BALTIMORE METROPOLITAN COUNCIL

BRTB
Baltimore Regional Transportation Board

Planning, Designing, Operating, and Maintaining Local Infrastructure in a Changing Climate

A Resource Guide for Departments of Public Works and Departments of Transportation in the Baltimore Region

City of Baltimore | City of Annapolis | Anne Arundel County | Baltimore County
Carroll County | Harford County | Howard County | Queen Anne's County

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Acknowledgments

This resource was developed with insights and input from the following Steering Committee members. For more information about the jurisdictional examples obtained through interviews and listed within the Resource Guide, reach out to the local points of contact.

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CHAPTER 1: Introduction and Toolkit

Overview of Resource Guide and Toolkit

Climate change threatens to upend many of the core assumptions about climate that local departments of public works (DPWs) and departments of transportation (DOTs) rely on to plan, design, and operate infrastructure, and to provide service to your communities. As examples, potential changes in rainfall patterns could affect drainage needs and lead to increased flooding if not adapted to, and increases in temperatures can lead to changes in energy demand, materials performance, and safety for outdoor workers.

To support local climate adaptation planning, this Resource Guide and Toolkit are intended to help local DPWs and DOTs across the Baltimore region develop a shared understanding of expected changes in climate, the primary expected impacts on infrastructure service areas, and the options available to build a more resilient community.

This decision-support package consists of:

- The **Resource Guide** is this full document with detailed information on each of the following topics to support climate adaptation planning:
  - Climate science: Chapter 2
  - Climate impacts: Chapter 3
  - Policies: Chapter 4
  - Adaptation options: Chapter 5
  - Funding and financing sources: Chapter 6
- The **Toolkit**, in the following section within this chapter, is a worksheet to guide users through the content in each chapter. It includes discussion questions for local DPWs and DOTs to consider, aimed to enhance climate resilience within your work – ranging from an individual capital project to overall infrastructure planning and decision-making.

KEY TERMS

There are two ways to take action on climate change:

- **Adaptation**: Measures to proactively adjust to a changing environment.

  Examples include ensuring sufficient building cooling systems given rising temperatures or siting assets outside future flood zones.
- **Mitigation**: Measures to reduce greenhouse gas emissions to slow or stop the impacts of climate change.

  Examples include transition to clean energy sources or electrification of building heating systems.

This Resource Guide and Toolkit focus on adaptation.

How to Use This Resource Guide and Toolkit

This Resource Guide and Toolkit are intended to provide practical information for local DPWs and DOTs across the Baltimore region. **Fill out the Toolkit worksheet questions as you review each of the relevant chapters within the Resource Guide**. For an example of a Toolkit populated with responses for a hypothetical infrastructure decision-making scenario, see Appendix C.

USER TIPS

This Resource Guide highlights information relevant to the following infrastructure service areas. *Look for the service area icons throughout the Resource Guide to jump to sections relevant to your work*.

TRANSPORTATION	WASTEWATER
STORMWATER	FACILITIES
WATER	SOLID WASTE

Recognizing that local jurisdictions across the Baltimore region may have different starting points on climate adaptation, use this Resource Guide to supplement existing local climate adaptation resources. *If your jurisdiction has already conducted a climate vulnerability assessment and climate adaptation plan:*

1. Review your local assessment and adaptation plan.
2. Skip ahead to this Resource Guide's Chapter 4 on policies, Chapter 5 on climate adaptation options, and Chapter 6 on funding and financing sources.

Toolkit

Fill out the Toolkit worksheet questions as you review each of the relevant chapters within the Resource Guide.

Toolkit Questions	Enter Your Responses
Climate science: Chapter 2 and Appendix A	
1. What climate hazards are relevant to your work or project? Use the information about current and future climate change in Chapter 2 (regional summary) and Appendix A (jurisdictional data) to determine relevant climate hazards. For each climate hazard, certain variables may be highly relevant to your service area or project (e.g., number of days above 90°F for worker safety; heating/cooling degree days for facilities; freeze/thaw days for transportation). Review the list of climate variables in Appendix A to identify variables particularly relevant to your work.	**Climate hazards** ☐ Temperature ☐ Precipitation ☐ Sea level rise and storm surge ☐ Other extreme weather **Climate variables**

Toolkit Questions	Enter Your Responses	
2. For each of the climate hazards: What are the historical climate conditions? How are the climate conditions changing in your jurisdiction? Use the information about current and future climate change in Chapter 2 (regional summary) and Appendix A (jurisdictional data) to evaluate how the climate hazards are changing. Consider your planning timeframe or asset's useful life when reviewing the projected climate conditions. For example, decisions about maintenance or replacement of facility mechanical components should consider medium-term projections (centered around 2050), while decisions about construction of new long-lived infrastructure should consider long-term projections (end of century and beyond).	**Historical climate conditions**	**Projected climate conditions**

Toolkit Questions	Enter Your Responses
Climate impacts: Chapter 3	
3. Given changing climate conditions, what are anticipated impacts to your service area or project? Consider impacts that your service area or project has recently experienced, and use the climate projections from Question 2 along with the information and examples from Chapter 3 to determine projected climate impacts. Which anticipated impacts are priorities to address? Consider prioritizing impacts based on potential damage, disruption of public services, and cost of repair. 4. Have climate impacts to your service area or project disproportionally affected vulnerable populations? Review the a) BMC Vulnerable Populations Index, b) Maryland Commission on Climate Change Adaptation and Resiliency Work Group's Justice, Equity, Diversity, and Inclusion Strategic Framework, and c) information on climate impacts from Chapter 3 to consider the uneven impacts to vulnerable populations who may face elevated climate risks. Are there areas where infrastructure investments could both reduce climate impacts and enhance social equity?	**Projected climate impacts**
Policies: Chapter 4	
5. Are there state and local policies on climate impacts that affect your work or project? Use the information from Chapter 4 to determine relevant climate policies. Are there policies that would help facilitate climate adaptation measures if approached from a climate perspective? For example, environmental justice policies may help show progress or build support when addressing climate. On the flipside, are there policy or planning barriers that limit your ability to address climate impacts?	

Toolkit Questions	Enter Your Responses
Adaptation options: Chapter 5	
6. Given the projected climate impacts, what are potential adaptation strategies within your service area or for your project, across relevant functions (e.g., design, maintenance)? Use the information and examples from Chapter 5 to begin to identify potential adaptation strategies. What adaptation options are no-regrets (i.e., generate benefits regardless of future climate) and/or could be implemented in the near-term? What adaptation options are no or low cost?	
Funding and financing: Chapter 6	
7. What funding and financing sources are available to help implement the adaptation options? Use the information and examples from Chapter 6 to begin to identify potential funding and financing strategies for adaptation.	
Next steps	
8. What are your next steps to address these climate impacts and plan for these adaptation options? For the selected adaptation strategies, would there be implications to other service areas? Are there other agencies or departments (inside or outside your jurisdiction) your DPW or DOT should coordinate with?	

CHAPTER 2: The Changing Climate in the Baltimore Region

Climate Science Overview

We know that the climate in Maryland and across the globe has been changing and will continue to change. This changing climate is primarily due to an increase in the concentration of greenhouse gases in the atmosphere, which trap the sun's energy and increase global temperatures.[1]

This chapter provides a snapshot of how the climate in the Baltimore region has changed historically and how it is projected to change in the coming decades. Climate hazards include temperatures, precipitation, sea levels, and extreme weather events. Detailed future climate projections for each jurisdiction, including data for additional temperature and precipitation variables that may be useful for infrastructure planning and design, are available in Appendix A: Jurisdictional Climate Data.[2]

KEY TERMS

Weather refers to the short-term atmosphere conditions, is very location-specific, and can change throughout the day.

Climate refers to the average of weather over time and space.

For example, weather affects whether you pack an umbrella because it is forecast to rain in the afternoon. Meanwhile, the average number of rainy days in a year is a reflection of the regional climate.

Historical Climate Trends in the Baltimore Region

Over the past century, the climate has been changing in the Baltimore region.

- Annual temperature in the region has increased by 0.2°F per decade; there is a clear upward trend since 1895 (Figure 1).[3]
- Annual precipitation in the region has increased slightly over the past century (Figure 2), though more of this precipitation has been falling in intense storms.[4]
- Sea levels in the Chesapeake Bay and its tributaries have been rising due to slowly sinking land as well as warming oceans. Relative sea level, measured at the Annapolis tide gauge, has risen by 1.22 feet between 1928 to 2020.[5] Nuisance flooding (from high tides even during sunny days) occurred fewer than 5 days per year in Annapolis in the 1950s but now occurs more than 40 days per year (Figure 3).[6]

[1] U.S. Global Change Research Program. Fourth National Climate Change Assessment: Chapter 2: Our Changing Climate. 2018. https://nca2018.globalchange.gov/chapter/2/
[2] These are the variables identified by the project Steering Committee as being of most interest to the local jurisdictions.
[3] NOAA. National Centers for Environmental Information. www.ncdc.noaa.gov
[4] NOAA. National Centers for Environmental Information. www.ncdc.noaa.gov
[5] NOAA. Sea Level Trends. https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8575512
[6] University of Maryland Center for Environmental Science. Sea-level Rise: Projections for Maryland 2018. 2018. https://mde.maryland.gov/programs/Air/ClimateChange/MCCC/Documents/Sea-LevelRiseProjectionsMaryland2018.pdf

Figure 1. Historical average annual temperature. Averaged across the Baltimore region with data from National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information.

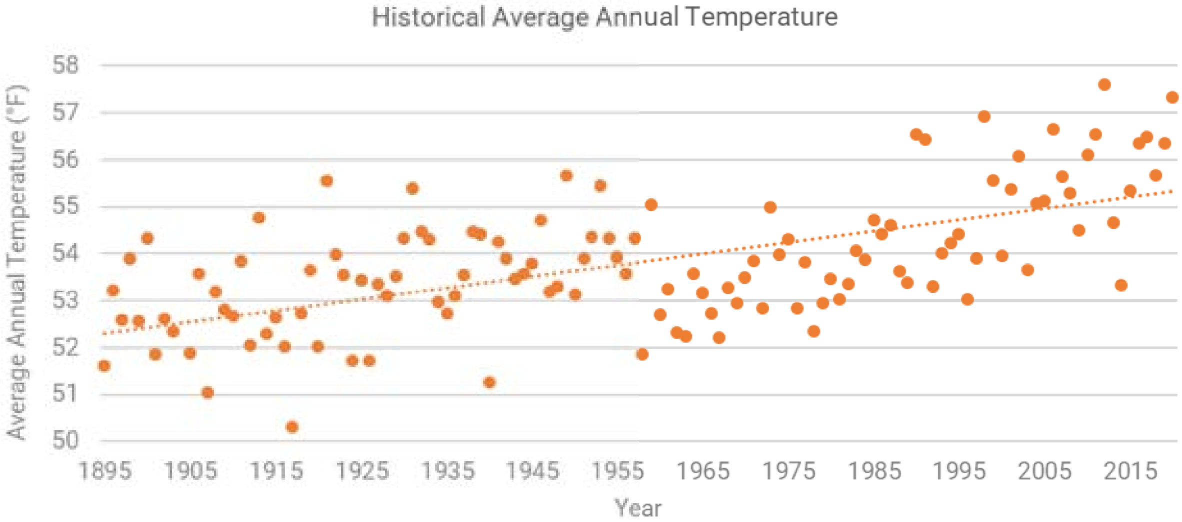


Figure 2. Historical average annual precipitation in inches. Averaged across the Baltimore region with data from NOAA's National Centers for Environmental Information.

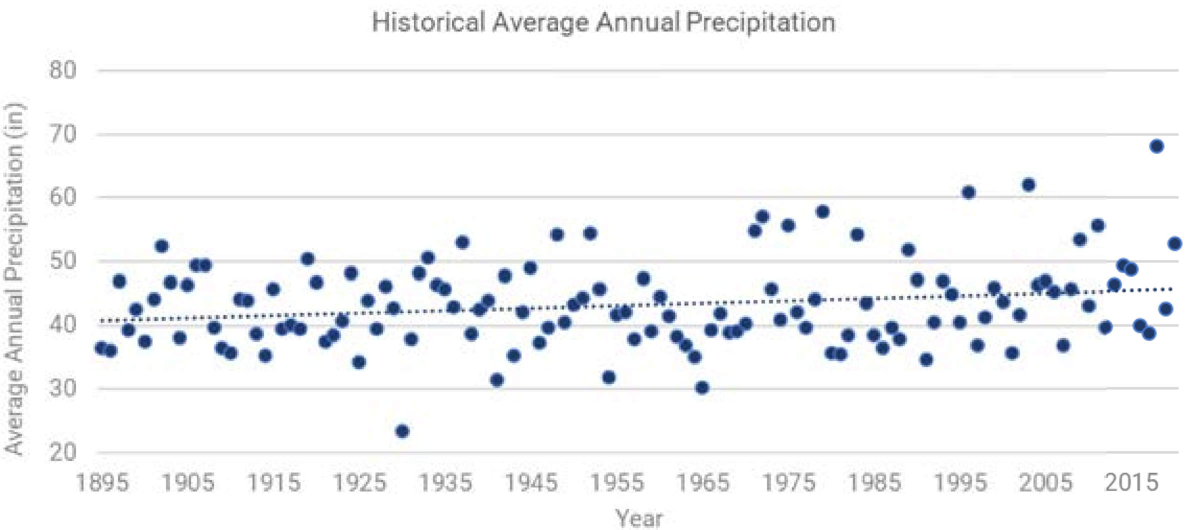
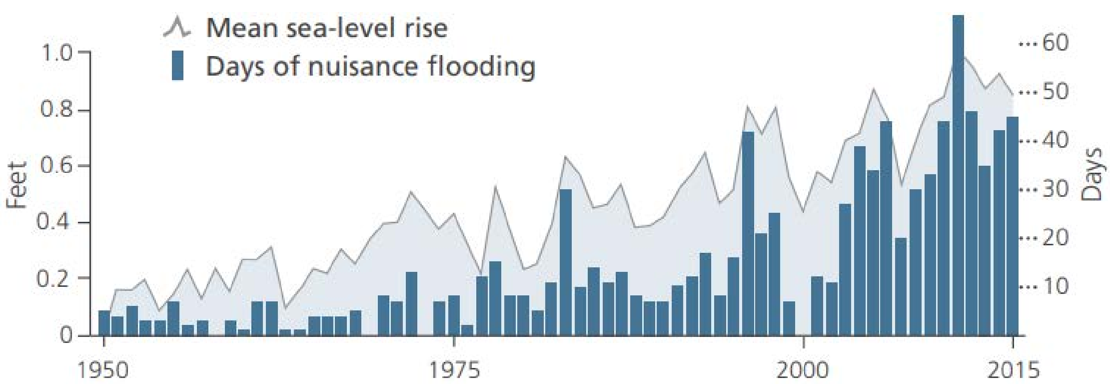


Figure 3. Historical sea-level rise and nuisance flooding in Annapolis.



Source: University of Maryland Center for Environmental Science. [Sea-level Rise: Projections for Maryland 2018](#).

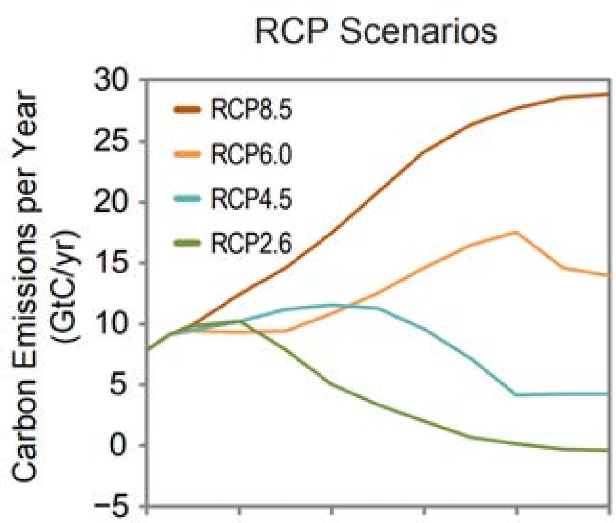
Future Climate Trends in the Baltimore Region

Climate projections come from models that simulate future climate. The group of models, also known as an ensemble, provides a range of projections. This Resource Guide presents the ensemble median,[7] as well as lower and upper bounds (10th and 90th percentiles, respectively) across the models. For this Resource Guide, the models assume a future greenhouse gas scenario referred to as Representative Concentration Pathway (RCP) 8.5, which assumes high emissions without much reduction throughout the 21st century. This higher emissions scenario leads to greater changes in climate; planning to this scenario follows a conservative approach. A comparison of RCP 8.5 and three other lower emissions scenarios is shown in Figure 4. The Federal Highway Administration (FHWA) recommends using the RCP 8.5 scenario given the criticality of infrastructure and impacts on infrastructure from even smaller changes. However, your jurisdiction might make different assumptions about the future given your tolerance for risk. For example, Baltimore County's Climate Action Plan uses RCP 4.5, a scenario assuming a stabilization and then decrease of emissions, yielding outcomes consistent with Sea Level Rise Projections in Maryland, a 2018 production of the University of Maryland Center for Environmental Science and the Maryland Commission on Climate Change. While there will be some inherent uncertainty in climate projections (e.g., we cannot exactly predict the amount of future emissions), it is certain that the climate is changing, so it is safest and most cost-effective to start planning for these changes now.

The projections for the climate variables are provided across three time horizons: near-term (centered around 2030); medium-term (centered around 2050); and long-term (to end of century).

For further detail on the climate science approach, please see Appendix B: Climate Science Data and Methods.

Figure 4. Carbon emissions throughout the century (2000–2100) for four future greenhouse gas scenarios, or Representative Concentration Pathways (RCPs).[8]



[7] There are minor differences in values between the projected median and mean within the Baltimore region. The table values and charts within this chapter present the median, and the temperature and precipitation maps and precipitation return values present the ensemble mean.

[8] U.S. Global Change Research Program. Climate Science Special Report: Fourth National Climate Assessment, Volume I. 2017. https://science2017.globalchange.gov/downloads/CSSR2017_FullReport.pdf

Changes in Temperature

Temperatures are projected to increase dramatically in the Baltimore region over the coming decades. For example, average temperatures could rise by nearly 5°F by mid-century. The region is also projected to experience approximately 66 days above 90°F and 6 heatwaves annually by mid-century. As temperatures warm, days below freezing also will decrease significantly. The table and charts below depict various variables highlighting the warming regional climate (Table 1, Figure 5, Figure 7, Figure 8).

Each jurisdiction within the region will experience similar projected changes; areas along the Bay will continue to be warmer compared to the inland areas, as shown in the map shown in Figure 6. Specific projections for each jurisdiction can be found in Appendix A: Jurisdictional Climate Data.

Figure 5. Annual temperature across the region.

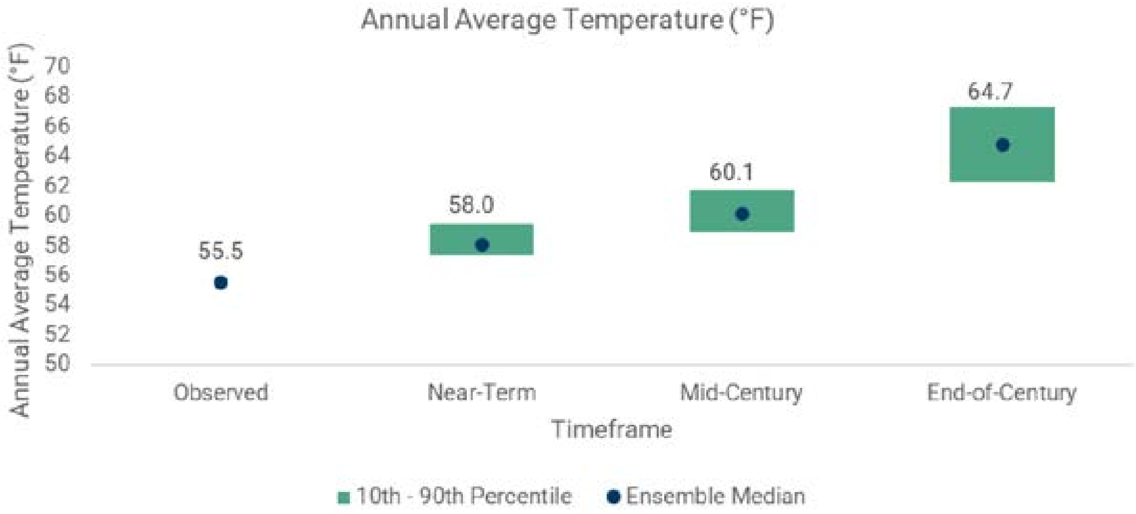


Table 1. Temperature variables across the region.

Variable	Observed Value (1986–2005)	Projected Values* | Change from Observed Near-Term (2020–2039)	Mid-century (2040–2059)	End-of-Century (2080–2099)
Annual average temperature (°F)	55.5	58.0 | +2.5 (57.3 – 59.5)	60.1 | +4.6 (58.8 – 61.7)	64.7 | +9.3 (62.2 – 67.3)
Days ≥ 90°F	26	49 | +23 (40 – 58)	66 | +40 (53 – 80)	105 | +79 (84 – 120)
Days ≥ 95°F	6	17 | +11 (12 – 25)	29 | +23 (20 – 42)	69 | +63 (40 – 90)
Annual number of heatwaves**	0.9	2.8 | +1.9 (1.8 – 5.1)	5.8 | +4.8 (3.5 – 9.6)	17.5 | +16.6 (8.3 – 25.6)
Days below freezing	94	79 | -15 (69 – 84)	66 | -28 (56 – 75)	41 | -53 (28 – 53)

* Projected values represent the 32-model ensemble median for RCP 8.5; values in parentheses indicate the 10th to 90th percentile range of model projections. Values in green (positive) and orange (negative) show the median change from observed; values may not add up due to rounding.

** Heatwaves defined as the average number of instances per year when there are 3 consecutive days above the observed 98th percentile.

Figure 6. Average annual temperature across the region. Projected values represent the 32-model ensemble mean for RCP 8.5.

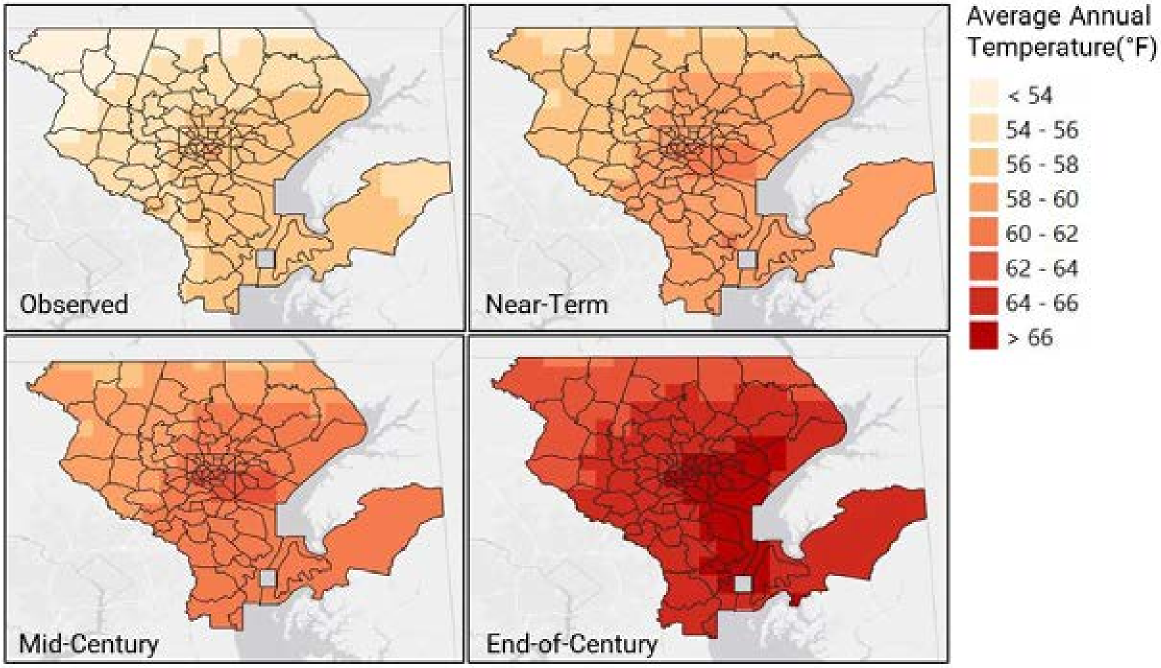
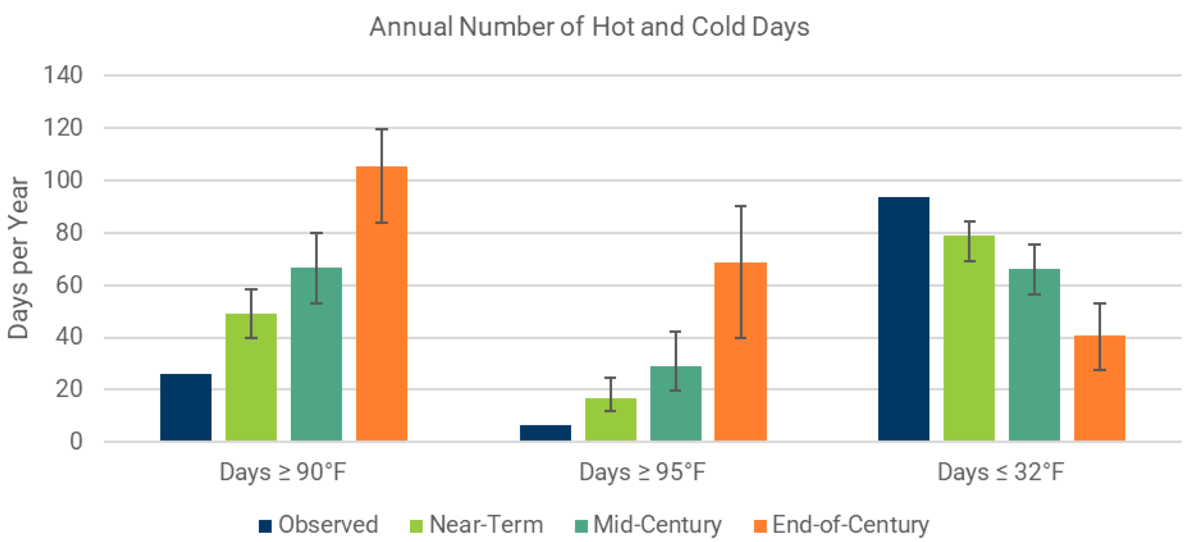
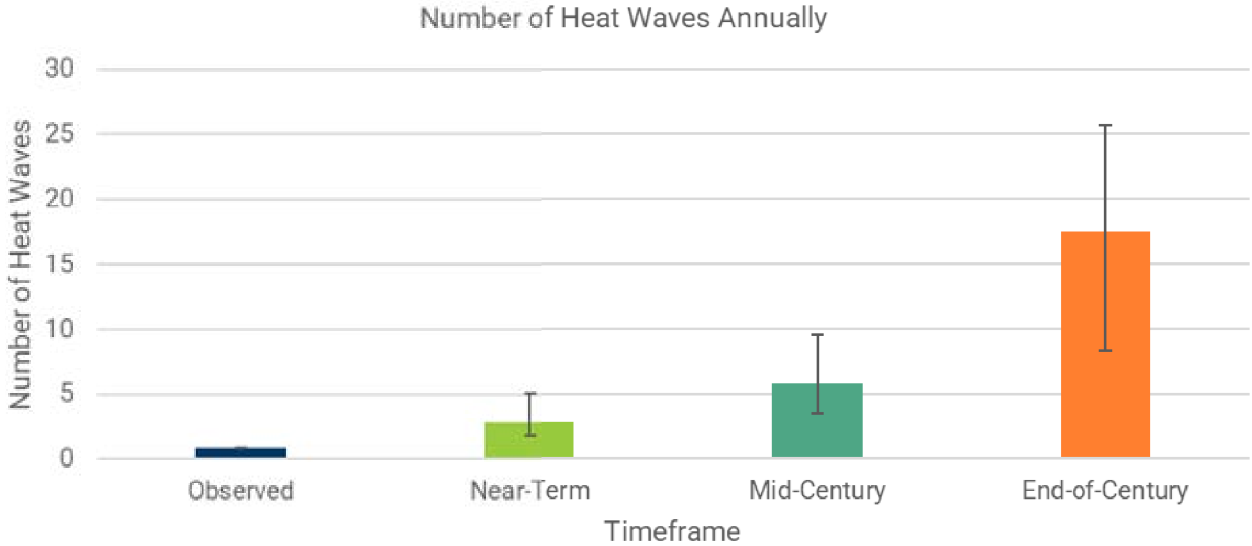


Figure 7. Annual number of hot and cold days.



* Error bars indicate 10th–90th percentile range across the 32-model ensemble. All projections are shown for RCP 8.5.

Figure 8. Number of heatwaves annually.



* Error bars indicate 10th–90th percentile range across the 32-model ensemble. All projections are shown for RCP 8.5.

** Heatwaves defined as the average number of instances per year when there are 3 consecutive days above the observed 98th percentile.

Changes in Precipitation

The Baltimore region will likely experience **more extreme precipitation events** over this century. Both the 24-hour 10-year and 100-year rainfall events are projected to be heavier, but overall average annual precipitation is not projected to increase notably. For example, annual precipitation is expected to increase by about 3 inches by mid-century. The projections indicate more precipitation falling in heavy events within a single day or consecutive days.

Precipitation increases are expected only during certain parts of the year. Precipitation is projected to **increase in the winter and spring months**, and stay relatively similar during summer and fall months. The tables and charts below summarize the shifting precipitation patterns within the region (Table 2, Table 3, Figure 9, Figure 10, Figure 11, Figure 12).

The projected changes will be similar across each jurisdiction. The northern part of the region will continue to experience greater annual precipitation relative to the southern portion, as shown in the map below (Figure 9). Specific projections for each jurisdiction can be found in Appendix A: Jurisdictional Climate Data.

Figure 9. Average annual precipitation across the region. Projected values represent the 32-model ensemble mean for RCP 8.5.

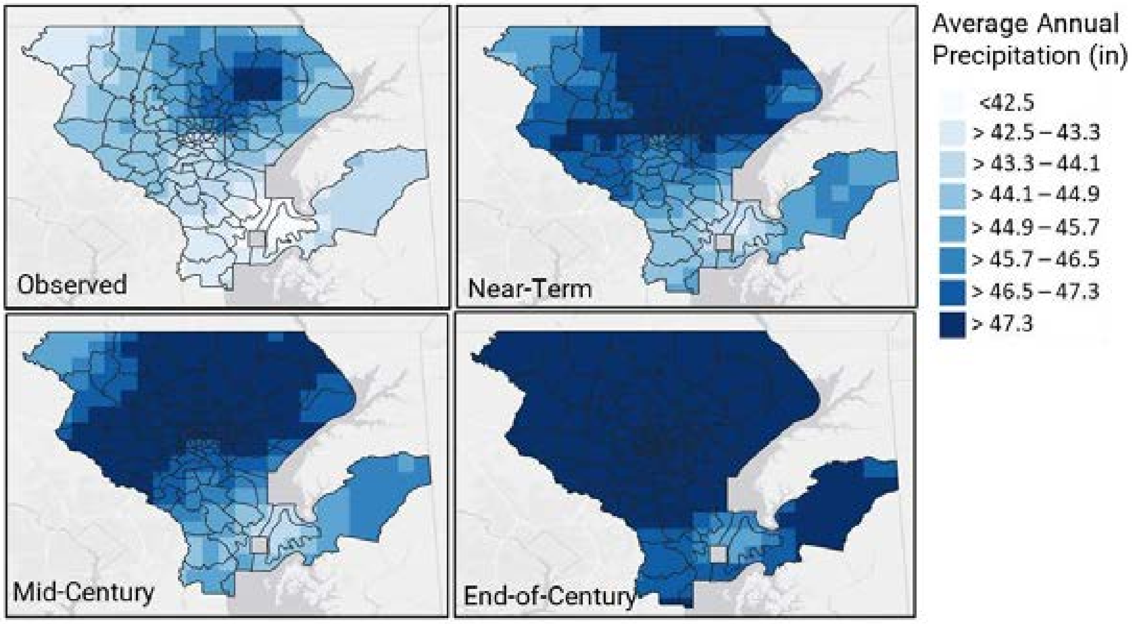


Table 2. Precipitation variables across the region.

Variable	Observed Value (1986–2005)	Projected Values* | Change from Observed Near-Term (2020–2039)	Mid-century (2040–2059)	End-of-Century (2080–2099)
Average annual precipitation (inches)	45.5	46.6 | +1.1 (44.2 – 49.7)	47.1 | +1.6 (44.1 – 49.8)	49.1 | +3.6 (45.0 – 53.7)
Maximum 5-day precipitation event (inches)	3.7	4.1 | +0.4 (3.6 – 4.6)	4.1 | +0.3 (3.6 – 4.5)	4.5 | +0.8 (3.9 – 5.0)

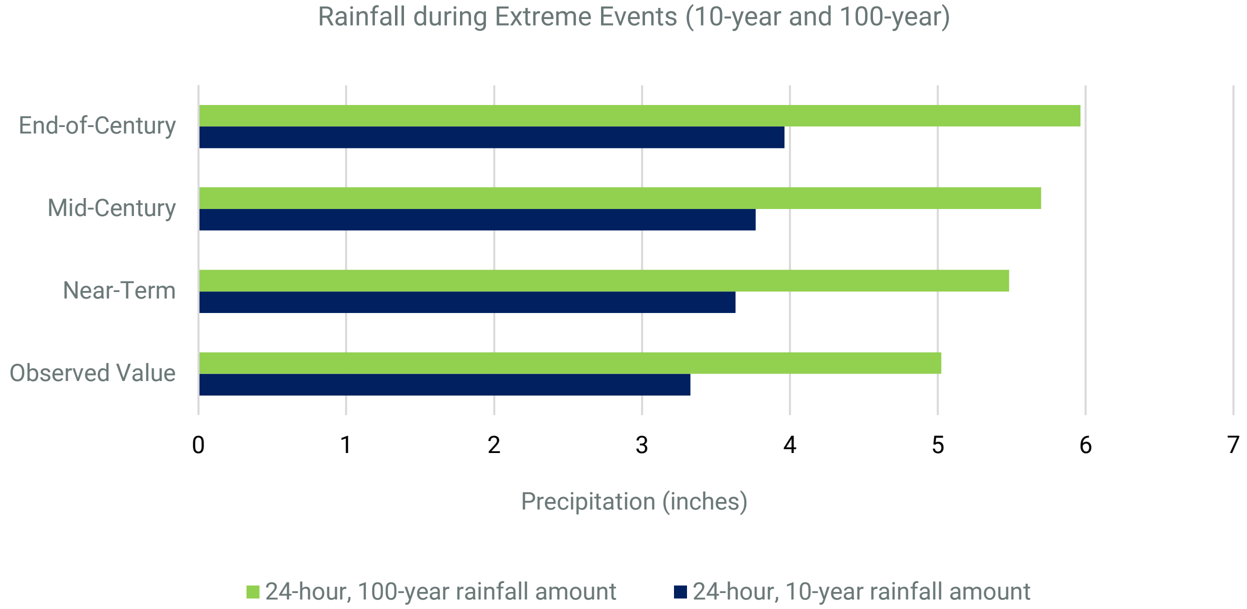
* Projected values represent the 32-model ensemble median for RCP 8.5; values in parentheses indicate the range of projections from the 10th to 90th percentile of model projections. Values in green show the median change from observed; values may not add up due to rounding.

Table 3. Precipitation return periods across the region.

Variable	Observed Value (1976–2005)	Projected Values* Near-Term (2015–2044)	Mid-century (2044–2064)	End-of-Century (2070–2099)
24-hour, 10-year rainfall amount (inches)	3.3	3.6 | +0.3	3.8 | +0.5	4.0 | +0.7
24-hour, 100-year rainfall amount (inches)	5.0	5.5 | +0.5	5.7 | +0.7	6.0 | +1.0

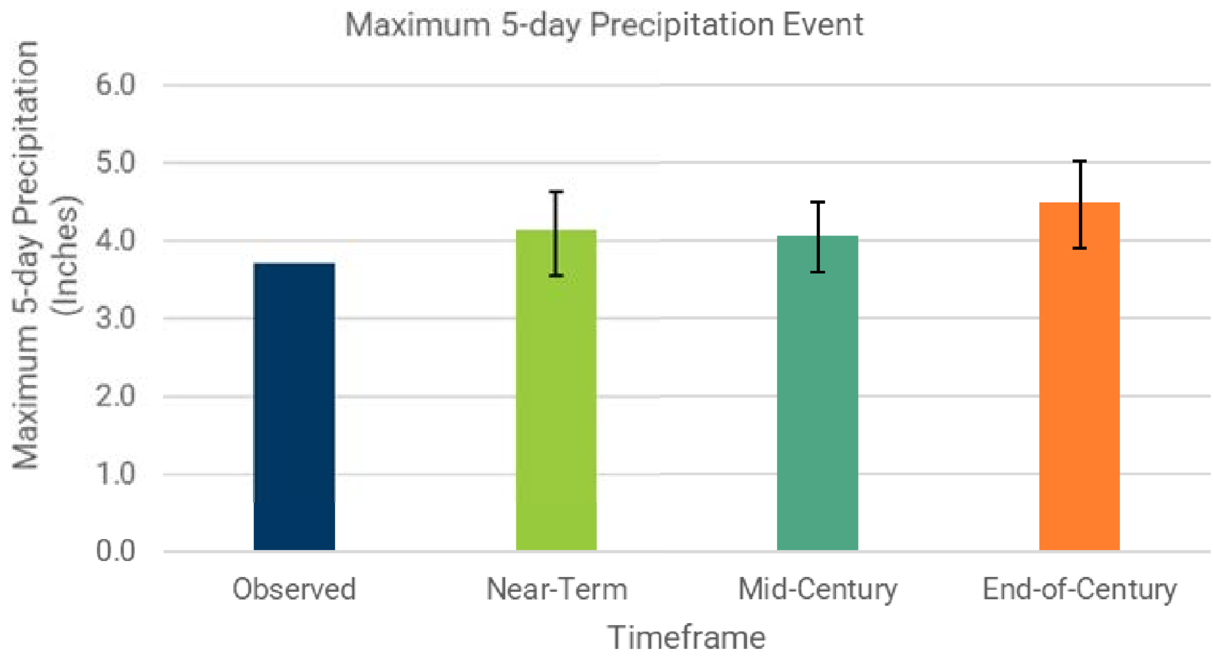
* Projected values represent the 32-model ensemble mean for RCP 8.5; 24-hour, 10- and 100-year rainfall projections do not have associated 10th and 90th percentile values, as the Coupled Model Intercomparison Project (CMIP) Climate Data Processing tool used to derive these data only calculates model ensemble means. Values in green show the mean change from observed; values may not add up due to rounding.

Figure 10. Rainfall during extreme events.



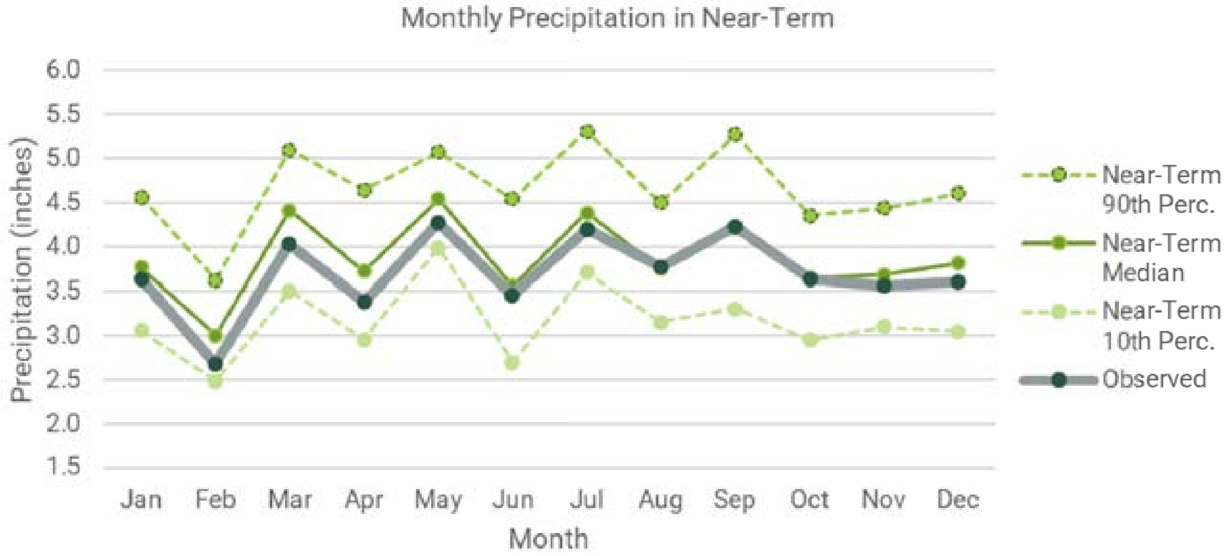
* All projections are shown for RCP 8.5.

Figure 11. Maximum 5-day precipitation event, which can be an indicator of flood hazard.



* Error bars indicate 10th–90th percentile range across the 32-model ensemble. All projections are shown for RCP 8.5.

Figure 12. Monthly precipitation in near-term.



* Solid lines represent the 32-model ensemble median for RCP 8.5. Dashed lines represent the 10th and 90th percentile. Colors indicate the different time periods.

The chart above illustrates the following about monthly precipitation in the near-term. These trends are similar in mid-century and end-of-century.

- Average monthly precipitation is projected to increase slightly, though not substantially.
- Precipitation is likely to increase in the winter and spring months, with spring months exhibiting the highest projected total precipitation amounts.
  - Although precipitation may increase in the winter, warming temperatures could result in less precipitation in the form of snow in the shoulder seasons.
  - Increased winter precipitation combined with shifts in temperatures could result in changes in the number of freeze/thaw days, which can deteriorate infrastructure.

Sea Level Rise and Coastal Storm Surge

Sea level rise will significantly impact the Baltimore region shoreline, as summarized in Table 4. Maryland's coastline will experience minor differences in sea level rise across locations due to local differences in vertical land movements. Scientists determine relative sea level rise based on data from tide gauge stations in the Chesapeake Bay; two of these stations are located in the Baltimore region.

- At the Baltimore tide gauge, sea level is projected to rise by over 1 foot by mid-century from the 2000 baseline and over 2 feet by the end of the century.
- At the Annapolis tide gauge, sea level by the end of the century is projected to differ 0.1 feet more compared with the Baltimore tide gauge.
- This finding likely means that Anne Arundel and Queen Anne's Counties (which should refer to the projections from the Annapolis tide gauge) will experience slightly greater increases in relative sea level compared to other coastal jurisdictions in the region (which should refer to the projections from the Baltimore tide gauge).

Table 4. Projected relative sea level rise at local tide gauges.

Tide Gauge	Projected Relative Sea Level Rise (ft)		
	Near-Term (2030)	**Mid-century** (2050)	**End-of-Century** (2080)
Baltimore	0.6 (0.4 – 0.9)	1.2 (0.8 – 1.6)	2.3 (1.6 – 3.1)
Annapolis	0.6	1.2	2.4

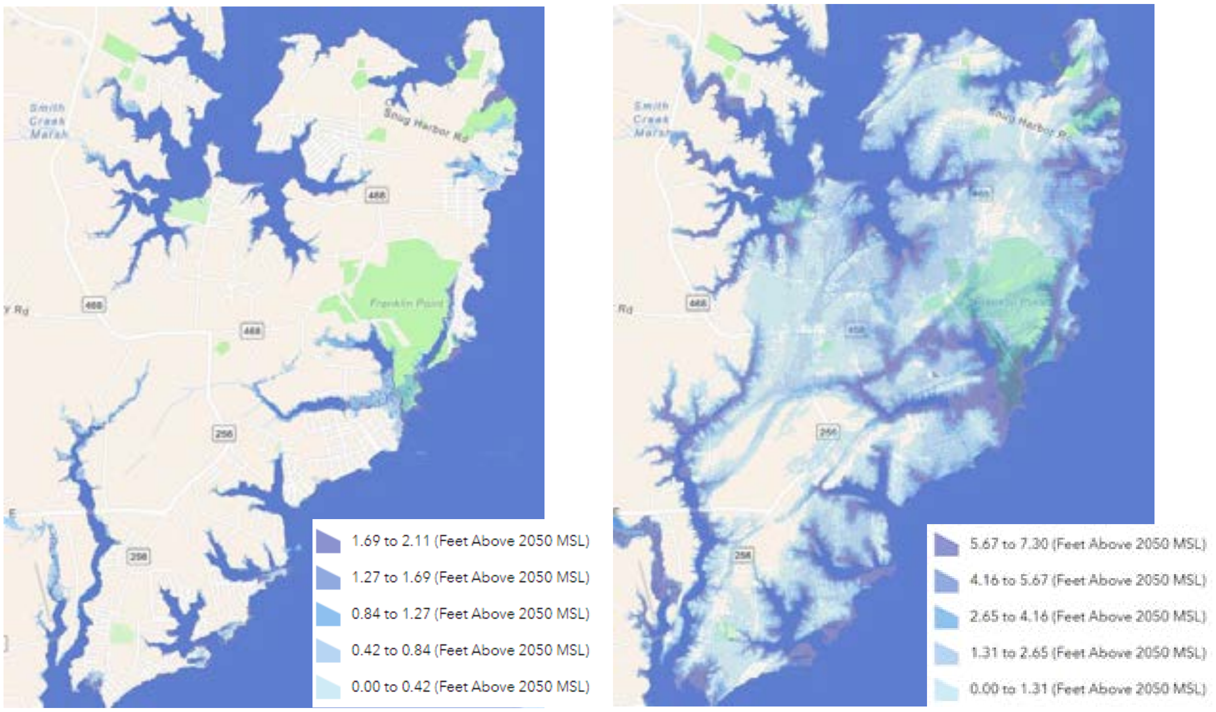
* Values shown are the state of Maryland's projected sea level rise values above 2000 levels. The projected value represents a central estimate, or the 50% probability that sea level rise is projected to meet or exceed. Values in parentheses indicate the likely range of projected sea level rise; sea level rise has a projected 67% probability of being between these values (not specified in the data source for the Annapolis tide gauge). The 2030 and 2050 projections for sea level rise are for RCP 4.5, though there is very little difference between RCP 4.5 and RCP 8.5 over the next 30 years. The 2080 projections are for RCP 8.5. Source: Sea-level rise: Projections for Maryland 2018.

As sea levels rise and storms become more intense, the **depth and extent of flooding from storm surges are also expected to become more severe.**

Interactive maps for the entire Baltimore region showing inundation depth under different sea level and storm scenarios are available in the MDOT SHA Climate Change Vulnerability Viewer. **Use the interactive MDOT SHA Climate Change Vulnerability Viewer** for visualization of potential inundation from sea level rise and storms.

The illustrative static maps shown in Figure 13 from the Viewer show projected change in coastal flooding for a small portion of the region's coastline. The first set of maps shows the projected inundation at high tide caused by sea level rise. The second series of maps show the increases in the level of storm surge during a 100-year flood with sea level rise.

Figure 13. Sea level rise inundation depths by 2050 (left) and flood depths during a 100-year flood by 2050 (right) in Anne Arundel County.



Other Projected Changes in Extreme Weather

Overall, **climate change will lead to an increase in both the frequency and intensity of extreme weather events in the Baltimore region**. The changes in storms include an increase in the strength and volume of thunderstorms and derechos (i.e., windstorms) due to warmer atmospheric temperatures, which provide energy to storms. Similarly, scientists expect that there will be a greater number of strong hurricanes (i.e., Category 3 hurricanes or stronger) through mid-century.[9]

In addition, extreme cold snaps may continue to occur due to weakened "polar vortex" events, where cold Arctic air is released to the continental United States. These weak polar vortexes could be the result of climate change–induced Arctic warming and decreases in sea ice. The result could be more frequent cold weather outbreaks in the region.[10,11,12,13]

Current climate models do not provide quantitative estimates for the degree of these changes in extremes in the Baltimore region, but such shifts towards more extreme weather should nonetheless be on the radar and included in climate-related decisions and scenario-based planning.

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[9] U.S. Global Change Research Program. Fourth National Climate Assessment: Volume II: Impacts, Risks, and Adaptation in the United States. 2018. https://nca2018.globalchange.gov/

[10] Kretschmer M, et al. More-Persistent Weak Stratospheric Polar Vortex States Linked to Cold Extremes. 2018. https://doi.org/10.1175/BAMS-D-16-0259.1

[11] Zhang P, et al. Prolonged Effect of the Stratospheric Pathway in Linking Barents–Kara Sea Sea Ice Variability to the Midlatitude Circulation in a Simplified Model. 2018. https://doi.org/10.1007/s00382-017-3624-y

[12] Overland J, et al. The Melting Arctic and Midlatitude Weather Patterns: Are They Connected? 2015. https://doi.org/10.1175/JCLI-D-14-00822.1

[13] Kim B, et al. Weakening of the Stratospheric Polar Vortex by Arctic Sea-ice Loss. 2014. https://doi.org/10.1038/ncomms5646

CHAPTER 3: Climate Change Impacts to Local Public Works and Transportation Departments

Introduction

Public works and transportation departments across the region are seeing impacts from a changing climate, including increased maintenance, damage to infrastructure, operational impacts, and rising costs. Climate impacts in the region arise from hazards including the following, as described in Chapter 2:

- HEAVY PRECIPITATION AND INLAND FLOODING
- COASTAL FLOODING
- EXTREME HEAT
- OTHER EXTREME WEATHER

This chapter summarizes climate impacts—both recent and projected—for the following service areas.

- TRANSPORTATION
- WASTEWATER
- STORMWATER
- FACILITIES
- WATER
- SOLID WASTE

Except where noted, the impacts presented in Chapter 3 were relayed through interviews conducted in 2021 with BMC jurisdictions (including Anne Arundel, Baltimore, Carroll, Harford, Howard, and Queen Anne's counties, Baltimore City, and City of Annapolis). Recent impacts in some jurisdictions may help illustrate how another jurisdiction may experience impacts in the future. Across the whole region, impacts are expected to be exacerbated given the future climate projections discussed in Chapter 2.

Across all service areas and jurisdictions, heavy rain in recent years was perceived as the most impactful hazard. This finding is consistent with the Fourth National Climate Assessment, which indicates that at a regional scale, the Northeast region of the United States has experienced a greater recent increase in heavy precipitation than any other region in the contiguous United

States.[14] As shown in the regional projections in Chapter 2, both the 24-hour 10-year and 100-year rainfall events are projected to increase in the future. Aside from heavy precipitation, flooding in the Baltimore region is becoming more frequent and more widespread. Recent flooding incidents are not limited to the Federal Emergency Management Agency (FEMA)-designated flood zones, as shown in the mapping in this chapter.

It is clear from the climate projections and recent observed impacts that climate change is exacerbating impacts across all hazards, including heavy precipitation and inland flooding, sea level rise and coastal flooding, extreme heat, and other extreme weather.

CLIMATE CHANGE IMPACTS AND SOCIAL EQUITY

Climate change impacts can be felt disproportionately by vulnerable populations, including people of color, those who are low-income or have disabilities, children, and the elderly, compared with the general population. Vulnerable populations may have a difficult time stabilizing during and after extreme weather events and recovering from personal property damage. Climate hazards themselves often present more severely in vulnerable populations, with higher rates of impervious surfaces and higher temperatures in urban areas. Communities that are low income or predominantly people of color may experience added impacts compared with populations that do not have these vulnerabilities.

For more information, review the BMC Vulnerable Populations Index and the Maryland Commission on Climate Change Adaptation and Resilience Work Group's Justice, Equity, Diversity, and Inclusion Strategic Framework.

[14] U.S. Global Change Research Program. Fourth National Climate Assessment. Chapter 18: Northeast. 2018. doi: 10.7930/NCA4.2018.CH18

Climate Impacts Summary Matrix

Below is a "cheat sheet" summary matrix to highlight what DPW and DOT staff need to know about recent and future climate impacts. It provides an overview of the key impacts to each service area for the main climate hazards to help department staff quickly identify the impacts most relevant to your work.

	Climate Impacts			
Service Area	Heavy Precipitation and Inland Flooding	Sea Level Rise and Coastal Flooding	Extreme Heat	Other Extreme Weather
Transportation	Erosion, washouts, and heavy precipitation affect the integrity of pavement by reducing strength of pavement, leading to further deterioration. Inundation and erosion affect the structural integrity of bridges and rail infrastructure. Flooded roadways can cause detours or delays. Heavy precipitation and flooding can result in transit/rail service delays.	Coastal roads already experiencing nuisance flooding will flood more frequently and potentially permanently. Low-lying coastal roads that are further inland may flood. Flooded roadways can cause detours or delays. Sea level rise with storm surge will decrease clearance levels and damage bridges. Flooding and erosion along coastal routes will affect the ability to safely continue transit service. Waterfront facilities supporting ports and other transportation services may be impacted by sea level rise, flooding, and strong storms.	Extreme heat can cause buckling or softening of surface pavement materials. Road crews are impacted by extreme temperatures, thus affecting worker safety. Public health impacts can result as transit riders wait for the bus/train during extreme heat days. Extreme heat can cause buckling and damage to rail lines and runways, and can stress bridge integrity.	Downed trees or power lines from storms can cause roadway closures. Extreme weather compounds damage to aging transportation infrastructure. Wide temperature swings can damage roadways and transportation infrastructure when ice expands in cracks during freeze/thaw days. High winds can result in bridge closures.
Stormwater	More frequent and intense storms can increase flooding, stormwater runoff, and erosion. Heavy rainfall can overwhelm stormwater capacity.	Gravity-fed systems may no longer function as designed if outfalls are submerged. Coastal flooding at outfalls could drive backflow into the system. Groundwater levels may increase, reducing the soil's ability to absorb stormwater and increasing runoff.	Limited documented impacts exist for this service area.	Storms could introduce debris that can clog storm drains, pipes, and outfalls.

Service Area	Climate Impacts			
	Heavy Precipitation and Inland Flooding	Sea Level Rise and Coastal Flooding	Extreme Heat	Other Extreme Weather
Water	Heavy precipitation can reduce water quality due to increased sediment, which could increase water treatment costs. Heavy rains can require dams at the reservoirs to be opened more frequently to discharge water.	Saltwater intrusion from sea level rise may contaminate groundwater.	Increased water temperatures can reduce water quality, with excess algal growth and added chlorine treatment. Extreme heat may stress electrical equipment and water service may be interrupted in the event of blackouts or brownouts.	Severe drought can lead to lower reservoir levels, reduced groundwater recharge and groundwater aquifer levels, and ultimately reduced water supplies.
Wastewater	Sewer overflows can occur during heavy rain events. Heavy rainfall and associated flooding could lead to failure of treatment plants or pump stations and/or cause generator failure.	Depending on the depth and extent of the coastal flooding, equipment at treatment plants and pump stations may experience corrosion and damage.	High temperatures can affect the efficiency of wastewater treatment processes. Extreme heat may stress electrical equipment and wastewater treatment service may be interrupted in the event of blackouts or brownouts.	Loss of power from severe storms is a significant weather-related risk of concern for wastewater facilities.
Facilities	Roof leaks due to heavy rainfall can occur. Potential for sump pump failures, which exacerbate water intrusion in the lower levels of facilities.	Temporary flooding or permanent inundation of low-lying coastal facilities can occur.	Air conditioning use and cost will increase. HVAC may need more frequent service or replacement earlier than planned. Extreme heat causes worker safety impacts for staff servicing rooftop HVAC or working outside.	Extreme weather events can stress the structural integrity of buildings.
Solid Waste	Erosion and loss of stability of earth embankments can occur. Heavy rainfall generates more leachate and can result in leachate contamination.	Solid waste facilities have had to temporarily close when flooding occurs. Flooding facilitates the spread of contaminants into soils and waterways.	Outdoor worker safety concerns for sanitation workers increase during extreme heat days.	Storms generate significant debris, requiring clean-up and use of large equipment.

Transportation Impacts

The transportation service area within this Resource Guide includes infrastructure managed by local DOTs.[15] Transportation assets include roadways, highways, buses, trains, and a supporting network of infrastructure.

Heavy Precipitation, Inland Flooding, and Coastal Flooding

- All types of flooding (caused by heavy rains, coastal storms, high tides) affect transportation infrastructure, operations, and travel efficiencies.
  - Temporary inundation of roadways, highways, bridges, and tunnels have been observed to occur more frequently over recent years, causing damage and travel delays.
    - In-kind replacements—especially with bridges—are often washed out just as quickly as the initial asset.
  - Roadway washouts from heavy rains are becoming more frequent. In some jurisdictions, soil remediation work is necessary to ensure health and safety on aging roads, bridges, and culverts.

A flash flood in northern Harford County caused major damage to approximately 20 roads and culverts, as streams rose 11 feet above normal water levels on August 31, 2018.

  - Slow-downs and detours cost travelers time and money when flooding results in delays and/or when damage to roadways prevents access to the most efficient travel route, which especially affects transit service delays.

IN MARYLAND…

As noted in an analysis of state-maintained highways across Maryland, disruptions from flooding affected 480,000 people annually, with 1,582 hours of traffic disruption per year on average between 2006 and 2020. For more information, see Flooding Impacts on Maryland's Transportation System and Users.

  - The anticipated lifespan of assets is reduced in flood prone areas and when exposed to the elements. Flooding can weaken structural supports for bridges, deteriorate soil that supports infrastructure, shorten the lifespan of pavement, and increase sedimentation in waterways.

[15] State agencies, including Maryland Department of Transportation (MDOT), MDOT's State Highway Administration (SHA), Maryland Transit Administration (MTA), Maryland Port Administration, and Maryland Aviation Administration (MAA), were also interviewed for regional context to develop this section.

- Heavy precipitation causes drainage infrastructure to be exceeded as more extreme precipitation trends continue.
  - As seen in Chapter 2, rain is expected to fall in more high-volume and high intensity events, which could potentially lead to more flooding and damage to transportation assets.
  - Heavy rains damage roadways when rainfall exceeds the capacity of the drainage system. Water accumulation on roads weakens the pavement and accelerates the formation of cracks which can lead to potholes and washouts. Vehicles traveling on wet roadways can compress water into the pavement (hydraulic scouring), which can cause further deterioration.

IN HARFORD COUNTY…

As seen in Harford County, aging transportation infrastructure nearing the end of its planned life expectancy is particularly sensitive to impacts and may require more funding for operations and maintenance as stream beds and coastal areas erode.

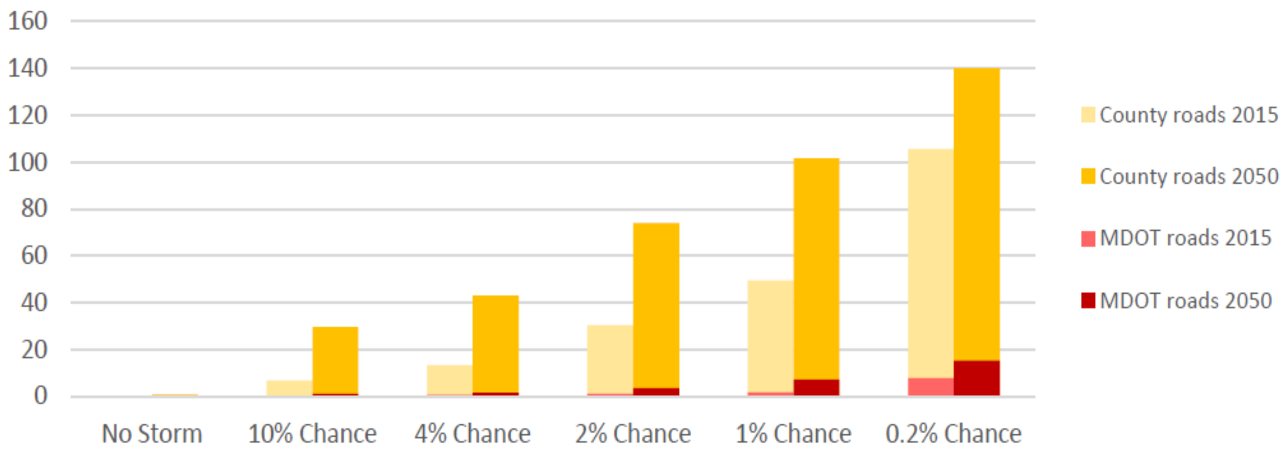
- Flooding from future sea level rise and storm surge also could inundate low-lying coastal transportation assets, as sea levels rise and storms become more intense.
  - Low-lying transportation assets that are further inland may experience flooding due to sea level rise and storm surge.
  - Sea level rise will decrease clearance levels under bridges for maritime traffic and for passing flood flow volumes.

IN ANNE ARUNDEL COUNTY…

Maryland Department of Transportation's State Highway Administration analyzed MDOT and County roadway inundation levels for jurisdictions under various coastal flooding scenarios to year 2050. In Anne Arundel County, the number of inundated roadway miles double between 2015 and 2050, with over 100 miles of county roadway projected to be inundated in 2050 for a 1% chance storm, compared to 50 miles in 2015 (Figure 14).

County roadway profiles are available for additional coastal counties. For additional data and maps, visit the MDOT SHA Climate Change Viewer and click on a county.

Figure 14. Anne Arundel roadway flooding projections (2015–2050). Total Miles Inundated Under Various Flooding Scenarios, by Road Ownership: 2015 vs. 2050. Source: MDOT SHA

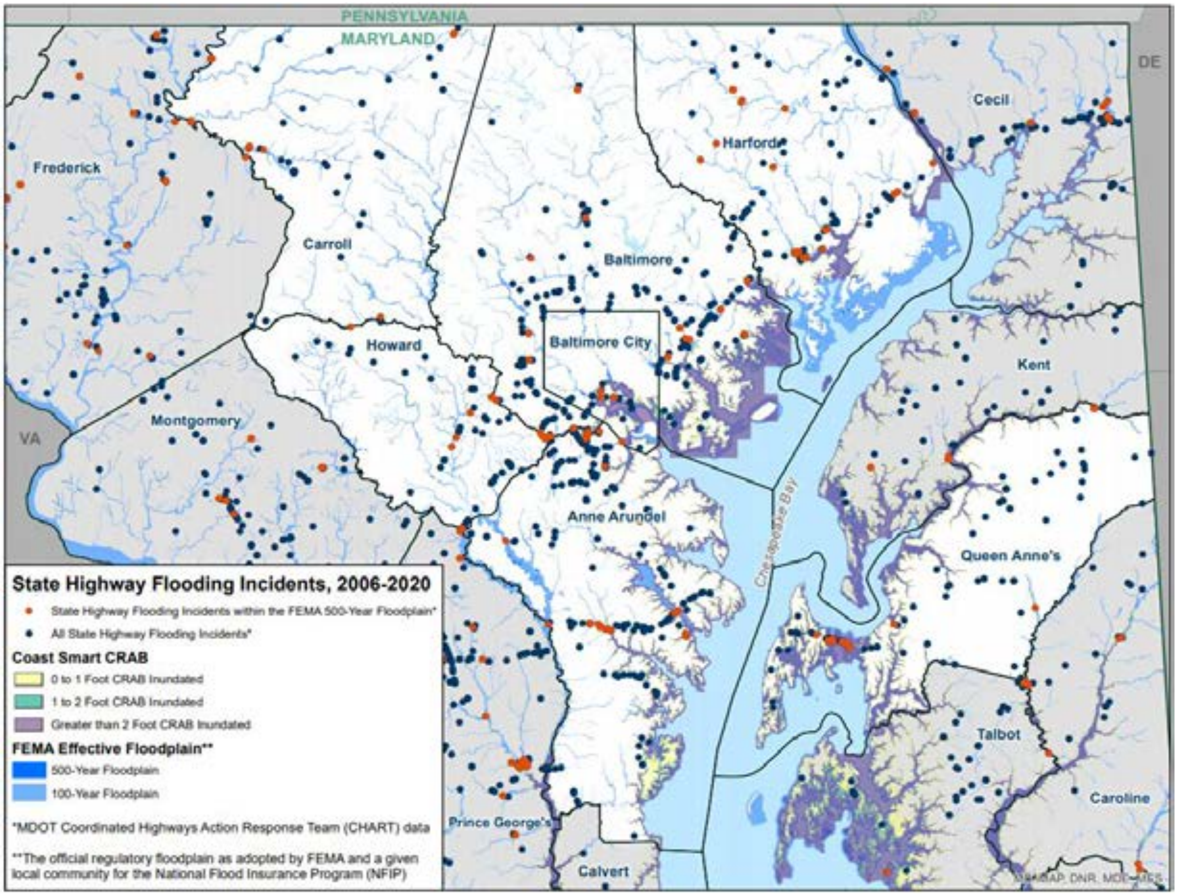


- Figure 15 shows recent flooding incidents on state highways throughout the Baltimore region. Though this map illustrates flooding incidents on state-maintained highways rather than on local highways and roadways, recent flooding incidents are not limited to the FEMA-designated flood zones. FEMA flood zones were developed based on historical data.

Flooding incidents are not limited to the FEMA-designated flood zones. Flood incidents have also occurred along the coast, where sea levels are projected to rise and extend the horizontal reach of coastal flooding. Areas of potential future coastal flooding, as delineated by the Maryland Coast Smart Climate Ready Action Boundary (CS-CRAB), are shown in the map in Figure 15 and are discussed further in Chapter 4: Relevant Policies. CS-CRAB was developed by the Department of Natural Resources and the Maryland Department of the Environment (MDE) and depicts areas vulnerable to future coastal flooding that are required to comply with Coast Smart practices.

To access the CS-CRAB Inundated Zones as it pertains to your jurisdiction, please visit this link for interactive mapping.

Figure 15. State highway flooding incidents in the Baltimore region, 2006–2020.



Blue dots indicate flood incidents outside the FEMA 500-year floodplain.

Extreme Heat

- **Extreme heat and freeze-thaw also have impacted transportation planning, operations, and capital and operational resources.**
  - The buckling or softening of surface pavement binders and/or aggregate materials from extreme heat affects access for private vehicles, trucks, and public transit to the roadway network.[16]

IN BALTIMORE CITY…

Extreme heat and heatwaves, in combination with steam infrastructure in Baltimore City, affects roadways by causing rutting in the pavement.

  - The lack of shade or shelter from inclement weather affects the health and safety of roadway workers and transit riders.
  - Freeze-thaw affects pavement integrity because water entering cracks will expand when temperatures drop, exacerbating damage to roadways (e.g., potholes).

[16] Learn more about these pavement effects through the Federal Highway Administration's Pavement Sustainability Program's technical briefs, case studies, webinars, and working groups, available at https://www.fhwa.dot.gov/pavement/sustainability/

- Extreme heat can stress bridge integrity by causing thermal expansion beyond the limits of the expansion joint design and can cause asphalt pavement rutting. It also can cause blow-ups, slab cracking or punch outs in concrete pavement. (Likewise, extreme cold can cause thermal contraction beyond the expansion joint design in bridges.)

- **Extreme heat is projected to increase in the region, with days above 90°Fprojected to increase from 25 days observed (1986–2005) to 105 days per year by the end of the century, as seen in Chapter 2's Changes in Temperature.**
  - With temperatures continuing to increase, more instances of softening of roadway pavement, softening of airport runways, and buckling of rail lines will occur under extreme heat.
  - Extreme heat will affect outdoor worker safety, with direct exposure to the dangerous summertime temperatures for long periods of time.

Other Extreme Weather

- **Severe storms cause disruptions and damage to transportation infrastructure.**
  - When severe storms occur, the entire transportation network is affected by service cancellations, which may include train services, bus service, and flights.
  - The cost of reconstruction following severe storms often draws funding away from other capital projects, which are then delayed.
- **Extreme weather events will increase in frequency and intensity, affecting transportation infrastructure and costs.**

IN HOWARD COUNTY…

There has been an increase in intensity of storms and impacts to roadways in Howard County. Flash flooding occurred in Ellicott City when 1,000-year floods recently occurred in 2016 and 2018. In 2016 in Howard County, there were 18 rainstorms with 6.5" rain within 4 hours. In June 2012, a derecho (severe wind event) caused damage to Howard County's transportation network and facilities.

  - The costs to repair and rebuild infrastructure (including maintenance and operation costs) will increase. Although adaptation costs can be an incremental cost, the costs of doing nothing can be a harder hit financially. Adaptation measures are discussed in Chapter 5.
  - As seen throughout the region, downed power lines, trees, and debris following extreme storms can cause road closures, wreaking havoc on road operations.

- **Long-term drought could lead to operational and infrastructure impacts.[17] Although not one of the primary impacts in this region, extreme weather includes the potential for lengthy dry periods.**
  - If groundwater usage increases during drought, sinkholes and potholes could potentially form as the ground subsides, or sinks, and can cause damage to transportation infrastructure.

[17] The extent and impacts of droughts on waterways, roads, railways, and airports are updated weekly at: https://www.drought.gov/sectors/navigation-and-transportation#

Stormwater Impacts

The stormwater service area includes stormwater management, combined stormwater and wastewater systems, and closed storm drain systems. Managed assets include stormwater drains, outfalls, tide gates, and conveyance systems. The stormwater service area is subject to National Pollutant Discharge Elimination System (NPDES) permit requirements and is heavily impacted by heavy precipitation and inland flooding, and sea level rise and coastal flooding.

Heavy Precipitation and Inland Flooding

- **Heavy rains could increase stormwater management needs, overwhelm stormwater infrastructure capacity, and lead to severe flooding.**
  - Precipitation is projected to increase in intensity in the future, which could increase runoff, overwhelm existing stormwater capacity, and exacerbate flooding.

> **IN HOWARD COUNTY…**
>
> In 2016 and 2018, Howard County's Ellicott City saw historic flooding, in both cases, seeing more than 6 inches of rain in less than a 4-hour duration. While the Ellicott City basin has experienced storms with heavy precipitation in the past, the short duration amplified the intensity of flooding, causing severe impacts. Over recent years, the County has been experiencing more frequent storms with short durations and high intensity, yielding significant flooding.

  - Heavy rains may overwhelm the capacity of combined stormwater and wastewater systems, leading to overflows of untreated waste.
  - Increases in heavy precipitation can increase the release of pollution and contaminant runoff.

Sea Level Rise and Coastal Flooding

- **Coastal storms and rising seas could overwhelm as well as damage stormwater infrastructure.**
  - Drainage outfalls could become inundated with sea level rise. Submerged drainage outfalls reduce the ability to drain and may even drive backflow into the system, causing flood waters to reach inland. Coastal flooding at outflows without tide gates may drive backflow into the system, causing upland flooding through street drains.
  - Shoreline erosion may expose stormwater infrastructure and lead to potential damage.
  - Sea level rise and coastal flooding can increase the release of pollution and contaminant runoff.
  - Failure of stormwater treatment devices during high flow events can lead to contaminated water.
  - Groundwater levels in coastal areas will increase given sea level rise, reducing the soil's ability to absorb stormwater and increasing runoff.

Other Extreme Weather

- **Severe storms could overwhelm capacity and damage existing stormwater infrastructure.**
  - Extreme storms introduce sediment and debris that can clog storm drains, pipes, and outfalls.

Water Impacts

The water service area within this Resource Guide includes supply, storage, treatment, and distribution systems. Specifically, we discuss impacts related to reservoirs, groundwater aquifers, water treatment facilities, pump stations, storage tanks, water mains, and service lines.

Heavy Precipitation and Inland Flooding

- **Heavy rains impact local water quality and infrastructure which could disrupt water services.**
  - Heavy rains and storm events increase water reservoir levels, which could require dams at the reservoirs to be opened more frequently to discharge water. This has downstream impacts.
  - Heavy rains can cause a reduction in capacity of reservoirs due to increased sediment from erosion.
  - Surface water quality may be reduced due to increased sediment or nutrient inputs associated with heavy rainfall events, which could increase water treatment costs.
  - When heavy precipitation exceeds soil infiltration capacity, there is an increase in surface runoff and decrease in groundwater recharge.
- **Flooding and overall wet conditions cause additional operational impacts for watershed management and infrastructure.**
  - Inland flooding impacts watershed management. It also imparts damage to restoration projects for water quality, as seen in Anne Arundel County.

Sea Level Rise and Coastal Flooding

- **Sea level rise could cause saltwater intrusion into groundwater,** which will affect jurisdictions including Queen Anne's County which rely on groundwater for their water supplies.
  - Saltwater intrusion will reduce the quality of water supply from groundwater aquifers and subsequently cause higher treatment costs.
- Rising sea levels, combined with reductions in freshwater runoff due to drought, will cause the saltwater-freshwater boundary to move further upstream in tidal estuaries, potentially reducing the water quality of surface water resources.

Extreme Heat

- **Extreme heat affects water supply and water quality.** These impacts will be exacerbated during droughts, described in greater detail under 'Other Extreme Weather' below.
  - As temperature increases, the rate of evaporation increases, which can contribute to reduction in water collection in reservoirs and wells.
  - Increased water temperatures will cause eutrophication and excess algal growth, which will reduce drinking water quality.
  - As temperature increases, chlorine dissipates quicker requiring more chlorine to be added to the system, but this increases the potential of disinfected by-products.

- **Extreme heat can stress electrical equipment.**
  - In the event of blackouts or brownouts and backup generators being stressed during extreme heat days, water treatment and service may be disrupted.

Other Extreme Weather

- **Severe drought presents risks to water supplies – both surface water and groundwater supplies.**
  - Drought limits the replenishment of surface water and reservoirs. This could potentially prompt counties to mandate water restrictions, as the region has experienced in the past. These events may become more frequent as temperatures increase and if longer periods with little rain occur.
  - Streamflow may decline during droughts, which can cause water levels to fall below intakes for water treatment plants. This may necessitate retrofits to accommodate lower flow or water levels.
  - If reservoirs are not an adequate water source for current and future demand because of climate change, jurisdictions may need to supplement the water supply with groundwater.
  - Severe droughts impact groundwater recharge of the aquifers, potentially causing groundwater aquifer levels to drop. Consequently, this may impact the water treatment plants and public water systems which receive the pumped groundwater through tapped wells.
  - Private wells will also be impacted by drought when groundwater aquifer levels drop. This may prompt future connections to the public water system.

IN QUEEN ANNE'S COUNTY…

Queen Anne's County depends on wells that tap into groundwater. Groundwater recharge of the aquifers could be a concern during times of severe drought.

  - Low reservoir levels due to drought will impact recreation opportunities in the area and may require additional outreach and safety warnings to users. Jurisdictions may be required to close reservoir-based recreational spaces to the public.

Wastewater Impacts

The wastewater service area within this Resource Guide includes treatment facilities, sewers, pump stations, and service lines.

Heavy Precipitation and Inland Flooding

- **Heavy rains impact local wastewater infrastructure and operations which could disrupt wastewater services.**
  - More extreme storm events will increase the amount of wet weather infiltration and inflow into sanitary and combined sewers. Sewage spills following heavy rain events have occurred in the region in recent years and are an ongoing concern.
    - Sanitary sewer overflows (SSOs) from the collection system can occur during heavy rain events. More intense rains and consecutive rainstorms can increase SSO discharges.
    - Both Baltimore County and Baltimore City are under a consent decree for SSOs, which has a significant financial impact.
  - Inland flooding can damage treatment plants and collection networks, requiring increases in maintenance and repair. Wastewater treatment plants are often located adjacent to water due to the need to discharge into waterways. In recent years, heavy rains and associated flooding have impacted sewage pump stations in the region.

IN HOWARD COUNTY…

In Howard County, sewer lines are usually along stream banks, and are therefore impacted by erosion and sediment that enters the sewer system.

  - Spray irrigation of treated effluent, as a form of disposal, is not permissible after heavy rain events or when the ground is saturated, to prevent runoff versus absorption. Future changes in heavy rain will affect how often this type of application is available.

Sea Level Rise and Coastal Flooding

- **Coastal flooding could damage wastewater infrastructure which could disrupt wastewater services.**
  - Sea level rise and coastal storm surge could potentially threaten coastal wastewater treatment plants if low-lying. Wastewater treatment plants are often located adjacent to water due to the need to discharge into waterways. Flooding could disrupt wastewater treatment services and lead to potential leakage of raw sewage.

IN BALTIMORE COUNTY…

In Baltimore County, several pumping stations are at risk to flooding associated with hurricanes (Figure 16). Flooding was becoming so common that the County installed flood doors at some pump stations.

- Storm events could lead to increases in water intake into the sewer system and lead to disruption of operations and potential damages of infrastructure.
- Sea-level rise and coastal storm surge can cause wastewater outlets to backflow.

Figure 16. Lynch Point Pumping Station in Baltimore County, and Exposure to Flooding from Hurricanes

Extreme Heat

- **Extreme heat may affect wastewater treatment operations.**
  - Extreme heat may stress electrical equipment. In the event of blackouts or brownouts and backup generators being stressed, wastewater service may be interrupted, and wastewater treatment may be disrupted.
  - High temperatures have an impact on wastewater treatment processes (for example, reduction of oxygen levels and transfer rates). High temperatures can affect the efficiency of anerobic digestion equipment.

Other Extreme Weather

- **Severe storms, including high winds, lightning strikes, heavy snowfall and ice cause risks to the power grid, and threaten operations of wastewater facilities.**
  - Power outages are a significant weather-related risk for wastewater facilities. This has been observed across the region and noted specifically in an interview with Harford County. Power outages without backup measures can lead to major impacts for wastewater services.
    - Backup generators are often a lifeline when power outages occur. However, relying on backup equipment has implications like increased maintenance and costs to keep the backup infrastructure running.

Facilities Impacts

The facilities service area within this Resource Guide includes the buildings and grounds managed by local jurisdictions across the region. Jurisdictions maintain facilities through preventative maintenance, routine maintenance and repairs, emergency repairs, and discretionary work.

Heavy Precipitation and Inland Flooding

- **Heavy precipitation causes damage to public facilities through flooding, heavy loads on facility roofs, and overload to systems that were not built to accommodate such events.**
  - The primary impact observed in public facilities is roof leaks, as well as sump pump failures.
  - When heavy precipitation causes flooding, there are often sump pump problems in buildings that have them. Buildings that do not have sump pumps may see water intrusion.
  - Facilities departments across the region invest in a preventative maintenance program for sump pumps, roofs, gutters, and other infrastructure, due to the amount of damage that has been caused in the past.

IN CARROLL COUNTY…

Carroll County sees more snowfall than other areas in the Baltimore region because of the more than 1,000 feet difference in elevation in the northern part of the County. Heavy precipitation in Carroll County takes a toll on facilities, causing a need for a robust preventative maintenance program to stay ahead of the impacts.

- **Precipitation, projected to increase in intensity, could continue to cause damage to public facilities through flooding, roof leaks, and sump pump issues.**

Sea Level Rise and Coastal Flooding

- **In the future, sea level rise and coastal flooding can cause facilities and equipment damage, resulting in higher maintenance costs and shorter replacement cycles. Impacts also include permanent inundation or temporary flooding of facilities.**

Extreme Heat

- **Extreme heat and temperature swings cause challenges for heating, ventilation, and air conditioning (HVAC) systems.**
  - As the region is experiencing more days with higher temperatures, air conditioning systems are seeing more use and therefore may need to be replaced earlier than originally planned.
  - Because HVAC units are often on the roof, workers risk overexposure as they repair equipment during intense heat.

IN HARFORD AND CARROLL COUNTIES…

As seen in Harford County, temperature swings from morning to afternoon tax the system because the chiller and heat systems cannot run simultaneously.

In Carroll County, non-crucial sites close during intense heat when the HVAC is not functioning.

- **Increased temperatures may require greater capacity for cooling of buildings and shading for outdoor facilities.**
  - Although there will be a reduction in heating needs, indoor cooling needs will increase given increases in temperature. Some buildings' HVAC systems may not be sized to accommodate increases in temperature.
  - Higher temperatures also will affect outdoor facilities like sports fields and courts, where surfaces and locations will need to be planned and designed to withstand increased temperatures (e.g., consider the need for additional shading).

Other Extreme Weather

- **Extreme weather events continue to stress facilities (e.g., from the effects of high winds). Severe and more frequent storms will impact public facilities by increasing the need for repairs.**
  - Preventative maintenance will continue to help mitigate repair costs as severe storms take a toll on the facilities located in the Baltimore region.

Solid Waste Impacts

The solid waste service area within this Resource Guide includes infrastructure managed by local solid waste and recycling departments. Managed assets include landfills, transfer stations, pick-up locations, waste-to-energy facilities, trash and recycling collection trucks, and materials processing vehicles.

Heavy Precipitation and Inland Flooding

- **Heavy precipitation impacts landfill infrastructure and operations.**
  - Heavy rainfall causes erosion and loss of stability of earth embankments, requiring additional reinforcements to solid waste facilities.
  - More rain leads to the production of more leachate. Leachate is generated in landfills from precipitation, liquids received in disposed waste, and waste breakdown. Leachate is highly toxic and can pollute the land, groundwater, and waterways. Increased erosion from stronger storms can result in leachate contamination.
    - There has been a notable increase in leachate in recent years because of the increase in precipitation. This increase in leachate requires extra efforts for operations. Local jurisdictions collect and transfer the substance for treatment, which is burdensome because not all wastewater treatment plans can handle leachate.
  - Cost of repairs could increase over time and take away from routine operations and maintenance of the solid waste service area, affecting available funding and resources.
  - Increased precipitation and sea level rise will contribute to the release of pollution and contaminant runoff from waste storage facilities. Increases in flood frequency and severity could increase the spread of contaminants from solid waste facilities into soils and waterways, resulting in increased risks to the health of nearby ecosystems, animals, and people.[18]

IN HARFORD COUNTY…

One impact seen in Harford County during wet conditions is that the Division of Solid Waste cannot properly dispose of biosolids, which cannot be land-applied in very wet conditions.

Sea Level Rise and Coastal Flooding

- **The increase in storms and flooding have caused a more frequent need to temporarily stop solid waste operations.**
  - Solid waste transfer stations have had to temporarily close during flood events, and to ensure that workers can stay out of flood waters.

[18] U.S. Global Change Research Program. Fourth National Climate Assessment. Chapter 18: Northeast. 2018. doi: 10.7930/NCA4.2018.CH18

IN BALTIMORE COUNTY…

Baltimore County has experienced flooding of the Western Acceptance Facility, which is a solid waste transfer facility and drop-off center.

Extreme Heat

- **Extreme heat Is increasingly impacting solid waste collection operations.**
  - Extreme heat can lead to outdoor worker safety concerns for sanitation workers.

IN BALTIMORE CITY…

Baltimore City adjusts shifts for summer crews to avoid peak heat exposure and also adjusts pickup schedules to account for passing storms. If a weekday shift is cut short, crews work on Saturday, which adds to the cost of overtime and also impacts employee morale.

  - Extreme heat can exacerbate odor and pest activity, potentially requiring more frequent trash collection.
- **Projected increases in extreme heat will continue to affect the safety of outdoor sanitation workers, which in turn, may impact solid waste collection operations.**

Other Extreme Weather

- **Severe and more frequent storms impact solid waste facilities and operations by generating significant debris, requiring more operational intensity and increased landfill capacity usage.**
  - Significant debris is discarded during storms, which requires major cleanup efforts. Even smaller precipitation events are generating more woody debris.

IN BALTIMORE COUNTY…

Significant cleanup is required after a storm event where flooding occurs, requiring equipment rentals to mitigate damage, which can be very expensive as seen in Baltimore County.

  - There is potential for extreme weather impacts to slope stability of landfills, because slope stability analyses do not account for the impacts from severe storms. At enclosed landfills, extreme storms have caused slope failures that were not planned for when the landfill enclosure was designed and installed.
- **Severe storms will continue to impact landfills as increased extreme weather exacerbates access, stability, capacity, and pollutants.**

Climate Change Impacts on Budgets and Current Financing Sources

Climate change will impact local budgets, as demonstrated through the impacts to operations, maintenance, and physical infrastructure across all services areas detailed in the previous sections of this Resource Guide.

- *Operating and maintenance budgets:* Changes in climate conditions will increase costs associated with operations, maintenance, and repair of infrastructure. Examples range from increased maintenance costs associated with clearing of debris from roadways following extreme storms to increased energy costs for facilities cooling during warmer days.
  - Municipal operating budgets currently are often the first to be reduced during budgeting difficulties. However, increased maintenance and operations expenses could help to proactively reduce costly damages to infrastructure amid changing climate conditions. For example, budgeting for additional cleaning of storm drainage ahead of more frequent and intense heavy rain events could mitigate costly damages from flooding.
- *Capital budgets:* Changes in climate conditions will shorten the lifecycle of infrastructure and increase the need for rehabilitation and/or replacement of capital infrastructure sooner than anticipated.

Additionally, climate change is shaping the availability of financing sources for local governments. Local governments may traditionally rely on borrowing through bonds to pay for much of your large infrastructure projects, with the cost of borrowing dictated by a jurisdiction's credit rating. Public credit rating agencies, such as Moody's and Standard & Poor's, have recently integrated climate change into their evaluation of credit for local governments. These new credit rating considerations are meant to reflect potential impacts of extreme weather and changing climate conditions on the financial health of the local governments and each locality's ability to repay. The credit rating agencies are increasingly paying attention to the vulnerability of localities to climate change and the local governments' ability to manage climate impacts.

As such, **climate adaptation efforts can help ensure that a locality's credit ratings are not downgraded; maintain or even improve a locality's bond rating; save millions of dollars for taxpayers; and boost availability of money for local infrastructure projects.**

- Example: In a recent credit evaluation, credit rating agencies highlighted Anne Arundel County's integration of climate resilience planning into its strategic growth and budget planning as factors for affirming the jurisdiction's high credit ratings.[19]
  - Anne Arundel County added a climate resilience component to the agency capital budget requests for the fiscal year (FY) 2022 budget and established a Resilience Authority to finance

[19] Anne Arundel County, Maryland. Anne Arundel County Retains Strong Bond Ratings in the Midst of COVID Pandemic. 2021. https://www.aacounty.org/news-and-events/news/anne-arundel-county-retains-strong-bond-ratings-in-the-midst-of-covid-pandemic#:~:text=Anne%20Arundel%20County%20has%20maintained,its%20bonds%20at%20favorable%20rates

projects and safeguard the County's property and assets. The Resilience Authority would be self-supported financially and not count against the County's debt limits and bonding authority.

- Anne Arundel County has retained high credit ratings from Moody's and Standard & Poor's for the past 15+ years, allowing the County to issue bonds at low interest rates and save millions of dollars for County taxpayers.

- Example: In the neighboring Charles County, Standard & Poor's affirmed the jurisdiction's high credit rating and cited the County's proactive long-term management for climate change.[20]
  - Charles County worked with the University of Maryland to create a Climate Resilience Action Strategy[21] and also partnered with the Maryland Climate Leadership Academy to train more than 20 county staff on climate change.

Moreover, city-owned infrastructure (e.g., buildings) might be used as collateral for bonds, so ensuring the resilience of such infrastructure is that much more critical.

[20] S&P Global Ratings. Summary: Charles County, Maryland; General Obligation. 2019. https://www.mdclimateacademy.org/s/ACCO-MarylandAcademy-CharlesCounty-SP.pdf

[21] University of Maryland, Center for Global Sustainability. Climate Resilience Action Strategy, Charles County, Maryland (draft). 2020. https://go.boarddocs.com/md/chrlsco/Board.nsf/files/BRPHA247795D/$file/Charles%20County%20Draft%20Resilience%20Report_7.15.2020.pdf

CHAPTER 4: Relevant Policies

Overview of Policy Context

This chapter summarizes the relevant policy context related to climate change impacts and adaptation that will affect the day-to-day work, decision-making, and investments of local DPWs and DOTs throughout the Baltimore region.

The broader policy context affects local DPWs' and DOTs' work related to climate change impacts and adaptation. Within this Resource Guide, the term "policy" encompasses processes established by State legislation (House and Senate bills) and regulations (administrative steps established by agencies), which could include programs to achieve goals related to climate change impacts and adaptation.

Local governance operates within the context of and is informed by Federal and State policy. The renewed Federal focus on addressing climate change supports an enabling environment, though to date has limited direct effect on local DPWs' and DOTs' day-to-day work and decision-making. From the State level, multiple policies, described in this chapter, are directly relevant to local government action to enhance climate resilience across Maryland. Additionally, there are opportunities within local level policies and codes to formalize considerations related to climate change impacts and adaptation.

State Policy Context

The following State-level policies are relevant to climate-related planning and management for local DPWs and DOTs:

- Local governments need to adhere to **existing environmental regulations** administered by the State. These regulations are based on historical climate data and may be affected under changing climate conditions. Two examples of such policies follow:
  - Maryland Department of the Environment's **dam safety regulations**[22] require dam owners—including local jurisdictions—to conduct regular inspections and develop Emergency Action Plans for dams classified as high or significant hazard (based on downstream damage that would result if the dam were to fail).
    - Required analyses include modeling the probable maximum flood (PMF), which represents the largest amount of flooding that could occur in a given area. However, this type of analysis does not yet require accounting for the more intense precipitation that is projected as a result of climate change.

[22] State of Maryland Government. Code of Maryland Regulations: Sec.27.17.04.05 Dams and Reservoirs. http://mdrules.elaws.us/comar/26.17.04.05

  - Heavy precipitation in recent years has caused high hazard dams to fail. For example, Carroll County had two dams fail in the past 5 years during storms that led to flooding.
- The Maryland Department of the Environment establishes **stormwater management regulations** in the state. Recognizing that outdated precipitation data and storm design standards result in insufficient stormwater controls, House Bill 295 (2021) now requires the Department to incorporate the most recent precipitation data available and review and update certain stormwater management regulations at least once every 5 years.[23]

Senate Bill 457 (2020) authorizes **local governments to establish a Resilience Authority to fund large-scale infrastructure projects** aimed at addressing the impacts from climate change.[24] The bill allows these Resilience Authorities flexibility in funding structures, ultimately allowing local governments to accelerate infrastructure financing and reduce implementation costs for climate change projects.

IN ANNE ARUNDEL COUNTY AND THE CITY OF ANNAPOLIS…

Anne Arundel County and the City of Annapolis partnered to establish a Resilience Authority to finance and support the construction of resilient infrastructure. For example, the Resilience Authority could help pay for an estimated $50 million worth of planned renovations to the City Dock in Annapolis, which regularly experiences flooding.

IN CHARLES COUNTY…

Neighboring Charles County was the first in the state to establish a Resilience Authority.

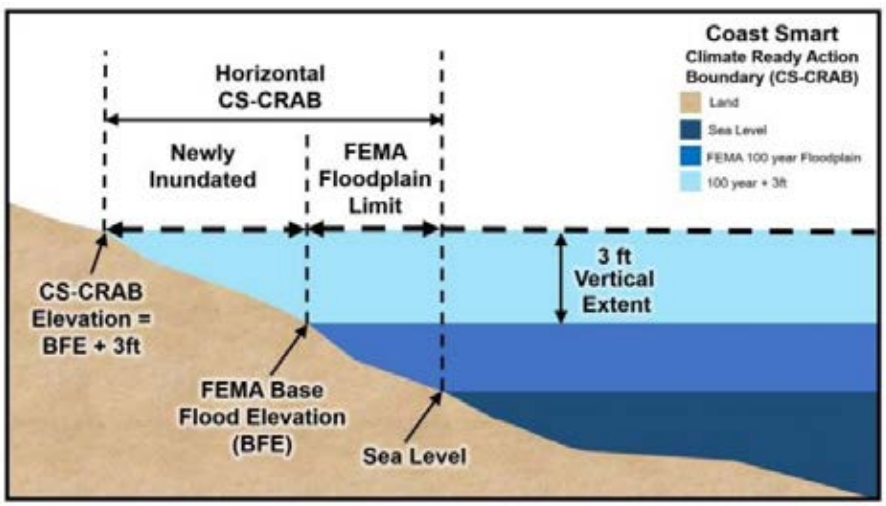
The State updates sea level rise projections every 5 years as required by House Bill 0514 (2015)/Senate Bill 0258 (2015).[25] The most recent report is the Sea-level rise: Projections for Maryland 2018, described in Chapter 2 of this Resource Guide. These regularly updated projections could be referenced in local design standards and applied by local DPWs and DOTs to support consistency in sea level rise planning across Maryland.

The **Coast Smart Construction Program**[26] by the Maryland Coast Smart Council provides **guidance on siting and design of capital projects given sea level rise and coastal flooding**. The Coast Smart Program is underpinned by several Maryland bills: House Bill 615 (2014); House Bill 1350/Senate Bill 1006 (2018); and House Bill 1427 (2019). Specifically, the Program:

[23] State of Maryland Government. House Bill 295. 2021. https://mgaleg.maryland.gov/2021RS/bills/hb/hb0295T.pdf
[24] Adaptation Clearinghouse. Maryland Senate Bill 457: Resilience Authorities. 2020. https://www.adaptationclearinghouse.org/resources/maryland-senate-bill-457-resilience-authorities.html
[25] Adaptation Clearinghouse. HB0514/SB0258 Maryland Commission on Climate Change. 2015. https://www.adaptationclearinghouse.org/resources/hb0514-sb0258-maryland-commission-on-climate-change.html
[26] Maryland Department of Natural Resources. Maryland Coast Smart Council Coast Smart Construction Program 2020. 2020. https://dnr.maryland.gov/climateresilience/Documents/2020-Coast-Smart-Program-Document-FINAL.pdf

- Applies to coastal projects—including at the local level—that involve the construction of a structure[27] or new highway facilities,[28] cost at least $500,000, and are funded with at least 50% State funds.[29]
- **Defines a new coastal flood planning area, called the Coast Smart Climate Ready Action Boundary (CS-CRAB),** that is used to determine minimum elevation requirements and other flood-related siting and design standards. CS-CRAB builds on the 100-year FEMA Base Flood Elevation (BFE) by adding a 3-foot vertical extent to the BFE and a corresponding horizontal extent, as illustrated in Figure 17. In using the CS-CRAB layer to characterize potential areas of flooding, Maryland is ensuring that flood protections apply to areas that are expected to experience flooding from projected climate change conditions.
- Provides specific guidance on siting in future coastal floodplains, generally discouraging siting new projects in areas that are prone to flooding as defined by the CS-CRAB.
- Provides specific guidance on **designing structures or highway facilities to reduce the impacts from future flooding** over the design life of the project. This includes structures to be constructed or reconstructed at or above the CS-CRAB elevation.[30]
- Requires applicable projects to complete a Coast Smart Project Screening Form (available in Appendix A of the Program guidelines) to document compliance with the siting and design criteria.

Figure 17. The CS-CRAB boundary and elevation for determining application of the siting and design criteria.



Courtesy of the Maryland Department of Natural Resources.

[27] "A 'structure' is defined as a walled or roofed building; a manufactured home; or a gas or liquid storage tank that is principally above ground." Maryland Department of Natural Resources. Maryland Coast Smart Council Coast Smart Construction Program 2020. 2020. https://dnr.maryland.gov/climateresilience/Documents/2020-Coast-Smart-Program-Document-FINAL.pdf

[28] "'Highway facility' is defined in § 3-101(f)(2) of the Transportation Article as any one or more or combination of projects involving the rehabilitation and reconstruction of highways in the State highway system to meet present and future needs and the development and construction in new locations of new highways necessitated by traffic demands to become parts of the State highway system, including federally-aided highway projects partially funded by this State and all incidental property rights, materials, facilities, and structures." Maryland Department of Natural Resources. Maryland Coast Smart Council Coast Smart Construction Program 2020. 2020. https://dnr.maryland.gov/climateresilience/Documents/2020-Coast-Smart-Program-Document-FINAL.pdf

[29] Exemptions for strict application of the criteria may apply to water-dependent uses, passive public access, historic structures, temporary structures or uses, and emergency use as long as the project is designed to include adaptation and resiliency features.

[30] Guidance does not outline potential conflicts with State or Federal permitting limitations on elevating bridges or upsizing culverts due to effects downstream.

Coastal local jurisdictions experiencing nuisance flooding need to develop a **local nuisance flood plan** and update the plan every 5 years, as required by House Bill 1350/Senate Bill 1006 (2018) and House Bill 1427 (2019). Nuisance flooding is defined by the bills as "high tide flooding that causes a public inconvenience" and is used to describe flooding to low-lying infrastructure caused simply by high tides without a coastal storm.

- The Department of Natural Resource's (DNR) Nuisance Flood Plan Development Guidance recommends that each plan include an inventory of known flood hazard areas where tidal nuisance flooding occurs; identification of flood thresholds/water levels/conditions that lead to tidal nuisance flooding; and a mechanism to document tidal nuisance flood events and response activities over the next 5 years.

IN BALTIMORE CITY, THE CITY OF ANNAPOLIS, AND ANNE ARUNDEL COUNTY…

Baltimore City, Annapolis, and Anne Arundel County have developed nuisance flood plans. Baltimore City developed a storyboard that walks through its plan.

To begin to address the impacts of shore erosion induced by sea level rise, the Maryland Living Shoreline Protection Act of 2008 (House Bill 973)[31], and the Tidal Wetland Regulations for Living Shorelines of 2013 that formalized the Act's requirements[32] require the use of **living shorelines** in tidal wetlands. Living shorelines are nonstructural shoreline stabilization methods, such as marsh creation. Exceptions apply in areas designated by the Maryland Department of the Environment as appropriate for structural measures or where nonstructural measures are demonstrably not feasible.

Local Policy Context

Jurisdictions in the Baltimore region have been working on addressing climate impacts through actions such as development of climate adaptation plans. In contrast to the multiple State level policies, climate impacts and adaptation have not been represented to date in local policies in the same codified way.

Notably, local DPWs and DOTs typically use local codes and design standards to inform infrastructure planning, design, and other decisions. Many of these codes and standards assume that future climate conditions, such as the frequency of high heat days or intense storms, will remain the same as historical conditions. However, the expected impacts of climate change (e.g., higher overall temperatures, more frequent and intense heat events and storms) mean that such assumptions will become outdated. **To ensure that infrastructure and other investments can withstand these changing conditions, local codes and standards should be updated using information on climate projections.** Chapter 5 contains a case study on climate resilience design standards.

[31] Adaptation Clearinghouse. Maryland's Living Shoreline Protection Act of 2008 (HB 973). 2008. https://www.adaptationclearinghouse.org/resources/maryland-s-living-shoreline-protection-act-of-2008-hb-973.html

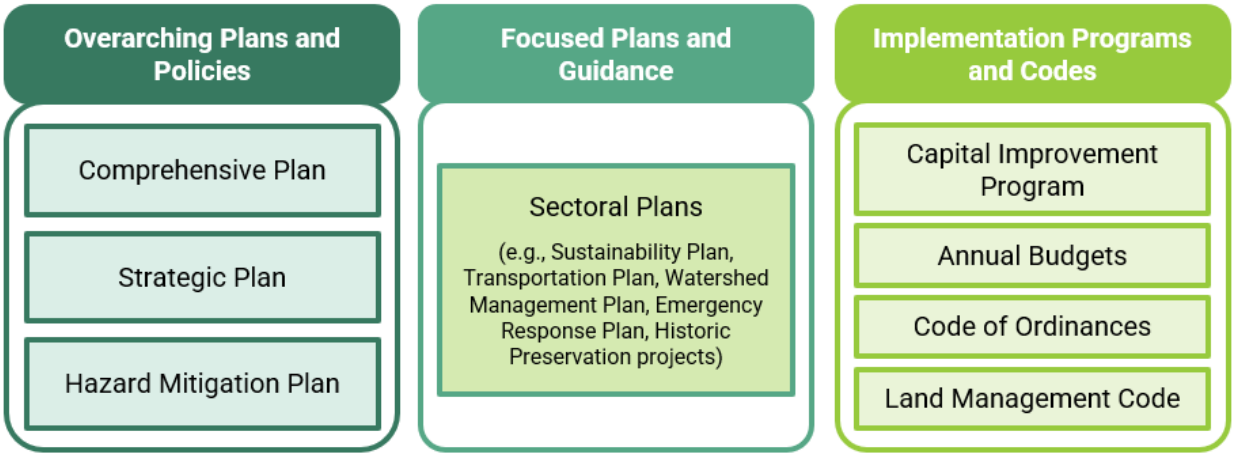
[32] Maryland Department of the Environment. New Tidal Wetland Regulations for Living Shorelines Effective February 4, 2013. https://mde.state.md.us/programs/Water/WetlandsandWaterways/Pages/LivingShorelines.aspx

Local codes and standards that such updates may apply to include:

- Local design standards and specifications (e.g., Harford County's Road Code book, Baltimore City's Green Book, Howard County's Design Manual, Volumes I–IV)
- Local development or floodplain regulations (e.g., Baltimore County's codes currently exceed the National Flood Insurance Program requirements and further mitigate vulnerability to flooding)
- Worker safety protocols (e.g., heat exhaustion prevention for outdoor workers)

Local DPWs and DOTs also operate within a broader ecosystem of local policies led by other departments such as planning. For example, the code of ordinances on zoning and development and the land management code affect DPWs and DOTs because these departments will be responsible for owning, maintaining, and operating the resulting public infrastructure assets. Figure 18 summarizes local policies, plans, and programs where climate change presents potential risks if future climate conditions are not considered and also presents potential opportunities to incorporate climate resilience considerations.

Figure 18. Examples of local policies, plans, and programs that could be affected by climate change.



Furthermore, continued coordination between localities and the State on policies related to resilience is vital.

- Many local codes, regulations, and standards are based on State-level codes, regulations, and standards. As State policies are updated to include climate considerations, so too should local policies be updated.
- Most State and local policies allow for a waiver or variance. Given that climate impacts are not confined within jurisdictional boundaries, decision-makers should consider the impacts of waivers or variances on neighboring jurisdictions. For example, one County waiving flood control of a development in the local watershed could result in flooding in downstream jurisdictions.

CHAPTER 5: Climate Adaptation Options for Local Public Works and Transportation Departments

Introduction

Adaptation Strategy Overview

Adaptation strategies help local jurisdictions proactively prepare for projected climate change by addressing anticipated impacts to infrastructure and assets. Employing adaptation strategies will help make communities more resilient.

Adaptation differs from emergency management in that adaptation measures help reduce vulnerabilities over the long-term that would otherwise result in a short-term emergency response. Climate change will undoubtedly increase the demand for emergency services and disaster management, though proactive climate adaptation measures will help to reduce mounting impacts under a changing climate.

Adaptation strategies can be incorporated at various stages of infrastructure lifecycle and across various functions relevant to DPWs and DOTs, which include Planning, Design/Construction, and Operations/Maintenance/Worker Safety.

Coordination across municipal departments and jurisdictions is a vital component of adaptation planning. Climate impacts, such as flooding, are not confined within jurisdictional boundaries and some adaptation strategies may be more cost-effective through joint solutions. Furthermore, one decision to positively impact resilience could have a negative impact on other municipal priorities or decision-making. For example, installing green infrastructure is a strategy to manage stormwater, but road salt to address snow and ice in the winter could be harmful to vegetation and would require re-planting every year at a high cost. As you undertake adaptation planning, consider implications to other service areas and jurisdictions and enhance coordination to build resilience within the region.

Chapter Overview

This chapter presents a range of climate adaptation options for local DPWs and DOTs and is intended to be used as a tool in adaptation planning. Jurisdictions can use it to quickly identify adaptation measures that apply to a hazard, service area, and/or governmental function.

Adaptation strategies and regional examples included in the tables below are organized by hazard type as follows:

Multi-Hazard

Changes in Temperature

Changes in Precipitation, Sea Level Rise, Coastal Storm Surge, and Flooding

Service areas are divided into six categories and are shown as follows (as presented in Chapter 3):

Transportation

Facilities

Water

Solid Waste

Wastewater

Stormwater

Adaptation measures can also be carried out across various DPW and DOT functions:

- **Planning:** Within the planning function, climate impacts and potential solutions can be considered holistically across a system. The infrastructure planning stage serves as an entry point to understand the impacts early enough to flag assets that need attention and incorporate adaptation measures into future planning initiatives, project scoping, and budgeting.
- **Design/Construction:** Integrating adaptation measures into infrastructure design and construction helps ensure assets can cost effectively operate until the end of their planned useful life given changing climate conditions. Examples of design/construction adaptation strategies include development of climate-resilient design standards, siting considerations for permanent or temporary infrastructure relocation, infrastructure hardening, and design of green infrastructure.
- **Operations, Maintenance, and Worker Safety:** Adaptation within this functional area involves changing existing processes and protocols to enable continued and safe operations in the face of climate change. Many operations and maintenance adaptation strategies are low-hanging fruit to prepare for climate change, in contrast to changes to physical infrastructure. For example, a jurisdiction may schedule more frequent cleaning of culverts in areas that are currently experiencing flooding during rain events. As another example, many of the operational technology elements used to support transportation safety, congestion mitigation, and traveler information objectives are already in place. To adapt to climate change, agencies will need to consider how these existing capabilities that already help improve operations and reliability need to evolve to meet the new and emerging requirements under a changing climate.

Examples of select adaptation measures are presented as case studies at the end of this chapter and show how jurisdictions beyond the Baltimore region are increasing their resilience.

Menu of Adaptation Strategies

The adaptation strategies in this "menu" offer a starting point of potential options for DPWs and DOTs in the Baltimore region. Below are three matrices, organized by hazard, that indicate the applicable service area and function. Given that some strategies are relevant across multiple service and functional areas, this matrix is organized to help you identify possible opportunities for synergy and collaboration across service areas. The corresponding jurisdictional examples show how strategies were applied "on the ground." Most of the example adaptation strategies were taken from interviews the team held with jurisdictions in the Baltimore region in 2021, with the location noted in bold font. Supplemental examples from outside the region are also noted within the table when additional examples help support the adaptation strategy at hand.

Costs to implement adaptation strategies vary widely given that both adaptation strategies specifications and costs are locally specific. Ideally, adaptation costs are marginal when climate change considerations are incorporated into existing decision-making on maintenance, operations, and capital projects (e.g., marginal cost to elevate a generator that a city was going to put into place anyway).

Multi-Hazard Strategies

Adaptation Strategy	Service Areas	Function	Examples[33]
Screen capital projects for climate change risks and opportunities and/or develop climate change resilience design standards		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	The **City of Baltimore** is tying resilience into capital programming by evaluating potential projects on how well they align with the city's Sustainability Plan, which includes citywide goals related to climate resilience. **Queen Anne's County** identified an adaptation strategy to incorporate climate change considerations into its Capital Improvement Plans. **Annapolis** developed a recommendation to prioritize resilience projects in its Capital Improvement Plans process. New York City developed Climate Resiliency Design Guidelines to provide step-by-step instructions on how to apply climate change data in the design of municipal facilities.
Incorporate backup power for critical infrastructure during power outages		✓ Planning ✓ Design/Construction ✓ Maintenance/ Operations/Worker Safety	**Baltimore County** currently has permanent backup power at critical facilities (e.g., fire stations, pump stations) and a fleet of portable generators with a contract for on-demand backup power. Transfer switches are being installed at key

[33] For additional information or details related to the examples, please contact the jurisdictions' points of contacts on the Acknowledgements page.

Adaptation Strategy	Service Areas	Function	Examples[33]
			buildings that may be used during an emergency. **Baltimore County** is completing a microgrid feasibility study, including added generators to facilities. The **City of Baltimore** requires that backup solar-powered streetlights and signals be installed along evacuation routes and high-traffic areas as a form of redundancy in the case of power outages. Many of **Howard County's** facilities are equipped with emergency power in case of power outages. Additional installation of emergency backup is underway for locations that were prioritized for backup power. A new, independent power grid is under review as a solution for County offices in case of power loss for an extended period.
Conduct regular monitoring, evaluation, and preventative maintenance of facilities and assets; **conduct cost tracking** to identify potential trends in damage		✓ Planning Design/Construction ✓ Maintenance/ Operations/Worker Safety	**Baltimore County's** Asset Management System across divisions considers risks of climate change. This system is used to make informed decisions on assets for preventative maintenance. **Carroll County** has a comprehensive preventative maintenance program. The County checks drains, electrical systems, and inspects roofs every month. After heavy rains, the County conducts a comprehensive check for roof leaks. **Harford County** conducts annual evaluations of assets, such as pumping stations and pipes, to determine whether the capacity of public infrastructure is adequate. **Harford County's** robust geographic information system (GIS), with geo-located infrastructure, combines layers of data that can be used for emergency and adaptation planning, coordinated response, and recovery efforts through cross-departmental collaboration. **MDOT** is tracking data on frequently flooded structures and roadways and will be creating a layer on the SHA Climate Change Vulnerability Viewer to show areas of frequent flooding.

Adaptation Strategy	Service Areas	Function	Examples[33]
Ensure inter-departmental and intra-jurisdictional coordination on climate change impacts and adaptation		✓ Planning Design/Construction Maintenance/ Operations/Worker Safety	**Anne Arundel County and Annapolis** have coordinated to establish a Resilience Authority, designed to help facilitate resilient infrastructure financing. **Howard County** has developed a Microgrid Planning Committee that comprises staff from DPW, Emergency Management, Facilities, Technology, Communications, Fire, and Police. **Queen Anne's County's** Vulnerability Assessment identifies a medium-term adaptation strategy to update a multijurisdictional hazard mitigation plan to address sea level rise.
Refine policies that encourage responsible development under changing climate conditions		✓ Planning Design/Construction Maintenance/ Operations/Worker Safety	**Anne Arundel County's DPW** is working together with land use agencies to align zoning and the general development plan to revise policies so new infrastructure is not planned in flood-prone areas. The County's DPW also has developed a topographic wetness index that identifies areas of potential wetland ponding. **Queen Anne's County's** Vulnerability Assessment recommends conducting an inventory of regulations and policies to remove barriers that hinder opportunities for sea level rise and coastal hazard adaptation. In addition, the assessment proposes a policy to create elevated County review procedures for projects in vulnerable areas.
Build capacity on climate change impacts and adaptation		✓ Planning ✓ Design/Construction ✓ Maintenance/ Operations/Worker Safety	**Queen Anne's County's** Vulnerability Assessment identified capacity building as an adaptation strategy. This strategy includes increasing the availability of data, technical expertise, regulations, coordination, and public support.

Changes in Temperature Strategies

Adaptation Strategy	Service Areas	Function	Examples
Adjust and expand worker safety plans		Planning Design/Construction ✓ Maintenance/ Operations/Worker Safety	In Austin, TX, the Climate Resilience Action Plan suggested expanding staff safety plans to adjust work schedules and safety policies for fieldworkers during extreme heat days, poor air-quality days, and other climate-related health risk days.
Plant more trees and vegetation to provide shading and lower ambient temperatures		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Baltimore County's** Climate Action Plan calls to increase the urban tree canopy, targeting areas with urban heat island impacts. Philadelphia, PA, is developing an Urban Forest Strategic Plan, prioritizing equity and environmental justice in service delivery, so that that the most vulnerable and underserved communities can benefit from healthy tree canopy.
Incorporate **shading into street and building code standards**		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	Phoenix, AZ, incorporated shade standards, such as requiring a minimum of 75% of public sidewalks be shaded, into the municipal code
Incorporate bus shelters, shading, and seating for transit riders and workers		✓ Planning ✓ Design/Construction ✓ Maintenance/ Operations/Worker Safety	Tacoma Park, MD, committed by resolution to develop a bus shelter prioritization plan and identified the need to make improvements to bus stops as a means of enhancing alternative transportation options. In Los Angeles, CA, *StreetsLA* is expanding street furniture and administering a program to install new bus shelters to thousands of bus stops in the region to protect riders from heat and maintain ridership.
Use cooler pavement mixes (e.g., light-colored aggregate) to reduce surface temperatures		Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	Chicago, IL's Green Alley program is repaving alleys in the city with permeable, high-albedo pavement, a lighter-colored surface that reflects sunlight instead of absorbing it. Chula Vista, CA's Climate Action Plan adaptation strategies include installation of cooler paving products, intended to incorporate reflective paving into all municipal projects (parking lots and streets).

Adaptation Strategy	Service Areas	Function	Examples
Adjust paving mix for higher extreme heat thresholds to minimize rutting		Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	In Philadelphia, PA, Bus Stop Pads made from rigid concrete materials were positioned in front of bus stops to prevent pavement rutting or waves, which can occur during high temperatures at locations with frequent stops. As part of Austin, TX's Climate Resilience Action Plan, DPW is reviewing new paving technology to make potential adjustments to pavement materials to account for summer temperatures.
Implement upgrades for building cooling systems when needed		Planning ✓ Design/Construction ✓ Maintenance/ Operations/Worker Safety	**Baltimore County's** Climate Action Plan recommends upgrading HVAC systems to be more efficient and resilient to extreme heat in the face of increased temperatures.
Improve building thermal efficiency by designing facilities according to U.S. Green Building Council's LEED standards		Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	By an executive order issued in February 2021, **Baltimore County** now requires all newly constructed County facilities or major renovation to be LEED Silver standard or higher. The **City of Annapolis** requires that new construction greater than 7,500 square feet achieve LEED certification by the U.S. Green Building Council or use equivalent energy and design standards. In **Howard County**, most publicly funded buildings greater than 10,000 square feet and new construction of at least 50,000 square feet must achieve a LEED certification or comply with equivalent standards.

Changes in Precipitation, Sea Level Rise, Coastal Storm Surge, and Flooding Strategies

Adaptation Strategy	Service Areas	Function	Examples
Develop green infrastructure/ nature-based solutions to absorb and convey excess stormwater and/or to protect coastal assets		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Anne Arundel County** has watershed restoration projects to address how the natural landscape can accommodate increases in rainfall and flooding. **Baltimore County** is focusing on green stormwater initiatives, converting underground conveyance to above-ground. The Climate Action Plan recommends installing vegetated best management practices (e.g., green infrastructure) that reduce or slow runoff, while allowing surface drainage to accommodate large volumes more cost effectively than buried pipes. The **City of Baltimore** has specified preserving and protecting natural drainage corridors as a main stormwater strategy, as well as using green roofs, rain gardens, cisterns, and bioswales to capture stormwater and increase permeable surfaces.
Enhance maintenance measures, such as cleaning drains and culverts, to alleviate flooding		Planning Design/Construction ✓ Maintenance/ Operations/Worker Safety	The **City of Baltimore** has prioritized conducting regular maintenance of streams and assets, such as clearing streams, increasing inspections, and cleaning of culverts and storms drains.
Site assets or services out of flood-prone areas		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Anne Arundel County** is looking at target areas that can accommodate development necessary for relocation. **Baltimore County** included relocation as an adaptation alternative in the Climate Action Plan. Permanently moving assets or services outside the range of flooding helps to support flood resilience by returning land to a natural state.
Elevate or floodproof assets that are subject to frequent flooding		Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Howard County** is systematically elevating or sealing manholes in the watershed or sewer area to prevent water intrusion. Like most counties in Maryland, **Anne Arundel County** DPW protects drinking water contamination by requiring facilities to install backflow prevention devices.

Adaptation Strategy	Service Areas	Function	Examples
Implement flood warning system and safety mechanisms		Planning Design/Construction ✓ Maintenance/ Operations/Worker Safety	**Anne Arundel County** has established an automated flood warning network on inland roadways that cross the riverine floodplain which involves radar sensors that will trigger dynamic warning signals. **Anne Arundel County** has a safety system where gates drop when high swift water is present. **Baltimore City** has an extensive automated flood warning system that tracks real-time data from rain gages and stream level gages. This system helps identify micro-bursts that could lead to inland and roadway flooding. The system is coordinated between DPW and the Office of Emergency Services, which operates the B'More Alert community notification system. The system is also connected to the National Weather Service.
Plan for supplemental temporary coastal flood protection (because coastal storm surge flooding often comes with advance notification)		✓ Planning Design/Construction ✓ Maintenance/ Operations/Worker Safety	Temporary measures noted in the **Baltimore County** Climate Action Plan include sandbags, emergency pumps, and other protective measures. In **Howard County**, some new buildings are being built so they can be used as emergency shelters in case of flooding, severe storms, flooding, or extreme heat.
Floodproof and protect critical assets		Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Baltimore County's** Climate Action Plan suggests dry or wet floodproofing as an adaptation measure to seal out water during floods or allow for water to pass through the lower portions of the building during an active flood event. **Howard County** has identified certain sewer lines that run parallel to streams and will require hardening or dry-proofing because of erosion. In addition to manholes, **Howard County** is planning to floodproof below-grade infrastructure (e.g., submarine doors, knee walls), so that it will continue to operate if flooded. New York City's Wastewater Resiliency Plan includes adaptation strategies to elevate and floodproof pumping stations and wastewater treatment plants.

Adaptation Strategy	Service Areas	Function	Examples
Implement system upgrades to accommodate increased rainfall/flooding		✓ Planning ✓ Design/Construction Maintenance/ Operations/Worker Safety	**Anne Arundel's** Climate Resilience Action Strategy includes a strategy to ensure all roads of a certain size can withstand a 25-year storm. This strategy involves updating the design manual, prioritizing at-risk roads, and planning for improvements. **Anne Arundel** is evaluating flood risk for County pumping stations to ensure stations are resilient to 100-year floods. **Baltimore County's** Climate Action Plan calls for improvements to existing drainage networks and culverts for increased capacity and resilience, especially when sea level rise causes coastal storm drain outfalls to be inundated. **Harford County** has increased capacity for storage of biosolids, which must be land-applied during dry conditions. **Howard County** has increased design requirements for storm drains after severe flooding. New York City's Stormwater Resiliency Plan includes integration of future-looking climate change projections into long-term drainage planning, changes to the City's flash flood emergency response procedure, and an increased focus on public communications related to rainfall-based flooding.

Adaptation Case Studies

Crosscutting Strategy: Resilience in Capital Improvement Programs

Ensure that municipal capital investments can continue to deliver infrastructure services in the face of climate change by identifying resilience design modifications for proposed capital projects.

Strategy Overview

Integrating resilience into Capital Improvement Programs (CIPs) entails asking project managers to:

1. Identify how a proposed capital investment might be impacted by future climate conditions.
2. Identify potential design modifications that could bolster the resilience of the project and appropriately budget for the selected resilience modification.

For example, the scope for an emergency generator capital project could be modified to include installation on an elevated platform to ensure that it remains operable during heavy storms and will not need to be replaced because of flooding. As another example, the scope for a mechanical equipment capital project could be modified to include shading to reduce overheating during very hot days (Figure 19).

This strategy can apply to all CIP projects, including maintenance for existing assets as well as construction of new assets.

- By considering how and when existing assets may be affected by climate change, local governments can plan for rehabilitation, relocation, and/or replacement.
- New projects can be proactively designed for resilience, saving money and effort in the long run.

Why this strategy?

✓ Increase efficiency and ease of implementation by integrating into existing municipal processes

✓ Save money by incorporating resilience upfront on long-lived investments instead of performing retrofits or replacements down the road

How to implement?

✓ Understand priority areas or assets for resilience

✓ Modify capital project scopes to include resilience measures

Resources:

University of Maryland Finance Center's best practice guide on Integrating Resilience into Local Capital Improvement Programs.

Example: City of Frederick, MD[34]

Frederick is developing a guide for project managers to integrate resilience into the CIP after the city issued a Climate Emergency Resolution that committed the city to consider all significant municipal actions through the lens of climate change. The guide lays out step-by-step instructions and resources to help project managers integrate resilience into your CIP

Examples within the Baltimore region:

- City of Baltimore, MD
- Queen Anne's County, MD
- City of Annapolis, MD

[34] For more details on this internal municipal resource, contact the City of Frederick's Sustainability Manager.

submissions by identifying and addressing climate change risks to a project (assessing sensitivity and exposure and then modifying project scope to address climate risks); identifying opportunities for adding climate resilience and greenhouse gas mitigation measures that would benefit the city as a whole; documenting the climate considerations in existing municipal project submission forms; and ensuring that resilience carries into project implementation (including sample RFP language). The goal of this Resource Guide is to help department staff comply with the Climate Emergency Resolution and proactively build the resilience of the city's investments.

Figure 19. Adjustment to a mechanical equipment capital project to incorporate shading to avoid overheating.

Image source: Boston Planning and Development Agency, Coastal Flood Resilience Design Guidelines.

Crosscutting Strategy: Climate Resilience Design Guidelines

Climate resilience design guidelines ensure that new infrastructure is designed and existing infrastructure is retrofitted, using data on future climate conditions.

Strategy Overview

Traditional infrastructure design guidelines rely on the idea of *climate stationarity*: The climate conditions that the infrastructure will experience will be similar to historical climate conditions.

Climate change means that this assumption is no longer true and that we cannot rely on historical conditions to accurately predict the future. With this in mind, locally developed climate resilience design guidelines and standards can help ensure that infrastructure will be built to withstand future conditions, such as higher temperatures and more intense and/or frequent floods.

Although there is currently a lack of nationally adopted standards for resilient infrastructure, jurisdictions can develop standards and guidelines that are specific to each's specific context and needs. For example, Maryland's Coast Smart Construction Program (described in Chapter 4) is an example of flood-related siting and design standards that takes into account future sea level rise above FEMA's base flood elevation.

Example: New York City[35]

New York City developed Climate Resiliency Design Guidelines to provide step-by-step instructions on how to apply climate change data in the design of municipal facilities. The Guidelines apply to all City capital projects to protect the City's public investments into the future. The Guidelines provide:

- ✓ Climate projections to incorporate into design
- ✓ Instructions for determining the useful life of capital projects and the corresponding timeframe for the future climate projections
- ✓ Advice on managing uncertainty (e.g., through adaptable design that can be modified or augmented over time)
- ✓ Project-specific considerations (e.g., financing requirements, interdependencies between services or resources, existing hazard mitigation projects and risk studies, and operations and maintenance)

Why this strategy?

- ✓ Ensure that capital projects are consistently designed to withstand future climate conditions
- ✓ This adaptation strategy requires a standardized approach by specifying design inputs, compared to the strategy to integrate resilience in CIP which encourages resilient design but does not specify "how resilient" infrastructure needs to be

How to implement?

- ✓ Use local downscaled climate projections. Choose which climate scenario(s) to use based on risk tolerance
- ✓ Set standards such as design flood elevation, stormwater drainage, and shade cover based on project type and climate projections

Resources:

Chapter 6 of the Planning for Infrastructure Resilience guidebook by the American Planning Association

[35] NYC Mayor's Office of Resiliency. Climate Resiliency Design Guidelines. Version 4. 2020. https://www1.nyc.gov/assets/orr/pdf/NYC_Climate_Resiliency_Design_Guidelines_v4-0.pdf

The Climate Resiliency Design Guidelines then provides detailed guidance on core resilience design elements for each of the climate hazards:

- ✓ Temperature—minimize contributions to the urban heat island effect; minimize impact to the asset from increasing temperatures
- ✓ Precipitation—consider precipitation design adjustments for on-site stormwater systems; incorporate climate change projections into the City's drainage planning
- ✓ Sea level rise—address risks in the current floodplain; address risks in the future floodplain given sea level rise (Figure 20).

The guidelines also emphasize equity as part of the design process, because climate impacts are often felt most severely by disadvantaged populations.

Figure 20. Design adjustments to the base flood elevation to incorporate sea level rise.

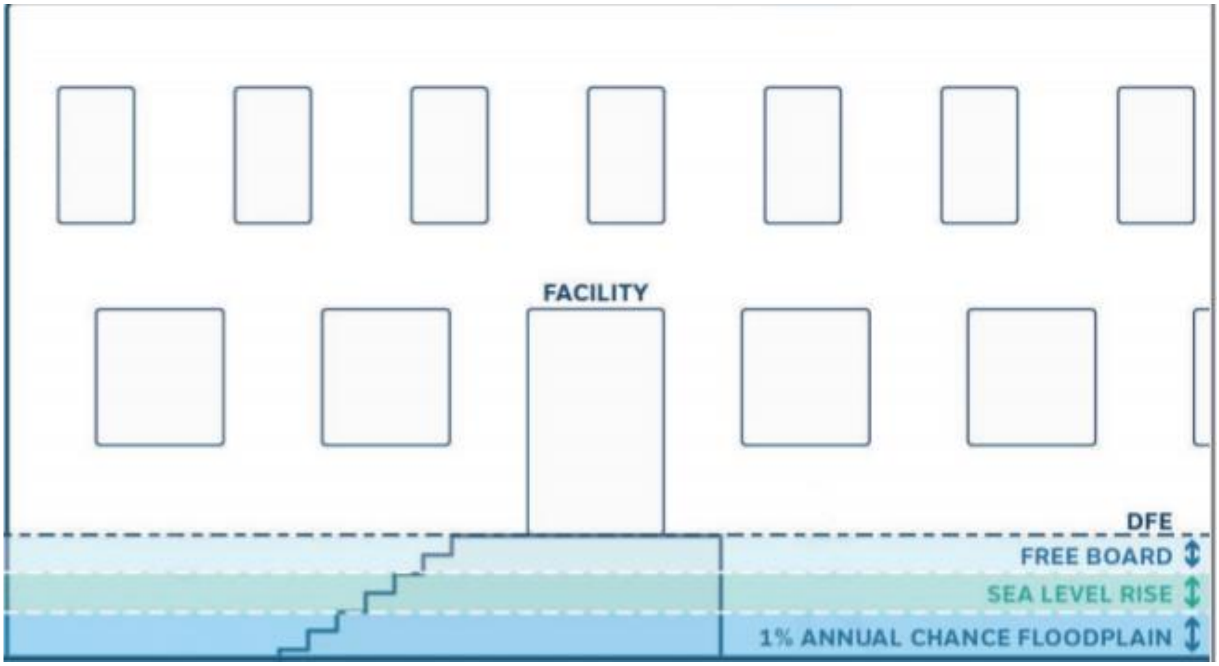


Image source: NYC Climate Resiliency Design Guidelines.

Case Study: Installing Green Infrastructure When Upgrading Road and Stormwater Infrastructure

Reduce stormwater runoff and temperatures while gaining other community co-benefits

Green infrastructure can help to infiltrate and filter rainwater, minimize local flooding, reduce the urban heat island effect, improve air quality, and create a more welcoming and greener neighborhood. Green infrastructure includes solutions like bioswales, porous pavement, rain gardens, rain barrels, and green roofs.

Green infrastructure is an important tool for handling stormwater runoff onsite rather than allowing the water to flow elsewhere, potentially causing flooding or sewer overflows. Some of the key locations where green infrastructure can be integrated are along the roadways through curb extensions and by planting strips that are designed as bioswales and rain gardens.

Why this strategy?

- ✓ Reduce stormwater, lower temperatures, and gain co-benefits

How to implement?

- ✓ Prioritize sites for green infrastructure
- ✓ Combine green infrastructure installation with road and stormwater work for reduced disruption and cost

Resources:

U.S. Environmental Protection Agency's guidance on Green Infrastructure Design and Implementation

Examples

Grand Rapids, MI[36]: Historically, Grand Rapids has had significant flooding when the Grand River overflows. This flooding has worsened with climate change because of increased intense rainfall. Grand Rapids has nearly completed its effort, begun in the 1980s, to separate its combined sewer system. Though this effort meets the requirements of reducing combined sewer overflows, it has not reduced the risk of localized flooding during heavy rainfall events. To help reduce this risk while also gaining other community benefits, Grand Rapids garnered public support for investments in green infrastructure.

Grand Rapids instituted guidelines that mandate green infrastructure when updating roadways and stormwater infrastructure. Projects must integrate green infrastructure or justify why it is not technically feasible. The projects are funded by an income tax extension. The mandate and income tax extension passed in 2014 and have resulted in significant investments in green infrastructure. The original mandate did not explicitly consider climate change; however, Grand Rapids is taking the next step to evaluate climate change projections and integrate them into its Stormwater Management Program.

Philadelphia, PA[37]: Philadelphia has been implementing green infrastructure along roadways since 2011 with its *Green City, Clean Waters* program. In the 10 years since the program began, Philadelphia has exceeded its goals, installing green infrastructure at 800 sites throughout the City and keeping more than 2.7 billion gallons of stormwater runoff out of the sewer system. Although

[36] Vogel J, et al. Climate Adaptation: The State of Practice in U.S. Communities. 2016. https://kresge.org/sites/default/files/library/climate-adaptation-the-state-of-practice-in-us-communities-full-report.pdf

[37] Philadelphia Water Department. *Green City, Clean Waters*. https://water.phila.gov/green-city/

initially started to reduce combined sewer overflows, the Philadelphia Water Department has integrated the program into its Climate Change Adaptation Program.

Figure 21. Bioswales along local roads help manage stormwater.

Image source: Philadelphia Water Department, Green City, Clean Waters.

Case Study:Preparing Facilities for Climate Change

Ensure that facilities are prepared to withstand the impacts of climate change via design, construction, and maintenance, as well as emergency protocols and preparedness.

Strategy Overview

Preparing facilities for climate change does not only involve hardening them against climate hazards. Increasing the resilience of facilities to climate change entails:

- ✓ Rehabilitating facilities to address priority risks (e.g., floodproofing, switching to energy-efficient systems, installing backup generators, installing green infrastructure such as shade trees or rain gardens).
- ✓ Updating maintenance and operations protocols in anticipation of more frequent and/or intense events and higher temperatures.
  - These updates also involve worker safety protocols to protect outdoor workers from extreme heat.
- ✓ Coordinating emergency response and evacuation protocols, including identifying public facilities that could serve as cooling centers and/or emergency shelters.

Why this strategy?

- ✓ Protect existing facilities and occupants
- ✓ Reduce repair/replacement costs in the long run
- ✓ Prepare emergency shelters and cooling centers

How to implement?

- ✓ Rehabilitate existing facilities and require resilient design for new facilities
- ✓ Update maintenance and operations protocols
- ✓ Update and coordinate between departments on emergency response and evacuation protocols

Example: Austin, TX[38]

The City of Austin, TX, completed a citywide climate vulnerability assessment of its utility infrastructure, transportation assets, and community facilities to extreme heat, drought, flooding, and wildfire. After assessing the vulnerability of City facilities and identifying infrastructure and resource needs, facilities managers and staff from 15 City departments identified resilience strategies under four broad categories. In the City's Climate Resilience Action Plan, each of these four categories is broken down into specific strategies with timelines (within 2 years and within the next decade), lead departments, status, and which budget is supporting the action. Strategies included establishing safe emergency and evacuation routes for city staff; upgrading air conditioning or ventilation to mitigate heat and air quality impacts; addressing deferred facilities maintenance; floodproofing critical infrastructure; improving building efficiency and redundancy; and exploring potential financial impacts of climate change on assets and operations when prioritizing projects and planning for new facilities. This Plan also involved an inventory of City facilities that would be suitable as a cooling center or emergency shelter based on factors such as emergency communication capabilities, food storage, generator hookups for backup power, and LEED certification for energy and water efficiency.

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[38] City of Austin (Texas). Climate Resilience Action Plan for City Assets and Operations. 2018. http://austintexas.gov/sites/default/files/files/Sustainability/Climate_Resilience_Action_Plan.compressed.pdf

Case Study: Protecting Wastewater Facilities from Flooding

Ensure that wastewater facilities can continue maintaining clean waterways in the face of flooding and sea level rise.

Wastewater facilities are major capital investments key to maintaining clean waterways for communities. These facilities may be vulnerable to several climate change hazards, including sea level rise and flooding.

Physical options for protecting these facilities could include, but are not limited to:

- Hardening the wastewater facility (e.g., building a sea wall)
- Raising key portions of the wastewater facility necessary to maintain functionality
- Moving the facility at the end of its useful life

Why this strategy?

- ✓ Protect major investments that provide a vital service to the community
- ✓ Avoid Clean Water Act violations

How to implement?

- ✓ Assess flood risk to wastewater facilities
- ✓ Evaluate range of flood protection measures that incorporate future projections through the end of its useful life

Resources:

U.S. Environmental Protection Agency's Climate Resilience Evaluation and Awareness Tool

U.S. Environmental Protection Agency's Resilient Strategies Guide for Water Utilities

Examples

Washington, DC[39]: The Blue Plains Wastewater facility serves all of Washington, DC, and portions of Maryland and Virginia. Located along the Potomac River in Washington, DC, this facility is vulnerable to riverine flooding and storm surge.

The facility has historically been protected by a sea wall designed to protect against the 100-year flood. However, with climate change projections showing that flooding and storms will become more frequent and severe, DC Water and Sewer Authority decided to raise the sea wall. The new sea wall was designed to be 3 feet higher than the 500-year flood level to protect against the rising river, storm surge, and more severe floods.

Boston, MA[40]: Boston's Deer Island Wastewater facility is highly vulnerable to sea level rise. In the late 1980s, the Massachusetts Water Resources Authority (MWRA) decided to raise key portions of the facility by 1.9 feet. This number was chosen based on projections through 2050, the facility's planned useful lifespan. MWRA chose to raise portions of the facility, instead of developing a sea

[39] U.S. Environmental Protection Agency. Blue Plains Wastewater Facility in Washington DC Reinforces Facility Against Floods. https://www.epa.gov/arc-x/blue-plains-wastewater-facility-washington-dc-reinforces-facility-against-floods

[40] U.S. Environmental Protection Agency. Boston Raises Wastewater Facility to Avoid Inundation. https://www.epa.gov/arc-x/boston-raises-wastewater-facility-avoid-inundation

wall, because of costs; a sea wall would have been extremely costly because the facility is surrounded by water on all sides.

Baltimore, MD[41]: In the past, heavy rains contributed to **sanitary sewer overflows (SSOs)** in Baltimore. To comply with the Sanitary Sewer Consent Decree, the City of Baltimore developed and adopted a comprehensive wet weather management plan, with a primary focus of eliminating SSOs. As part of that effort, the Headworks Project at the Back River Wastewater Treatment Plant (Figure 22) was designed to increase the capacity of the wastewater treatment process to handle the excess flows that typically come into the plant during heavy rain events. The $430-million investment consisted of new piping, construction of a new pumping station, and installation of new storage tanks to handle excess flows into the plant.

Figure 22. Back River Wastewater Treatment Plant.

Image source: The Baltimore Sun.

[41] City of Baltimore (Office of the Mayor). Mayor Scott, Federal, State and Regional Leaders Officially Open Newly Completed Headworks Project (press release). 2021. https://mayor.baltimorecity.gov/news/press-releases/2021-05-10-mayor-scott-federal-state-and-regional-leaders-officially-open-newly

CHAPTER 6: Funding and Financing Sources

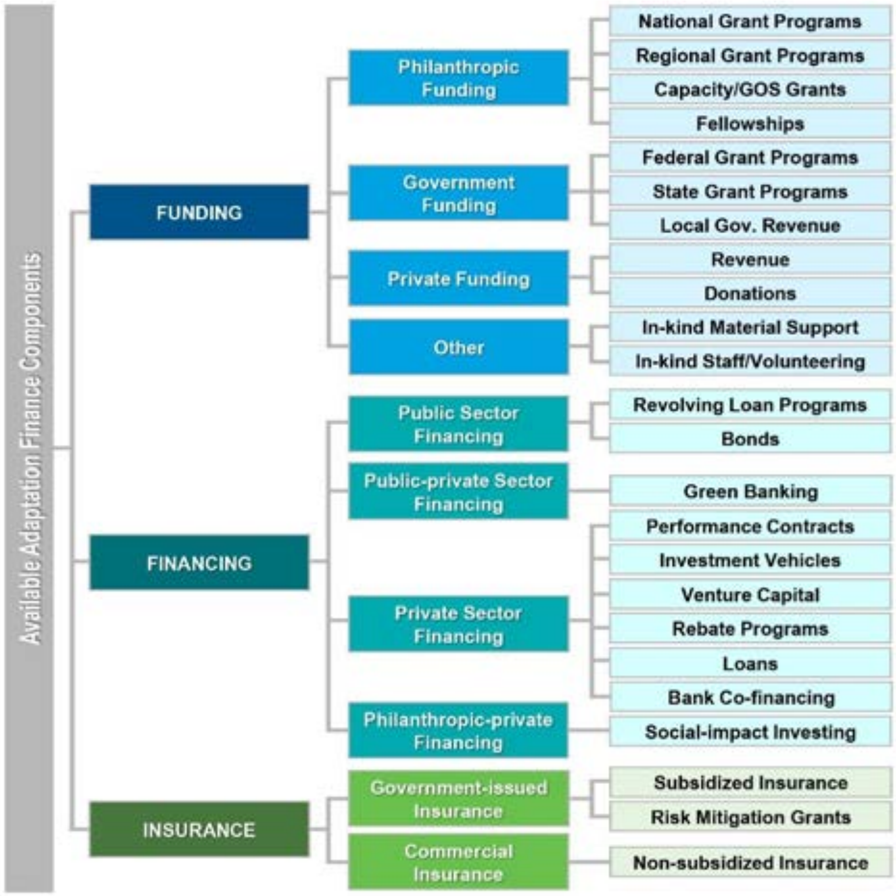
Overview of Funding and Financing Opportunities

This chapter on Funding and Financing Sources summarizes highly relevant grants and low-cost financing opportunities to support work on local infrastructure adaptation.

There are a variety of potential avenues for local governments to access pots of money for climate adaptation. As summarized in Figure 23, there are generally three types of ways to pay for adaptation:

1. **Funding** refers to money that does not need to be repaid, such as government or philanthropic grants
2. **Financing** refers to money that needs to be repaid over time, such as loans and bonds
3. **Insurance** pays out when a disaster occurs in return for payment of a premium

Figure 23. Potential funding, financing, and insurance mechanisms for local-level adaptation strategies.



Source: California's Natural Resources Agency. California's Fourth Climate Change Assessment. 2018.

Funding and low-cost financing are the most common ways to pay for local government infrastructure adaptation. However, adaptation funding and financing space are continually innovating to create new mechanisms. For example, environmental impact bonds engage the public and private sector in a "pay for success" model; the public pays off the bond over time based on success of the project, and risks are mediated by the private sector in the pursuit of public goals. The City of Baltimore issued an environmental impact bond to fund stormwater management projects.[42] As another example, DC Water was first in the country to issue an environmental impact bond in order to finance green infrastructure for stormwater management challenges.[43]

Existing Funding and Financing Sources

This subsection identifies specific sources of traditional funding and low-cost financing options from the State and Federal government.

The Maryland Resiliency Partnership and Maryland Environmental Service maintain an interactive database of grants. The database contains more than 200 Federal, State, and private foundation grants related to hazard mitigation, floodplain management, green infrastructure, water quality improvement, and related disciplines. **Review this interactive Database of Grants to supplement the curated list of funding and financing sources discussed below and for the latest updates**.

State Sources

Maryland offers several funding opportunities specifically for climate adaptation and resilience. The Department of Natural Resources' **Chesapeake and Coastal Grants Gateway program** is a key resource for Counties and City or local governments seeking technical and financial support for a range of projects to increase your resilience to climate impacts, restore local waterways, and strengthen local economies. **The Grants Gateway serves as a one-stop location for annual Maryland-specific funding opportunities to which entities can submit proposals**.

Funding opportunities through the Grants Gateway is organized under five "Outcomes," two of which are directly related to addressing impacts and enhancing resilience to climate change:

- *Outcome 2* focuses on enhancing the capacity to understand and effectively plan to address flood risks associated with a changing climate.
  - Funding is available for local governments seeking to improve understanding of potential short- and long-term impacts and vulnerabilities associated with flooding from rising waters and increased precipitation.
    - Examples of projects may include assessing flood hazards and existing stormwater infrastructure to identify improvements to reduce flood risk, and evaluating impacted infrastructure (built and natural) to expected flood impacts.

[42] Baltimore City Department of Public Works. 'Pay for Success' Model Will Help Fund Baltimore's Stormwater Projects (press release). 2018. https://publicworks.baltimorecity.gov/news/press-releases/2018-03-26-%E2%80%98pay-success%E2%80%99-model-will-help-fund-baltimore%E2%80%99s-stormwater-projects#:~:text=Baltimore%20will%20work%20with%20CBF,ve%20been%20used%20in%20Maryland

[43] Quantified Ventures. DC Water: First Ever Environmental Impact Bond. https://www.quantifiedventures.com/dc-water

- *Outcome 3* focuses on utilizing natural and nature-based infrastructure to enhance community resilience to climate change.
  - Funding is available for local governments to design, engineer, and implement projects that restore, create, and strengthen natural infrastructure and enhance the community resilience to climate-related events.
    - Possible projects include using nature-based solutions to address flooding impacts on community infrastructure and integrating green infrastructure to address stormwater risks. The initiatives should dovetail with existing climate adaptation plans.

Additional sources within Maryland include:

- **Department of the Environment's Comprehensive Flood Management Grant Program**[44]
  - Grant funding for projects to mitigate the impact of flooding and climate change. This program assists local jurisdictions with comprehensive watershed studies to better understand flood risks; implementation of capital projects within the comprehensive flood management plans; and infrastructure repairs, watershed restoration, and emergency work associated with a flood event.
  - Grants from this program can be used as a portion of the local share for FEMA's Hazard Mitigation Assistance grants.
- **Chesapeake Bay Trust Grant Opportunities**[45]
  - Grants are based around three core objectives: 1) environmental education, 2) demonstration-based restoration, and 3) community engagement. Grant programs include forestry and tree planting, watershed restoration, stormwater solutions, and outreach and education.

Federal Sources

In addition to sources within Maryland, there are multiple Federal sources of funding and financing. **The table below summarizes highly relevant Federal funding and financing sources for local government climate adaptation for infrastructure**.[46]

[44] Maryland Department of the Environment. Comprehensive Flood Management Grant Program. https://mde.maryland.gov/programs/water/floodhazardmitigation/pages/floodmgmt.aspx
[45] The Chesapeake Bay Trust. Grants and Opportunities. https://cbtrust.org/grants/
[46] The information summarized in the table of funding sources reflects funding program descriptions and criteria as of August 2021. As funding programs evolve over time, please refer to the funding programs directly for the most up-to-date information.

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Crosscutting	Federal Emergency Management Agency (FEMA), Building Resilient Infrastructure and Communities (BRIC) Program	Supports proactive investment in community resilience through funding for planning and infrastructure resilience efforts in preparation for natural hazard events. Priorities include public infrastructure and community lifelines.	Up to 6% of estimated disaster expenditures. For FY2021, a total of $1 billion is available. Cost share: 75% Federal/25% non-Federal. For economically disadvantaged rural communities, up to 90% Federal/10% non-Federal.	Local governments, states, tribes, and territories Applicants must have a FEMA-approved hazard mitigation plan. Proposals are submitted to Maryland Department of Emergency Management (MDEM); MDEM prepares the application for submittal to FEMA.	Annual
Crosscutting	FEMA, Flood Mitigation Assistance Grant Program (FMA)	Funding for planning and projects that reduce or eliminate the long-term risk of flood damage to structures insured under the National Flood Insurance Program.	Illustrative maximums from FY2019 include: ▪ $25,000 for local mitigation plans ▪ $50,000 for technical assistance ▪ $200,000 for community flood mitigation assistance, such as project scoping ▪ $10 million for community flood mitigation projects Cost share: 75% Federal/25% non-Federal	Local governments, states, tribes, and territories Applicants must have a FEMA-approved hazard mitigation plan. Proposals are submitted to MDEM; MDEM prepares the application for submittal to FEMA.	Annual

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Crosscutting	FEMA, Hazard Mitigation Grant Program (HMGP)	Funding for planning and projects that improve resilience following a Major Presidential Disaster Declaration, particularly as it relates to flooding and natural hazards.	No Federal statutory maximum exists for eligible activities. Cost share: 75% Federal/25% non-Federal	Applicant must be in a state that received a Major Presidential Disaster Declaration. Local governments, states, tribes, and territories Applicants must have a FEMA-approved hazard mitigation plan. Proposals are submitted to MDEM; MDEM prepares the application for submittal to FEMA.	After a Presidential Disaster Declaration
Crosscutting	FEMA, Public Assistance (PA) Program	Funding for disaster recovery, including grants for restoring public infrastructure. Can support additional hazard mitigation measures in conjunction with the repair of disaster-damaged infrastructure to improve future resilience.	No Federal statutory maximums exist for eligible activities. Cost share: 75% Federal/25% non-Federal	Applicant must be in a state that received a Major Presidential Disaster Declaration. Local governments, states, tribes, and territories Applicants must have a FEMA-approved hazard mitigation plan. Proposals are submitted to MDEM; MDEM prepares the application for submittal to FEMA.	After a Presidential Disaster Declaration

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Crosscutting	Economic Development Administration (EDA), Public Works Assistance Program	Funding to support the construction, expansion or upgrade of public infrastructure and facilities to mitigate future disaster-related infrastructure losses through resilience measures.	$600,000 to $3 million, with an average award of $1.4 million Cost share: 50% Federal/50% local	Cities, counties, states, tribal governments, higher education institutions, economic development districts, and nonprofit organizations working with public officials	Rolling
Crosscutting	EDA, Economic Adjustment Assistance	Funding to support the design and implementation of strategies to help communities that have experienced or are under the threat of serious damage to the underlying economic base. Includes planning or construction grants.	$150,000 to $1 million, with an average award of $650,000 Cost share: 50% Federal/50% local	Cities, counties, states, tribal governments, higher education institutions, economic development districts, and nonprofit organizations working with public officials	Rolling
Crosscutting	U.S. Department of Agriculture (USDA), National Resources Conservation Service, Watershed Protection and Flood Prevention Program	Program purpose is to protect watersheds; prevent floods; prevent erosion and control sediment; and improve water quality.	In 2017, awarded a total of $150 million for 51 new projects in 48 states	Local, state, federal, and tribal governments	Once every few years

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Crosscutting	National Fish and Wildlife Foundation (NFWF), National Coastal Resilience Fund	Funding for nature-based solutions to protect coastal communities and infrastructure from the impacts of storms, floods, and other natural hazards.	Average awards: ▪ $250,000 for community capacity building and planning ▪ $250,000 for project preliminary design and site assessment ▪ $350,000 for project final design and permitting ▪ $1 million to $5 million for project restoration and monitoring Cost share: Minimum 50% Federal/50% local	Coastal communities	Annual
Crosscutting	NFWF, Resilient Communities Program	Funding to prepare communities for future environmental challenges by enhancing community capacity to plan and implement nature-based resiliency projects. Preference towards traditionally underserved applicants.	Average awards: ▪ Category 1 (adaptation through conservation projects): $200,000 to $500,000 ▪ Category 2 (community capacity-building and demonstration projects): $200,000 to $500,000 ▪ Category 3 (adaptation for affordable housing and small businesses): $100,000 to $500,000 Cost share: Minimum 50% Federal/50% local	Local governments, state government agencies, tribes, and nonprofit organizations	Annual

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Crosscutting	National Oceanic and Atmospheric Administration (NOAA), Effects of Sea Level Rise Program (ESLR)	Provides a suite of science products to inform coastal managers of local coastal vulnerability and solutions to mitigate flood risk given sea level rise. Supports resilience planning for coastal ecosystems, communities, infrastructure, and surface transportation.	In FY2021, the program awarded $4.6 million to five new and eight continuing projects.	Past awards went to partnerships between universities, metropolitan planning organizations (MPOs), state agencies, Federal agencies, and nonprofit organizations	Once every few years
Transportation	U.S. Department of Transportation (USDOT), Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Discretionary Grant program[47]	Funding for planning, preparation, design, or construction of transportation capital projects. Priority projects include those that demonstrate reductions of climate change impacts.	Maximum award of $25 million. Minimum award of $5 million in urban areas and $1 million in rural areas. Cost share: Minimum 50% Federal/50% non-Federal	Local governments, states, tribes, territories, MPOs, transit agencies, port authorities, and other political subdivisions of State or local governments.	Annual
Transportation	USDOT, Infrastructure for Rebuilding America (INFRA) Program	Funding for nationally or regionally significant highway and freight projects. For the first time in 2021, USDOT began prioritizing projects that address climate change and environmental justice and promote racial equity.	Minimum award of $5 million to a small project and $25 million to a large project. 25% of total funding is reserved for projects in rural areas, and 10% is reserved for small projects. In FY2021, $889 million was available. Cost share: INFRA grants may be used for up to 60% of project costs.	Local governments, MPOs that serve a population of > 200,000 individuals, states, special purpose district or public authority with a transportation function, and tribes	Annual

[47] For a full list of USDOT grants that may be less competitive, but less specific to climate adaptation, see the USDOT Discretionary Grant Funding Matrix at https://www.transportation.gov/rural/toolkit/routes-discretionary-grant-funding-matrix

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Water, wastewater, stormwater	U.S. Environmental Protection Agency (EPA), Clean Water State Revolving Fund	Low-cost loans to support a wide range of water quality and wastewater infrastructure projects, including those dealing with stormwater and green infrastructure.	No Federal statutory maximum exists for eligible activities. Cost share: Loans have to be repaid 100%.	Municipality or intermunicipal; interstate or state agency; public, private, or nonprofit entity	Annual
Water, wastewater, stormwater	EPA, Water Infrastructure Finance and Innovation Act (WIFIA) Program	Low-cost loans to upgrade aging water and wastewater infrastructure and manage stormwater to enhance resilience to flooding.	$5 million minimum for small communities (i.e., less than 25,000 people) $20 million minimum for all other communities Cost share: Up to 49% Federal/51% local	Local, state, tribal, and Federal government entities	Not specified
Water	EPA, Drinking Water State Revolving Loan Fund	Low-cost loans for projects aimed at preserving the availability of clean drinking water. Funds could be leveraged to incorporate resilience measures, such as modifications to ensure system capacity during flooding and water quality treatment adjustments due to sea level rise.	No Federal statutory maximum exists for eligible activities. Cost share: Loans have to be repaid 100%	Includes existing publicly owned community water systems.	Not specified

Service Area	Agency and Program	Purpose of Funds	Amount of Available Funds	Eligible Applicants	Application Frequency
Water, wastewater, stormwater, solid waste	USDA, Water and Environment Programs (WEP)	Funding and low-cost loans for water, wastewater, stormwater, and solid waste disposal infrastructure. WEP also provides funding to organizations that provide technical assistance and training to rural communities for water and waste activities.	$3,000–$100,000 (varies by subprogram) Cost share: Ranges by program. Varies from 75% Federal/25% local for grants; maximum guarantee of 90% for loans	Rural communities with populations of < 10,000.	Not specified

APPENDIX A: Jurisdictional Climate Data

Introduction

To supplement the regional climate data in Chapter 2, this appendix provides temperature and precipitation data specific to each jurisdiction. **For sea level rise and coastal storm surge in your jurisdiction, use the interactive MDOT SHA Climate Change Vulnerability Viewer for visualization of potential inundation.**

The following definitions are the climate variables described in this appendix. These terms are listed in the order of appearance in the temperature and precipitation tables within this appendix.

Temperature Variables

Annual Average Temperature: The average temperature over the course of a year.

Annual Maximum Temperature: The highest average daily temperature over the course of a year.

Annual Minimum Temperature: The lowest average daily temperature over the course of a year.

Days ≤ 32°F: The number of days per year with average daily temperatures reaching 32°F or lower.

Days ≥ 90°F, 95°F, 100°F, or 105°F: The number of days per year with average daily temperatures of 90°F, 95°F, 100°F, 105°F, or higher.

Heatwaves: The average number of instances per year when there are 3 consecutive days above the observed 98th percentile.

Heating Degree Days (HDD): Number of degrees by which a daily average temperature is below 65°F. The reference temperature of 65°F loosely represents an average daily temperature above which space heating is not needed. The sum of the number of heating or cooling degree days over a year is roughly proportional to the annual amount of energy that would be needed to heat a building. This climate variable is particularly useful for facilities planning, design, operations, and maintenance.

Cooling Degree Days (CDD): Number of degrees by which a daily average temperature exceeds 65°F. The reference temperature of 65°F loosely represents an average daily temperature below which space cooling (e.g., air conditioning) is not needed. The sum of the number of heating or cooling degree days over a year is roughly proportional to the annual amount of energy that would be needed to cool a building. This climate variable is particularly useful for facilities planning, design, operations, and maintenance.

Freeze/Thaw Days: The number of days where the daily maximum temperature is above freezing (higher than 32°F), and the minimum temperature is below freezing (32°F or lower). Moisture from thawing snow and ice can seep into cracks in transportation infrastructure and expand during freezing periods, which can deteriorate infrastructure. This climate variable is particularly useful for transportation planning, design, operations, and maintenance.

Days with Nighttime Temperature ≥ 70°F or 80°F: The number of days per year with nighttime temperatures of 70°F or 80°F or above.

Hottest/Coldest Annual Temperatures: The highest/lowest temperature in a year.

Seasonal Diurnal Temperature Ranges: The change of temperature from the daytime maximum temperature to the nighttime minimum temperature within a season.

Winter Low: The lowest temperature in a year's winter season.

Seasonal Days ≥ 90°F, 95°F, 100°F, or 105°F: The number of days in a season with average daily temperatures of 90°F, 95°F, 100°F 105°F, or higher.

Monthly Average Temperature: The average daily temperature within a month.

Precipitation Variables

Annual Average Precipitation: The average total precipitation within a year.

Maximum 5-Day Precipitation Event: The maximum cumulative amount of precipitation over 5 consecutive days in a year. This climate variable can be considered a flood hazard indicator.

Days with Precipitation > 1", 2", or 3": The number of days per year with more than 1, 2, or 3 inches of precipitation.

Maximum Consecutive Dry Days: The maximum number of days in a row per year without precipitation.

Very Heavy Precipitation: The amount of precipitation on a day at the 95th percentile.

Extremely Heavy Precipitation: The amount of precipitation on a day at the 99th percentile.

3-Day Seasonal Precipitation: The maximum cumulative amount of precipitation over 3 consecutive days in a season.

Monthly Average Precipitation: The average total precipitation within a month.

User’s Guide

The figure below shows an example of how to read the climate data tables in this appendix.

This is the past.

Observed value refers to historical averages of 1986–2005, and is useful for comparing with future projections.

These are the future.

This figure shows projections for three future timeframes.

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	56.7	59.2	*2.5*	58.4	60.6	61.2	*4.5*	59.9	62.7	65.8	*9.1*	63.1	68.2
Annual Max. Temp. (°F)	67.0	69.5	*2.6*	68.6	70.9	71.7	*4.8*	70.0	73.2	75.8	*8.8*	73.6	78.7
Annual Min. Temp. (°F)	46.4	48.8	*2.4*	48.3	50.2	50.8	*4.4*	49.9	52.5	55.4	*9.0*	53.2	57.7
Days ≤ 32 °F	87	73	*-14*	64	78	60	*-27*	51	69	36	*-51*	24	48
Days ≥ 90°F	31	55	*24*	47	65	72	*41*	61	87	110	*78*	91	124

This is the “typical” expected value for the future.

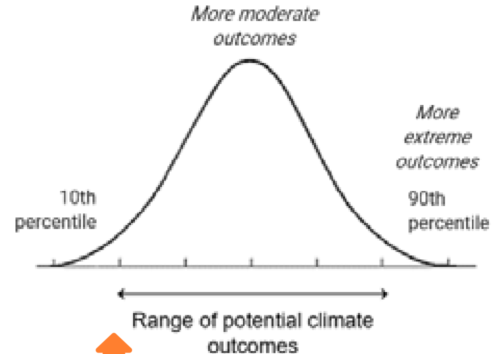
Median refers to the middle value of the climate model projections within the relevant timeframe.

This is how much the future will change.

Delta is the difference between the projected median and the observed value. Note, any discrepancies in sums are due to rounding.

This is the lower/upper bound for the future.

The **10th and 90th percentile** help indicate the range of how much the future may change. The 10th percentile represents the lower bound of future change. The 90th percentile indicates greater change in climate conditions. Both are less likely compared to the median. The figure to the right visually shows this range.



Anne Arundel County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039) Median	*Delta*	10th	90th	Mid-Century (2040–2059) Median	*Delta*	10th	90th	End-of-Century (2080–2099) Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	56.7	59.2	*2.5*	58.4	60.6	61.2	*4.5*	59.9	62.7	65.8	*9.1*	63.1	68.2
Annual Max. Temp. (°F)	67.0	69.5	*2.6*	68.6	70.9	71.7	*4.8*	70.0	73.2	75.8	*8.8*	73.6	78.7
Annual Min. Temp. (°F)	46.4	48.8	*2.4*	48.3	50.2	50.8	*4.4*	49.9	52.5	55.4	*9.0*	53.2	57.7
Days ≤ 32 °F	87	73	*-14*	64	78	60	*-27*	51	69	36	*-51*	24	48
Days ≥ 90°F	31	55	*24*	47	65	72	*41*	61	87	110	*78*	91	124
Days ≥ 95°F	9	22	*13*	16	30	36	*27*	26	49	75	*67*	50	94
Days ≥ 100°F	1	4	*3*	2	9	9	*8*	5	19	37	*37*	13	63
Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	4	10	*10*	2	31
Number of Heatwaves	1	4	*2*	3	7	7	*6*	5	11	20	*19*	11	27
Heating Degree Days	4374	3889	*-486*	3572	4045	3481	*-894*	3115	3723	2760	*-1614*	2303	3131
Cooling Degree Days	1341	1762	*421*	1619	1959	2111	*769*	1913	2406	3007	*1666*	2492	3501
Freeze/Thaw Days	79.1	67.8	*-11.3*	60.4	73.3	57.2	*-21.9*	49.5	65.9	34.7	*-44.4*	22.1	47.3
Days with Nighttime Temp. ≥ 70°F	28	49	*22*	43	58	67	*39*	57	81	105	*77*	84	122
Days with Nighttime Temp. ≥ 80°F	0	1	*1*	0	2	3	*3*	1	6	22	*22*	8	41
Hottest Annual Temp. (°F)	98.3	101.6	*3.3*	100.5	103.4	104.3	*6.0*	102.5	105.8	109.4	*11.1*	105.2	113.0
Coldest Annual Temp. (°F)	7.2	11.5	*4.2*	8.5	14.2	14.8	*7.6*	10.5	17.3	20.4	*13.1*	17.5	23.5
Seasonal													
Winter Diurnal Temp. Range (°F)	18.1	17.7	*-0.4*	16.1	19.6	18.0	*-0.1*	16.7	19.7	17.5	*-0.6*	16.0	19.9
Spring Diurnal Temp. Range (°F)	24.0	24.3	*0.4*	22.0	26.5	24.3	*0.3*	22.5	26.7	24.1	*0.1*	21.7	27.0
Summer Diurnal Temp. Range (°F)	22.6	22.7	*0.1*	20.5	24.9	23.2	*0.6*	20.5	25.6	22.9	*0.3*	21.1	26.2
Fall Diurnal Temp. Range (°F)	23.6	23.3	*-0.3*	21.3	25.2	23.2	*-0.4*	21.2	26.2	24.0	*0.4*	21.2	26.0
Winter Low (°F)	12.4	16.7	*4.2*	14.0	18.6	19.1	*6.7*	15.7	21.7	24.4	*12.0*	21.8	26.9
Spring Days ≥ 90°F	2	4	*2*	3	5	6	*4*	4	9	14	*12*	8	17

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Summer Days ≥ 90°F	27	45	*18*	39	53	57	*30*	50	67	77	*49*	70	83
Fall Days ≥ 90°F	2	6	*4*	4	8	9	*7*	7	12	18	*16*	13	25
Spring Days ≥ 95°F	0	1	*1*	0	1	2	*2*	1	3	6	*6*	3	8
Summer Days ≥ 95°F	8	20	*11*	14	27	31	*23*	23	42	61	*52*	42	71
Fall Days ≥ 95°F	0	2	*1*	1	3	3	*3*	2	4	9	*9*	5	15
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	1	2	*2*	0	3
Summer Days ≥ 100°F	1	3	*3*	2	8	8	*7*	4	17	32	*32*	12	53
Fall Days ≥ 100°F	0	0	*0*	0	1	1	*1*	0	1	3	*3*	1	8
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	1
Summer Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	4	10	*10*	1	27
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	3
Monthly													
Jan Avg.	35.2	38.2	*3.0*	36.0	39.5	39.4	*4.1*	37.6	41.3	43.7	*8.5*	41.1	46.1
Feb Avg.	37.2	39.4	*2.2*	38.2	41.4	40.5	*3.3*	39.0	44.1	45.3	*8.1*	42.4	48.1
Mar Avg.	44.3	45.9	*1.6*	44.0	47.9	49.0	*4.7*	46.6	51.2	51.9	*7.6*	48.9	55.6
Apr Avg.	54.7	56.9	*2.2*	55.4	59.4	58.9	*4.2*	57.7	61.2	63.7	*9.0*	61.0	66.4
May Avg.	63.8	66.6	*2.8*	65.2	67.6	68.6	*4.8*	66.8	70.0	73.4	*9.6*	70.5	74.9
Jun Avg.	73.0	75.5	*2.5*	74.4	77.2	77.6	*4.7*	76.7	79.4	82.6	*9.6*	80.0	84.0
Jul Avg.	78.3	81.0	*2.6*	80.1	82.7	83.2	*4.9*	81.9	85.3	88.3	*10.0*	84.9	90.7
Aug Avg.	76.6	79.8	*3.2*	78.6	81.1	81.9	*5.3*	80.4	84.2	87.8	*11.2*	83.8	91.1
Sep Avg.	70.5	73.6	*3.1*	72.0	75.0	75.6	*5.1*	74.1	77.7	80.8	*10.3*	78.2	83.9
Oct Avg.	58.4	61.3	*3.0*	59.7	62.4	62.9	*4.5*	61.4	65.1	67.4	*9.0*	65.8	71.2
Nov Avg.	48.4	50.7	*2.4*	49.3	52.9	52.3	*3.9*	51.0	54.5	56.2	*7.8*	54.4	59.4
Dec Avg.	38.8	41.4	*2.7*	39.4	42.9	43.7	*4.9*	40.8	44.7	47.2	*8.4*	43.6	50.1

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	43.2	45.1	*1.9*	42.7	48.5	45.6	*2.4*	43.0	48.6	48.0	*4.8*	43.8	52.3
Max. 5-Day Precip. Event (in)	3.6	4.0	*0.4*	3.4	4.5	3.9	*0.3*	3.5	4.3	4.4	*0.7*	3.7	5.0
Days with Precip. > 1”	7	8	*1*	7	10	9	*1*	7	10	10	*2*	8	12
Days with Precip. > 2”	1	1	*0*	0	1	1	*0*	0	1	1	*0*	1	2
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	17	18	*0*	12	22	18	*1*	12	23	19	*2*	14	26
Very Heavy Precip. (95th Perc.) (in)	0.8	0.9	*0.1*	0.8	1.0	0.9	*0.1*	0.9	1.0	1.0	*0.1*	0.9	1.1
Extremely Heavy Precip. (99th.) (in)	1.5	1.6	*0.1*	1.4	1.7	1.6	*0.1*	1.5	1.7	1.7	*0.2*	1.6	1.9
Seasonal Variables													
3-Day Winter Precip. (in)	2.0	2.2	*0.2*	1.8	2.4	2.2	*0.3*	2.0	2.5	2.5	*0.5*	2.2	2.8
3-Day Spring Precip. (in)	2.1	2.2	*0.1*	2.0	2.7	2.3	*0.2*	2.0	2.7	2.6	*0.4*	2.2	3.0
3-Day Summer Precip. (in)	2.4	2.5	*0.1*	2.2	3.1	2.5	*0.1*	2.1	3.1	2.7	*0.3*	2.2	3.4
3-Day Fall Precip. (in)	2.7	2.8	*0.2*	2.2	3.3	2.8	*0.2*	2.3	3.3	2.9	*0.2*	2.4	3.7
Monthly Variables													
Jan Avg. Total	3.5	3.6	*0.1*	2.8	4.4	3.7	*0.2*	3.0	4.5	4.2	*0.7*	3.4	5.1
Feb Avg. Total	2.7	3.0	*0.3*	2.4	3.6	3.2	*0.5*	2.6	3.9	3.3	*0.6*	2.8	4.1
Mar Avg. Total	4.0	4.4	*0.4*	3.4	5.1	4.6	*0.6*	4.0	5.4	4.9	*0.9*	4.0	5.3
Apr Avg. Total	3.3	3.6	*0.3*	2.8	4.5	3.4	*0.1*	2.9	4.4	3.7	*0.5*	2.9	4.6
May Avg. Total	4.1	4.4	*0.3*	3.9	5.0	4.3	*0.2*	3.5	5.0	4.6	*0.4*	3.8	5.2
Jun Avg. Total	3.4	3.5	*0.1*	2.7	4.5	3.3	*-0.1*	2.6	4.2	3.4	*0.0*	2.2	4.7
Jul Avg. Total	4.2	4.3	*0.1*	3.7	5.4	4.2	*0.0*	3.4	5.4	4.4	*0.3*	3.2	5.9
Aug Avg. Total	3.8	3.7	*-0.1*	3.1	4.4	3.9	*0.1*	2.8	4.7	4.1	*0.3*	3.0	5.2
Sep Avg. Total	4.0	4.0	*0.0*	3.1	5.1	4.1	*0.1*	3.0	4.8	4.0	*0.1*	2.7	4.9
Oct Avg. Total	3.3	3.2	*0.0*	2.6	3.9	3.3	*0.0*	2.7	3.9	3.1	*-0.2*	2.4	4.1
Nov Avg. Total	3.4	3.5	*0.1*	2.9	4.4	3.7	*0.3*	3.1	4.3	3.6	*0.2*	3.1	4.6
Dec Avg. Total	3.5	3.8	*0.2*	3.1	4.5	3.9	*0.4*	3.1	4.5	4.3	*0.7*	3.4	4.9

Baltimore County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	55.4	58.0	*2.6*	57.2	59.5	60.2	*4.7*	58.8	61.8	64.9	*9.4*	62.3	67.4
Annual Max. Temp. (°F)	65.6	68.3	*2.7*	67.3	69.7	70.6	*5.0*	68.7	72.0	74.8	*9.2*	72.4	77.7
Annual Min. Temp. (°F)	45.3	47.8	*2.5*	47.1	49.3	49.8	*4.5*	48.9	51.6	54.7	*9.4*	52.5	57.1
Days ≤ 32 °F	92	76	*-15*	67	82	63	*-28*	53	73	38	*-54*	25	50
Days ≥ 90°F	25	47	*23*	38	56	65	*40*	50	78	105	*80*	82	119
Days ≥ 95°F	6	15	*10*	11	23	27	*22*	18	40	66	*60*	36	90
Days ≥ 100°F	0	3	*2*	1	6	6	*6*	3	16	29	*28*	9	55
Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	3	8	*8*	1	28
Number of Heatwaves	1	3	*2*	2	5	5	*4*	3	9	17	*16*	7	26
Heating Degree Days	4678	4145	*-533*	3807	4325	3685	*-992*	3302	3991	2906	*-1772*	2414	3306
Cooling Degree Days	1187	1605	*418*	1457	1793	1934	*747*	1729	2235	2795	*1608*	2309	3338
Freeze/Thaw Days	80.6	70.0	*-10.6*	63.1	75.6	60.0	*-20.6*	51.3	69.5	36.5	*-44.0*	23.2	49.1
Days with Nighttime Temp. ≥ 70°F	20	38	*18*	33	47	54	*35*	46	70	95	*75*	72	116
Days with Nighttime Temp. ≥ 80°F	0	1	*1*	0	1	2	*2*	1	4	15	*15*	5	34
Hottest Annual Temp. (°F)	97.0	100.4	*3.4*	99.0	102.3	103.2	*6.2*	101.0	104.8	108.3	*11.3*	103.7	112.0
Coldest Annual Temp. (°F)	5.0	9.4	*4.3*	6.7	12.0	13.1	*8.0*	9.0	15.6	18.9	*13.9*	15.8	22.2
Seasonal													
Winter Diurnal Temp. Range (°F)	18.1	17.8	*-0.3*	16.0	19.5	18.0	*-0.1*	16.7	19.7	17.5	*-0.6*	15.7	19.9
Spring Diurnal Temp. Range (°F)	24.4	25.0	*0.6*	22.3	27.1	24.7	*0.3*	23.1	26.7	24.7	*0.3*	22.3	27.7
Summer Diurnal Temp. Range (°F)	23.4	23.6	*0.2*	21.4	25.5	23.9	*0.5*	21.1	26.5	23.6	*0.2*	21.9	27.0

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Fall Diurnal Temp. Range (°F)	23.9	24.0	*0.2*	21.9	25.4	23.3	*-0.5*	21.4	26.3	24.3	*0.4*	21.9	26.8
Winter Low (°F)	10.6	15.0	*4.4*	12.4	17.1	18.0	*7.4*	13.9	20.3	23.7	*13.1*	20.6	26.7
Spring Days ≥ 90°F	1	3	*1*	2	4	5	*3*	3	7	12	*10*	6	15
Summer Days ≥ 90°F	22	39	*17*	32	47	52	*30*	43	62	76	*54*	64	82
Fall Days ≥ 90°F	1	5	*3*	2	7	7	*6*	5	10	17	*16*	11	25
Spring Days ≥ 95°F	0	1	*0*	0	1	1	*1*	1	2	5	*5*	2	7
Summer Days ≥ 95°F	6	14	*8*	10	21	24	*18*	16	35	54	*48*	31	68
Fall Days ≥ 95°F	0	1	*1*	0	2	2	*2*	1	4	8	*8*	4	15
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	3
Summer Days ≥ 100°F	0	2	*2*	1	6	6	*5*	3	14	25	*25*	8	46
Fall Days ≥ 100°F	0	0	*0*	0	1	1	*1*	0	1	2	*2*	1	8
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	1
Summer Days ≥ 105°F	0	0	*0*	0	0	1	*1*	0	3	7	*7*	1	24
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	3
Monthly													
Jan Avg.	33.7	37.1	*3.4*	34.6	38.2	38.5	*4.8*	36.1	40.6	43.0	*9.3*	40.3	45.3
Feb Avg.	35.6	37.8	*2.1*	36.7	40.0	39.1	*3.4*	37.2	43.0	43.9	*8.3*	40.9	47.4
Mar Avg.	42.8	44.4	*1.5*	42.5	46.5	47.4	*4.6*	45.1	49.5	50.5	*7.6*	47.3	54.3
Apr Avg.	53.7	56.0	*2.3*	54.3	58.4	58.0	*4.4*	56.7	60.5	63.1	*9.5*	60.3	66.0
May Avg.	62.9	65.6	*2.6*	64.2	66.7	67.7	*4.7*	65.5	69.0	72.6	*9.7*	69.5	74.1
Jun Avg.	71.8	74.4	*2.6*	73.3	76.1	76.6	*4.8*	75.7	78.2	81.5	*9.7*	79.0	82.9
Jul Avg.	77.0	79.7	*2.7*	78.8	81.6	81.9	*4.9*	80.5	84.0	87.1	*10.1*	83.5	89.7
Aug Avg.	75.4	78.6	*3.2*	77.3	79.9	80.7	*5.3*	79.1	83.0	86.6	*11.3*	82.4	90.9
Sep Avg.	69.2	72.5	*3.3*	70.7	74.1	74.5	*5.3*	72.9	76.6	80.1	*10.9*	77.1	83.8
Oct Avg.	57.3	60.6	*3.3*	58.9	61.7	62.1	*4.8*	60.4	64.6	66.9	*9.6*	65.3	70.7
Nov Avg.	47.3	49.9	*2.6*	48.2	52.2	51.6	*4.3*	49.9	53.9	55.9	*8.6*	53.8	59.0
Dec Avg.	37.4	40.4	*2.9*	38.1	41.8	42.7	*5.3*	39.6	44.0	46.6	*9.2*	42.7	49.5

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	45.9	48.1	*2.2*	45.8	51.3	48.7	*2.8*	45.4	51.5	50.8	*4.9*	46.6	55.8
Max. 5-Day Precip. Event (in)	3.7	4.1	*0.4*	3.5	4.7	4.0	*0.3*	3.5	4.5	4.5	*0.8*	3.9	5.0
Days with Precip. > 1"	7	8	*1*	7	10	9	*2*	7	10	10	*3*	8	12
Days with Precip. > 2"	1	1	*0*	0	1	1	*0*	0	1	1	*1*	1	2
Days with Precip. > 3"	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	15	15	*0*	12	20	16	*1*	12	20	17	*2*	13	23
Very Heavy Precip. (95th Perc.) (in)	0.8	0.9	*0.1*	0.8	0.9	0.9	*0.1*	0.8	1.0	1.0	*0.1*	0.9	1.1
Extremely Heavy Precip. (99th.) (in)	1.5	1.6	*0.1*	1.4	1.8	1.6	*0.1*	1.5	1.8	1.8	*0.3*	1.6	2.0
Seasonal Variables													
3-Day Winter Precip. (in)	2.0	2.2	*0.2*	1.9	2.4	2.3	*0.3*	2.0	2.6	2.6	*0.5*	2.2	2.9
3-Day Spring Precip. (in)	2.1	2.3	*0.2*	2.0	2.7	2.4	*0.2*	2.0	2.7	2.6	*0.5*	2.3	3.1
3-Day Summer Precip. (in)	2.3	2.4	*0.1*	2.1	2.9	2.5	*0.2*	2.0	2.9	2.5	*0.2*	2.1	3.1
3-Day Fall Precip. (in)	2.9	3.1	*0.2*	2.4	3.7	3.2	*0.3*	2.5	3.7	3.2	*0.3*	2.6	4.0
Monthly Variables													
Jan Avg. Total	3.8	3.9	*0.1*	3.2	4.8	4.0	*0.2*	3.2	4.9	4.4	*0.7*	3.7	5.4
Feb Avg. Total	2.7	3.0	*0.3*	2.5	3.7	3.2	*0.5*	2.7	4.1	3.5	*0.8*	2.8	4.3
Mar Avg. Total	4.1	4.6	*0.4*	3.6	5.3	4.9	*0.8*	4.0	5.6	5.0	*0.9*	4.2	5.5
Apr Avg. Total	3.5	3.9	*0.4*	3.1	4.9	3.7	*0.1*	3.1	4.7	4.0	*0.5*	3.1	5.0
May Avg. Total	4.4	4.7	*0.3*	4.1	5.2	4.7	*0.2*	3.8	5.2	4.9	*0.5*	4.2	5.7
Jun Avg. Total	3.5	3.5	*0.1*	2.6	4.5	3.5	*0.0*	2.6	4.3	3.4	*0.0*	2.3	4.7
Jul Avg. Total	4.3	4.5	*0.2*	3.8	5.4	4.4	*0.0*	3.4	5.5	4.6	*0.3*	3.4	5.8
Aug Avg. Total	3.7	3.7	*0.0*	3.1	4.5	3.8	*0.1*	3.1	4.6	4.1	*0.4*	2.7	5.1
Sep Avg. Total	4.4	4.3	*0.0*	3.3	5.4	4.5	*0.1*	3.3	5.2	4.4	*0.0*	3.1	5.4
Oct Avg. Total	4.0	4.1	*0.0*	3.3	4.8	4.1	*0.1*	3.3	4.7	3.9	*-0.1*	3.1	4.9
Nov Avg. Total	3.7	3.9	*0.2*	3.3	4.7	4.1	*0.3*	3.2	4.8	4.0	*0.2*	3.3	5.0
Dec Avg. Total	3.7	3.9	*0.2*	3.1	4.8	4.0	*0.3*	3.2	4.8	4.4	*0.7*	3.5	5.2

Carroll County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039) Median	*Delta*	10th	90th	Mid-Century (2040–2059) Median	*Delta*	10th	90th	End-of-Century (2080–2099) Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	53.5	56.1	*2.6*	55.3	57.5	58.2	*4.7*	56.9	59.9	62.9	*9.4*	60.5	65.5
Annual Max. Temp. (°F)	64.3	67.0	*2.7*	66.0	68.4	69.4	*5.1*	67.5	70.8	73.5	*9.2*	71.2	76.7
Annual Min. Temp. (°F)	42.6	45.2	*2.6*	44.5	46.7	47.2	*4.6*	46.3	49.0	52.1	*9.5*	50.0	54.5
Days ≤ 32 °F	110	95	*-15*	85	101	83	*-27*	73	92	57	*-54*	42	68
Days ≥ 90°F	17	39	*22*	29	48	57	*39*	43	70	98	*81*	74	113
Days ≥ 95°F	4	11	*8*	7	20	22	*19*	13	36	62	*59*	30	87
Days ≥ 100°F	0	2	*1*	1	5	5	*5*	2	15	26	*25*	7	55
Days ≥ 105°F	0	0	*0*	0	1	0	*0*	0	3	6	*6*	0	28
Number of Heatwaves	1	2	*1*	1	4	4	*4*	2	8	16	*15*	6	25
Heating Degree Days	5152	4594	*-558*	4249	4772	4122	*-1030*	3736	4428	3321	*-1831*	2807	3712
Cooling Degree Days	936	1345	*409*	1199	1512	1658	*722*	1455	1939	2499	*1563*	2037	3069
Freeze/Thaw Days	96.0	86.7	*-9.3*	79.0	91.7	77.0	*-19.0*	69.9	86.7	54.9	*-41.0*	41.3	67.0
Days with Nighttime Temp. ≥ 70°F	7	19	*12*	16	29	34	*27*	28	51	78	*70*	50	101
Days with Nighttime Temp. ≥ 80°F	0	0	*0*	0	0	0	*0*	0	1	6	*6*	2	20
Hottest Annual Temp. (°F)	95.3	98.7	*3.4*	97.4	100.9	101.7	*6.4*	99.3	103.8	107.0	*11.7*	102.2	112.0
Coldest Annual Temp. (°F)	0.6	5.6	*5.0*	2.5	8.4	8.8	*8.2*	4.7	11.6	14.8	*14.2*	12.0	18.4
Seasonal													
Winter Diurnal Temp. Range (°F)	17.4	17.2	*-0.1*	15.3	18.8	17.3	*0.0*	15.9	18.9	16.8	*-0.6*	14.8	19.4
Spring Diurnal Temp. Range (°F)	25.5	25.8	*0.4*	23.0	28.1	25.8	*0.3*	23.7	27.8	25.5	*0.0*	23.2	28.7
Summer Diurnal Temp. Range (°F)	25.1	25.3	*0.2*	23.4	27.5	25.9	*0.8*	22.9	28.7	25.3	*0.2*	23.9	29.1

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Fall Diurnal Temp. Range (°F)	24.7	24.8	*0.1*	23.1	26.4	24.4	*-0.4*	21.8	27.5	25.4	*0.7*	22.9	28.0
Winter Low (°F)	6.9	11.4	*4.6*	8.7	13.7	14.4	*7.5*	10.0	16.7	20.4	*13.5*	17.0	23.4
Spring Days ≥ 90°F	1	2	*1*	1	3	4	*3*	2	6	10	*10*	5	13
Summer Days ≥ 90°F	16	33	*17*	25	43	46	*31*	37	57	73	*57*	58	80
Fall Days ≥ 90°F	1	3	*3*	2	5	6	*5*	4	8	15	*14*	9	23
Spring Days ≥ 95°F	0	0	*0*	0	1	1	*1*	0	2	4	*4*	1	6
Summer Days ≥ 95°F	3	10	*7*	6	18	19	*16*	12	32	51	*47*	26	68
Fall Days ≥ 95°F	0	1	*1*	0	2	2	*2*	1	3	7	*7*	3	14
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	2
Summer Days ≥ 100°F	0	1	*1*	1	4	4	*4*	2	13	23	*23*	6	45
Fall Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	1	2	*2*	0	8
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Summer Days ≥ 105°F	0	0	*0*	0	1	0	*0*	0	3	6	*6*	0	23
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	3
Monthly													
Jan Avg.	31.7	35.1	*3.5*	32.6	36.3	36.6	*4.9*	34.4	38.5	41.0	*9.3*	38.1	43.1
Feb Avg.	33.7	35.8	*2.1*	34.7	38.0	37.0	*3.3*	35.0	40.8	41.5	*7.8*	38.7	45.2
Mar Avg.	41.0	42.4	*1.5*	40.4	44.6	45.3	*4.3*	43.1	47.3	48.2	*7.3*	45.2	52.1
Apr Avg.	51.8	54.1	*2.3*	52.5	56.6	56.0	*4.2*	54.7	58.2	60.8	*8.9*	58.4	63.6
May Avg.	61.0	63.5	*2.5*	62.1	64.8	65.9	*4.9*	63.5	67.2	70.9	*9.9*	67.8	72.2
Jun Avg.	69.9	72.6	*2.7*	71.4	74.2	74.9	*5.0*	73.9	76.6	80.0	*10.1*	77.4	81.5
Jul Avg.	75.0	77.7	*2.7*	76.8	79.8	80.2	*5.2*	78.6	82.3	85.6	*10.6*	81.7	88.6
Aug Avg.	73.3	76.5	*3.2*	75.4	78.2	78.6	*5.3*	77.1	80.8	84.7	*11.4*	80.3	89.2
Sep Avg.	66.9	70.3	*3.3*	68.5	71.9	72.3	*5.3*	70.6	74.1	77.9	*11.0*	75.0	81.8
Oct Avg.	55.3	58.6	*3.3*	56.9	59.8	60.1	*4.9*	58.6	62.6	65.1	*9.8*	63.4	69.0
Nov Avg.	45.5	48.2	*2.7*	46.3	50.6	49.8	*4.4*	48.2	52.1	54.2	*8.8*	52.1	57.4
Dec Avg.	35.3	38.3	*3.0*	36.0	39.9	40.6	*5.3*	37.7	41.9	44.5	*9.1*	40.7	47.3

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	44.1	46.2	*2.1*	43.9	48.8	47.0	*3.0*	43.4	49.2	48.4	*4.3*	44.5	53.5
Max. 5-Day Precip. Event (in)	3.6	4.0	*0.4*	3.6	4.5	4.0	*0.4*	3.6	4.4	4.4	*0.7*	4.0	5.0
Days with Precip. > 1”	6	7	*1*	6	8	7	*1*	6	8	8	*3*	7	10
Days with Precip. > 2”	0	1	*0*	0	1	1	*0*	0	1	1	*0*	1	1
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	16	16	*0*	13	21	17	*1*	13	21	17	*2*	14	23
Very Heavy Precip. (95th Perc.) (in)	0.8	0.8	*0.0*	0.8	0.9	0.8	*0.1*	0.8	0.9	0.9	*0.1*	0.8	1.0
Extremely Heavy Precip. (99th.) (in)	1.3	1.4	*0.1*	1.3	1.6	1.5	*0.1*	1.3	1.6	1.6	*0.3*	1.4	1.8
Seasonal Variables													
3-Day Winter Precip. (in)	2.0	2.1	*0.2*	1.8	2.3	2.2	*0.2*	1.9	2.5	2.5	*0.5*	2.1	2.8
3-Day Spring Precip. (in)	2.0	2.2	*0.2*	1.9	2.5	2.3	*0.2*	2.0	2.6	2.5	*0.5*	2.2	2.9
3-Day Summer Precip. (in)	2.2	2.4	*0.2*	2.1	2.9	2.4	*0.2*	2.0	2.7	2.5	*0.3*	2.0	3.1
3-Day Fall Precip. (in)	2.9	3.1	*0.2*	2.6	3.6	3.2	*0.3*	2.6	3.7	3.3	*0.4*	2.7	3.9
Monthly Variables													
Jan Avg. Total	3.6	3.8	*0.2*	3.1	4.5	3.9	*0.3*	3.1	4.7	4.1	*0.6*	3.6	5.1
Feb Avg. Total	2.5	2.8	*0.3*	2.4	3.4	3.0	*0.5*	2.5	3.7	3.2	*0.7*	2.7	4.0
Mar Avg. Total	3.9	4.3	*0.4*	3.4	4.9	4.6	*0.7*	3.7	5.2	4.7	*0.8*	4.0	5.3
Apr Avg. Total	3.5	3.8	*0.3*	3.1	4.7	3.6	*0.2*	3.1	4.6	4.0	*0.6*	3.2	4.9
May Avg. Total	4.3	4.5	*0.3*	4.1	5.0	4.6	*0.3*	3.6	4.9	4.8	*0.5*	3.9	5.4
Jun Avg. Total	3.5	3.5	*0.0*	2.7	4.4	3.4	*0.0*	2.6	4.2	3.4	*0.0*	2.5	4.5
Jul Avg. Total	4.1	4.3	*0.2*	3.6	5.1	4.2	*0.1*	3.3	5.1	4.3	*0.2*	3.4	5.6
Aug Avg. Total	3.5	3.6	*0.0*	3.0	4.3	3.6	*0.1*	3.0	4.4	3.8	*0.3*	2.6	5.0
Sep Avg. Total	4.4	4.4	*0.0*	3.4	5.4	4.5	*0.1*	3.4	5.4	4.4	*0.0*	3.3	5.4
Oct Avg. Total	3.8	3.9	*0.1*	3.1	4.6	3.9	*0.1*	3.2	4.5	3.7	*-0.1*	3.0	4.7
Nov Avg. Total	3.5	3.7	*0.2*	3.2	4.3	3.8	*0.3*	3.1	4.5	3.8	*0.3*	3.2	4.6
Dec Avg. Total	3.6	3.8	*0.2*	2.9	4.5	3.8	*0.2*	3.1	4.5	4.2	*0.7*	3.4	5.1

City of Baltimore

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	57.2	59.7	*2.5*	58.9	61.1	61.8	*4.5*	60.4	63.4	66.3	*9.0*	63.7	69.0
Annual Max. Temp. (°F)	66.7	69.3	*2.6*	68.2	70.6	71.5	*4.8*	69.6	72.9	75.5	*8.8*	73.3	78.4
Annual Min. Temp. (°F)	47.8	50.1	*2.3*	49.6	51.6	52.1	*4.3*	51.3	53.8	56.9	*9.0*	54.4	59.1
Days ≤ 32 °F	75	60	*-15*	53	66	49	*-26*	39	57	28	*-48*	15	38
Days ≥ 90°F	33	55	*23*	45	64	71	*38*	58	84	107	*75*	88	123
Days ≥ 95°F	10	22	*12*	17	30	34	*24*	26	47	72	*62*	45	95
Days ≥ 100°F	1	5	*3*	3	10	10	*9*	5	19	35	*34*	13	60
Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	5	11	*11*	2	31
Number of Heatwaves	2	4	*2*	3	6	7	*5*	5	11	18	*17*	9	27
Heating Degree Days	4286	3792	*-493*	3481	3972	3370	*-915*	3018	3666	2673	*-1612*	2231	3033
Cooling Degree Days	1454	1871	*417*	1712	2079	2210	*756*	1999	2533	3113	*1659*	2592	3654
Freeze/Thaw Days	66.2	55.3	*-10.9*	48.6	60.3	46.2	*-19.9*	37.1	53.1	25.6	*-40.6*	12.9	37.1
Days with Nighttime Temp. ≥ 70°F	38	60	*22*	53	68	75	*37*	66	88	110	*72*	92	129
Days with Nighttime Temp. ≥ 80°F	1	4	*3*	2	6	8	*7*	5	15	36	*35*	15	59
Hottest Annual Temp. (°F)	99.0	102.0	*3.0*	100.7	104.0	104.5	*5.5*	102.5	106.4	109.7	*10.7*	104.9	113.1
Coldest Annual Temp. (°F)	9.2	13.3	*4.1*	10.5	15.6	16.5	*7.3*	12.5	18.9	21.8	*12.6*	19.0	24.9
Seasonal													
Winter Diurnal Temp. Range (°F)	16.5	16.2	*-0.3*	14.7	17.8	16.6	*0.1*	15.2	18.2	16.2	*-0.3*	14.5	18.4
Spring Diurnal Temp. Range (°F)	21.0	21.5	*0.5*	19.3	23.4	21.2	*0.2*	19.8	23.1	21.1	*0.2*	19.2	23.7
Summer Diurnal Temp. Range (°F)	20.0	20.2	*0.1*	18.1	21.9	20.5	*0.4*	18.1	22.7	20.2	*0.2*	18.5	23.0
Fall Diurnal Temp. Range (°F)	21.0	21.1	*0.2*	19.2	22.5	20.5	*-0.4*	18.9	23.4	21.3	*0.4*	19.1	23.8
Winter Low (°F)	13.6	17.7	*4.1*	15.0	19.6	20.3	*6.6*	16.9	22.8	25.4	*11.8*	22.6	27.8
Spring Days ≥ 90°F	3	4	*2*	3	6	6	*4*	4	9	13	*11*	8	16

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Summer Days ≥ 90°F	28	44	*17*	37	52	55	*27*	47	65	76	*48*	68	82
Fall Days ≥ 90°F	2	6	*4*	4	8	9	*7*	7	12	19	*16*	12	26
Spring Days ≥ 95°F	0	1	*1*	1	2	2	*2*	1	3	6	*6*	3	9
Summer Days ≥ 95°F	10	20	*10*	15	27	29	*20*	23	40	57	*48*	38	70
Fall Days ≥ 95°F	0	2	*1*	1	3	3	*3*	2	5	9	*8*	5	16
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	1	2	*2*	0	4
Summer Days ≥ 100°F	1	4	*3*	3	9	9	*7*	5	17	30	*28*	13	51
Fall Days ≥ 100°F	0	0	*0*	0	1	1	*1*	0	2	3	*3*	1	8
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	1
Summer Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	5	10	*10*	2	27
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	4
Monthly													
Jan Avg.	35.7	38.8	*3.1*	36.4	39.8	40.1	*4.5*	37.9	42.2	44.3	*8.7*	41.9	46.7
Feb Avg.	37.3	39.6	*2.2*	38.5	41.7	40.8	*3.5*	39.2	44.6	45.3	*8.0*	42.5	48.5
Mar Avg.	44.5	46.2	*1.7*	44.3	48.3	49.3	*4.8*	46.8	51.5	52.5	*8.0*	49.5	56.1
Apr Avg.	55.4	57.5	*2.2*	55.9	60.1	59.7	*4.3*	58.2	62.2	64.8	*9.5*	61.7	67.6
May Avg.	64.6	66.9	*2.3*	65.7	67.9	68.9	*4.3*	66.9	70.3	73.9	*9.3*	70.8	75.4
Jun Avg.	73.8	76.3	*2.5*	75.2	78.1	78.3	*4.5*	77.6	80.0	83.1	*9.3*	80.4	84.7
Jul Avg.	79.1	81.5	*2.4*	80.6	83.4	83.5	*4.4*	82.4	85.6	88.3	*9.2*	85.0	91.1
Aug Avg.	77.4	80.3	*3.0*	78.9	81.5	82.2	*4.8*	80.6	84.8	88.1	*10.8*	83.9	92.3
Sep Avg.	71.1	74.1	*3.0*	72.4	75.7	76.2	*5.0*	74.5	78.3	81.6	*10.5*	78.6	85.1
Oct Avg.	59.0	62.2	*3.2*	60.4	63.2	63.8	*4.8*	62.0	66.1	68.3	*9.3*	66.9	72.1
Nov Avg.	48.9	51.4	*2.5*	49.6	53.7	53.1	*4.3*	51.5	55.3	57.1	*8.3*	55.3	60.2
Dec Avg.	39.1	41.9	*2.8*	39.8	43.4	44.3	*5.2*	41.3	45.6	47.8	*8.7*	44.2	50.4

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	45.6	48.1	*2.4*	45.1	51.7	48.6	*2.9*	45.5	51.8	51.0	*5.4*	46.3	56.3
Max. 5-Day Precip. Event (in)	3.8	4.3	*0.5*	3.5	4.8	4.2	*0.4*	3.6	4.6	4.6	*0.8*	3.9	5.2
Days with Precip. > 1”	9	10	*1*	9	11	10	*2*	9	12	12	*3*	9	14
Days with Precip. > 2”	1	1	*0*	1	2	1	*0*	1	2	2	*1*	1	2
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	17	17	*1*	13	21	18	*1*	12	22	19	*2*	15	25
Very Heavy Precip. (95th Perc.) (in)	0.9	1.0	*0.1*	0.9	1.1	1.0	*0.1*	0.9	1.1	1.1	*0.2*	1.0	1.2
Extremely Heavy Precip. (99th.) (in)	1.7	1.8	*0.1*	1.7	2.0	1.8	*0.2*	1.7	2.0	1.9	*0.3*	1.8	2.2
Seasonal Variables													
3-Day Winter Precip. (in)	2.1	2.3	*0.2*	2.0	2.6	2.4	*0.3*	2.1	2.7	2.7	*0.6*	2.4	3.0
3-Day Spring Precip. (in)	2.2	2.3	*0.1*	2.1	2.9	2.4	*0.2*	2.1	2.8	2.6	*0.4*	2.3	3.3
3-Day Summer Precip. (in)	2.5	2.7	*0.2*	2.3	3.1	2.6	*0.1*	2.2	3.3	2.7	*0.2*	2.2	3.4
3-Day Fall Precip. (in)	2.8	2.9	*0.1*	2.3	3.8	3.0	*0.2*	2.3	3.5	3.0	*0.2*	2.4	4.0
Monthly Variables													
Jan Avg. Total	3.7	3.8	*0.1*	3.1	4.9	4.0	*0.3*	3.0	4.9	4.5	*0.8*	3.7	5.6
Feb Avg. Total	2.8	3.2	*0.4*	2.6	3.7	3.4	*0.6*	2.8	4.3	3.6	*0.8*	2.9	4.5
Mar Avg. Total	4.2	4.7	*0.5*	3.6	5.5	5.0	*0.8*	4.2	5.8	5.3	*1.1*	4.2	5.8
Apr Avg. Total	3.4	3.8	*0.4*	2.9	4.9	3.5	*0.1*	3.0	4.7	4.0	*0.5*	3.0	5.0
May Avg. Total	4.3	4.6	*0.3*	4.0	5.2	4.5	*0.2*	3.7	5.2	4.8	*0.5*	4.1	5.5
Jun Avg. Total	3.4	3.4	*0.0*	2.4	4.5	3.4	*0.0*	2.4	4.3	3.4	*0.0*	1.9	4.7
Jul Avg. Total	4.3	4.4	*0.1*	3.7	5.7	4.3	*-0.1*	3.4	5.5	4.5	*0.2*	3.3	5.7
Aug Avg. Total	3.8	3.9	*0.1*	3.1	4.7	4.0	*0.1*	3.0	4.9	4.2	*0.4*	2.8	5.4
Sep Avg. Total	4.4	4.4	*0.0*	3.3	5.5	4.4	*0.0*	3.2	5.2	4.4	*0.0*	2.9	5.5
Oct Avg. Total	3.8	3.8	*0.0*	3.1	4.6	4.0	*0.1*	3.2	4.6	3.7	*-0.1*	2.9	4.9
Nov Avg. Total	3.7	3.8	*0.1*	3.2	4.7	4.0	*0.4*	3.2	4.7	3.9	*0.3*	3.3	4.9
Dec Avg. Total	3.7	4.0	*0.3*	3.3	5.0	4.1	*0.4*	3.2	5.0	4.7	*0.9*	3.7	5.4

Harford County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039) Median	*Delta*	10th	90th	Mid-Century (2040–2059) Median	*Delta*	10th	90th	End-of-Century (2080–2099) Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	54.7	57.3	*2.6*	56.6	58.7	59.4	*4.7*	58.1	60.9	64.0	*9.3*	61.5	66.4
Annual Max. Temp. (°F)	65.1	67.9	*2.7*	66.9	69.1	70.1	*5.0*	68.3	71.4	74.2	*9.1*	71.9	77.0
Annual Min. Temp. (°F)	44.2	46.8	*2.5*	46.2	48.2	48.8	*4.5*	47.9	50.5	53.6	*9.3*	51.5	56.0
Days ≤ 32 °F	101	85	*-16*	74	90	72	*-29*	62	82	46	*-55*	31	59
Days ≥ 90°F	24	47	*23*	37	55	64	*40*	50	76	103	*79*	79	115
Days ≥ 95°F	5	15	*9*	10	23	27	*22*	17	39	64	*59*	36	87
Days ≥ 100°F	0	2	*2*	1	5	6	*6*	3	15	28	*28*	9	53
Days ≥ 105°F	0	0	*0*	0	0	1	*1*	0	2	7	*7*	1	26
Number of Heatwaves	1	2	*2*	1	4	5	*4*	3	9	16	*15*	7	24
Heating Degree Days	4874	4329	*-545*	4008	4489	3878	*-995*	3498	4141	3095	*-1779*	2579	3492
Cooling Degree Days	1108	1518	*410*	1374	1706	1859	*751*	1649	2135	2689	*1581*	2211	3196
Freeze/Thaw Days	89.4	78.4	*-11.0*	71.1	84.0	68.5	*-20.9*	60.4	79.0	44.9	*-44.5*	30.0	57.9
Days with Nighttime Temp. ≥ 70°F	14	32	*18*	27	42	50	*35*	41	67	90	*76*	67	111
Days with Nighttime Temp. ≥ 80°F	0	0	*0*	0	1	1	*1*	0	2	11	*11*	3	27
Hottest Annual Temp. (°F)	97.5	100.9	*3.4*	99.5	103.1	104.0	*6.5*	101.7	105.4	109.1	*11.6*	104.5	112.7
Coldest Annual Temp. (°F)	4.0	8.4	*4.4*	5.9	11.1	12.1	*8.1*	7.7	14.7	18.1	*14.1*	15.0	21.0
Seasonal													
Winter Diurnal Temp. Range (°F)	17.6	17.5	*-0.1*	15.5	19.2	17.6	*0.0*	16.0	19.0	16.8	*-0.8*	15.4	19.4
Spring Diurnal Temp. Range (°F)	24.1	24.7	*0.5*	21.5	27.0	24.3	*0.2*	22.6	26.7	24.4	*0.3*	21.9	27.3
Summer Diurnal Temp. Range (°F)	22.9	22.9	*0.0*	20.9	24.9	23.2	*0.3*	20.4	26.2	23.0	*0.1*	21.4	27.0
Fall Diurnal Temp. Range (°F)	23.8	24.0	*0.2*	21.9	25.4	23.2	*-0.6*	21.2	26.1	24.3	*0.5*	22.0	26.5
Winter Low (°F)	9.8	14.1	*4.3*	11.7	16.4	17.1	*7.3*	13.1	19.5	23.0	*13.2*	20.0	26.6

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Spring Days ≥ 90°F	1	3	*1*	2	3	4	*3*	3	6	10	*9*	6	13
Summer Days ≥ 90°F	22	40	*18*	32	47	53	*31*	43	62	76	*55*	65	82
Fall Days ≥ 90°F	1	4	*3*	2	6	6	*5*	5	9	16	*14*	10	23
Spring Days ≥ 95°F	0	0	*0*	0	1	1	*1*	0	2	4	*4*	2	6
Summer Days ≥ 95°F	5	14	*8*	9	21	24	*19*	16	34	53	*48*	32	67
Fall Days ≥ 95°F	0	1	*1*	0	2	2	*2*	1	3	7	*7*	3	14
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	2
Summer Days ≥ 100°F	0	2	*2*	1	5	6	*5*	3	13	25	*25*	8	45
Fall Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	1	2	*2*	1	7
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Summer Days ≥ 105°F	0	0	*0*	0	0	1	*1*	0	2	7	*7*	1	24
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	2
Monthly													
Jan Avg.	32.6	36.0	*3.4*	33.6	37.3	37.4	*4.8*	35.4	39.4	42.1	*9.5*	39.1	44.2
Feb Avg.	34.6	36.7	*2.1*	35.6	38.7	37.9	*3.2*	36.1	41.5	42.8	*8.1*	39.6	46.0
Mar Avg.	41.9	43.3	*1.4*	41.5	45.3	46.2	*4.3*	43.9	48.1	48.8	*6.9*	45.8	52.4
Apr Avg.	52.6	54.6	*2.0*	53.2	56.9	56.5	*3.9*	55.5	58.9	61.2	*8.6*	58.6	64.4
May Avg.	62.2	65.0	*2.9*	63.6	66.0	67.1	*4.9*	64.9	68.3	71.8	*9.6*	68.6	73.3
Jun Avg.	71.3	73.9	*2.6*	72.7	75.6	76.1	*4.9*	75.0	77.7	81.0	*9.8*	78.3	82.3
Jul Avg.	76.5	79.3	*2.8*	78.4	81.2	81.8	*5.3*	80.2	83.7	87.0	*10.5*	83.4	89.4
Aug Avg.	75.1	78.3	*3.3*	77.1	79.8	80.7	*5.6*	79.0	82.7	86.4	*11.3*	82.4	90.4
Sep Avg.	68.7	72.0	*3.3*	70.1	73.6	73.9	*5.3*	72.4	76.0	79.4	*10.7*	76.5	83.0
Oct Avg.	56.7	59.9	*3.2*	58.3	60.9	61.5	*4.8*	60.0	63.8	66.0	*9.4*	64.4	69.7
Nov Avg.	46.5	49.2	*2.7*	47.6	51.5	50.8	*4.3*	49.3	52.9	55.0	*8.5*	53.0	57.9
Dec Avg.	36.6	39.7	*3.1*	37.6	41.1	42.0	*5.4*	39.0	43.2	46.0	*9.4*	42.1	49.0

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	45.5	47.8	*2.3*	45.5	51.1	48.4	*2.9*	45.0	51.0	50.2	*4.7*	46.2	54.8
Max. 5-Day Precip. Event (in)	3.9	4.3	*0.4*	3.7	4.8	4.2	*0.3*	3.7	4.7	4.6	*0.7*	4.1	5.2
Days with Precip. > 1”	7	8	*1*	7	9	8	*2*	7	10	9	*2*	8	11
Days with Precip. > 2”	1	1	*0*	1	1	1	*0*	1	2	1	*1*	1	2
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	16	16	*0*	13	20	16	*1*	12	21	17	*2*	14	23
Very Heavy Precip. (95th Perc.) (in)	0.8	0.9	*0.1*	0.8	0.9	0.9	*0.1*	0.8	1.0	1.0	*0.1*	0.9	1.1
Extremely Heavy Precip. (99th.) (in)	1.4	1.6	*0.1*	1.4	1.7	1.6	*0.1*	1.4	1.7	1.7	*0.3*	1.5	1.9
Seasonal Variables													
3-Day Winter Precip. (in)	2.1	2.3	*0.2*	1.9	2.5	2.3	*0.3*	2.0	2.6	2.6	*0.5*	2.2	2.9
3-Day Spring Precip. (in)	2.1	2.3	*0.2*	2.0	2.6	2.3	*0.2*	2.0	2.7	2.6	*0.4*	2.2	3.0
3-Day Summer Precip. (in)	2.5	2.7	*0.2*	2.2	3.2	2.7	*0.2*	2.2	3.2	2.9	*0.3*	2.2	3.5
3-Day Fall Precip. (in)	2.9	3.1	*0.2*	2.3	3.7	3.2	*0.3*	2.5	3.6	3.2	*0.3*	2.6	4.0
Monthly Variables													
Jan Avg. Total	3.8	4.0	*0.2*	3.3	4.7	3.9	*0.2*	3.3	4.9	4.5	*0.7*	3.7	5.4
Feb Avg. Total	2.6	3.0	*0.3*	2.5	3.6	3.1	*0.4*	2.7	4.0	3.3	*0.7*	2.7	4.1
Mar Avg. Total	4.0	4.4	*0.4*	3.5	5.1	4.7	*0.7*	3.9	5.4	4.8	*0.8*	4.1	5.4
Apr Avg. Total	3.4	3.8	*0.3*	3.0	4.7	3.6	*0.1*	3.0	4.6	3.9	*0.5*	2.9	4.8
May Avg. Total	4.3	4.6	*0.3*	4.0	5.2	4.5	*0.2*	3.6	5.1	4.9	*0.6*	4.0	5.5
Jun Avg. Total	3.4	3.6	*0.2*	2.7	4.5	3.5	*0.1*	2.8	4.2	3.5	*0.1*	2.6	4.6
Jul Avg. Total	4.3	4.7	*0.4*	3.8	5.5	4.3	*0.0*	3.3	5.6	4.6	*0.3*	3.3	6.1
Aug Avg. Total	4.0	3.9	*-0.1*	3.4	4.8	4.0	*0.0*	3.3	4.8	4.4	*0.4*	2.8	5.3
Sep Avg. Total	4.3	4.3	*0.0*	3.3	5.4	4.5	*0.2*	3.2	5.2	4.4	*0.0*	3.1	5.5
Oct Avg. Total	3.9	3.9	*0.0*	3.2	4.7	4.0	*0.1*	3.2	4.6	3.9	*-0.1*	3.1	4.6
Nov Avg. Total	3.7	3.8	*0.1*	3.2	4.6	4.1	*0.4*	3.3	4.7	3.9	*0.2*	3.3	4.8
Dec Avg. Total	3.7	3.8	*0.1*	3.0	4.8	4.0	*0.3*	3.2	4.7	4.3	*0.6*	3.4	5.1

Howard County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	54.9	57.5	*2.6*	56.8	59.0	59.6	*4.7*	58.3	61.3	64.4	*9.5*	61.8	67.0
Annual Max. Temp. (°F)	65.8	68.5	*2.7*	67.5	69.9	70.8	*5.0*	68.9	72.2	74.9	*9.2*	72.6	78.0
Annual Min. Temp. (°F)	44.0	46.6	*2.5*	46.0	48.0	48.6	*4.6*	47.7	50.4	53.5	*9.5*	51.3	56.0
Days ≤ 32 °F	102	87	*-15*	76	91	73	*-29*	63	83	46	*-56*	33	59
Days ≥ 90°F	25	48	*24*	39	58	65	*41*	52	79	106	*82*	85	121
Days ≥ 95°F	6	17	*11*	12	25	28	*22*	20	42	69	*63*	39	93
Days ≥ 100°F	0	3	*2*	2	7	7	*6*	3	17	32	*32*	10	61
Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	3	9	*9*	1	30
Number of Heatwaves	1	3	*2*	2	5	6	*5*	3	10	18	*17*	8	26
Heating Degree Days	4792	4234	*-558*	3881	4412	3774	*-1019*	3385	4058	2993	*-1799*	2488	3368
Cooling Degree Days	1100	1509	*409*	1384	1690	1815	*716*	1636	2119	2700	*1600*	2210	3223
Freeze/Thaw Days	91.1	80.2	*-10.9*	71.9	84.8	68.6	*-22.5*	59.5	78.5	44.7	*-46.4*	31.0	56.8
Days with Nighttime Temp. ≥ 70°F	13	28	*15*	25	38	42	*29*	36	60	86	*73*	60	110
Days with Nighttime Temp. ≥ 80°F	0	0	*0*	0	1	1	*1*	0	2	8	*8*	2	23
Hottest Annual Temp. (°F)	97.3	100.5	*3.2*	99.4	102.5	103.2	*5.9*	101.1	105.1	108.4	*11.1*	103.7	112.3
Coldest Annual Temp. (°F)	3.1	8.0	*4.9*	5.1	11.1	11.8	*8.7*	7.1	14.4	17.7	*14.6*	14.7	21.3
Seasonal													
Winter Diurnal Temp. Range (°F)	18.0	17.5	*-0.5*	15.4	19.5	18.0	*0.0*	16.4	19.6	17.2	*-0.8*	15.3	20.1
Spring Diurnal Temp. Range (°F)	24.8	25.4	*0.6*	22.5	27.7	25.2	*0.4*	23.0	27.9	25.1	*0.3*	22.3	27.9
Summer Diurnal Temp. Range (°F)	23.9	24.1	*0.2*	21.8	26.4	24.8	*0.9*	21.3	27.3	24.3	*0.4*	22.5	28.2
Fall Diurnal Temp. Range (°F)	24.1	24.1	*0.0*	21.9	25.8	23.5	*-0.6*	21.3	27.2	24.9	*0.8*	22.1	27.4
Winter Low (°F)	9.0	13.6	*4.6*	11.2	16.0	16.8	*7.8*	12.3	19.0	22.7	*13.6*	19.6	25.4
Spring Days ≥ 90°F	1	3	*2*	2	5	5	*4*	3	8	13	*12*	7	17
Summer Days ≥ 90°F	22	40	*18*	32	48	51	*30*	44	62	74	*53*	64	82
Fall Days ≥ 90°F	1	5	*4*	3	7	8	*6*	5	10	17	*16*	11	25
Spring Days ≥ 95°F	0	1	*0*	0	1	2	*1*	1	2	6	*6*	2	9
Summer Days ≥ 95°F	6	15	*9*	10	23	24	*18*	17	37	55	*49*	33	69

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Fall Days ≥ 95°F	0	1	*1*	0	2	2	*2*	1	4	8	*8*	4	15
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	4
Summer Days ≥ 100°F	0	3	*2*	1	7	6	*5*	3	16	27	*26*	9	49
Fall Days ≥ 100°F	0	0	*0*	0	1	1	*1*	0	1	3	*3*	1	8
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	1
Summer Days ≥ 105°F	0	0	*0*	0	1	1	*1*	0	3	8	*8*	1	26
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	4
Monthly													
Jan Avg.	33.5	36.8	*3.3*	34.3	38.0	38.2	*4.7*	36.0	40.2	42.7	*9.3*	39.9	45.1
Feb Avg.	35.4	37.7	*2.3*	36.6	39.9	39.1	*3.6*	37.3	43.2	44.1	*8.6*	41.1	47.7
Mar Avg.	42.5	44.2	*1.6*	42.2	46.3	47.4	*4.8*	45.0	49.4	50.5	*8.0*	47.3	54.3
Apr Avg.	53.1	55.4	*2.3*	53.8	57.9	57.5	*4.4*	56.1	59.8	62.4	*9.3*	59.5	65.1
May Avg.	62.3	64.9	*2.6*	63.6	66.1	67.2	*4.9*	65.0	68.6	72.3	*10.0*	69.2	73.8
Jun Avg.	71.2	73.8	*2.6*	72.7	75.5	75.9	*4.8*	75.0	77.6	81.0	*9.9*	78.3	82.4
Jul Avg.	76.4	79.0	*2.6*	78.2	80.9	81.1	*4.7*	79.9	83.3	86.3	*9.8*	82.7	88.6
Aug Avg.	74.7	77.7	*3.0*	76.6	79.2	79.5	*4.9*	78.1	82.1	85.6	*11.0*	81.4	90.0
Sep Avg.	68.4	71.7	*3.3*	70.0	73.2	73.6	*5.2*	72.0	75.6	79.1	*10.7*	76.3	83.0
Oct Avg.	56.4	59.7	*3.3*	58.1	60.9	61.2	*4.8*	59.7	63.4	65.8	*9.4*	64.4	69.7
Nov Avg.	46.8	49.5	*2.8*	47.9	52.0	51.2	*4.5*	49.7	53.6	55.5	*8.8*	53.5	58.6
Dec Avg.	36.9	40.0	*3.1*	37.7	41.6	42.3	*5.4*	39.4	43.6	46.2	*9.4*	42.4	48.8

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	44.6	47.0	*2.4*	44.6	50.2	47.4	*2.8*	44.6	50.6	49.7	*5.1*	45.3	54.9
Max. 5-Day Precip. Event (in)	3.8	4.3	*0.5*	3.5	4.8	4.1	*0.4*	3.6	4.6	4.5	*0.8*	3.9	5.1
Days with Precip. > 1”	8	9	*1*	7	10	9	*2*	8	10	10	*3*	9	12
Days with Precip. > 2”	1	1	*0*	1	2	1	*0*	1	2	1	*1*	1	2
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	17	17	*0*	13	21	17	*1*	12	22	18	*2*	14	25
Very Heavy Precip. (95th Perc.) (in)	0.9	0.9	*0.0*	0.9	1.0	0.9	*0.1*	0.9	1.0	1.0	*0.2*	0.9	1.1
Extremely Heavy Precip. (99th.) (in)	1.5	1.7	*0.1*	1.5	1.8	1.7	*0.2*	1.5	1.9	1.8	*0.3*	1.6	2.1
Seasonal Variables													
3-Day Winter Precip. (in)	2.0	2.2	*0.2*	1.9	2.5	2.3	*0.3*	2.0	2.6	2.6	*0.6*	2.2	2.9
3-Day Spring Precip. (in)	2.1	2.3	*0.1*	2.0	2.9	2.4	*0.2*	2.0	2.8	2.7	*0.5*	2.3	3.2
3-Day Summer Precip. (in)	2.5	2.7	*0.3*	2.3	3.2	2.6	*0.1*	2.1	3.1	2.7	*0.3*	2.1	3.3
3-Day Fall Precip. (in)	2.9	3.0	*0.2*	2.5	3.6	3.1	*0.3*	2.6	3.6	3.2	*0.3*	2.5	3.9
Monthly Variables													
Jan Avg. Total	3.7	3.8	*0.1*	3.1	4.6	3.9	*0.2*	3.0	4.8	4.3	*0.6*	3.6	5.4
Feb Avg. Total	2.8	3.1	*0.3*	2.5	3.8	3.3	*0.6*	2.8	4.1	3.5	*0.7*	2.9	4.4
Mar Avg. Total	4.1	4.5	*0.4*	3.6	5.2	4.9	*0.8*	4.0	5.6	5.1	*1.0*	4.2	5.7
Apr Avg. Total	3.3	3.8	*0.5*	2.9	4.7	3.5	*0.2*	2.9	4.6	3.9	*0.6*	3.1	4.9
May Avg. Total	4.3	4.7	*0.3*	4.0	5.1	4.6	*0.3*	3.7	5.2	4.8	*0.5*	4.2	5.7
Jun Avg. Total	3.5	3.7	*0.2*	2.8	4.8	3.5	*0.0*	2.7	4.4	3.5	*-0.1*	2.2	5.1
Jul Avg. Total	4.0	4.2	*0.2*	3.6	5.3	4.0	*0.0*	3.2	5.3	4.2	*0.2*	3.0	5.7
Aug Avg. Total	3.7	3.6	*-0.1*	3.0	4.5	3.8	*0.2*	2.8	4.6	4.0	*0.4*	2.8	5.1
Sep Avg. Total	4.3	4.2	*0.0*	3.5	5.4	4.4	*0.1*	3.3	5.2	4.2	*0.0*	3.0	5.4
Oct Avg. Total	3.6	3.7	*0.1*	3.0	4.4	3.7	*0.1*	3.1	4.5	3.6	*-0.1*	2.8	4.7
Nov Avg. Total	3.7	3.8	*0.1*	3.2	4.6	4.0	*0.3*	3.2	4.7	3.9	*0.2*	3.4	4.9
Dec Avg. Total	3.6	3.8	*0.2*	3.0	4.7	3.9	*0.3*	3.2	4.6	4.4	*0.9*	3.5	5.2

Queen Anne's County

Temperature

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual													
Annual Avg. Temp. (°F)	56.3	58.6	*2.4*	57.8	60.1	60.6	*4.3*	59.4	62.1	65.2	*8.9*	62.5	67.7
Annual Max. Temp. (°F)	66.5	69.0	*2.5*	68.1	70.4	71.1	*4.5*	69.4	72.6	75.2	*8.6*	72.9	78.1
Annual Min. Temp. (°F)	46.0	48.3	*2.3*	47.7	49.8	50.2	*4.2*	49.3	51.7	54.8	*8.8*	52.7	57.3
Days ≤ 32 °F	88	73	*-15*	64	79	60	*-28*	51	69	34	*-54*	22	47
Days ≥ 90°F	29	51	*23*	43	61	70	*41*	55	84	107	*79*	86	123
Days ≥ 95°F	6	17	*10*	12	23	29	*23*	20	41	70	*64*	41	88
Days ≥ 100°F	0	2	*2*	1	5	6	*6*	3	14	30	*29*	10	51
Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	2	7	*7*	1	21
Number of Heatwaves	1	3	*2*	2	5	6	*5*	4	9	18	*17*	9	25
Heating Degree Days	4462	3971	*-491*	3640	4148	3553	*-910*	3174	3792	2783	*-1679*	2308	3158
Cooling Degree Days	1268	1646	*378*	1522	1841	1968	*700*	1777	2240	2844	*1576*	2314	3325
Freeze/Thaw Days	79.6	68.4	*-11.1*	60.9	73.9	57.4	*-22.2*	49.6	66.5	32.2	*-47.4*	20.9	46.9
Days with Nighttime Temp. ≥ 70°F	24	43	*19*	36	50	57	*34*	48	71	96	*73*	75	116
Days with Nighttime Temp. ≥ 80°F	0	0	*0*	0	1	1	*1*	0	4	13	*13*	4	31
Hottest Annual Temp. (°F)	97.6	100.6	*3.1*	99.6	102.3	103.2	*5.6*	101.3	104.6	107.9	*10.3*	104.0	111.8
Coldest Annual Temp. (°F)	6.5	10.6	*4.1*	8.1	13.2	14.2	*7.7*	10.3	17.0	19.8	*13.3*	17.5	23.3
Seasonal													
Winter Diurnal Temp. Range (°F)	16.4	16.3	*-0.1*	14.4	18.3	16.4	*0.0*	15.0	18.0	16.0	*-0.4*	14.5	18.0
Spring Diurnal Temp. Range (°F)	22.5	23.0	*0.5*	20.2	25.3	23.0	*0.5*	20.9	25.2	22.9	*0.4*	20.3	25.8
Summer Diurnal Temp. Range (°F)	22.4	22.5	*0.1*	20.4	24.5	22.6	*0.2*	19.9	25.1	22.4	*0.0*	20.8	25.8
Fall Diurnal Temp. Range (°F)	22.2	22.2	*0.0*	20.1	23.5	21.8	*-0.5*	19.5	24.3	22.5	*0.3*	19.8	24.6
Winter Low (°F)	11.8	15.8	*4.1*	13.7	18.2	18.6	*6.8*	15.2	21.1	24.1	*12.3*	21.7	27.3
Spring Days ≥ 90°F	2	3	*1*	2	4	5	*3*	3	7	11	*10*	7	14
Summer Days ≥ 90°F	25	43	*18*	35	51	56	*31*	46	66	78	*52*	70	84
Fall Days ≥ 90°F	2	5	*3*	3	7	8	*6*	6	11	18	*16*	13	24
Spring Days ≥ 95°F	0	0	*0*	0	1	1	*1*	1	2	4	*4*	2	6
Summer Days ≥ 95°F	6	15	*9*	10	22	26	*20*	18	35	58	*52*	36	69

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Fall Days ≥ 95°F	0	1	*1*	0	2	2	*2*	1	3	8	*8*	4	14
Spring Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	0	1	*1*	0	2
Summer Days ≥ 100°F	0	2	*2*	1	5	6	*5*	3	13	27	*26*	9	45
Fall Days ≥ 100°F	0	0	*0*	0	0	0	*0*	0	1	2	*2*	1	6
Spring Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Summer Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	2	6	*6*	1	19
Fall Days ≥ 105°F	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	2
Monthly													
Jan Avg.	34.9	37.8	*3.0*	35.7	39.1	39.2	*4.3*	37.6	41.4	43.9	*9.0*	41.7	46.3
Feb Avg.	36.7	38.8	*2.2*	37.7	40.8	40.1	*3.4*	38.5	43.5	45.1	*8.4*	42.1	47.7
Mar Avg.	43.8	45.2	*1.4*	43.4	47.2	48.0	*4.2*	45.4	50.4	50.6	*6.8*	47.9	54.7
Apr Avg.	54.0	55.9	*1.9*	54.7	58.1	57.7	*3.7*	56.4	60.3	62.0	*8.0*	59.6	65.1
May Avg.	63.2	66.0	*2.8*	64.4	66.8	67.5	*4.3*	65.9	69.0	72.2	*9.0*	69.5	73.8
Jun Avg.	72.4	74.7	*2.3*	73.7	76.6	76.7	*4.2*	75.6	78.5	81.3	*8.9*	78.9	83.2
Jul Avg.	77.7	80.2	*2.5*	79.3	81.5	82.4	*4.6*	81.1	83.8	87.4	*9.7*	84.0	89.6
Aug Avg.	76.2	79.1	*2.9*	78.0	80.2	80.9	*4.7*	79.5	83.0	86.9	*10.7*	82.8	88.9
Sep Avg.	69.9	72.8	*2.9*	71.4	74.4	74.7	*4.8*	73.3	76.6	79.9	*10.0*	77.2	82.3
Oct Avg.	58.2	61.2	*3.0*	59.7	62.3	63.0	*4.8*	61.4	65.2	67.3	*9.1*	65.9	71.2
Nov Avg.	48.4	51.0	*2.7*	49.5	53.3	52.7	*4.4*	51.3	54.9	56.8	*8.4*	55.1	59.7
Dec Avg.	38.5	41.2	*2.7*	39.0	42.6	43.5	*5.0*	40.7	44.8	47.4	*8.9*	43.5	50.3

Precipitation

Variables	Observed Value (1986–2005)	Near-Term (2020–2039)				Mid-Century (2040–2059)				End-of-Century (2080–2099)			
		Median	*Delta*	10th	90th	Median	*Delta*	10th	90th	Median	*Delta*	10th	90th
Annual Variables													
Annual Avg. Precip. (in)	43.6	45.4	*1.8*	42.7	48.3	45.4	*1.8*	43.4	48.0	47.3	*3.7*	43.5	51.5
Max. 5-Day Precip. Event (in)	3.9	4.2	*0.3*	3.7	4.7	4.1	*0.2*	3.8	4.5	4.6	*0.7*	4.0	5.1
Days with Precip. > 1”	7	8	*1*	7	9	8	*1*	7	10	9	*2*	8	12
Days with Precip. > 2”	1	1	*0*	1	1	1	*0*	1	1	1	*0*	1	2
Days with Precip. > 3”	0	0	*0*	0	0	0	*0*	0	0	0	*0*	0	0
Max. Consecutive Dry Days	17	17	*0*	13	21	18	*1*	14	22	19	*2*	15	25
Very Heavy Precip. (95th Perc.) (in)	0.9	0.9	*0.0*	0.9	1.0	0.9	*0.1*	0.9	1.0	1.0	*0.1*	0.9	1.1
Extremely Heavy Precip. (99th.) (in)	1.5	1.5	*0.1*	1.4	1.7	1.6	*0.1*	1.5	1.7	1.7	*0.2*	1.5	1.9
Seasonal Variables													
3-Day Winter Precip. (in)	2.0	2.1	*0.2*	1.9	2.4	2.2	*0.3*	1.9	2.4	2.4	*0.5*	2.2	2.8
3-Day Spring Precip. (in)	2.1	2.3	*0.1*	2.0	2.6	2.3	*0.2*	2.0	2.6	2.5	*0.4*	2.2	3.0
3-Day Summer Precip. (in)	2.3	2.4	*0.1*	2.1	2.8	2.4	*0.1*	2.0	2.8	2.6	*0.3*	2.1	3.2
3-Day Fall Precip. (in)	2.7	2.8	*0.1*	2.3	3.2	2.8	*0.2*	2.4	3.3	2.9	*0.2*	2.5	3.6
Monthly Variables													
Jan Avg. Total	3.6	3.6	*0.1*	2.9	4.5	3.7	*0.1*	3.0	4.6	4.2	*0.6*	3.4	5.0
Feb Avg. Total	2.8	3.2	*0.3*	2.6	3.8	3.3	*0.5*	2.8	3.9	3.4	*0.5*	2.9	4.2
Mar Avg. Total	4.0	4.4	*0.3*	3.5	5.0	4.5	*0.5*	4.0	5.2	4.8	*0.8*	3.9	5.4
Apr Avg. Total	3.3	3.6	*0.3*	2.9	4.5	3.3	*0.1*	3.0	4.2	3.7	*0.4*	2.9	4.5
May Avg. Total	4.1	4.3	*0.2*	3.8	4.9	4.2	*0.1*	3.4	4.9	4.5	*0.4*	3.8	5.0
Jun Avg. Total	3.5	3.7	*0.1*	2.8	4.6	3.5	*0.0*	2.9	4.2	3.6	*0.1*	2.5	4.7
Jul Avg. Total	4.1	4.3	*0.2*	3.7	5.1	4.0	*-0.1*	3.4	5.3	4.1	*0.0*	3.2	5.7
Aug Avg. Total	3.9	3.9	*0.0*	3.3	4.5	3.9	*0.0*	3.1	4.8	4.3	*0.4*	2.6	5.2
Sep Avg. Total	4.2	4.2	*0.0*	3.3	5.0	4.3	*0.1*	3.2	5.2	4.1	*0.0*	3.1	5.2
Oct Avg. Total	3.2	3.1	*-0.1*	2.7	3.8	3.3	*0.1*	2.5	3.7	3.2	*0.0*	2.6	3.8
Nov Avg. Total	3.4	3.5	*0.1*	2.9	4.1	3.7	*0.3*	3.0	4.1	3.5	*0.1*	2.9	4.4
Dec Avg. Total	3.5	3.7	*0.2*	3.1	4.5	3.9	*0.3*	2.9	4.4	4.2	*0.6*	3.3	4.9

APPENDIX B: Climate Science Data and Methods

This Resource Guide presents temperature and precipitation data from the Localized Constructed Analogs (LOCA) dataset.[48,49] For sea level rise, the data source of projected values within this Resource Guide is from the State's official resource, Sea-level rise: Projections for Maryland 2018. These data sources represent the best available climate science for the region.

The LOCA dataset was processed using two climate change analysis tools. The specifications for both are summarized in Table 5 below.

- ICF's in-house Climate Data Processing Tool was used to arrive at nearly all the temperature and precipitation variables in this Resource Guide.
- The FHWA CMIP Climate Data Processing Tool[50] was used to arrive at projections for two precipitation variables in this Resource Guide—24-hour, 10-year rainfall amount and 24-hour, 100-year rainfall amount. The FHWA CMIP Tool is specifically designed to provide projections of future precipitation return intervals. Due to capacity constraints and tool requirements, the projections from the FHWA CMIP Tool are derived from a different number of climate models and over different time periods than the other projections from the ICF Climate Data Processing Tool.

Table 5. Temperature and precipitation data analysis specifications.

	ICF Climate Data Processing Tool (nearly all variables)	**FHWA CMIP Climate Data Processing Tool** (24-hour precipitation return intervals)
Dataset	1/16-degree LOCA	
Emission scenario	RCP 8.5	
Number of models	32	12*
Time period ranges		
Baseline	1986–2005	1976–2005
Near-term (centered around 2030)	2020–2039	2015–2044
Mid-century (centered around 2050)	2040–2059	2035–2064
End-of-century	2080–2099	2070–2099

* The following models for use in the CMIP Climate Data Processing Tool were selected due to constraints of this tool, guidance from the NCHRP 15-61 design guidelines, and their coverage of a range of climate sensitivities: GISS-E2-H, GISS-E2-R, MRI-CGCM3, BCC-CSM1.1-m, CCSM4, CNRM-CM5, MIROC5, CSIRO-Mk3.6.0, GFDL-CM3, HadGEM2-CC, Had-GEM2-AO, and IPSL-CM5A-LR.

** 2005 is the latest available year for the baseline time period.

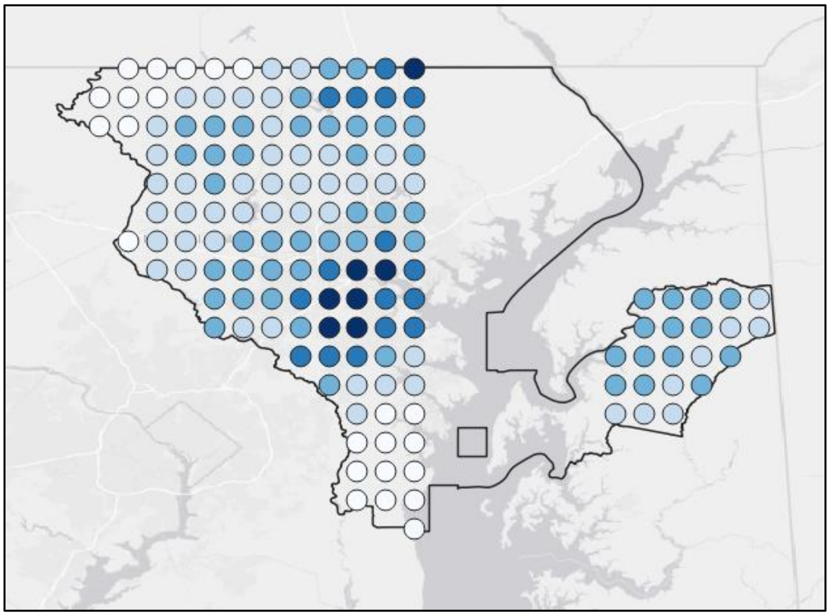
The LOCA dataset provide 1/16th-degree gridded geospatial data. To create the regional information for this Resource Guide, projected values for the climate variables were averaged across each

[48] Pierce DW, et al. Statistical Downscaling Using Localized Constructed Analogs (LOCA). 2014. https://doi.org/10.1175/JHM-D-14-0082.1
[49] Pierce DW, et al. Improved Bias Correction Techniques for Hydrological Simulations of Climate Change. 2015. https://doi.org/10.1175/JHM-D-14-0236.1
[50] Federal Highway Administration. CMIP Climate Data Processing Tool 2.1. https://fhwaapps.fhwa.dot.gov/cmip

jurisdiction (Anne Arundel County, Carroll County, Baltimore County, Baltimore City, Howard County, Harford County, and Queen Anne's County).

Notably, the FHWA CMIP Climate Data Processing Tool cannot generate data for grid cells that are partially or entirely water. As such, the 24-hour, 10-year rainfall amount and the 24-hour, 100-year rainfall projections in this Resource Guide represent spatial averages of two large swaths of land in the Baltimore region. Figure 24 shows the spatial distribution of datapoints used to calculate region-wide projections for these two variables. The datapoints used to calculate region-wide projections are representative of the Baltimore region, despite a slight gap in geographic coverage.

Figure 24. Spatial distribution of datapoints used to calculate region-wide projections, representative of the Baltimore region.



Additional Climate Data Resources

A wealth of climate resources is available beyond this Resource Guide. These include:

- MDOT SHA Climate Change Vulnerability Viewer for interactive mapping of sea level rise and storm scenarios.
- Sea-level rise: Projections for Maryland 2018. Sea level rise projections for Maryland are updated at least every 5 years.
- U.S. Climate Resilience Toolkit for a compendium of resilience resources, including case studies on local adaptation, more than 200 digital tools, experts and reports, training courses, state climate summaries, and topic-specific information for the built environment, transportation, coasts, and other climate-related topics.
  - The U.S. Climate Resilience Toolkit is also home to the Climate Explorer, which provides interactive graphs and maps showing climate observations and projections for any city and county in the contiguous United States.

- USGS National Climate Change Viewer for visualizing historical and projected changes in climate for any state or county in the United States through maps, graphs, and tables.
- FHWA CMIP Climate Data Processing Tool for local-level climate projections with statistics that are relevant to transportation planners.
- NOAA Coastal and Ocean Climate Applications to support decision-makers on climate-related issues in coastal and marine environments.
- NOAA Atlas 14 for historical rainfall data. While projected rainfall data should be applied to understand forward-looking conditions, the projections have limitations, such as granularity beyond 24-hour rainfall patterns.

APPENDIX C: Toolkit Example

In this example populated Toolkit, the Department of Transportation in Jurisdiction X is considering how to accommodate drainage along a stretch of urban roadway, which also serves as an emergency or snow route during inclement weather. Jurisdiction X is also more broadly considering planning for climate change across the County's overall roadway network. This sample uses climate values and projections from Anne Arundel County.

Toolkit Questions	Enter Your Responses
Climate science: Chapter 2 and Appendix A	
1. What climate hazards are relevant to your work or project? Use the information about current and future climate change in Chapter 2 (regional summary) and Appendix A (jurisdictional data) to determine relevant climate hazards. For each climate hazard, certain variables may be highly relevant to your service area or project (e.g., number of days above 90°F for worker safety; heating/cooling degree days for facilities; freeze/thaw days for transportation). Review the list of climate variables in Appendix A to identify variables particularly relevant to your work.	**Climate hazards** ☑ Temperature ☑ Precipitation ☐ Sea level rise and storm surge ☑ Other extreme weather **Climate variables** ▪ Daily freeze/thaw cycle ▪ Annual Avg. Precip. (in) ▪ Max. 5-Day Precip. Event (in) ▪ Days with Precip >1" ▪ Very Heavy/Extremely Heavy Precip (in)

Toolkit Questions	Enter Your Responses	
2. For each of the climate hazards: What are the historical climate conditions? How are the climate conditions changing in your jurisdiction? Use the information about current and future climate change in Chapter 2 (regional summary) and Appendix A (jurisdictional data) to evaluate how the climate hazards are changing. Consider your planning timeframe or asset's useful life when reviewing the projected climate conditions. For example, decisions about maintenance or replacement of facility mechanical components should consider medium-term projections (centered around 2050), while decisions about construction of new long-lived infrastructure should consider long-term projections (end of century and beyond).	**Historical climate conditions**	**Projected climate conditions** The following are projections for mid-century (2040–2059) / end-of-century (2080–2099) respectively.
	Freeze/thaw Days: 79.1 days	57.2 days/34.7 days Number of freeze-thaw days will decrease with warmer temperatures.
	Annual Avg. Precip. (in): 43.2”	45.6”/48.0” Amount of annual precip. is expected to increase by approximately 4.8” by end-of-century.
	Max. 5-Day Precip. Event (in): 3.6”	3.9”/4.4” The amount of rain falling in a 5-day event, will increase to 4.4” by end-of-century. The amount of rain falling in a 5-day event is a proxy indicator for potential flooding.

Toolkit Questions	Enter Your Responses	
	Days with Precip >1”: 7 days	9 days/10 days By end-of-century, there will be +2 days annually with more than an inch of rain (discrepancy due to rounding).
	Very Heavy Precip (in): 0.8” Extremely Heavy Precip (in): 1.5”	Very heavy and extremely heavy precip. will increase 0.1 inches between observed, to mid-century, and between mid-century to end-of-century.
	24-hour, 100-year rainfall amount (in): 5.0”	5.7”/6.0” The 100-year rainfall amount will increase by 20% by end-of-century.
	Our jurisdiction has seen strong wind events and tropical storms in the past five years.	Extreme weather events will increase in frequency and intensity with climate change.

Toolkit Questions	Enter Your Responses
Climate impacts: Chapter 3	
3. Given changing climate conditions, what are anticipated impacts to your service area or project? Consider impacts that your service area or project has recently experienced, and use the climate projections from Question 2 along with the information and examples from Chapter 3 to determine projected climate impacts. Which anticipated impacts are priorities to address? Consider prioritizing impacts based on potential damage, disruption of public services, and cost of repair.	**Projected climate impacts** Based on climate projections, heavy precipitation and associated flooding will be of greatest impact, especially given the projected increases in the amount of precipitation falling in a 5-day event, and rainfall amount during a 100-year event. Potential priority impacts for this roadway project include: heavy precipitation and inland flooding, which can cause erosion, deterioration and structural damage to roadways, and exceeded capacity of existing drainage infrastructure along the roadway system.
4. Have climate impacts to your service area or project disproportionally affected vulnerable populations? Review the a) BMC Vulnerable Populations Index, b) Maryland Commission on Climate Change Adaptation and Resiliency Work Group's Justice, Equity, Diversity, and Inclusion Strategic Framework, and c) information on climate impacts from Chapter 3 to consider the uneven impacts to vulnerable populations who may face elevated climate risks. Are there areas where infrastructure investments could both reduce climate impacts and enhance social equity?	Based on the interactive map of vulnerable populations, the index indicates vulnerable populations are situated along the northern border, near BWI Airport, and the roadways leading to the airport. A heightened vulnerability (vulnerable population index of 8-10) exists in the northern area of the county near several key roadway intersections. There is a relatively high disabled population at the intersection of the interstate as compared to the rest of the county. These areas will be prioritized when planning drainage design and construction along roadways.

Toolkit Questions	Enter Your Responses
Policies: Chapter 4	
5. Are there state and local policies on climate impacts that affect your work or project? Use the information from Chapter 4 to determine relevant climate policies. Are there policies that would help facilitate climate adaptation measures if approached from a climate perspective? For example, environmental justice policies may help show progress or build support when addressing climate. On the flipside, are there policy or planning barriers that limit your ability to address climate impacts?	House Bill 295 (2021): The Maryland Department of the Environment (MDE) establishes stormwater management regulations in the state. This is relevant to localities because MDE will update stormwater management regulations at least once every 5 years. Senate Bill 457 (2020) authorizes local governments to establish a Resilience Authority to fund large-scale infrastructure projects.
Adaptation options: Chapter 5	
6. Given the projected climate impacts, what are potential adaptation strategies within your service area or for your project, across relevant functions (e.g., design, maintenance)? Use the information and examples from Chapter 5 to begin to identify potential adaptation strategies. What adaptation options are no-regrets (i.e., generate benefits regardless of future climate) and/or could be implemented in the near-term? What adaptation options are no or low cost?	Given future priority impacts from heavy precipitation and inland flooding, we should prioritize addressing roadway drainage infrastructure along arterial roadways and emergency routes to account for future climate projections. Project-specific adaptation measures: ▪ Enhance maintenance measures, such as cleaning drains and culverts, to alleviate flooding. This measure is relatively low cost! ▪ Develop green infrastructure / nature-based solutions to absorb and convey excess stormwater. ▪ Implement system upgrades to accommodate increased rainfall/flooding. Keep the following adaptation measures in mind: ▪ Use cooler pavement mixes (e.g., light-colored aggregate) to reduce surface temperatures.

Toolkit Questions	Enter Your Responses
Funding and financing: Chapter 6	
7. What funding and financing sources are available to help implement the adaptation options? Use the information and examples from Chapter 6 to begin to identify potential funding and financing strategies for adaptation.	Potential funding and financing options: ▪ U.S. Department of Transportation (USDOT), Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Discretionary Grant program ▪ National Fish and Wildlife Foundation's Resilient Communities Program, planning and implementation for nature-based resiliency projects ▪ Federal Emergency Management Agency (FEMA), Building Resilient Infrastructure and Communities (BRIC) Program
Next steps	
8. What are your next steps to address these climate impacts and plan for these adaptation options? For the selected adaptation strategies, would there be implications to other service areas? Are there other agencies or departments your DPW or DOT should coordinate with?	Next Steps/Priorities: 1. Coordinate with Jurisdiction X's stormwater manager. 2. Further analyze specific roadways to prioritize for adaptation implementation based on historic and future flooding incidents on our roadways and the Vulnerable Population Index. 3. Identify where adaptation measures that are low-cost can be easily integrated into an existing project. Once priority locations are determined, we will begin to implement adaptation strategies that have co-benefits and first implement in areas serving vulnerable populations.

Glossary

The following definitions are drawn from sources including: the Maryland Coast Smart Council, the Federal Highway Administration, and the U.S. Global Change Research Program.

100-year flood: A flood or storm that has a 1% probability of occurring in any given year. The 100-year flood zone is the extent of the area of a flood that has a 1% chance of occurring or being exceeded in a given year.

500-year flood: A flood or storm that has a 0.2% probability of occurring in any given year. The 500-year flood zone is the extent of the area of a flood that has a 0.2% chance of occurring or being exceeded in a given year.

Adaptation: Adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.

Climate change: Any change in climate over time, whether due to natural variability or as a result of human activity. Climate refers to long-term trends in weather that extend multidecadal periods.

Coast Smart Climate Ready Action Boundary (CS-CRAB): CS-CRAB is the corresponding horizontal landward boundary created by the CS-CRAB Elevation.

Coast Smart Climate Ready Action Boundary (CS-CRAB) Elevation: A selected flood elevation fixed at the 100-year FEMA floodplain elevation, also known as the Base Flood Elevation, plus a 3-foot vertical extent.

Cooling degree day (CDD): Number of degrees by which a daily average temperature exceeds 65°F. The reference temperature of 65°F loosely represents an average daily temperature below which space cooling (e.g., air conditioning) is not needed. The sum of the number of heating or cooling degree days over a year is roughly proportional to the annual amount of energy that would be needed to cool a building.

Design life: The period of time during which the structure is expected by its designers to work within its specified parameters; in other words, this term refers to the life expectancy of the structure. It is the length of time between placement into service of a single structure and that structure's onset of wear-out—that is, where additional maintenance is no longer sufficient to prolong its life expectancy.

Extreme weather: A weather event that is rare at a particular place and time of year, including heatwaves, cold waves, heavy rains, periods of drought and flooding, and severe storms.

Freeze/thaw days: The number of days where the maximum temperature is above freezing (higher than 32°F), and the minimum temperature is below freezing (32°F or lower). Moisture from thawing snow and ice can seep into cracks in transportation infrastructure and expand during freezing periods, which can deteriorate infrastructure.

Heating degree day (HDD): Number of degrees by which a daily average temperature is below 65°F. The reference temperature of 65°F loosely represents an average daily temperature above which space heating is not needed. The sum of the number of heating or cooling degree days over a year is roughly proportional to the annual amount of energy that would be needed to heat a building.

Heatwaves: The average number of instances per year when there are 3 consecutive days above the observed 98th percentile.

Maximum 5-day precipitation event: The maximum amount of precipitation that could fall within 5 days. This precipitation variable can be an indicator of flood hazard.

Mitigation: Measures to reduce the amount and speed of future climate change by reducing emissions of heat-trapping gases or removing carbon dioxide from the atmosphere.

Nuisance flooding: High-tide flooding that causes public inconvenience.

Resilience: Capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment.

Storm Surge: An abnormal and significant rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge is produced by water being pushed toward the shore by the force of the winds moving around the storm.