Changing Climate Hazards in Cumberland County, A Review of the Evidence

Neil Leary, August 14, 2023

Summary

The Earth's climate is warming and changing in ways that are exposing people, economies, and natural systems to greater climate hazards throughout the world and here in Central Pennsylvania. The risks to our wellbeing, while substantial, can be reduced significantly by making deep reductions in emissions of greenhouse gas pollutants that cause climate change. However, even if deep emission reductions are achieved, climate change will still pose significant risks. We will also need to adapt to the changing climate and build community resilience for limiting harms from climate hazards.

Actions are being taken and progress made, though efforts need to be scaled up and accelerated. Cumberland County, the Borough of Carlisle, and Dickinson College have each adopted climate action plans that are focused on reducing emissions. Largely unaddressed are the challenges of adapting to and building resilience against climate change.

To address this gap, a joint initiative has been launched, *Building Climate Resilience at Dickinson and in Central Pennsylvania*. Building climate resilience requires widespread understanding in the community of the climate hazards we face, how they are changing, and how they are likely to change in the future. This review presents information about these questions for Cumberland County, putting them in context with wider regional, national, and global changes. It is intended to be a resource for the initiative.

Building Climate Resilience at Dickinson and in Central Pennsylvania

- Spring 2023: Initiative is launched.
- Fall 2023 – Spring 2024: Assess climate vulnerabilities and resilience.
- Fall 2024 – Spring 2025: Investigate strategies for adapting and building resilience.
- Fall 2025: Develop and adopt plans of action.
- Spring 2026: Take Action.

Residents are welcome to participate. Contact sustainability@dickinson.edu to learn more.

Climate resilience is the capacity to anticipate, prepare for, limit, prevent, withstand, and recover from impacts of the changing climate and to adapt and thrive in an uncertain future.

The review of the evidence supports the following conclusions for climate hazards in Central Pennsylvania:

- **Average temperatures** have increased and are virtually certain to continue to increase in coming decades.
- **Very hot days** have increased slightly in number per year and are very likely to increase in number and intensity in the future.
- **Cold days** below freezing have decreased in number per year and are very likely to decrease in number in the future.
- **Average annual precipitation** has increased and is very likely to increase in the future.
- **Heavy rain** events have increased in number and are very likely to continue to increase in number and in rainfall intensity.
- **River and flash floods** are frequent in the County and increases in heavy rain events have the potential to increase exposures to flood hazards.
- **Droughts** that reach emergency status are relatively infrequent in the County and have not changed in frequency or intensity. But they have the potential to become more frequent and severe in a warmer future.
- **Extreme rain and windstorms** are relatively frequent in the County and exposures may increase in frequency and/or severity.

In summary, many climate hazards are expected to become increasingly severe in the near term and over the century as the global climate warms. The changes threaten the wellbeing of current and future generations. But the harms that result can be limited with thoughtful planning, adaptation, and investments in building community resilience. These actions need to be accompanied by deep reductions in emissions of greenhouse gases that are driving climate change.

Why Plan for Climate Resilience?

The Earth's climate is warming and changing in ways that are exposing people, economies, and natural systems to greater climate hazards in Central Pennsylvania and throughout the world. The risks to our wellbeing, and the wellbeing of our children and future generations, while substantial, can be reduced significantly. Success will require strong and urgent actions by public and private sector actors working locally, nationally, and internationally.

States, communities, businesses, and other institutions across the United States and in other countries are stepping forward with plans and actions to make deep reductions in emissions of greenhouse gas pollutants that cause climate change, adapt to the changing climate, and build community resilience to climate and other hazards. Progress is being made. But actions need to be scaled up and accelerated at all these levels if efforts called for by the Paris Agreement on climate change are to be effective in lowering the risks we face.

Cumberland County, the Borough of Carlisle, and Dickinson College have each adopted climate action plans that focus primarily on reducing their greenhouse gas emissions (Cumberland County, 2022; Carlisle Borough, 2022; and Dickinson College, 2009). Largely unaddressed by the action plans are the challenges of adapting to climate change and building resilience.

To address the gap, a joint initiative has been launched, *Building Climate Resilience at Dickinson and in Central Pennsylvania*. The initiative seeks to improve understanding of climate vulnerabilities, risks, and resilience in our region and help mobilize planning and action for greater climate resilience. The timeline and steps of the initiative are:

- Spring 2023: Initiative is launched.
- Fall 2023 – Spring 2024: Assess climate vulnerabilities and resilience.
- Fall 2024 – Spring 2025: Investigate and evaluate strategies for adapting and building resilience.
- Fall 2025: Develop and adopt a plan of action for Dickinson College.
- Spring 2026: Take Action.

The Dickinson plan will focus on building climate resilience of the college but will also address support for climate resilience in the wider community. Carlisle Borough and Cumberland County, as participants in the initiative, will consider if and how they might undertake planning efforts for their jurisdictions. Climate resilience is an important component of a comprehensive portfolio of strategies for responding to climate change. It is the capacity to anticipate, prepare for, prevent, limit, withstand, and recover from impacts of the changing climate and to adapt and thrive in an uncertain future.

Building resilience in our region can limit the potential harms we may experience from climate change and climate hazards. If we do not build resilience, and do not account for climate change in our plans and investments for the future, we will put ourselves at greater risk. But if we take climate change into account as we plan and invest, we can collectively create a resilient future in which all residents are able to thrive.

What is the Purpose of the review?

This document reviews current knowledge about Cumberland County's climate and climate hazards, how they are changing, and how they are likely to change in the future. The review is intended to serve as a resource for conversations about the risks we face and possible responses, and as an input to the initiative *Building Climate Resilience at Dickinson and in Central Pennsylvania*. While the focus of the review is on ways that climate may change in Cumberland County, local resilience planning efforts should also take into account changes beyond the County's borders that can impact County residents. For that reason, the review includes information about changing climate hazards at regional, national, and global scales.

Information for the review is drawn from credible, peer-reviewed scientific sources, which are cited in relevant places in the document. Key sources include the 6th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2021a), the 4th National Climate Assessment of the U.S. Global Change Research Program (USGCRP, 2017), and the 2021 Pennsylvania Climate Impacts Assessment from the Pennsylvania Department of Environmental Protection (PA DEP, 2021). Climate projections for Cumberland County are sourced from the same dataset used by the USGCRP for the 4th National Climate Assessment.

Much is known with a high degree of confidence about the changing climate. But there are uncertainties about the magnitudes, rates, and nature of the changes that will be experienced in specific times and places. To communicate levels of confidence and uncertainties, statements in the review about changes in the climate are qualified by the following language describing the estimated likelihood that a change will be realized. The language matches that used by the IPCC.

- *Virtually certain*: Likelihood is greater than or equal to 99%.
- *Extremely likely*: Likelihood is greater than or equal to 95%.
- *Very likely*: Likelihood is greater than or equal to 90%.
- *Likely*: Likelihood is greater than or equal to 66%.

How and Why is the Climate Changing?

The global climate warmed during the 20th century and early 21st century and is projected to continue to warm this century and beyond unless deep reductions are made in emissions of greenhouse gas pollutants. Warming has been, and will be, accompanied by other changes in climate such as increasing annual precipitation and changes in the frequencies and intensities of heavy rain events, heat waves, droughts, and severe storms. Collectively, the changes are referred to as climate change.

Climate is different from weather. Climate refers to average climate conditions and their variability over long time periods, typically multiple decades, that are regional or global in scope. Climate change refers to changes in climate over time. In contrast, weather refers to short-term meteorological conditions in a particular place, typically over hours, days, weeks, or seasons.

Climate scientists have documented changes in climate from the mid-1800s to the present using observations from thousands of weather stations and other sources. Different teams of scientists using different data sets and methods have found, universally, that globally averaged surface air temperatures have risen.

Drawing on multiple studies and datasets, the Intergovernmental Panel on Climate Change (IPCC) estimates that the global average surface temperature for the first two decades of the 21st century, 2001-2020, was 1.5 to 2.0°F higher than the average for the period 1850-1900.[1] The rate of warming since 1970 was faster than for any other 50-year period in at least 2000 years. Each of the last four decades has been successively warmer than the decade that preceded it and are warmer than any other decades since 1850. (IPCC, 2021a, p. 5 and p. 8).

Most of the recent observed warming has been attributed by scientific analyses to greenhouse gas pollutants such as carbon dioxide, methane, and nitrous oxide that are produced by burning fossil fuels and other human activities (IPCC, 2021a, p. 4-5). Annual emissions of these gases greatly exceed the capacity of Earth systems to remove them from the atmosphere. Consequently, concentrations of the gases are increasing in the atmosphere, where they absorb and reemit heat energy.

The atmospheric concentration of carbon dioxide has grown to its highest level in over 2 million years. Concentrations of methane and nitrous oxide are higher than they have been in over 800,000 years. Higher concentrations of these gases increase the capacity of the atmosphere to hold heat, which causes the climate to warm. These properties of greenhouse gases are readily measured and confirmed in laboratory and natural settings. The high present-day concentrations are exerting a powerful influence on the Earth's energy balance and climate. (IPCC, 2021a, p. 8-9).

Other potential causes of the warming observed in the late 20th and early 21st century, both natural and human, have also been investigated by research scientists. These include changes in the energy output of the sun, internal variability of the climate system from natural causes such as the El Nino Southern Oscillation and the Atlantic Multidecadal Oscillation, aerosols ejected into the atmosphere by volcanic activity, and aerosol pollutants from human activity.

Observations of changes in these and other potential drivers of climate change, as well as observations of changes in greenhouse gas concentrations, have been compared with observed patterns of temperature changes over time, geographic locations, and altitude. The comparisons have used multiple approaches and lines of evidence. They provide overwhelming empirical support for the conclusion that humans' emissions of greenhouse gases have warmed the climate and that greenhouse gases are very likely the primary cause of warming since 1979 (IPCC, 2021a, pp. 4 and 6-8).

Potential causes of warming other than greenhouse gas emissions from human activities have been shown

[1] The upper and lower estimates of warming represent a 90% confidence interval, meaning that there is a 90% likelihood that the true value lies within the estimated range and a 10% likelihood that it lies above or below the range.

to have had only very minor influences on climate, or to have had a cooling effect, for this period. Assertions that natural causes, not humans, are the primary cause of warming over the past 40 years are not supported by scientific evidence.

How Can We Anticipate and Plan for Future Climate?

We cannot know the future climate with certainty. Just as we cannot know with certainty what future social, economic, and technological changes will come. Yet, to make good choices and to manage risks effectively, we need to use the best information available to anticipate the range of plausible futures we may experience. One thing about which we can be confident is that the future climate will almost certainly be different from the present climate and the differences will be consequential for our wellbeing.

The information available to us to anticipate and plan for future climate includes observed climate trends, general understanding of the climate system, the carbon cycle, and social and economic systems, and projections of future climate produced with climate models. Drawing on each of these sources of information enables us to develop understanding of the ranges of plausible future climates for our region.

Recent observed trends indicate our climate has gotten warmer and wetter, with more frequent and extreme hot days and heavy rain days. The observed trends may continue and extrapolating them a few years into the future may give plausible scenarios of what the near future may bring. But there are many reasons why the path followed by the changing climate could diverge from recent trends, and extrapolations become more tenuous the further into the future we try to look.

We can supplement our knowledge of past trends with additional knowledge. From carbon cycle science, we know that the atmospheric concentration of carbon dioxide would be stabilized if global emissions were limited to a level that can be removed from the atmosphere by natural and human-engineered processes. An equal balance between emissions and removals is referred to as net zero emissions. But emissions and removals are not in balance, and we can be highly confident that the global economy will continue to produce carbon dioxide and other greenhouse gas emissions at levels above net zero for at least two decades and longer if deep reductions in emissions are not made soon. The result will be growing concentrations of greenhouse gases.

Further, from firmly established principles of physics, we can be nearly certain that the increases in atmospheric concentrations of greenhouse gases will cause further rises in surface temperatures averaged across the Earth and in most regions of the world, including Cumberland County. We can also infer from physical principles that it is very likely that our warmer future will have an intensified water cycle that would generate more annual rainfall, more frequent and more severe heavy rain events, and possibly more frequent and severe droughts and storms as well.

The above already gives an initial foundation from which to begin to think concretely about the future, investigate and weigh options for adaptation, and develop plans for building resilience. But if this was all we knew, we would be handicapped by uncertainties concerning the magnitudes and rates of change in specific places and time periods.

Projections of future climate from climate models are an additional source of information that helps reduce the uncertainties by quantifying potential magnitudes and rates of change in climate variables at global to local scales. Climate models are tested and have been found to demonstrate skill for simulating important aspects of the Earth's climate, including changes in large-scale patterns of temperature and precipitation, general characteristics of storm tracks and extratropical cyclones, and observed changes in global mean temperature and ocean heat content (USGCRP, 2017a, p. 142).

Climate models are not forecast tools. The models produce projections of future climate that are conditional on assumptions about future concentrations of greenhouse gases. A range of concentration pathways from low to high have been constructed to represent different possible futures for population, economic activity, technology, energy sources, and other factors. The concentration pathways are input to climate models to simulate future climate.

Projections of future climate differ for different greenhouse gas concentration pathways, with higher concentrations corresponding to projections of greater and more rapid changes in climate. Projections can also differ across climate models when they are run with a common concentration pathway. For some climate variables and regions, the differences can be small. For others they can be large, and sometimes the models can disagree on the direction of change for some variables in some locations. The differences reflect differences in how the models represent climate processes, incomplete data, and uncertainties in the underlying science.

This presents a problem for planning: which model projections are most appropriate to use? Some models perform better than others for some climate variables in some regions and less well for other variables or other regions. Because the models have different strengths and weaknesses, there is no consensus on whether some of the models have more overall skill than others and no consensus on whether some models should be preferred over others for planning purposes.

Because of the uncertainties and differences in model projections, it is typically recommended that ranges and medians of projections from multiple climate models be used for assessing climate change vulnerabilities and for planning adaptation and resilience strategies.

What Changes in Climate Should We Plan For?

Presented in this document are projections for Cumberland County of changes in average temperatures, extreme temperature events, average precipitation, heavy rain events, droughts, extreme storms, and compound weather events. The source of the climate projections for the County is the Cumberland County grid box from the Localized Constructed Analogues (LOCA) dataset of the U.S. Global Change Research Program (USGCRP, 2018). To provide context for the County climate projections, we also present observed trends and future projections at global, regional, and statewide levels.

The LOCA dataset includes climate projections from 32 global climate models downscaled to the county level for every county in the United States. It is the same climate projection dataset used by the USGCRP for the Fourth National Climate Assessment and by the Pennsylvania Department of Environmental Protection for the 2021 Pennsylvania Climate Impacts Assessment.

Changes are measured relative to baseline observations for 1971-2000 and are presented for three 20-year time periods: the near-term (2016-2035), mid-century (2046-2065), and late century (2076-2095). The time periods match those used in the Fourth National Climate Assessment and the Pennsylvania Climate Impacts Assessment.

The LOCA dataset includes projections for multiple pathways of future greenhouse gas emissions and concentrations. This review focuses on projections for Representative Concentration Pathway 8.5 (RCP 8.5), a scenario of high global emissions and concentrations.[2]

It is important to note that future greenhouse gas emissions and concentrations may be lower than is represented by the RCP 8.5 pathway. Should global efforts to reduce greenhouse gas emissions succeed in achieving or exceeding the international Paris Agreement goals, which is not guaranteed, climate change likely would be less than projected for the RCP 8.5 scenario (UNFCCC, 2015).

But even if commitments made under the Paris Agreement to reduce emissions are realized, if global emissions are not reduced to net zero, concentrations of greenhouse gases would continue to grow such that the climate changes presented in this review would still be realized, thought at later dates. Bearing this in mind, we focus on the high emission RCP 8.5 scenario to support planning and preparation for plausible futures that pose high-consequence hazards.

Ranges and medians of model projections for selected climate hazards for the RCP 8.5 scenario are presented below. The lower and upper ends of the ranges are the 10th and 90th percentile values projected by the 32 climate models included in the LOCA dataset. This means 80% of the model projections lie within the range for a hazard, 10% below the range, and 10% above. The median corresponds to the 50th percentile, with 50% of the projections lying below and 50% above the median value.

The ranges and medians provide characterizations of the degree of confidence, or uncertainty, that might be associated with the climate projections for planning purposes, keeping in mind that the projection ranges likely understate the scientific uncertainties, and that they are based on a high emission scenario.

[2] The LOCA dataset includes projections for four scenarios of future greenhouse gas emissions and resulting atmospheric concentrations, called Reference Concentration Pathways. The four concentration pathways were analyzed by the Intergovernmental Panel on Climate Change (IPCC) and are described in its Fifth Assessment Report. RCP 8.5 has the highest emissions and concentrations of the four pathways and would produce greater and more rapid climate change than the other pathways.

Higher Average Temperatures

As the global climate warmed in recent decades, so too did climates in the United States, Pennsylvania, and Cumberland County. In Pennsylvania, average temperatures were 1.2°F higher from 2000 to 2020 relative to the average for 1971-2000 (PA DEP, 2021, p. 5). Cumberland County experienced temperature increases at the rate of 0.2°F per decade over the time scale of 1895-2018 and the period July 2015 to June 2019 is the warmest 4-year period in the County going back to 1895 (Cumberland County, 2020, p. 41).

Looking to the future, global average surface temperatures and average surface temperatures in Eastern North America are *virtually certain* to increase, with increases growing progressively greater as greenhouse gas concentrations rise from the near-term, to mid-century, and to late century. For a high emission scenario, global average temperature is *very likely* to rise 4.4°F to 8.7°F by the end of the century relative to the period 1995-2014, with a central estimate of 6.4 °F.[3] (Seneviratne, 2021, pp. 218-223; IPCC, 2021a, p. 14).

Warming in the Northeastern United States is projected to be greater than the global average (USGCRP, 2017c, p. 197) and Cumberland County is expected to warm at a similar rate as the rest of the Northeast. Projected changes in annual average temperatures in Cumberland County for the RCP 8.5 high emission scenario are reported in Table 1 and displayed in Figure 1. Average temperatures in the County are projected to increase 2.0 to 3.8 °F in the near-term future (2016-2035) relative to the 1971-2000 baseline period, 4.3 to 7.2°F by mid-century (2046-2065), and 6.5 to 11.4°F by late century (2076-2095). The projected increases in temperature for the high emission RCP 8.5 scenario are substantial and likely exceed rates of warming experienced for thousands of years.

Extreme Temperature Events

The frequency and intensity of extreme hot weather events have increased on average globally and in most regions of the world since 1950, while extreme cold weather events have decreased. Heat waves have become more frequent and intense in most regions of North America, although the observed trends in

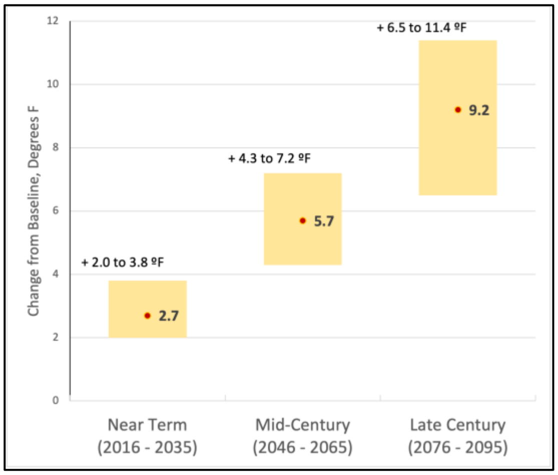
Table 1: Present and Future Temperature-Related Climate Hazards in Cumberland County, PA

Climate Hazard Indicators	Baseline Value (1971 - 2000)	Projected Changes					
		Near Term (2016 - 2035)		Mid-Century (2046 - 2065)		Late Century (2076 - 2095)	
		Median	Range	Median	Range	Median	Range
Average temperatures							
Average annual temperature (F)	50.0	2.7	2.0 to 3.8	5.7	4.3 to 7.2	9.2	6.5 to 11.4
Average annual maximum temperture (F)	59.9	2.8	2.0 to 3.7	5.9	4.2 to 7.8	9.1	6.6 to 12.2
Average annual minimum temperature (F)	40.1	2.7	1.9 to 3.9	5.7	4.4 to 7.2	9.0	6.7 to 11.1
Extreme Heat							
Days max temperature > 90 F (no. days per year)	6.7	16.1	8.2 to 25.7	40.0	23.4 to 53.4	69.7	40.6 to 88.8
Days max temperature > 95 F (no. days per year)	0.9	5.3	2.9 to 12.2	17.8	8.2 to 33.8	40.4	15.5 to 69.4
Days max temperture > 100 F (no. days per year)	0.0	1.0	0.4 to 3.2	4.5	1.4 to 16.7	15.8	3.3 to 45.3
Days min temperture > 68 F (no. days per year)	7.7	15.4	10.4 to 24.4	37.6	27.6 to 54.9	67.2	44.0 to 89.1
Extreme Cold							
Days below freezing (no. days per year)	128.0	-14.5	-22.8 to -9.2	-32.0	-46.3 to -22.0	-51.8	-69.4 to -38.9

Values in the table are the medians and 10th to 90th percentile ranges of projected changes relative to 1971-2000 baseline from the LOCA dataset of 32 global climate model simulations for the RCP 8.5 emissions scenario.

[3] Italicized descriptions of likelihood have the following definitions in the IPCC 2021 report: *virtually certain*, ≥ 99% probability; *extremely likely*, ≥ 95% probability; *very likely*, ≥ 90% probability; *likely*, ≥ 66% probability.

Figure 1: Projected Changes in Average Annual Temperature, Cumberland County, PA



Medians and 10th to 90th percentile ranges of projected changes relative to 1971-2000 baseline from LOCA dataset of 32 global climate model simulations for RCP 8.5 emissions scenario.

Eastern North America are weaker and less consistent than in other regions of North America. As global warming increases over the century, hot extremes will continue to increase in frequency and intensity in nearly all inhabited regions of the world. In Eastern North America, extreme heat events are *very likely* to increase in intensity and frequency by mid-century and are *virtually certain* to increase in intensity and frequency by late-century. (IPCC, 2021a, pp. 8 and 10; Seneviratne et al, 2021, pp. 1556-1557).

Changes in the number of very hot and extremely hot days per year can serve as an indicator of changes in exposure to extreme heat events. Focusing on Cumberland County, the number of days with maximum temperatures > 90°F shows a weak positive trend over the period 1971-2013 but the trend is not statistically significant. Days over 95°F occurred less frequently than once per year on average in the baseline period and no days were over 100°F.

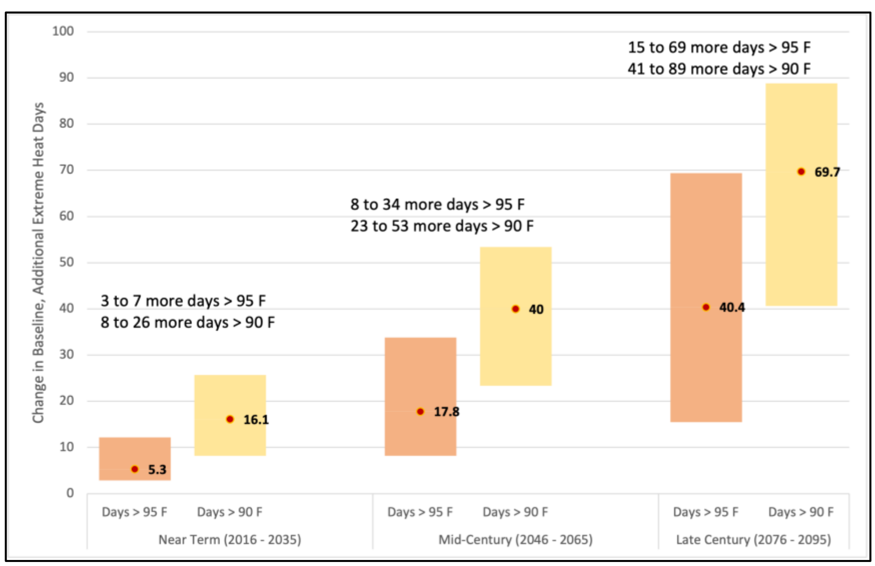
In the near-term future, the average number of days projected to exceed 90°F increases from 7 days per year in the baseline period to 15 to 33 days per year for the RCP 8.5 scenario. By mid-century temperatures are projected to exceed 90°F 30 to 60 days per year on average, and by late-century 48 to 96 days will exceed 90°F. The number of days exceeding 95 and 100°F per year are also projected to increase with each passing decade. Days over 100°F, which are absent in the historical baseline period, are projected to occur 3 to 45 days per year by late century. Projections for the different indicators of extreme heat events indicate a hot future in Cumberland County that will have more extreme heat events and extreme heat events will be hotter and longer. (Figure 2 and Table 1).

In contrast to heat events, extreme cold events are *very likely* to decrease in intensity and frequency by mid-century in Eastern North America and are *virtually certain* to decrease by late century (Seneviratne et al, 2021, pp. 218-223). In Cumberland County, freezing days, or days with daily minimum temperature below 32°F, occurred 128 days per year on average from 1971 to 2000. The number has decreased during that time period. As the climate warms, the average number of freezing days per year are projected to decrease to a range of 105 to 119 days per year in the near-term, 82 to 106 days per year by mid-century, and 58 to 89 days by late-century. (Table 1).

Greater Average Precipitation

Globally, average annual precipitation has increased since 1950, with greater increases since the 1980s. In the United States, average annual precipitation increased roughly 4% from 1901 to 2015, with regional differences that include northern areas

Figure 2: Projected Changes in Average Numbers of Days Per Year Above 90 °F and 95°F, Cumberland County, PA



Medians and 10th to 90th percentile ranges of projected changes relative to 1971-2000 baseline from LOCA dataset of 32 global climate model simulations for RCP 8.5 emissions becoming wetter and southern areas becoming drier. In Pennsylvania, average annual precipitation increased 4.6 inches, or roughly 10%, for the period 2000-2020 compared to 1971-2000. Average annual precipitation increased 4.7 inches, or 12%, in Cumberland County from 1971 to 2013, but the County trend is not statistically significant. (IPCC, 2021a, p. 5; USGCRP, 2017d, p. 216; PA DEP, 2021, p. 13).

Global average annual precipitation is projected to increase 1 to 13% by end of the century relative to 1995-2014 for the RCP 8.5 scenario. In Eastern North America, annual mean precipitation is *very likely* to increase, with increases growing progressively greater from near-term to mid-century to late century as the global climate warms. The projected increases are greater in winter and spring than other seasons. (IPCC, 2021a, p. 19; IPCC 2021b; USGCRP 2017d, p. 207).

Projected changes for Pennsylvania range from increases in precipitation of 2% to 14% by mid-century relative to 1971-2000, with a median projection of 8%. By late-century, the projections range from 3% to 18% increases, with a median projection of 12%. (PA DEP, 2021, pp. 19-20).

Average annual precipitation is projected to increase in Cumberland County (see Table 2). Near-term projections for average annual precipitation range from 0.2 to 13% increases, with a 6% median increase projected from a baseline of 45.2 inches to 47.8 inches. By mid-century, projected increases range from 2 to 16% and by late century they range from 4 to 22%.

Heavy Rain Events and Floods

Heavy precipitation has increased in frequency and intensity at the global scale and over most land regions that have good observational systems, likely due primarily to the rise in greenhouse gases in the atmosphere. Increases in frequency and intensity have been observed in most regions of the United States, with the largest increases occurring in the Northeast. In Pennsylvania, increases in heavy rain events have been observed at many sites and in Cumberland County the average number of days per year with over 1 inch of rainfall increased 2.8 days, almost 60%, from 1971 to 2013. (IPCC, 2021a, p. 8; USGCRP, 2017d, p. 207; PA DEP, 2021, p. 16).

Heavy precipitation events are projected to increase in frequency, intensity, and amount of rainfall at the global scale and for most regions of the world, with increases becoming greater for greater levels of warming. For global warming of 7.2°F, intensification of heavy precipitation events is *virtually certain* in North America and *very likely* for Eastern North America. Heavy rain events that occurred only once every 10 years on average (10% annual likelihood) or once every 50 years on average (2% annual likelihood) in the past are projected to double and triple in frequency with 7.2°F warming. (Seneviratne et al, 2021, pp. 1563-1567; USGCRP, 2017d, p. 207).

Table 2: Present and Future Precipitation-Related Climate Hazards in Cumberland County, PA

Climate Hazard Indicators	Baseline Value (1971 - 2000)	Projected Changes					
		Near Term (2016 - 2035)		Mid-Century (2046 - 2065)		Late Century (2076 - 2095)	
		Median	Range	Median	Range	Median	Range
Average Precipitation							
Annual precipitation (inches)	45.2	2.6 (6%)	0.1 to 5.6 (0.2 to 13%)	4.2 (9%)	1.1 to 7.1 (2 to 16%)	5.9 (13%)	2.0 to 9.7 (4 to 22%)
Extreme precipitation							
Very heavy rain days (no. days with > 0.8 inches rain)	11.3	1.7 (15%)	0.4 to 3.1 (3 to 27%)	2.7 (24%)	1.5 to 4.2 (14 to 38%)	4.0 (35%)	2.0 to 5.9 (18 to 52%)
Extremely heavy rain days (no. days with > 1.4 inches rain)	2.3	0.4 (18.0%)	0.1 to 1.0 (3 to 42%)	0.8 (36%)	0.4 to 1.5 (18 to 65%)	1.4 (60%)	0.7 to 2.2 (31 to 96%)
Drought							
Consecutive dry days, annual maximum (no. days)	13.1	0.25 (1.9%)	-.8 to 1.6 (-6 to 12%)	0.7 (6%)	-0.7 to 2.5 (-5 to 19%)	1.2 (9%)	-0.3 to 2.9 (-2 to 22%)
Consecutive dry days, maximum in 30 yr time horizon (no. days)	23.0	0.0 (0%)	-5.4 to 6.9 (-24 to 30%)	1.0 (4%)	-4.5 to 8.4 (-20 to 36%)	3.0 (13%)	-2.9 to 11.4 (-13 to 50%)

Values in the table are the medians and 10th to 90th percentile ranges of projected changes relative to 1971-2000 baseline from the LOCA dataset of 32 global climate model simulations for the RCP 8.5 emissions scenario

Extreme rainfall events are also projected to become more frequent and more intense in Pennsylvania (PA DEP, 2021, p. 15) and in Cumberland County (Table 2). Very heavy rain events are defined as events with rainfall volumes that occur less than 5% of the time. Extremely heavy rain events are defined as events with rainfall volumes that occur less than 1% of the time. The number of days in Cumberland County with very heavy rain, 0.8 inches or more, is projected to increase 14% to 38% by mid-century and 18% to 52% by late century. The number of days with extremely heavy rain, 1.4 inches or more, is projected to increase 18% to 65% by mid-century and 31% to 96% by late century. The volume of rain that falls in very heavy and extremely heavy rain events is also expected to increase.

Extreme rainfall events can result in river and flash flooding, particularly if they occur in winter and spring when high soil moisture, snow melt, and frozen ground can enhance runoff (USGCRP, 2017d, p. 240). With extreme rainfall frequency and volumes projected to increase in Cumberland County, the County could see an increase in the frequency and magnitude of flood events.

The frequency of exposure to flood events is already high in the County. From 1970 to 2020, 90 flood events were recorded in Cumberland County, several of which caused substantial damages and a dozen that were declared Presidential disaster emergencies. (Cumberland County Planning Department, 2020, pp 59-64). With a history of frequent flood events, coupled with projected increases in extreme rainfall events, it would be prudent to anticipate the potential for increased flood risks in the County.

Droughts

Increased evapotranspiration in a warming climate has increased the occurrence of agricultural and ecological drought over most land areas in the world for which there is sufficient observational data to evaluate. In the United States, some regions have experienced record intensity droughts in recent years, but evidence is limited and mixed for regional observed trends, including in Eastern North America. The megadrought afflicting the western United States is the driest 22-year period in at least the last 1200 years and over 40% of the soil moisture deficit is estimated to be attributable to human-caused climate change. (IPCC, 2021a, p. 8; Seneviratne et al, 2021, Table 11.21; Williams et al, 2022, pp. 232 and 234).

In the future, some regions of all inhabited continents except Asia are projected to experience more frequent and/or severe agricultural and ecological droughts if global average temperatures rise 2.7ºF. With greater warming, drought impacts would be amplified, and more regions would be affected. At 7.2ºF warming, about 50% of all inhabited regions would be affected by increases in agricultural and ecological droughts. (IPCC, 2021a, p. 24; Seneviratne et al, 2021, p. 1519).

Warming is *likely* to lead to increases in frequencies and severities of agricultural droughts in the continental United States. In Pennsylvania, an increase in drought conditions and reduced water availability are possible due to higher temperatures and evaporative demand, despite projected increases in average and extreme precipitation. (USGCRP, 2017e, pp. 237; PA DEP, 2021, p. 17).

Cumberland County experienced 49 declared drought watches, warnings, and emergencies from 1980 to 2020. Eleven of the declared droughts were designated as emergencies by the Governor of Pennsylvania and warranted water use restrictions and other measures to protect public health and safety. Based on past drought frequency and climate conditions, the County would be expected to experience 7 to 8 emergency drought events lasting two to four years per century (Cumberland County Planning Department, 2020, pp. 40-41). But conditions are projected to change in ways that may make droughts more frequent and severe, despite increases in average annual rainfall.

Projected changes in the number of consecutive days without rain range from -6% to +12% in the near-term, -5% to +19% by mid-century, and -2% to +22% by late-century (Table 2). The projected changes in the number of consecutive dry days per year, combined with the soil drying effects of higher future temperatures, signal the potential for more frequent and more severe droughts in the County.

Extreme Storms

Evidence of observed global trends in extreme storms such as tropical cyclones (hurricanes), convective storms (thunderstorms), and extratropical cyclones is limited and mixed. Rainfall volumes associated with tropical cyclones have increased, as have the proportion of tropical cyclones that reached high intensity categories 3-5, and the frequency of rapid intensification. Hurricane activity has increased in the North Atlantic since the 1970s but not in other regions. Rainfall associated with severe convective storms has also increased, but no changes have been detected in other features of convective storms such as tornadoes, hail, and severe winds. Evidence of regional changes in extratropical cyclones is limited.

(IPCC, 2021a, p. 9; Seneviratne et al, 2021, p. 1519 and 1592-1594; USGCRP, 2017f, p. 257).

Global warming is projected to have a variety of effects on extreme storms. Maximum wind speeds of tropical cyclones that form, the proportion that reach category 4-5 strength, and the amount of rainfall they generate are projected to increase in a warmer climate with high confidence, while the effect on the frequency of tropical cyclones is uncertain. (IPCC, 2021a, p. 16; Seneviratne et al, 2021, p. 1519).

At the global scale, the intensity of precipitation produced by convective storms is projected to increase with high confidence and conditions will be more favorable to the formation of severe convective storms. However, the consequences for the frequencies of convective storms are uncertain and will vary by region. Studies for the United States project more frequent severe convective storms in the spring and a longer storm season. (Seneviratne et al, 2021, p. 1597).

Hundreds of severe windstorms with sustained winds of 40 mph or greater for one hour or more, or winds of 58 mph or greater for any duration, have impacted Cumberland County since 1950. These include hurricanes, tropical storms, and Nor'easters, which can impact very large areas extending hundreds to thousands of miles, and thunderstorms and tornados that are usually more localized in their impacts. (Cumberland County Planning Department, 2020, pp 78-87; 103-113). These storms can produce substantial damages from high winds, heavy rain, and flooding. Statewide, Pennsylvania has experienced 45 storm events from 2000 to 2020 that each produced over $1 billion in damages (PA DEP, 2021, p. 25).

Historically, the annual probability of Cumberland County experiencing windstorms with wind speeds equal or greater in strength to tropical storms (over 39 mph) is > 90% and the probability for storms to produce winds equal or greater than category 1 or 2 hurricanes (78-118 mph) is > 8%. For winds equal to major hurricanes, categories 3-5 (> 118 mph), the annual probability is less than 0.1%. (Cumberland County Planning Department, 2020, p. 85).

Warming of the climate may change and amplify these risks, but it is uncertain whether the frequencies and severities of extreme storms in Cumberland County would follow patterns projected at the global scale. Planning should recognize that current exposure to severe storms is high and there is significant potential for more damaging storms in the future with stronger winds and greater rainfall.

Compound Weather Events

Compound weather events are the occurrence of two or more weather events at the same time and place, in close succession, or in close geographic proximity that pose societal and environmental risks. The events combine to stress coping capacities and can produce highly amplified impacts. Examples include concurrent heat waves and droughts; high humidity heat waves; hot, dry, and windy conditions that combine to create fire weather; extreme rainfall, river flow and/or coastal storm surge that combine to cause compound flood events; concurrent cyclones and thunderstorms; and hot, stagnant weather conditions that create hazardous air quality.

The probability of some types of compound weather events has *likely* increased in recent decades and is *likely* to increase further with global warming. Increases have been observed in concurrent heatwaves and droughts globally, fire weather in some regions, and compound flooding in some locations. Further increases are projected at global scale in the future with high confidence for these compound events. (Seneviratne, 2021, pp. 1519-1520 and 1598-1600).

Understanding and analysis of compound events is an emerging area of research and information is sparse for assessing the likelihood for changes in compound events and their potential impacts in Cumberland County. Heat waves with drought, high humidity heat waves, compound flooding, fire weather, and weather that produces hazardous air quality all pose the potential for substantial risks to County residents, businesses, and resources that warrant further evaluation. As demonstrated by the Canadian wildfires of summer 2023, and the hazardous air quality they generated for our region, even distant compound events can impact residents of Cumberland County.

Changing Climate Exposures in Cumberland County

Residents of Cumberland County are currently exposed to many climate hazards. Global climate change is changing our exposures. Some of the changes can be anticipated with high confidence, while others are less certain. In Table 3 we synthesize the information presented in this review to

Table 3: Climate Hazard Exposures and Changes in Cumberland County, PA

Climate Hazard	Current Exposure	Projected Change in Exposure	Confidence in Projected Change	Key Features of Changing Climate Hazards
Higher Average Temperatures	Very High	Increase	Very High	Exposure to rising average temperatures is already very high in the County and will increase throughout the century. Average temperatures are projected to rise at rates greater than experienced in 1000s of years.
Extreme Heat Events	Very High	Increase	Very High	Exposure to extreme heat events is already very high in the County and will increase throughout the century. The number of very hot and extremely hot days per year are projected to increase in frequency and intensity in the County, with greater increases projected the more the global climate warms.
Extreme Cold Events	Very High	Decrease	Very High	Exposure to extreme cold events is very high in the County, will decrease throughout the century, but will still be very high at century's end. The number of days below freezing are projected to decrease in frequency in the County, with greater decreases projected the more the global climate warms.
Higher Average Precipitation	High	Increase	High	Exposure to increasing average annual precipitation is high in the County and very likely will increase throughout the century. Average annual precipitation is projected to increase in the County, with greater increases projected the more the global climate warms.
Heavy Rain Events	Very High	Increase	High	Exposure to extreme precipitation events is already very high in the County and very likely will increase throughout the century. Heavy rain events are projected to increase in frequency and intensity in the County, with greater increases projected the more the global climate warms.
Floods	Very High	Increase	Low	Exposure to floods is very high in the County. Projections of more frequent and more intense heavy rain suggest flood exposures may increase in future but floods are complex events that have multiple contributing factors.
Droughts	Low	Increase	Low	Exposure to emergency drought events is low in the County but may increase. Consecutive dry days are projected to increase modestly in the County. Rising temperatures are expected to dry soils and increase the potential for more intense droughts, with drought potential increasing the more the global climate warms.
Extreme Storms	Very High	Increase	Low	Exposure to extreme storms is very high in the County and may increase. Greater wind speeds and greater rainfall are projected for tropical cyclones and thunderstorms; thunderstorms are projected to increase in frequency in U.S.; magnitudes of changes may increase the more the global climate warms.
Compound Events	Unknown	Increase	Very Low	Some types of compound events are projected to increase at global and regional scales. Data and projections are not available for the County but there is potential for compound events to increase in frequency and severity in the County.

characterize current exposures to selected climate hazards, projected changes in exposures, confidence in the projections, and key features of the hazards for a future with high emissions of greenhouse gases. While the review highlights quantitative climate projections for the RCP 8.5 scenario, a high scenario of greenhouse gas emissions and concentrations, the qualitative conclusions presented in Table 3 are valid for scenarios with lower emissions and concentrations.

Current exposure to each hazard is rated from very low to very high. Confidence in projected changes is also rated on a scale from very low to very high. Both scales are presented in the Appendix.

The County is virtually certain to be hotter in the future and extreme heat events will be more frequent and intense with each passing decade. In contrast, extreme cold events are virtually certain to decrease.

The County is very likely to be wetter in the future, is very likely to experience more frequent and more intense heavy rain events and may experience increased flood risks. Droughts may increase in frequency and severity as the number of days without rain increase and rising temperatures enhance the drying of soils. Wind speeds and rainfall volumes associated with tropical cyclones and thunderstorms and the frequency of thunderstorms are projected to increase at global scale and changes in the County may follow the projected global trend.

Some types of compound events are projected to increase in frequency and severity at global scale, which suggests the potential for increases in the County. But their potential has not been formally examined.

In summary, County climate hazards are expected to grow in magnitude from the near term, to mid-century, and into late century as the global climate warms. The changes threaten our wellbeing, now and in the future. The next phase of the climate resilience initiative will evaluate vulnerabilities to the changing hazards presented in this review, to be followed by investigation of strategies for limiting harms by adapting and building resilience to climate change. These actions need to be accompanied by deep reductions in regional, national, and global emissions of greenhouse gases that are driving climate change.

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Appendix: Rating Scales for Exposures and Confidence Levels

Rating scales used in constructing Table 3 are presented below.

Rating Scale for Climate Hazard Exposures

Exposure	**Score**	**Criteria**
Very High	5	Annual likelihood ≥ 90%. Likely to occur in 18 or more years during a 20-year time period.
High	4	Annual likelihood between 66% and 90%. Likely to occur in 13 to 17 years during a 20-year time period.
Medium	3	Annual likelihood between 33% and 66%. Likely to occur in 7 to 13 years during a 20-year time period.
Low	2	Annual likelihood between 5% and 33%. Likely to occur in 1 to 6 years during a 20-year time period.
Very Low	1	Annual likelihood less than 5%. Likely to occur less than once during a 20-year time period.

Rating Scale for Confidence Levels for Projected Changes

Confidence level	Criteria
Very high	Agreement across all 32 climate model projections for Cumberland County; consistent with projections for Pennsylvania and Northeastern United States; projected trend is strongly supported by accepted understanding of climate processes.
High	Agreement across 10^{th} to 90^{th} percentile of 32 climate model projections for Cumberland County; consistent with projections for Pennsylvania and Northeastern United States; projected trend is strongly supported by accepted understanding of climate processes.
Medium	Median projected trend for Cumberland County is consistent with projections for Pennsylvania and Northeastern United States but 10^{th} to 90^{th} percentile range includes projections opposite in direction of median projection; median projected trend is generally supported by accepted understanding of climate processes.
Low	Median projected trend for Cumberland County is consistent with global and large regional scale projections but range of projections are mixed for the County, Pennsylvania, and/or Northeastern United States; median projected trend is generally supported by accepted understanding of climate processes.
Very low	Model projections are very mixed, very limited, or not available; projected trend is consistent with but not conclusively supported by accepted understanding of climate processes.