Resilient Fairfax

Climate Projections Report

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Prepared for the Fairfax County Office of Environmental and Energy Coordination (OEEC)

Disclaimer: These projections provide an indication of future conditions based on the state of the science and current best practices in projection analyses. It is not known with certainty how the future society may evolve, and conditions may change.

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Executive Summary

This Climate Projections Report provides an analysis of projected future climate conditions in Fairfax County, Virginia. It answers the following question: "**what climate conditions and hazards are we likely to face in Fairfax County by 2050 and by 2085?**" The climate projections report is one component of the larger Resilient Fairfax Climate Adaptation and Resilience Plan.

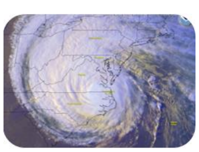
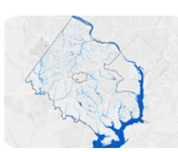
Two emissions scenarios were used for these projections: the Representative Concentration Pathway (RCP) 4.5 "lower emissions scenario," and the RCP 8.5 "higher emissions scenario." Climate data was obtained through multiple avenues including: the Localized Constructed Analogues (LOCA) technique (which includes 32 climate models), observation station data (from stations at the Washington Reagan National Airport, Washington Dulles International Airport, and Vienna, Virginia), METDATA (which draws on the NASA North American Land Data Assimilation System (NL-DAS2)), NASA DEVELOP satellite data, and reviews of existing data from Fairfax County, the Metropolitan Washington Council of Governments (MWCOG), the Northern Virginia Regional Commission (NVRC), the National Oceanic and Atmospheric Administration (NOAA), the United States Army Corps of Engineers (USACE), the Chesapeake Bay Program, the Interstate Commission on the Potomac River Basin (ICPRB) and other sources.

This analysis included the following climate hazards: extreme heat, extreme cold, heavy precipitation/inland flooding, coastal flooding, severe storm and wind events, and drought. The results of the study showed that some of these hazards are projected to become more severe for the county, as summarized in the graphic below. The more severe projections for the county are extreme heat and heavy precipitation and inland flooding. While storm activity is projected to intensify as the planet warms, which would place it under the "most severe" category, there is less confidence compared to heat and precipitation, which is why it is placed under "moderate." Drought projections for the county are comparatively minor as precipitation is projected to increase, but intermittent drought may occur. Extreme cold is projected to decrease as temperatures warm.

Most severe:
Extreme heat, heavy precipitation and inland flooding

Minor:
Drought

Moderate:
Severe storm and wind events, coastal flooding

Opportunities (Reduced):
Extreme cold

This report focuses only on the data of projected climate conditions. It does not discuss the impacts or vulnerabilities associated with those projected conditions. The impacts are discussed in a subsequent vulnerability and risk assessment (VRA) report. The climate projections detailed in this report lay the groundwork for the subsequent deliverables of Resilient Fairfax, including the climate VRA, the audit of existing policies, plans, and programs, the adaptation and resiliency strategies, and the implementation roadmap.

1. Introduction

Over the past century, Fairfax County has experienced increased temperature, precipitation, storm severity, and rising water levels along its shorelines. Climate change is anticipated to continue to increase the number and intensity of these events. Resilient Fairfax is an initiative to help our county prepare for and become more resilient to these hazards. This report is one component of the Resilient Fairfax climate adaptation and resilience plan. The purpose of this report is to identify future climate conditions and hazards in Fairfax County. A subsequent report, the vulnerability and risk assessment, will describe the *impacts* of those projected conditions. The following diagram shows how this report relates to the other deliverables of Resilient Fairfax. **This report is shown in green.**

Resilient Fairfax Climate Adaptation and Resilience Plan

Climate Projections Report: *How has the climate changed? What will the future climate look like?*

- Will there be change in temperature?
- Will there be change in storm severity?
- Will there be change in precipitation and intensity of rain events?
- Will there be coastal flooding?
- Will there be drought?

Climate Vulnerability and Risk Assessment: *Where are we vulnerable? What are the top risks?*

- Which of our infrastructure, populations, and systems are *exposed* to climate hazards?
- Which are *sensitive* to these climate hazards?
- Which lack the *adaptive capacity* to handle changing conditions?
- What are our top vulnerabilities?
- Which are most likely? Which have the most severe consequences?

Audit of Existing Plans, Policies, and Programs: *Do our policies, plans, and programs include resilience?*

- How do our policies, plans, and programs compare to best practices?
- Which programs are working well and should be potentially expanded?
- Where are the gaps or opportunities to update policies and programs?

Strategies for Climate Adaptation & Resilience: *What should we do to enhance the county's resilience?*

- What strategies would help the county address our climate vulnerabilities and risks?
- Which of these strategies are top priority?

Implementation Roadmap: *What is the plan to implement the priority strategies?*

- What actions would be taken to implement the strategies?
- Who would be responsible for implementation?
- What is the timeframe for implementation?

"Climate" is often confused with "weather." Climate refers to long-term statistical averages of 20 years or more, while weather refers to day-to-day conditions. Climate models provide projections of how the future climate may change.

"Climate" vs. "Weather"

Climate means long-term statistical averages of 20 years or more.

Weather means day-to-day conditions.

This Climate Projections Report presents future conditions under two greenhouse (GHG) scenarios: (1) a moderate warming future scenario, Representative Concentration Pathway (RCP) 4.5, where global GHG emissions peak around 2040 and then, through climate policies, stabilize at around 540 parts per million (ppm) by 2100 (referred to "lower emissions" in this report), and (2) a high future warming scenario, RCP8.5, where there is little curbing of emissions and concentrations continue to increase rapidly reaching about 940 ppm by 2100 (referred to as "higher emissions" in this report).[i] For reference, the global average atmospheric carbon dioxide level in 2020 was over 410 ppm.

The two emissions scenarios (RCP4.5 and RCP8.5) are used to help address uncertainty associated with how society may evolve over the coming century. Over the course of this century, there are significant differences in the possible rates of accelerated change, largely dependent on future greenhouse gas emissions. This means that today's decisions and actions concerning GHG mitigation may have profound consequences on the long-term outcome of Fairfax County's future climate. If global society successfully reduces our greenhouse gas emissions, future climate scenarios may be milder. If global society does not take action to reduce our emissions, future climate scenarios may be more extreme.

Regardless of which future scenario best aligns with our trajectory, Fairfax County's governance of assets, systems, and population is likely to be strained if the county is not adequately prepared for these plausible futures. Based on discussions with local stakeholders and a review of local resources, the following climate-related hazards were selected for analysis in Fairfax County:

- Extreme Heat
- Heavy Precipitation and Inland Flooding
- Severe Storm and Wind Events
- Coastal Flooding
- Drought
- Extreme Cold

While some of these hazards may overlap during an event, such as heavy precipitation and storm and wind events, they are analyzed distinctly in this study because the hazards do not *always* occur simultaneously. For example, strong wind leading to power outages would not be factored in under "heavy precipitation," and flooding from "heavy precipitation" that is not the result of a storm would not be factored in under "storm events."

To determine how these hazards may change over the coming century, climate indicators were identified to consistently quantify and analyze these hazards (see Appendix A). An analysis of climate projections was then conducted for the climate indicators. This analysis compared the results of daily maximum temperature, daily minimum temperature, and daily precipitation projections from 32 downscaled climate models. The analysis was conducted for two 30-year future time periods: 2035-2064 (termed "2050" for the mid-point or "mid-century") and 2070-2099 (termed "2085" or "end of century"), for comparison to a "baseline period" of 1976-2005 and a "current period" of 1991-2020. These indicators were supplemented with desktop reviews of applicable climate data and regional literature.

This Climate Projections Report presents the findings of the climate projections analysis and desktop review for Fairfax County, Virginia specifically. This analysis focuses only on climate projection data; it does not discuss the *impacts* or vulnerabilities and risks associated with those projections.

2. Glossary[ii]

To ensure consistency in terminology, the following definitions were adopted for this analysis.

- **Acute Hazard**: An event-driven hazard that may damage or impact an area, people, asset, and/or system. Blizzards, heat events, and heavy rainfall events are all examples of acute hazards.
- **Baseline Conditions** (also referred to as Baseline Period): The Baseline Conditions are used for comparison with current and future climate conditions. The 30-year baseline period for this study is from 1976 to 2005, with a centered year of 1991. This period was selected as the reference period for consistency with other local, regional, national, and international analyses. Climate simulations begin to divert from each other when emissions scenarios are introduced into climate model analysis in 2006 (see Section III.I)).
- **Chronic Hazard**: A long-term change that can impact an area, people, asset, and/or system. Rising temperatures, rising sea level, and changes in seasonal precipitation are all examples of chronic hazards.
- **Concentrations**: Measure of a chemical species such as a greenhouse gas in the Earth's atmosphere. For long-lived gases, concentrations can accumulate over time as emissions continue.
- **Cooling Degree Days (CDD)**: The hotter the temperature, the more "cooling" through air conditioning is required. CDD is a measure of temperature and energy needed for space cooling. Despite the name, the metric does not refer to number of days. It is calculated for days above 65°F by subtracting 65°F from the outdoor temperature. The higher the cooling degree days, the more energy is needed. For example, a day with an average temperature of 80°F has a CDD of 15, because 80°F - 65°F = 15.
- **Climate**: A statistical average of weather conditions over a 20-year or 30-year period.
- **Climate Change**: Changes in average weather conditions that persist over multiple decades or longer.
- **Climate Models**: Computer code that simulates the climate system using advanced mathematical equations and powerful supercomputers, based on well-documented physical processes.
- **Climate Projections**: Simulated response of the climate system to a scenario of future emissions derived from climate models.
- **Climate Indicator**: Quantifiable variable that can be used to represent changes in the hazard. For example, the climate indicator "number of days above 95°F" can be used to represent change for the climate hazard "extreme heat."

- **Current Climate:** The "current climate" is a time period used for comparison with future climate conditions. For this study, the "current climate" period is based on observations from 1991 to 2020, with a centered year of 2006.
- **Downscaled Projections**: Projections from climate models that have been post-processed to better represent local- and regional-scale conditions.
- **Drought**: Based on the meteorological drought, "drought" is the degree of dryness or rainfall deficit and the length of the dry period. Hydrologic drought is based on the impact of rainfall deficits on the water supply such as stream flow, reservoirs and lake levels, and ground water table.
- **Emissions**: Gases and particles released into the Earth's atmosphere.
- **End-of-century**: For the purposes of this study, "end-of-century" is defined as 2085, based on an average across 2070-2099.
- **Exposure**: The presence of people, assets, and systems in places where they could be adversely affected by hazards.
- **Freeze-thaw Day**: Defined as a day when maximum temperature is at/above 32°F and minimum temperature drops below 30.2°F.
- **Greenhouse Gas (GHG)**: Gases that absorb heat in the atmosphere near the Earth's surface, preventing the heat from escaping into space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase. This is a phenomenon known as the greenhouse effect. Greenhouse gases include, for example, carbon dioxide, water vapor, and methane.
- **Hazard**: An event or condition that may cause injury, illness, harm, or death to people, unsafe conditions, damage to assets and systems, and/or impact on services.
- **Heating Degree Days (HDD)**: When temperatures are colder, more heat is needed in buildings. HDD is a measure of temperature and energy needed for space warming. Despite the name, HDD does not refer to number of days. HDD is calculated for cold days below 65°F by subtracting the outdoor temperature from 65°F. The higher the HDD, the more energy use is needed for heating. For example, a day with an average temperature of 30°F would have an HDD of 35, because 65°F - 30°F = 35.
- **Mid-century**: For the purposes of this study, "mid-century" is defined as 2050, based on an average across 2035-2064.
- **Representative Concentration Pathways (RCPs)**: Scenarios that include time series of emissions and concentrations of the full suite of greenhouse gases, aerosols, and other chemically active gases, as well as land use/land cover. The word "representative" signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term "pathway" emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome. Emissions scenarios are labeled as "RCP" followed by a number, such as RCP 2.5, RCP 4.5, RCP 6.0, and RCP 8.5. The numbers refer to the warming (in watts) per square meter across the planet by the end of century. For example, "RCP 8.5" means the

emissions scenario where the concentration of carbon results in warming at an average of 8.5 watts per square meter over the planet in 2100.

- **Sea Level Rise**: Average long-term rise of sea level. When measured at a site-specific tide gage, it may be referred to as “relative” sea level rise.
- **Storm Surge**: The sea height during storms such as hurricanes and tropical storms that is above the normal level expected at that time and place based on the tides alone.
- **Tropical Cyclones**: Low pressure system (not associated with a front) that develops over tropical and sometimes sub-tropical waters and has organized deep convection with a closed wind circulation about a well-defined center. Tropical depression, tropical storms, and hurricanes are all examples of tropical cyclones.
- **Urban Heat Island Effect (UHI)**: The tendency for higher air temperatures to persist in urban areas as a result of heat absorbed and emitted by buildings and asphalt, tending to make urbanized areas warmer than the areas with ample green space.

3. Methodology

This section describes the approach in estimating current and future conditions for Fairfax County. The climate descriptions of historic and projected change provided in this document are based on: (1) in-house processing of publicly available observed and climate model simulation data, (2) review of scientific literature provided through peer reviewed journal articles and government reports; and (3) review of vetted grey matter such as a National Oceanic and Atmospheric Administration (NOAA) website and publicly available governmental tools.

Two types of climate conditions were considered: (1) chronic hazards that demonstrate historic and future trends in long-term baseline conditions, such as rising sea levels and rising annual temperatures, and (2) acute hazards, or events that may increase or decrease over time, such as very heavy rainfall events or severe storms. There is greater confidence in projecting future conditions in chronic changes than acute events.

3.1 Planning Horizons

Climate projections are generally provided as statistically averaged data over a 20-year or 30-year period. Time periods shorter than 20-years are not considered representative of climate change. For the Fairfax County study, **30-year** planning horizons were chosen for a more robust analysis of the heavy precipitation and extreme heat events. A time period longer than 30 years was not adopted because the climate is changing over the coming century, and the longer the time period selected, the less likely the future signal of change would be effectively captured for planning purposes. The exception to this stance is for the projected change in precipitation events for 2-year through 500-year return periods, which are based on 40-year time periods. The longer time frame was chosen specifically for this precipitation component because estimates of future return periods are based on the annual maximum data (that is, the heaviest 24-hr precipitation event of each year). The more years used in the precipitation analysis, the more robust the result.

Climate models study the statistical change in future conditions compared to baseline conditions. Therefore, both baseline and future time periods are identified for the analysis. For Fairfax County, the 1976-2005 time period, centered in 1991, was used to represent **baseline** conditions. This baseline time period ensures a "clean" comparison across each emissions scenario where the results are representative of simulated projected change. This baseline period was chosen in part because the climate projections used in this analysis begin to consider potential changes described by the emissions scenarios in 2006 (see next section for more detail). This period was also selected for consistency with other local, regional, national, and international analyses.

However, because this report was written in 2021, using this baseline also creates a 16-year gap between the baseline end year (2005) and today. To address this gap, this analysis includes not only a "baseline" period (1976 – 2005), but also a **current period** of 1991 – 2020, centered in 2006.

For future conditions, this climate projections report primarily focuses on the **mid-century** timeframe, which means the time period from 2035-2064, centered at the year 2050. This mid-century horizon was chosen for several reasons. First, it enables staff to plan for current and near-term vulnerabilities. Second, the 2050 timeframe aligns with other county and regional climate planning-related efforts. Third, projections after 2050 have a greater degree of uncertainty.

However, to complement this detailed analysis of mid-century projections with additional context of future change, this report also includes less detailed **end-of-century** results for the time period 2070-2099, centered at the year 2085.

Table 1 provides a reference for the time horizons used (unless otherwise noted in the text in the following sections).

Table 1. Time period and planning horizons adopted for the Fairfax County study.

Time Period / Planning Horizon	Reference ID	Time period	Centered Year
Baseline period	"Baseline"	1976-2005	1991
Current period	"Current Climate"	1991-2020	2006
Mid-century horizon	"2050"	2035-2064	2050
End-of-century horizon	"2085"	2070-2099	2085

3.2 Future Scenarios

To investigate future changes in climate, climate models are used to simulate a range of climate futures that represent, in part, how global society may evolve over the coming century. These conditions can be connected to society's choices and behavior in fossil fuel use, land use, population growth, technology advances, policies to mitigate greenhouse gas emissions, and other factors. Based on a monumental undertaking supported by the Intergovernmental Panel on Climate Change (IPCC), a suite of emissions scenarios was developed to provide a range of plausible climate futures that could be used to "drive" climate models, which in turn estimate projected changes based on each emissions scenario (see Table 2). [iii] Climate projections based on climate models driven by these emissions scenarios were adopted by and presented in the 2014 IPCC Fifth

Assessment Report and the 2018 National Climate Assessment (NCA4) (see Figure 1). Emissions scenarios are labeled as "RCPs," which stands for "Representative Concentration Pathway."

Table 2. Emissions scenarios developed by the IPCC.

Emissions Scenario	Description
RCP 2.5	Emissions peak in the early part of this century and then decline substantially. This is not considered a plausible scenario because this aggressive reduction in emissions would need to have occurred already.
RCP 4.5	There is a continued increase in emissions until 2040 and then a decline, with stabilization achieved by end of century.
RCP 6.0	There is a continued increase in emissions until 2080 and then a decline (this scenario is not shown in Figure 1 as the NCA4 did not include this scenario).
RCP 8.5	Significant increases in emissions continue through the end of century. This scenario aligns with our current trajectory.

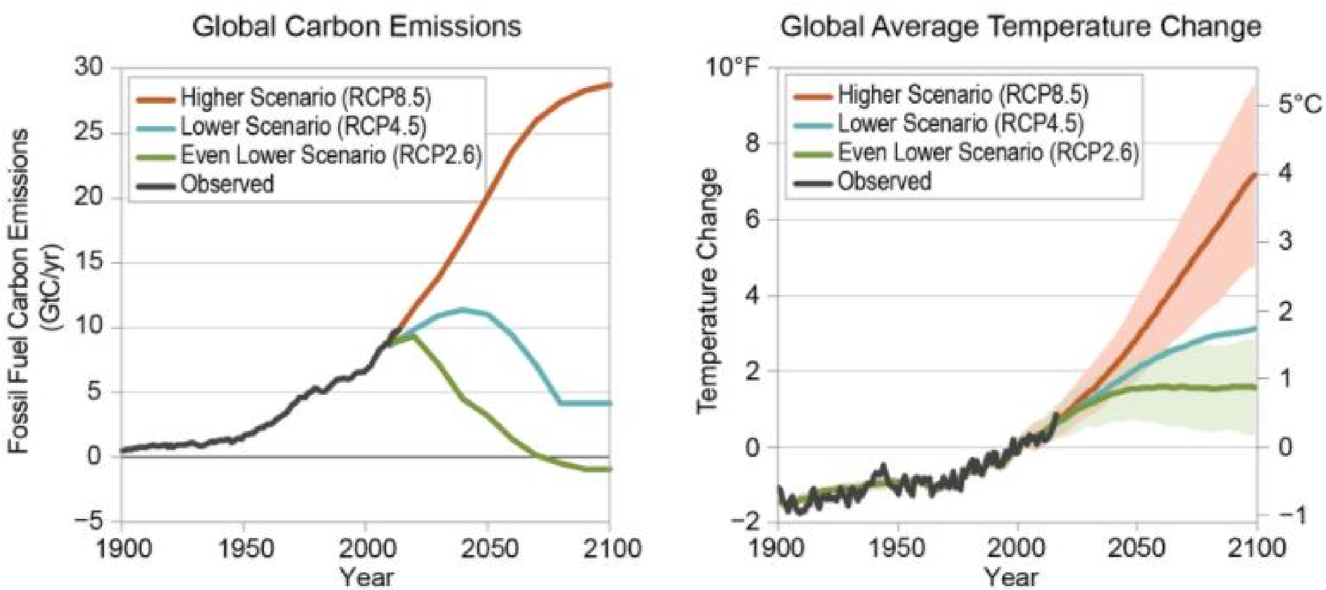


Figure 1. Observed and projected change in carbon emissions and temperature. (The thick lines represent the average of multiple climate models; the shaded regions represent the 5% to 95% confidence intervals for each projection; the global average temperature change is relative to 1986-2015; source: NCA4 2018[iv].)

The Fairfax County Climate Projections Report study adopted the higher emissions scenario (RCP8.5) and the lower emissions scenario (RCP4.5), which is generally consistent with climate assessments in the United States. Though some studies simply focus on the RCP8.5, this analysis included two emissions scenarios (RCP4.5 and RCP8.5) to quantify some of the uncertainty associated with how future society may evolve over the coming century (see "Uncertainty and Confidence" section below). There is more warming projected for RCP8.5 than RCP4.5. However, in some locations, future precipitation may be projected to be greater for the RCP4.5 than RCP8.5. This is because precipitation is based on complex atmospheric conditions and changes in other emissions such as particles that serve as cloud condensation nuclei. Hence, when possible, it is preferred to consider both scenarios.

3.3 Climate Model Data

Climate models simulate past and future climate using computer code. The computer code is based on mathematical representations of the important processes within the climate system. This includes the use of atmospheric principles for large-scale atmospheric phenomena (such as the upper-level winds) and parameterizations based on empirical data of small-scale phenomena (such as cloud development). Climate models are developed and run at institutions around the world, where each climate model may use a distinct selection of algorithms to simulate these large-scale to small-scale processes.

This Fairfax County Climate Projections study collected publicly available statistically downscaled climate model data developed by the Scripps Institute of Oceanography at the University of California, San Diego and supported by the United States federal government.[v] Global climate models are available in a range of geographic resolutions. “Statistical downscaling” applies relationships to transform these large-scale projections to the local level. The process is similar to turning a blurry, low-resolution image into a clearer, high-resolution image. Statistical downscaling develops statistical relationships by comparing fine spatial scale observed conditions to climate model simulations of the same time period. These statistical relationships are then applied to the entire time period of the climate model simulation to produce finer geographic resolution for analysis. Downscaling is particularly important where climate projections may be affected by localized conditions such as topography elements that are too fine to be captured by the global climate models.

The statistical downscaling methodology used in the Fairfax County study is known as the Localized Constructed Analogues (LOCA) technique. The LOCA data includes 32 climate models covering the 1950-2100 time period, where 1950-2005 is considered the historical period and projections are provided for 2006-2100, influenced by the emissions scenarios. The LOCA data provides daily maximum temperature, daily minimum temperature, and daily precipitation at a $1/16^{th}$ degree spatial resolution. Each grid cell has a spatial area of approximately 3.7-miles by 3.7miles).[vi] The LOCA technique was selected for this analysis because it is a well-vetted source for downscaled projections in the contiguous United States that was used to inform the NCA4 report amongst other United States federal government resources. Additionally, once calibrated with observations, LOCA is considered an acceptable choice for estimating future changes in extreme precipitation events.[vii]

All 32 climate models available as processed LOCA data were collected and used in the analysis.[viii] Using multiple climate models for developing future projections helps quantify some of the scientific uncertainty in modeling the climate system as well as natural variability (see “Uncertainty and Confidence” section below).

Climate projections used for this study also include results based on the Multivariate Adaptive Constructed Analogs (MACA)v2-METDATA, MACA-CMIP5 ensemble, among others. For a list of observed and projected climate data sources, please see Appendix B.

3.4 Geographic Scale

The LOCA data provides processed climate model data for about 40 grid cells (see Figure 2; each red box is representative of 4 grid cells). The climate projections were analyzed for both chronic and acute hazards. The results showed minimal differentiation within the county. This means that generally speaking, the projected *changes* in temperature and precipitation seen in one area of the county are also seen in other areas of the county. It should be noted that tidal flooding *is* specific to certain areas of the county, but that hazard uses a different data source and is not included in the LOCA data. It should also be noted that there are "urban heat islands" where certain areas of the county are hotter than others, but this has also been analyzed separately.

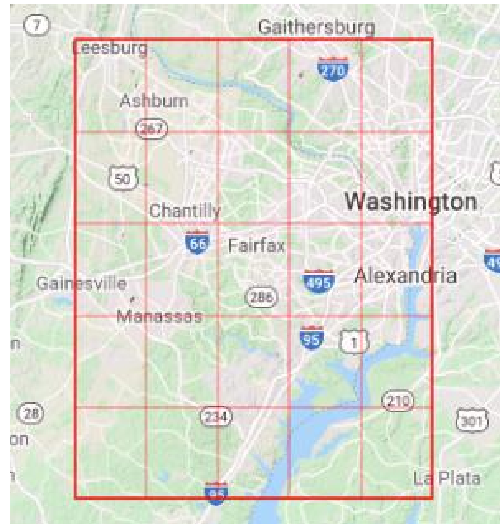


Figure 2. Grid cells of the LOCA data collected for this effort.

For general projected changes in temperature and precipitation, this relative consistency across the county is not unusual for such a small area. This consistency supported the use of averaged results across the grid cells for estimation of projected future changes. The Fairfax County geographic information system (GIS) county border shapefile was then overlaid with the gridded climate projection results to estimate an area-weighted average of results for all temperature and precipitation climate projections. This reduced the number of dimensions associated with the projection results (for example, with results varying by emissions scenario and time period). This also provided a benefit of increased robustness by presenting county-scale results in lieu of reliance on individual cells to represent potential change. (Using an individual grid cell is typically not an acceptable practice given the uncertainty at this scale).

For heavy precipitation data, this county-wide approach was supplemented with analyses developed for each of the three observation stations in the area and compared to the NOAA Atlas 14 results for each station's latitude and longitude.

3.5 Observation Data

Three observation stations were identified by the county and used in this analysis: Washington Reagan National Airport, Washington Dulles International Airport, and Vienna (see Table 3). For the observation data, climate indicators were developed for two horizons: baseline (1976-2005) and current climate (1991-2020) (see "Planning Horizons" Section for more detail). To reduce uncertainty associated with any particular observation station representing all of the county, and to provide a means for comparison against projections, climate indicator values were first developed for each of the three observation stations. These values were then averaged for a final "county" value.

Table 3. The observation stations used in this analysis.

Station Name	Identifier	Location (latitude, longitude)	Length of Record	Data Coverage
Washington Reagan National Airport	USW00013743	38.8472°, -77.03454°	1936-2021	90%
Washington Dulles International Airport	USW00093738	38.9349°, -77.4473°	1960-2021	97%
Vienna	USC00448737	38.8922°, -77.2892°	1925-2021	85%

3.6 Uncertainty and Confidence

The scientific consensus is that human activities are causing the changes in climate being experienced within the United States and around the world, and continued emissions of greenhouse gases anticipated over the coming century will accelerate the impacts of climate change. However, as with any analysis of future outlook, there is uncertainty in estimating the degree or severity of this future change.

There are three primary drivers to uncertainty[ix]:

- **Scientific Uncertainty**: Limitations to simulating the climate system with climate models, due to factors such as cloud development and some processes between atmosphere, ocean, land, and cryosphere systems. Climate scientists continually work towards reducing this uncertainty.
- **Scenario Uncertainty**: Unknowns in estimating how global society will evolve over the coming century, including changes in technology, policy, population, land-use, and fossil-fuel use.
- **Natural Variability**: Characterized by the unpredictable nature of some events within the climate system, such as a volcanic eruption and the El Niño/Southern Oscillation (ENSO).

The analysis provides some consideration of these uncertainties by providing results as both the ensemble mean (the average across the climate models for a given RCP) and a confidence range around the mean that is based on the span of results across the climate models. In addition, the scenario uncertainty is considered when comparing the results of the two emissions scenarios, RCP8.5 and RCP4.5. These uncertainties grow with future planning horizons, because there is more notable range across climate model and emissions scenario results for the end-of-century compared to mid-century. This suggests a degree of future change is not already "locked in" based on current emissions. Finally, the uncertainty associated with natural variability is considered by averaging the climate projection results over 30-year time periods.

There is greater uncertainty and less confidence in some chronic and acute events than others. In general, there is greater confidence in temperature projections than precipitation projections due to the complexities in modeling precipitation. There is also greater confidence in chronic projected changes than in acute extreme events. For example, there is more confidence in predicting monthly precipitation patterns than in predicting a specific 1-in-50-year precipitation event. Within acute events, there is more confidence in predicting events that already occur with some regularity, such as number of days per year above 90°F, than in predicting the less frequent very extreme event. There is also greater confidence in results projected in the near-term opposed to the end-of-century.

Even though uncertainty is intrinsically embedded within projections, the results are informative for long-term planning purposes and investment decisions to reduce future risk. In some cases, strategies may be deemed "no-regret" strategies when there are additional benefits associated with the strategies beyond reducing climate risk, so that implementing the strategies is defensible without even considering climate risk. For example, strengthening the resilience of critical facilities such as hospitals may be deemed a "no regret" strategy because it is beneficial regardless of the specific severity of climate projections.

3.7 Climate Indicators

There are numerous ways to assess the climate hazards identified as a concern to the county. "Climate indicators" provide a way to consistently measure, project, and represent the chronic and acute changes associated with the climate hazards (see Table 4). The indicators for this report were identified based on an initial review of sensitivities across sectors to ensure the indicators were representative and applicable to the vulnerability analysis, as well as a literature review of similarly vetted efforts undertaken in nearby communities. The "examples of impacts" in Table 4 serve as a small sample of potential impacts to Fairfax County for illustrative purposes. For a comprehensive analysis of impacts, please see the **Climate Vulnerability and Risk Assessment**, the report that follows this one.

Table 4. Climate hazards and indicators selected for the analysis along with examples of impacts to identify why these hazards/indicators were chosen. (Please see Vulnerability Assessment for a comprehensive discussion of impacts in response to these indicators/subsectors).

Climate Hazards	Climate Indicators	Examples of Impacts* **Please see Vulnerability and Risk Assessment for detailed analysis of impacts*
Warming Conditions	Annual and monthly average, minimum, and maximum temperatures	*Impacts to ecosystems and populations*
Changes in Precipitation Patterns	Annual and monthly precipitation	*Impacts to ecosystems, groundwater table*
Extreme Heat	Number of days above 95°F, 100°F, 105°F per year Number of consecutive days above 95°F per year	*Impacts to health and mortality; Increased water and energy demand; Impacts to operations of electric bus fleet, charging stations, and wastewater treatment plants; Damage (thermal stress) to bridges, pavement, rail, electrical lines, and hazardous storage containers*
Drought	Standardized Precipitation index	*Impacts to water supply for communities; Potential loss of fire protection; Impacts to operations of drinking water treatment plants and wastewater treatment plants; May affect fire potential*
Extreme Cold	Number of days below 32°F Freeze-thaw days	*Impacts to health and mortality; Increased energy demand; Damage to roads*
Heavy Precipitation Events	24-hr, 12-hr, 6-hr, 3-hr, 2-hr, 1-hr durations, IDF curve shifts, 1-percentile of daily precipitation 5 day maximum precipitation	*Flood damage to communities from under-designed stormwater infrastructure or excessive rainfall*

Climate Hazards	Climate Indicators	Examples of Impacts* *Please see Vulnerability and Risk Assessment for detailed analysis of impacts*
Inland Flooding	Data from past flood complaints, FEMA Flood Insurance Rate Maps (FIRMs) of the 1% annual chance flood (100-year) and 0.2% annual chance flood (500-year) *Proxy using heavy precipitation indicators (see Heavy Precipitation Events)*	*Damage to exposed infrastructure and critical facilities; Population health and safety risks*
Coastal Flooding	Sea Level Rise (SLR): 3 feet for 2050 (high/NOAA 2017) and 1 foot for 2050 (intermediate USACE 2013/low NOAA 2017) Storm events: 2050 - USACE NACCS Category 2 as proxy for FEMA 100-BFE + 3 feet[x]	*Damage to exposed infrastructure, buildings, and critical facilities*
Extreme Storms such as tropical storms, derechos	Qualitative review of literature and data focusing on changes in this area	*Damage to infrastructure from wind and storm damage; Population health and safety risks; Economic impacts*
Impact Indicators	Cooling degree days (CDD) Heating degree days (HDD)	*Impact energy availability and outages if power demand outpaces supply*

4. Climate and Weather Hazards

According to the Köppen-Geiger Climate Classification System, Fairfax County experiences a "humid subtropical climate," which means relatively high temperatures and evenly distributed precipitation throughout the year. For Virginians, this translates to a temperate climate.

Located in the mid-latitudes and in the eastern United States, Fairfax County experiences a range of storm events including snow and ice storms, severe thunderstorms strong enough to produce flash floods and tornadoes, and the occasional tropical storm. From 2010 to 2019, four events were responsible for substantial county-wide financial impacts: the North American Blizzard (2010) resulted in $2 million loss; Tropical Storm Lee (2011) cost the county $10 million in repairs to bridges and roads; Hurricane Sandy (2012) cost the county more than $1.5 million; and the July 2019 rainfall/flooding event led to costs of $14.8 million of which $2 million were damages to the Fairfax County Government.[xi]

Figure 3. (Left) Tropical Storm Lee flooded Reston Park and Ride facility in Fairfax County (Source: weather.gov, courtesy of NBC Washington); (Right) Tropical Storm Lee damaged Lorton Road in Fairfax County (Source: Virginia Department of Transportation).

The NOAA National Centers for Environmental Information (NCEI) Storm Events Database includes numerous extreme weather events that have occurred in Fairfax County, ranging from winter storms to extreme heat to tropical cyclones.[xii] The database generally includes large events that lead to mortality or economic loss such as through damage to infrastructure and/or crops. The database does not include smaller events that have little impact to the community. Table 5 summarizes the number of total impactful events to Fairfax County recorded from 1990 to 2021 and suggests an estimated chance of the event occurring in any given year based on 32 years of data.[xiii] Winter weather, frost/freeze, heat, flash flood, and hail are the most recorded notable events, all of which have a high chance of occurring in any given year. Since 1990, damaging tropical cyclones have been limited to tropical storms; no hurricane-level events were recorded.[xiv]

Table 5. Recorded Notable Storm Events in Fairfax County from 1990 to 2021 (Source: based on analysis of NOAA NCEI Storm Events Database; storm definitions provided by NOAA's National Weather Service Instruction 10-1605 (2018) for Storm Data Preparation).

Storm Category	Storm Event	Definition	Total Number of Occurrences (1990-2021)	Chance of Occurring in any Given Year
Winter Storms	Blizzard	A winter storm which produces the following conditions for 3 consecutive hours or longer: (1) sustained winds or frequent gusts 30 knots (35 mph) or greater, and (2) falling and/or blowing snow reducing visibility frequently to less than ¼ mile.	3	9%
	Heavy Snow	Snow accumulation meeting or exceeding locally/regionally defined 12 and/or 24-hour warning criteria.	6	19%
	Winter Weather	A winter weather event that has more than one significant hazard (i.e., heavy snow and blowing snow; snow and ice; snow, sleet and ice; or snow, sleet and ice) and meets or exceeds locally or regionally defined 12 and/or 24-hour warning criteria for at least one of the precipitation elements.	97	>100%
	Ice Storm	Ice accretion meeting or exceeding locally/regionally defined warning criteria (typical value is 1/4 or 1/2 inch or more).	4	13%

Storm Category	Storm Event	Definition	Total Number of Occurrences (1990-2021)	Chance of Occurring in any Given Year
	Frost/Freeze	A surface air temperature of 32°F or lower, or the formation of ice crystals on the ground or other surfaces, for a period long enough to cause human or economic impact, during the locally defined growing season.	30	94%
Extreme Cold	Cold/Wind Chill	Period of low temperatures or wind chill temperatures reaching or exceeding locally/regionally defined advisory (typical value of -18°F or colder).	7	22%
	Extreme Cold/Wind Chill	A period of extremely low temperatures or wind chill temperatures reaching or exceeding locally/regionally defined warning criteria (typical value of -35°F or colder).	5	16%
Extreme Heat	Heat	A period of heat resulting from the combination of high temperatures (above normal) and relative humidity. A heat event occurs and is reported in Storm Data whenever heat index values meet or exceed locally/regionally established advisory thresholds.	48	>100%
	Excessive Heat	Excessive Heat results from a combination of high temperatures (well above normal) and high humidity. An Excessive Heat event occurs and is reported in Storm Data whenever heat index values meet or exceed locally/regionally established excessive heat warning thresholds.	9	28%
Rain and Flooding	Heavy Rain	Unusually large amount of rain which does not cause a Flash Flood or Flood event, but causes damage (e.g., roof collapse or other human/economic impact).	21	66%
	Flash Flood	A life-threatening, rapid rise of water into a normally dry area beginning within minutes to multiple hours of the causative event (e.g., intense rainfall, dam failure, ice jam).	37	>100%
	Flood	Any high flow, overflow, or inundation by water which causes damage. In general, this would mean the inundation of a normally dry area caused by an increased water level in an established watercourse, or ponding of water, that poses a threat to life or property.	18	56%
Thunderstorms	Hail	Frozen precipitation in the form of balls or irregular lumps of ice. Hail 3/4 of an inch or larger in diameter. Hail accumulations of smaller size, which cause property and/or crop damage or casualties.	85	266%
	Lightning	A sudden electrical discharge from a thunderstorm, resulting in a fatality, injury, and/or damage.	14	44%
	Tornado	A violently rotating column of air, extending to or from a cumuliform cloud or underneath a cumuliform cloud,	6	19%

Storm Category	Storm Event	Definition	Total Number of Occurrences (1990-2021)	Chance of Occurring in any Given Year
	(May also be caused by other types of events)	to the ground, and often (but not always) visible as a condensation funnel.		
	Funnel Cloud	A rotating, visible extension of a cloud pendant from a convective cloud with circulation not reaching the ground.	6	19%
Wind	High Wind	Sustained non-convective winds of 35 knots (40 mph) or greater lasting for 1 hour or longer, or gusts of 50 knots (58 mph) or greater for any duration (or otherwise locally/regionally defined).	7	22%
	Strong Wind	Non-convective winds gusting less than 50 knots (58 mph), or sustained winds less than 35 knots (40 mph), resulting in a fatality, injury, or damage. Consistent with regional guidelines, mountain states may have higher criteria.	22	69%
Tropical Cyclones	Hurricane	A tropical cyclone in which the maximum 1-minute sustained surface wind is 64 knots (74 mph) or greater.	0	0%
	Tropical Depression	A tropical cyclone in which the 1-minute sustained wind speed is 33 knots (38 mph), or less.	0	0%
	Tropical Storm	A tropical cyclone in which the 1-minute sustained surface wind ranges from 34 to 63 knots (39 to 73 mph).	7	22%
Coastal Flooding	Coastal Flood	Flooding of coastal areas due to the vertical rise above normal water level caused by strong, persistent onshore wind, high astronomical tide, and/or low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries. Coastal areas are defined as those portions of coastal land zones (coastal county/parish) adjacent to the waters, bays, and estuaries of the ocean.	1	3%
	Storm Surge/Tide	For coastal and select lakeshore areas, the vertical rise above normal water level associated with a storm of tropical origin (e.g., hurricane, typhoon, tropical storm, or subtropical storm), caused by any combination of strong, persistent onshore wind, high astronomical tide and low atmospheric pressure, resulting in damage, erosion, flooding, fatalities, or injuries.	2	6%
Drought	Drought	Drought is a deficiency of moisture that results in adverse impacts on people, animals, or vegetation over a sizeable area.	10	31%

Storm Category	Storm Event	Definition	Total Number of Occurrences (1990-2021)	Chance of Occurring in any Given Year
Total			445	

5. Temperature

This section is organized into types of temperature analysis to enable clearer comparisons of trends. Each of these sections begins with historic and current conditions and is followed by discussion of projected future conditions.

5.1 Annual Trends

Historic & Current Conditions

Based on current climate conditions (1991-2020), the annual average temperature in Fairfax County is about 57°F. Since 1895, the annual average temperature in the county has increased approximately 2.2°F per century (Figure 4).

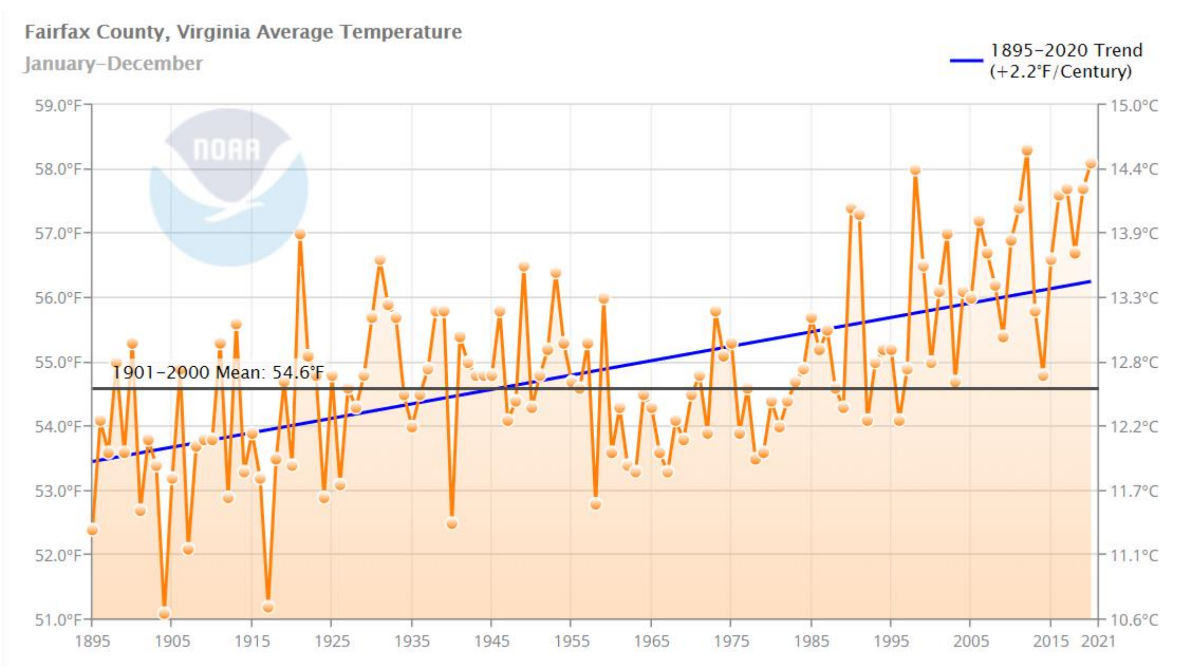


Figure 4: Average Annual Temperature for Fairfax County from 1895 to 2021 (Source: NOAA National Centers for Environmental information, Climate at a Glance: County Time Series, published April 2021, retrieved on May 5, 2021, from https://www.ncdc.noaa.

Projected Conditions

Annual average temperature is projected to become warmer over the coming century (see Figure 5). Between now (1991 -2020) and the end of the century (2085), the projected annual temperatures suggest an increase of close to 4.4°F for the lower scenario and nearly 9°F for the higher scenario. This projected temperature increase is an accelerated rise compared to the observed warming trend over the past century. These rising temperatures for 2050 and 2085 are statistically higher than the current year-to-year annual temperatures experienced today.

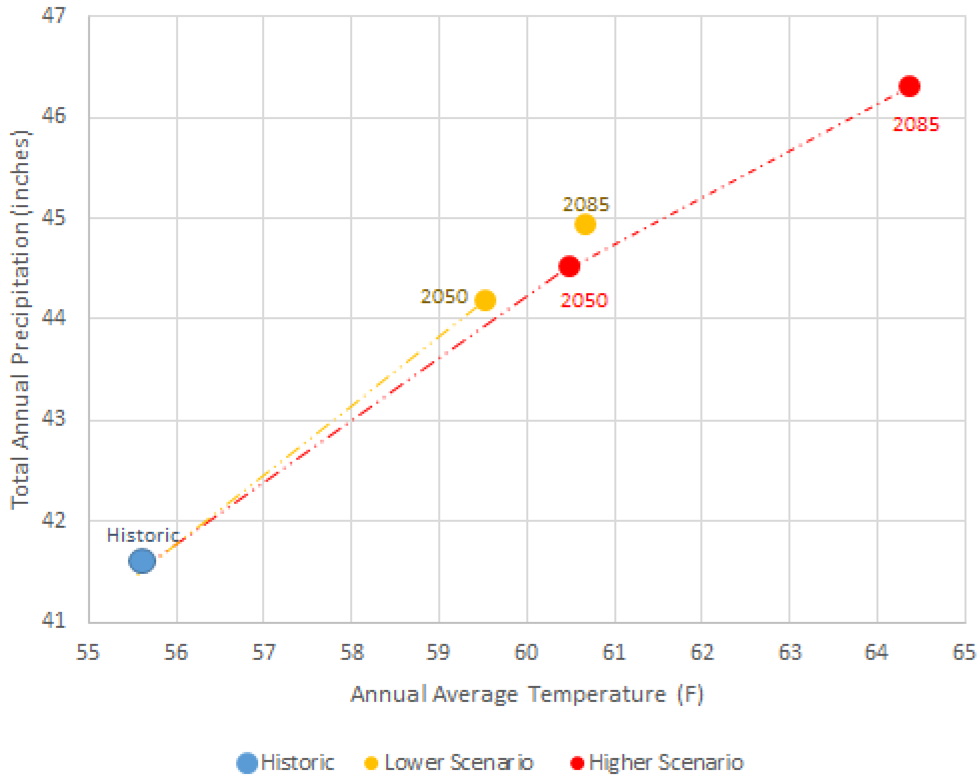


Figure 5: Projected Annual Average Temperature (and Precipitation) for Fairfax County, VA

5.2 Seasonal and Monthly Trends

Historic and Current Conditions

Fairfax County follows a general trend of warmer temperatures during the summer months and colder temperatures during the winter months. July is the hottest month with a current average maximum temperature of 87°F. January is the coldest month with a current average minimum temperature of 26.5°F (see Figure 6).

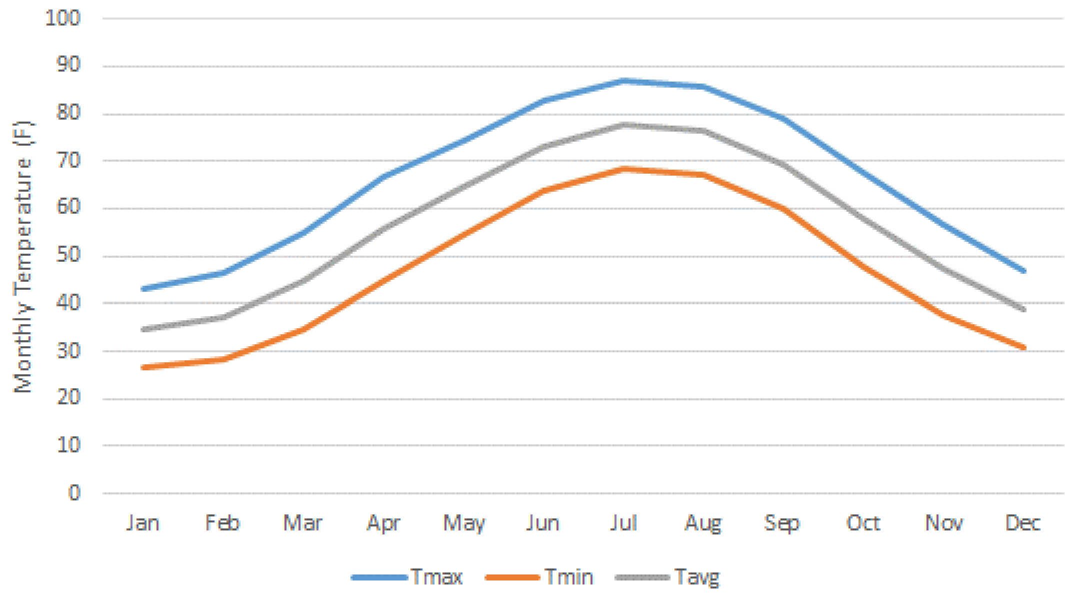


Figure 6. Current monthly temperatures for Fairfax County based on analysis of observations from 1991 to 2020

From 1895 to 2021, monthly temperatures have increased. The *range* between monthly maximum temperatures and monthly minimum temperatures has reduced in July and August, with monthly maximum temperatures increasing by 2°F (July) to 2.3°F (August) and monthly minimum temperatures increasing by 2.5°F (July) to 2.4°F (August) per century (see Table 6). Overall annual minimum temperature has increased at a slightly faster rate than maximum temperature. This trend is potentially concerning because it suggests less cooling occurring at night.[xv]

Table 6. Observed trends in annual and monthly maximum and minimum temperature for Fairfax County (source: 1895-2021).

	Changes in maximum temperatures (°F/century)	Changes in minimum temperatures (°F/century)
Annual	+ 2.1	+ 2.4
Jan	+ 1.4	+ 1.0
Feb	+ 4.5	+ 4.1
Mar	+ 2.1	+ 1.3
Apr	+ 2.8	+ 2.9
May	+ 0.1	+ 1.9
Jun	+ 2.0	+ 2.0
Jul	+ 2.0	+ 2.5
Aug	+ 2.3	+ 2.4
Sep	+ 0.6	+ 1.9
Oct	+ 0.8	+ 2.2
Nov	+ 2.7	+ 2.8
Dec	+ 4.3	+ 3.8

Projected Conditions

Average seasonal temperatures are projected to continue to increase in Fairfax County, with future values higher than what is experienced today (see Figures 7 and 8). Further, warmer, traditionally "summer" temperatures are projected to expand into the late spring and early fall months.

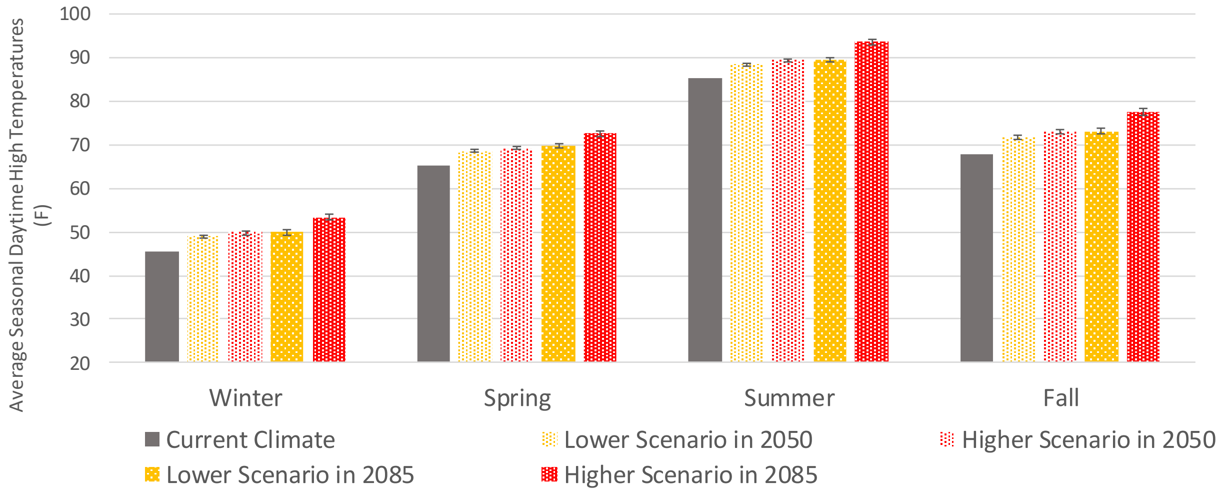


Figure 7. Current and projected seasonal daily high temperatures.

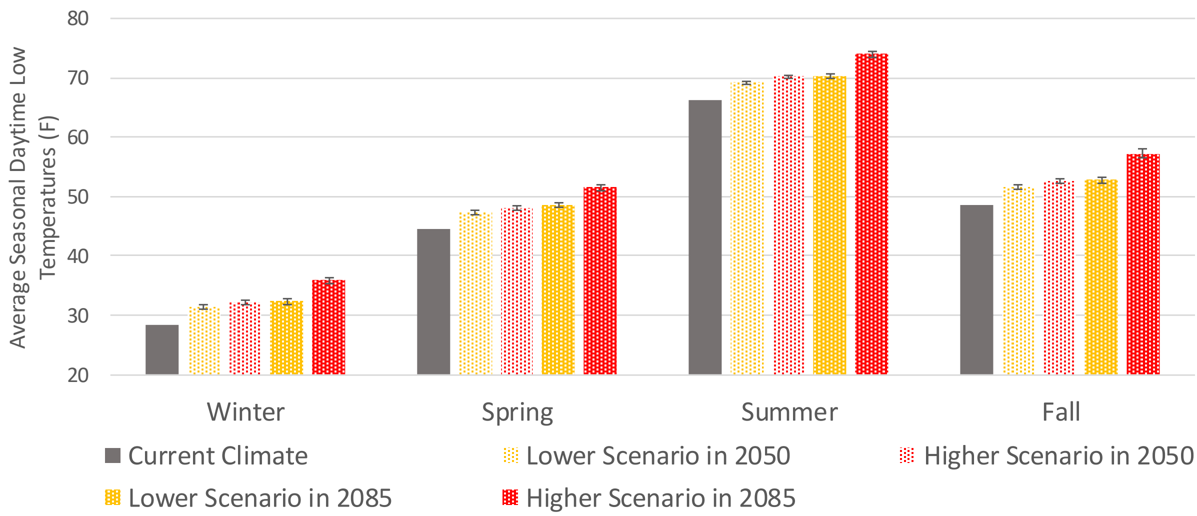


Figure 8. Current and projected seasonal daily low temperatures.

5.3 Extreme Heat & Humidity

As defined by the Federal Emergency Management Agency (FEMA) and the Centers for Disease Control (CDC), "extreme heat is a period of high heat and humidity with temperatures above 90°F for at least two to three days." In applying this definition to specific locales within the United States, the impact of this threshold can vary and depends on what the population is accustomed to and has built infrastructure to sustain. Therefore, this study considered six extreme heat indicators, including the following: the number of days above four temperature thresholds of 90°F, 95°F, 100°F, and 105°F, the consecutive number of hot days above 95°F that could be experienced in a row, and the top 1-percentile of maximum temperature days. Five of these indicators are discussed in this section. All six indicators are presented in Appendix A.

Heat Events

Historic and Current Conditions

Fairfax County already experiences some extreme heat during the summer months. On average, Fairfax County currently experiences almost one month of days (28.7 days) at or above 90°F each year (see Table 7). Hotter temperatures are notable with a few days on record at or above 105°F.

Table 7. Number of days at or above 90℉, 95℉, 100℉, 105℉ for 1991-2020, averaged for the three observation stations.

Extreme heat threshold	Number of days per year
90°F	28.7
95°F	7.4
100°F	0.6
105°F	<0.1

Projected Conditions

Extreme heat events are projected to increase significantly upon the backdrop of rising seasonal temperatures. The number of hot days at or above 90°F, 95°F, 100°F, and 105°F per year is projected to significantly increase from what was experienced from 1991-2020. By 2050, the number of days above 90°F is projected to increase by an additional 32 days (lower scenario) to 41 days (higher scenario).[xvi] This means that Fairfax County will experience an *additional* month to a month and a half total of these high temperatures each year. By 2085, the higher scenario suggests that most days of the summer will reach temperatures of or above 90°F. Days above 95°F and 100°F per year are also projected to significantly increase (see Figures 9 and 10). By 2050, Fairfax County is projected to experience one (lower scenario) to two days (higher scenario) above 105°F. By 2085, however, this increases to two (lower scenario) days to 12 days (higher scenario). This demonstrates the large difference in warming that is projected to occur under the lower scenario compared to the higher scenario.

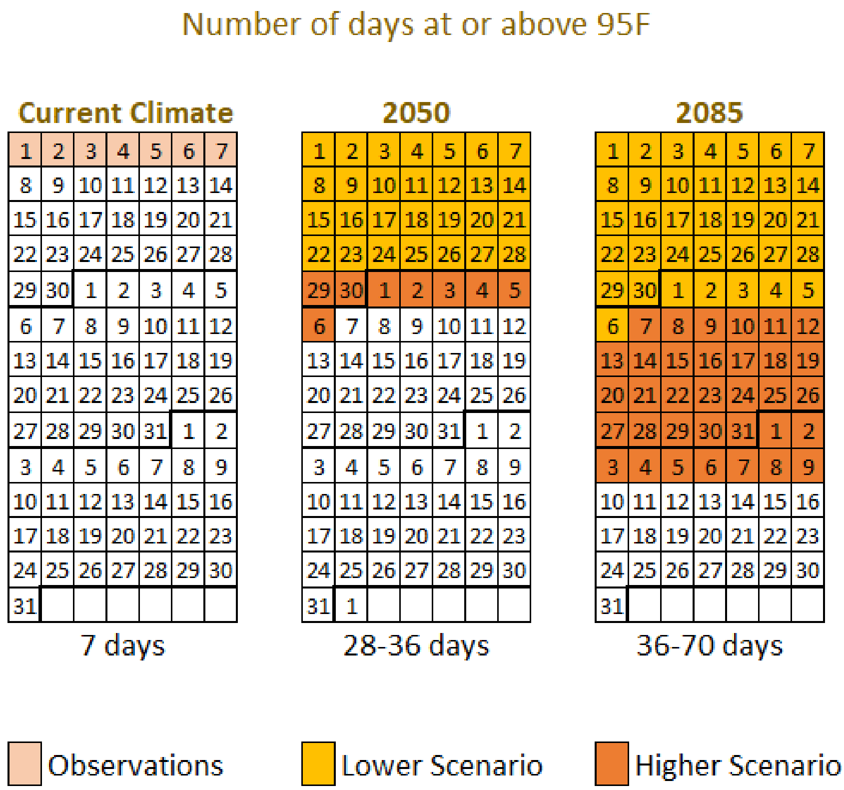


Figure 9. Number of days at or above 95℉ under current climate conditions (averaged over 30-year period), 2050 and 2085. Future conditions projected under the lower scenario (RCP4.5) and higher scenario (RCP8.5).

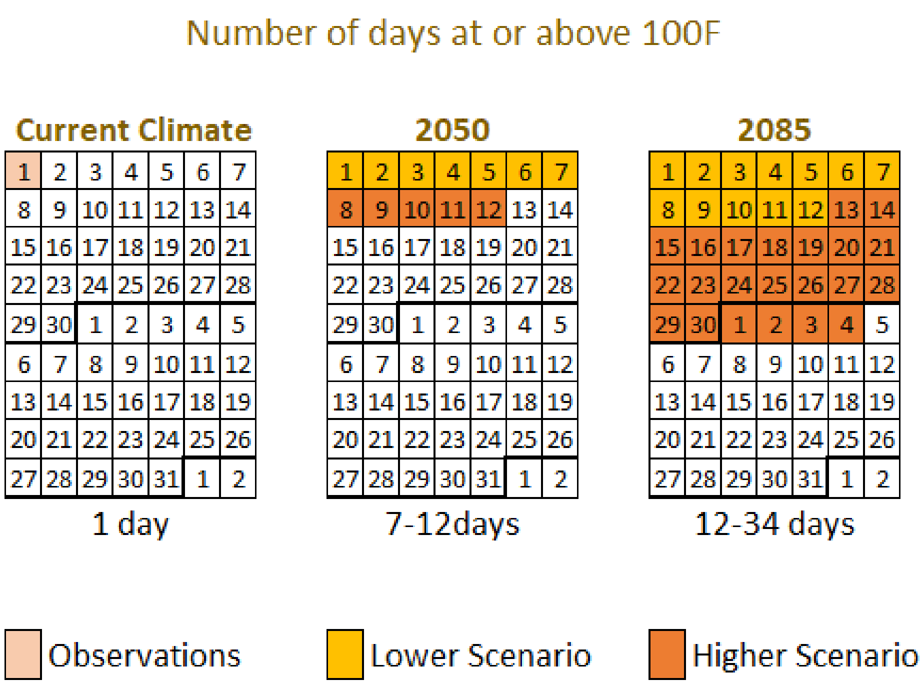


Figure 10. Number of days at or above 100℉ under current climate conditions (averaged over 30-year period), 2050 and 2085. Future conditions projected under the lower scenario (RCP4.5) and higher scenario (RCP8.5).

Consecutive Hot Days

In addition to general increases in temperatures and extreme heat event days, it is important to examine *consecutive* days of extreme heat, because such consecutive days without relief can lead to increased vulnerability.

Historic and Current Conditions

The maximum number of *consecutive* days at or above 95°F is currently 2.6 consecutive days per year.

Projected Conditions

The maximum number of *consecutive* hot days at or above 95°F is projected to increase. The lower emissions scenario projects a maximum number of seven (7) consecutive days by 2050 and nine (9) consecutive days by 2085, while the higher scenario projects nine (9) consecutive days by 2050 and twenty-two (22) consecutive days by 2085.

Humidity

Humidity is also an important consideration because it can exacerbate high temperature effects.

Historic and Current Conditions

The National Weather Service has developed a heat index that considers both daytime temperature highs and humidity to calculate "feels like" temperatures (see Figure 11). The index assumes a person is situated in somewhat favorable shady conditions with light wind.

NWS Heat Index — Temperature (°F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution | Extreme Caution | Danger | Extreme Danger

Figure 11. Heat index developed by the National Weather Center.

A person exposed to the sun is associated with a heat index that may increase by up to 15°F.[xvii] Any temperatures at or above 105°F, regardless of humidity, are considered extremely dangerous for prolonged exposure or strenuous activity, while high temperatures around 90°F become dangerous when relative humidity reaches about 70%. (Extreme caution is suggested for relative humidity at or above 40%).

Based on the gridded surface meteorological dataset METDATA (which draws on the NASA North American Land Data Assimilation System (NL-DAS2)), most of Fairfax County experiences maximum relative humidity of 80% to 90%, with the remainder of the county experiencing maximum relative humidity between 70% to 80% (see Figure 12).[xviii] This high relative humidity suggests that for current conditions, when coupled with daily highs of 88-90°F or above, the heat index is considered dangerous for prolonged outdoor exposure or strenuous activity.

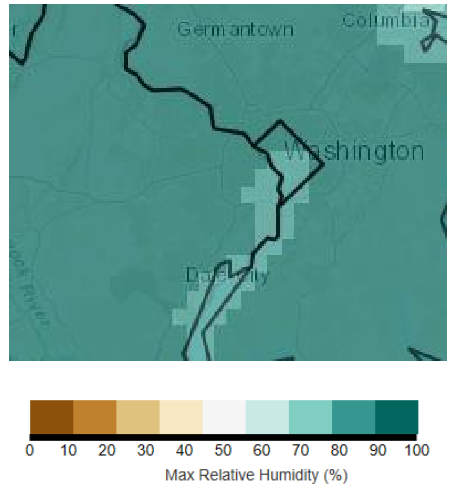


Figure 12. Summer (June-July-August) maximum relative humidity for historic conditions from 1971-2005 (Source: MACAv2-METDATA).

Projected Conditions

Summertime maximum relative humidity is projected to remain constant or slightly decrease in mid-century compared to historic conditions (see Figure 12). By 2050, more of the eastern portion of the county is projected to experience 70% to 80% relative humidity under both emissions scenarios. For the purposes of this analysis and in the absence of more humidity data, a maximum relative humidity around 80% is conservatively assumed, where daily summertime highs of at/above 90°F will be in the danger zone and temperatures at/above 95°F will be in the extreme danger zone for sensitive individuals, those sustaining long exposure to outdoor conditions, or those undertaking strenuous activities.

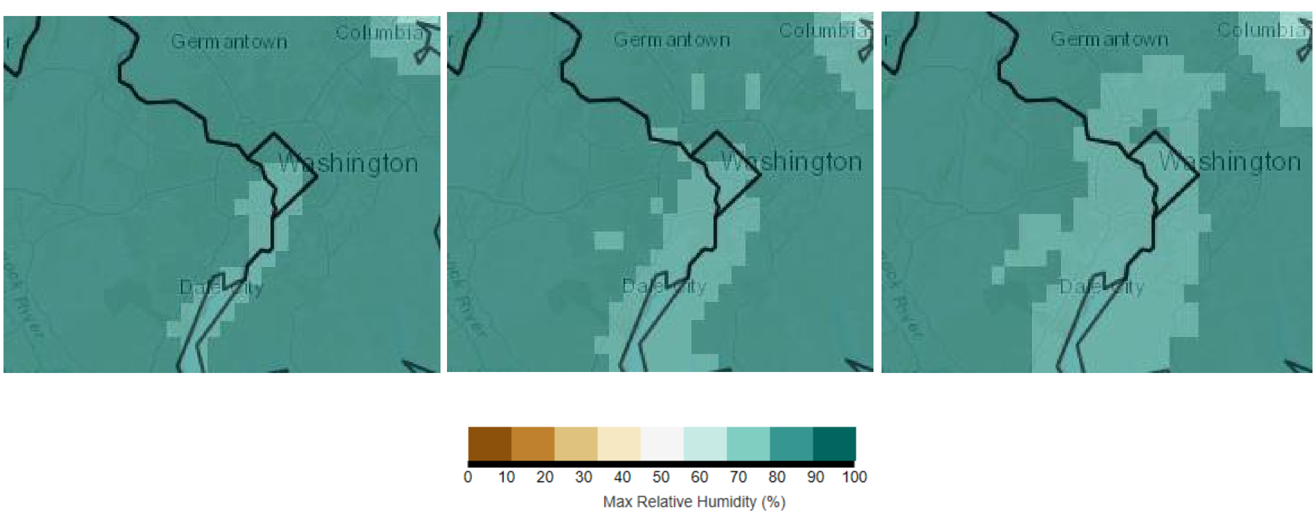


Figure 13. Summer (June-July-August) maximum relative humidity for historic conditions from 1971-2005 (left figure), RCP4.5 in 2040-2069 (center figure), RCP8.5 in 2040-2069 (right figure) (Source: MACAv2-METDATA, MACA-CMIP5 Ensemble of 20 climate models[xix]; time periods shown are hard-coded into the MACA results).

Urban Heat Island Effect

In addition to countywide temperature increases and extreme heat events, there is a phenomenon called the "urban heat island effect" that creates temperature "hot spots" in certain parts of the county. Urban areas with dense buildings and dark-colored surfaces such as asphalt absorb and radiate more heat. Areas of the county with ample green space, trees providing evapotranspiration, and lighter-colored surfaces remain significantly cooler.

Historic and Current Conditions

As part of the 2021 Summer National Aeronautics and Space Administration (NASA) DEVELOP project, "Identifying Urban Heat Mitigation Strategies for Climate Adaptation Planning in Fairfax County, Virginia," NASA DEVELOP provided data and maps to show which areas in Fairfax County experience hotter temperatures than other areas in the county. The following information is extracted from and available in NASA DEVELOP's full technical paper.[xx]

"The DEVELOP team used data from Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS), as well as the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) for the years 2013 to 2021. The team found that the hottest spots in the county were in densely urbanized areas, with temperatures as much as 47°F above that of undeveloped forested reference areas. The team used the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) urban cooling model and determined that areas with higher tree canopy cover had greater heat mitigation capacity. Estimates from the InVEST model showed that a 4.5% increase in canopy cover across the county could result in a temperature reduction of up to 2.4°F in some areas."

The NASA DEVELOP team provided a range of urban heat island effect maps, including maps showing daily and nightly average summer surface temperatures, heat anomaly data compared to reference areas, areas above 100°F, albedo, evapotranspiration, heat mitigation capacity, and distance to cooling centers, among others. These data are available in NASA DEVELOP's full technical paper and are also included where applicable in the climate vulnerability and risk assessment.

Figure 14 shows the daily average summer surface temperatures across Fairfax County from 2013-2021. Hotter areas are shown in red and cooler areas are shown in blue. As can be seen in the figure, the urbanized areas of the county experience significantly hotter daytime temperatures compared to less urbanized areas. Urban heat islands in the county include areas such as Tysons, Annandale, Chantilly, Centreville, Springfield, and Herndon, among others.

Daytime Summer Average Surface Temperatures 2013-2021

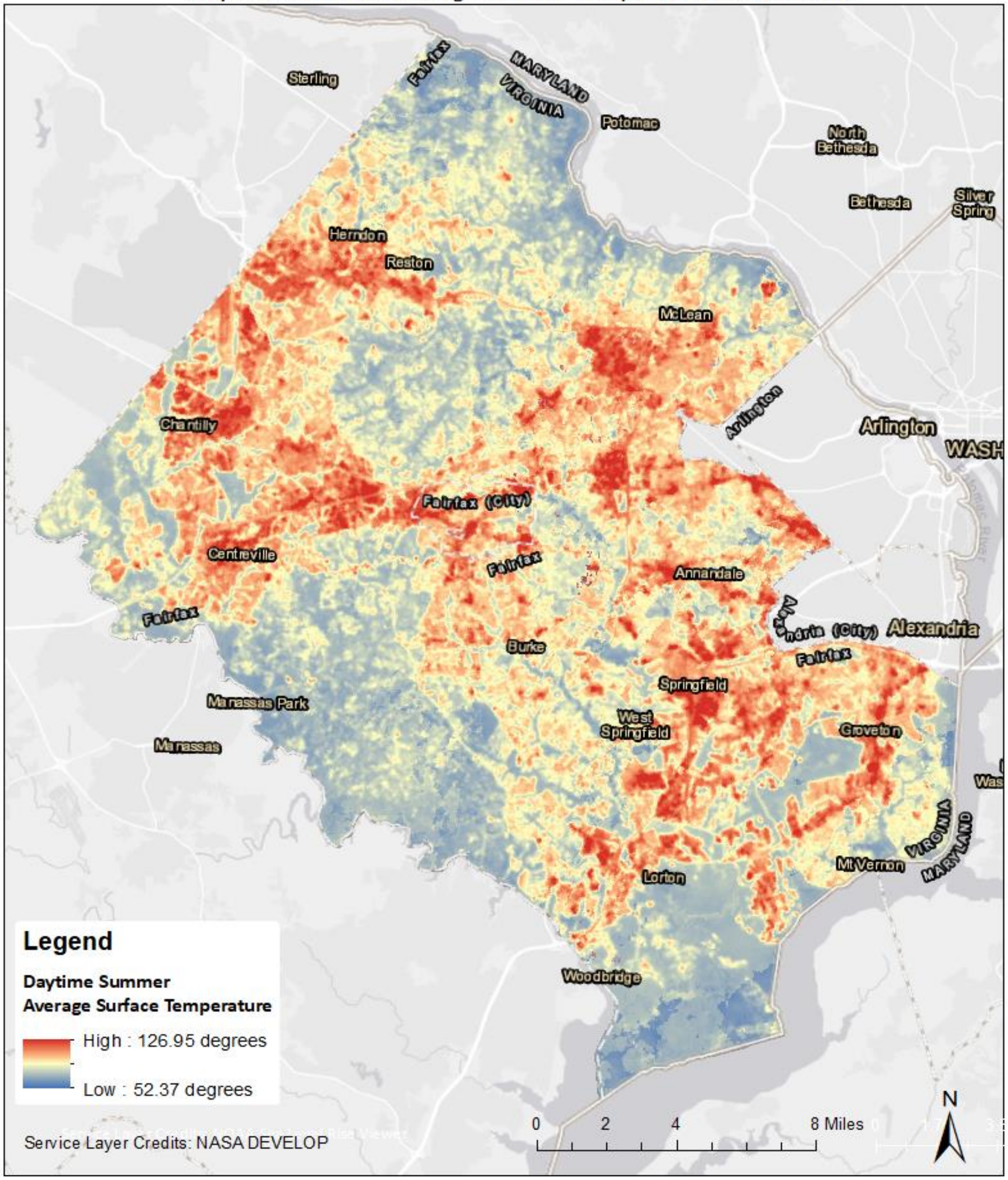


Figure 14: Daytime Summer Average Surface Temperatures 2013-2021

Projected Conditions

The urban heat island effect is projected to continue to cause additional warming on top of the projected warming discussed in the previous sections, exacerbating those underlying heat risks.[xxi] The urban heat island effect is also projected to get stronger with climate change.[xxii] This suggests those areas currently experiencing hotter temperatures are at particular risk over the coming century.

5.4 Extreme Cold

Historic and Current Conditions

From 1991-2020, the county experienced approximately 86 days below freezing and close to 69 freeze-thaw days annually.

Projected Conditions

The number of days below freezing on average per year is projected to decrease under future conditions. This is consistent with the trend of a warming winter (see Figure 15). The number of freeze-thaw days per year is also projected to decrease (see Figure 16).

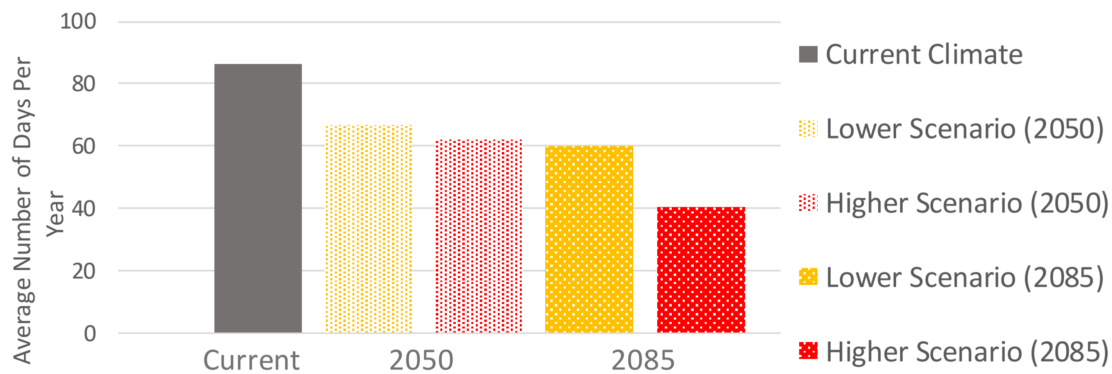


Figure 15. The current and projected number of freeze-thaw days per year.

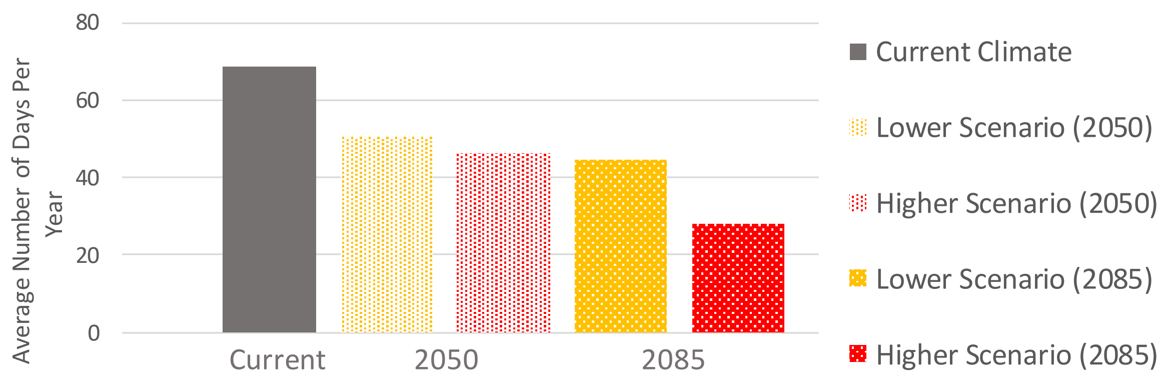


Figure 16. The current and projected number of days below freezing per year.

5.5 Heating and Cooling Degree Days

Historic and Current Conditions

Heating Degree Days (HDD) and Cooling Degree Days (CDD) provide a means to quantify how much energy may be needed to heat and cool a building to maintain comfort during low and high outdoor temperatures. Despite the name, the metric does not refer to number of days. Instead, it is a calculation of the difference between the outdoor temperature and a baseline temperature 65°F. For example, if there is a day with an average temperature of 80°F, cooling would likely be needed. A calculation of 80°F - 65°F would equal a CDD of 15. If there is a cold day with an average temperature of 30°F, heating would likely be needed. A calculation of 65°F - 30°F would equal an HDD of 35. The HDD and CDD is calculated for each day, based on the average temperature of that day. From 1991 to 2020, the county experienced on average 1,308 CDDs and 4,474 HDDs annually.

Projected Conditions

The projected hot summers translate to increased energy demand for air conditioning or "cooling." The number of cooling degree days is projected to rise quite substantially by 2050 in either emissions scenario. Compared to current rates, demand is projected to be 1,798 cooling degree days for the lower scenario and 1,976 cooling degree days for the higher scenario. By 2085, cooling degree days could increase to 1,991 in the lower scenario and to 2,733 in the higher scenario (see Table 8). Heating degree days are projected to decrease as winters warm and demand for heating declines.

Table 8. Historic (1991-2020) and projected change in cooling degree days and heating degree days for Fairfax County.

	Current Climate	2050	2050	2085	2085
		Lower Scenario	Higher Scenario	Lower Scenario	Higher Scenario
Cooling degree days	1308	1798	1976	1991	2733
Heating degree days	4474	3824	3656	3599	2983

6. Precipitation

6.1 Annual Trends

Historic and Current Conditions

The total annual precipitation quantity in Fairfax County is currently approximately 42 inches (based on data from 1991 to 2020). Between 1895 to 2020, annual total precipitation observed for Fairfax County increased by 0.29 inches per decade, translating to a total increase of 2.89 inches in annual precipitation over the past 100 years (see Figure 17). In terms of number of days with precipitation, Fairfax County currently experiences approximately 101 days of precipitation a year (based on 1991-2020). This is a reduction from 108 days over 1976-2005. When there is an increase in total annual precipitation amount but a decrease in number of days with precipitation, this can signify that precipitation events are becoming more intense, with higher volumes of precipitation provided despite fewer days of precipitation. As can be seen in Figure 17, annual precipitation patterns can be erratic, with high variability.

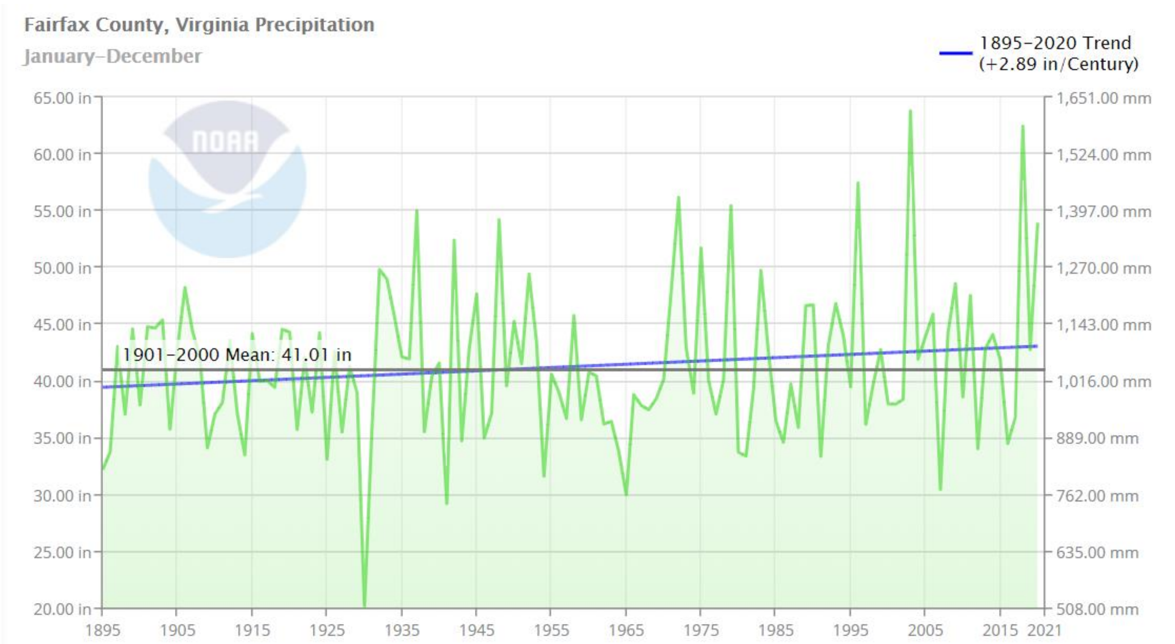


Figure 17. Average Total Annual Precipitation for Fairfax County from 1895 to 2021
(Source: NOAA National Centers for Environmental information, Climate at a Glance: County Time Series, published April 2021, retrieved on May 5, 2021, from https://www.ncdc.noaa.gov/cag/).

Projected Conditions

Fairfax County is projected to become wetter over the coming century. By 2085, compared to 1991 to 2020 "current conditions," total annual precipitation is projected to increase by close to three inches in the lower scenario and by more than four inches in the higher scenario. This projected acceleration is also a faster rate than the observed trend. However, total annual precipitation can vary by quite a bit year-to-year; the trend is increasing, but the projected total annual precipitation averaged across climate models is still within the variability of what is experienced today.

In terms of precipitation changes, the more notable change is the *severity* of precipitation events, which is projected to continue to increase (see "Heavy Precipitation & Inland Flooding section" below). The higher scenario suggests a small reduction in total precipitations *days,* of two days by 2050 and four days by 2085. Given that annual and seasonal precipitation *amounts* are projected to rise, this suggests that Fairfax County will experience fewer rainy days, but higher accumulations when it does rain. This translates to fewer gentle precipitation events that are spread out over multiple days and more heavier precipitation events.

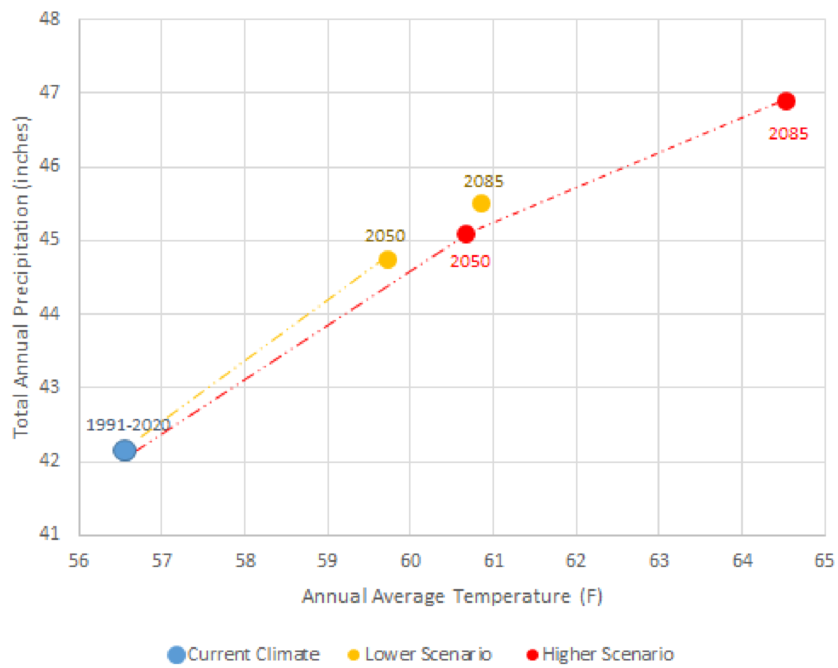


Figure 18: Projected Total Annual Precipitation (and Temperature) for Fairfax County, VA
Note: Figure 18 is the same as Figure 5. It is included in both sections because it includes both precipitation and temperature projections.

6.2 Seasonal and Monthly Trends

Historic and Current Conditions

Currently, average monthly precipitation in Fairfax County is about 3.5 inches. Precipitation tends to be slightly higher from late spring through summer than the rest of the year (see Figure 19).

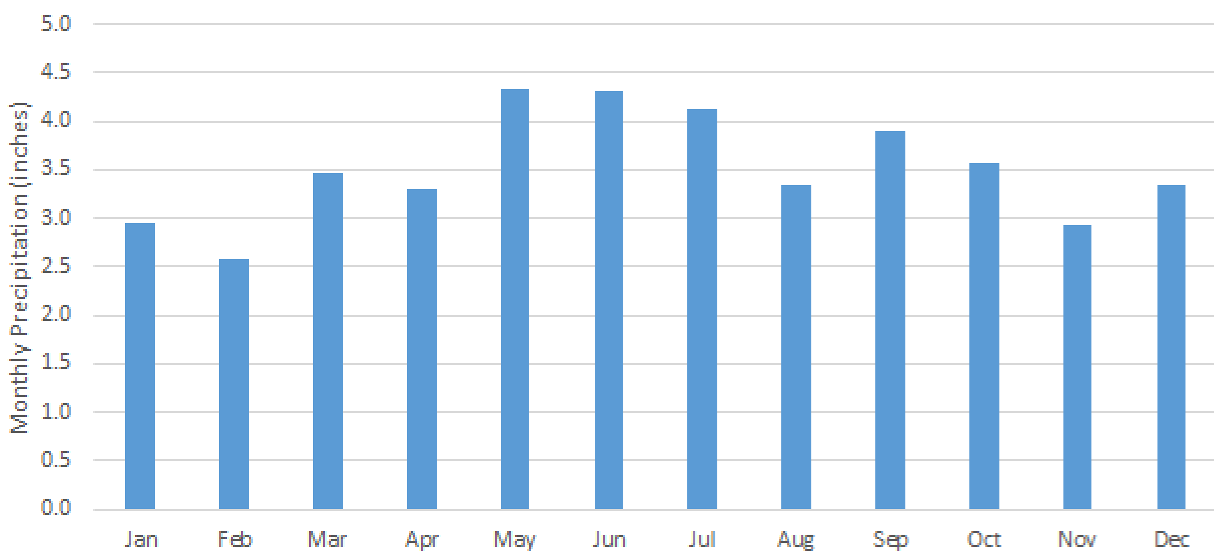


Figure 19: Monthly precipitation for Fairfax County (Source: based on analysis of observations from 1991 to 2020).

Between 1895 and 2021, monthly precipitation (averaged per century) has increased for all months except for January, February, June, and August (see Table 9). Eight months have experienced increases, ranging from small trace amounts (March, April) to nearly one inch per month (September, October).

Table 9. Observed trends in annual and monthly precipitation for Fairfax County (source: 1895-2021).

	Precipitation Change (inches)
Annual	2.89
Jan	-0.31
Feb	-0.26
Mar	+0.01
Apr	+0.02
May	+0.75
Jun	-0.13
Jul	+0.32
Aug	-0.73
Sep	+0.94
Oct	+0.96
Nov	+0.79
Dec	+0.52

Projected Conditions

Precipitation is projected to increase across all seasons and future scenarios (see Figure 20). A greater amount of rainfall is noted during spring and summer. All scenarios suggest that precipitation will shift from snow events to rain events. More information on heavy or severe precipitation can be found in the section below.

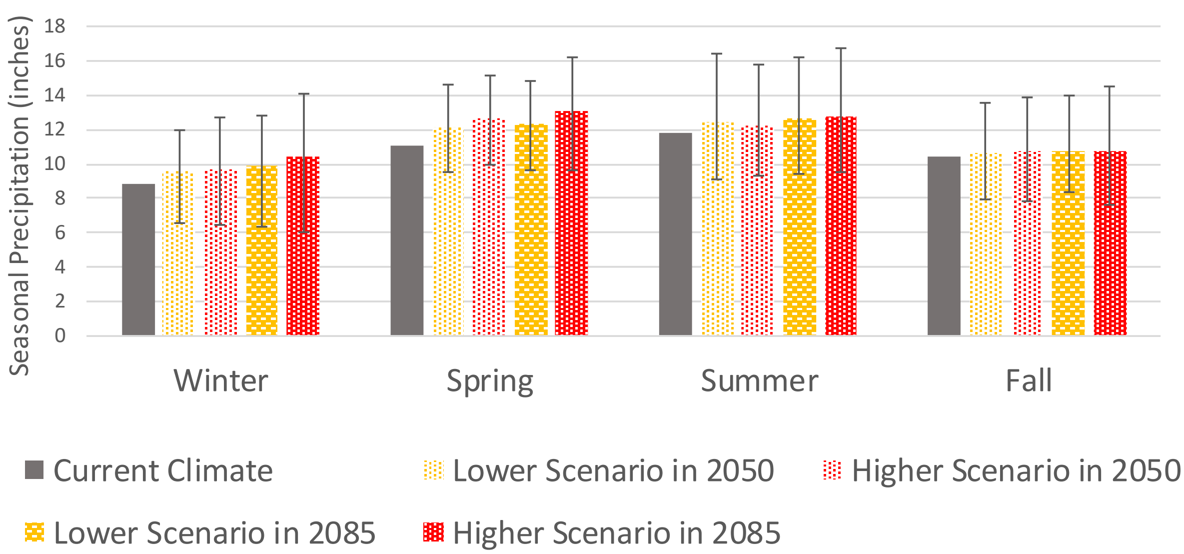


Figure 20. Projected seasonal precipitation for Fairfax County.

6.3 Heavy Precipitation & Inland Flooding

Historic and Current Conditions

Over the last 50 years, the Southeast has experienced an 18% increase in the heaviest 1% of precipitation events (see Figure 21).[xxiii] This is consistent with the understanding that warmer air can contain more water vapor than cooler air, allowing for heavier precipitation events associated with fronts as they travel across the country, heavier and more powerful tropical cyclones, and potentially stronger convective activity for more powerful thunderstorms. However, it should be noted that weather systems are inherently complex and other atmospheric characteristics may come into play that counteract the effects of increased water vapor (such as reduction in cloud condensation nuclei, changes in upper-level wind shear, increase in temperature inversions).

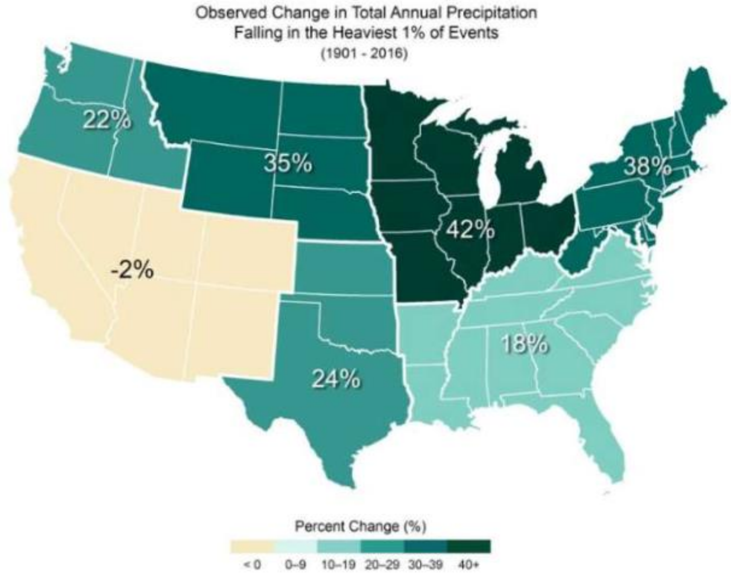


Figure 21. Heaviest precipitation days (i.e., the top 1% of daily events) has been increasing across most of the country from 1901 to 2016. (Source: USGCRP Indicators 2018).

Based on the Fairfax County Public Facility Manual, 8.41 inches is considered representative for a 100-year, 24-hour storm design based on NOAA Atlas 14. This analysis used the same source, NOAA Atlas 14, for identifying historic precipitation depths for each of the three observation stations, based on the station's latitude and longitude. The values provided at the stations are specific to those locations and not generalized for the county; see Table 10.[xxiv] Historic precipitation depths for additional durations are provided in Appendix A.

Table 10. Precipitation depths for 24-hour storms for different return periods, based on NOAA Atlas 14 for the 3 observation stations.

Return Period	Washington Reagan National Airport	Washington Dulles International Airport	Vienna
2-year	2.86	2.79	2.91
5-year	3.90	3.80	3.97
10-year	4.72	4.60	4.81
25-year	5.94	5.79	6.05
50-year	6.99	6.82	7.13
100-year	8.19	7.98	8.35
200-year	9.54	9.30	9.74
500-year	11.6	11.3	11.9

Fairfax County is situated in the Potomac River watershed, which includes numerous rivers and streams flowing through the county. These water bodies have the potential to overflow their banks during heavy or prolonged rainfall events. Flooding may also occur far from rivers and floodplains, for example in low-lying areas or developed areas when existing stormwater management infrastructure systems are overwhelmed during heavy precipitation events.

The Federal Emergency Management Agency (FEMA) has identified flood hazard areas in Fairfax County in their Flood Insurance Rate Map (FIRMs). These areas, identified as special flood hazard areas (SFHA), have at least a 1% chance of being flooded in any given year (also known as the "100-year" floodplain). Fairfax County has 2 SFHAs, Zone A and Zone AE, which are considered high risk areas (Figure 22). FEMA has base flood elevations for Zone AE areas, but not for Zone A. The FEMA flood zones are used to identify areas exposed to flooding today.

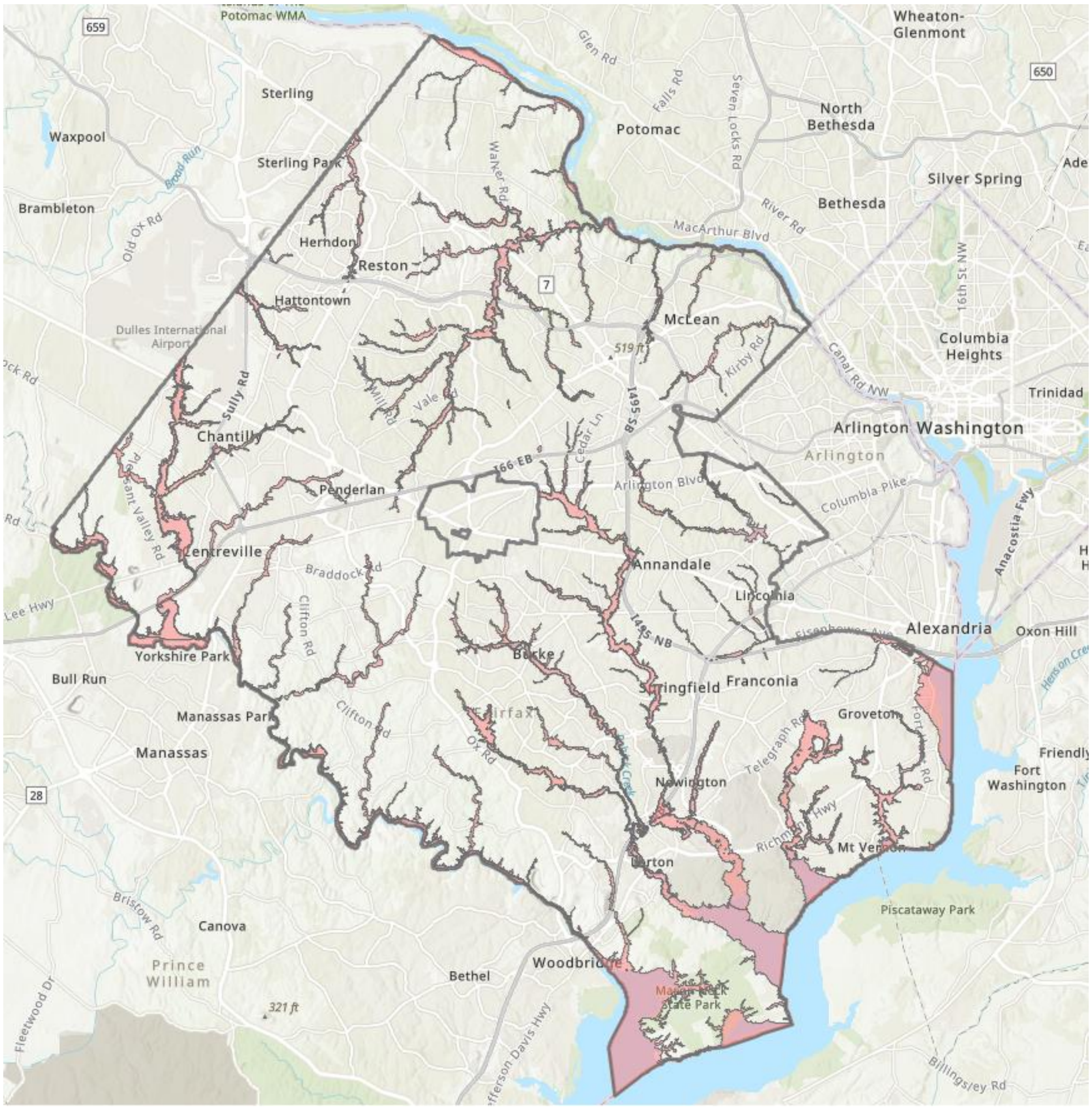


Figure 22: FEMA's Preliminary Flood Hazard Zones for Fairfax County, 2021, including zones A, A99, AE, AH, and X.

In addition to floodplains designated by FEMA's National Flood Insurance Program, Fairfax County also requires their own mapping of floodplains as part of the site development process and restricts activities in these areas (see Figure 23).[xxv] These floodplains are referred to as "county recorded floodplains." The county defines major floodplains along waterways with drainage areas greater than 360 acres and minor floodplains greater than 70 acres of drainage. The floodplains' limits are based on the 100-year 24-hour design storm.

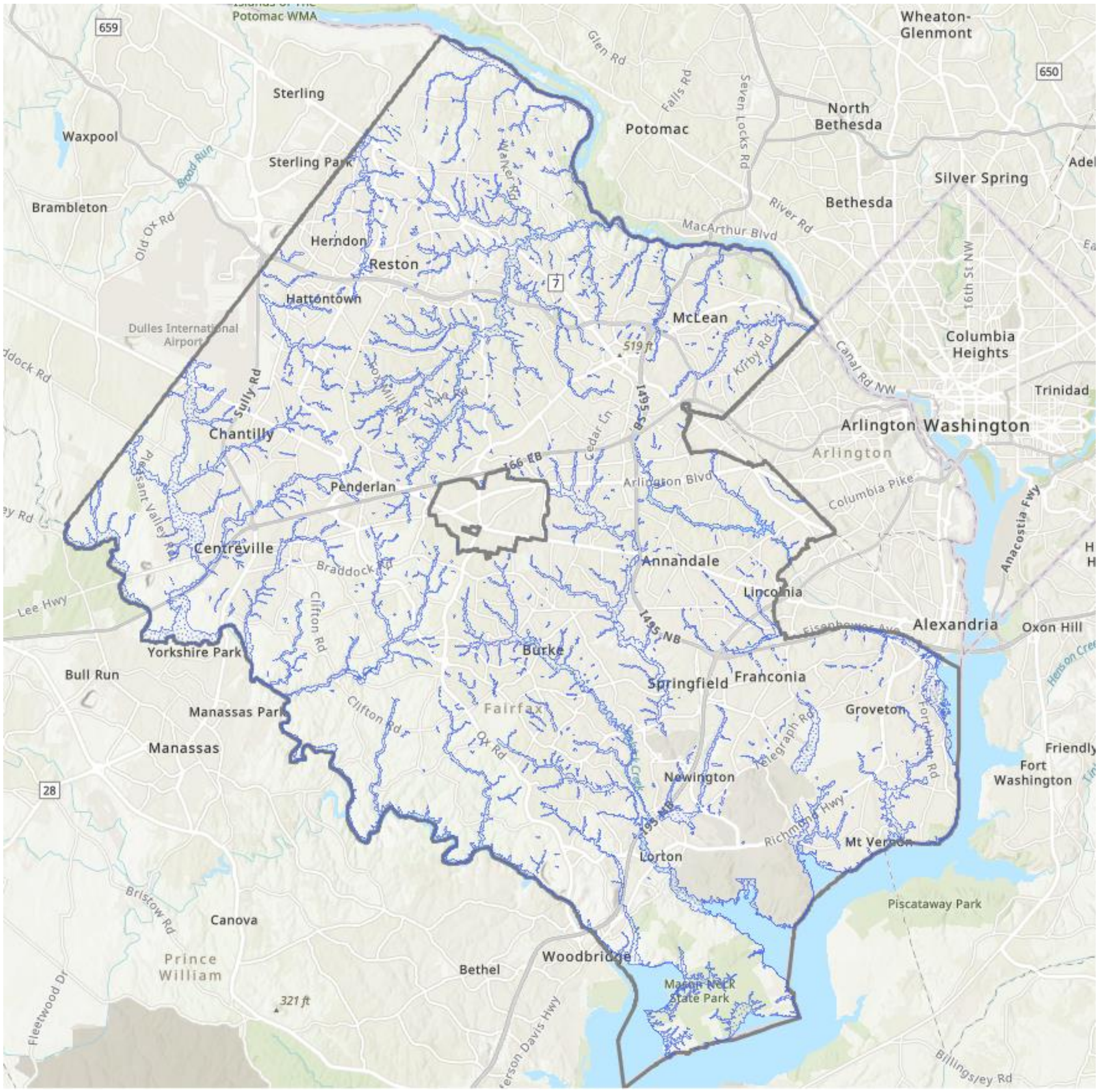


Figure 23: Fairfax County's Recorded Floodplains. (See https://www.fairfaxcounty.gov/publicworks/stormwater/flood-information)

Projected Conditions

Over the coming century, precipitation events are projected to become more intense. In the lower scenario, the top 1-percentile of daily precipitation experienced today at 2.9 inches are projected to increase to 3.0 inches by 2050 and to 3.1 inches by 2085. In the higher scenario, this is projected to increase to 3.1 inches by 2050 and to 3.3 inches by 2085. In addition, the maximum 5-day precipitation event is also projected to increase.

In both the lower and higher emission scenarios, the precipitation depth is projected to increase for the 24-hour 2-year, 10-year, 25- year, 50-year, 100-year, 200-year, and 500-year return periods (see Table 11). As this analysis is based on 40 years of data, there is significantly more confidence in the more common 2-year and 10-year events than there is in the less frequent events, such as the 100-year to 500-year events. Utilizing FHWA HEC-17 guidance, estimates for the 12-hour, 6-hour, 3-hour, 2-hour, and 1-hour events along with the other stations for the 24-hour events are provided in Appendix A for the three observation stations.[xxvi] Overall, the more extreme precipitation events were simulated to experience a greater increase in precipitation depths (i.e., the 100-year event was projected to experience a greater increase in precipitation depths than the 2-year to 25-year events).

Table 11. Future precipitation depths (inches) for 24-hour return periods under the lower and higher scenarios for Vienna station.

Return Period	Exceedance Probability (%)	Historic		2050			
		NOAA Atlas 14	90% CI	Lower Scenario	90% CI	Higher Scenario	90% CI
2 year	50	2.91	(2.64-3.25)	3.11	(2.81- 3.41)	3.17	(2.79- 3.54)
5 year	20	3.97	(3.59-4.43)	4.27	(3.94- 4.6)	4.37	(3.94- 4.8)
10 year	10	4.81	(4.34-5.34)	5.24	(4.83- 5.64)	5.36	(4.84- 5.89)
25 year	4	6.05	(5.42-6.69)	6.82	(6.22- 7.42)	6.97	(6.25- 7.69)
50 year	2	7.13	(6.34-7.86)	8.39	(7.53- 9.25)	8.54	(7.57- 9.5)
100 year	1	8.35	(7.36-9.17)	10.44	(9.17- 11.71)	10.55	(9.21- 11.88)
200 year	0.5	9.74	(8.49-10.7)	13.21	(11.4- 15.02)	13.17	(11.38- 14.96)
500 year	0.2	11.9	(10.2-13.0)	18.60	(15.56- 21.65)	18.05	(15.26- 20.85)

In addition to the climate projection data shown in the table above, the NOAA Mid-Atlantic Regional Integrated Sciences and Assessment team (MARISA) provides a tool that presents the projected intensity-duration-frequency (IDF) curves for the Chesapeake Bay watershed and Virginia (released in summer of 2021). These curves represent the projected 2-year, 5-year, 10-year, 25-year, 50-year, and 100-year return periods for 2020 to 2070 and 2050 to 2100 for the higher emissions scenario (RCP8.5) and lower emissions scenario (RCP4.5).[xxvii] The MARISA study found that, on average, projected changes in return periods and across durations range from an increase of 8% to 20%. For Fairfax County, results were provided for Vienna and Washington Reagan National Airport stations, as well as a county-level IDF curve. An example of the results for Vienna is provided in the figure below. The 100-year return period for the 24-hr storm duration shown on Figure 24 suggests 9.15 inches with a 90% confidence interval of 7.89 inches to 11.83 inches, which is slightly lower than the 10.55 suggested by Table 11 developed for this report (though this value is within the 90% confidence interval in the figure below). In part, there are a few study parameters that may contribute to these differences including the methodology, climate models, and time periods.

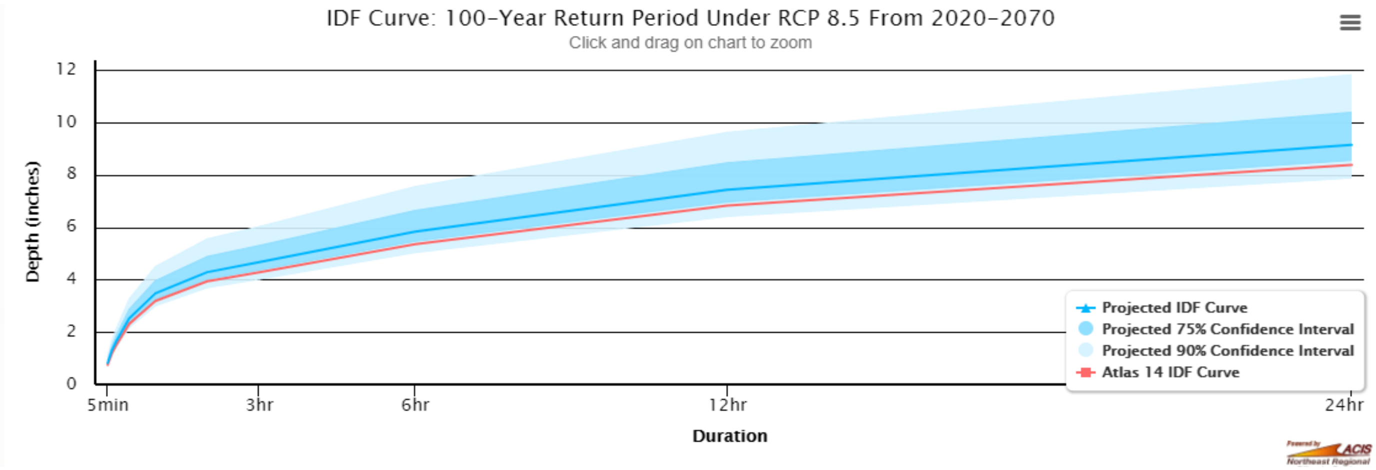


Figure 24. Projected IDF Curve for Vienna for 100-year return period under RCP8.5 (2020-2070) (Source: https://midatlantic-idf.rcc-acis.org/).

7. Drought

Historic Conditions

Traditionally, drought can be defined as a "period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrologic imbalance in the affected area."[xxviii] However, there are different ways to summarize whether drought conditions are occurring. The 4 main types of droughts include: (1) meteorological drought, (2) hydrological drought, (3) agricultural drought, and (4) socioeconomic drought.[xxix] This analysis focuses on meteorological drought when dry conditions occur in response to lack of precipitation. This may lead to hydrological and agricultural droughts.

Fairfax County has experienced more significant drought events that were classified as drought federal disaster declarations than other parts of the state. From 1950 to 2016, the county recorded over 47 events (see Figure 25). The Virginia Department of Emergency Management identified Fairfax County at medium risk of drought.

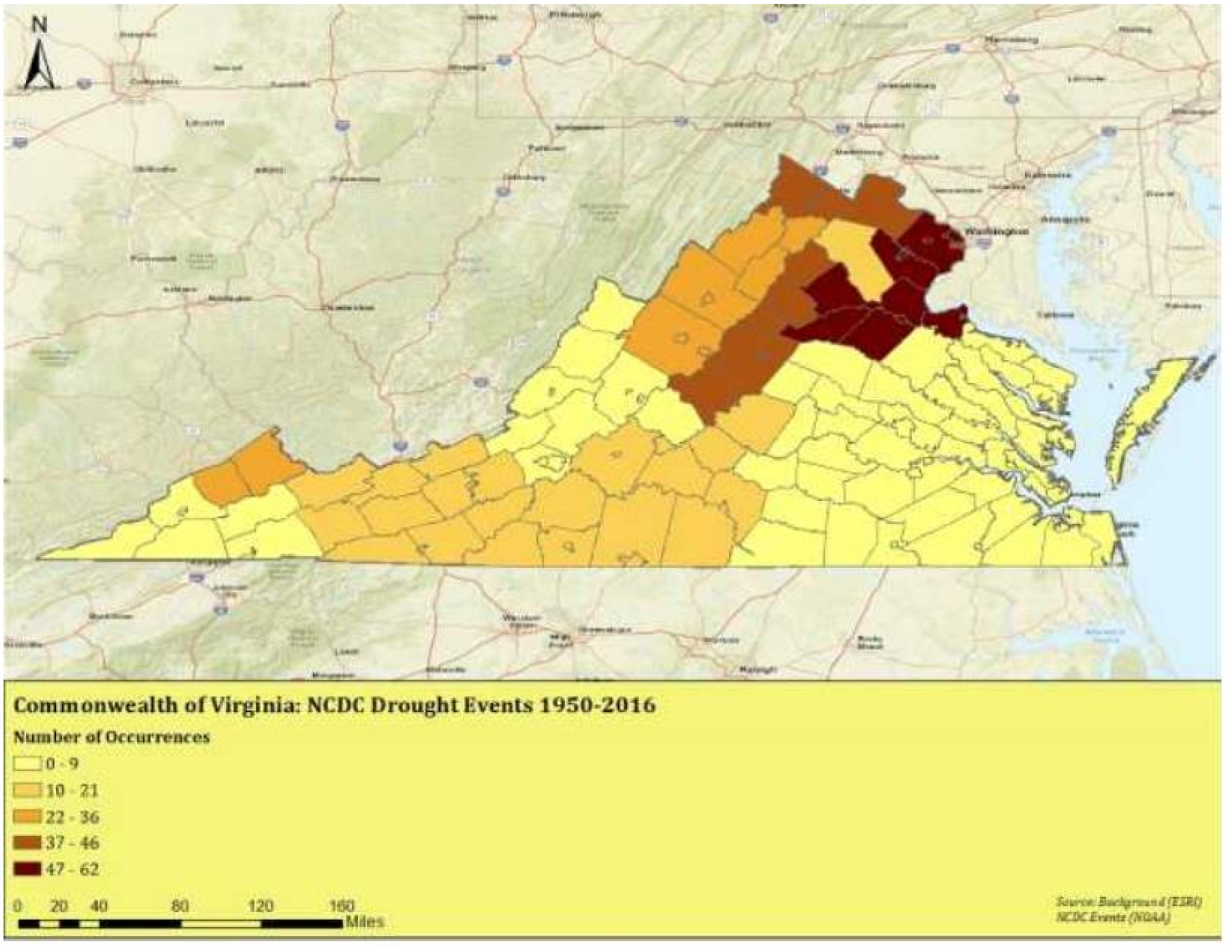


Figure 25. Number of drought events by county for the Commonwealth of Virginia (2018 Commonwealth of Virginia Hazard Mitigation Plan).

The Palmer Drought Severity Index (PDSI) is a useful tool that is based on precipitation, temperature, and water content of soils to estimate long-term drought conditions, where a negative value suggests drying with a “-0.5” for incipient dry spell and “-4.0” for extreme drought. NOAA provides long-term mapping of monthly drought conditions across the lower 48-states. For Virginia, the driest period on record is November 1968 with a PDSI of -1.73.[xxx]

NOAA’s National Integrated Drought Information System (NIDIS) provides historic changes in drought conditions over the long-term record using another widely used indicator, the standardized precipitation index (SPI), which characterizes meteorological drought over time scales of 1 month to several years. A positive SPI suggests wet conditions and a negative SPI suggests dry. An SPI of -1.0 to -1.5 is moderately dry; -2.0 to -1.5 is very dry; an SPI greater than -2.0 is extremely dry. Figure 26 translates SPI into a visual timeline of the percent of Fairfax County that experienced drought conditions from 1980 to present. Red shading indicates drought conditions, with darker red shading indicating more extreme drought. As shown in Figure 27, there have been numerous drought events in the past, interspersed with intermittent periods of heavier precipitation. Since 2003, wet events in Fairfax County appear to be increasing.

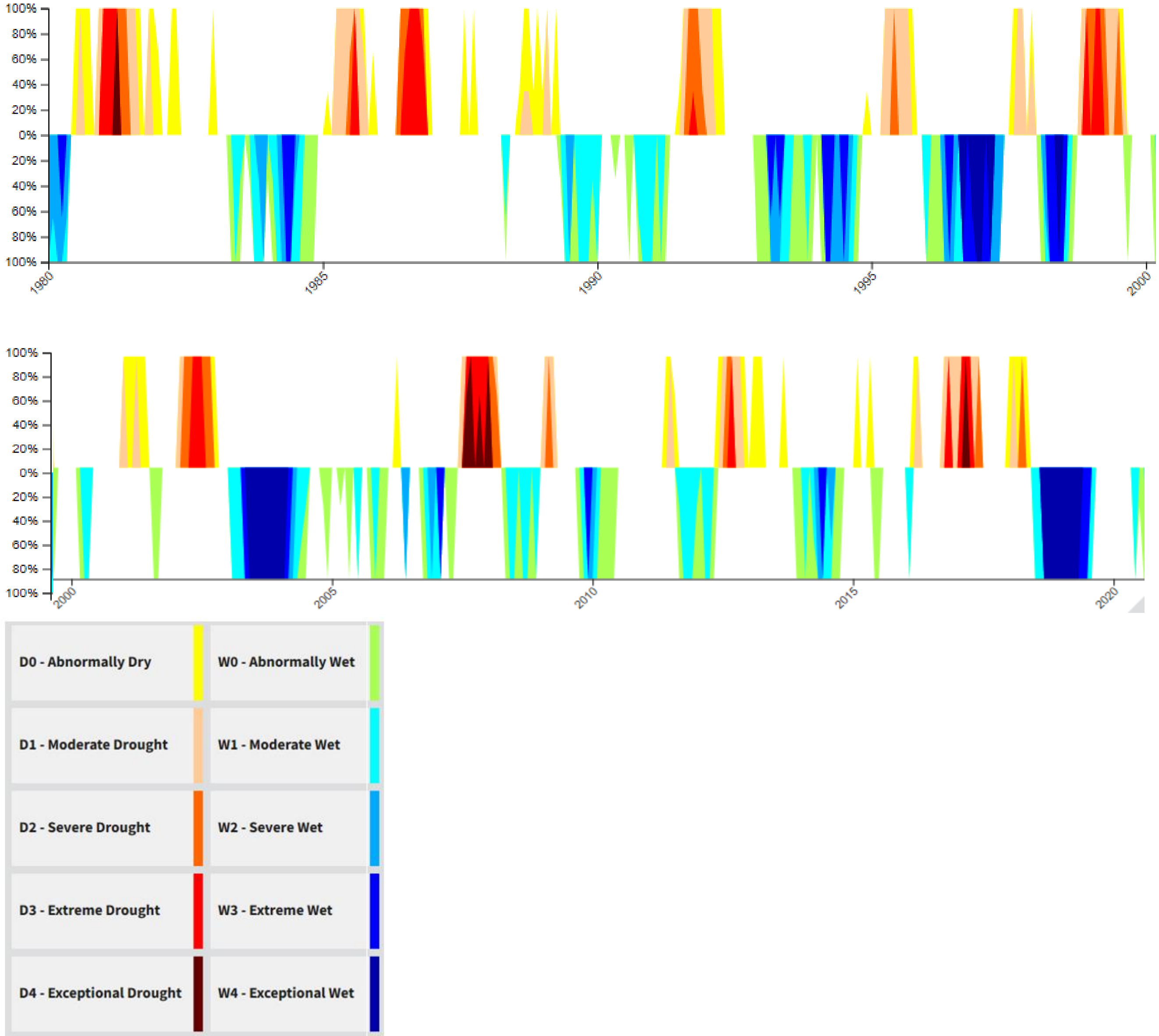


Figure 26. Historical meteorological drought conditions in Fairfax County based on the SPI (Source: NDIS Drought.Gov).

When considering hydrologic droughts, Fairfax County relies on the groundwater monitoring well in Reston, Virginia (USGS 385638077220101 52V 2D) as an indication of drought conditions and potential effects on nearby drinking wells (see Figure 27). The highest water level recorded was 6.47 feet below land-surface datum (March 30, 1984). The lowest recorded was 24.92 feet below land-surface datum (December 7 & 8, 1998). The 1998 year is also identified by the SPI index to be an extreme meteorological drought year.

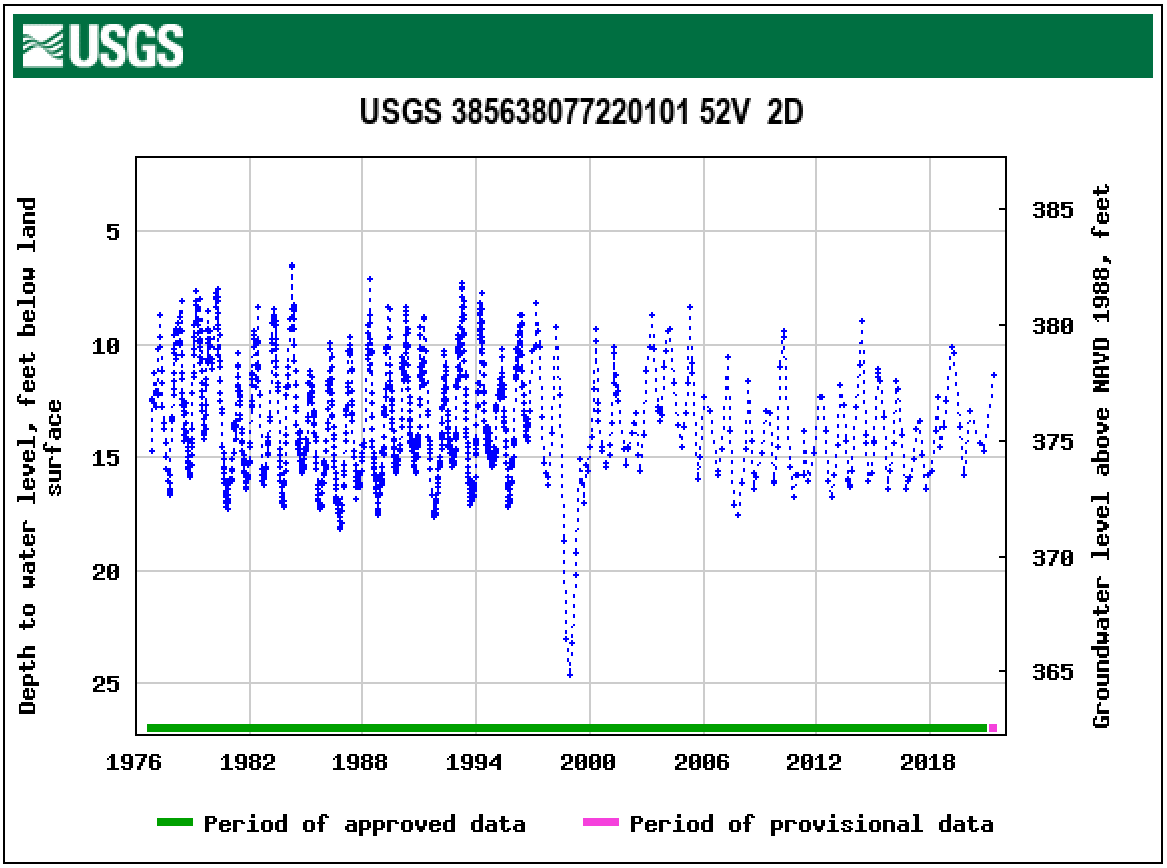


Figure 27. Depth to water level (feet below land surface) from October 28, 1976, through July 25, 2021 (USGS Virginia Water Science Center[xxxi]).

Projected Conditions

Over the coming century, the NCA4 report suggests that drought conditions will be particularly problematic for the Southwest and southern Great Plains of the United States; the Mid-Atlantic region where Fairfax County is located has comparatively less drought concern.[xxxii] Though Virginia is not noted in comparison to these drought hot spots, the region may find that when meteorological drought conditions do occur, these droughts may be amplified compared to today given the rising temperatures. For example, soil moisture may reduce at a greater rate during the summer months in the future due to rising summer temperatures (even with summertime precipitation remaining close to or slightly increasing from today's conditions).

This analysis investigated changes in the 3-month SPI, which is useful for assessing agricultural drought, and the 12-month SPI, which may be representative of hydrological drought.[xxxiii] The projected SPI for 3-month durations suggests a small possibility of increased drought conditions for Fairfax County under the lower scenario for very dry conditions. Otherwise, small-to-moderate *decreases* in drought conditions are suggested (see Table 12). This finding is consistent with the small increases in precipitation that are projected for mid-century. However, for drought, there is significant uncertainty across the climate models, with some climate models projecting an increase in drought conditions. Due to this uncertainty and the relatively simple approach applied in this analysis, it is recommended that drought conditions be considered a minor but ongoing risk until a more in-depth analysis is conducted. This is particularly important as drought is currently considered a medium risk to the county.

Table 12. Projected change in the running number of 3-month and 12-month drought events over a 30-year time period that fall within each of the Standardized Precipitation Index (SPI) for Fairfax County (lower and higher scenarios provided the projected change for mid-century relative to the modeled baseline).

Standard Precipitation Index	2050	2050
	Lower Scenario	Higher scenario
3-month drought		
Dry conditions	-10%	-6%
Very dry conditions	+5%	-12%
Extremely dry conditions	-3%	- <1%
12-month drought		
Dry conditions	-9%	-17%
Very dry conditions	-37%	-36%
Extremely dry conditions	0%	0%

In addition to this study, the Interstate Commission on the Potomac River Basin (ICPRB) has conducted regular studies of drought for relevance to the water supply of the region. The 2020 Washington Metropolitan Area Water Supply Study: Demand and Resource Availability Forecast for the Year 2050[xxxiv] includes a climate projection analysis for climate hazards including drought. The study uses an ensemble of 224 climate projections for the Potomac River watershed upstream of Little Falls dam, derived from the Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble, statistically downscaled using monthly bias-correction and spatial disaggregation. The ICPRB report notes that the region is becoming "wetter," with increasing precipitation, but that when droughts do occur, they may be more severe than droughts historically seen in the region. The report notes "tremendous uncertainty about how climate change will affect streamflows," but that "the changes in annual flows for lower flow years are found to be very different than those for higher flow years, indicating that droughts may become more extreme even in a future where average flows rise." ICPRB's next water supply study is planned for 2025 and will include a reassessment of the potential impact of climate change on regional water supply.

8. Coastal Flooding

Historic and Current Conditions

"Coastal flooding" in Fairfax County refers to flooding of the Potomac River and associated water bodies due to tidal flooding, sea level rise, coastal storm surge, or a combination thereof. The southeastern portion of Fairfax

County is most at exposed to coastal flooding hazards. Of the 443 storm events recorded from 1990 to 2021 in NOAA's Storm Events Database for Fairfax County, one of these events was indicated as a coastal flooding event and two were indicated as surge/tidal events.

Tides are measured with tide gauges. The nearest tide gauge is located across the river in Washington D.C., near East Potomac Park. Based on long-term records from 1924 to 2020, this site has already experienced an increase in sea level rise of 3.43 mm/year (0.135 inches/year) with a 95% confidence interval of +/- 0.28 mm/year (0.011 inches/year) (see Figure 28).[xxxv] This is equivalent to a rise of 1.35 inches per decade or 13.56 inches per century. This local water level rise is greater than the global mean sea level rise of 0.06 in/year experienced over the past century.[xxxvi]

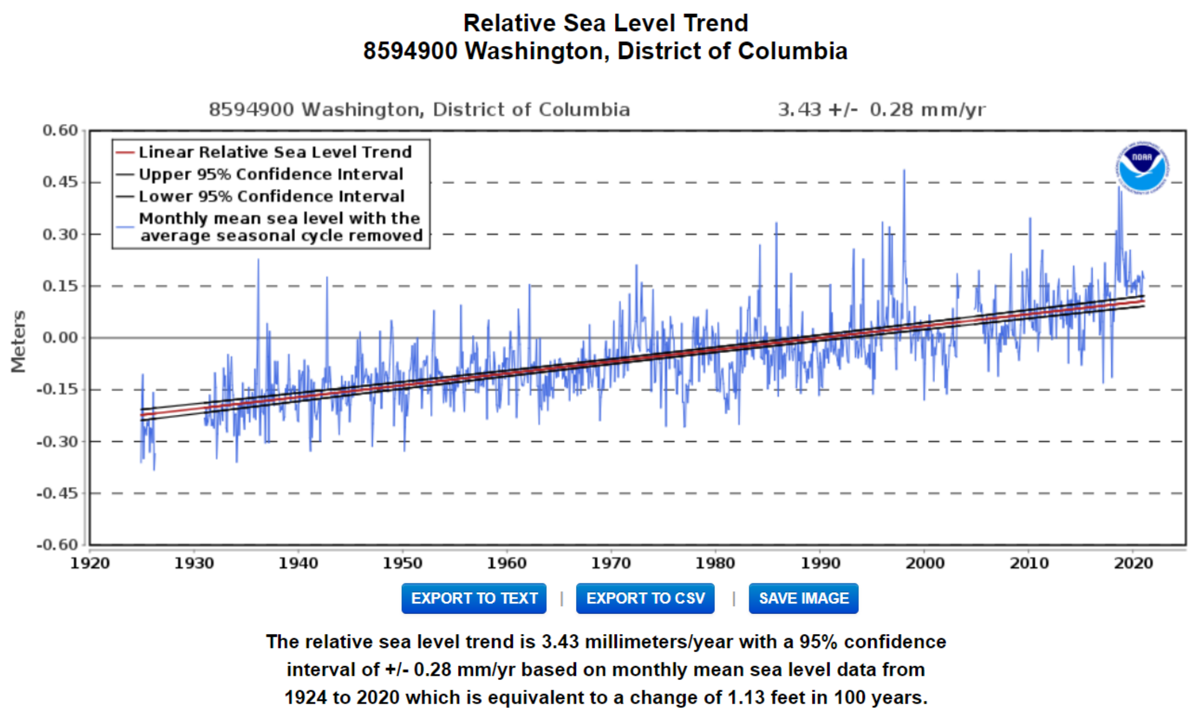


Figure 28. Relative sea level trend for Washington DC tide gauge (8594900). Source: https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8594900).

Projected Conditions

In 2017, NOAA produced a series of curves to reflect possible future trajectories of future sea level rise, as captured in its technical report outlining global and regional sea level rise scenarios for the United States.[xxxvii] Globally, the mean sea level rise is projected to range from 0.3 meters (~1 foot) to 2.5 meters (8.2 feet) by the end of century (2100). This range represents the scientifically plausible lower and upper bounds.

To translate this global data into information that is relevant at the local level, the US Army Corps of Engineers (USACE) provides a sea level rise calculator tool that calculates future relative sea level rise for specific tide gauges (see Figure 29).[xxxviii] The tide gauge in Washington DC is projected to see sea level rise of 1.10 to 3.56 feet (13.2 to 42.72 inches, or 0.34 to 1.09 meters) by 2050 relative to a 1991 to 2009 baseline, based on the low and high scenarios.[xxxix] Using these same scenarios, by end of century (2100), the projected sea level rise for the Washington DC tide gauge accelerates to a range of 1.76 to 11.27 feet (21.12 to 135.24 inches, or 0.54

to 3.44 meters).[xl]

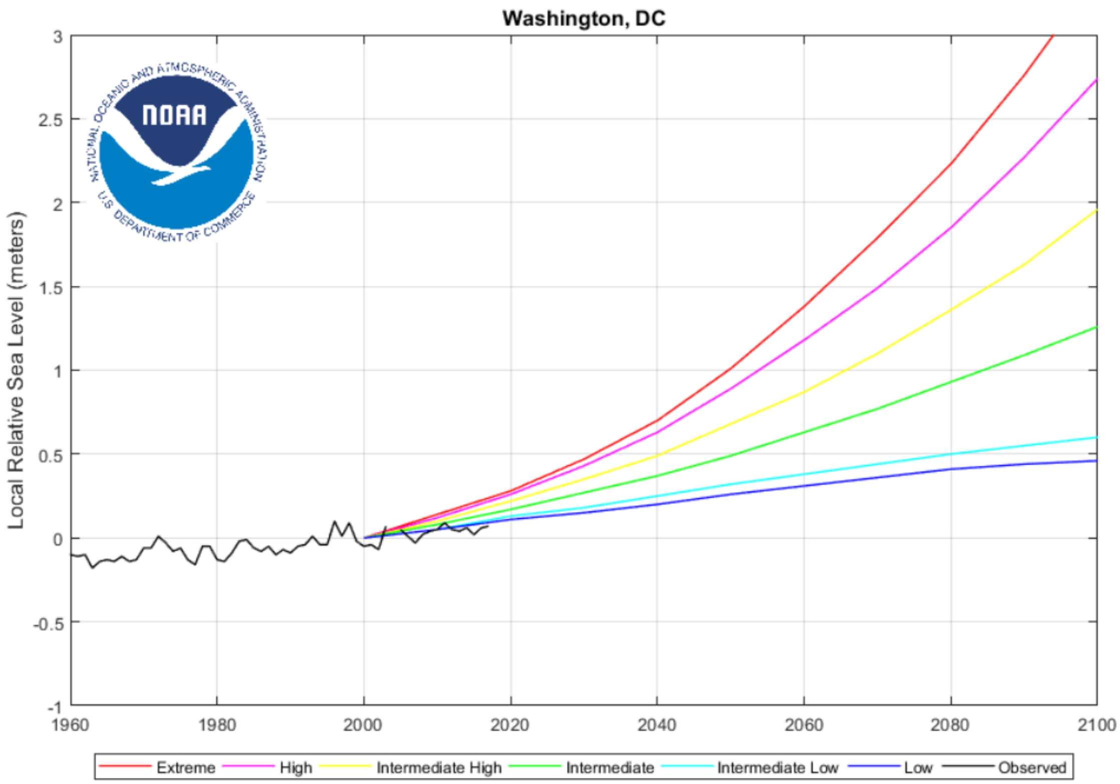


Figure 29. Projections of relative sea level rise for Washington DC tide gauge (8594900) (Source: https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html).

In addition to sea level rise quantities, NOAA has produced data to spatially map areas that would be affected under different sea level rise scenarios. Focusing on sea level scenarios for 2050, Figure 30 illustrates potential flooded areas in the county under sea level rise of one (1) foot (low emissions scenario for 2050) and three (3) feet (high emissions scenario for 2050).[xli] The flooding occurs along the southeastern portion of the county and is largely an expansion of tidally influenced areas. Because it can be difficult to detect increased flooding at the county scale, additional maps are provided to view potential flooding in specific exposed areas by 2050 (see Figures 31-33).

Projected Coastal Flooding : Fairfax County

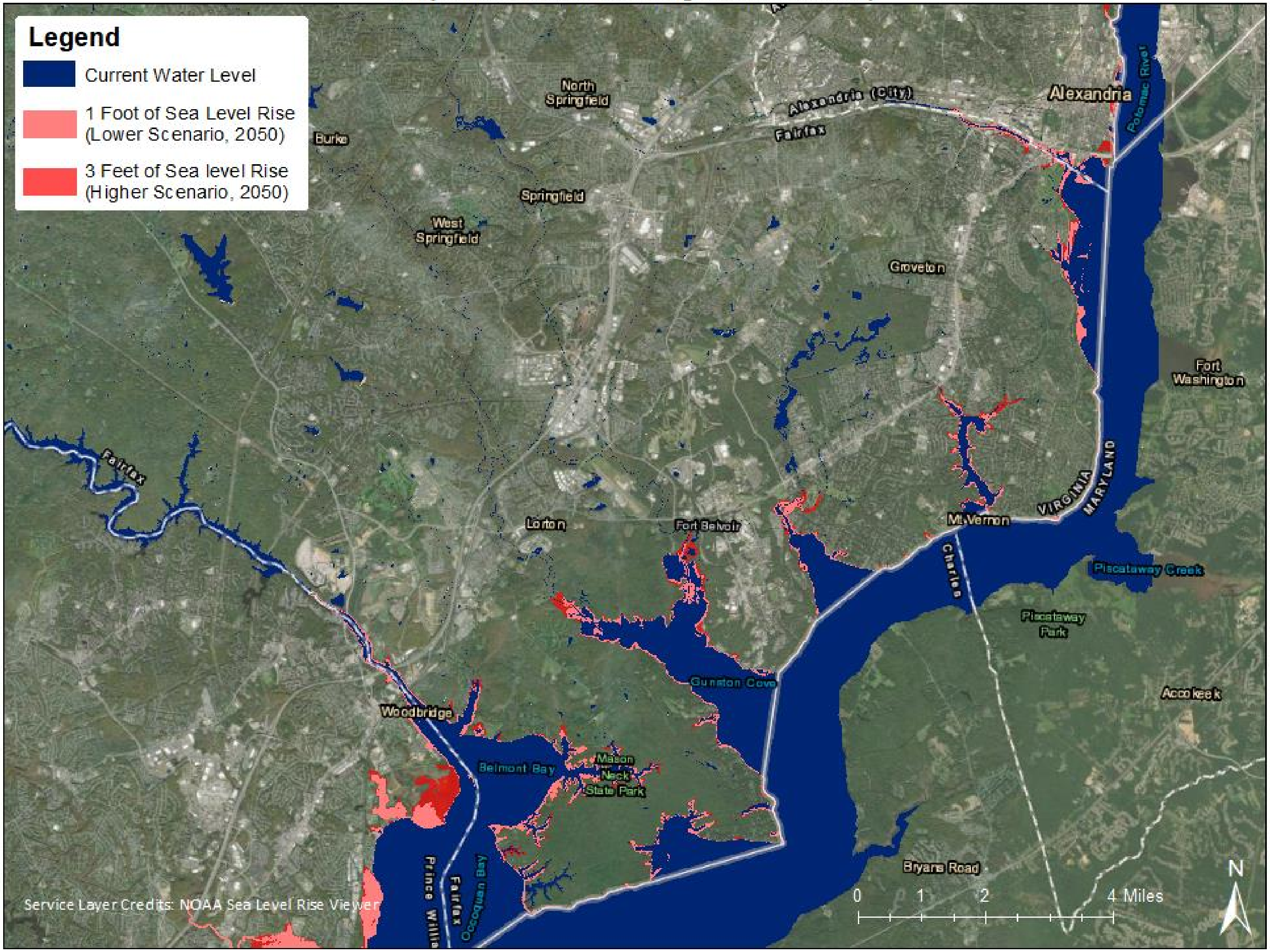


Figure 30: Projected Coastal Flooding due to Sea Level Rise for Fairfax County Shoreline by 2050

Projected Coastal Flooding: Occoquan Bay to Gunston Cove (Mason Neck, Fort Belvoir)

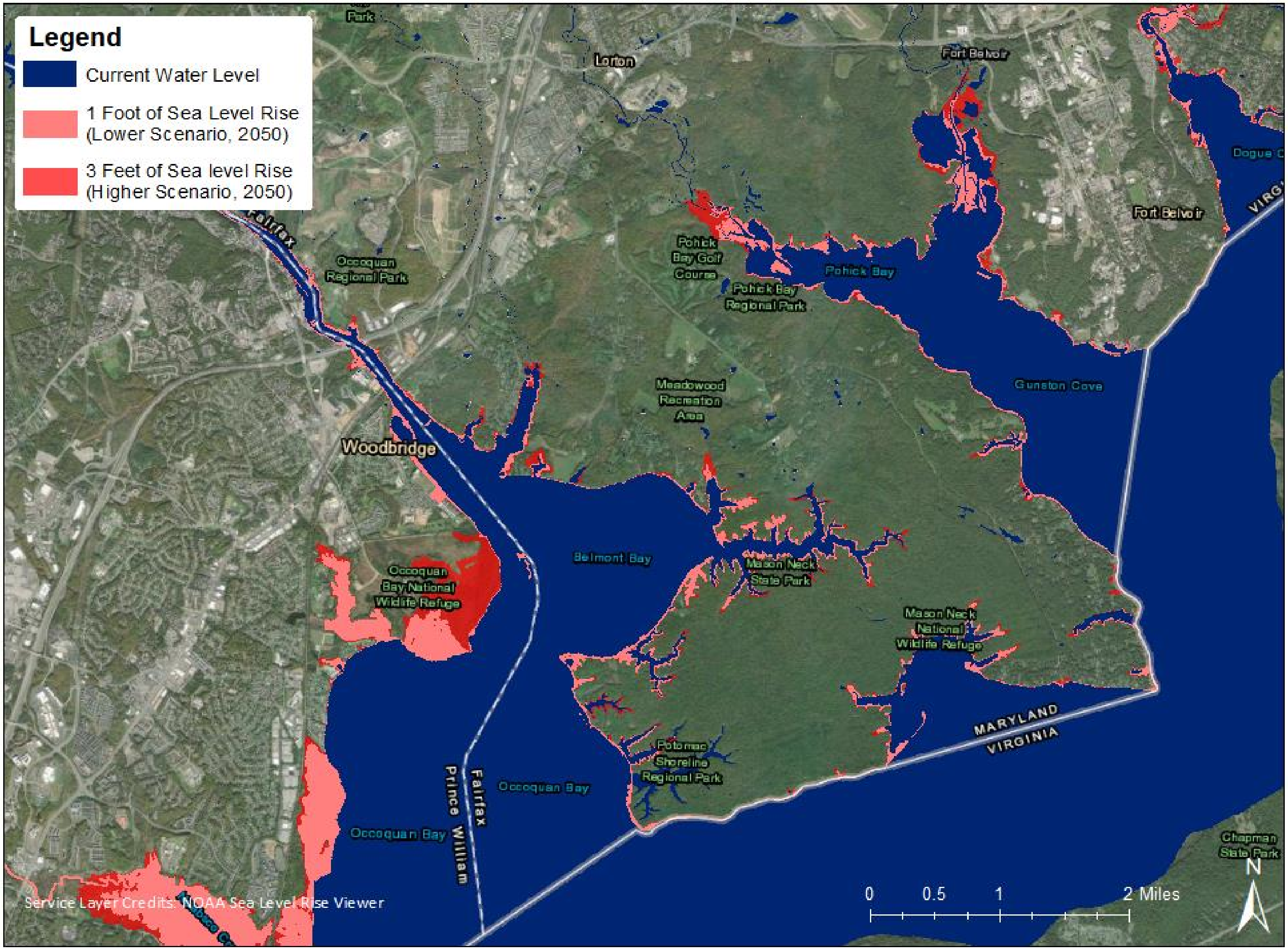


Figure 31: Sea Level Rise Projections for Mason Neck / Fort Belvoir Area

Projected Coastal Flooding : Dogue Creek to Little Hunting Creek

Figure 32: Projected Coastal Flooding due to Sea Level Rise for Mount Vernon Area between Dogue Creek and Little Hunting Creek

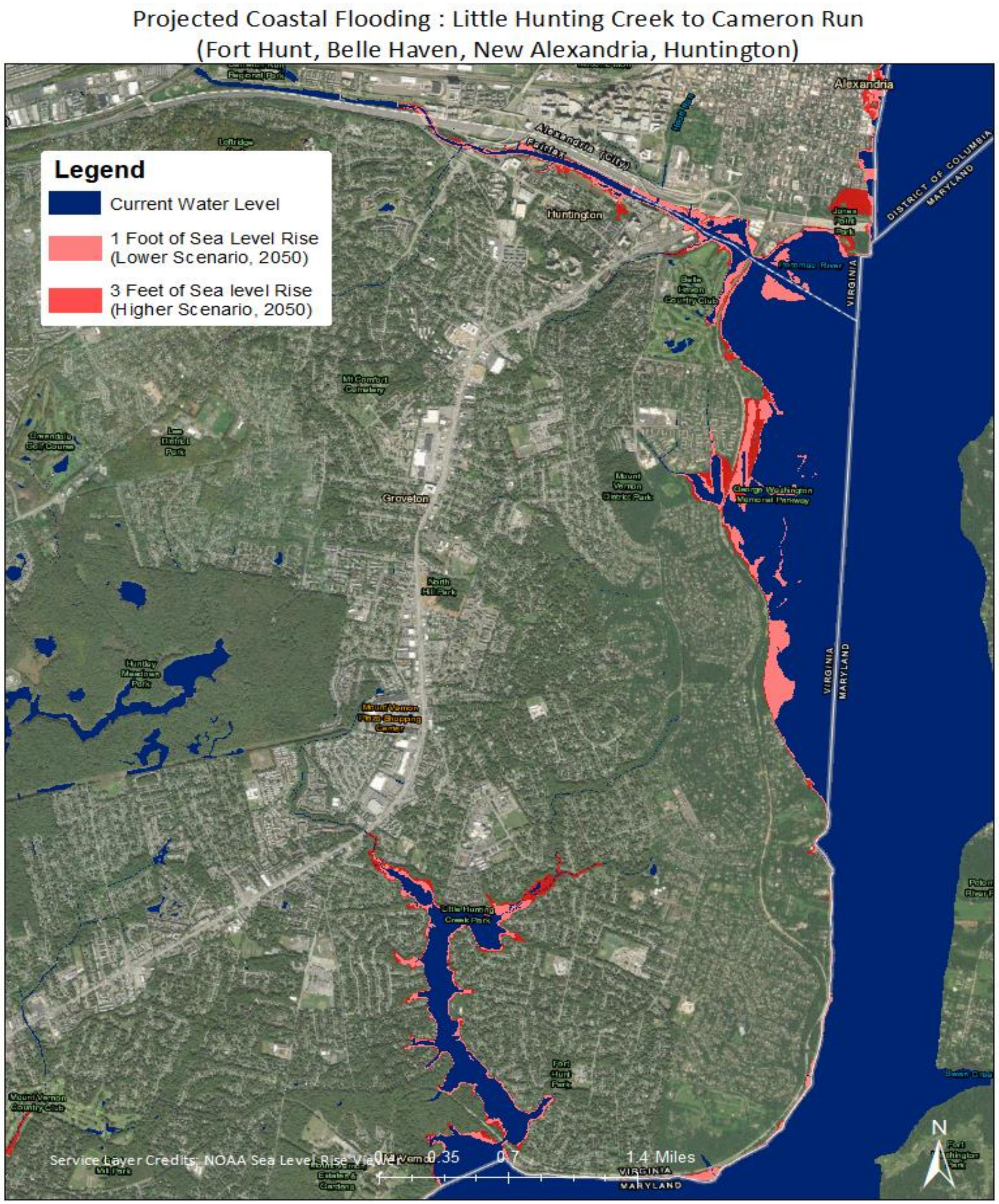


Figure 33: Projected Coastal Flooding due to Sea Level Rise: Little Hunting Creek to Cameron Run

In addition to the areas directly flooded by sea level rise, there are low-lying areas that may be inundated with flooding if the flood water is able to access and seep into those areas. In Figure 34, these low-lying areas that could be exposed are shown in bright green. In Fairfax County, this is primarily a concern for the New Alexandria/Belle View area.

Possible Inundation of Low-Lying Areas due to Sea Level Rise: New Alexandria
(Low Lying Areas Shown in Green)

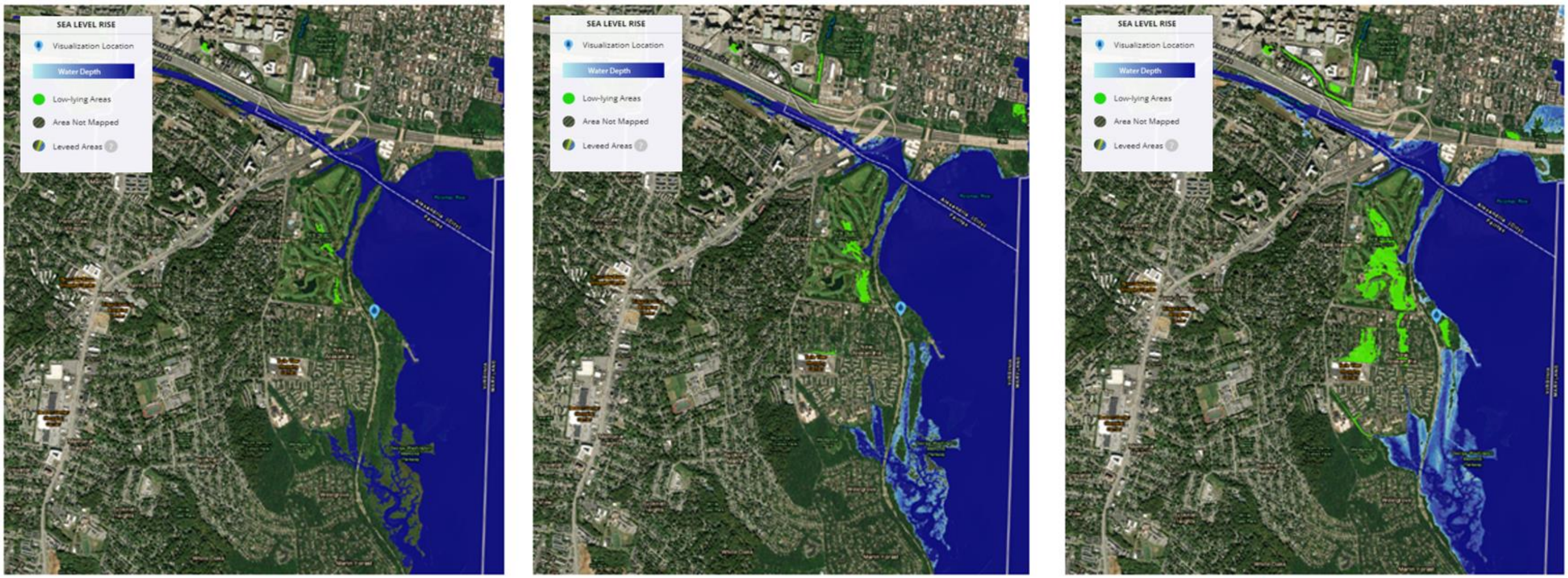


Figure 34. Inundation of low-lying areas at current Mean High High Water (left figure), with sea level rise of 1 foot (center figure) and with sea level rise of 3 feet (right figure). Source based on data from NOAA's Sea level rise viewer; note the "green" shading represents disconnected areas that could become inundated if there is a way for water to reach that location such as a culvert.

In addition to sea level rise flooding, there is a type of flooding called “coastal storm surge,” which refers to water that is pushed on shore during severe storm and wind events such as tropical storms. Fairfax County has coastal storm surge modeling available for current conditions, but not future conditions. It is anticipated that the US Army Corps of Engineers (USACE) Northern Virginia Coastal Storm Risk Management Study will complete a draft feasibility study in 2022 that will assess the feasibility of implementing system-wide and site-specific coastal storm risk management solutions in response to changes in coastal flooding under a changing climate.[xlii] The completed draft report is scheduled for April 2022 and the completed report is scheduled for March 2024. During the interim until the new coastal flooding data is available, this study used the USACE Category 2 hurricane storm surge extent maps developed for the 2015 North Atlantic Coast Comprehensive Study (NAACS) as a proxy for the current FEMA 100-year base flood elevation, with an additional 3 feet of sea level rise to represent 2050 conditions (see Figure 33).[xliii] Unlike the sea level rise maps shown in Figures 30-33, which suggest areas of land that will be submerged under water, the Category 2 hurricane map (Figure 35) identifies vulnerable areas during a storm (and where the water will dissipate after).

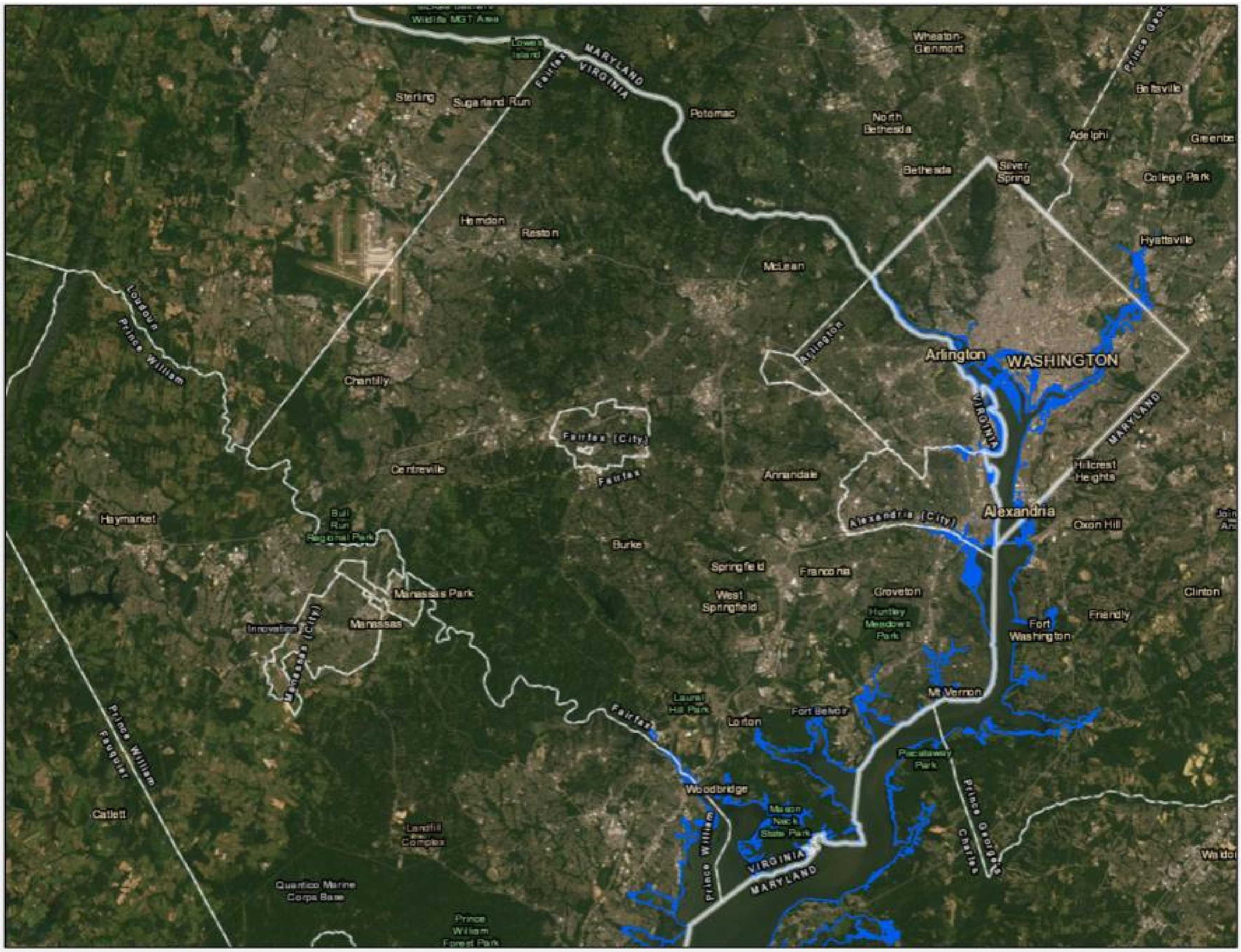


Figure 35. Flooding based on the USACE Category 2 hurricane storm surge extent maps for Fairfax County. (Based on data provided by https://usace.contentdm.oclc.org/digital/collection/p16021coll10/id/9411).

9. Storm and Wind Events

Each year, Fairfax County experiences a range of storm events from tropical cyclones to severe thunderstorms to mid-latitude frontal storm events. Over the past 40 to 50 years, extreme weather events have become more frequent.[xliv] From 1996 to 2021, there were a total of 10 countywide FEMA Major Disaster Declarations including blizzards and winter storms (6), tropical cyclones (3), and severe storm with tornadoes, flooding and/or straight-line winds (1).

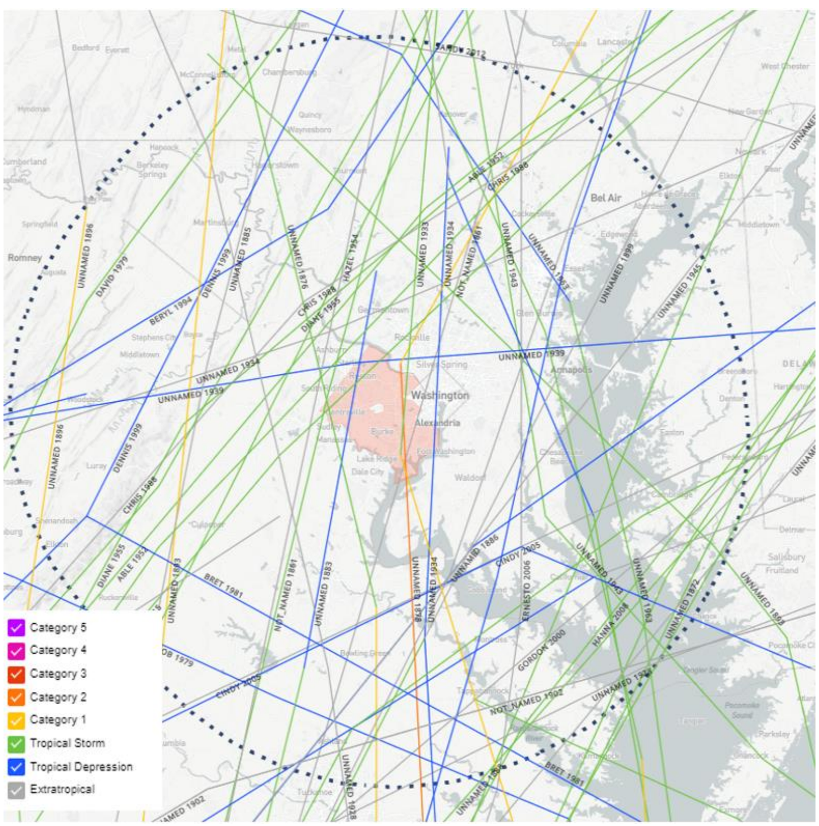
As temperatures warm, the air has an increased capacity to hold water vapor, leading to amplified conditions for storm events. However, extreme storms are complex and affected by several environmental conditions such as upper-level wind shear, surface-level temperature inversions, mid-latitude jet stream, and others. There is varying confidence in projecting how storm events may change under a warming climate, but the consensus is that intensity and frequency of some types of extreme storms will increase due to climate change.[xlv,xlvi] Much of the following is summarized from scientific consensus findings from the National Climate Assessment Report (2017) (NCA4).[xlvii]

9.1 Tropical Cyclones

Historic and Current Conditions

Tropical cyclones include tropical depressions, tropical storms, and hurricanes. They develop over tropical waters. Fairfax County tends to experience the remnants of these storms or downgraded storms which can still cause significant rain, high winds, and flooding. Based on NOAA records of historical hurricane track dating back to 1851, a total of nine tropical cyclones storm tracks have crossed the county (see Figure 36). However, tropical cyclones that traveled in the general vicinity of the county can have significant impact.

Figure 36. Overlay of tropical cyclones storm tracks and Fairfax County, Virginia (NOAA Historical Hurricane Tracks).



Projected Conditions

Scientific consensus suggests that though there may be a reduction in overall storm frequency in the Atlantic basin, there will be an increase in the intensity of the storms that do occur. Under a global warming scenario of 3.6°F, which is projected to occur around mid-century under the higher emissions scenario, tropical cyclone wind intensity is projected to increase bv 5% and precipitation rates are projected to increase by 14%.[xlviii] However, future conditions suggest no change or even a decrease in overall frequency of tropical cyclones.[xlix] There is some evidence that the storm track has been migrating poleward over the past 30 years. If this trajectory continues, it could change which states are more likely to be exposed to these storms.

9.2 Severe Thunderstorms

Historic and Current Conditions

In Fairfax County, severe thunderstorms can occur at any time of year, causing hail, lightning, tornadoes, and strong winds. Derechos are particularly damaging widespread, long-lived, straight-line windstorms that are associated with severe thunderstorms and typically occur during summer months. Based on analysis conducted by the National Weather Service (NWS), a derecho has a chance of occurring once every two to four years in Fairfax County, on average.[l]

Severe thunderstorms refer to dangerous thunderstorms with wind gusts above 58 miles per hour and/or hail at a diameter of ¾" or more.[li] Severe thunderstorms can be associated with flash flooding, lightning, strong winds, hail, tornadoes, and wildfires.[lii] On average, Fairfax County currently experiences around 37 to 45 days of thunderstorms per year (see Figure 37), with the majority occurring from May through August.[liii]

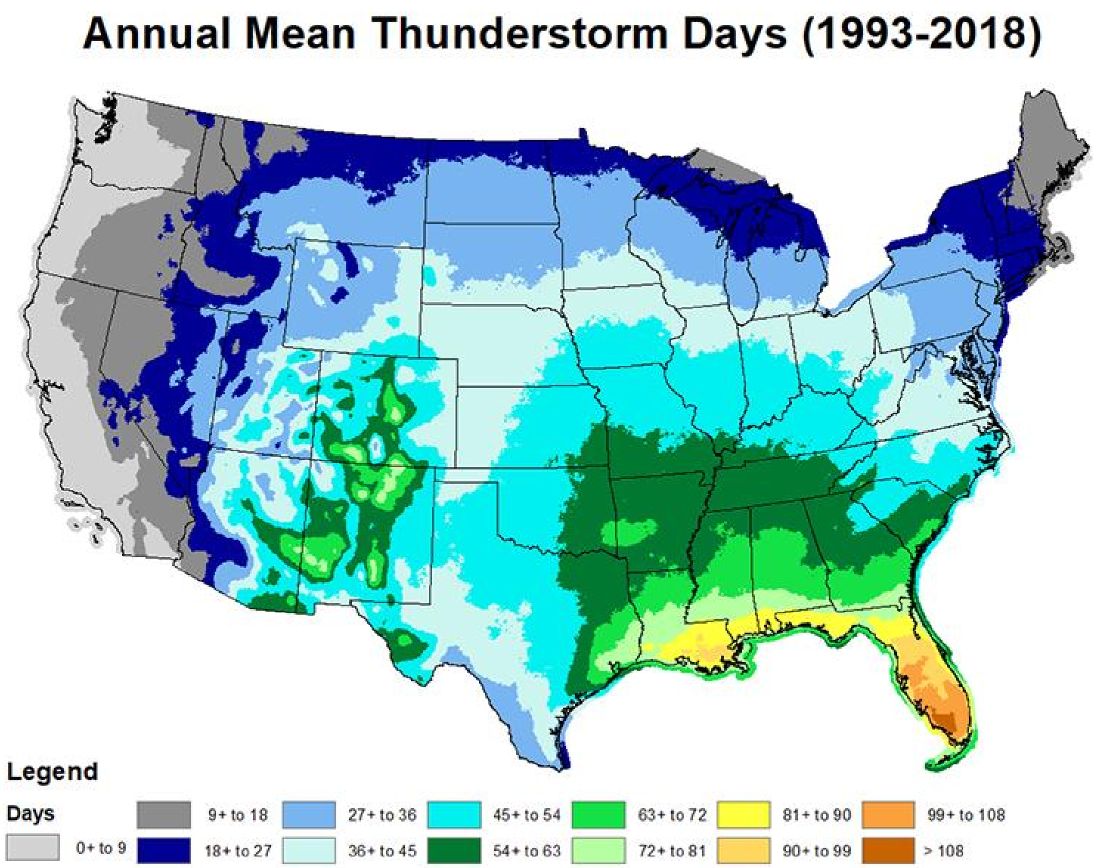


Figure 37. Annual number of thunderstorms across the contiguous United States (Koehler 2019[liv]).

Projected Conditions

Based on the U.S. Global Change Research Program (USGCRP) Climate Science Report (2017), temperature, humidity and wind are critical to understanding how thunderstorms may (or may not) develop.[lv] Overall, there is a projected overall increase in the frequency of severe thunderstorm environments. However, there is a notable gap in available studies exploring long-term trends in wind events including derechos.[lvi]

9.3 Winter Storms

Historic and Current Conditions

Winter storms in Fairfax County may range from moderate snow over a relatively short duration of a few hours to blizzard conditions lasting for several days. The latter is generally associated with Nor'easters.[lvii] Significant damage in the form of downed power lines, fallen trees, power disruption, and hazardous travel conditions can occur.

Between 1950 and the current period, the United States saw an increase in winter storm frequency and intensity, with storm tracks shifting slightly poleward. Heavier-than-normal snowfalls were experienced in the Northeast while a decrease in snowfalls has occurred for the southern United States.[lviii]

The number of extreme snowstorms in the eastern United States (mostly in the northeastern states) increased, with approximately twice as many occurring in the latter half of the 20th century than the first.[lix] This may have been due to warmer-than-average surface temperatures for the Atlantic Ocean, which allows for a higher amount of moisture to fuel the storm (global ocean surface temperatures have increased at a rate of +0.18°F per decade since 1950), the presence of El Niño conditions, and the reductions in the Arctic sea ice which has been linked to atmospheric circulation patterns conducive to winter storm development.[lx] Fairfax County was identified by the Commonwealth of Virginia Hazard Mitigation plan (2018) as one of the jurisdictions with a higher winter weather risk than other parts of the state. (Generally, the risk has been higher in western and northern Virginia than in southern and eastern Virginia).

Projected Conditions

Based on the USGCRP Climate Science Report (2017), an increase in storm activity generally is projected over the eastern United States with the higher scenario (RCP8.5) projecting the most intense of these storms. There are large regional variations and significant uncertainty with these findings, however, as the global climate models suggest a range across whether these storms will decrease or increase.

Regarding winter storms specifically in Fairfax County, a reduction is possible in the number of snow days, shifting to an increase in rain days as temperatures warm. However, this does not mean that the county will not continue to experience some winter storms or mixed precipitation conditions.

10. Conclusions

Fairfax has already experienced warmer and slightly wetter conditions over the past century. These trends are projected to continue and accelerate. Information on the *impacts* of such projected conditions can be found in the vulnerability and risk assessment. The following list summarizes key climate projection findings for 2050:

- **Warmer annual and seasonal temperatures**. Annual average temperatures in Fairfax County will rise from the current average of 56.6°F to between 59.7°F (lower scenario) and 60.7°F (higher scenario). Seasonal temperatures are projected to increase across all seasons. The hotter temperatures traditionally associated with summer will expand into the late spring and early fall months.

- **Increase in frequency and intensity of hot days**. Very hot days at or above 90°F in Fairfax County are projected to rise significantly from 29 days per year today to more than 60 days per year in 2050. Areas across the county that already experience hotter temperatures due to the urban heat island effect will be particularly exposed to high temperatures. Cooling degree days are likewise projected to increase.
- **Reduction in cold days**. The number of days per year below freezing is projected to decrease from 86 days currently down to 67 days (lower scenario) and 62 days (higher scenario) in 2050. Freeze-thaw days are also projected to reduce from 69 days today to 50 days (lower scenario) and 46 days (higher scenario) in 2050. Heating degree days are also projected to decrease. A reduction in total snow days per year is projected with more precipitation falling as rain.
- **Increase in frequency and intensity of heavy precipitation events**. Heavy precipitation events are projected to become more intense, amplifying inland flooding. Overall, it is anticipated that Fairfax County will experience fewer rain/snow days, but higher accumulations when it does rain/snow, and higher total annual precipitation amounts.
- **Increase in coastal flooding**. By 2050, coastal inundation due to sea level rise is projected along some of the southeastern county coastline, largely as an expansion of tidally influenced areas.
- **Increase in storm events, particularly the intensity of tropical cyclones.** Tropical cyclones in the Atlantic basin are projected to become more intense with stronger winds and heavier precipitation. Other storm events, in general, are projected to intensify, but there are conflicting findings depending on storm type.

Through this analysis, a few areas for future research were identified that the county may want to consider, including:

- An inland flood assessment that uses advanced stormwater modeling with future climate projections, to account for stormwater management infrastructure in addition to floodplains.
- Groundwater analysis to understand how future conditions may affect groundwater and runoff that impacts inland flooding.
- A coastal flood assessment to analyze storm surge under various storm conditions and sea level rise scenarios.
- Additional drought research that takes into consideration not only precipitation (that is, meteorological drought) but also temperature.
- Continued monitoring for new research from the climate science community regarding climate change impacts on storm events, as this is still an emerging area of research.

Appendix A. Projected Change

Chronic and Acute Indicators

This analysis used statistically downscaled climate data. Specifically, the analysis uses the statistically downscaled World Climate Research Programme's (WCRP) Coupled Model Intercomparison Project (CMIP5) data which relies on a method known as the Localized Constructed Analogues (LOCA) technique, developed by the Scripps Institute of Oceanography at the University of California, San Diego.[lxi] Daily temperature and precipitation projections were processed across about 40 grid cells over Fairfax County and two future scenarios, a moderate future warming scenario (RCP4.5) and a high future warming scenario (RCP8.5) across an ensemble of 32 climate models.[lxii] The 90th confidence intervals for the projections show the range in future values across the climate models, an indication of model uncertainty. Note that these estimates are averages over a time period and the year-to-year variability can be much greater or less than the averages. That said, these numbers are based on an ensemble of climate models which are developed to provide results on a climate-based timeframe (i.e., 30-year average).

The following tables present the results. After mapping the climate indicators (i.e., inspecting the change projected across the roughly 40 grid cells that overlap with the Fairfax County political boundary), it was determined the differences across the grid cells were not large and averaging across the grid cells would provide a more reasonable future projection for the vulnerability and risk assessments. The averaging used an area-weight to consider grid cells that were only partially included in the county.

Table A.1 Historic climate indicators for current climate (1991-2020) and baseline climate (1976-2005) averaged across the 3 observation stations, and the projected change from baseline for each climate indicator for 2050 and 2085 under the lower RCP4.5 emissions scenario and the higher RCP8.5 emissions scenario (where variability and "CI" represent the 90th confidence interval). To calculate future value, add the future change to the baseline period (observed) value or if the projection is a percent, multiply the baseline period value by the percent and add to the baseline value.

Climate Indicator	Current Climate (Observed)	Baseline Period (Observed)	2050				2085			
			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			Future	CI	Future	CI	Future	CI	Future	CI
Number of days at/above 90°F	28.7	24.9	35.45	(31.95-38.4)	44.41	(40.93-47.62)	44.67	(40.53-48.45)	76.32	(71.58-81.02)
Number of days at/above 95°F	7.4	6.5	21.28	(18.16-23.4)	29.81	(26.11-32.36)	29.67	(25.37-32.79)	63.14	(56.33-68.36)
Number of days at/above 100°F	0.6	0.6	6.82	(5.1-8.08)	11.00	(8.64-12.71)	11.21	(8.38-13.41)	33.82	(27.72-38.42)
Number of days at/above 105°F	0.0	0.0	1.09	(0.52-1.57)	2.28	(1.24-3.16)	2.46	(1.23-3.49)	12.40	(8.43-15.56)
Top 1-percentile of Maximum Temperature	96.0	97.0	4.72	(4.14-5.26)	6.10	(5.42-6.77)	6.08	(5.36-6.78)	10.67	(9.53-11.75)
Maximum number of consecutive days at/above 95°F	2.6	2.1	4.81	(4.01-5.38)	7.30	(5.99-8.22)	7.14	(5.74-8.15)	19.59	(15.66-22.34)
Number of days below 32°F	86.3	90.9	-24.00	(-25.55-21.17)	-29.15	(-30.52-26.28)	-31.04	(-33.03-27.6)	-50.87	(-52.93-47)
Number of Freeze-Thaw days	68.6	72.3	-18.35	(-19.72-16.14)	-22.49	(-23.73-20.18)	-23.97	(-25.7-21.16)	-40.47	(-42.36-37.21)
Number of Snow Days	8.8	9.4	-5.67	(-6.15- -5)	-6.60	(-7--5.94)	-6.77	(-7.25--6.08)	-9.25	(-9.7--8.61)
Number of Rain Days	92.8	98.7	8.57	(6.16-10.67)	8.11	(5.7-10.27)	10.33	(7.73-12.58)	11.60	(8.18-14.77)
Number of Mixed Precipitation Days	N/A	N/A	-3.02	(-3.49 - 2.47)	-3.59	(-4.06-3.02)	-3.87	(-4.39-3.21)	-5.95	(-6.55--5.3)
Cooling degree days	1308.3	1194.0	603.95	(549.53 - 657.48)	782.48	(723.93-842.35)	796.60	(721.72-871.92)	1539.44	(1423.49-1658.4)
Heating degree days	4474.0	4655.6	-831.15	(-889.06-743.5)	-999.09	(-1049.83-915.88)	-1056.90	(-1127.17-955.54)	-1672.89	(-1753.8-1561.93)
Top 1-percentile of Daily Precipitation (inches)	2.9	2.8	7.1%	(5.29%-9.0%)	9.7%	(7.9%-11.4%)	10.6%	(8.4%-12.9%)	16.4%	(14.4%-19.1%)
Maximum 5-day Precipitation (inches)	4.6	4.0	8.0%	(5.8%-10.7%)	9.7%	(7.5%-12.6%)	11.9%	(9.3%-15.1%)	19.1%	(16.4%-22.8%)

Climate Indicator	Current Climate (Observed)	Baseline Period (Observed)	2050				2085			
			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			Future	CI	Future	CI	Future	CI	Future	CI
Annual Precipitation (inches)	42.1	41.6	6.2%	(4.7%-7.7%)	7.0%	(5.7%-8.5%)	8.0%	(6.4%-9.8%)	11.3%	(9.4%-13.5%)
Winter Precipitation (inches)	8.9	8.9	7.8%	(4.8%-10.2%)	8.6%	(5.4%-11.6%)	11.1%	(7.5%-14%)	17.5%	(13.1%-21.2%)
Spring Precipitation (inches)	11.1	11.2	9.6%	(7%-12.1%)	13.8%	(11%-16.3%)	11.3%	(8.6%-13.8%)	17.8%	(14.4%-20.9%)
Summer Precipitation (inches)	11.8	10.9	5.9%	(2.5%-9.9%)	4.0%	(1.2%-7.7%)	7.3%	(4.1%-10.9%)	8.9%	(5.6%-12.8%)
Fall Precipitation (inches)	10.4	10.7	2.5%	(-0.2%-5.4%)	3.3%	(0.3%-6.5%)	3.6%	(1.2%-6.8%)	3.5%	(0.4%-7.3%)
Annual Maximum Temperature (°F)	66.0	65.5	4.0	(3.61-4.33)	5.0	(4.57-5.29)	5.2	(4.66-5.56)	8.9	(8.23-9.47)
Winter Maximum Temperature (°F)	45.5	44.9	4.2	(3.6-4.5)	5.0	(4.4-5.3)	5.2	(4.5-5.6)	8.5	(7.8-9.1)
Spring Maximum Temperature (°F)	65.3	65.0	3.5	(3.1-3.9)	4.2	(3.8-4.6)	4.6	(4.2-5.1)	7.5	(6.9-8.1)
Summer Maximum Temperature (°F)	85.1	84.3	4.1	(3.6-4.4)	5.2	(4.7-5.5)	5.2	(4.7-5.6)	9.4	(8.6-10)
Fall Maximum Temperature (°F)	67.7	67.4	4.3	(3.9-4.8)	5.5	(5.1-6)	5.6	(5-6.2)	10.1	(9.3-10.9)
Annual Minimal Temperature (°F)	47.1	46.1	3.8	(3.49-4.12)	4.8	(4.45-5.03)	5.0	(4.55-5.36)	8.7	(8.16-9.17)
Winter Minimum Temperature (°F)	28.4	27.3	4.2	(3.7-4.4)	4.9	(4.4-5.2)	5.1	(4.5-5.5)	8.6	(7.9-9.1)
Spring Minimum Temperature (°F)	44.6	43.8	3.4	(3-3.8)	4.2	(3.8-4.6)	4.7	(4.3-5.1)	7.7	(7.2-8.2)
Summer Minimum Temperature (°F)	66.3	65.4	3.8	(3.4-4)	4.8	(4.4-5)	4.9	(4.5-5.2)	8.7	(8.2-9.2)
Fall Minimum Temperature (°F)	48.5	47.5	4.0	(3.6-4.4)	5.1	(4.8-5.5)	5.3	(4.8-5.8)	9.7	(9-10.4)

Monthly Precipitation

Month	Current Climate (Observed) [inches]	Baseline Period (Observed) [inches]	2050				2085			
			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			Future Change	CI	Future Change	CI	Future Change	CI	Future Change	CI
January	3.0	3.2	10.2%	(5.7%-14.2%)	9.4%	(4.2%-14.2%)	11.1%	(5.9%-15.6%)	22.3%	(16.7%-27%)
February	2.6	2.7	10.9%	(6.2%-14.8%)	15.2%	(10.3%-19.6%)	12.3%	(7.6%-16.5%)	19.3%	(13.8%-24%)
March	3.5	3.9	9.0%	(4.5%-13.2%)	15.0%	(10.9%-18.8%)	10.7%	(6.1%-15%)	18.0%	(14.4%-21.1%)
April	3.3	3.2	10.3%	(6.2%-15.1%)	12.1%	(7.2%-17.1%)	12.2%	(7.7%-16.7%)	17.2%	(11%-23.7%)
May	4.3	4.1	10.0%	(6.8%-13.9%)	5.2%	(1.7%-9%)	7.7%	(3.7%-12.3%)	9.9%	(6.1%-14.9%)
June	4.3	3.7	2.3%	(-2.5%-8.4%)	1.9%	(-1.8%-7.1%)	1.7%	(-3.1%-7.3%)	2.0%	(-2.5%-8.2%)
July	4.1	3.8	5.9%	(0.2%-11.3%)	6.1%	(0%-12.3%)	13.6%	(7.6%-19.1%)	15.8%	(7.4%-22.7%)
August	3.3	3.4	7.7%	(2.9%-11.8%)	6.3%	(1.2%-10.8%)	9.8%	(5.1%-14.7%)	11.2%	(4%-17.8%)
September	3.9	4.1	-0.5%	(-4.6%-3.9%)	3.7%	(-1.2%-9.4%)	3.4%	(-1.4%-9%)	1.1%	(-3.6%-6.8%)
October	3.6	3.4	1.2%	(-4.1%-7.2%)	0.4%	(-4.5%-5.9%)	-1.9%	(-6.9%-4.5%)	-1.5%	(-6.4%-4.8%)
November	2.9	3.2	4.8%	(-1.1%-9.9%)	5.5%	(1.2%-10.1%)	6.4%	(1%-11.6%)	8.9%	(3.4%-13.8%)
December	3.3	3.0	9.6%	(5.3%-13.5%)	11.7%	(6.6%-16.3%)	16.4%	(11.4%-20.4%)	22.0%	(16.2%-27%)

Monthly Maximum Temperature

Month	Current Climate (Observed) [°F]	Baseline Period (Observed) [°F]	2050				2085			
			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			Future Change	CI	Future Change	CI	Future Change	CI	Future Change	CI
January	43.2	42.0	3.9	(3.3-4.3)	4.7	(4.2-5.1)	4.6	(3.9-5.1)	8.2	(7.3-8.8)
February	46.6	46.6	3.3	(2.7-3.8)	4.1	(3.5-4.7)	4.7	(4.1-5.3)	7.7	(6.9-8.4)
March	54.9	54.9	3.7	(3.3-4.1)	4.2	(3.7-4.7)	4.3	(3.9-4.8)	7.0	(6.3-7.7)
April	66.6	66.3	3.4	(3-3.9)	4.3	(3.8-4.8)	4.7	(4.3-5.3)	8.0	(7.4-8.6)
May	74.5	74.0	3.8	(3.3-4.2)	4.8	(4.3-5.1)	5.0	(4.4-5.4)	9.1	(8.2-9.6)
June	82.7	82.0	4.1	(3.7-4.4)	5.2	(4.7-5.5)	5.3	(4.8-5.6)	9.5	(8.7-10)
July	87.0	86.0	4.3	(3.8-4.7)	5.5	(5-6)	5.4	(4.8-5.9)	9.6	(8.8-10.5)
August	85.6	84.9	4.3	(3.8-4.8)	5.6	(5.1-6.2)	5.7	(5-6.4)	10.4	(9.3-11.4)
September	78.8	78.2	4.5	(4-5)	5.6	(5-6)	5.7	(5-6.2)	10.1	(9.2-11)
October	67.5	66.7	4.2	(3.6-4.7)	5.4	(4.9-5.9)	5.5	(4.9-6.2)	9.8	(9.1-10.6)
November	56.8	57.4	4.3	(3.8-4.6)	4.9	(4.4-5.2)	5.3	(4.6-5.7)	8.5	(8-9)
December	47.1	46.1	4.3	(3.6-4.7)	5.4	(4.6-5.8)	5.3	(4.7-6.1)	8.9	(7.9-9.6)

Monthly Minimum Temperature

Monthly Minimum Temperature	Current Climate (Observed)[°F]	Baseline Period (Observed)[°F]	2050				2085			
			RCP4.5		RCP8.5		RCP4.5		RCP8.5	
			Future	CI	Future	CI	Future	CI	Future	CI
January	26.5	25.1	4.4	(3.8-4.7)	5.2	(4.6-5.5)	5.2	(4.6-5.6)	8.9	(8.1-9.4)
February	28.2	27.7	3.5	(2.9-3.9)	4.3	(3.8-4.7)	4.9	(4.4-5.4)	8.2	(7.5-8.8)
March	34.8	34.4	3.3	(3-3.8)	4.1	(3.7-4.5)	4.2	(3.8-4.7)	6.9	(6.3-7.5)
April	44.6	43.8	3.5	(3.1-4)	4.3	(4-4.8)	4.8	(4.4-5.3)	8.1	(7.5-8.6)
May	54.4	53.2	3.7	(3.3-4)	4.6	(4.1-4.8)	4.7	(4.2-5.1)	8.5	(7.8-8.8)
June	63.6	62.6	3.8	(3.4-4)	4.8	(4.4-5)	4.9	(4.4-5.2)	8.7	(8.1-9.1)
July	68.4	67.3	3.9	(3.6-4.2)	5.0	(4.7-5.4)	5.1	(4.6-5.5)	9.0	(8.4-9.7)
August	67.0	66.3	3.9	(3.6-4.3)	5.2	(4.9-5.7)	5.3	(4.8-5.9)	9.8	(9.1-10.6)
September	60.0	58.8	4.2	(3.7-4.6)	5.2	(4.8-5.6)	5.3	(4.8-5.8)	9.8	(-6.4-4.8)
October	47.9	46.2	3.8	(3.3-4.3)	5.0	(4.6-5.4)	5.2	(4.6-5.8)	9.6	(8.9-10.4)
November	37.5	37.5	4.0	(3.5-4.3)	4.6	(4.1-4.9)	4.8	(4.2-5.3)	8.2	(7.6-8.8)
December	30.7	29.1	4.1	(3.5-4.4)	5.1	(4.4-5.4)	5.4	(4.6-5.8)	8.7	(7.9-9.4)

Precipitation Events

The following tables provide projected changes in precipitation depths for various storm events in and around Fairfax County. The precipitation projections were first bias corrected using the quantile method at each of 3 locations with long-term observational records (1960-2005) which includes Vienna, Washington Dulles International Airport, and Washington Reagan National Airport. For each scenario and climate model, the generalized extreme distribution curves were then fitted to 40-years of annual maxima data centered at 1985 (1966-2005) for the baseline and 2050 (2030-2070) for mid-century to obtain 24-hour change. The ratio of future value to baseline value was then applied to NOAA Atlas 14 precipitation depths for the latitude and longitude of the observation stations. The climate model ensemble average was then estimated along with the 90% confidence interval.[lxiii] Projections for the 24-hour return period events are provided in the tables below. Note the overall confidence in results of projected preciptitation depths reduces with the more extreme events.

24-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 24-HOUR EVENTS

	NOAA ATLAS 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.91	(2.64-3.25)	3.11	(2.81- 3.41)	3.17	(2.79- 3.54)
5-year	3.97	(3.59-4.43)	4.27	(3.94- 4.60)	4.37	(3.94- 4.80)
10-year	4.81	(4.34-5.34)	5.24	(4.83- 5.64)	5.36	(4.84- 5.89)
25-year	6.05	(5.42-6.69)	6.82	(6.22- 7.42)	6.97	(6.25- 7.69)
50-year	7.13	(6.34-7.86)	8.39	(7.53- 9.25)	8.54	(7.57- 9.50)
100-year	8.35	(7.36-9.17)	10.44	(9.17- 11.71)	10.55	(9.21- 11.88)
200-year	9.74	(8.49-10.7)	13.21	(11.4- 15.02)	13.17	(11.38- 14.96)
500-year	11.9	(10.2-13.0)	18.60	(15.56- 21.65)	18.05	(15.26- 20.85)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 24-Hour Events

	NOAA ATLAS 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.79	(2.51-3.14)	2.92	(2.73- 3.11)	2.97	(2.71- 3.22)
5-year	3.80	(3.41-4.28)	3.96	(3.79- 4.13)	4.10	(3.79- 4.42)
10-year	4.60	(4.12-5.16)	4.81	(4.62- 5.00)	5.05	(4.65- 5.46)
25-year	5.79	(5.14-6.46)	6.14	(5.88- 6.40)	6.58	(5.99- 7.16)
50-year	6.82	(6.02-7.57)	7.39	(7.01- 7.77)	8.03	(7.22- 8.83)
100-year	7.98	(6.98-8.84)	8.93	(8.38- 9.48)	9.85	(8.76- 10.93)
200-year	9.30	(8.04-10.3)	10.87	(10.08- 11.65)	12.18	(10.74- 13.62)
500-year	11.3	(9.63-12.5)	14.27	(13.03- 15.51)	16.35	(14.24- 18.45)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 24-Hour Events

	NOAA ATLAS 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.86	(2.60-3.18)	2.97	(2.80- 3.14)	3.07	(2.74- 3.39)
5-year	3.90	(3.54-4.34)	4.06	(3.88- 4.23)	4.26	(3.85- 4.66)
10-year	4.72	(4.26-5.23)	5.01	(4.73- 5.29)	5.32	(4.73- 5.91)
25-year	5.94	(5.32-6.54)	6.62	(6.05- 7.19)	7.14	(6.14- 8.14)
50-year	6.99	(6.22-7.67)	8.24	(7.32- 9.16)	8.96	(7.51- 10.41)
100-year	8.19	(7.22-8.95)	10.41	(8.95- 11.87)	11.35	(9.27- 13.42)
200-year	9.54	(8.33-10.4)	13.32	(11.12- 15.52)	14.48	(11.61- 17.35)
500-year	11.6	(9.98-12.6)	18.95	(15.27- 22.62)	20.26	(15.93- 24.60)

Understanding the interest by Fairfax County for events with duration less than 24-hours, the following tables have been provided for estimates of the future change for the 12-hour, 6-hour, 3-hour, 2-hour, and 1-hour events. These were developed assuming the historical ratio of the 24-hour storm to the faster duration storms remains the same in the future. Though this is unlikely, this is a current state of practice for developing these tables and does not introduce additional uncertainty into the application of climate model projections.

12-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 12-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.52	(2.27-2.83)	2.70	(2.41- 2.98)	2.74	(2.38- 3.1)
5-year	3.40	(3.05-3.81)	3.66	(3.34- 3.97)	3.74	(3.33- 4.15)
10-year	4.07	(3.63-4.55)	4.43	(4.05- 4.81)	4.54	(4.05- 5.03)
25-year	5.04	(4.46-5.63)	5.68	(5.14- 6.22)	5.81	(5.16- 6.46)
50-year	5.88	(5.14-6.56)	6.92	(6.15- 7.68)	7.04	(6.19- 7.9)
100-year	6.80	(5.88-7.61)	8.50	(7.45- 9.55)	8.59	(7.48- 9.69)
200-year	7.84	(6.68-8.80)	10.63	(9.18- 12.09)	10.60	(9.16- 12.04)
500-year	9.42	(7.87-10.6)	14.73	(12.48- 16.98)	14.29	(12.23- 16.36)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 12-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.44	(2.19-2.75)	2.55	(2.37- 2.74)	2.60	(2.34- 2.85)
5-year	3.28	(2.94-3.69)	3.42	(3.25- 3.59)	3.54	(3.22- 3.86)
10-year	3.92	(3.49-4.39)	4.10	(3.91- 4.29)	4.31	(3.9- 4.72)
25-year	4.85	(4.28-5.43)	5.14	(4.89- 5.4)	5.51	(4.94- 6.08)
50-year	5.64	(4.93-6.30)	6.11	(5.75- 6.47)	6.64	(5.88- 7.4)
100-year	6.52	(5.64-7.29)	7.29	(6.79- 7.79)	8.04	(7.05- 9.03)

200-year	7.50	(6.41-8.39)	8.76	(8.05- 9.48)	9.82	(8.52- 11.12)
500-year	8.99	(7.54-10.1)	11.35	(10.29- 12.42)	13.01	(11.2- 14.82)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 12-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.46	(2.21-2.75)	2.55	(2.39- 2.71)	2.64	(2.33- 2.94)
5-year	3.31	(2.98-3.71)	3.44	(3.28- 3.61)	3.61	(3.23- 3.99)
10-year	3.97	(3.55-4.44)	4.21	(3.95- 4.47)	4.48	(3.94- 5.01)
25-year	4.94	(4.37-5.51)	5.50	(5.01- 6.00)	5.94	(5.06- 6.81)
50-year	5.76	(5.04-6.43)	6.79	(6.02- 7.56)	7.38	(6.17- 8.59)
100-year	6.68	(5.77-7.48)	8.49	(7.36- 9.62)	9.25	(7.65- 10.86)
200-year	7.70	(6.55-8.66)	10.75	(9.16- 12.34)	11.69	(9.61- 13.76)
500-year	9.25	(7.71-10.5)	15.11	(12.77- 17.45)	16.16	(13.4- 18.92)

6-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 6-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.09	(1.89-2.32)	2.24	(1.92- 2.55)	2.27	(1.87- 2.68)
5-year	2.80	(2.52-3.11)	3.01	(2.67- 3.35)	3.08	(2.63- 3.53)
10-year	3.32	(2.98-3.68)	3.62	(3.20- 4.03)	3.70	(3.17- 4.23)
25-year	4.06	(3.61-4.50)	4.57	(3.99- 5.16)	4.68	(3.98- 5.38)
50-year	4.67	(4.12-5.18)	5.49	(4.69- 6.30)	5.59	(4.69- 6.50)
100-year	5.34	(4.67-5.93)	6.68	(5.54- 7.81)	6.74	(5.55- 7.93)
200-year	6.06	(5.25-6.75)	8.22	(6.65- 9.78)	8.20	(6.65- 9.74)
500-year	7.13	(6.08-7.99)	11.15	(8.81- 13.48)	10.82	(8.67- 12.96)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 6-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.02	(1.82-2.26)	2.11	(1.92- 2.31)	2.15	(1.88- 2.42)
5-year	2.71	(2.43-3.02)	2.83	(2.64- 3.01)	2.93	(2.58- 3.27)
10-year	3.21	(2.87-3.58)	3.36	(3.16- 3.55)	3.53	(3.10- 3.95)
25-year	3.93	(3.48-4.38)	4.17	(3.90- 4.43)	4.46	(3.87- 5.06)
50-year	4.52	(3.98-5.03)	4.90	(4.53- 5.27)	5.32	(4.54- 6.11)
100-year	5.17	(4.50-5.75)	5.78	(5.25- 6.31)	6.38	(5.34- 7.42)
200-year	5.87	(5.07-6.54)	6.86	(6.12- 7.60)	7.69	(6.33- 9.04)
500-year	6.91	(5.88-7.73)	8.73	(7.62- 9.83)	10.00	(8.11- 11.88)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 6-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	2.05	(1.86-2.26)	2.13	(1.94- 2.31)	2.20	(1.85- 2.55)
5-year	2.74	(2.48-3.03)	2.85	(2.66- 3.04)	2.99	(2.56- 3.42)
10-year	3.25	(2.93-3.59)	3.45	(3.16- 3.74)	3.66	(3.06- 4.27)
25-year	3.98	(3.55-4.40)	4.44	(3.89- 4.98)	4.78	(3.83- 5.74)
50-year	4.58	(4.05-5.07)	5.40	(4.56- 6.24)	5.87	(4.55- 7.19)
100-year	5.23	(4.58-5.80)	6.65	(5.40- 7.89)	7.25	(5.48- 9.01)
200-year	5.94	(5.14-6.61)	8.30	(6.54- 10.05)	9.02	(6.72- 11.31)
500-year	6.97	(5.94-7.83)	11.39	(8.82- 13.95)	12.18	(9.15- 15.2)

3-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 3-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.70	(1.54-1.89)	1.82	(1.51- 2.13)	1.85	(1.46- 2.25)
5-year	2.29	(2.07-2.54)	2.46	(2.12- 2.81)	2.52	(2.06- 2.98)
10-year	2.71	(2.44-3.01)	2.95	(2.55- 3.35)	3.02	(2.50- 3.54)
25-year	3.30	(2.94-3.65)	3.72	(3.12- 4.32)	3.80	(3.09- 4.52)
50-year	3.77	(3.34-4.17)	4.43	(3.60- 5.27)	4.52	(3.58- 5.45)
100-year	4.26	(3.75-4.72)	5.33	(4.17- 6.49)	5.38	(4.16- 6.60)
200-year	4.80	(4.18-5.33)	6.51	(4.90- 8.12)	6.49	(4.90- 8.09)
500-year	5.57	(4.79-6.22)	8.71	(6.29- 11.12)	8.45	(6.23- 10.67)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 3-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.64	(1.48-1.84)	1.72	(1.52- 1.91)	1.74	(1.48- 2.01)
5-year	2.22	(1.99-2.47)	2.31	(2.13- 2.5)	2.40	(2.04- 2.75)
10-year	2.63	(2.35-2.93)	2.75	(2.55- 2.95)	2.89	(2.46- 3.32)
25-year	3.20	(2.84-3.56)	3.39	(3.12- 3.66)	3.63	(3.03- 4.24)
50-year	3.66	(3.23-4.06)	3.97	(3.58- 4.35)	4.31	(3.50- 5.12)
100-year	4.15	(3.63-4.61)	4.64	(4.11- 5.18)	5.12	(4.07- 6.17)
200-year	4.68	(4.06-5.21)	5.47	(4.72- 6.21)	6.13	(4.76- 7.49)
500-year	5.45	(4.67-6.08)	6.88	(5.75- 8.02)	7.88	(5.95- 9.82)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 3-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.68	(1.53-1.86)	1.74	(1.57- 1.92)	1.80	(1.47- 2.13)
5-year	2.27	(2.05-2.50)	2.36	(2.16- 2.56)	2.48	(2.03- 2.93)
10-year	2.68	(2.41-2.96)	2.84	(2.55- 3.13)	3.02	(2.41- 3.63)
25-year	3.25	(2.91-3.58)	3.62	(3.06- 4.18)	3.91	(2.91- 4.90)
50-year	3.71	(3.30-4.09)	4.37	(3.50- 5.25)	4.76	(3.38- 6.13)
100-year	4.19	(3.69-4.63)	5.32	(4.04- 6.61)	5.81	(3.97- 7.64)
200-year	4.70	(4.11-5.21)	6.56	(4.74- 8.39)	7.13	(4.75- 9.52)
500-year	5.43	(4.68-6.06)	8.87	(6.14- 11.6)	9.49	(6.27- 12.71)

2-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 2-HOUR EVENTS

	NOAA ATLAS 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.59	(1.44-1.76)	1.70	(1.38- 2.03)	1.73	(1.32- 2.14)
5-year	2.15	(1.94-2.37)	2.31	(1.94- 2.68)	2.36	(1.88- 2.85)
10-year	2.53	(2.28-2.79)	2.76	(2.32- 3.19)	2.82	(2.26- 3.38)
25-year	3.06	(2.74-3.37)	3.45	(2.82- 4.07)	3.53	(2.77- 4.28)
50-year	3.48	(3.10-3.84)	4.09	(3.24- 4.95)	4.17	(3.21- 5.12)
100-year	3.93	(3.47-4.34)	4.91	(3.71- 6.11)	4.96	(3.70- 6.22)
200-year	4.40	(3.85-4.87)	5.97	(4.30- 7.63)	5.95	(4.30- 7.60)
500-year	5.08	(4.18-5.33)	7.94	(5.43- 10.45)	7.71	(5.40- 10.01)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 2-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.53	(1.38-1.70)	1.60	(1.39- 1.81)	1.63	(1.34- 1.91)
5-year	2.07	(1.86-2.29)	2.16	(1.96- 2.36)	2.24	(1.86- 2.61)
10-year	2.45	(2.19-2.71)	2.56	(2.35- 2.78)	2.69	(2.23- 3.15)
25-year	2.97	(2.64-3.29)	3.15	(2.87- 3.43)	3.37	(2.74- 4.00)
50-year	3.38	(3.00-3.75)	3.66	(3.28- 4.04)	3.98	(3.17- 4.79)
100-year	3.83	(3.37-4.24)	4.28	(3.73- 4.84)	4.73	(3.63- 5.82)
200-year	4.30	(3.75-4.76)	5.03	(4.24- 5.81)	5.63	(4.18- 7.08)
500-year	4.99	(4.30-5.54)	6.30	(5.11- 7.49)	7.22	(5.19- 9.25)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 2-Hour Events

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.58	(1.43-1.74)	1.64	(1.45- 1.83)	1.69	(1.34- 2.05)
5-year	2.12	(1.93-2.33)	2.20	(2.00- 2.41)	2.31	(1.85- 2.77)
10-year	2.50	(2.26-2.75)	2.65	(2.35- 2.95)	2.82	(2.18- 3.45)
25-year	3.01	(2.71-3.32)	3.35	(2.80- 3.91)	3.62	(2.64- 4.60)
50-year	3.42	(3.05-3.77)	4.03	(3.16- 4.91)	4.38	(3.01- 5.76)
100-year	3.84	(3.41-4.24)	4.88	(3.58- 6.18)	5.32	(3.47- 7.17)
200-year	4.28	(3.77-4.75)	5.98	(4.17- 7.78)	6.50	(4.14- 8.85)
500-year	4.92	(4.27-5.49)	8.04	(5.3- 10.77)	8.60	(5.37- 11.82)

1-Hour Events (precipitation depths provided in inches)

VIENNA (USC00448737), 1-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.36	(1.23-1.50)	1.45	(1.12- 1.79)	1.48	(1.05- 1.91)
5-year	1.82	(1.65-2.01)	1.96	(1.60- 2.32)	2.00	(1.52- 2.48)
10-year	2.13	(1.92-2.35)	2.32	(1.89- 2.75)	2.38	(1.82- 2.93)
25-year	2.54	(2.27-2.80)	2.86	(2.24- 3.48)	2.93	(2.18- 3.67)
50-year	2.86	(2.54-3.15)	3.36	(2.49- 4.23)	3.43	(2.45- 4.40)
100-year	3.18	(2.81-3.51)	3.98	(2.77- 5.18)	4.02	(2.75- 5.28)
200-year	3.51	(3.09-3.90)	4.76	(3.16- 6.36)	4.75	(3.16- 6.33)
500-year	3.98	(3.46-4.44)	6.22	(3.79- 8.66)	6.04	(3.80- 8.28)

WASHINGTON DULLES INTERNATIONAL AIRPORT (USW00093738), 1-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.31	(1.18-1.45)	1.37	(1.15- 1.59)	1.39	(1.10- 1.69)
5-year	1.75	(1.58-1.95)	1.82	(1.64- 2.01)	1.89	(1.54- 2.24)
10-year	2.06	(1.84-2.28)	2.15	(1.94- 2.37)	2.26	(1.80- 2.72)
25-year	2.45	(2.19-2.71)	2.60	(2.31- 2.88)	2.78	(2.14- 3.42)
50-year	2.76	(2.45-3.06)	2.99	(2.61- 3.37)	3.25	(2.43- 4.06)
100-year	3.08	(2.72-3.41)	3.45	(2.89- 4.00)	3.80	(2.71- 4.89)
200-year	3.42	(2.99-3.78)	4.00	(3.20- 4.80)	4.48	(3.01- 5.95)
500-year	3.88	(3.37-4.32)	4.90	(3.74- 6.06)	5.61	(3.64- 7.58)

WASHINGTON REAGAN NATIONAL AIRPORT (USW00013743), 1-HOUR EVENTS

	NOAA Atlas 14	90% CI	RCP4.5	90% CI	RCP8.5	90% CI
2-year	1.37	(1.25-1.51)	1.42	(1.24- 1.61)	1.47	(1.12- 1.82)
5-year	1.83	(1.66-2.02)	1.90	(1.71- 2.10)	2.00	(1.56- 2.44)
10-year	2.14	(1.94-2.36)	2.27	(1.97- 2.56)	2.41	(1.79- 3.03)
25-year	2.55	(2.29-2.82)	2.84	(2.30- 3.38)	3.06	(2.11- 4.02)
50-year	2.86	(2.56-3.17)	3.37	(2.55- 4.20)	3.67	(2.37- 4.97)
100-year	3.18	(2.82-3.53)	4.04	(2.81- 5.27)	4.41	(2.65- 6.16)
200-year	3.51	(3.10-3.91)	4.90	(3.16- 6.64)	5.33	(3.06- 7.60)
500-year	3.97	(3.45-4.44)	6.49	(3.81- 9.16)	6.94	(3.78- 10.09)

Appendix B. Observed and Projected Data & Resources for Fairfax County

This Appendix presents two tables of data and resources available for:

- Table B.1. Observed Climate Data and Resources
- Table B.2. Projected Climate Data and Resources

This information helped inform this report.

Table B.1. Observed Climate Data and Resources (Data Type – "X" identifies data that is already processed ("ready to go"); "D" identifies data that can be processed to estimate conditions; "N" identifies a narrative that describes current and/or future conditions; "P" is processed data).

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
	Heavy Precipitation				
X	NOAA Atlas-14 Volume 2[lxiv]	Precipitation frequency estimates	Point frequency GIS grids		Annual exceedance probabilities from 1/2 to 1/100 for durations of 5-min through 60-day
X	Northern Virginia Regional Commission's Climate Resilience Dashboard	Number of days with precipitation above 1", 2", and 3" thresholds	Grid cell [4 km]	1976-Present	Present change from 2006-2017 relative to 1976-2005 Based on Mid-Atlantic RISA, interpolates daily precipitation observations for the Chesapeake Bay watershed (ChesWx) Tool is excerpted from the Chesapeake Bay Watershed Climate Impacts Summary and Outlook for 2018

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
D	NASA's Modern-Era Retrospective Analysis for Research and Applications (MERRA-2)	Hourly precipitation that can be used to develop estimates of interest	0.5 degree latitude and 0.67 degrees longitude for the entire globe	Hourly	Reanalysis model that combines physics-based modeling with satellite, airborne, ship, radiosonde, and buoy measurements
D	NOAA's Global Historical Climate Network (GHCN)	Daily precipitation	Station locations	Time period is station dependent	No hourly precipitation data source identified for a station in the County Stations with Daily precipitation: McLean: GHCND:US1VAFX0041 (2008-2021) McLean: GHCND:US1VAFX0052 (2010-2021) McLean: GHCND:US1VAFX0053 (2011-2018) Falls Church: GHCND:US1VAFX0064 (2013-2021) Fairfax: GHCND:US1VAFX0059 (2013-2018) Mantua: GHCND:US1VAFX0037 (2006-2021) Oakton: GHCND:US1VAFX0060 (2013-2021) Herndon: GHCND:US1VAFX0001 (2005-2021) Vienna: GHCND:USC00448737 (1925-2021)[lxv] Washington Dulles Airport: GHCND: USW00093738 (1960 – 2021)[lxvi] Reagan National Airport GHCND:USW00013743 (1936-2021)[lxvii]

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
X	The Climate Explorer	Precipitation thresholds	Vienna USC00448737	1927-2021	Precipitation total events above thresholds (e.g., 1" in 1 day)
N	Northern Virginia Hazard Mitigation Plan (2017), NCDC data	Weather metrics	Station data	1960-2000	
D	Livneh dataset	Daily precipitation	1/16th degree	Daily 1950-2005	Gridded set of daily precipitation values for the U.S based on observations that have been spatially averaged and smoothed *[Generally used with LOCA climate projections]*
	Inland Flooding				
X	FEMA Flood Hazard Areas maps	Zone A, Zone AE			Zone A - "Areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage. Because detailed analyses are not performed for such areas, no depth or base flood elevations are shown within these zones." Zone A is considered a high-risk area and flood insurance is required for properties with a federally backed mortgage. Zone AE - "The base floodplain where base flood elevations are provided. AE Zones are now used on new format Flood Insurance Rate Maps instead of A1-A30 Zones." Zone AE is considered a high risk area and flood insurance is required for properties with a federally backed mortgage.
X	Resource protection areas	1993 RPAs 2003 RPAs 2003 (Rev)RPAs			Corridors of environmentally sensitive lands that lie alongside or near the shorelines of streams, rivers and other waterways.
D	NOAA Storm Event Database	Heavy rain, flash flood, flood (damaged crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	Chance of occurring in any given year: Heavy rain: 66% Flash flood: 116% Flood: 56%

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
D	NFIP Policies & Claims Paid	Flood policies	Policy	1978-2016	607 policies; 50 claims totaling $888,560 since 1978 Repetitive loss claims: $3,395,839.21 *Source: VA 2018 Hazard Mitigation Plan*
N	NOAA's Flood Exposure Snapshot for Fairfax County, VA	Population in flood plain	NA	NA	6% (62,731 of 1,101,701 population) in FEMA Floodplain 6% (6,850 of 113,503 population) over 65 in FEMA floodplain 4% (2,887 of 64,274 population) in poverty in FEMA floodplain 0% critical infrastructure in FEMA floodplain
P	USGS Trend Analysis Tool	Streamflow	Locations		Shows significant to non-significant upward trend
	Extreme storms (wind, thunderstorms, blizzards, hurricanes, tornadoes)				
D	NOAA's Global Historical Climate Network (GHCN)	Snow/ice/hail Weather type	2 Stations	1925-2021 & 1960-2021	Vienna: GHCND:USC00448737 (1925-2021) Washington Dulles Airport: GHCND: USW00093738 (1960 – 2021)
D	NOAA hurricane tracker	Past hurricanes traveled across county	Storm tracks	1800s to 2021	Identifies 9 storms in 1861 to 1939
D	NOAA Storm Event Database	Past storm events (damaged crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	100% chance of occurring in any given year: winter weather, frost/freeze, heat, flash flood, hail Other events at less than 100% chance of occurring
D	NOAA U.S. Tornado Climatology	Tornado event	Event	1991-2010	18 events in state of Virginia
P	Northern Virginia Hazard Mitigation Plan (2017), NCDC data	Average number of days per year with snow >= 3”, >=6”	Interpolated between stations	1960-2000	Based on NCDC station data available from 1960 to 2000 & then interpolated for mapping Figures 4.24 & 4.25

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N/P	Northern Virginia Hazard Mitigation Plan (2017), FEMA source	Thunderstorm activity	NA	1948-1977	"50 to 60 thunderstorm events occur annually in Northern Virginia"
N/P	Northern Virginia Hazard Mitigation Plan (2017), FEMA source	Wind zones (wind speed susceptibility)	NA		Zone 2 (160 mph) in hurricane-susceptible region "Straight-line winds, which in extreme cases have the potential to cause wind gusts that exceed 100 miles per hour, are responsible for most thunderstorm wind damage." Downburst are a type of these winds. Also includes tornado activity and hurricane history
N/P	Northern Virginia Hazard Mitigation Plan (2017), American Society of Civil Engineers	Tornado Activity	NA	Not provided	Map shows 1-5 tornadoes recorded per 1,000 square miles Based on NOAA Storm Prediction Center Statistics
N/P	Northern Virginia Hazard Mitigation Plan (2017), FEMA source	Number of days with hailstorms	NA		Less than 2 days per year Hailstones defined as masses of ice > 0.75"
N/P	Northern Virginia Hazard Mitigation Plan (2017), source - NWS Forecast Office, Cleveland Ohio	Derecho	NA	NA	Map suggests one derecho every 4 years
N/P	VA Hazard Mitigation Plan (2018)	Winter weather	NA	NA	Suggests NOAA's NCEI shows "frequency of extreme snowstorms in the eastern US has increased over the past century, with approximately twice as many extreme snowstorms occurring in the last half of the 20th century as in the first half." [page 477]

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N	USGCRP Climate Science Report (2017)	Extreme storms	NA	NA	"Upward trend in North Atlantic hurricane activity since 1970s; increase in tropical cyclone (TC) intensity in a warmer world, and the models generally show an increase in the number of very intense TCs; Tornado activity in the United States has become more variable, particularly over the 2000s, with a decrease in the number of days per year with tornadoes and an increase in the number of tornadoes on these days; Winter storm tracks have shifted northward since 1950 over the Northern Hemisphere"
	Coastal flooding & sea level rise				
D	NOAA tide gauge	Relative sea level rise trends	1 station	1924-2021	Washington DC tide gage: 8594900
D	NOAA Storm Event Database	Coastal flood crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	Chance of coastal flood occurring in any given year: 3%
D	VA 2018 Hazard Mitigation Plan	Hurricane wind	Events in VDEM Region 7		$1,617,701 annualized hurricane wind annualized loss estimate
N	VA 2018 Hazard Mitigation Plan	Coastal erosion	NA	NA	"Northern Virginia ranked coastal erosion as a low risk hazard" [page 192]
P	NOAA Sea level rise data	Coastal flood	~500m	NA	Layer at 0 feet of sea level rise (MHHW- the average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch (NTDE) ~19 years))
P	NOAA Sea level rise viewer	High tide flooding	~500m	NA	Illustrates Fort Hunt, Mt Vernon vulnerability

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N	Climate Resilience Dashboard	Sea level rise	DC tide gauge	1924-2018	"In Northern Virginia, the reach of the Potomac River downstream of the Great Falls in Great Falls National Park is hydrologically connected to the ocean. Therefore, it is influenced by tides and storm surge. In addition to the aforementioned sea level rise contributors, land subsidence (or land sinking) contributes to the rate of sea level rise. The relative sea level trend observed at the tidal gauge on the Potomac River in Washington, D.C. is 3.33 mm/year of rise. This trend is based on observed monthly mean sea level data from 1924 to 2018 which is equivalent to a change of 1.09 feet in 100 years."
	Extreme Heat				
D	NOAA's Global Historical Climate Network (GHCN)	24 hour maximum temperature	2 Stations	1925-2021 & 1960-2021	Vienna: GHCND:USC00448737 (1925-2021) Washington Dulles Airport: GHCND: USW00093738 (1960 – 2021)
D	NOAA Storm Event Database	Heat event (damaged crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	Chance of occurring in any given year: Heat: 150% Excessive Heat: 28%
N/P	Northern Virginia Hazard Mitigation Plan (2017), based on NCDC data	Heat index (temperature/humidity)	NA	Unknown	"future probability of some type of extreme temperature may be estimated as high" for Northern Virginia Table 4.133 presents heat index in health hazard categories (80F to > 130F)
	Extreme cold				

Type	Source	Climate Variables	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
D	NOAA's Global Historical Climate Network (GHCN)	24 hour minimum temperature	2 Stations	1925-2021 & 1960-2021	Vienna: GHCND:USC00448737 (1925-2021) Washington Dulles Airport: GHCND: USW00093738 (1960 – 2021)
D	NOAA Storm Event Database	Extreme cold (damaged crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	Chance of occurring in any given year: Cold/Wind Chill: 22% Extreme Cold/Wind Chill: 16%
N/P	Northern Virginia Hazard Mitigation Plan (2017), based on NCDC data	Windchill (extreme cold, wind, precipitation)	NA	Unknown	future probability of some type of extreme temperature may be estimated as high" for Northern Virginia Temperatures feel like -30F or colder for at least several hours
	Drought				
D	NOAA's Global Historical Climate Network (GHCN)	24 hour minimum temperature	2 Stations	1925-2021 & 1960-2021	Vienna: GHCND:USC00448737 (1925-2021) Washington Dulles Airport: GHCND: USW00093738 (1960 – 2021) Could use temperature/precipitation values as input into a developing a drought indicator
D	NOAA Storm Event Database	Drought (damaged crops/properties/loss of life)	Event	1950-2021 (evaluated 1990-2021)	Chance of drought occurring in any given year: 31%
N/P	Northern Virginia Hazard Mitigation Plan (2017), National Drought Mitigation Center	% of time in severe/extreme drought based on Palmer Drought Severity Index (PDSI)	NA	1895-1995	% of time PSDI <= -3, Fairfax County: 5-9.99% Meteorological drought based on temperature, precipitation, and available water content of soil data [-0.5 is a dry spell to -4.0 as extreme drought]

Table B.2. Projections of Climate Data and Resources (Data "Type" – "X" already processed ("ready to go"); "D" data that can be processed to estimate conditions; "N" narrative that describes conditions; "P" is processed data)

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
	Heavy Precipitation						
N	NOAA NCEI Climate State Summaries	Extreme Precipitation Events	NA	NA	State of Virginia	NA	"The number and intensity of extreme heat and extreme precipitation events are projected to increase."
P	The Climate Explorer	Total Precipitation Days >1", 2", 3" Dry days	LOCA data	RCP4.5 RCP8.5	Fairfax County	1950-2099	Rolling 10-year average line graph for county
P	Northern Virginia Regional Commission's Climate Resilience Dashboard	Number of days with precipitation above 1", 2", and 3" thresholds	LOCA data	RCP4.5 RCP8.5	6 km	2006-2035 2036-2065 2066-2095 Relative to 1976 to 2005	Based on Mid-Atlantic RISA
D	Localized Constructed Analog (LOCA)	Precipitation	32 CMIP5 GCMs	RCP4.5 RCP8.5	1/16th (6 km)	Daily 1950-2099	Statistical downscaling Develop extreme precipitation events for various exceedance probabilities *Also provides daily temperatures*
D	North American Coordinated Regional Downscaling Experiment (NA-Cordex)	Precipitation	7 CMIP5 GCMs coupled with regional models	RCP4.5 RCP8.5	25 km	Daily 1950-2099	Dynamical downscaling *Also provides temperature, wind, evaporation, etc., depending on simulation]*

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
D	Multivariate Adaptive Constructed Analogs (MACA)	Precipitation	20 CMIP5 GCMs	RCP4.5 RCP8.5	4 & 6 km	Daily 1950-2099	Statistical downscaling *Also provides temperatures, humidity, wind, radiation*
	Inland Flooding						
P	USACE North American Comprehensive, Appendix D-10: Commonwealth of Virginia	Storm surge inundation of Category 2	NA	Low, Intermediate, High of USACE 2013		2050, 2080	Used in the DC vulnerability assessment with 2050 as a proxy for FEMA 100-year base elevation + 3 feet of SLR With 2080 as a proxy for FEMA 100-year base elevation + 4 feet of SLR
	Extreme storms (wind, thunderstorms, blizzards, hurricanes, tornadoes)						
N	VA Hazard Mitigation Plan (2018)	Tropical Cyclones	NA	NA	NA	NA	Suggests increased hurricane development/ intensification based on: Warming of tropical Atlantic SSTs over 21st century, (2) even more warming of upper tropospheric temperatures, (3) Increasing levels of vertical wind shear over parts of the western tropical Atlantic [citing GFDL]
N	VA Hazard Mitigation Plan (2018)	Tornados	NA	NA	NA	NA	Not conclusive future change. Cites some studies suggest conditions that produce more severe storms are likely to occur with more frequency in a warmer climate (though possible reduction in frequency of thunderstorms]. [see page 425]

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N	VA Hazard Mitigation Plan (2018)	Winter weather	NA	NA	NA	NA	Some suggestion of favorable winter storm development for eastern U.S. based rising SSTs and reduction in Arctic sea ice. [see page 477]
N	USGCRP Climate Science Report (2017)	Extreme storms	NA	NA	NA	NA	Overall low confidence in findings - "Projections of winter storm frequency and intensity over the United States vary from increasing to decreasing depending on region."
	Coastal flooding & sea level rise						
P	NOAA Sea level rise data	Coastal flood	NA	0 foot to 10 feet above present day	~500m	NA	1 foot increments – linked to SLR levels over uncertainty range using nearby gauge for 2050 and end of century (MHHW)
P	Northern Virginia Regional Commission's Climate resilience dashboard using NOAA SLR data	Coastal flood	NA	1, 3, 5 feet of rise	~500m	NA	Number of parcels and acres flooded, value of exposed properties
P	USACE Sea Level Rise Calculator	Relative sea level rise	NA	USACE 2013 NOAA 2017	Tide gauge	Today to 2100	Washington DC tide gauge
	Extreme heat						
P	Northern Virginia Regional Commission's Climate Resilience Dashboard for Fairfax County	Average number of days per year with min temps above 70, 75, 80F	LOCA	RCP4.5 RCP8.5	6km	1981, 2011, 2041, 2071	Based on Mid-Atlantic RISA

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N	NOAA NCEI Climate State Summaries	Extreme heat	NA	NA	State of Virginia	NA	"The number and intensity of extreme heat and extreme precipitation events are projected to increase."
P	The Climate Explorer	Average daily maximum temperature Days above 90F, 95F, 100F, 105F CDD	LOCA data	RCP4.5 RCP8.5	Fairfax County	1950-2099	Rolling 10-year average line graph for county
D	Localized Constructed Analog (LOCA)	Maximum Temperature	32 CMIP5 GCMs	RCP4.5 RCP8.5	$1/16^{th}$ (6 km)	Daily 1950-2099	Statistical downscaling *Also provides daily precipitation, min temp*
D	North American Coordinated Regional Downscaling Experiment (NA-Cordex)	Maximum Temperature	7 CMIP5 GCMs coupled with regional models	RCP4.5 RCP8.5	25 km	Daily 1950-2099	Dynamical downscaling Also provides precipitation, wind, *evaporation, etc., depending on simulation*
D	Multivariate Adaptive Constructed Analogs (MACA)	Maximum Temperature	20 CMIP5 GCMs	RCP4.5 RCP8.5	4 & 6 km	Daily 1950-2099	Statistical downscaling *Also provides precipitation, humidity, wind, radiation*
	Extreme cold						

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
P	Mid-Atlantic RISA projections	Freeze-thaw	LOCA data	RCP4.5 RCP8.5	6km	1981-2010, 2011-2040, 2041-2070, 2071-2099	Defined as days with Tmax >=32F and Tmin <=28F
N	NOAA NCEI Climate State Summaries	Extreme cold	NA	NA	State of Virginia	NA	"Extreme cold waves are projected to be less intense."
P	The Climate Explorer	Avg Daily Min Temp Days Tmin or Tmax below 32 HDD	LOCA data	RCP4.5 RCP8.5	Fairfax County	1950-2099	Rolling 10-year average line graph for county
D	Localized Constructed Analog (LOCA)	Minimum Temperature	32 CMIP5 GCMs	RCP4.5 RCP8.5	$1/16^{th}$ (6 km)	Daily 1950-2099	Statistical downscaling *Also provides daily precipitation, max temp*
D	North American Coordinated Regional Downscaling Experiment (NA-Cordex)	Minimum Temperature	7 CMIP5 GCMs coupled with regional models	RCP4.5 RCP8.5	25 km	Daily 1950-2099	Dynamical downscaling Also provides precipitation, wind, *evaporation, etc., depending on simulation*
D	Multivariate Adaptive Constructed Analogs (MACA)	Minimum Temperature	20 CMIP5 GCMs	RCP4.5 RCP8.5	4 & 6 km	Daily 1950-2099	Statistical downscaling *Also provides precipitation, humidity, wind, radiation*
	Drought						

Type	Source	Climate Variables	GCMs Downscaling	Scenarios	Spatial Resolution	Temporal Resolution & Time Period	Additional Description
N	NOAA NCEI Climate State Summaries	Drought	NA	NA	State of Virginia	NA	"Naturally occurring droughts are projected to be more intense because higher temperatures will increase evaporation rates, depleting soil moisture more rapidly and adversely affecting agriculture."

I. Endnotes

[i] Australia Climate Change, “Greenhouse Gas Scenarios.” https://www.climatechangeinaustralia.gov.au/en/changing-climate/future-climate-scenarios/greenhouse-gas-scenarios/

[ii] Sources for the Glossary: U.S. Energy Information Administration, “Units and Calculators Explained.” https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php; USGCRP glossary for climate change, https://www.globalchange.gov/climate-change/glossary; IPCC glossary https://www.ipcc.ch/sr15/chapter/glossary/; NOAA’s Climate.gov, “Climate Models.” https://www.climate.gov/maps-data/primer/climate-models; NOAA, “Tropical Definitions.” https://www.weather.gov/mob/tropical_definitions

[iii] IPCC Expert Meeting Report, Towards New Scenarios For Analysis Of Emissions, Climate Change, Impacts, And Response Strategies, IPCC 2007

[iv] Figure 2.2 in the National Climate Assessment report (2018). Wuebbles, D.J., D.R. Easterling, K. Hayhoe, T. Knutson, R.E. Kopp, J.P. Kossin, K.E. Kunkel, A.N. LeGrande, C. Mears, W.V. Sweet, P.C. Taylor, R.S. Vose, and M.F. Wehner, 2017: Our globally changing climate. Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 35-72. http://dx.doi.org/10.7930/J08S4N35

[v] LOCA data, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections, https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/

[vivi] LOCA data, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections, https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About

[vii] Miro, M., A. DeGaetano, T. Lopez-Cantu, C. Samaras, M. Webber, and K. Grocholski, (2021). Developing Future Projected Intensity-Duration-Frequency (IDF) Curves. Sponsored by Chesapeake Bay Trust.

[viii] Climate models used in this study: access1-0.1, access1-3.1, bcc-csm1-1.1, bcc-csm1-1-m.1, canesm2.1, ccsm4.6, cesm1-bgc.1, cesm1-cam5.1, cmcc-cm.1, cnrm-cm5.1, csiro-mk3-6-0.1, ec-earth.8, fgoals-g2.1, gfdl-cm3.1, gfdl-esm2g.1, gfdl-esm2m.1, giss-e2-r.6, hadgem2-ao.1, hadgem2-cc.1., hadgem2-es.1, inmcm4.1, ipsl-cm5a-lr.1, ipsl-cm5a-mr.1, miroc-esm.1, miroc-esm-chem.1, miroc5.1, mpi-esm-lr.1., mpi-esm-mr.1, mri-cgcm3.1, noresm1-m.1, cmcc-cms.1, giss-e2-h.6.

[ix] Hawkins, E., Sutton, R. The potential to narrow uncertainty in projections of regional precipitation change. *Clim Dyn* 37, 407–418 (2011). https://doi.org/10.1007/s00382-010-0810-6

[x] As used in the DC study.

[xi] Fairfax County Government, “Extreme Weather Events in Fairfax County.” https://www.fairfaxcounty.gov/boardofsupervisors/sites/boardofsupervisors/files/assets/meeting-materials/2020/june16_enviornmental_agenda%20item%202_extreme%20weather%20events%20handout.pdf

[xii] NOAA NCEI Storm Events Database accessed in May 2021 at https://www.ncdc.noaa.gov/stormevents/choosedates.jsp?statefips=51%2CVIRGINIA

[xiii] Though the database provides recorded observations prior to 1990, the 1990 to 2021 time period was chosen to provide a more representative snapshot of recent conditions.

[xiv] Note that the database captures the tropical cyclone type at the time the storm travels over the County. For example, Hurricane Isabel was downgraded to a tropical storm as it moved across central Virginia.

[xv] National Climate Assessment Report (2018): Southeast Chapter. https://nca2018.globalchange.gov/chapter/19/

[xvi] This is similar to the projections for Washington DC that are based on another statistically downscaled data set. That report found an increase of hot days above 95?F between 30 and 45 days for the 2045-2064 (slightly later time period) for Reagan National Airport observation data from 1950-2010 (earlier time period so would expect more change to be represented). (Hayhoe and Stoner (2015), Climate Change Projections for the District of Columbia)

[xvii] Northern Virginia Mitigation Plan 2017.

[xviii] MACA Training Data, https://climate.northwestknowledge.net/MACA/MACAtrainingdata.php

[xix] MACA Training Data, https://climate.northwestknowledge.net/MACA/tool_summarymaps3.php

[xx] NASA DEVELOP National Program Virginia – Langley. (2021). Fairfax County Urban Development – Identifying Urban Heat Mitigation Strategies for Climate Adaptation Planning in Fairfax County, Virginia. For full report, please contact the Office of Environmental and Energy Coordination at ResilientFairfax@fairfaxcounty.gov

[xxi] Huang, Li, Liu, and Seto, 2019: Projecting global urban expansion and heat island intensification through 2050. Environmental research letters, (14) 114037.

[xxii] Hibbard, K. A., F. M. Hoffman, D. Huntzinger, and T. O. West, 2017: Changes in Land Cover and Terrestrial Biogeochemistry. *Climate Science Special Report: Fourth National Climate Assessment, Volume I*. Wuebbles, D. J., D. W. Fahey, K. A. Hibbard, D. J. Dokken, B. C. Stewart, and T. K. Maycock, Eds., U.S. Global Change Research Program, Washington, DC, USA, 277–302. doi:10.7930/J0416V6X

[xxiii] USGCRP Indicators Platform, https://www.globalchange.gov/indicators

[xxiv] NOAA ATLAS 14, https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html

[xxv] Fairfax County Floodplain Management: Flood Information | Public Works and Environmental Services (fairfaxcounty.gov); see Part 9 of Article 2 of Zoning Ordinance: Document Viewer | Zoning Ordinance (encodeplus.com); Chapter 6-0700 of Public Facilities Manual; Document Viewer | Public Facilities Manual (encodeplus.com)

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[xxvii] See https://midatlantic-idf.rcc-acis.org/ that provides the tool, technical resources and guidance in using the data.

[xxviii] Glossary of Meteorology (1959). https://www.ametsoc.org/ams/index.cfm/publications/glossary-of-meteorology/

[xxix] NOAA NCEI, “Definition of Drought.” https://www.ncdc.noaa.gov/monitoring-references/dyk/drought-definition#:~:text=As%20a%20result%2C%20the%20climatological,weather%20patterns%20dominate%20an%20area.

[xxx] NOAA National Centers for Environmental information, “Climate at a Glance: Statewide Time Series”, https://www.ncdc.noaa.gov/cag/statewide/rankings/44/pdsi/196811

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[xxxv] NOAA Tides & Current, "Relative Sea Level Trend for Washington, District of Columbia", https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8594900

[xxxvi] NOAA, "Climate Change: Global Sea Level." https://www.climate.gov/news-features/understanding-climate/climate-change-global-sea-level. Note that sea level rise varies around the world due to a number of local factors including subsidence, upstream flood control, erosion, regional ocean currents, variations in land height, and whether the land is still rising in response to the compressive weight of Ice Age glaciers (i.e., uplift).

[xxxvii] NOAA, 2017. Global And Regional Seas Level Rise Scenarios For the United States. NOAA Technical Report NOS CO-OPS 083. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

[xxxviii] USACE Sea-Level Change Curve Calculator, https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

[xxxix] The observed scenario simply extends the current trend to the end of the century. It is highly likely this underestimates the future rise as evidenced by the recent uptick in rise that has occurred over the past few decades compared to the past century.

[xl] There are a number of challenges in first projecting global sea level rise estimates based on the potential changes in ice sheet and glacier mass in response to changes in climate as well as capturing the thermal expansion and atmosphere-ocean dynamics appropriately. These curves assume that the rate of ice-sheet mass loss increases with a constant acceleration. Then there are challenges to translate the global rise to relative sea level rise (locally) as it may be impacted by land-water storage relationships such as population demands, groundwater withdrawal and dam storage, and long-term contributors of tectonics, sediment compaction, and uplift. A vertical land movement was estimated to be 0.043 feet/decade and used in these calculations.

[xli] Scenarios are based on NOAA (2017), Global and regional sea level rise scenarios for the United States. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

[xlii] USACE DC Coastal Study website. https://www.nab.usace.army.mil/DC_Coastal_Study/

[xliii] This methodology is also consistent with the future flood exposure maps developed for the District of Columbia. (https://doee.dc.gov/publication/climate-adaptation-planning-vulnerability-and-risk-assessment)

[xliv] Northern Virginia Hazard Mitigation Plan (2017). https://www.alexandriava.gov/uploadedFiles/fire/info/HazMit%20Final%20Draft%208.24.17.pdf

[xlv] This analysis also reviewed climate projection results based on the Multivariate Adaptive Constructed Analogs (MACA) ensemble data and found no notable change in projected seasonal wind speed.

[xlvi] NOAA State of the Science FACT SHEET: How Changing Climate Affects Extreme Events, March 2021.

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[xlix] Tropical cyclones develop best with high sea surface temperatures and low wind shear conditions.

[l] NOAA, “About Derechos.” https://www.spc.noaa.gov/misc/AbtDerechos/derechofacts.htm

[li] Northern Virginia Hazard Mitigation Plan (2017).

[lii] Fairfax County Government Office of Emergency Management. https://www.fairfaxcounty.gov/emergency/readyfairfax/thunderstorm

[liii] Koehler, 2019. A U.S. thunderstorm climataology based on 25 years of NLDN Observations (1993-2017).

[liv] Koehler, 2019. A U.S. thunderstorm climataology based on 25 years of NLDN Observations (1993-2017).

[lv] For example, severe thunderstorms require upper-level wind shear conditions to ensure the storm updrafts and downdrafts remain separated.

[lvi] USGCRP, 2017: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp, doi:

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[lix] NOAA NCEI. Climate Change and extreme snow in the United States. https://www.ncdc.noaa.gov/news/climate-change-and-extreme-snow-us

[lx] NOAA NCEI. Climate Change and extreme snow in the United States. https://www.ncdc.noaa.gov/news/climate-change-and-extreme-snow-us

[lxi] LOCA data, Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections, https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html#About

[lxii] Climate models include: access1-0.1, access1-3.1, bcc-csm1-1.1, bcc-csm1-1-m.1, canesm2.1, ccsm4.6, cesm1-bgc.1, cesm1-cam5.1, cmcc-cm.1, cnrm-cm5.1, csiro-mk3-6-0.1, ec-earth.8, fgoals-g2.1, gfdl-cm3.1, gfdl-esm2g.1, gfdl-esm2m.1, giss-e2-r.6, hadgem2-ao.1, hadgem2-cc.1., hadgem2-es.1, inmcm4.1, ipsl-cm5a-lr.1, ipsl-cm5a-mr.1, miroc-esm.1, miroc-esm-chem.1, miroc5.1, mpi-esm-lr.1., mpi-esm-mr.1, mri-cgcm3.1, noresm1-m.1, cmcc-cms.1, giss-e2-h.6.

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