AECOM

Vulnerability Assessment Report

Prince William County

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Prepared by	Checked by	Verified by	Approved by
Ricky Torres-Cooban, Milani Chatterji-Len	Emily Dhingra	Chris Levitz	Tauhirah AbdulMatin

Revision History

Revision	Revision date	Details	Name	Position
0	11/7/22	Original	Tauhirah Abdul-Matin	Project Manager
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Prepared for:

Prince William County

Prepared by:

AECOM
3101 Wilson Boulevard
Arlington, VA 22201
aecom.com

Figures

Tables

Executive Summary

Prince William County is located in the Washington, DC metropolitan area and is a fast-growing county currently home to over 482,000 people as of the 2020 census. The Draft 2022 Northern Virginia Hazard Mitigation Plan and the Metropolitan Washington Council of Governments 2030 Climate and Energy Action Plan each provide an assessment of natural hazard risks within the region and Prince William County. This report strives to provide an overview of the vulnerability of Prince William County's assets to climate hazards with a particular focus on how future conditions will exacerbate existing vulnerabilities. At the county-level, this report categorizes the relevant assets, evaluates their exposure to climate hazards, and rates each assets' sensitivity and adaptive capacity. Vulnerability assessments are an essential part of the planning process as they help identify the areas of greatest need within the community and can help to focus resiliency planning efforts on the most beneficial projects.

Hazards reviewed in this report include precipitation, temperature, drought, coastal flooding, sea level rise, earthquakes, and high winds/tornadoes. Future conditions were only assessed for the precipitation, temperature, drought, and sea level rise hazards. Two future climate scenarios were evaluated for the years 2050 and 2075. The future climate scenarios to predict precipitation, temperature and drought changes represent a scenario where greenhouse gas emissions continue to increase through the middle of the 21st century and are then stabilized and another scenario that is a business-as-usual or worst-case scenario with GHG emissions increasing throughout the 21st century. Sea level rise (SRL) future scenarios were based on the National Oceanic and Atmospheric Administration's (NOAA's) 2017 SRL estimates (Sweet, 2017).

Assets within the county were grouped to align with the Federal Emergency Management Agency's (FEMA's) Community Lifelines, which are also used by the Prince William County Office of Emergency Management (PWC EM). The FEMA Lifeline categories are safety and security; food, water and shelter; health and medical; communications; transportation; energy; and hazardous materials. For this study, the energy and hazardous materials lifeline categories have been combined and two additional categories have been included in this analysis which are: natural resources and socially vulnerable populations.

The vulnerability assessment calculated risk based on the exposure, sensitivity, and adaptive capacity of each asset category to each natural hazard. Ratings were assigned numerical values and summed to determine vulnerability scores for each asset category, time horizon, and hazard. Each asset category's vulnerability ratings for each timeline and climate hazard are shown in Table E-1. Vulnerability scores within each asset category were combined and used to assign a Low, Medium, or High combined vulnerability rating for each of the two future timelines (2050 and 2075) as shown in Table E-2.

Overall, assets in Prince William County were determined to be most vulnerable to Extreme Temperatures followed by Precipitation and Strong Winds/Tornadoes. Socially Vulnerable Populations, Transportation, and Natural Resources were the most vulnerable asset categories followed by Energy & Hazardous Materials. The most vulnerable asset categories were determined to be the Socially Vulnerable Populations, Transportation, and Natural Resources categories, which had High combined vulnerability ratings in both 2050 and 2075. Energy & Hazardous Materials received a Medium combined vulnerability rating for 2050 and a High combined vulnerability rating for 2075. Food, Water, and Shelter and Health and Medical asset categories received Medium combined vulnerability ratings for both 2050 and 2075 while Safety and Security and Communications asset categories received Low vulnerability ratings for both 2050 and 2075.

Table E-1. Summary of Vulnerability Ratings for All Climate Hazards

Climate Hazard	Asset Category															
	Safety and Security		Food, Water, and Shelter		Health and Medical		Communications		Transportation		Energy & Hazardous Materials		Natural Resources		Socially Vulnerable Populations	
	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075
Precipitation	L	L	M	M	M	M	L	L	H	H	M	M	H	H	H	H
Extreme Temperature	M	M	M	H	M	M	M	M	M	H	M	M	M	H	H	H
Drought	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	H
Coastal Flooding and SLR	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M
Earthquakes	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M
Strong Winds/Tornadoes	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M

Table E-2. Summary of Combined Vulnerability Ratings

Asset Category	Combined Vulnerability Rating	
	2050	2075
Safety and Security	L	L
Food, Water, and Shelter	M	M
Health and Medical	M	M
Communications	L	L
Transportation	H	H
Energy & Hazardous Materials	M	H
Natural Resources	H	H
Socially Vulnerable Populations	H	H

1. Introduction

Prince William County is located in the Washington, DC metropolitan area and is a fast-growing county currently home to over 482,000 people as of the 2020 census. The county is bounded on the north by Loudoun and Fairfax Counties, west by Fauquier County, on the south by Stafford County, and on the east by the Potomac River.
As reported in the Draft 2022 Northern Virginia Hazard Mitigation Plan, the county currently faces risks from many natural hazards including: High Wind/Severe Storms, Winter Weather, Floods/Flash Floods, Tornados, Earthquakes, Droughts, Extreme Temperatures, Wildfires, Landslides, Karst/Sinkholes. The Metropolitan Washington Council of Governments 2030 Climate and Energy Action Plan includes an assessment of climate hazards for the region including extreme heat, drought, lightning and thunderstorms, flash and riverine flooding, coastal flooding, and extreme winter conditions (2020).

While these documents provide an overview of climate risk for the region, this Climate Vulnerability Assessment for Prince William County provides a more in-depth review of climate risks for specific asset categories within the County. This includes an analysis of present-day risks for: precipitation, extreme temperature, drought, coastal flooding, earthquakes, and strong winds and tornadoes. Future conditions are considered for precipitation, extreme temperature, drought, and sea level rise. The hazards are discussed in more detail in Section 2 of this report. Prince William County's assets are described in Section 3. Section 4 discusses the vulnerability assessment methodology, which focuses on exposure, sensitivity, and adaptive capacity. This section also discusses the vulnerability of each hazard for each asset category. A rating system is established to quantify the risk from each hazard for each asset category and the final ratings and vulnerability are discussed in Section 5. References are included in Section 6.

2. Climate Hazards

Climate hazards are environmental phenomena that have the potential to impact societies and the human environment. Prince William County and its residents are exposed to many natural hazards including riverine and coastal flooding, extreme temperatures, droughts, strong winds, tornadoes, and even earthquakes. Climate hazards that have been determined to have the highest risk of causing harm are discussed. For some climate hazards, only present-day conditions and assessments are available, but for some climate hazards, future conditions for the years 2050 and 2075 are discussed. The Forecasting Local Extremes (FLEx) tool is used for some of the future assessments and is discussed in more detail in Section 2.1.2

2.1. Future Conditions Methodology

2.1.1. Scenarios

To better quantify the climate hazard risks, the Prince William County team analyzed climate hazards by comparing projected climate threats from 2050 and 2075 to a historical climate baseline (based on a "baseline" period of analysis from 1950 through 2005). The Prince William County greenhouse gas emissions forecasts include the years 2030 and 2050. The 2030 timeline is considered too near-term to see substantial changes in the climate compared with today's conditions, so the 2050 time was selected as the first projected time. The 2075 time was selected to represent a longer-term climate scenario, which aligns with the approximate useful life of many transportation and residential building assets if they were built within the next 5 years. For each future timeline, two different climate scenarios were evaluated. The first climate scenario called the Representative Concentration Pathway (RCP) 4.5 represents a stabilization scenario through greenhouse gas (GHG) mitigation strategies and technological interventions that produce a moderate GHG emissions increase until the middle of the twentieth century followed by a leveling off of these emissions. A second scenario (RCP 8.5) represents a business-as-usual or worst-case scenario with GHG emissions increasing throughout the 21st century (van Vuuren, et al., 2011). These two scenarios are commonly used to provide a most likely range of possible future climate conditions.

2.1.2. Forecasting Local Extremes (FLEx) Tool

AECOM conducted post-processing of the localized constructed analogs (LOCA) dataset to calculate future temperature, precipitation, and drought statistics using the Forecasting Local Extremes (FLEx) tool. Developed by AECOM, the FLEx tool uses general circulation model (GCM) output that has been downscaled by research scientists to achieve higher spatial resolutions for future climate scenarios. The FLEx tool efficiently condenses the data into a few key indicators that help describe future hazard exposure for a local area.

The future conditions statistical analyses performed for this study are driven by gridded observed data and statistically downscaled GCM outputs developed by the Bureau of Reclamation. The dataset provides a high spatial resolution (6-kilometer x 6-kilometer) of daily downscaled maximum/minimum temperature and precipitation data from 32 GCMs through the LOCA statistical downscaling method (Pierce, et. al, 2014).

In the future conditions assessment, all 32 GCMs were equally weighted as an ensemble and analyzed to capture the full range of model variability, based on guidance from the United Nations Intergovernmental Panel on Climate Change (IPCC) that an ensemble average of several GCMs is expected to outperform the results of individual ensemble members and provide an improved “best estimate” forecast (IPCC, 2007). Statistics were calculated separately for each grid cell that intersects with the County boundary and then averaged.

2.1.3. Indicators

This section defines each of the indicators used in the future conditions analyses. All indicators are calculated separately for each model and then averaged equally to create a single ensemble-average value. Generally, average annual and seasonal values represent an understanding of long-term trends such as a tendency for wetter or warmer conditions. On the other hand, the values tied to 95th and 99th percentiles, days above a temperature threshold (e.g., 95° F) and maximum 3-day/5-day events demonstrate trends in more extreme events or volatility. Long-term trends can show more or less rainfall on average while the volatility represents short-term extremes.

Precipitation

- **Average Annual Maximum:** the maximum annual daily precipitation value averaged across the time horizon
- **Average Annual Total:** the sum of annual precipitation averaged across the time horizon
- **95th/99th Percentile:** the 24-hour precipitation depth that is greater than or equal to 95%/99% of storm events across the time horizon
- **Average Annual Maximum 5-Day Event:** the maximum annual precipitation event lasting 5 days averaged across the time horizon
- **Epoch Maximum 3-Day/5-Day Event:** the maximum precipitation event lasting 3/5 days which occurs during the time horizon
- **Autumn/Winter/Spring/Summer:** the sum of precipitation occurring during each season averaged across the time horizon
- **Number of Days Equal to or Above 95th/99th Percentile:** the number of days each year that precipitation was greater than or equal to the 95th/99th Percentile from the baseline period averaged across the time horizon
- **Fraction of Rain due to 95th/99th Percentile:** the sum of precipitation depths each year from days with precipitation greater than or equal to the 95th/99th Percentile from the baseline period divided by the sum of all precipitation for each year; averaged across the time horizon

Temperature

- **Average Annual Maximum:** the maximum annual daily temperature value averaged across the time horizon
- **Average Annual Minimum:** the minimum annual daily temperature value averaged across the time horizon
- **95th/99th Percentile:** the daily maximum temperature value that is greater than or equal to 95%/99% of daily maximum temperature values across the time horizon

- **Autumn/Winter/Spring/Summer:** the average maximum/minimum daily temperature occurring during each season averaged across the time horizon
- **Number of Days Equal to or Above 95° F/105° F:** the number of days each year that maximum daily temperature was greater than or equal to 95° F/105° F averaged across the time horizon
- **Number of Days Equal to or Above 95th/99th Percentile:** the number of days each year that maximum daily temperature was greater than or equal to the 95th/99th Percentile from the baseline period averaged across the time horizon
- **Number of Days Equal to or Below 75° F:** the number of days each year that minimum daily temperature was less than or equal to 75° F averaged across the time horizon

Drought

- **Average Change in the Average Number of Months per Year with Mild/Moderate/Severe/Extreme Drought:** the change in the average number of months each year with PDSI values within the range for each severity rating (Mild/Moderate/Severe/Extreme Drought as described in Section 2.4.2) averaged across the time horizon

2.2. Precipitation

2.2.1. Current Conditions

Prince William County has a temperate climate with rainfall occurring throughout the year. The County has been impacted by tropical storms, hurricanes, and severe winter storms/nor'easters. There have been 9 major disaster declarations due to tropical storms or hurricanes[1] for the County as recorded by the Federal Emergency Management Agency (FEMA) between 1972 and 2021 as well as 242 recorded flood events[2] and 134 winter storm events[3] as recorded by the National Oceanic and Atmospheric Administration (NOAA) from 1996 to 2021. Over $4 million in National Flood Insurance Program (NFIP) claims were paid out from 1978 to 2015 including over $1.7 million in repetitive loss properties. In the most recent Northern Virginia Hazard Mitigation Plan (2022), flooding was identified as one of the highest risk hazards for Prince William County. Prince William County participates in the Virginia Stormwater Management Program (VSMP), managed by the state Department of Environmental Quality, which provides guidelines for managing water from the municipal storm sewer system and construction activities.

Nuisance Flooding and Road Closures

Prince William County has had 60 reported Swift Water Rescue events and 178 reported VDOT road closures since 2018 due to intense precipitation events. Locations of these events are shown in Figure 1. Detailed stormwater modeling is needed to better understand how flooding occurs throughout the County during precipitation events and to better understand the limitations of existing stormwater infrastructure.

[1] FEMA Disaster Declarations for Hurricanes and Tropical Storms, Virginia, 1972 – 2021.
[2] NOAA, NCEI Storm Events Database, 1950 to June 30, 2021. The search encompassed a cross-section of NCEI flood-related categories: flood; coastal flood; flash flood; heavy rain; thunderstorm wind; heavy rain; storm surge/tide; and tropical storm. County reported events include impacts in towns, where applicable.
[3] NOAA, National Centers for Environmental Information, Storm Events Database, 1996–June 30, 2021

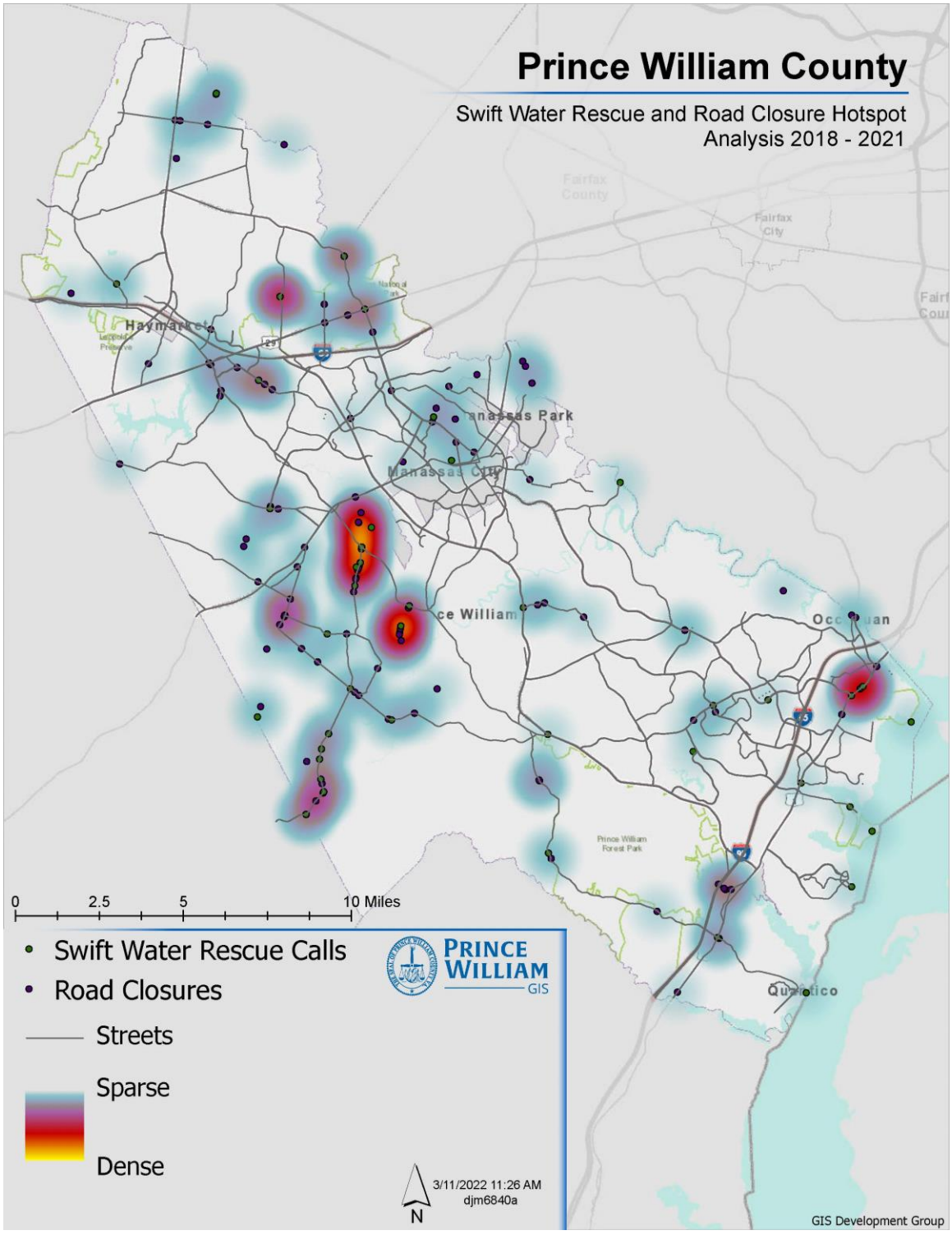


Figure 1. Swift Water Rescue and Road Closures from 2018 - 2021

2.2.2. Future Conditions

Changes in precipitation can be measured using multiple indicators to understand different aspects of the future climate. Change in the average seasonal total precipitation as well as a change in the average annual total precipitation help provide an idea of how the typical year is expected to change. Changes to the maximum 3- and 5-day events, annual maximum precipitation, and changes to the 95th or 99th percentile storms show how extreme precipitation is expected to change on average each year. The 95th and 99th percentile storms represent the average 24-hour precipitation depth that is greater than or equal to 95% and 99% of storm events, respectively, for a given time period. In other words, these are extreme events that occur infrequently. These statistics are shown for the years 2050 and 2075 for the RCP4.5 and RCP8.5 scenarios in Table 1.

Table 1. Future Average Seasonal and Annual Precipitation Indicators

Precipitation Indicators	RCP4.5[4]				RCP8.5[5]			
	Average 2050 Change (Inches)	Average 2075 Change (Inches)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change (Inches)	Average 2075 Change (Inches)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
Average Annual Maximum	0.10	0.12	5	6	0.11	0.19	6	10
Average Annual Total	2.24	2.87	6	7	2.38	3.33	6	8
95th Percentile	0.05	0.07	6	7	0.06	0.09	7	11
99th Percentile	0.08	0.11	6	7	0.10	0.16	7	11
Average Annual Maximum 5-Day Event	0.23	0.31	6	8	0.28	0.41	7	11
Epoch Maximum 3-Day Event	0.13	0.33	1	3	0.33	0.60	3	6
Epoch Maximum 5-Day Event	0.12	0.46	1	5	0.59	0.67	5	6
Autumn	0.34	0.39	4	4	0.33	0.38	3	4
Winter	0.73	0.96	9	12	0.75	1.23	9	15
Spring	0.79	1.05	8	10	0.91	1.17	9	12
Summer	0.42	0.52	4	5	0.44	0.62	4	6

Projections for Prince William County show a small to moderate increase in seasonal and average annual precipitation indicators. The most significant increases in seasonal precipitation occur in Winter and Spring (9%-15%) while average annual total precipitation as well as average annual maximum daily precipitation are projected to increase by approximately 5% to 6% by 2050 and 6% to 10% by 2075.

Increases to annual extreme precipitation indicators such as the 95th and 99th percentiles of average annual daily precipitation are projected to be between 6% and 7% by 2050 and 7% to 11% by 2075 which suggest a moderate increase in storm intensities.

Table 2 shows the change in the average number of days per year with precipitation greater than or equal to the baseline 95th and 99th percentile which are projected to increase by approximately 1 day (17% - 29%) by 2050 and 2 days (23% - 48%) by 2075. These changes indicate a small increase to the frequency of extreme events. Similarly, Table 3 shows that the average annual fraction of precipitation which occurs during events that are equal to or above the 95th and 99th percentile is projected to increase by 11% to 20% in 2050 and 15% to 33% by 2075 which indicates

[4] Representative Concentration Pathway 4.5 (See Section 2.1.1)
[5] Representative Concentration Pathway 8.5 (See Section 2.1.1)

that more of the annual total precipitation will occur during extreme events. Table 4 shows small to moderate increases to return period storm events. Storm return period refers to the average recurrence interval associated with a particular storm intensity and duration. For example, the 10-year, 24-hour storm has an average recurrence interval of 10 years and a duration of 24 hours; the recurrence interval corresponds to an annual chance of exceedance (ACE) equal to 10% (1/10) so this event can also be called the 10%-annual-chance-exceedance (10% ACE) event. It is important to note that nuisance flooding and flash floods are not well represented by daily precipitation data as these events typically occur on a sub-daily scale. Thus, the results of this analysis do not fully capture the increases which are likely to occur on a sub-daily scale and may result in increased flash floods and stormwater/nuisance flooding.

Table 2. Future Number of Days Equal to or Above the Baseline 95th/99th Percentile

Precipitation Indicators	RCP4.5				RCP8.5			
	Average 2050 Change (Days)	Average 2050 Percent Change (%)	Average 2075 Change (Days)	Average 2075 Percent Change (%)	Average 2050 Change (Days)	Average 2050 Percent Change (%)	Average 2075 Change (Days)	Average 2075 Percent Change (%)
Number of Days Equal to or Above 95th Percentile	1.2	17	1.5	23	1.4	22	2.1	31
Number of Days Equal to or Above 99th Percentile	0.3	26	0.5	35	0.4	29	0.6	48

Table 3. Future Average Annual Fraction of Precipitation due to events equal to or above the Baseline 95th/99th Percentile

Precipitation Indicators	RCP4.5				RCP8.5			
	Average 2050 Change	Average 2075 Change	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change	Average 2075 Change	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
Fraction of Rain due to 95th Percentile	0.024	0.032	11	15	0.032	0.047	15	21
Fraction of Rain due to 99th Percentile	0.012	0.016	17	23	0.014	0.022	20	33

Table 4. Future Return Period Storms

Return Period Storm	RCP4.5				RCP8.5			
	Average 2050 Change (Inches)	Average 2075 Change (Inches)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change (Inches)	Average 2075 Change (Inches)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
100% ACE (1-yr)	0.05	0.08	5	8	0.08	0.09	7	8
50% ACE (2-yr)	0.10	0.13	6	7	0.11	0.18	7	10
10% ACE (10-yr)	0.13	0.14	5	5	0.13	0.26	5	9
4% ACE (25-yr)	0.14	0.13	4	4	0.13	0.30	4	9
1% ACE (100-yr)	0.15	0.12	3	3	0.14	0.39	3	8

2.3. Extreme Temperature

2.3.1. Current Conditions

Historically, both extreme heat and extreme cold events have occurred in Prince William County. According to NOAA, at least 33 extreme heat and 39 extreme cold events occurred between January 1950 and June 2021[6] and were documented to have resulted in crop losses as well as over 100 reported injuries (Mitigation Advisory Committee, 2022). In the most recent Northern VA Hazard Mitigation Plan (2022), Prince William County was identified as being at medium risk to impacts from extreme temperatures.

2.3.2. Future Conditions

Average annual temperatures for Prince William County are projected to increase in the future. Table 5 shows projected average changes to seasonal and annual maximum and minimum temperature indicators. Most maximum temperature indicators show an increase of approximately 2°C (3.6°F) by 2050 and 3°C (5.4°F) to 4°C (7.2°F) by 2075 while minimum temperatures are also expected to increase by approximately 2°C (3.6°F) to 3°C (5.4°F) by 2050 and 2°C (3.6°F) to 5°C (9°F) by 2075.

As shown in Table 6, extreme temperatures are also projected to increase as shown by the increases to the 95th and 99th percentile as well as the number of extreme heat and cold days. The 95th and 99th percentile maximum temperatures represent the average maximum daily temperature that is greater than or equal to 95% and 99% of daily maximum temperatures, respectively, for a given time period. The average annual number of extreme heat days increases by approximately two weeks in 2050 and approximately three weeks to one month by 2075. Accordingly, the average number of days with minimum temperatures below 75°F is projected to decrease by 4 to 5 days by 2050 and 9 to 18 days by 2075. It is important to note that while the general trend is towards increasing temperatures it will continue to be possible to have extreme cold events though the likelihood decreases over time.

Tree Cover and the Urban Heat Island Effect

Approximately 54% of Prince William County has some form of tree cover. Tree cover can help naturally mitigate high temperatures and is essential in combating the urban heat island effect. Urban heat islands can be defined as developed urban areas that experience consistently higher temperatures than surrounding areas with lower population density and more pervious ground cover (unpaved area that allows water to flow through) and vegetation. The urban heat island effect is the result of multiple factors often associated with urbanization, such as a concentration of construction materials that absorb and store more heat than the natural environment and then re-emit that heat when temperatures would normally decrease; minimal or no evapotranspiration (transfer of water from land to the atmosphere) due to lack of exposed soil and vegetation; concentrated heat generation from air conditioning and vehicle exhaust; and diminished wind flow due to building placement and concentration. The urban heat island effect was not directly quantified as a part of this Vulnerability Assessment, but it would likely increase extreme temperature experienced in urban parts of the County

[6] National Oceanic and Atmospheric Administration (2021). National Center for Environmental Information Storm Events Database, 1950-June 30, 2021 [Data set]. https://www.ncdc.noaa.gov/stormevents/

Table 5. Future Average Seasonal and Annual Temperature Indicators

Maximum Temperature Indicators	RCP4.5				RCP8.5			
	Average 2050 Change (°C)	Average 2075 Change (°C)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change (°C)	Average 2075 Change (°C)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
Average Annual Maximum	2.1	3.1	6	9	2.4	4.1	7	12
95th Percentile	2.0	2.9	6	9	2.3	4.0	7	12
99th Percentile	2.2	3.1	6	9	2.5	4.4	7	12
Autumn	1.9	2.7	9	13	2.0	3.5	10	18
Winter	1.5	2.3	21	32	1.7	3.0	24	41
Spring	1.6	2.3	8	12	1.6	2.9	9	15
Summer	1.8	2.7	6	9	6.8	3.6	7	12
Minimum Temperature Indicators	**Average 2050 Change (°C)**	**Average 2075 Change (°C)**	**Average 2050 Percent Change (%)**	**Average 2075 Percent Change (%)**	**Average 2050 Change (°C)**	**Average 2075 Change (°C)**	**Average 2050 Percent Change (%)**	**Average 2075 Percent Change (%)**
Average Annual Minimum	2.7	4.1	17	26	3.0	5.0	19	31
Autumn	1.7	2.5	23	33	1.9	3.3	25	44
Winter	1.7	2.4	50	60	1.9	3.1	56	94
Spring	1.5	2.2	27	38	1.6	2.8	28	48
Summer	1.6	2.4	9	14	1.8	3.3	10	19

Table 6. Future Number of Extreme Heat and Cold Days

Maximum Temperature Indicators	RCP4.5				RCP8.5			
	Average 2050 Change (Days)	Average 2075 Change (Days)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change (Days)	Average 2075 Change (Days)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
Number of Days Equal to or Above 95° F	13	21	296	499	15	32	351	763
Number of Days Equal to or Above 105° F	0.3	1.0	-	-	0.5	2.9	-	-
Number of Days Equal to or Above 95th Percentile	22	35	123	191	25	48	139	262
Number of Days Equal to or Above 99th Percentile	12	20	318	540	14	31	377	831
Minimum Temperature Indicators	**Average 2050 Change (Days)**	**Average 2075 Change (Days)**	**Average 2050 Percent Change (%)**	**Average 2075 Percent Change (%)**	**Average 2050 Change (Days)**	**Average 2075 Change (Days)**	**Average 2050 Percent Change (%)**	**Average 2075 Percent Change (%)**
Number of Days Equal to or Below 75° F	-4	-9	-1	-2	-5	-18	-1	-5

2.4. Drought

2.4.1. Current Conditions

NOAA records contain 12 drought events for Prince William County from 1950 to 2021[7]. Drought conditions have resulted in crop failures as well as water restrictions and the need for upstream dam releases to supplement drinking water supplies. In the most recent Northern VA Hazard Mitigation Plan (2022), the County was found to be at medium risk for drought impacts.

2.4.2. Future Conditions

Future changes to drought were evaluated by calculating the monthly Palmer Drought Severity Index (PDSI) and then calculating the average annual number of months of mild, moderate, severe, and extreme drought. These types of droughts are defined by the National Oceanic and Atmospheric Administration (NOAA) using the following PDSI values:

- PDSI 1 to -2 = Mild Drought
- PDSI -2 to -3 = Moderate Drought
- PDSI -3 to -4 = Severe Drought
- PDSI -4 or less = Extreme Drought

Table 7 shows the average change in the number of months per year projected for each drought type. Mild droughts increase by 2050 but by 2075 begin to decrease as more intense droughts become more common. Moderate,

[7] National Oceanic and Atmospheric Administration (2021). National Center for Environmental Information Storm Events Database, 1950-June 30, 2021 [Data set]. https://www.ncdc.noaa.gov/stormevents/

Severe, and Extreme droughts all show significant increases by 2050 and 2075. Drought conditions can be affected by a multitude of climate processes operating at local, regional, and even global scales and the development and relief of drought conditions can span weeks, months or even years. The indicator used in this assessment should not be understood to imply that drought will necessarily occur on an annual basis. Rather, this analysis shows an overall trend of increases to both frequency and severity of drought in the future. Increases in both temperature and precipitation extremes discussed earlier in this report are drivers of increased drought. The combined trends of large increases in extreme precipitation indicators combined with relatively small increases in average annual precipitation indicators suggest that precipitation will fall in more intense bursts followed by longer dry periods which may result in drought.

Table 7. Future Drought Indicators

Drought Indicators	RCP4.5				RCP8.5			
	Average 2050 Change (Months)	Average 2075 Change (Months)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)	Average 2050 Change (Months)	Average 2075 Change (Months)	Average 2050 Percent Change (%)	Average 2075 Percent Change (%)
Mild Drought (PDSI between -1 and -2)	0.034	0.030	2	1	0.057	-0.110	3	-4
Moderate Drought (PDSI between -2 and -3)	0.417	0.543	43	56	0.462	0.790	39	67
Severe Drought (PDSI between -3 and -4)	0.289	0.462	114	182	0.320	0.743	151	350
Extreme Drought (PDSI less than -4)	0.114	0.244	201	434	0.152	0.563	393	1534

2.5. Coastal Flooding and Sea Level Rise

2.5.1. Current Conditions

Coastal flooding is a present-day risk for areas along the Potomac River and tributaries. FEMA delineates the risk of the 1-percent-annual-chance coastal flood event (including storm surge and wave effects) on the Flood Insurance Rate Maps (FIRMs). Figure 2 shows a portion of a FIRM for Prince William County (effective date: August 3, 2015). The image shows coastal flood areas with high waves (Zone VE) and moderate to low waves (Zone AE) with a 1-percent-annual-chance of occurrence. Additionally, the 0.2-percent-annual-chance coastal floodplain is shown as an area with black dots.

The FEMA FIRMs are considered present-day conditions and include any sea level rise (SLR) that has occurred since the last Flood Insurance Study for the county, but do not include a prediction of future conditions.

High Coastal Hazard Areas

Most coastal areas in Prince William County are undeveloped and not of significant concern for coastal flooding. There are however some notable exceptions to this that should be noted though they do not figure prominently in the County-wide assessment. Woodbridge has several developed coastal areas near Marumsco Creek, the Occoquan River, and Featherstone National Wildlife Refuge that are located within the effective FEMA 1%-ACE (100-year) and 0.2%-ACE (500-year) floodplains. These areas include commercial and residential properties, including socially vulnerable populations, as well as marinas and piers all of which are likely to be impacted significantly by storm surge. Other critical assets that are near the coastal shoreline but currently outside the Effective FEMA floodplains include the County's primary wastewater treatment facility for the County, located on Neabsco Creek Dominion Energy's Possum Point facility, and the Marine Corps Base Quantico may be impacted by coastal flooding and sea level rise.

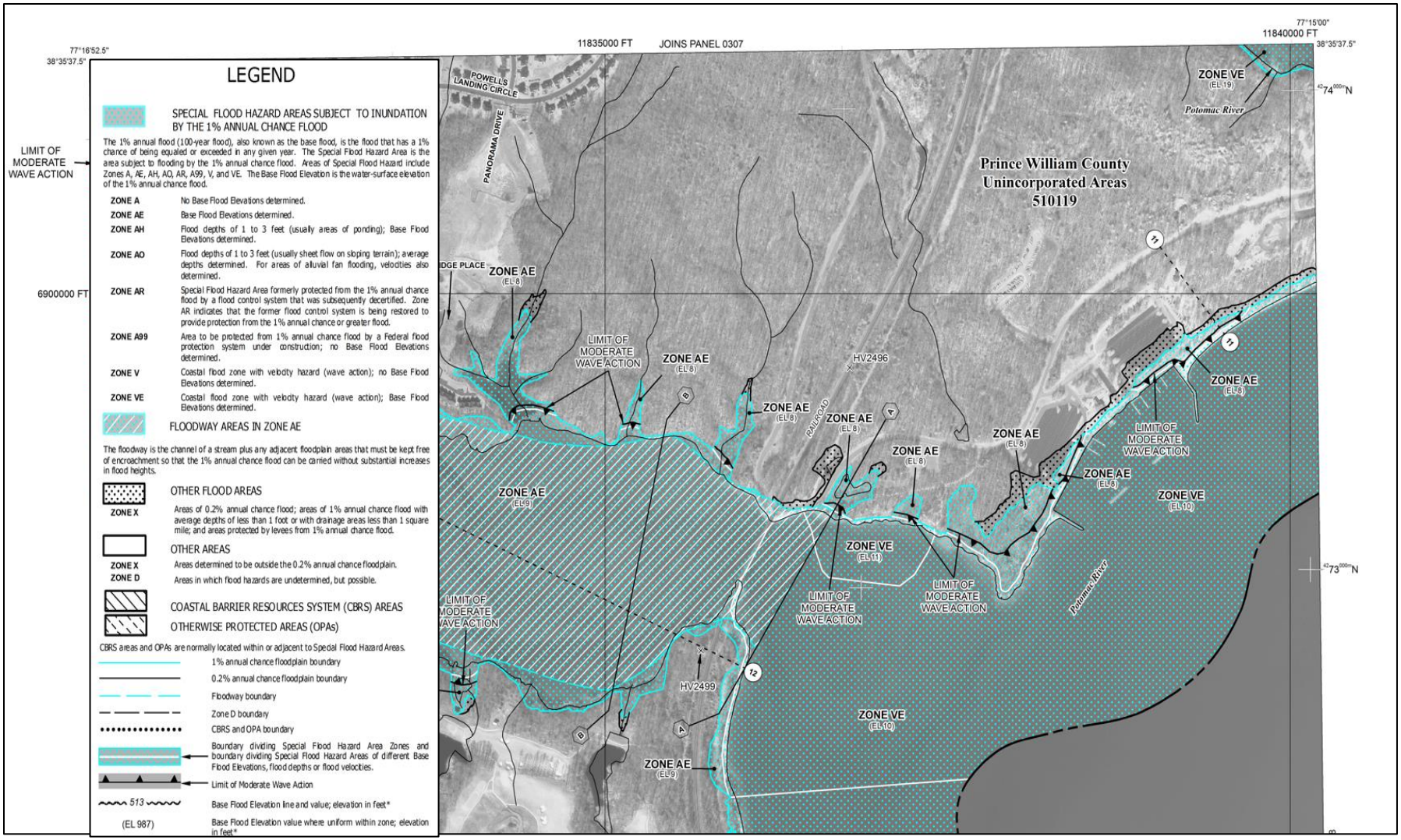


Figure 2. Section of Prince William County Flood Insurance Rate Map

2.5.2. Future Conditions

Projecting hurricane patterns for the future has been a challenge for scientists. Factors to predict hurricane sizes, numbers, strength, etc. depend on competing factors such as increase sea surface temperature which is favorable to hurricanes and increased vertical wind share which is unfavorable to hurricanes; however, some statistical downscaling methods have shown a likely increase in large-scale (i.e., Hurricane Katrina-type) events (Grinstead, et al., 2013). Other recent studies demonstrate challenges in predicting future hurricane patterns as the future scenarios seem highly correlated with greenhouse gas emissions (Murakami and Wang, 2022). Due to the complexity and uncertainty in predicting future hurricane patterns, along with the modeling effort needed to downscale this information for Prince William County, no future condition storm surge modeling has been conducted.

Storm surge is a low-frequency event (meaning the occurrence is relatively rare), that causes short-term inundation of flood waters (usually on the order of a day). While these events can be catastrophic, this assessment will focus instead on higher-frequency flooding caused by tides that are amplified by SLR. This SLR flooding can also cause permanent inundation even at a low tide level. To determine future SLR scenarios, several reports and data sources were reviewed.

Several sources of SLR estimates were reviewed including the U.S. Army Corps of Engineers (USACE) 2013 data (USACE, 2013), the U.S. Department of Defense (DoD) 2016 Coastal Assessment Regional Scenario Working Group (CARSWG) estimates (Hall et al, 2016), the National Oceanic and Atmospheric Administration's (NOAA's) 2017 data (Sweet, et al. 2017), and the NOAA 2022 data (Sweet, et al. 2022).

The NOAA 2017 projections were produced with the dual purposes of updating scenarios of global mean sea level (GMSL) rise and integrating the global scenarios with regional factors contributing to sea level change for the entire U.S. coastline. This data was also used in the recently published VTrans: Virginia's Transportation Plan Trends Analysis: VTrans Vulnerability Assessment (VTrans 2021).

The NOAA 2022 projections were published most recently and build upon the NOAA 2017 projections to provide updated timing and exceedance probabilities based on different levels of global warming. The new report is based on the latest generation of GCMs and the IPCC Sixth Assessment Report (AR6) and uses a longer observational record as well as an improved understanding of ice-sheet dynamical processes. Therefore, this data was chosen as the sea level change projection for this assessment. The nearby Washington, D.C. tide gage was used to provide an adjustment for regional subsidence.

The NOAA projection include the 17th, 50th, and 83rd percentile levels for each of five scenarios: low, intermediate-low, intermediate, intermediate-high, and high. Each scenario describes future potential conditions to support decision-making under conditions of uncertainty. The 83rd percentile values were selected for this assessment as the most conservative estimate for planning purposes. The projected sea-level change values are shown in Table 8.

Table 8. NOAA 2022 projected sea-level change values (feet) at Washington, DC gage (83rd Percentile)

Year	Low	Intermediate-Low	Intermediate	Intermediate-High	High
2020	0.43	0.49	0.49	0.49	0.46
2030	0.75	0.82	0.85	0.89	0.92
2040	1.05	1.15	1.21	1.35	1.48
2050	1.35	1.44	1.57	1.94	2.13
2060	1.57	1.74	2.00	2.59	2.99
2070	1.74	2.03	2.49	3.35	3.97
2080	1.94	2.33	3.05	4.20	5.09
2090	2.10	2.62	3.71	5.05	6.40
2100	2.33	2.99	4.49	6.00	7.74

The NOAA et al. 2022 low, intermediate, and high projections were used to estimate ranges of years that will results in 1-ft increments of SLR. The approximate sea level change projection timings are presented in Table 9. These sea level change for these three projections along with boxes highlighting the range of years where the 1ft, 3ft, 5ft, and 7ft increases occur is illustrated in Figure 3.

Table 9. Approximate sea level change projection time horizons for increments of 1 to 7 feet of sea level rise based on NOAA et al. 2022 projection

Sea Level Change (feet)	Approximate SLC Projection Timing		
	Earliest (High)	*Intermediate*	*Latest (Low)*
+1	2031	2034	2038
+2	2048	2060	2084
+3	2061	2079	>2100
+4	2071	2094	>2100
+5	2079	>2100	>2100
+6	2087	>2100	>2100
+7	2095	>2100	>2100

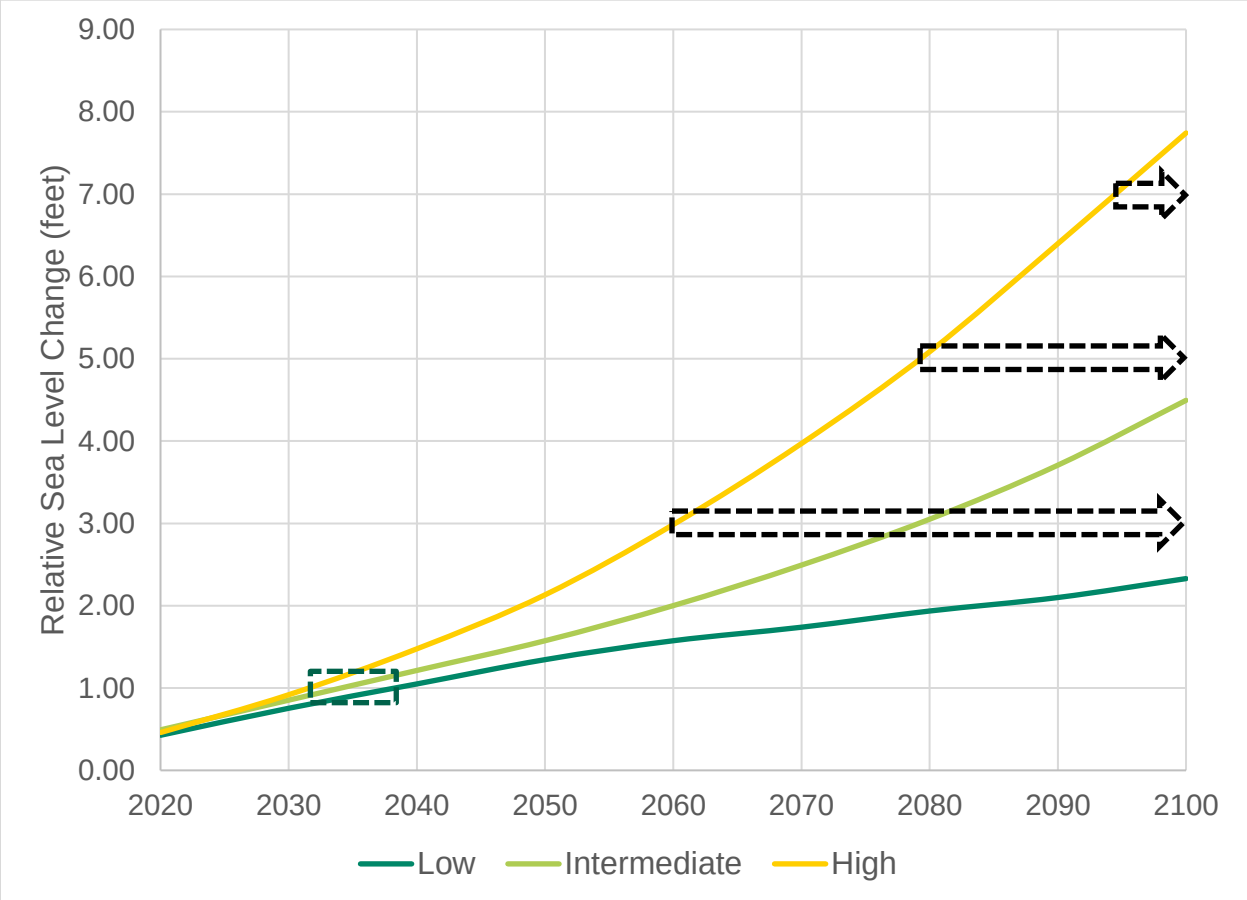


Figure 3. NOAA 2022 Sea Level Change with 1ft, 3ft, 5ft, and 7ft of Expected Sea Level Rise at Washington, DC Gage

NOAA's SLR Viewer allows users to specify sea level rise values in 1 ft increments and displays the corresponding water levels in the map viewer. The viewer illustrates the scale of potential flooding but does not account for erosion, subsidence, future construction, or impacts of aging or inadequate stormwater infrastructure (NOAA, 2022). The

extent of +2 ft of sea-level change roughly corresponds to a time horizon of 2050 with an intermediate SLR projection. Due to the relatively steep shoreline, there are relatively small differences in the extent of inundation from 1 to 7 ft of increase as shown in Figure 4.

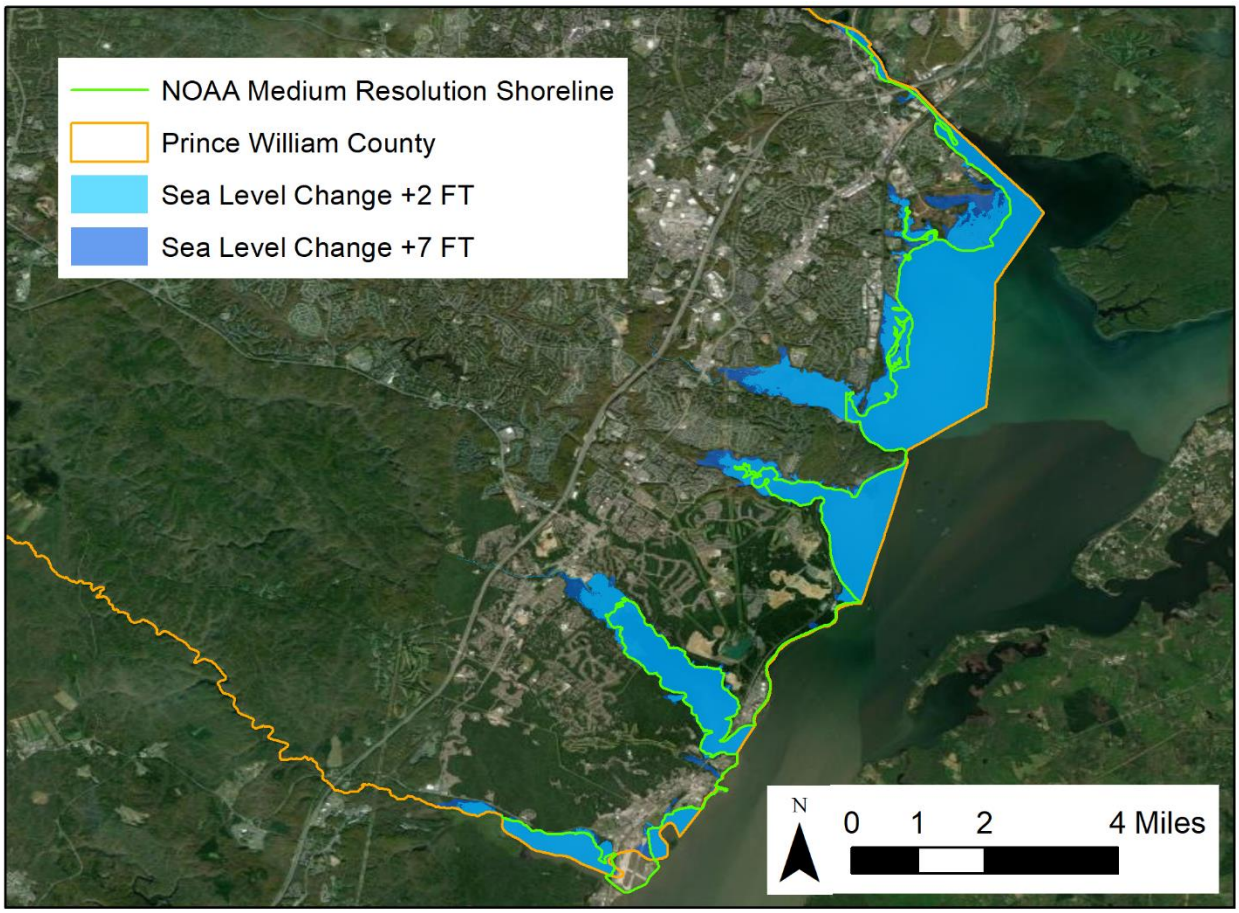


Figure 4. Sea-level change of +2 ft and +7 ft according to NOAA Sea Level Change Viewer in Prince William County, VA.

2.6. Earthquakes

2.6.1. Current Conditions

Prince William County has the potential to be impacted by earthquakes in the Central Virginia Seismic Zone. The largest recorded event in this area likely occurred in 1875. Although this was before the invention of effective seismographs, the event was estimated to be a 4.8 on the Richter scale. More recent earthquakes were felt in December 2003 and August 2011. The National Risk Index Community Report for Prince William County lists the earthquake risk for the county as “very low” compared to other areas of the United States (FEMA, 2021b) while the 2022 Northern VA Hazard Mitigation Plan identifies the County as being at medium risk of earthquake impacts due to the fact that infrastructure and buildings are not explicitly designed to withstand seismic events. The expected annual loss is “relatively low” with an expected annual loss of $389,799 out of an exposure of buildings, people, and agricultural land of over $3.1 Trillion (or approximately 0.00001%).

2.6.2. Future Conditions

Changes in earthquake patterns in the future due to a changing climate will not be evaluated in this report as clear trends have not yet been established in the academic literature.

2.7. Strong Wind/Tornadoes

2.7.1. Current Conditions

Strong winds can affect the region in the form of a Derecho, straight line winds, a tornado, winds from a thunderstorm, or hurricanes. In June 2012, a Derecho impacted the Washington, D.C. metro region causing power outages affecting more than 1.5 million people in Northern Virginia (MWCOG, 2020).

The National Risk Index ranks the risk to Prince William County from strong winds as “very low” and the risk from tornadoes as “relatively low.” The expected annual loss for strong winds is “relatively moderate” while the loss from tornadoes is considered “relatively high“ with a project annualized loss value of $520,401 due to strong wind and $3,787,493 from tornadoes out of a total exposure of buildings, people, and agricultural land of over $3.1 Trillion. The 2022 Northern VA Hazard Mitigation Plan found the County to be at high risk of impacts due to High Winds/Severe Storms and at medium risk of impacts due to Tornadoes.

2.7.2. Future Conditions

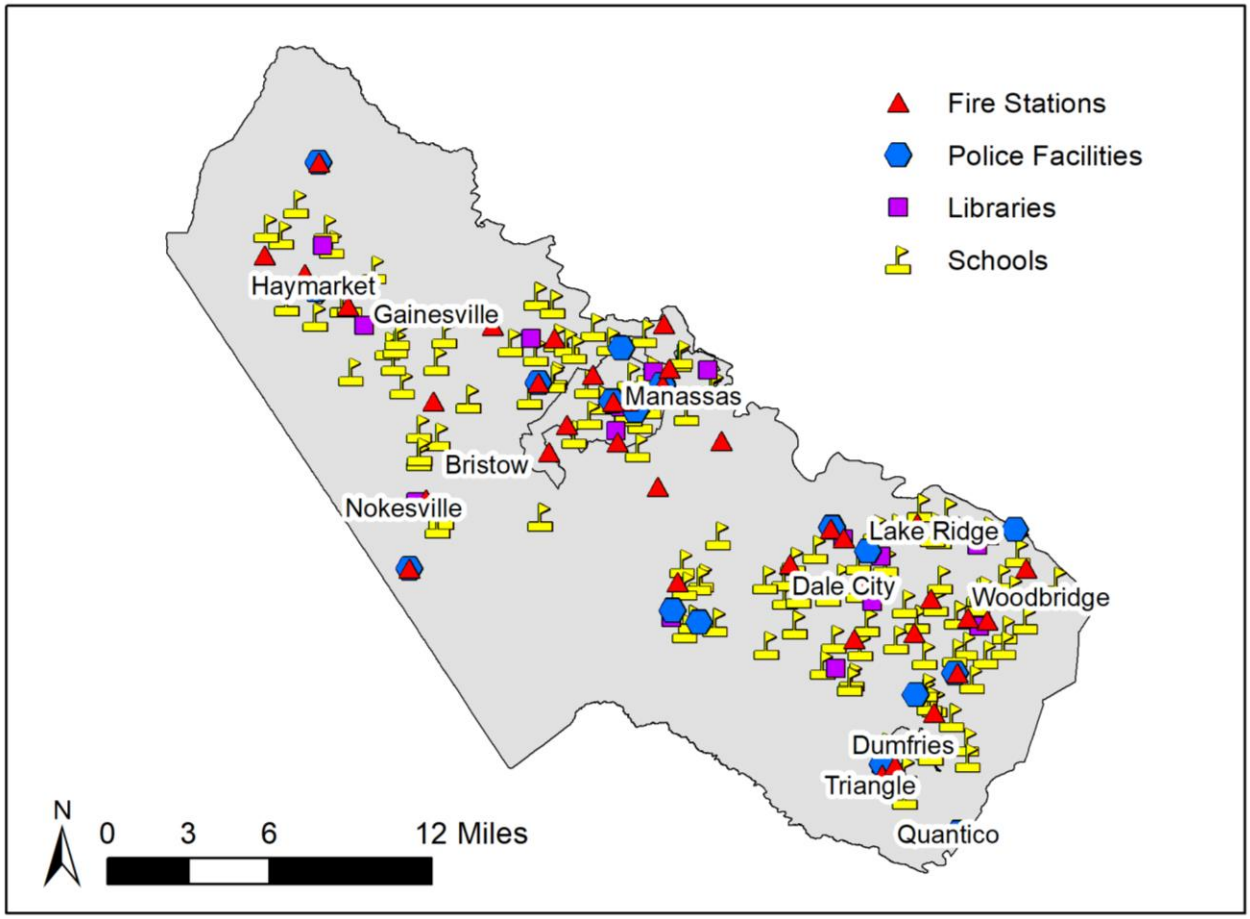
Changes in strong winds and tornado patterns in the future due to a changing climate will not be evaluated in this report as clear trends have not yet been established in the academic literature.

3. County Asset Definition

Assets have been collected into categories that align with FEMA’s Community Lifelines. Lifelines are the most fundamental services that a community has, and when stabilized, promote expansion of other aspects of society. The FEMA Lifeline categories are safety and security; food, water and shelter; health and medical; communications; transportation; energy; and hazardous materials. While these lifelines were developed to support response planning and operations, the concept resonates with preparedness planning and resilience and has been embraced by the Prince William County Office of Emergency Management (PWC EM). For this study, the energy and hazardous materials lifeline categories have been combined and two additional categories have been included in this analysis which are: natural resources and socially vulnerable populations. The assets discussed in the Vulnerability Assessment are all within Prince William County, but most are not owned by the County. The following sections further describe the assets included in each of the Lifeline categories plus the two additional asset categories.

3.1. Safety and Security

The Safety and Security Community Lifeline category includes a range of sites from police and fire stations to schools and government buildings. The Prince William County Geospatial Technology Services Program manages and maintains the County's geospatial data, which includes the following layers that apply to this Lifeline category: police stations, fire stations, libraries, schools. Additionally, government buildings are included in this category, but the County does not maintain a geospatial layer of these building locations.



Note: Government buildings are not shown on this map.

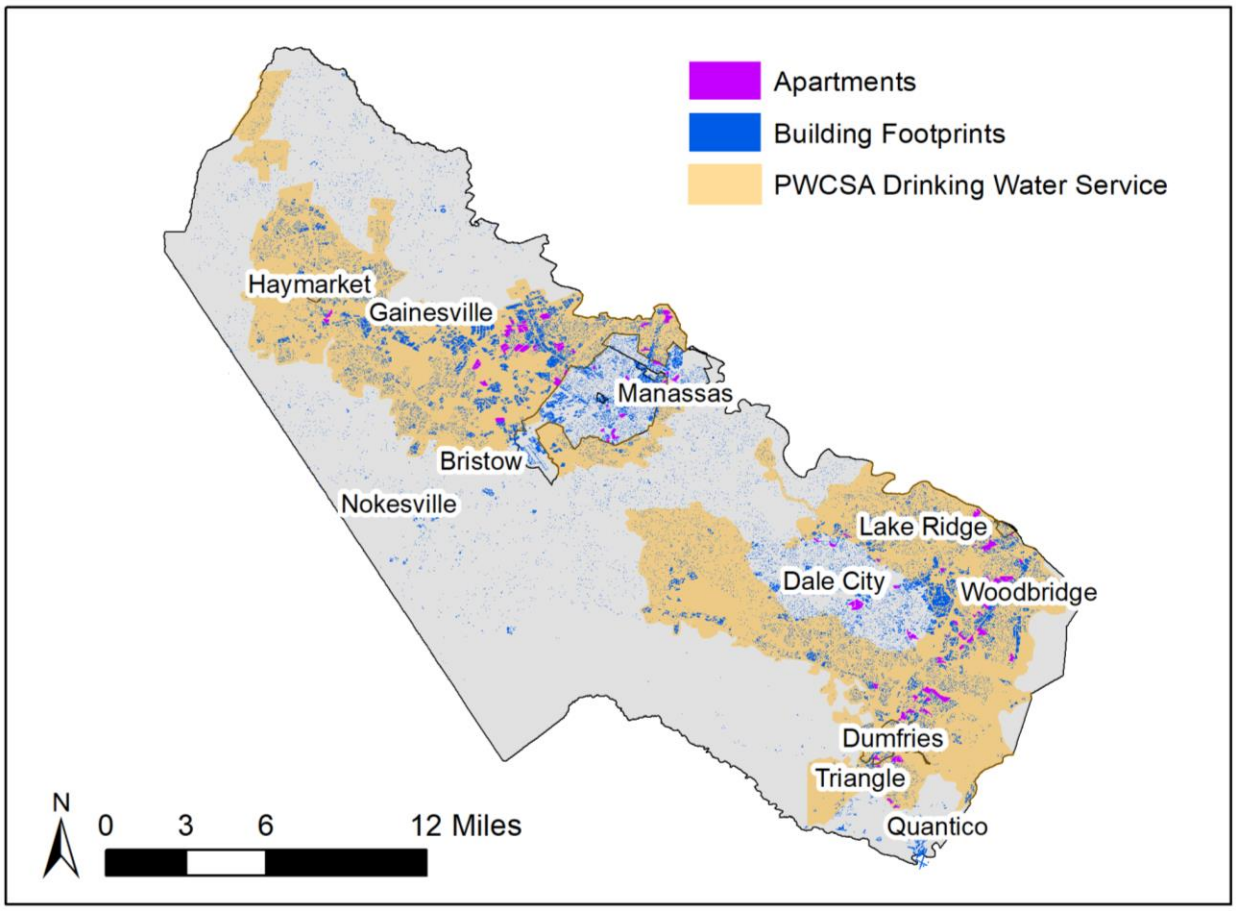
Figure 5. Safety and Security Assets within Prince William County

3.2. Food, Water, and Shelter

The Food, Water, and Shelter asset category includes resources that provide stability to our day-to-day lives. This includes all housing units which are available from the Prince William County Geospatial Technology Services Program as layers of building footprints and apartments. Building footprints include but are not limited to commercial and non-commercial structures, parking lots and recreation areas. Food is included in this asset category as grocery stores and food markets though geospatial data was not available. Drinking water is provided to County residents by either of two service providers (Virginia American Water or Prince William County Service Authority (PWCSA)) or through well water. Drinking water support infrastructure and wastewater pump station locations were not available geospatially, Natural sources of water such as streams and lakes that have been created behind dams are covered in Section 4.8: Natural Resources.

Climate Change and Food Security

The U.S. Global Change Research Program recognizes the challenge for food security as the climate-driven changes affect all in their 2015 report *Climate Change, Global Flood Security and the U.S. Food System.* Climate change affects agricultural production as well as food processing, packaging, transportation, storage, waste and consumption and should be considered in planning efforts for Prince William County.



Note: Drinking water data, drinking water support infrastructure, and wastewater pump station locations are not shown on this map.

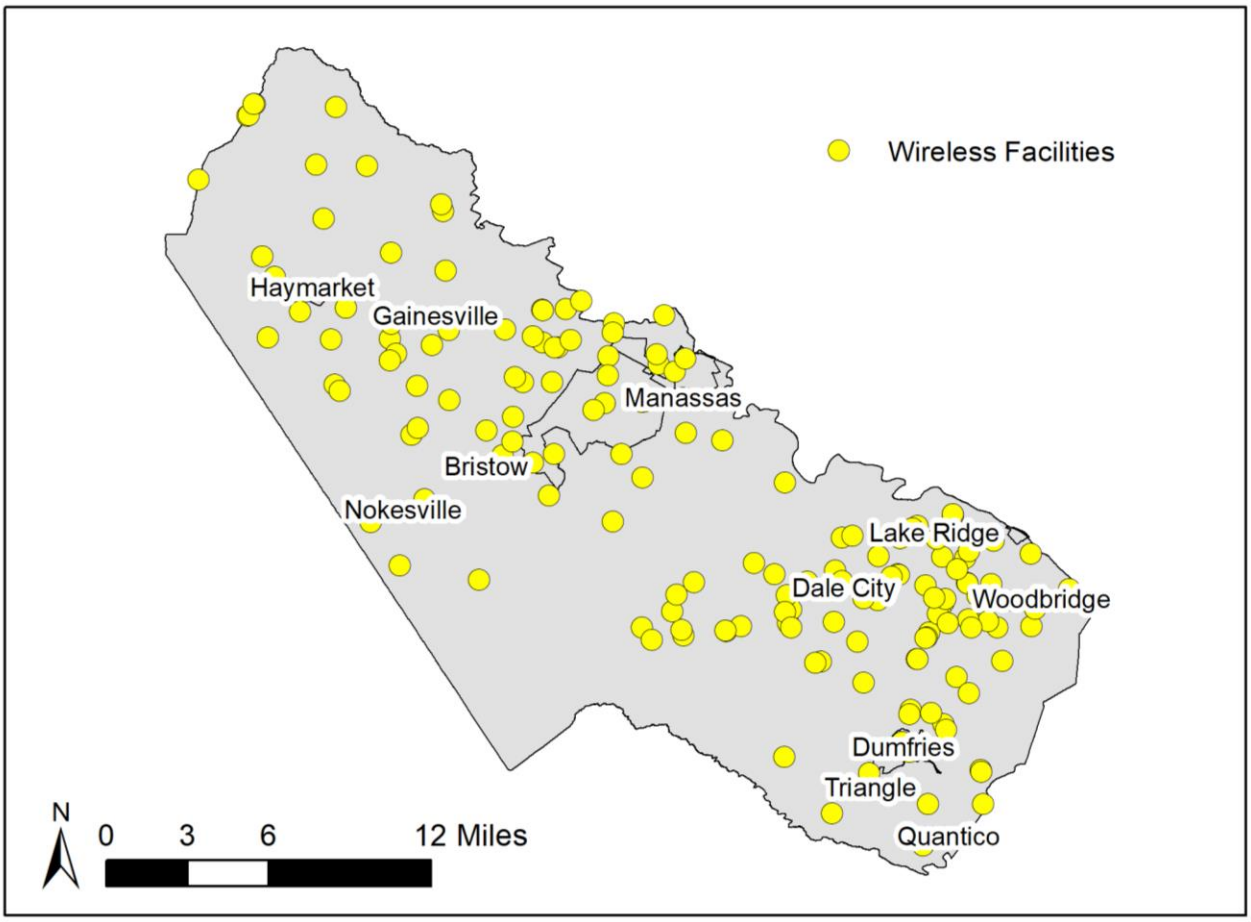
Figure 6. Food, Water, and Shelter Assets within Prince William County

3.3. Health and Medical

The Health and Medical asset category includes hospitals and other medical centers, long-term care facilities, dialysis centers, and pharmacies. Hospital locations are available through the Prince William County Geospatial Technology Services Program as a geospatial deliverable and includes one hospital in the City of Manassas that services Prince William County. The other types of medical care facilities were supplied by PWC EM as a list of addresses. Due to limited availability of geospatial data, no maps were prepared for this asset category.

3.4. Communications

For FEMA's definition of the Communications lifeline, many non-structural aspects are included such as alert and warning systems and first responder communications. For this study, the Communications asset category will focus on the infrastructure components of communication including radio towers, data centers, financial service locations (e.g., banks), cable systems and broadcast facilities, and wireless service towers. Only the wireless facilities locations are available as geospatial data from the Prince William County Geospatial Technology Services Program. All other asset locations are available as addresses in a list from PWC EM.



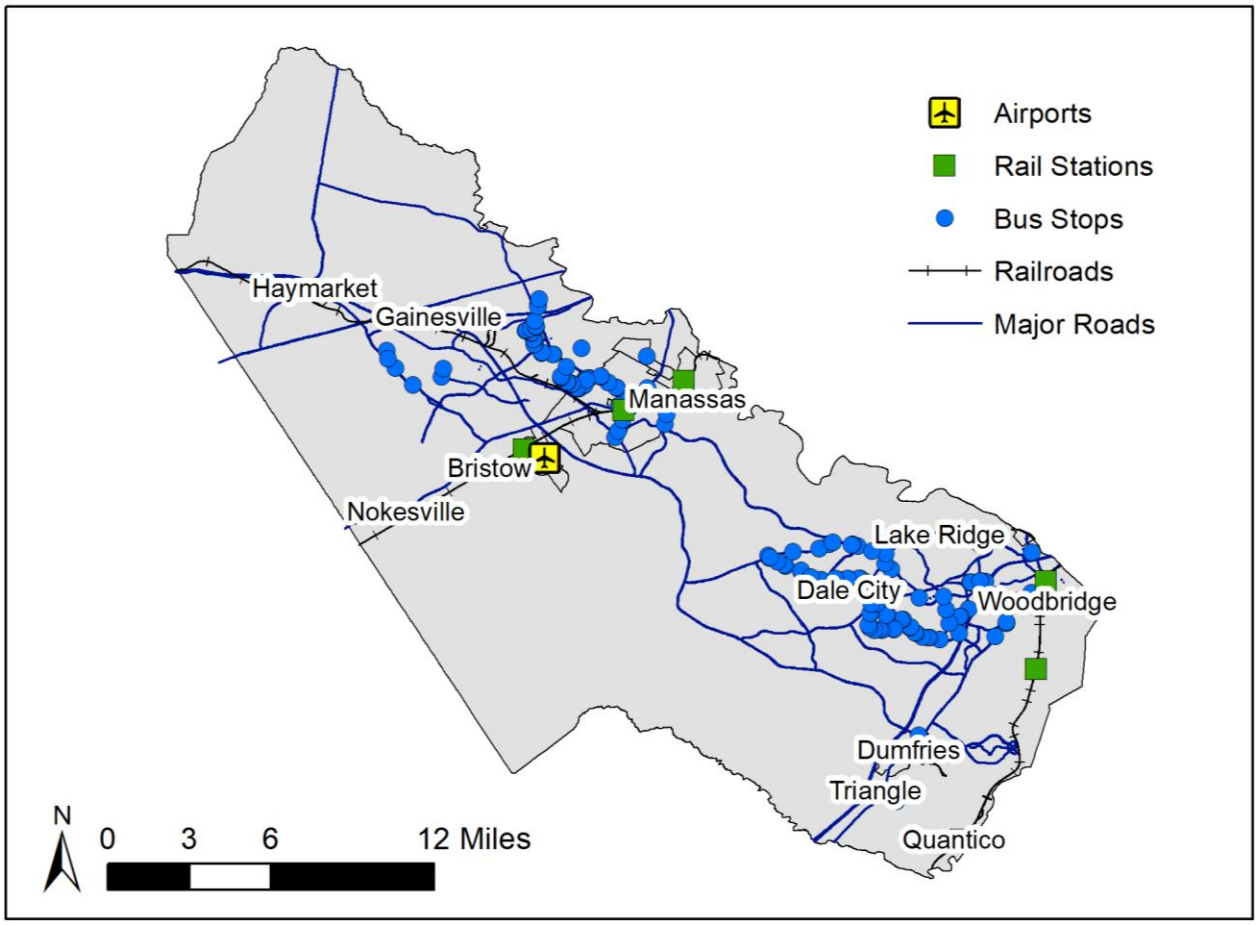
Note: Radio towers, data centers, financial service locations (e.g., banks), cable systems and broadcast facilities are not shown on this map.

Figure 7. Communication Assets within Prince William County

3.5. Transportation

Transportation systems are important for the residents and visitors of Prince William County and include roads, mass transit, railways, aviation, maritime, and pedestrian. Through the Prince William County Geospatial Technology Services Program, geospatial data is available that includes bus stops, commuter parking lots, rail stations, railroads, roads, and sidewalks. Additionally, PWC EM has compiled a list of bridge locations (for roads and railroads), port facilities, marinas, and airport and heliport locations. All ports in the County are privately owned and maintained.

Similarly, most transportation assets within the County are not owned by the County but rather are owned and maintained by the Virginia Department of Transportation (VDOT) or private entities. To better understand the impacts of flooding on roads, the stormwater system and culverts are included in the Transportation asset category. The Stormwater management facility locations, stormwater management lines, and culverts are available as geospatial data and has been provided by the Prince William County Geospatial Technology Services Program.



Note: Commuter parking lots, sidewalks, bridge locations (for roads and railroads), port facilities, heliport locations, stormwater management facility locations, stormwater management lines, and culverts are not shown on this map.

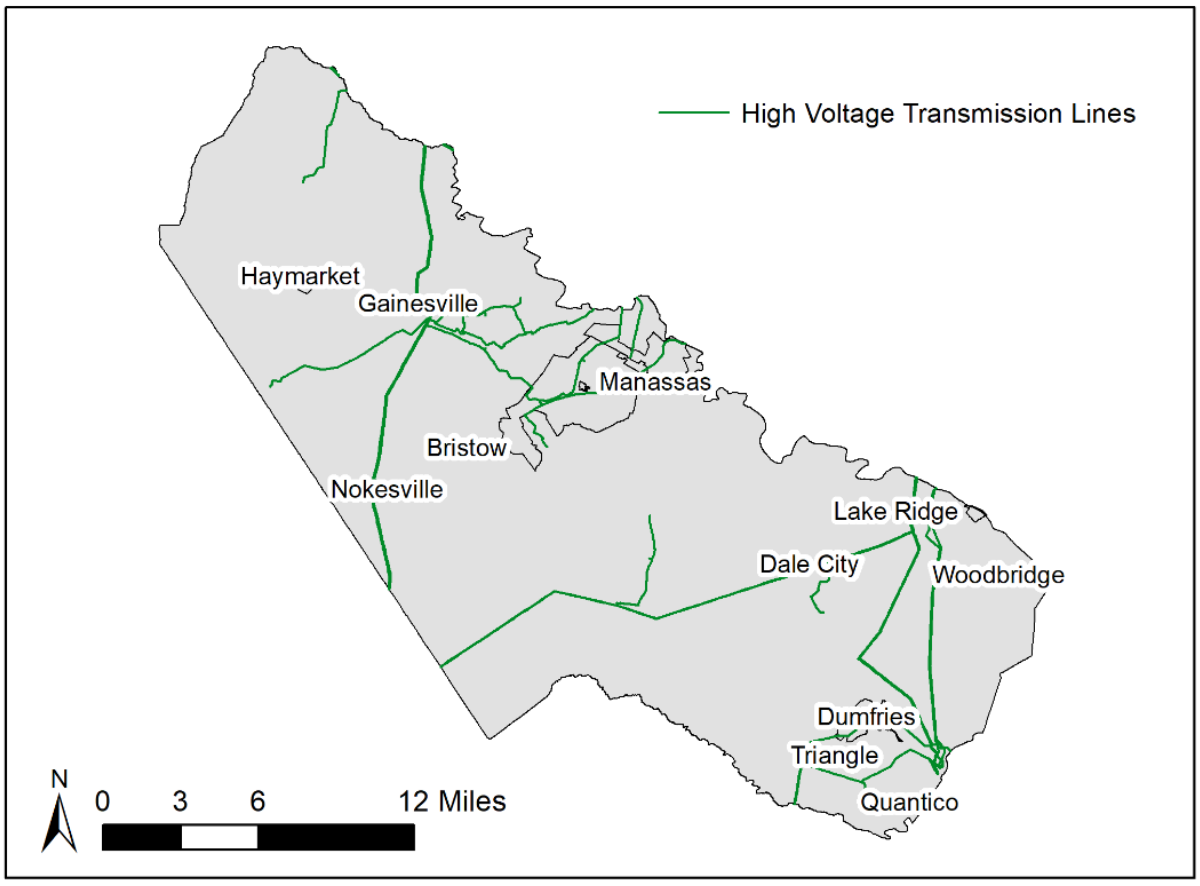
Figure 8. Transportation Assets within Prince William County

3.6. Energy and Hazardous Materials

Climate Change and Energy Supply

The U.S. Global Change Research Program's *Fourth National Climate Assessment* includes a chapter on Energy Supply, Delivery, and Demand which recognizes that the Nation's energy system is already affected by extreme weather events and that climate change will increase the threat. The report details the state of the Nation's energy sector and provides suggestions for improving resilience including hardening measures (including physical barriers, protective casing or other upgrades) and development and deployment of new technologies to enhance system residence.

The Energy and Hazardous Materials lifeline categories have been combined into a single asset category for this study. This category includes electrical lines, power generation plants and substations, County-run fuel distribution centers, natural gas pipelines, and hazardous materials storage sites. The Prince William County Geospatial Technology Services Program has geospatial data for the electrical power line locations. All other asset locations are available from PWC EM as a list of addresses.



Note: Power generation plants and substations, County-run fuel distribution centers, natural gas pipelines, and hazardous materials storage sites are not shown on this map.

Figure 9. Energy and Hazardous Materials Assets within Prince William County

3.7. Natural Resources

Natural Resources are not considered a Lifeline category, but are important to healthy, resilient communities, and thus, are included as an asset category. Included in this assessment are streams, resource protection areas, trees, agricultural areas, and tree cover. Resource protection areas are defined as any land within 100 feet of a perennial stream bank or edge of wetlands adjacent to the perennial stream and are protected under state law and local ordinances. Additionally, dams were included in this category due to the lakes that are associated with these man-made features. All data layers are available geospatially from the Prince William County Geospatial Technology Services Program.

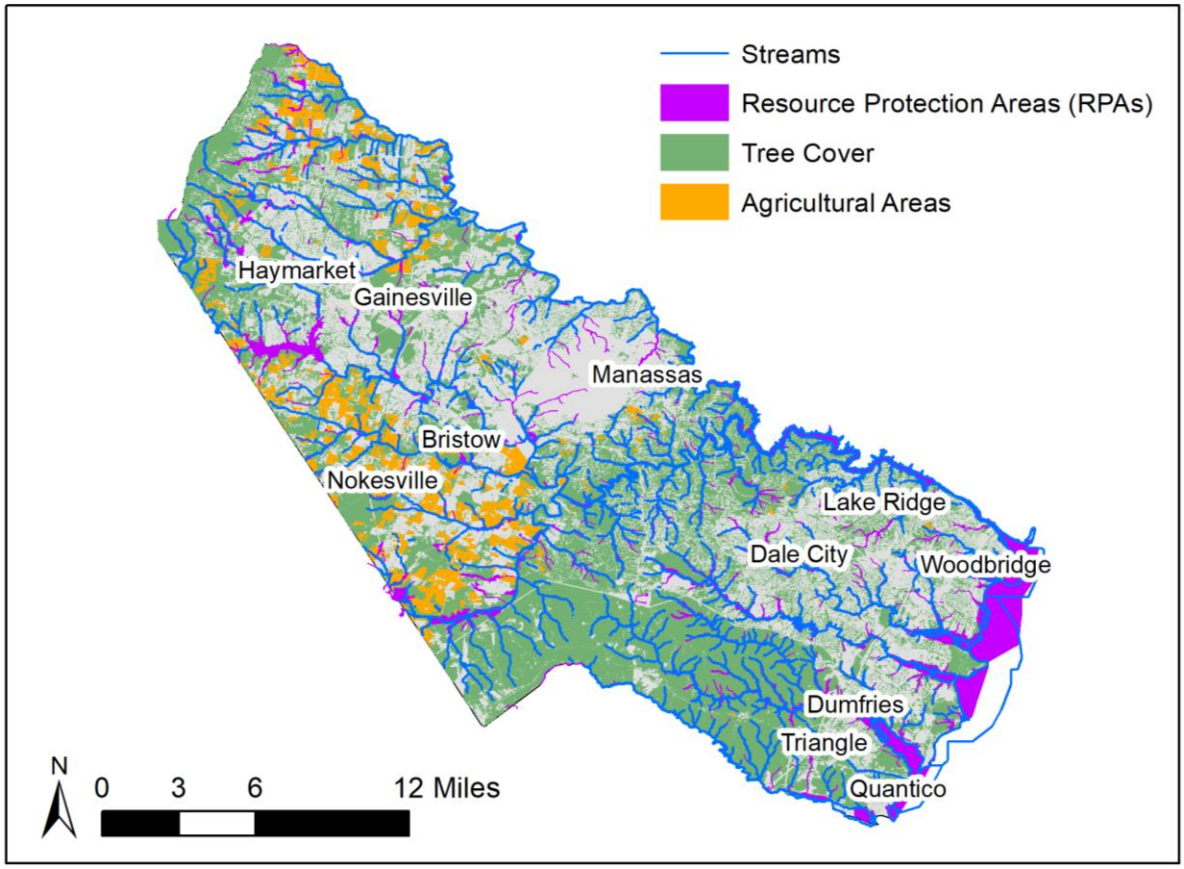


Figure 10. Natural Resources Assets within Prince William County

Dams

Prince William County contains 21 dams as listed in the Virginia Department of Conservation and Recreation (DCR) Dam Safety Inventory System including 5 that are classified as having significant hazard potential. While some dams are County-owned, most dams in Prince William County are privately-owned. The Upper Occoquan Dam, owned by the Fairfax County Water Authority, and the T. Nelson Elliott Dam, owned by the City of Manassas, are the largest dams in the area. The Upper Occoquan Dam is used for hydroelectric power generation, and both are used for water supply. These dams have significant drainage areas and would result in catastrophic flooding in the event of a dam break. Both are inspected annually and most recently have been found to be in satisfactory condition.

3.8. Socially Vulnerable Populations

The National Capital Region Transportation Planning Board (TPB) developed a methodology for determining Equity Emphasis Areas (EEAs). Tract-level Census data was used to identify communities that have a high concentration of low-income individuals and/or traditionally disadvantaged racial and ethnic population groups as well as a higher share of households who rent, individuals with disabilities, and workers without telecommuting options compared to neighboring communities (National Capital Region Transportation Planning Board, 2018). The Metropolitan Washington Council of Governments and Prince William County have adopted the same definition of Equity Emphasis Areas (EEAs) as a planning tool to help define areas with socially vulnerable populations. These areas will be used to better understand climate impacts on socially vulnerable populations within Prince William County and are shown in Figure 11

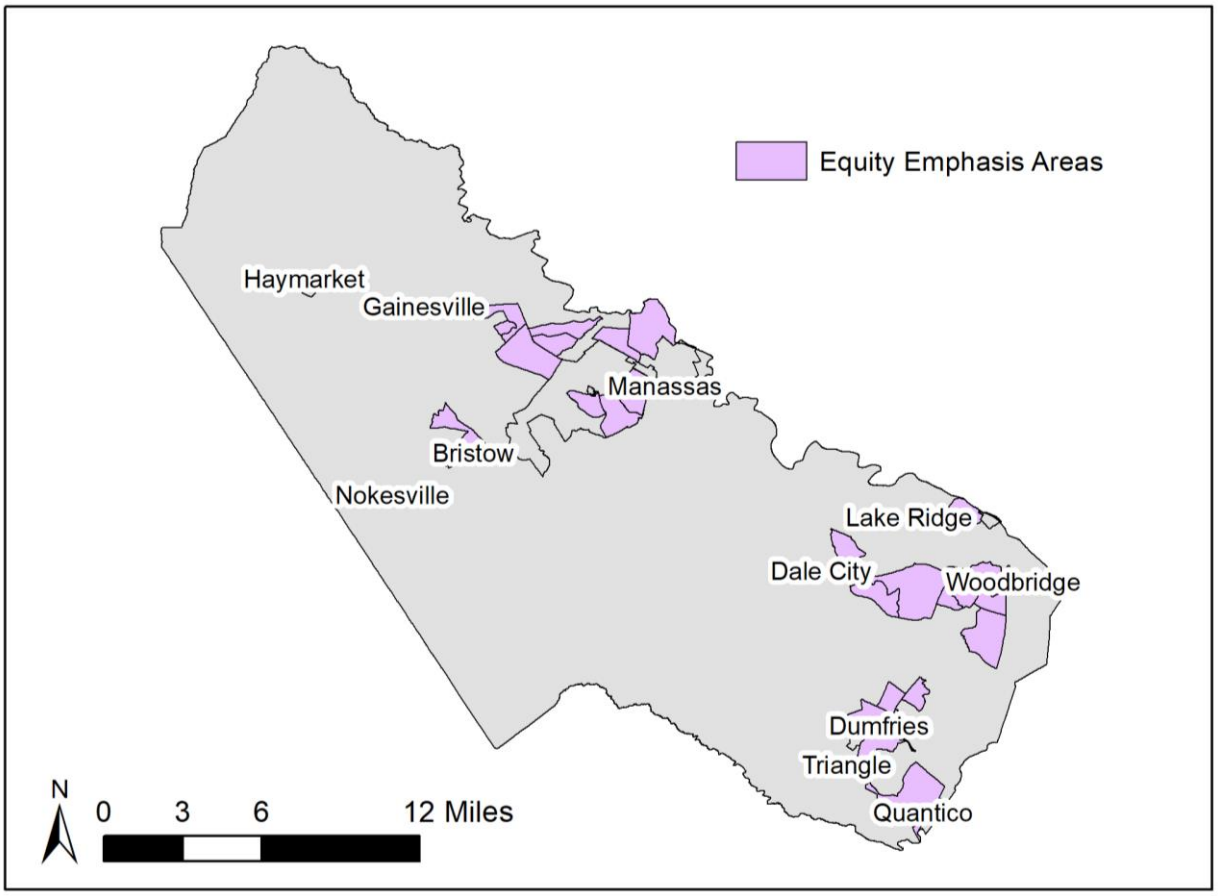


Figure 11. Socially Vulnerable Population Assets within Prince William County

4. Asset Vulnerability Assessment

4.1. Vulnerability Assessment Methodology

The vulnerability assessment analyzes the impacts of the climate hazards on a variety of community asset categories. This assessment broadly identifies asset groups that are expected to be adversely impacted by changing climate hazards through an evaluation of the Exposure, Sensitivity, and Adaptive Capacity of the assets within each category. The methodology, asset category definitions, and detailed discussion of vulnerability for each asset category and each hazard are provided in the following sections.

The vulnerability assessment is based on a review of the exposure to natural hazards, the sensitivity of the asset to those hazards, and the ability to enact change to manage and adapt to those hazards. This approach is based on the Federal Highway Administration's (FHWA's) Vulnerability Assessment Scoring Tool (VAST) framework that uses exposure, sensitivity, and adaptive capacity to create a holistic view of vulnerability to future climate change. The sections below further explain the methodology to determine the exposure, sensitivity, and adaptive capacity of each asset category.

The rating system gives each asset category a Low, Medium, or High rating for each hazard and each of the evaluation criteria (Exposure, Sensitivity, and Adaptative Capacity). Every category has been setup so that a Low rating means that there is less vulnerability and should be a lower concern for Prince William County when determining how to focus adaptation measures. A Medium rating means that some vulnerability exists for this asset. The High rating shows a high vulnerability and should be a focus of adaptation measure for the County. This assessment is primarily focused on assets located within Prince William County, including the people that may work or live within or in proximity to physical assets, and does not consider broader regional systems which may affect the hazard impacts.

4.1.1. Exposure

The most fundamental component of an asset's vulnerability is whether it is exposed to a climate hazard. The exposure component of the vulnerability assessment measures if an asset is affected by a climate hazard and, if so, to what extent. Exposure is a prerequisite for vulnerability so assets that have effectively no likelihood of exposure to a climate hazard are not assessed for sensitivity or adaptive capacity of that climate hazard. To facilitate a quantification of the vulnerability from exposure to the hazards, each asset class will be given a rating (Low, Medium, or High) to correspond to the exposure likelihood and extent from each climate hazard and future scenario (2050 and 2075). Due to the large number of individual assets within each category, exposure is considered relative to the total body of assets within each category. As a result, while exposure for some individual assets may be high, the asset category may be rated lower if most assets within the category are not exposed or have low exposure. A summary of how exposure ratings were assigned is shown in Table 10.

Precipitation exposure ratings were estimated based on asset proximity to effective FEMA riverine floodplains and frequently flooded areas. Detailed stormwater, riverine, or coastal flood modeling of future scenarios was not within the scope of this assessment. Review of available sea level rise and coastal storm surge floodplains revealed that most County assets were unlikely to be exposed coastal flooding; thus, all assets received a Low exposure rating for Sea Level Rise.

For other climate hazards, the scale of hazard exposure is greater than the county so it is assumed that assets within the county will be exposed to the hazard uniformly. Accordingly, the exposure rating is applied consistently across all asset categories. Exposure to extreme temperatures for all assets is rated as Medium for 2050 and High for 2075 as projections clearly show a warming trend in the local climate (see Section 2.3.2). Drought exposure for all assets was rated as Low for 2050 and Medium for 2075 based on increases in frequency and severity of drought events discussed in Section 2.4.2. As future changes to earthquake and strong wind/tornado exposure were not considered in this assessment, exposure ratings for 2050 and 2075 were both scored as Medium for strong winds/tornadoes and Low for earthquakes which approximately represents present day exposure.

Table 10. Exposure Criteria

Climate Hazard	Vulnerability Rating - Exposure	
	2050	2075
Precipitation	L- less than 10% of assets are within effective 100-year riverine floodplain or within 100 ft of frequently flooded area M – 10-50% of assets are within effective 100-year riverine floodplain or within 100 ft of frequently flooded area H- more than 50% of assets are within effective 100-year riverine floodplain or within 100 ft of frequently flooded area	L – less than 10% of assets are within effective 500-year riverine floodplain or within 250 ft of frequently flooded area M – 10-50% of assets are within effective 500-year riverine floodplain or within 250 ft of frequently flooded area H – more than 50% of assets are within effective 500-year riverine floodplain or within 250 ft of frequently flooded area
Extreme Temperature	All assets scored M	All assets scored H
Drought	All assets scored L	All assets scored M
Sea Level Rise	All assets scored L	All assets scored L
Earthquakes	All assets scored L	All assets scored L
Strong Winds/Tornadoes	All assets scored L	All assets scored L

Abbreviations: L=Low; M=Medium; H=High

4.1.2. Sensitivity

Sensitivity measures how an asset is affected by exposure to a climate hazard. Given the broad nature of asset categories used in this assessment (See Section 3), asset sensitivity is focused on the most sensitive assets present in Prince William County within each category as well as the functions each asset category is meant to perform during normal conditions. Similar to the rating of exposure, assets are assigned a High, Medium, or Low rating for sensitivity. High sensitivity rating is given if exposure would result in complete asset failure; Medium sensitivity rating is given if an exposed asset would remain partially functional; and Low sensitivity rating is given when an exposed asset is fully or close to fully functional during asset exposure. Detailed explanations of sensitivity ratings are included in the respective asset vulnerability sections of this report below.

4.1.3. Adaptive Capacity

Adaptive capacity measures the ability of an asset to adjust, repair, or flexibly respond to damage caused by climate hazards. Redundancy is a key measure of adaptive capacity considered in this assessment, but the rating also considers Prince William County's authority to enact adaptive measures, the range of adaptation measures that could be implemented, and types of adaptation actions that could be implemented.

Generally, high adaptive capacity means that an asset has high resiliency, high redundancy and can be easily adapted to deal with climate hazards. However, this is inconsistent with the rating system for Exposure and Sensitivity. In those rating systems, a "High" rating implies high asset vulnerability. The Adaptative Capacity rating system measures the contribution to asset vulnerability instead of the adaptive capacity itself which may appear counter-intuitive. To avoid confusion, the Adaptive Capacity rating is called a "Vulnerability Rating for Adaptative Capacity" and ratings are defined as follows:

- Low = low vulnerability due to high adaptive capacity
- Medium = medium vulnerability due to medium adaptive capacity

  High = high vulnerability due to low adaptive capacity

4.2. Safety and Security Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Safety and Security Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 11.

Table 11. Vulnerability Ratings for Safety and Security Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	L	L	M	L
Extreme Temperature	M	H	M	L
Drought	L	M	L	L
Coastal Flooding and SLR	L	L	M	L
Earthquakes	L	L	M	L
Strong Winds/Tornadoes	L	L	M	L

Abbreviations: L=Low; M=Medium; H=High

4.2.1. Safety and Security – Precipitation

The percent of each asset within the Safety and Security asset category exposed to precipitation hazards in 2050 and 2075 is shown in Table 12. Exposure in both 2050 and 2075 is classified as Low due to the low percent of Safety and Security assets exposed to precipitation hazard.

Table 12. Safety and Security Asset Exposure to Precipitation Hazard

Safety and Security Asset	Number of Assets	2050 Percent Exposed to Precipitation Hazard	2075 Percent Exposed to Precipitation Hazard
Police Facilities	19	5%	11%
Fire Facilities	38	0%	5%
Libraries	16	6%	19%
Schools	126	0%	0%

The sensitivity of Safety and Security assets to precipitation hazards is Medium because flooding of these assets may cause some damage and disruption to functionality, but parts of the assets should still be operational. Safety and Security Assets were assigned a Low Vulnerability Rating for Adaptive Capacity due to the relatively high redundancy among the buildings in this asset category as well as the availability of technology that allows for some functions to be performed remotely when climate hazard events may limit access to buildings.

4.2.2. Safety and Security - Temperature

As extreme temperatures rise across the county, Safety and Security assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Safety and Security assets received a Medium Sensitivity rating for extreme temperatures. The Medium Sensitivity rating was assigned because Safety and Security assets in Prince William County are currently exposed to extreme temperatures and can maintain at least partial functionality. As temperatures increase, buildings in this asset category will experience increased energy demands and stress on air conditioning systems, particularly libraries which are used as cooling centers during extreme heat events. Additionally, this asset category includes groups of people that typically spend at least part of the day outdoors. Extreme temperature events may limit the amount of time individuals can spend outside and may require some restructuring of how some functions are performed with the understanding that students and employees may have higher individual sensitivities to extreme temperatures than the overall asset category. The Vulnerability Rating for Adaptive Capacity was rated Low due to the relatively high redundancy among the buildings in this asset category and the ability for the County to incorporate adaptation measures to decrease energy demand for these assets.

4.2.3. Safety and Security - Drought

Drought Exposure throughout the County is rated Low for 2050 and Medium for 2075. Safety and Security assets received a Low Sensitivity rating for drought and a Low Vulnerability Rating for Adaptive Capacity. A Low Sensitivity rating was assigned because Safety and Security assets can maintain functionality during most drought conditions.

Drought conditions can still impact Safety and Security assets particularly when conditions persist for extended periods and may make buildings inhospitable for students and employees if drought is associated with water restrictions and increased heat.

4.2.4. Safety and Security – Coastal Flooding and Sea Level Rise

Safety and Security assets received a Low Exposure rating for coastal flooding and sea level rise because none of the assets available as spatial data were within the present-day FEMA coastal floodplain or the 3 ft sea level rise area, which corresponds to the intermediate estimate for 2075. Sensitivity is rated as Medium because any Safety and Security assets that may be impeded by coastal flooding and sea level rise would likely still be partially functional. Safety and Security Assets were assigned a Low Vulnerability Rating for Adaptive Capacity due to the relatively high redundancy among the buildings in this asset category as well as the availability of technology that allows for some functions to be performed remotely when climate hazard events may limit access to buildings.

4.2.5. Safety and Security – Earthquakes

The National Risk Assessment ranks the exposure of Safety and Security assets within Prince William County as a Low risk. During both the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA, minimal damage was reported to buildings within Prince William County. However, earthquakes of this size originating closer to the County have the potential to cause structural damage to Safety and Security assets so the sensitivity of this asset category to earthquakes was considered to be Medium. Safety and Security assets within the County are assumed to be built to current structural standards and there is some existing redundancy in the location of police, fire, schools, and other Safety and Security assets. There are also opportunities to increase resilience to earthquake hazards through retrofitting buildings to higher earthquake resilience standards. The Vulnerability Rating for Adaptive Capacity has been given a Low rating based on the relatively high redundancy among the buildings in this asset category as well as the availability of technology that allows for some functions to be performed remotely when climate hazard events may limit access to buildings. Additionally, structural modifications could be made to most Safety and Security assets to increase resilience to earthquake hazards.

4.2.6. Safety and Security - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes leading to an Exposure rating of Low for this Vulnerability Assessment. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes demonstrating an average Sensitivity ranking of Medium. There is some redundancy in the Safety and Security assets and there are some measures (such as wind retrofits for roofs) that can be taken to enhance resilience. Life safety is usually a consideration when aiming for increased resilience from tornadoes and safe rooms can be built in public spaces such as schools to provide a safe place of shelter. Due to the relatively low risk of needing to close safety and security assets due to high winds due to redundancy in the system, the Vulnerability Rating for Adaptive Capacity of Safety and Security assets is Low.

4.3. Food, Water, and Shelter Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Food, Water, and Shelter Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 13.

Table 13. Vulnerability Ratings for Food, Water, and Shelter Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	L	L	M	M
Extreme Temperature	M	H	H	M
Drought	L	M	H	M

Coastal Flooding and SLR	L	L	M	M
Earthquakes	L	L	M	M
Strong Winds/Tornadoes	L	L	M	M

Abbreviations: L=Low; M=Medium; H=High

4.3.1. Food, Water, and Shelter – Precipitation

The percent of the area of each asset within the Food, Water, and Shelter asset category exposed to precipitation hazards in 2050 and 2075 is shown in Table 14.Exposure in both 2050 and 2075 is classified as Low because the percentage of Food, Water, and Shelter assets exposed is relatively small.

Table 14. Food, Water, and Shelter Asset Exposure to Precipitation Hazard

Food, Water, and Shelter Asset	Number of Assets	2050 Percent of Area Exposed to Precipitation Hazard	2075 Percent of Area Exposed to Precipitation Hazard
Apartments	534	5%	6%
Building Footprints	200,310	2%	4%

The Sensitivity of Food, Water, and Shelter assets to precipitation hazards is Medium because flooding of these assets may cause some damage, but they will remain partially functional. Food, Water, and Shelter assets were assigned a Medium Vulnerability Rating for Adaptive Capacity as housing, water, and grocery stores/food markets have some redundancy within the County and though they are not easily relocated they can be retrofitted to improve resilience.

4.3.2. Food, Water, and Shelter - Temperature

As extreme temperatures rise across the county, Food, Water, and Shelter assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Food, Water, and Shelter assets received a High Sensitivity rating for extreme temperatures and a Medium rating for Vulnerability Rating for Adaptive Capacity. A High Sensitivity rating was assigned because Food, Water, and Shelter assets in Prince William County can be severely impacted by extreme temperature events. Sudden temperature shifts, timing, and duration of seasons, as well as extended periods of extreme temperature can make drinking water resource management significantly more challenging. Additionally, shelter assets will increase in demand as will the demand for climate-controlled environments. Extreme temperature events may limit the amount of time individuals and machinery can work outside and may require some restructuring of how some functions are performed.

4.3.3. Food, Water, and Shelter - Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Food, Water, and Shelter assets received a High Sensitivity rating for drought and a Medium Vulnerability Rating for Adaptive Capacity. A High Sensitivity rating was assigned because water resources are significantly impacted by drought conditions. When drought conditions persist for extended periods, drinking water restrictions may be triggered.

4.3.4. Food, Water, and Shelter - Coastal Flooding and Sea Level Rise

Food, Water, and Shelter assets received a Low Exposure rating for coastal flooding and sea level rise because less than 1% of assets available as spatial data were within the 3 ft sea level rise area, which corresponds to the intermediate estimate for 2075. The Sensitivity of Food, Water, and Shelter assets to coastal flooding and sea level rise hazards is Medium because flooding of these assets may cause some damage, but they will remain partially functional. Food, Water, and Shelter assets were assigned a Medium for the Vulnerability Rating for Adaptive Capacity rating because while water resource management practices can be modified to increase resilience to climate hazards, these assets lack significant redundancy and have inherent limitations to their ability to adapt to a changing climate (e.g., reservoir storage).

4.3.5. Food, Water, and Shelter – Earthquakes

The National Risk Assessment ranks the exposure of Food, Water, and Shelter assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure such as housing or water treatment plants. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded, so the sensitivity is determined to be Medium. Overall, the Vulnerability Rating for Adaptive Capacity for Food, Water, and Shelter assets was determined to be Medium. This is a combination of the structural modifications that could be made to increase resiliency of many apartments, single family homes, and other dwellings, and the moderate redundancy in water treatment facilities.

4.3.6. Food, Water, and Shelter - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes demonstrating an average Sensitivity ranking of Medium for housing. The overall Sensitivity rating for this category is Medium based on the potential housing damages. The Vulnerability Rating for Adaptative Capacity is Medium. This is due to a combination of the structural modifications that could be made to increase resiliency of many apartments, single family homes, and other dwellings, and the moderate redundancy in water treatment facilities.

4.4. Health and Medical Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Health and Medical Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 15.

Table 15. Vulnerability Ratings for Health and Medical Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	L	L	M	M
Extreme Temperature	M	H	M	M
Drought	L	M	M	M
Coastal Flooding and SLR	L	L	M	M
Earthquakes	L	L	M	M
Strong Winds/Tornadoes	L	L	M	M

Abbreviations: L=Low; M=Medium; H=High

4.4.1. Health and Medical - Precipitation

Exposure of Health and Medical assets to precipitation hazard in both 2050 and 2075 is classified as Low. None of the three hospitals which comprise the asset category are exposed to precipitation hazard. The Sensitivity of Health and Medical assets to precipitation hazard is Medium because flooding of these assets may cause some damage and disruption to functionality, but parts of the assets should still be operational. Health and Medical assets were assigned a Medium Vulnerability Rating for Adaptive Capacity. The County has three major hospitals which provide some limited redundancy and coordination with larger hospital systems outside of the County on a regional level may add to this redundancy; however, health and medical assets are limited in their ability to adapt because their functions can only be performed in certain controlled environments and require significant resources to maintain normal operations.

4.4.2. Health and Medical - Temperature

As extreme temperatures rise across the county, Health and Medical assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Health and Medical assets received a Medium Sensitivity rating for extreme temperatures and a Medium Vulnerability Rating for Adaptive Capacity. A Medium Sensitivity rating was assigned because Health and Medical assets can maintain most functionality during extreme temperature events. Extreme temperature events simultaneously increase the demand for medical assets while also making it more difficult for medical personnel to commute to hospitals and medical facilities. Energy and human resource demands are likely to increase with rising temperatures.

4.4.3. Health and Medical - Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Health and Medical assets received a Medium Sensitivity rating for drought and a Medium Vulnerability Rating for Adaptive Capacity. A Medium Sensitivity rating was assigned because Health and Medical assets can maintain most functionality during droughts. Drought conditions inherently impact human health and will thus inevitably impact Health and Medical assets by limiting resources and increasing demand.

4.4.4. Health and Medical - Coastal Flooding and Sea Level Rise

Exposure of Health and Medical assets to coastal flooding and sea level rise hazard in both 2050 and 2075 is classified as Low. None of the three hospitals which comprise the asset category are exposed to a sea level rise of 3 ft corresponding to the intermediate estimate for 2075. The Sensitivity of Health and Medical assets to coastal flooding and sea level rise is Medium because flooding of these assets may cause some damage and disruption to

functionality, but parts of the assets should still be operational. Health and Medical assets were assigned a Medium Vulnerability Rating for Adaptive Capacity. The County has three major hospitals which provide some limited redundancy; however, health and medical assets are limited in their ability to adapt because their functions can only be performed in certain controlled environments and require significant resources to maintain normal operations.

4.4.5. Health and Medical - Earthquakes

The National Risk Assessment ranks the Exposure of Health and Medical assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure such as hospitals and other health care facilities. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded, so the sensitivity is determined to be Medium. Health and Medical assets were assigned a Vulnerability Rating for Adaptive Capacity of Medium due to the relatively low redundancy in terms of available patient space if one or more hospitals within the county are damaged or other medical facilities were unsafe to occupy after an earthquake. However, structural modifications could be made to many buildings within this asset category to increase resilience to earthquake hazards.

4.4.6. Health and Medical - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes resulting in an average Sensitivity ranking of Medium for Health and Medical Facilities. The Vulnerability Rating for Adaptative Capacity is Medium due to the low redundancy in hospitals and other medical facilities, but the likelihood that a strong wind or tornado would damage on a small section of the county during an event.

4.5. Communications Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity Communications Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 16.

Table 16. Vulnerability Ratings for Communications Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	L	L	M	L
Extreme Temperature	M	H	M	L
Drought	L	M	L	L
Coastal Flooding and SLR	L	L	M	L
Earthquakes	L	L	M	L
Strong Winds/Tornadoes	L	L	M	L

Abbreviations: L=Low; M=Medium; H=High

4.5.1. Communications – Precipitation

Exposure of Communications assets to precipitation hazard in both 2050 and 2075 is classified as Low since the percent of spatially available Communications assets exposed to precipitation hazard is 3% and 5%, respectively. The Sensitivity of Communications assets to precipitation hazard is Medium because flooding of these assets may cause some damage and disruption to functionality, but parts of the assets should still be operational. Communication assets are given a Low Vulnerability Rating for Adaptive Capacity. This low rating means that this category has a low vulnerability due to the high redundancy of assets in this category and the ease of relocation of assets for future resiliency.

4.5.2. Communications – Temperature

As extreme temperatures rise across the county, Communication assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Communications assets received a Medium Sensitivity rating for extreme temperatures and a Low Vulnerability Rating for Adaptive Capacity. A Medium Sensitivity rating was assigned because communications assets in Prince William County are currently exposed to extreme temperatures and can maintain at least partial functionality. Extended extreme temperature events may negatively impact communications assets which are typically located outdoors; however, since these assets are designed to function outdoors, they are resilient to extreme temperature exposure. Extreme temperature events may limit the amount of time maintenance workers can spend outside and may require some restructuring of how some tasks are performed.

4.5.3. Communications – Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Communications assets received a Low Sensitivity rating for Drought and a Low Vulnerability Rating for Adaptive Capacity. A Low Sensitivity rating was assigned because communications assets can continue to operate normally during drought conditions.

4.5.4. Communications - Coastal Flooding and Sea Level Rise

Exposure of Communications assets coastal flooding and sea level rise is classified as Low since none of the spatially available Communications assets are exposed to this hazard. The Sensitivity of Communications assets to coastal flooding and sea level rise is Medium because flooding of these assets may cause some damage and disruption to functionality, but parts of the assets should still be operational. Communication assets are given a Low Vulnerability Rating for Adaptive Capacity. This Low rating means that this category has a low vulnerability due to the high redundancy of assets in this category and the ease of relocation of assets for future resiliency.

4.5.5. Communications – Earthquakes

The National Risk Assessment ranks the Exposure of Communication assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure such as cell phone towers, telephone poles, etc. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded. The Sensitivity is determined to be Medium as damages from large earthquakes could impact much of the communications infrastructure. Communication assets were assigned a Vulnerability Rating for Adaptive Capacity of Low due to the relative redundancy of communication systems and the ability to further stabilize communication towers to increase resilience to earthquake hazards.

4.5.6. Communications - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes demonstrating an average Sensitivity rating of Medium for the Communication assets. The Vulnerability Rating for Adaptative Capacity is Low due to the relative redundancy of communication systems.

4.6. Transportation Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Transportation Assets. The justifications for these ratings are further explained in the subsections below and summarized in

Table 17.

Table 17. Vulnerability Ratings for Transportation Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075

Precipitation	M	M	H	H
Extreme Temperature	M	H	M	H
Drought	L	M	L	H
Coastal Flooding and SLR	L	L	H	H
Earthquakes	L	L	M	H
Strong Winds/Tornadoes	L	L	L	H

Abbreviations: L=Low; M=Medium; H=High

4.6.1. Transportation – Precipitation

The percent of each asset class exposed to precipitation hazards in 2050 and 2075 within the Transportation asset category is shown in Table 18. Exposure in both 2050 and 2075 is classified as Medium due to the relatively high percentage of railroads and major roads exposed to precipitation hazards in both 2050 and 2075. Railroads and major roads have the greatest exposure to this hazard.

Table 18. Transportation Asset Exposure to Precipitation Hazard

Transportation Asset	Number of Assets (or Length)	2050 Percent Exposed to Precipitation Hazard	2075 Percent Exposed to Precipitation Hazard
Airports	1	0%	0%
Bus Stops	156	3%	4%
Rail Stations	6	0%	0%
Railroads	80 (miles)	6%	8%
Major Roads	432 (miles)	4%	6%

The Sensitivity of Transportation assets to precipitation hazard is High because there are major disruptions to the functionality of these assets during heavy precipitation events. Transportation assets were assigned a High Vulnerability Rating for Adaptive Capacity due to the limited redundancy within the County as well as difficulty in relocating or creating new assets.

4.6.2. Transportation – Temperature

As extreme temperatures rise across the county, Transportation assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Transportation assets received a Medium Sensitivity rating for extreme temperatures and a High Vulnerability Rating for Adaptive Capacity. A Medium Sensitivity rating was assigned because Transportation assets in Prince William County are currently exposed to extreme temperatures and can maintain at least partial functionality. Transportation assets are designed to function outdoors, but during extended extreme temperature events some assets may deteriorate or fail. Accordingly, operation of rail and other transportation assets are typically suspended or significantly delayed during extreme temperature events (both extreme heat and extreme cold). Extreme temperature events may also limit the amount of time maintenance workers can spend outside and may require some restructuring of how some tasks are performed.

4.6.3. Transportation – Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Transportation assets received a Low Sensitivity rating for drought and a High Vulnerability Rating for Adaptive Capacity. A Low Sensitivity rating was assigned because transportation assets can continue to operate normally during drought conditions.

4.6.4. Transportation - Coastal Flooding and Sea Level Rise

Exposure of Transportation assets coastal flooding and sea level rise is classified as Low. Only 1% of major roads and 4% of railroads are potentially exposed to sea level rise of 3 ft corresponding to the intermediate estimate for 2075, and some may already be elevated enough to not be exposed. No airports, bus stops, or rail stations are exposed to sea level rise of 3 ft. The Sensitivity of Transportation assets to coastal flooding and sea level rise is High because there are major disruptions to the functionality of these assets during heavy precipitation events.

Transportation assets were assigned a High Vulnerability Rating for Adaptive Capacity due to the limited redundancy within the County as well as difficulty in relocating or creating new assets.

4.6.5. Transportation – Earthquakes

The National Risk Assessment ranks the exposure of Transportation assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure such as roads and mass transit. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded, so the sensitivity is determined to be Medium.

4.6.6. Transportation - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes; however, that mostly applies to buildings and other similar structures. For transportation assets, high winds and tornadoes may result in suspension of operations or impact roads and rail lines with fallen trees and debris. A Sensitivity rating of Low for Transportation assets for strong winds/tornadoes was assigned due to the relatively minor impact of these events to overall asset functionality.

4.7. Energy and Hazardous Materials Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Energy and Hazardous Materials Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 19.

Table 19. Vulnerability Ratings for Energy and Hazardous Materials Assets

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	L	L	M	H
Extreme Temperature	M	H	L	H
Drought	L	M	L	H
Coastal Flooding and SLR	L	L	H	H
Earthquakes	L	L	M	H
Strong Winds/Tornadoes	L	L	M	H

Abbreviations: L=Low; M=Medium; H=High

4.7.1. Energy and Hazardous Materials – Precipitation

Energy and Hazardous Materials assets received a Low Exposure rating for precipitation hazard. Although power lines cross over precipitation-vulnerable areas, they are expected to be elevated and therefore will not be exposed to the hazard. Some areas in the County also have underground power lines but these typically have minimal impact from precipitation events and are often made to operate in submerged conditions where they are buried under the water table. A Medium Sensitivity rating was assigned because Energy and Hazardous Materials assets may be damaged by precipitation hazards but are expected to remain partially operational. Energy and Hazardous Materials assets were assigned a High Vulnerability Rating for Adaptive Capacity due to the limited redundancy within the County as well as difficulty in relocating or creating new assets.

4.7.2. Energy and Hazardous Materials – Temperature

As extreme temperatures rise across the county, Energy and Hazardous Materials assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Energy and Hazardous Materials assets received a Low Sensitivity rating for extreme temperatures and a High Vulnerability Rating for Adaptive Capacity. A Low

Sensitivity rating was assigned because Energy and Hazardous Materials assets in Prince William County are currently exposed to extreme temperatures and can function without interruption. Energy and Hazardous Materials assets are designed to function outdoors, but during extended extreme temperature events some assets may deteriorate more quickly and require increased maintenance. Extreme temperature events may limit the amount of time maintenance workers can spend outside and may require some restructuring of how some tasks are performed.

4.7.3. Energy and Hazardous Materials – Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Energy and Hazardous Materials assets received a Low Sensitivity rating for drought and a High Vulnerability Rating for Adaptive Capacity. A Low Sensitivity rating was assigned because Energy and Hazardous Materials assets can continue to operate normally during drought conditions.

4.7.4. Energy and Hazardous Materials - Coastal Flooding and Sea Level Rise

Energy and Hazardous Materials assets received a Low Exposure rating for coastal flooding and sea level rise. Although power lines cross over areas with sea level rise of 3 ft, they are expected to be elevated and therefore will not be exposed to the hazard. A High Sensitivity rating was assigned because Energy and Hazardous Materials assets may be severely damaged by coastal flooding and sea level rise. Energy and Hazardous Materials assets were assigned a High Vulnerability Rating for Adaptive Capacity due to the limited redundancy within the County as well as difficulty in relocating or creating new assets.

4.7.5. Energy and Hazardous Materials – Earthquakes

The National Risk Assessment ranks the Exposure of Energy and Hazardous Materials assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure such as electrical lines, power generation plants and substations, County-run fuel distribution centers, natural gas pipelines, and hazardous materials storage sites. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded, so the Sensitivity is determined to be Medium. Energy and Hazardous Material assets were assigned as having High Vulnerability Rating for Adaptative Capacity, due to two factors. First, most of the Energy and Hazardous Materials assets are outside the domain of Prince William County leaving the county with limited ability to enact change. Additionally, a solution to increased resiliency of power lines is to take them underground to avoid the risk of damage from high wind events, but this strategy can put the lines at higher risk to damage from earthquakes.

4.7.6. Energy and Hazardous Materials - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes resulting in an average Sensitivity rating of Medium for Energy and Hazardous Materials. The Vulnerability Rating for Adaptative Capacity is High due to the lack of redundancy for the energy and hazardous materials systems.

4.8. Natural Resources Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Natural Resources Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 20

Table 17.

Table 20. Vulnerability Ratings for Natural Resources

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	H	H	H	M
Extreme Temperature	M	H	H	M
Drought	L	M	H	M
Coastal Flooding and SLR	L	L	H	M
Earthquakes	L	L	M	M
Strong Winds/Tornadoes	L	L	M	M

Abbreviations: L=Low; M=Medium; H=High

4.8.1. Natural Resources – Precipitation

The percent of each asset within the Natural Resources asset category exposed to precipitation hazards in 2050 and 2075 is shown in Table 21. Exposure in both 2050 and 2075 is classified as High since the percent of Natural Resources assets exposed to precipitation hazard ranges from 10-90% and 11-90%, respectively. Dams, streams, and resource protection areas are all highly vulnerable to precipitation hazard.

Table 21. Natural Resources Asset Exposure to Precipitation Hazard

Natural Resources Asset	Number of Assets (or Length/Area of Assets)	Unit of Exposure Measurement		2050 Percent Exposed to Precipitation Hazard	2075 Percent Exposed to Precipitation Hazard
Dams	10	Number Exposed		90%	90%
Streams	1,040 miles	Length Exposed		59%	59%
Resource Protection Areas	50 square miles	Area Exposed		42%	43%
Tree Cover	187 square miles	Area Exposed		10%	11%
Agricultural Areas	36 square miles	Area Exposed	14%	15%	

Sensitivity of Natural Resources assets to precipitation hazards is considered High since the hazard could potentially cause irreparable damages to these assets. Natural Resources were assigned a Medium Vulnerability Rating for Adaptive Capacity rating as most have some tolerance for climate hazards as well as redundancy.

4.8.2. Natural Resources – Temperature

As extreme temperatures rise across the county, Natural Resources assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Natural Resources received a High Sensitivity rating for extreme temperatures and a Medium Vulnerability Rating for Adaptive Capacity. A High Sensitivity rating was assigned because Natural Resource assets can be severely impacted by extreme temperature events. Sudden temperature shifts, timing, and duration of seasons, as well as extended periods of extreme temperature can devastate crops as well as animal and plant life which reside exclusively outdoors. Extreme temperature events may limit the amount of time individuals and machinery can work outside and may require some restructuring of how some maintenance and rehabilitation functions are performed. As the climate shifts, agricultural techniques and even the types of crops grown may need to change to account for shifts in seasonality and temperature. Animal and plant species may migrate into and out of areas within the County, adding or removing natural resource assets and changing the way these resources are managed.

4.8.3. Natural Resources – Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Natural Resources received a High Sensitivity rating for drought and a Medium Vulnerability Rating for Adaptive Capacity. A High Sensitivity rating was assigned because both flora and fauna are significantly impacted by drought conditions. When drought conditions persist for extended periods, crops can fail and species populations may be decimated or forced to migrate out of the County.

4.8.4. Natural Resources - Coastal Flooding and Sea Level Rise

The percent of each asset within the Natural Resources asset category exposed to coastal flooding and sea level rise hazards in 2050 and 2075 is shown in Table 22. Exposure in both 2050 and 2075 is classified as Low. Resource protection areas experience the greatest exposure to coastal flooding and sea level rise since they are currently located in coastal areas.

Table 22. Natural Resources Asset Exposure to Coastal Flooding and Sea Level Rise

Natural Resources Asset	Number of Assets (or Length or Area of Assets)	Unit of Exposure Measurement	Exposed to Sea Level Rise of 2 ft	Exposed to Sea Level Rise of 3 ft
Dams	10	Number Exposed	0%	0%
Streams	1,040 miles	Length Exposed	6%	6%
Resource Protection Areas	50 square miles	Area Exposed	20%	20%
Tree Cover	187 square miles	Area Exposed	0%	1%

Sensitivity of Natural Resources assets to coastal flooding and sea level rise is considered High since the hazard could potentially cause irreparable damages to these assets by significantly changing the natural environment in which they reside. Natural Resources were assigned a Medium Vulnerability Rating for Adaptive Capacity as most have some tolerance for climate hazards as well as redundancy.

4.8.5. Natural Resources – Earthquakes

The National Risk Assessment ranks the Exposure risk to Prince William County from earthquakes as a Low risk. Although earthquakes usually don't cause extensive damage for natural resources, this category includes dams (as the dams create the natural resource of a lake. During the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, there was no major damage reported in Prince William County except for the dam at Lake Jackson. Damage from this earthquake cause loss of water in the lake and officials released water from the dam to relieve pressure to avoid collapse of the structure. The dam rehabilitation cost was approximately $900,000. Although most of the natural resources in this category are not very sensitive to earthquakes, due to the documented damage to the Lake Jackson Dam, the Sensitivity is rated Medium. The Vulnerability Rating for Adaptative Capacity is Medium. For Natural Resources, the Adaptive Capacity considerations are focused mostly on dams. The Medium rating for this category is due to the challenge to reinforce dams (or other natural resources) for earthquake hazards.

4.8.6. Natural Resources - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Based on the projected annual damages to the agriculture sector in the National Risk Assessment due to strong winds and tornadoes the sensitivity to these hazards is ranked Low. High winds and tornadoes can cause extensive tree loss or other damage to natural resources resulting in a Sensitivity rating of Medium. The Vulnerability Rating for Adaptative Capacity is Medium. For Strong Winds and Tornadoes, the Adaptive Capacity considerations are focused mostly on tree cover. The Medium rating for this category is due to the high redundancy of tree cover while acknowledging that the loss of large, established trees can be hard to replace.

4.9. Socially Vulnerable Populations Asset Vulnerability

This section describes the Exposure, Sensitivity, and Vulnerability Rating for Adaptative Capacity for Transportation Assets. The justifications for these ratings are further explained in the subsections below and summarized in Table 23.

Table 23. Vulnerability Ratings for Socially Vulnerable Populations

Climate Hazard	Exposure Rating		Sensitivity Rating	Vulnerability Rating for Adaptive Capacity
	2050	2075	2050 & 2075	2050 & 2075
Precipitation	H	H	H	H
Extreme Temperature	M	H	H	H
Drought	L	M	H	H
Coastal Flooding and SLR	L	L	H	H
Earthquakes	L	L	M	H
Strong Winds/Tornadoes	L	L	H	H

Abbreviations: L=Low; M=Medium; H=High

4.9.1. Socially Vulnerable Populations – Precipitation

Socially Vulnerable Populations received a High Exposure rating for precipitation hazards, as 24 of 26 Equity Emphasis Areas are impacted by the hazard in both 2050 and 2075 scenarios. Socially Vulnerable Populations have a High Sensitivity rating to precipitation hazards, as precipitation-related damages may significantly impact the wellbeing of individuals in Equity Emphasis Areas. Socially Vulnerable Populations were assigned a High Vulnerability Rating for Adaptive Capacity as they have limited resources and access to resources that would facilitate adaptation to climate hazard exposure.

4.9.2. Socially Vulnerable Populations – Temperature

As extreme temperatures rise across the county, Energy and Hazardous Materials assets were given a Medium Exposure rating for 2050 and a High Exposure rating for 2075. Socially Vulnerable Populations received a High Sensitivity rating for extreme temperatures and a High Vulnerability Rating for Adaptive. A High Sensitivity rating was assigned because Socially Vulnerable Populations can be severely impacted by extreme temperature events due to limited access to climate-controlled environments. Extended periods of extreme temperature can create or exacerbate health conditions.

4.9.3. Socially Vulnerable Populations – Drought

Drought Exposure throughout the County is rated Low of 2050 and Medium for 2075. Socially Vulnerable Populations received a High Sensitivity rating for drought and a High Vulnerability Rating for Adaptive Capacity. A High Sensitivity rating was assigned because Socially Vulnerable Populations are more severely impacted by drought conditions as they have fewer resources available to alleviate drinking water restrictions and may have increased water demand due to increased exposure to extreme temperatures that often accompany drought conditions.

4.9.4. Socially Vulnerable Populations - Coastal Flooding and Sea Level Rise

Socially Vulnerable Populations received a Low Exposure rating for coastal flooding and sea level rise, as 5 of 26 Equity Emphasis Areas are impacted by the hazard in both 2050 and 2075 scenarios. Socially Vulnerable Populations have a High Sensitivity rating to coastal flooding and sea level rise, as related damages may significantly impact the wellbeing of individuals in Equity Emphasis Areas. Socially Vulnerable Populations were assigned a High Vulnerability Rating for Adaptive Capacity as they have limited resources and access to resources that would facilitate adaptation to climate hazard exposure.

4.9.5. Socially Vulnerable Populations – Earthquakes

The National Risk Assessment ranks the Exposure of all assets within Prince William County as a Low risk. Large earthquakes could have an impact on the built infrastructure, which is likely to impact socially vulnerable populations more severely than other residents of Prince William County. However, the 5.8 magnitude earthquake out of Mineral, VA and 4.2 magnitude aftershock earthquake outside of Fredericksburg, VA in August 2011, resulted in no major impacts being recorded, so the Sensitivity is determined to be Medium. The Vulnerability Rating for Adaptative Capacity is rated High due to the limited ability for Socially Vulnerable Populations to be able to make changes to their built environment to better adapt to earthquake hazards.

4.9.6. Socially Vulnerable Populations - Strong Winds/Tornadoes

Prince William County has experienced multiple high wind events from hurricanes and straight-line winds as well as tornadoes; however, the National Risk Assessment ranks the Exposure of the county to these types of events as Low for strong winds and Relatively Low for tornadoes. Projected damages due to these events are ranked Relatively Moderate for strong winds and Relatively High for tornadoes; however, Socially Vulnerable Populations generally have fewer options in terms of housing when they are displaced due to natural hazard events including strong wind or tornadoes resulting in a Sensitivity rating of High. The Vulnerability Rating for Adaptative Capacity is High due to the lack of redundancy in affordable housing.

6. Vulnerability Ratings and Conclusions

An asset category's vulnerability to a particular climate hazard can be defined as the combination of the asset category's exposure, sensitivity, and adaptive capacity to the climate hazard. The development of exposure, sensitivity, and adaptive capacity ratings in Section 4 lay the foundation for the evaluation of climate hazard vulnerability presented in this section. The rating system has been set up such that Low scores mean there is a lower vulnerability, and High scores mean that there is a higher vulnerability and that adaptation actions should be focused in these areas.

County-wide versus individual asset vulnerability

The results of this vulnerability assessment are generalized and while they provide valuable information on the County-wide scale, individual assets may score differently than the overall asset category. For example, while most of the County has almost no coastal flood vulnerability, there are homes and businesses located along the coastline that will likely be impacted by rising sea levels. This report did not include detailed modeling of how changing precipitation would impact riverine or overland flooding or the performance of the County's stormwater management system, which could be included in a more detailed study focused on areas of the county that are already being impacted by frequent flooding events.

Summaries of exposure, sensitivity, and adaptive capacity ratings are shown in Table 24, Table 25, and Table 26, respectively. Exposure, sensitivity, and adaptive capacity ratings were assigned scores and summed to determine vulnerability ratings for each climate hazard and combined vulnerability ratings for each asset category. High exposure, sensitivity, or adaptive capacity ratings received a score of 3, Medium ratings received a score of 2, and Low ratings received a score of 1. Vulnerability scores for each climate hazard were calculated by adding the exposure, sensitivity, and adaptive capacity scores for each time horizon. Total scores of 3 – 4 received a Low vulnerability rating, total scores of 5 – 7 received a Medium vulnerability rating, and total scores of 8 – 9 received a High vulnerability rating as shown in Table 27.

Vulnerability scores for each climate hazard were then added together to determine combined vulnerability scores for each asset category and time horizon. Total hazard scores of 18 – 27 received a Low combined vulnerability rating, total hazard scores of 28 – 36 received a Medium combined vulnerability rating, and total hazard scores of 37 – 54 received a High combined vulnerability rating as shown in Table 28.

Vulnerability scores can be used to understand how vulnerable an asset category is to a particular future climate hazard. Overall, assets in Prince William County were determined to be most vulnerable to Extreme Temperatures followed by Precipitation and Strong Winds/Tornadoes though most vulnerability scores are Medium or Low. The Safety and Security and Communications asset categories received Low vulnerability ratings for all future climate hazards except for Medium ratings for both 2050 and 2075 for extreme temperatures. Energy & Hazardous Materials; Food, Water, and Shelter; and Health and Medical asset categories received Medium vulnerability ratings for all hazards with the notable exception of a High extreme temperature vulnerability rating for Food, Water, and Shelter assets in 2075. Socially Vulnerable Populations received the highest vulnerability ratings with High ratings for precipitation and extreme temperature in 2050 and 2075 and a High vulnerability rating for drought in 2075. All other ratings for Socially Vulnerable populations were Medium. Similarly, Natural Resources and Transportation assets received Medium ratings for all hazards with the exceptions of High ratings for precipitation in 2050 and 2075 and extreme temperature in 2075.

Combined vulnerability scores can be used to summarize overall vulnerability for each asset category. Socially Vulnerable Populations, Transportation, and Natural Resources were the most vulnerable asset categories with High combined vulnerability ratings in both 2050 and 2075. Energy & Hazardous Materials received a Medium combined vulnerability rating for 2050 and a High combined vulnerability rating for 2075. Food, Water, and Shelter and Health and Medical asset categories received Medium combined vulnerability ratings for both 2050 and 2075 while Safety and Security and Communications asset categories received Low vulnerability ratings for both 2050 and 2075.

Table 24. Summary of Asset Exposure Ratings

Climate Hazard	Asset Category															
	Safety and Security		Food, Water, and Shelter		Health and Medical		Communications		Transportation		Energy & Hazardous Materials		Natural Resources		Socially Vulnerable Populations	
	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075
Precipitation	L	L	L	L	L	L	L	L	M	M	L	L	H	H	H	H
Extreme Temperature	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Drought	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M
Coastal Flooding and SLR	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Earthquakes	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L
Strong Winds/Tornadoes	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L	L

Table 25. Summary of Asset Sensitivity Ratings

Climate Hazard	Asset Category							
	Safety and Security	Food, Water, and Shelter	Health and Medical	Communications	Transportation	Energy & Hazardous Materials	Natural Resources	Socially Vulnerable Populations
Precipitation	M	M	M	M	H	M	H	H
Extreme Temperature	M	H	M	M	M	L	H	H
Drought	L	H	M	L	L	L	H	H
Coastal Flooding and Sea Level Rise	M	M	M	M	H	H	H	H
Earthquakes	M	M	M	M	M	M	M	M
Strong Winds/ Tornadoes	M	M	M	M	L	M	M	H

Table 26. Summary of Asset Adaptive Capacity Vulnerability Ratings

Asset Category	Vulnerability Rating of Adaptive Capacity
Safety and Security	L
Food, Water, and Shelter	M
Health and Medical	M
Communications	L
Transportation	H
Energy & Hazardous Materials	H
Natural Resources	M
Socially Vulnerable Populations	H

Table 27. Summary of Vulnerability Ratings for All Climate Hazards

Climate Hazard	Asset Category															
	Safety and Security		Food, Water, and Shelter		Health and Medical		Communications		Transportation		Energy & Hazardous Materials		Natural Resources		Socially Vulnerable Populations	
	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075	2050	2075
Precipitation	L	L	M	M	M	M	L	L	H	H	M	M	H	H	H	H
Extreme Temperature	M	M	M	H	M	M	M	M	M	H	M	M	M	H	H	H
Drought	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	H
Coastal Flooding and SLR	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M
Earthquakes	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M
Strong Winds/Tornadoes	L	L	M	M	M	M	L	L	M	M	M	M	M	M	M	M

Table 28. Summary of Combined Vulnerability Ratings

Asset Category	Combined Vulnerability Rating	
	2050	2075
Safety and Security	L	L
Food, Water, and Shelter	M	M
Health and Medical	M	M
Communications	L	L
Transportation	H	H
Energy & Hazardous Materials	M	H
Natural Resources	H	H
Socially Vulnerable Populations	H	H

7. References

Federal Emergency Management Agency (FEMA). 2021a. National Risk Index Technical Documentation. https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

Federal Emergency Management Agency (FEMA). 2021. National Risk Index: Community Report – Prince William County, Virginia.

Grinstead, A., J. Moore, S. Jevrejeva. 2013. Projected Atlantic hurricane surge threat from rising temperatures. *Proceedings of the National Academy of Sciences, 110 (14), April 2, 2013.* https://doi.org/10.1073/pnas.1209980110

Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger. 2016. Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp. https://www.hsdl.org/?abstract&did=792698

IPCC. (2007). *The Multi-Model Ensemble Approach. Retrieved June 2018, from IPCC Fourth Assessment Report: Climate Change 2007: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch10s10-5-4-1.html*

Metropolitan Washington Council of Governments (MWCOG). 2008. National Capital Region Climate Change Report. https://www.mwcog.org/documents/2008/11/12/national-capital-region-climate-change-report-climate-change/

Metropolitan Washington Council of Governments (MWCOG). 2020. Metropolitan Washington 2030 Climate and Energy Action Plan. November 2020.

Mid-Atlantic Regional Assessment (MARA) Team. 2001. Preparing for a Changing Climate: The Potential Consequences of Climate Variability and Change. Report to the U.S. Global Change Research Program. Mid-Atlantic Foundations. January 2001. http://www.usgcrp.gov/usgcrp/nacc/midatlantic.htm.

Mitigation Advisory Committee. 2017. Northern Virginia Hazard Mitigation Plan. https://www.fairfaxcounty.gov/emergencymanagement/sites/emergencymanagement/files/assets/documents/pdf/draft_hazard_mitigation_plan.pdf

Mitigation Advisory Committee. 2022. Northern Virginia Hazard Mitigation Plan. https://engage.fairfaxva.gov/northern-virginia-hazard-mitigation-plan-2022

Murakami, H., Wang, B. Patterns and frequency of projected future tropical cyclone genesis are governed by dynamic effects. *Communications Earth Environ 3, 77.* https://doi.org/10.1038/s43247-022-00410-z

National Capital Region Transportation Planning Board (TPB), 2018. Methodology for Equity Emphasis Areas. https://www.mwcog.org/assets/1/6/methodology.pdf

National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management. (2022). Sea Level Rise Viewer v 3.0.0. https://coast.noaa.gov/slr/#/layer/slr/1/-8631532.789978385/4683320.91692228/11/satellite/none/0.8/2050/interHigh/midAccretion

National Oceanic and Atmospheric Administration (NOAA). 2022. Accessed October 14, 2022: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8594900

Pierce, D. W., Cayan, D. R., & Thrasher, B. L. (2014). Statistical Downscaling Using Localized Constructed Analogs (LOCA). Journal of Hydrometeorology, 2558-2585.

Sweet, W.V., R.E. Kopp, C.P. Weaver, J. Obeysekera, R.M. Horton, E.R. Thieler, C. Zervas. 2017. Global and Regional Sea Level Rise Scenarios for the United States. National Oceanic and Atmospheric Administration. 75 pp. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, 2022. Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

U.S. Army Corps of Engineers (USACE). 2013. Incorporating Sea Level Change in Civil Works Programs. ER 1100-2-8162. https://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1100-2-8162.pdf

U.S. Army Corps of Engineers (USACE). 2022. Sea-Level Change Curve Calculator (Version (2022.60)). https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., et al. (2011). The representative concentration pathways: an overview. Climactic Change.

VTrans (Virginia's Transportation Plan). 2021. VTrans Macrotrend 1: Flooding Risk Assessment Technical Memorandum. https://vtrans.org/resources/2021_VTrans_Vulnerability%20Assessment_TechMemo.pdf

Warrick RA, LeProvost C, Meier MF, Oerlemans J, Woodworth PL (1996) Changes in sea level. In: Hougton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A and Maskell K (eds). Climate Change 1995: The Science of Climate Change. Cambridge University Press: Cambridge, UK, p. 359-405

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