Hurricane Irene in 2011, and Tropical Storm Lee in 2011.¹

In general, the study area has a lower concentration of 311 flooding calls than the rest of the City; out of the 975 flooding complaints in the City's database, only 31 are within the study area. Most flooding complaints are concentrated in the eastern part of the city, along the Hooffs Run and Four Mile Run watersheds. This aligns with the results of the 2016 CASSCA study, which evaluated the

capacity of existing stormwater infrastructure and identified Hooffs Run and Four Mile Run as having the highest potential flooding density and severity.⁸

The ongoing Flood Action Alexandria initiative aims to reduce flooding through stormwater projects throughout the City, including one project within the study area.⁹ The City also received a grant in 2024 to support the development of a Flood Resilience Plan, which will expand upon the 2021 Resilience Plan to identify flood mitigation solutions.¹⁰ The Flood Resilience Plan is a parallel effort to this Climate Change Vulnerability and Risk Assessment for the Duke Street Land Use Plan, and results may overlap between these studies. Although the draft Flood Resilience Plan report will not be released until August 2026, preliminary findings were presented during an April 16, 2026 public meeting. Based on the flood vulnerability assessment results presented during the meeting, several watersheds within the Duke Street corridor were identified as having higher vulnerability to flooding impacts; the Backlick Run watershed and the eastern Holmes Run watershed. The Holmes Run, Backlick Run, and Cameron Run watersheds were identified as priority areas for future watershed planning efforts.

Dam failure causes an uncontrollable release of impounded water, which can create flash flooding. Dam failure was given a medium ranking for the City of Alexandria in the 2022 Northern Virginia Hazard Mitigation Plan.⁶ The only dam that impacts the study area is the Lake Barcroft Dam, located in Fairfax County. The Virginia Department of Conservation and Recreation (DCR) classifies the Lake Barcroft dam as a high-hazard dam, which is based not on the structural integrity of the dam, but rather on the potential adverse effects associated with dam failure. A high-hazard dam indicates that dam failure would cause probable loss of life or serious economic damage.¹¹ The dam previously failed in 1972 during heavy rains associated with Hurricane Agnes, causing approximately \$300,000 in damage and an additional \$200,000 to clear trees and debris from Holmes Run; however, due to rigorous dam inspection and oversight measures in the area, the likelihood of future dam failure was rated as low in the 2022 Northern Virginia Hazard Mitigation Plan.⁶ High-hazard dams are required to be inspected by a Professional Engineer once every two years and must have an Emergency Action Plan.¹¹

Water Quality

Under the Clean Water Act, Virginia requires all municipalities to maintain a Municipal Separate Storm Sewer System (MS4) General Permit to discharge to surface waters in Virginia. Each state is also required by the Clean Water Act to develop Total Maximum Daily Loads (TMDLs) for all streams identified as “impaired”, which means that they have high pollutant loads. The TMDL is the maximum amount of a pollutant that is allowed to enter a waterbody. The City of Alexandria has an active MS4 permit, and the 2023-2028 MS4 Program Plan highlights how the City will control pollutant discharges and meet TMDL requirements for any impaired waterways.¹² The City also administers the Virginia Erosion and Stormwater Management Program (VESMP), which requires stormwater pollution prevention plans (SWPPPs) for development and redevelopment projects.

One stream within the study area, Holmes Run, has a TMDL impairment for E. coli. Cameron Run, which is downstream of Holmes Run and Strawberry Run, also has an impairment for E. coli. All other streams within the study area have not been assessed for TMDL impairment. The City created a Bacterial TMDL Action Plan to address TMDLs for Holmes Run, Cameron Run, Hunting Creek, and Four Mile Run. A possible significant source of bacteria was identified as dog waste, and as a result, dog parks were identified as locations with a high potential for bacteria pollutant loads. Several strategies have already been implemented to reduce bacterial loadings, including

fining pet owners for not cleaning up after their pets, installing pet waste stations, maintaining an IDDE program, and conducting routine infrastructure cleaning and maintenance.¹³

The City is within the Chesapeake Bay watershed, and most of the Bay is impaired due to high nutrient levels, which can cause eutrophication and “dead zones” where aquatic life cannot survive. The EPA established the Chesapeake Bay TMDL in 2010, which set pollutant reduction requirements for six states within the watershed, as well as the District of Columbia. The 2025 Phase 3 Chesapeake Bay TMDL Action Plan highlights steps that the City is taking to meet the 100 percent pollutant reduction targets for nitrogen and phosphorus. The City’s strategy includes tree planting, retrofitting existing stormwater BMPs, and requiring green infrastructure on all new development and redevelopment.¹⁴ Two recent stormwater BMP retrofit projects include Ben Brenman Pond and Lake Cook, which are adjacent to the study area and part of the Cameron Run watershed.¹⁵

A portion of the City is regulated by a Combined Sewer System permit instead of an MS4 permit since the older sewer system was designed to capture both sewage and stormwater flows. The combined sewer system is generally sent to a wastewater treatment plant before discharging into the Potomac River, but during heavy rainfall events, combined sewage overflow (CSO) can occur, leading to environmental and public safety hazards. The study area is not within the combined sewer system drainage area, so it is not directly impacted by CSO. Part of the City’s ongoing Chesapeake Bay TMDL plan includes the rehabilitation of the combined sewer system through the RiverRenew program, which will reduce the number and volume of sewage overflows.¹⁴

Extreme Heat

The City of Alexandria Energy and Climate Change Action Plan identified extreme heat as a priority risk for the City due to public health and infrastructure impacts. Not only can extreme heat cause illness and death, it can also damage infrastructure such as overhead electrical transmission wires and rail lines. During a community workshop on March 1, 2022, the public identified extreme heat/urban heat island as the most concerning climate vulnerability, closely followed by extreme precipitation/inland flooding.¹

High temperatures can cause illnesses such as heat exhaustion and heat stroke, which can be potentially deadly. Hot temperatures can also contribute to deaths from heart attacks, strokes, and other forms of cardiovascular disease. Between 2004 and 2018, the Centers for Disease Control and Prevention recorded 10,527 heat-related deaths in the United States (an average of 702 per year). The actual number of these deaths may be higher because the reported cause of death may not be listed as “heat-related”. As temperatures increase due to climate change, the increase in heat-related deaths is projected to outweigh the reduction in cold-related deaths in nearly all regions of the United States.¹⁶ According to the National Integrated Heat Health Information System (NIHHIS), those most at risk of extreme heat include children, older adults (65+), people with pre-existing conditions, people with disabilities, first responders, and those in lower income communities.¹⁷ See the **Social Vulnerability** section for further discussion of social vulnerability within the study area.

As part of the Energy and Climate Change Action Plan, the City conducted a heat vulnerability assessment which analyzed heat exposure, sensitivity, and adaptive capacity for each census block. Land surface temperatures from two hot summer days in 2020 and 2021 were used as the basis for assessing heat exposure. The criteria used to assess sensitivity were the percentage of people in each block with a disability; under the age of five; 65 and older; in poverty; and identifying

as Black, Indigenous, and People of Color (BIPOC). Adaptive capacity, defined as the ability to cope with and recover from heat impacts, was evaluated using the total tree canopy cover, the distance to a cooling center, and the distance to a recreation facility. Overall, the results showed high vulnerability scores for two neighborhoods that overlap the Duke Street study area: Landmark/Van Dorn and Eisenhower Valley.¹

The City is already undertaking several extreme heat mitigation efforts, including the Senior Cool Care Program and the Virginia Energy Assistance Cooling Program, which provide financial aid to residents for the increased energy burdens of residential cooling. The City is also focusing on adding additional cooling centers in recreation centers, libraries, and schools.¹ Additionally, the City's Environmental Action Plan 2040 set a goal to increase the tree canopy coverage to 40 percent by 2035 and maintain the ratio of 7.3 acres of publicly accessible open space per 1,000 residents.⁵

D. ENVIRONMENTAL RISK PROFILE

An environmental risk profile was developed throughout the study area corridor by assigning composite scores for flood risk, water quality risk, and heat risk for each City Real Estate Parcel. Each parameter was assessed based on a weighted risk matrix to calculate a total environmental risk score. See **Appendix A** for more detailed descriptions of criteria scoring and weighting.

Flood Risk

Three categories of flood risk were analyzed:

1. Fluvial flood risk
2. Pluvial flood risk
3. Flash flooding

Sea level rise was not considered in this study since the study area was outside the limits of the National Oceanic and Atmospheric Administration (NOAA) sea level rise data. The sea level rise risk is low for the study area, but other areas of the City, especially adjacent to the Potomac River, are impacted by future sea level rise.

Because most of the study area is not impacted by storm surge, it was not included in this analysis. The National Weather Service's National Hurricane Center (NHC), a division of NOAA, calculated potential storm surge inundation limits for Category 1 through Category 5 hurricanes.¹⁸ Based on this data, the eastern corner of the site adjacent to Timber Branch may experience greater than 6 feet of inundation during a Category 4 hurricane; however, the rest of the site is outside of the storm surge inundation limits.

Future rainfall was not included in this analysis since the increased rainfall impacts were assumed to be uniform across the study area. Future rainfall is discussed further in the **Future Risks** section.

Fluvial Flood Risk

The fluvial flood risk for this study was evaluated based on the following criteria:

- FEMA 100-year floodplain
- FEMA 500-year floodplain

FEMA maintains and updates maps for the 100-year and 500-year floodplains throughout the country, and these floodplains are regulated by local municipalities. The 100-year floodplain limits are the limits of flooding caused by the 1-percent annual chance storm event. The 500-year floodplain is defined as the inundation limits of the 0.2-percent annual chance storm event.

Fluvial flood risk was scored based on the percentage of the parcel covered by the 100-year or 500-year floodplains. The 100-year floodplain was weighted higher than the 500-year floodplain since it is associated with a higher likelihood of flooding.

Pluvial Flood Risk

The pluvial flood risk was based on the following criteria:

- The presence of stormwater inlets on the parcel
- The presence of 311 flooding complaints on the parcel

The presence of stormwater inlets was identified as a risk factor due to the potential for the inlet surcharging if the pipe network does not have enough capacity during high intensity storm events. The results from the 2016 CASSCA study can help refine this risk further based on modeled pipe network capacity. The data from the 2016 study was not publicly available, so it was not included in this risk assessment.

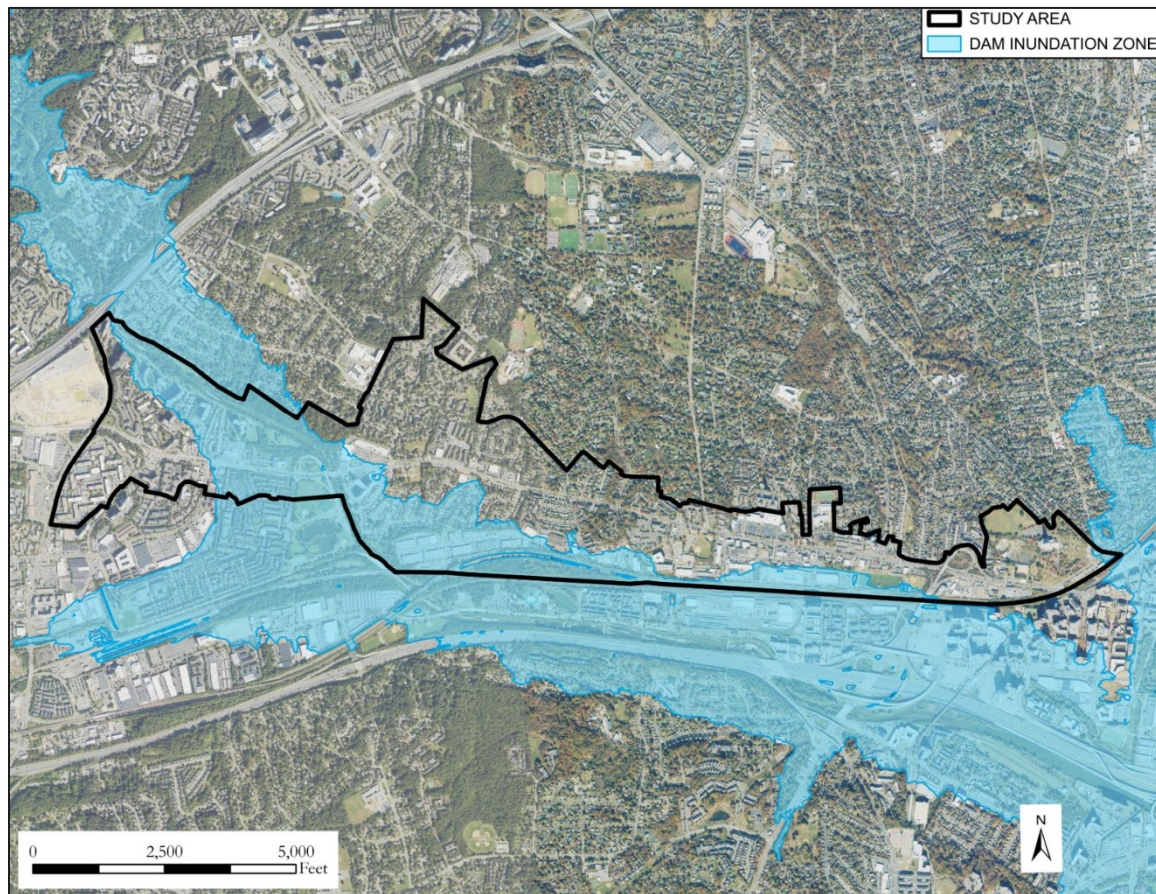
The presence of 311 flooding calls on the parcel was identified as a risk factor since it indicates that flooding has happened at that location in the past. It was assumed that 311 flooding complaints were related to pluvial flooding rather than fluvial flooding. For future analysis, obtaining metadata on the context of the complaint may help to provide more insight into the cause of flooding at each location. 311 calls were given a higher weight than stormwater inlets since they indicate that flooding has occurred there in the past, while the presence of stormwater inlets is a more speculative risk.

The ongoing S Jordan Street Stormwater Improvement Phase II is a Flood Action Alexandria project located in the southwestern section of the study area along S Jordan Street between Venable Avenue and Holmes Run Parkway. This project is planned to reduce pluvial flooding in the backyards of private homes through storm drainage improvements.⁹ Since the ongoing project is already addressing the high concentration of 311 calls along S Jordan Street between Venable Avenue and Holmes Run Parkway, no further mitigation strategies to address pluvial flooding are needed in that area, even though the results map of this study may show it as a flood risk hotspot. See **Appendix B** for locations of the fluvial and pluvial flood risk criteria mentioned above.

Flash Flood Risk

The flash flood risk was based on the likelihood and impacts of dam failure. Lake Barcroft Dam is the only state-regulated dam upstream of the study area. The dam inundation zone is available through the Virginia DCR database and was overlaid on the study area to assess risk due to a dam breach event. A flash flood risk score was applied to each parcel based on the percentage of the parcel within the dam inundation zone. See **Figure 2** below, as well as **Appendix C**, for the dam inundation zone affecting the study area.

Figure 2: Lake Barcroft Dam Inundation Zone

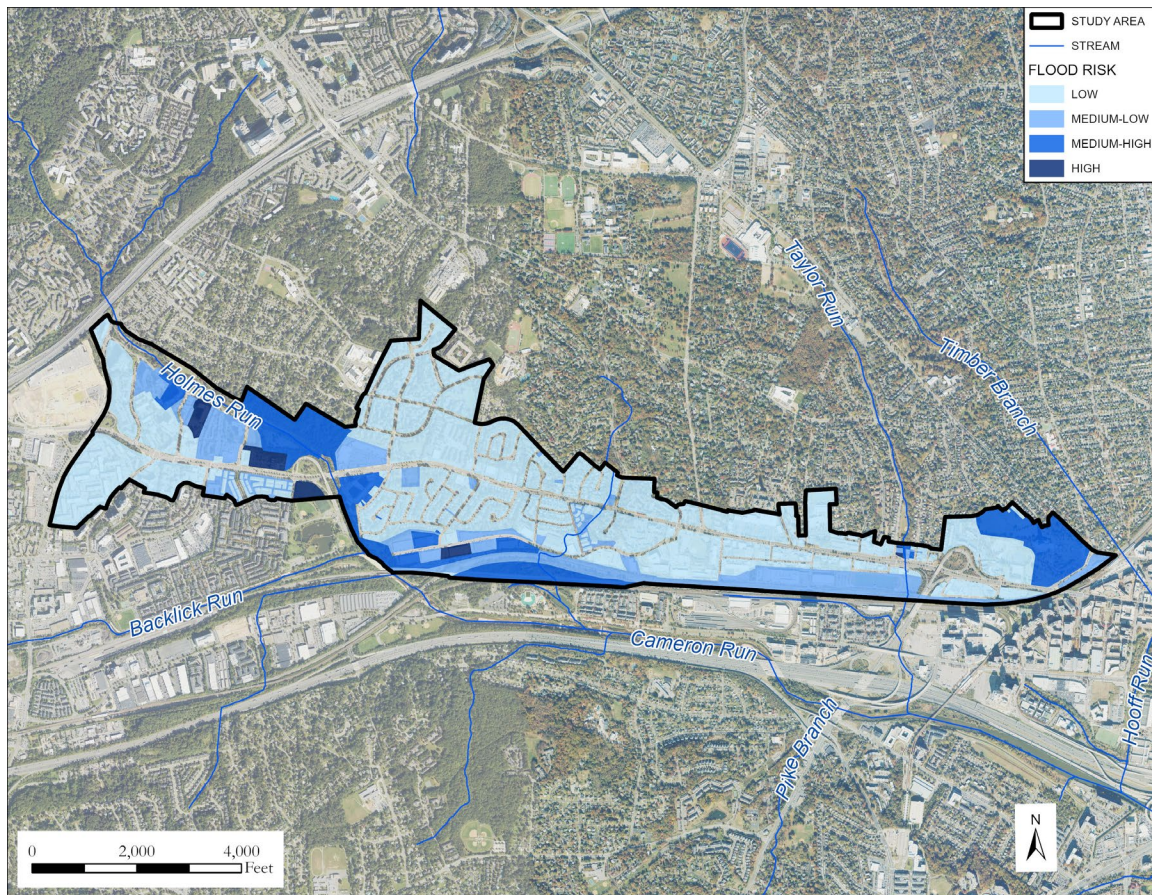


Overall Flood Risk

The total flood risk score was calculated based on a weighted average of the fluvial flood risk, pluvial flood risk, and flash flood risk. The pluvial flood risk was prioritized given the high likelihood of pluvial flooding occurring; most storm drainage systems are designed to handle the 10-year storm, and pluvial flooding occurs when the system reaches capacity. In contrast, fluvial flooding was analyzed only for the 100-year and 500-year storms, which are less likely than the 10-year storm. Pluvial flooding has also been demonstrated to be a priority issue for the City through the high level of 311 complaints and the Flood Action Alexandria initiative. Dam inundation was weighted the least due to the very low likelihood of a dam breach occurring.

Appendix D and **Figure 3** below show the results of the total flood risk throughout the study area. The highest flood risk areas were along streams and at low points within the study area. The greatest flood risk was at the southwestern corner of the study area and along Holmes Run. Because the area is generally sloped from north to south, it makes sense that the southern portion of the study area has higher flood risk as it receives runoff from all upstream area draining to Cameron Run. The high-risk areas also correlate with the dam inundation zone along Holmes Run and Cameron Run. Other hotspots were identified due to 311 calls that were not located along streams, and the eastern corner of the site near Timber Branch was also identified as a hotspot due to its low elevation along the stream.

Figure 3: Total Flood Risk Map



Water Quality Risk

Water quality risk was evaluated based on the following criteria:

- The presence of existing BMPs on the parcel, and whether the BMP meets the latest stormwater management criteria
- The presence of automobile-related hotspots, including gas stations, car washes, auto repair shops, and registered DEQ petroleum storage tanks
- The percent impervious area of the parcel
- The percentage of tree coverage of the parcel
- The percentage of RPA coverage of the parcel

Existing BMPs

BMP locations were provided by the City as a GIS shapefile. BMP drainage areas were not available in shapefile format, so it was assumed for the purposes of this study that each BMP treats only its own parcel area. The Virginia Stormwater BMP Clearinghouse design standards underwent significant revisions in 2013, which established Level 1 and Level 2 requirements for 15 non-proprietary types of BMPs. It was assumed for this assessment that facilities designed to meet these 2013 requirements would not have been installed until starting in 2015, so the BMP data was filtered to identify BMPs which were constructed after 2015, which would meet the updated standards, and those constructed before 2015, which were assumed to not meet the 2013

standards. Based on this analysis, roughly 15 percent of the existing BMPs within the study area were assumed to meet the updated 2013 standards. The Virginia Stormwater Management Handbook v1.1, released in 2024, was not considered in this analysis since there are no BMPs in the City's database that have been installed since this update. Parcels containing BMPs that meet current standards were given the lowest risk score, while parcels with no BMP and significant impervious coverage were given the highest risk score.

Stormwater Hotspots

"Hotspots" were identified as areas which have a higher risk of contaminated stormwater runoff, posing a risk to downstream water quality. Contaminants such as oil, soaps, or other chemicals can run off into waterways and cause negative environmental impacts. Auto-related hotspots, which have a high potential for oil or chemical leaks and spills, were taken from several different data sources. City parcels with a land description of "Gas Kiosk", "Repair Services", or "Service Stations" were identified as hotspots. In addition to those parcels, parcels containing buildings with a use description of "Gas", "Car wash", or "Auto repair" were also identified. The Virginia DEQ online GIS database of registered petroleum tank facilities was used to identify parcels with active petroleum storage tanks, and these were added to the hotspot list. Sites with multiple hotspots (e.g., a gas station and an active petroleum tank) were not double counted. Although these auto-related businesses pose a higher risk to water quality than other land uses, it is not feasible or preferred to avoid these land uses entirely. Recommendations will focus on mitigating the potential water quality impacts of these facilities, as discussed in **Section II: Climate Change Adaptation Measures**.

Based on the Parks dataset available in the City GIS database and the Bacterial TMDL Action Plan, three dog parks were identified within the study area: Holmes Run Dog Park, Duke Street Dog Park, and Fort Williams Park. These are hotspots for increased bacterial contamination, although the effect is mitigated by the fact that these parks have higher levels of pervious cover and vegetation. As stated in the Bacterial TMDL Action Plan, the City has been actively working to encourage proper disposal of pet waste, especially at dog parks. Since the City has already identified these locations as sites to focus on pet waste efforts, these hotspots were not factored into this study.

Another potential land use that can cause higher discharges of pollutants includes lawns, which generally use fertilizers to maintain grass cover. These fertilizers can contain concentrated levels of nitrogen and phosphorus, which have negative environmental impacts when they run off into streams. Lawns were not included in this assessment since it is difficult to determine which property owners are using fertilizers on their property. However, a general mitigation strategy is to regulate or discourage fertilizer use within the City. The City already encourages sustainable landscaping practices through the Stormwater Utility Fee Credit Program as discussed further in **Section II: Climate Change Adaptation Measures**.

Impervious Cover

The percent impervious surface area of the parcel was considered because pollutant runoff increases with impervious area. Impervious surfaces lead to higher runoff velocity and less infiltration, allowing less time for pollutants to settle out or be taken up by plants. Impervious surfaces are also correlated with large expanses of building/roof areas with associated surface parking, which are more likely to produce contaminated runoff. This criterion was given the highest weight as it was determined to have the greatest impact on water quality.

Tree Canopy Cover

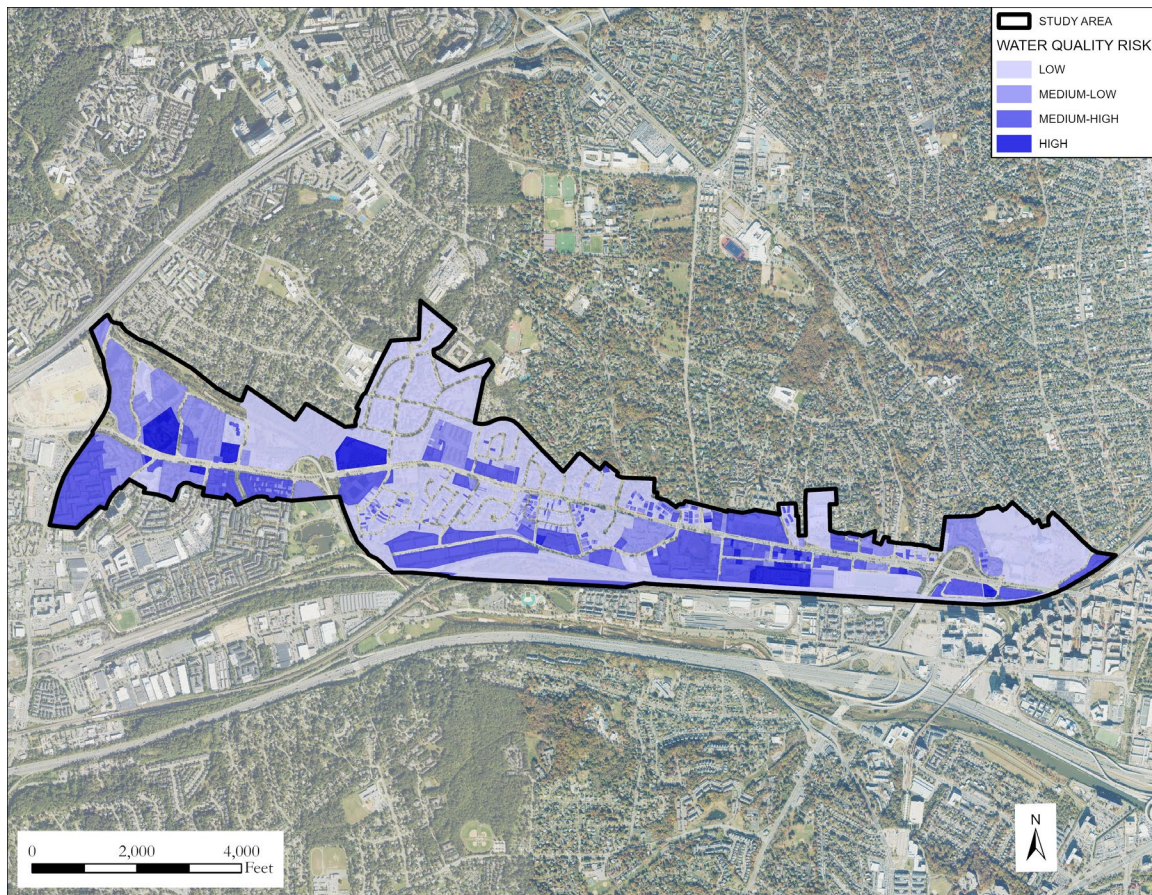
Tree cover was considered due to the ability of trees to reduce stormwater runoff through interception and to reduce pollutant load through biological uptake. Trees also provide shade, which reduces the temperature of the water entering natural systems. Trees were weighted lower than impervious since, although trees play an important role in treating stormwater runoff, the impervious vs pervious land cover is a more important indicator in the overall water quality of the parcel. See the ***I-Tree Canopy Tool*** Section for further discussion of tree canopy cover and tree benefits.

RPA Cover

The percentage of RPA within a parcel was considered because it is an indicator of environmentally sensitive areas on the site. Surface runoff contaminated with pollutants from sites with RPA have less travel time and available space to be filtered out before causing negative impacts. Therefore, parcels with RPA should be prioritized to minimize negative environmental impacts. This criterion was given a low weight since it is less impactful on water quality risk than the other factors, and it is more focused on water quality impacts. It was noted that the RPA criterion may be partially or completely canceled out by the impervious surface and tree coverage criteria, since RPA is generally associated with higher levels of trees and open space. In the future, assessing RPA separately instead of within the water quality risk framework may be a more useful approach.

The results of the water quality risk assessment are shown in **Appendix F** and **Figure 4** below, and **Appendix E** shows a summary of the criteria used to evaluate the water quality risk. The water quality risk is highest along corridors where large expanses of building/roof areas with associated surface parking exist, due to higher impervious surface concentrations and more auto-related hotspots. Existing BMP locations tended to correlate with the auto-related hotspot locations, but most of the existing BMPs were not constructed to be compliant with the most updated standards. Parcels with the highest water quality risk included the Landmark Honda auto dealership, the NT Auto Body shop, and the 4600 Duke Street Condominiums. The lowest water quality risks were concentrated around residential or open space land uses with low impervious surface coverage. Areas with especially low water quality risk included Foxchase Apartments, the residential communities north of Duke Street between North French Street and North Quaker Lane, and the vacant Virginia Passenger Rail Authority property at 4050 Wheeler Avenue.

Figure 4: Water Quality Risk Map



Heat Risk

To better understand the severity of heat risk, datasets for temperature anomalies and urban heat islands were reviewed. Heat risk was based on the following criteria:

- Urban Heat Island Severity (Summer 2025)

Heat islands are determined by monitoring “temperature anomalies” within a given area. A temperature anomaly is the difference between the observed temperature of a given location compared to a baseline average temperature.¹⁹ A positive anomaly means the temperature was observed as warmer than the baseline, while a negative anomaly means temperature was observed as cooler than the baseline. Using temperature anomalies, The Trust for Public Land created a heat island dataset that scored the severity between 1 and 5.²⁰ A score of 1 is considered a relatively mild heat area (slightly above the average temperature for the city), and a 5 is considered a severe heat area (significantly above the average). The 5 classes were created using the Jenks natural breaks classification method, which is designed to determine the best arrangement of values (surface temperatures) into different classes. Using the 2025 urban heat island data from the Trust for Public Land, a heat risk score was calculated for each parcel within the study area.

The temperature anomaly map is shown in **Appendix G**, and the results of the per-parcel heat risk assessment are shown in **Appendix H** and **Figure 5**. **Appendix N** shows heat island severity

overlaid with parking lots within the study area. Based on the heat anomaly and urban heat island datasets, the warmest regions of the study area were observed as areas of commercial development, industrial parks, and dense apartment complexes. These areas were anywhere between 5 and 21 degrees Fahrenheit warmer than the average for the entire city. Properties with large expanses of building/roof areas with associated surface parking tend to have a higher percentage of impervious surfaces, poor urban geometry, a limited amount of established tree canopy cover, and increased heat-generating human activities like vehicle traffic and HVAC production. Some of the most intense heat islands include the following locations of the study area:

- Neighborhood of Landmark-Van Dorn Southwest of Brookvalley Park
- Shoppes of Foxchase
- Alexandria Commons
- Business/Industrial Park between South Quaker Lane and Roth Street
- Witter Soccer Field

Although the City-owned Witter Fields is mostly green space, it is observed as one of the largest heat islands in the study area. Due to the dark colored artificial turf, the field acts as a heat sink. This creates a higher risk for heat-related health issues for athletes and other at-risk members of the community who frequent the facility. Turf surfaces can cause an increase in surface temperatures (7° F on average), which ultimately can cause an increase in evening temperatures.²¹ Witter Fields is already under renovation to the turf and subdrainage system,²² which may provide an opportunity to replace the turf with a material that absorbs less heat.

Roadways were observed as some of the most intense heat islands. Roads generate heat from solar exposure, impervious surfaces, and vehicle traffic. The intensity of the heat islands increased or decreased depending on the road orientation, established tree canopy cover, and the surface temperatures of the surrounding development. South Van Dorn Street and portions of Duke Street were observed under intense heat islands with limited established tree canopy. Options for tree canopy are limited in this location due to the overhead utilities requiring clearance from any vegetation and both roads being bound by private property. Existing trees appeared to be strategically pruned to reduce the height of their canopy. Additionally, portions of both roads were observed to be between areas of positive heat anomalies.

Unlike South Van Dorn Street, Duke Street runs east to west. Roads that run in this orientation have an increased daily exposure to direct sunlight due to the sun rising in the east and setting in the west. With limited existing tree canopy, surrounding heat islands, and extended solar exposure, the heat islands of Duke Street and South Van Dorn Street are bound to increase in intensity over time. Some of the most intense heat islands found within roadways include the following:

- South Van Dorn Street between Duke Street and Stevenson Avenue
- Duke Street between North Van Dorn Street and Somerville Street
- Duke Street between Cockrell Street and West Taylor Run Parkway

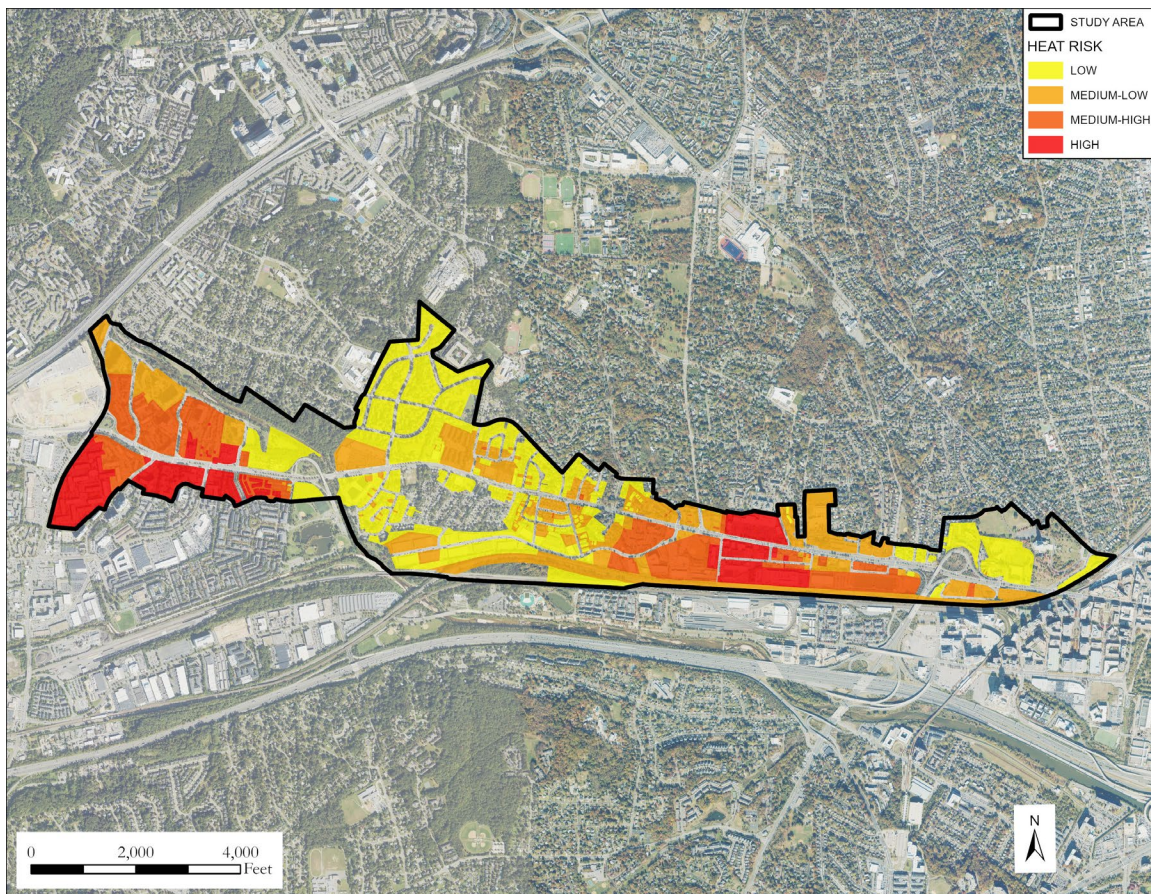
Though most of the study area was observed within some level of a positive temperature anomaly, several areas were identified as within negative temperature anomalies or low intensity heat islands. Cooler areas were observed in places like parks, residential communities with established tree canopy, and parcels with undisturbed forest stands and open green space.

Undisturbed forests stands were recorded as the lowest temperature anomalies, between 5 to 15 degrees Fahrenheit cooler than the average temperature of the City. Additionally, these drastically cooler areas were observed as assisting with reducing temperatures in the surrounding areas. They

provide sanctuary for both humans and wildlife and support the management of stormwater runoff. Large stands of trees tend to adapt to change in temperatures better than those of individual trees in some of the more urban parts of the city. Extended heat exposure with limited growing space and minimal rainfall can cause trees to become stressed, which can be exhibited through twig die back, leaf wilting or scorch, premature leaf drop, and cracks in bark, in more severe cases. This can cause individual trees to be more susceptible to pests and disease. Some of the areas observed in low intensity heat islands and negative temperature anomalies include the following:

- Brook Valley Park
- Taney Avenue Park
- Angel Park
- George Washington Masonic National Memorial
- Forest on vacant Virginia Passenger Rail Authority (VPRA) property located south of Wheeler Avenue

Figure 5: Heat Risk Map



I-Tree Canopy Tool

As discussed above, impervious surfaces and tree cover directly influence urban heat islands, water quality, and flooding. To further analyze the different land cover types within the corridor, an analysis was completed using the U.S. Department of Agriculture (USDA) Forest Service i-Tree

Canopy tool, and the results are shown in **Appendices I and J**. This tool is used to classify land and tree cover across a given area using random sampling of aerial imagery.²³ Additionally, the benefits of tree canopy are estimated based on carbon dioxide, air pollution, and stormwater (hydrological). A total of 500 random points were sampled and classified into the following cover classes:

- Grass/Herbaceous
- Impervious Buildings
- Impervious Roads (includes parking lots)
- Impervious Other (Sidewalks, driveways, patios, etc)
- Soil/Bare Ground
- Trees/Shrubs
- Water

The results of the sampling found that the highest individual land cover types were trees and shrubs with 146 points or approximately 29 percent, followed by impervious roads with 140 points or approximately 28 percent. The lowest individual land cover types were water and soil/bare ground with a total of 7 points for water (1.4%) and 2 points for soil/bare ground (0.4%). Though trees and shrubs were recorded as the highest individual land cover type, impervious surfaces were recorded as the highest total land cover type with a total of 264 points combined between the three cover classes. This is approximately 52 percent of the total points recorded. This provides an overall picture of the corridor as highly developed, and the results align with the tree canopy coverage of 29 percent calculated from the City's tree canopy GIS data. Residents have expressed interest in increased tree canopy and green space in the Duke Street neighborhood, and this analysis can serve that effort by providing an initial baseline for the area.²⁴

Based on the results of the analysis, the tool estimated that the tree canopy within the corridor removed or stored over 9,700 tons of carbon, which is equivalent to nearly 36,000 tons of carbon dioxide. The monetary value of this benefit is estimated at just over \$4,200,000 (~\$118.02/T of carbon dioxide). Additional estimates include the annual removal of over 21,900 lbs of different forms of air pollution (carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, PM2.5, and PM10) and approximately 393 million gallons of stormwater. The monetary value of air pollution was estimated at just over \$7,200. Hydrological benefits are estimated through avoided runoff, evaporation, interception, transpiration, potential evaporation, and potential evapotranspiration. The monetary value of avoided runoff was estimated at approximately \$2,273. These monetary benefits are estimates that are calculated as annual totals based on state, regional, and national data (utility costs, pollution control costs, stormwater management rates). It should be noted that these values are high-level estimates based on aerial imagery. Site specific data would require a more formal inventory of tree species, size, condition, and other information. The data from this statistical analysis was not used for the overall environmental risk scoring, but rather as a standalone dataset to document the benefits of tree canopy and provide a baseline analysis for land cover. The results of this study can be used to provide a monetary basis for increasing the tree coverage within the community. The analysis is based on estimates from the 500 random points, which is the minimum requirement of points to run the tool. Accuracy of the estimates is based on number of points sampled and the standard error set by the tool.

Total Environmental Risk Ranking

The total environmental risk was calculated using a weighted average of the total flood risk score, the water quality risk score, and the heat risk score. Heat risk was prioritized due to the high public

concern over extreme heat effects, as indicated by public engagement sessions for the Duke Street Land Use Plan²⁴ and the Energy and Climate Change Action Plan,¹ as well as the potentially deadly public health impacts of heat. Flood risk was prioritized second because it has also received high levels of public concern and has been demonstrated to be a problem throughout the City during past heavy rainfall events. Intense rainfall events have the potential to severely damage infrastructure, as shown by historical flooding. Water quality was weighted the lowest because there is not a high level of public concern for this issue, and the potential impacts to infrastructure and public safety are lower. However, it is important to keep addressing water quality issues, even though the public interest is not as high, to meet TMDL requirements and reduce impacts to public health and the environment.

Appendix L and **Figure 6** below show the distribution of the total environmental risk per parcel over the study area.

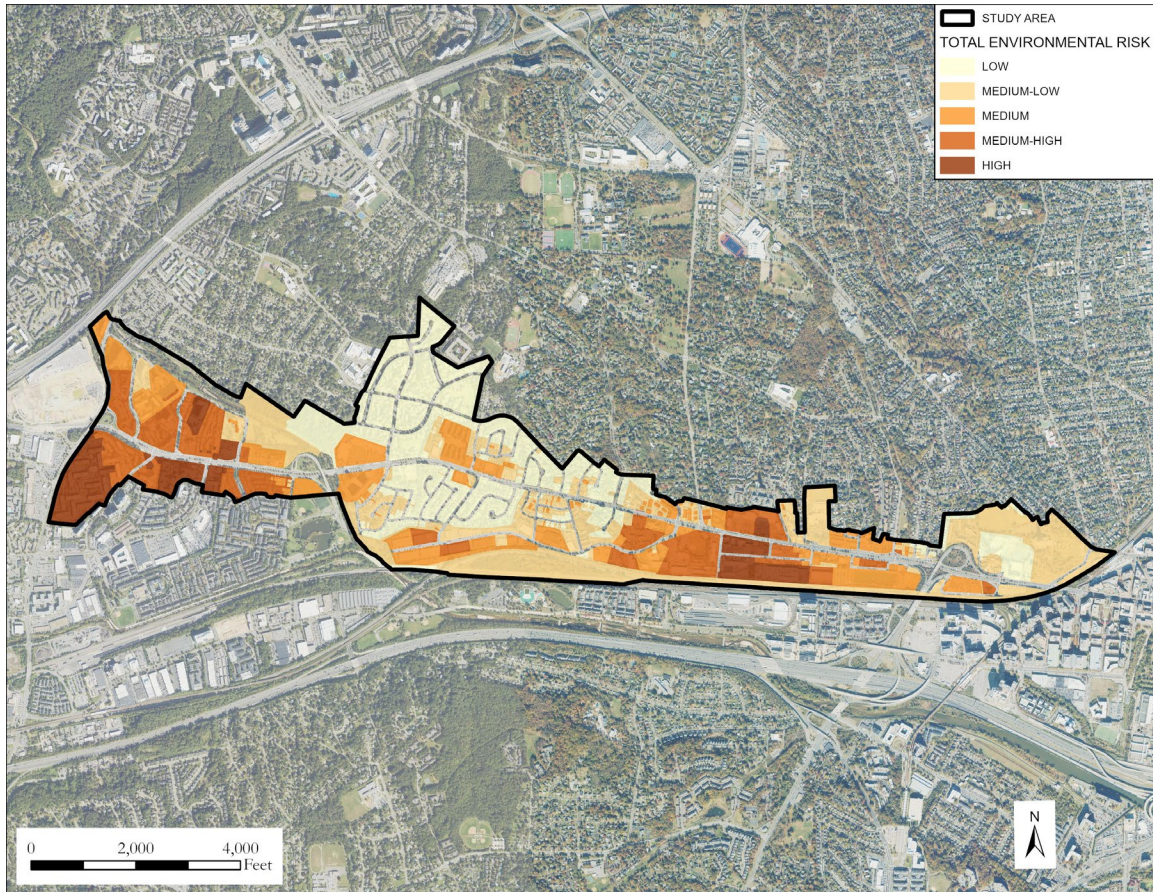
One area of high environmental risk was the Landmark neighborhood on the western side of the study area. This area was identified as having a high temperature anomaly due to high levels of impervious surfaces. The impervious surface concentration, combined with low levels of tree coverage, also contributed to high water quality risk in the area. There were moderate levels of flood risk in the neighborhood, mostly concentrated around Holmes Run. Combined, these factors contributed to high overall environmental risk.

Another hotspot for environmental risk was centered around Alexandria Commons and Alexandria City Campus, which is an area that includes large expanses of building/roof areas and associated surface parking. The high levels of impervious surfaces in this area led to a higher water quality risk ranking, and there were also high temperature anomalies based on the Trust for Public Land heat island data.

The elevated environmental risk also extends west along Wheeler Avenue in the southwestern corner of the study area, which correlates with a block of buildings with high impervious surface coverage and low tree canopy. The southwestern corner of the study area also overlaps both 100-year and 500-year floodplains and is within the dam inundation zone, which elevates the environmental risk.

Areas of low environmental risk included the Foxchase Apartments community north of Duke Street and the residential area south of Duke Street between Ewald Park and South French Street. These areas had higher levels of tree coverage, lower levels of impervious surfaces, and were located outside of the floodplain.

Figure 6: Total Environmental Risk Map



E. SOCIAL VULNERABILITY

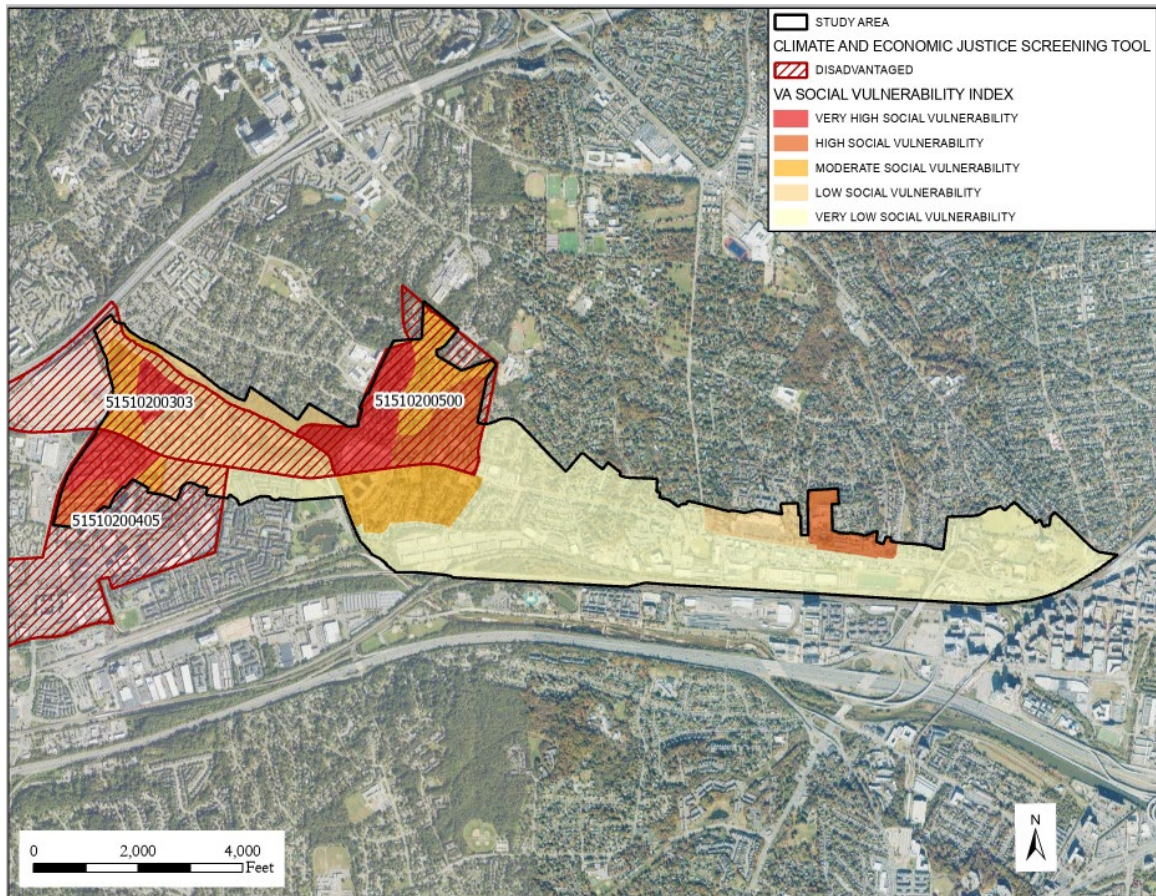
The Climate and Economic Justice Screening Tool (CEJST), developed by the NDC Partnership, was reviewed to identify areas of enhanced social vulnerability to climate change impacts. Within the study area, three census tracts on the western side of the area are classified as a disadvantaged community. The tool identifies a tract as disadvantaged if it is at or above the threshold for one or more environmental, climate, or other burdens, and at or above the threshold for an associated socioeconomic burden. Tracts 51510200500 and 51510200303 are considered disadvantaged due to workforce development disadvantages, as well as having greater than 10 percent of people ages 25 years or older whose high school education is less than a high school diploma. Tract 51510200405 was identified as disadvantaged due to being above the 90th percentile for lack of green space, as well as being above the 65th percentile for low income.²⁵

The FEMA Community Resilience Challenges Index (CRCI) was reviewed, and one census tract, 51510200304, on the western side of the study area was identified as having higher resilience challenges. The CRCI is a composite index of the 22 most used indicators of community resilience and social vulnerability.²⁶

The Virginia Social Vulnerability Index (SVI),²⁷ adapted from the VIMS Social Vulnerability Index, was also evaluated to assess patterns of social vulnerability across the site. The SVI classifies census tracts into five categories—ranging from Very Low to Very High social vulnerability—based on 12 variables representing key determinants of social vulnerability. Within the site boundaries, three census tracts are classified as having Very High social vulnerability. It was noted that there was overlap of high vulnerability areas identified by all three social justice frameworks in the western part of the study area, specifically within census tract 51510200303.

Social vulnerability was not included in the environmental risk score, but identified areas of disadvantaged communities are shown in **Appendix K** and in **Figure 7** below. To ensure an equitable community, it is important to consider social vulnerability when considering where to implement potential climate change mitigation strategies. For example, financial assistance programs for floodproofing measures could be focused in areas with lower incomes, and green infrastructure strategies could be prioritized in areas that have historically had fewer trees and parks.

Figure 7: Social Vulnerability Map



F. EXISTING CONDITIONS CONCLUSIONS

The key takeaways from this assessment are summarized below:

- The highest environmental risks were concentrated in the western and central portions of the study area
- The strongest indicators of environmental risk were the following risk factors:
 - High impervious surface coverage (e.g., large roof areas with associated surface parking)
 - Low tree coverage

As discussed above, the areas with the most environmental risk were identified as the western and central portions of the study area. The Landmark neighborhood has high environmental risk and has also been identified as socially disadvantaged, so this area should be a high priority for mitigation efforts. The Foxchase Apartments residential neighborhood north of Duke Street was found to have low environmental risk, but it was ranked high for social vulnerability. This could be a good area to focus on more social mitigation efforts like public outreach and education. The central portion of the study area was ranked low for social vulnerability, but since the area is industrial and commercial, there are not many residents in the area. Focusing efforts in this industrial and commercial block can provide benefits to those working in the area, as well as the surrounding residential areas.

Overall, environmental risk was correlated with high levels of impervious surfaces. Finding ways to reduce impervious surfaces and increase open space and trees will help mitigate the urban heat island and provide stormwater quantity and quality benefits. The City is already working on increasing green space through strategies such as green infrastructure requirements for new development and the Environmental Action Plan 2040. This assessment can aid in those efforts by providing a baseline for the Duke Street corridor and helping to prioritize areas with the highest risk. Reducing the coverage of parking lots or adding green infrastructure or trees within parking lots could help mitigate their environmental risk.

Other strategies may involve preparing for the impacts of disasters, including protecting critical infrastructure, providing cooling centers for residents, and elevating or floodproofing buildings. Undergrounding overhead utilities could provide dual benefits of preparing for intense storms, while also allowing for better growth of street trees. See **Section II: Climate Change Adaptation Measures** for further discussion of climate change mitigation strategies.

Future Risks

In the future, climate change is projected to cause increased rainfall levels, which will increase flooding risk throughout the City. Increased rainfall will also negatively impact water quality, as it will cause increased surface runoff that will transport pollutants at higher volumes and velocities. Climate change will also cause more intense storm events and hurricanes, as well as increased temperatures. Cities must consider how to design and plan for resilient neighborhoods against these potentially devastating impacts.

Publicly available data was reviewed through the IPCC WGI Interactive Atlas for both the SSP2-4.5 and SSP5-8.5 scenarios using a baseline of 1995-2014 to understand potential changes in future rainfall for periods 2041-2060 (medium term) and 2081-2100 (long term).²⁸ These changes for the region of Eastern North America are shown in **Table 2** below.

Table 2: Estimated Total Change in Future Annual Precipitation

Scenario	Period	P75	P90	P95
SSP2-4.5	2041-2060	5.8%	7.9%	8.5%
	2081-2100	7.8%	11.2%	11.4%
SSP5-8.5	2041-2060	7.0%	8.2%	9.1%
	2081-2100	10.1%	12.4%	12.8%

The same scenarios were reviewed for mean temperature through the IPCC WGI Interactive Atlas using a baseline of 1995-2014.²⁸ In the eastern North America region, the potential changes in mean temperature in degrees Celsius for periods 2041-2060 (medium term) and 2081-2100 (long term) are shown in **Table 3** below.

Table 3: Estimated Total Change in Future Annual Mean Temperature

Scenario	Period	P75	P90	P95
		Degrees Celsius		
SSP2-4.5	2041-2060	1.9	2.2	2.3
	2081-2100	3.0	3.5	3.8
SSP5-8.5	2041-2060	2.6	2.9	3.2
	2081-2100	5.6	6.2	6.8

Based on these projections, both annual rainfall and mean annual temperature are expected to increase significantly due to the effects of climate change. Increasing urbanization often compounds this risk by increasing the percentage of impervious surfaces, causing stormwater runoff volumes and velocities to increase, and worsening the urban heat island effect.

The City has historically experienced temperatures exceeding 95 degrees Fahrenheit nearly eight days per year on average; however, the number of days in Alexandria with temperatures over 95 degrees Fahrenheit is projected to increase to 19-20 days by 2030 and 26-33 days by 2050. The City's Energy and Climate Change Action Plan proposes several strategies for mitigating increasing temperatures, including urban greening, using different building materials, expanding heat relief programs, and establishing a heat preparedness program.¹

The City of Alexandria is currently addressing future rainfall increases through stormwater improvements programs such as Flood Action Alexandria. The City also utilizes higher design intensities than statewide standards and the standards of neighboring jurisdictions for the design of stormwater inlets and pipes. The 2016 CASSCA study found that the City's design rainfall intensities are greater than the projected rainfall intensities for the years 2050 and 2100 for most storm durations less than 12 hours.⁸ This design approach will help the City's infrastructure be designed with resiliency in mind and mitigate the impacts of increasing rainfall intensities.

II. Climate Change Adaptation Measures

The purpose of this section is to present a range of short-, mid-, and long-term climate resilience adaptation/mitigation strategies within the Duke Street Corridor that can be incorporated into the Duke Street Land Use Plan.

A. CITYWIDE EFFORTS

Citywide efforts to mitigate climate change range from planning-level recommendations to regulatory requirements. Ongoing actions and recent recommendations have been summarized in **Table 4** below.

Table 4: Ongoing Citywide Environmental Efforts

Name	Description	Implication for Duke Street Land Use Plan	Environmental Risk(s) Mitigated
Flood Action Alexandria⁹	An initiative to address flooding throughout the City, including spot improvement projects and large capacity projects.	The City is already addressing identified flooding issues through Capital Projects, so this plan will not include specific flooding improvement projects.	Flood
Stormwater Utility Fee Credit Program²⁹	Allows residents and condo associations to reduce their fee by implementing stormwater management practices, sustainable landscaping practices, or floodproofing measures.	Since the City already has an incentive program to encourage sustainable practices on residential private properties, incentive programs are not highlighted in this plan.	Flood, Water Quality, Heat
Flood Resilience Plan¹⁰	Ongoing effort to assess the current scope and scale of flooding throughout the City and identify areas for further study and improvements.	Large-scale flood studies are not included in this plan.	Flood
Environmental Action Plan 2040⁵	Highlights Citywide short-, mid-, and long-term goals for multiple environmental issues.	The Environmental Action Plan 2040 already establishes a tree canopy coverage goal and Citywide action items for water resources, so these recommendations will not be duplicated in this Land Use Plan.	Flood, Heat, Water Quality

Name	Description	Implication for Duke Street Land Use Plan	Environmental Risk(s) Mitigated
Energy & Climate Change Action Plan (ECCAP)¹	A plan for the City to reduce greenhouse gas emissions and minimize the impacts of flooding and extreme heat.	Recommendations already included in the ECCAP are not duplicated in this Land Use Plan.	Flood, Heat
Chesapeake Bay TMDL Action Plan¹⁴	Summarizes strategies that the City is implementing to meet the Chesapeake Bay TMDL requirements by the end of the permit cycle in 2028.	This Land Use Plan aims to focus on opportunities within the Duke Street Corridor, rather than duplicating Citywide strategies already in the TMDL Action Plan.	Water Quality
Bacteria TMDL Action Plan¹³	A plan to address bacterial sources and meet TMDL requirements within the Holmes Run, Cameron Run, Hunting Creek, and Four Mile Run watersheds.	This Land Use Plan aims to focus on opportunities within the Duke Street Corridor, rather than duplicating Citywide strategies already in the TMDL Action Plan.	Water Quality
MS4 Program Plan¹²	A plan for how the City will meet the TMDL requirements required by the Clean Water Act through six minimum control measures (MCM).	Citywide strategies already implemented as part of the MS4 Program are not included in this plan. The City is already conducting public outreach and education through MCM 1, so public outreach is not a focus of this Land Use Plan.	Water Quality
Memorandum to Industry No. 01-18³⁰	Established that for all new development and redevelopment, a minimum of 65% of the total phosphorus removal required by the Virginia Stormwater Management Program must be achieved using non-proprietary surface BMPs.	This Land Use Plan focuses on specific locations where green infrastructure can be beneficial, rather than regulatory requirements for new development and redevelopment.	Water Quality
Senior Cool Care Program³¹	Provides cooling assistance to seniors over 60 years of age who meet income and other guidelines.	Since cooling assistance programs already exist in the City, they are not a focus of this Land Use Plan.	Heat

Name	Description	Implication for Duke Street Land Use Plan	Environmental Risk(s) Mitigated
Virginia Energy Assistance Cooling Program³¹	Provides qualifying households with a \$400 maximum benefit payment to their Dominion Energy account during the summer.	Since cooling assistance programs already exist in the City, they are not a focus of this Land Use Plan.	Heat
Urban Forestry Master Plan³²	Established recommendations for the management and improvement of the City's urban forest.	Citywide strategies for tree planting, maintenance, and outreach are already covered under the master plan and are not included in this Land Use Plan.	Heat, Flood, Water Quality

B. ASCE 24-24 UPDATES

As of 2024, the new ASCE 24-24 standard³³ has elevated the recommended finished floor elevation for various flood design classifications. In general, most properties in the City will fall under design class 2, which includes most residential, commercial and industrial building; however, places of gathering – such as schools, community centers, or preschools – are considered design class 3 facilities. Facilities that are essential, such as hospitals, fire stations, and emergency shelters, are categorized as design class 4.

The relevance of this policy change is that the target design flood elevation (DFE), or finished floor elevation, for properties is no longer focused exclusively on the 100-year floodplain. Instead, this document defines the target DFE as shown in **Table 5**.

Table 5: Flood Design Classifications

Flood Design Class	DFE Target
1	100-Year
2	500-Year
3	750-Year
4	1,000-Year

Consideration of integrating or adopting these more aggressive DFE targets is recommended to better influence developers in the City to build for the future and mitigate long-term flood risk.

C. MITIGATION STRATEGIES FOR THE DUKE STREET CORRIDOR

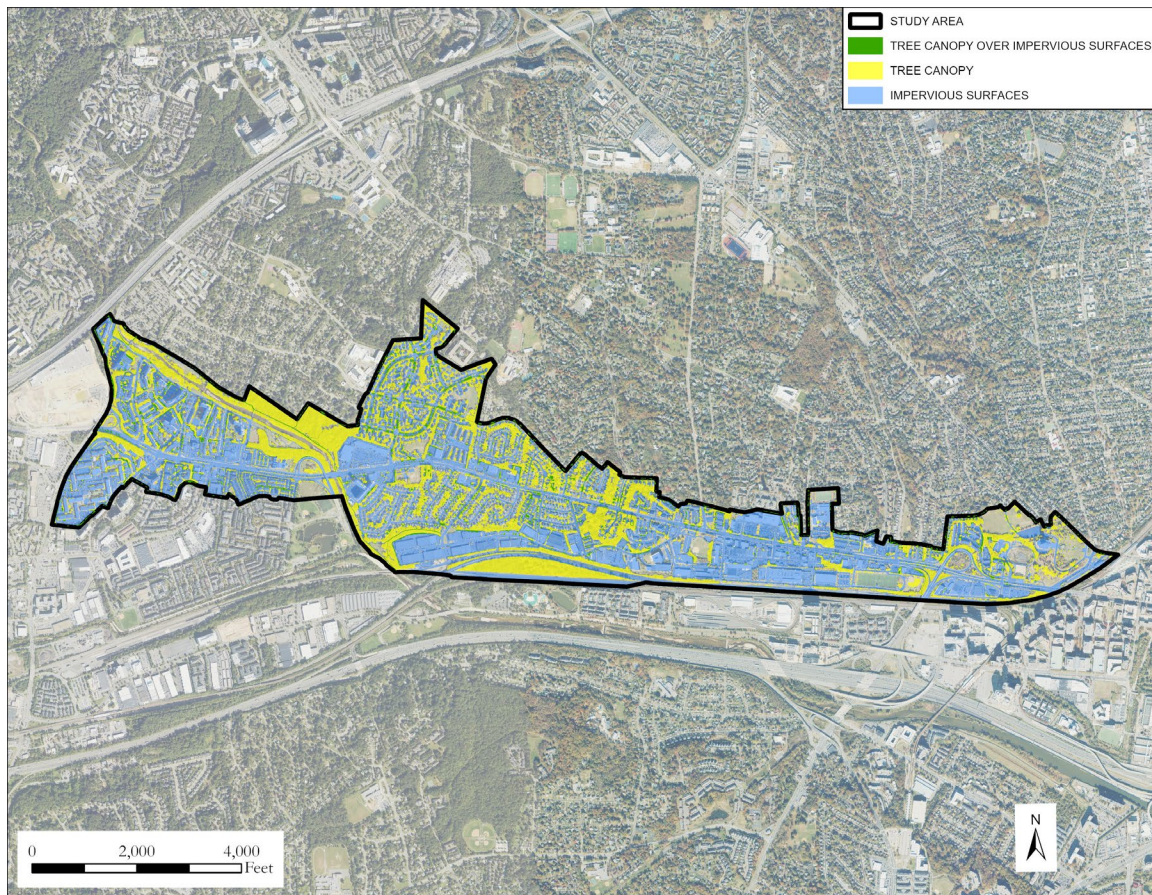
As part of this study, a “toolbox” of strategies was created that can be integrated with the Duke Street Land Use Plan to guide redevelopment and transportation improvements within the corridor. As the population continues to increase and the Duke Street area changes in unforeseen ways, these strategies can be used where new opportunities present themselves, or as general land development practices. As these strategies are implemented, it will be important to prioritize communities that are socially vulnerable to protect those who will be most impacted by climate change in the future. See **Table 6** for the environmental mitigation toolbox.

Each strategy has been assigned a development type, the environmental risk being addressed, and a cost magnitude for planning level considerations. Note that costs provided herein are qualitative and relative to the strategies proposed in this memorandum. Actual financial estimates for implementation of these costs are outside the scope of this analysis and will require site specific concept plan development with detailed cost breakdowns.

The strategies were categorized into three horizon windows of short-, mid-, and long-term strategies. These horizons are approximate and should not be taken as definitive timelines. Short-term strategies are those that can be implemented within about 2 years, mid-term strategies are those that can be implemented in 2 to 5 years, and long-term strategies are those that may take more than 5 years.

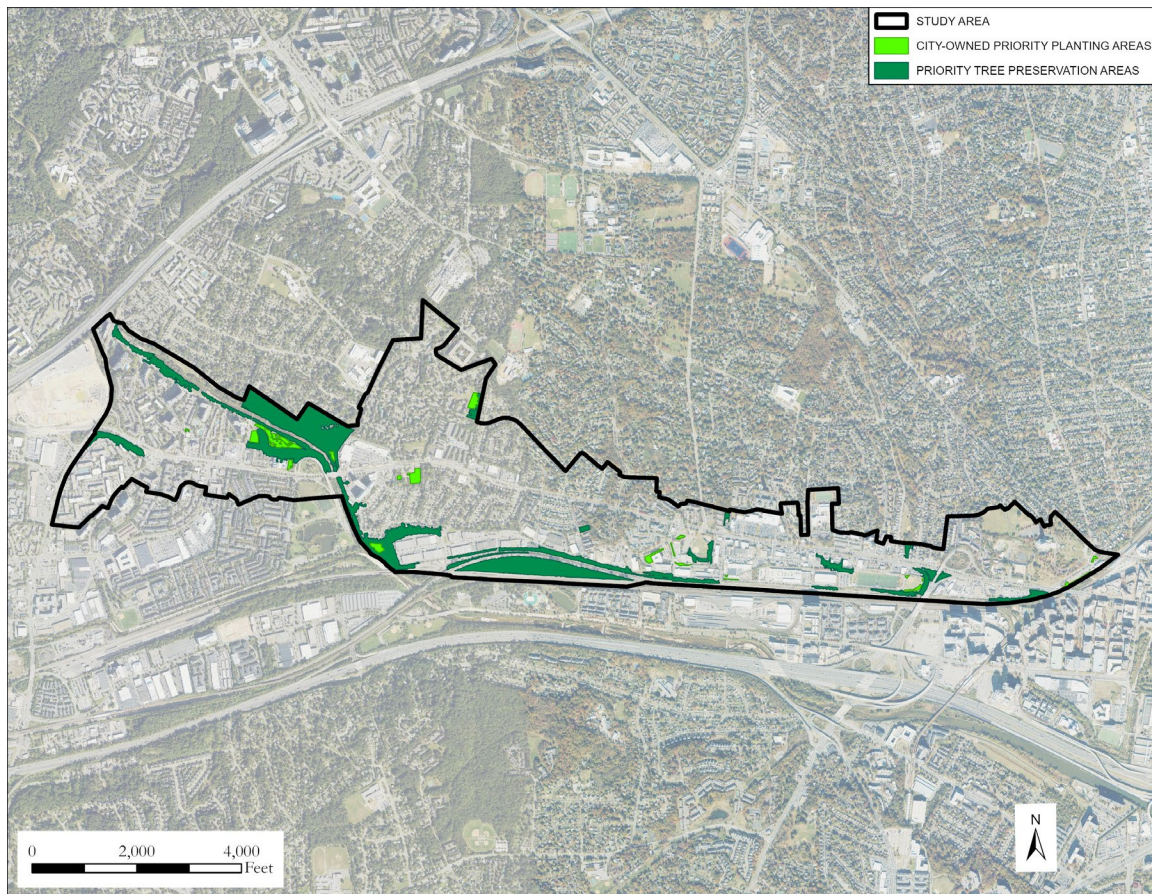
As part of this study, existing access to shade and City-designated “cooling centers” (public buildings where people can cool down during extreme heat events)³¹ were analyzed within the study area. There is only one designated cooling center within the study area – the Charles E. Beatley, Jr. Central Library on the western side of the corridor. Another cooling center, the Patrick Henry Recreation Center, is adjacent to the western study area boundary. It is important to note that these cooling centers are located in proximity to the areas identified as socially vulnerable by the CEJST and SVI, which indicates that there are already some resources in place to help those who may be most vulnerable to heat. The eastern side of the corridor does not have nearby access to a designated cooling center, but the residential areas have relatively high levels of tree canopy cover. See **Appendix M** and **Figure 8** for a map of existing impervious surface and tree canopy cover in the study area.

Figure 8: Tree Canopy Map



As shown in **Appendix O** and in **Figure 9** below, large existing tree stands were identified as priority preservation areas based on their value as habitats, noise buffers, and/or water quality buffers. Additionally, priority tree planting areas on City-owned properties were identified based on available space and their location within or in proximity to urban heat islands. Many of the suggested planting locations are outside an urban heat island but adjacent to impervious surfaces and other areas that have the potential to become a heat island. Though assessment of tree canopy was completed using available desktop resources, this information does not provide details on the overall condition of the tree canopy within the City. To further develop planting areas and areas in need of tree care, an inventory and analysis of trees and assessment of large forest stands would be a short-term action that provides long-term benefits.

Figure 9: Tree Planting and Preservation Map



One proposed strategy includes “dual-purpose solar”, which is a term used to describe solar panels implemented in such a way that the land can also be used for other purposes. Some examples of dual-purpose solar panels include bus stop shades/shelters, parking lot covers, or integrated solar panels into building design.³⁴ These are especially helpful in urban environments where land is in high demand for housing and commercial uses.

Another strategy is to install “cool roofs”, which are roofs designed to reflect more sunlight and can reduce roof temperatures and indoor cooling needs.³⁵ This can reduce the building’s energy consumption and mitigate the urban heat island effect. Cool roofs can vary in material and cost – options include painting the roof a lighter color, applying a cool coating, or using more reflective materials. However, in general, cool roof products usually cost no more than conventional roofing products for new roof installation.

Converting overhead utility lines to underground utilities is a strategy that has dual purposes – it increases resiliency by reducing the risk of power loss during intense rainfall events and periods of extreme heat, and it also creates space for tree planting to offset the urban heat island effect.

Table 6: Environmental Mitigation Toolbox

ID ¹	Description	Development Type ²	Environmental Risk(s) Mitigated	Cost
			 = Flooding  = Water Quality  = Urban Heat Island	
S.1	Install Floodproofing Measures	I, C, R		Low
S.2	Plant Street Trees	ROW, Public Land	  	Low
S.3	Tree Inventory Of City Street Trees And Trees On City-Owned Property	C, ROW, and Public Land	  	Medium
S.4	Incentivize Green Infrastructure and Green Roofs through Policy and Proffers	I, C, R	  	High
M.1	Set Proposed Building FFEs Above 100-YR Floodplain	I, C, R		Medium
M.2	Preserve Large Stands Of Trees Through Conservation Easements	ROW	  	Low
M.3	Add Dual-Purpose Solar	I, C, ROW and Public Land		Medium
M.4	Install Cool Roofs On Public Buildings	Public Land	  	Medium
M.5	Reduce Impervious Area	ROW, I, C, R	  	Medium
M.6	Underground Overhead Utility Wires	ROW	 	High
L.1	Construct New / Designate Existing Buildings as Cooling Centers	Public Properties		High / Low
L.2	Encourage Mixed-Use Development	I, C, R		Low
L.3	Reduce Parking Requirements For New Development	I, C	  	Low
L.4	Reduce Roadway and Travel Lane Widths	ROW	  	High

¹ ID fields indicate the associated horizon for implementation based on the first letter. For example, S refers to short-, M refers to mid-, and L refers to long-term.

² Development types are defined as:

I = Industrial

C = Commercial

R = Residential

ROW = Public Right-of-Way

Site-Specific Conceptual Recommendations

Based on the existing conditions assessment and the social vulnerability sources discussed in the **Social Vulnerability** section, specific locations were identified where potential strategies could be further evaluated to address environmental risks.

Typology 1: Residential Areas Adjacent to Floodplain

Environmental Risk: Flooding

Mitigation Strategy: Education, outreach, private floodproofing, and flood mitigation

Cost: Low



Figure 11: Example of Stream with Floodplain



Figure 11: Example of Floodproofing Technique

Typology 2: Large Expanses of Building/Roof Area with Lack of Green Space

Environmental Risk: Urban Heat Island, Flooding, Water Quality

Mitigation Strategy: Green roofs, cool roofs, dual-purpose solar, and tree planting

Cost: Low to High, Depending on Measures Implemented



Figure 13: Example of Large Building/Roof Area with Lack of Green Space



Figure 13: Example of Green Roof

Typology 3: Streets with Overhead Utilities and Lack of Mature Canopy Growth

Environmental Risk: Urban Heat Island, Flooding

Mitigation Strategy: Underground utility lines and plant street trees

Cost: High



Figure 15: Example of Street Trees Trimmed Under Utility Lines



Figure 15: Example of a Street with Mature Trees

Typology 4: Large Surface Parking Lots with Lack of Mature Canopy Growth

Environmental Risk: Urban Heat Island, Flooding, Water Quality

Mitigation Strategy: Mixed-use development, green infrastructure, dual-purpose solar, and tree planting

Cost: High



Figure 17: Example of Large Surface Parking Lot with Lack of Canopy



Figure 17: Example of Green Infrastructure

D. CONCLUSION

The goal of this environmental risk and adaptation strategies assessment is to:

- (1) Understand existing environmental conditions associated with flooding, water quality, and the urban heat island effect throughout the Study Area, and
- (2) Identify both typology-specific and general strategies that can be implemented throughout the Study Area as part of the Land Use Plan to mitigate these risks

In order to meet these goals, Kimley-Horn:

- Reviewed existing Citywide efforts to avoid duplication of ongoing strategies;
- Developed criteria for assessing flood, water quality and urban heat island risks;
- Created a comprehensive environmental risk assessment to normalize the data throughout the study area;
- Developed general mitigation strategies for the City to consider in addressing these risks; and
- Developed mitigation strategies specific to Duke Street, which may loosely serve as a guide for different types of development as areas of opportunity continue to change in the future.

The existing conditions assessment was used as a guide to help the City identify locations where project implementation may have the greatest impact. Potential mitigation strategies have been proposed for four specific typologies throughout the corridor, alongside general mitigation strategies for consideration throughout the City. It is important to note that the areas identified in this assessment will require site-specific planning efforts to better understand the feasibility and cost implications of implementing these types of mitigation strategies.

As climate change continues to increase temperatures and precipitation levels, and as residents become increasingly concerned about the effects of climate change, the Duke Street Land Use Plan will serve as a critical planning tool for integrating climate mitigation strategies into the future development of the corridor.

References

1. City of Alexandria, Virginia Energy & Climate Change Action Plan
[https://www.alexandriava.gov/sites/default/files/2023-07/ECCAP%20Final_07.2023.pdf]
2. What Are Heat Islands? [<https://www.epa.gov/heatislands/what-are-heat-islands>]
3. City of Alexandria Zoning Ordinance
[https://library.municode.com/va/alexandria/codes/zoning?nodeId=ARTXIIENMA_13-105DECHBAPRAROVDI]
4. Duke Street Land Use Plan Background Packet
[<https://media.alexandriava.gov/content/planning/202506DukeStreetLandUseBackgroudInfor mation.pdf>]
5. Environmental Action Plan 2040 [<https://www.alexandriava.gov/eco-city-alexandria/environmental-action-plan-2040>]
6. Northern Virginia Hazard Mitigation Plan [<https://engage.fairfaxva.gov/northern-virginia-hazard-mitigation-plan-2022>]
7. Northern Virginia Hazard Mitigation Plan Annex 2: City of Alexandria
[<https://www.alexandriava.gov/sites/default/files/2023-10/02%20City%20of%20Alexandria%20Annex%20-%202022%20NOVA%20HMP%20FINAL.pdf>]
8. 2016 City of Alexandria Storm Sewer Capacity Analysis
[<https://media.alexandriava.gov/docs-archives/tes/stormwater/cassca-final-summary-report.pdf>]
9. Flood Action Alexandria [<https://www.alexandriava.gov/FloodAction>]
10. Flood Resiliency Plan [<https://www.alexandriava.gov/flood-action/flood-resilience-plan>]
11. Dam Safety Program [<https://www.dcr.virginia.gov/dam-safety-and-floodplains/dam-safety-index>]
12. Municipal Separate Storm Sewer System (MS4) Program Plan
[<https://media.alexandriava.gov/content/tes/AlexandriaMS4ProgramPlan.pdf>]
13. Bacteria Total Maximum Daily Load (TMDL) Action Plan
[<https://media.alexandriava.gov/content/tes/BacteriaTMDLActionPlan2025.pdf>]
14. Phase 3 Chesapeake Bay TMDL Action Plan for 100% Compliance
[<https://media.alexandriava.gov/content/tes/BayTMDLPhase3ActionPlan11012024.pdf>]
15. Stormwater Quality [<https://www.alexandriava.gov/stormwater-management/stormwater-quality>]
16. Heat Island Trends [<https://www.epa.gov/heatislands/heat-island-trends>]
17. Who is Most at Risk to Extreme Heat? [<https://heat.gov/who-is-most-at-risk-to-extreme-heat/#:~:text=Extreme%20heat%20can%20be%20uncomfortable,and%20Service%20and%20Support%20Animals>]
18. NOAA National Storm Surge Risk Maps [<https://www.nhc.noaa.gov/nationalsurge/>]
19. Anomalies vs. Temperature [<https://www.ncei.noaa.gov/access/monitoring/dyk/anomalies-vs-temperature>]
20. Urban Heat Island Severity (USA 2025)
[<https://tpl.maps.arcgis.com/home/item.html?id=48edb3800dab4f70ae42eb0ccf5e08f4>]
21. As the world heats up, so does the debate around artificial turf
[<https://www.thenewlede.org/2024/08/as-the-world-heats-up-so-does-the-debate-around-artificial-turf/>]

22. Witter Fields Turf Renovation [<https://www.alexandriava.gov/parks/location/witter-fields>]
23. i-Tree Canopy [<https://canopy.itreetools.org/>]
24. Duke Street Land Use Plan [<https://www.alexandriava.gov/DukeStreetPlan>]
25. Climate and Economic Justice Screening Tool (CEJST)
[<https://ndcpartnership.org/knowledge-portal/climate-toolbox/climate-and-economic-justice-screening-tool-cejst>]
26. FEMA Resilience Analysis and Planning Tool
[<https://experience.arcgis.com/experience/0a317e8998534c30a9b2d3861c814d42/>]
27. Virginia Social Vulnerability Index
[[Updated Social Vulnerability Index Description 2021.pdf](#)]
28. Intergovernmental Panel on Climate Change (IPCC) Interactive Atlas [<https://interactive-atlas.ipcc.ch/>]
29. Stormwater Utility Fees and Credits for Residential Properties
[<https://www.alexandriava.gov/stormwater-management/stormwater-utility-fees-and-credits-for-residential-properties>]
30. Memorandum to Industry No. 01-18 [<https://media.alexandriava.gov/docs-archives/tes/info/memotoindustry01-18=use-of-manufactured-bmps.pdf>]
31. Seasonal and Emergency Warming and Cooling Options
[<https://www.alexandriava.gov/homeless-services/seasonal-and-emergency-warming-and-cooling-options>]
32. City of Alexandria Urban Forestry Master Plan [<https://media.alexandriava.gov/docs-archives/planning/info/masterplan/urbanforestrymasterplanfinal2009.pdf>]
33. ASCE 24-24 Flood Design Standard Updates [<https://www.structuremag.org/article/major-changes-to-asce-7-22-flood-loads/>]
34. Innovative Approach to Dual – Purpose Solar
[<https://www.nlc.org/article/2025/04/03/innovative-approaches-to-dual-purpose-solar>]
35. Cool Roofs [<https://www.energy.gov/energysaver/cool-roofs>]