

Pennsylvania Climate Impacts Assessment



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Department of
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Pennsylvania Climate Impacts Assessment 2024

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Contents

Executive Summary	1
CHAPTER 1: Introduction	7
1.1 Purpose and Objectives	7
1.2 Scope	9
CHAPTER 2: Expected Climate Changes in Pennsylvania	10
2.1 Key Findings	10
2.2 Overview of Key Updates	11
2.3 Temperature Changes	12
2.4 Precipitation Changes	22
2.5 Coastal Changes	32
2.6 Extreme Weather Events	36
2.7 Landslides and Sinkholes	38
2.8 Climate Change Attribution Science and Extreme Weather in Pennsylvania	38
2.9 Climate Change Impacts Outside of Pennsylvania	40

CHAPTER 3: Risk Assessment Overview	42
3.1 Key Findings and Overall Climate Risks	42
3.2 Approach Overview	50
CHAPTER 4: Spotlight Issues	53
4.1 Flooding Impacts to Air Quality and Health	53
4.2 Heat Impacts to Occupational Exposure and Public Health	59
4.3 Climate Change Impacts to Energy Resilience	66
CHAPTER 5: Economic Opportunities	75
5.1 Climate Adaptation and Economic Opportunities	75
5.2 Agriculture	76
5.3 Outdoor Recreation	78
5.4 Energy Production & Transition	79
5.5 Potential Housing Pricing Impacts	81

CHAPTER 6: Conclusions and Recommendations	82
6.1 Adaptation Priorities	82
6.2 Opportunities to use Mitigation and Adaptation Strategies for Economic Benefits	83
6.3 Equity Considerations	83
6.4 Continued Research Needs	83
APPENDIX A: Risk Assessment Methodology	85
APPENDIX B: Risk Assessment Details	92
Increasing Average Temperatures	93

Heavy Precipitation and Inland Flooding	103
Heat Waves	115
Landslides	126
Sea Level Rise	136
Severe Tropical and Extra-Tropical Cyclones	143
APPENDIX C: Climate Analysis Details	151
Endnotes	162

Table 1. Glossary of key terms

Term	Definition
Adaptation	The process of adjusting to the effects of climate change to build long-term resilience. Adaptation may include changing behavior, adapting infrastructure, supporting natural systems and more.
BIPOC	Black, Indigenous, and people of color (BIPOC); this is a term for certain ethnicities that are a minority within the United States.
Climate hazard	Changes or events related to global climate change. Climate hazards can be discrete (e.g., severe storms) or ongoing (e.g., increasing average temperatures).
Consecutive dry days	Number of days in a row when precipitation is equal to 0 mm.
Consequence	A measure of the severity of impacts from a climate hazard.
Cooling degree days (CDD)	Cumulative degree difference between average daily temperature (Tavg) and 65°F when Tavg > 65°F.
Critical threshold	A defined tipping point for an ongoing hazard at which significant impacts occur.
Environmental Justice (EJ) areas	A geographic area characterized by increased pollution burden, and sensitive or vulnerable populations based on demographic and environmental data. EJ areas in Pennsylvania are defined through DEP's EJ Policy at the census block group level in the PennEnviroScreen tool based on more than 30 environmental, health, and socioeconomic indicators.
Emission scenario	Used for representative concentration pathway to describe scenarios of projected greenhouse gas emissions and atmospheric concentrations used in climate modeling.
Exposed areas	Geographic areas projected to be affected by climate change based on climate change projections.
"Extremely hot" temperature	99 th percentile maximum daily temperature reported in degrees.
Growing degree days (GDD)	Cumulative degree difference between average daily temperature (Tavg) and 50°F when Tavg > 50°F.
Heating degree days (HDD)	Cumulative degree difference between average daily temperature (Tavg) and 65°F when Tavg < 65°F.
Likelihood	The probability or expected frequency a climate hazard is expected to occur.
Mitigation	There are two types of mitigation: greenhouse gas mitigation, or the reduction in greenhouse gas emissions that drive global climate change, and hazard mitigation, the investment in physical or operational strategies to reduce known vulnerabilities and risks.
Shared Socioeconomic Pathways (SSPs)	Scenarios of projected greenhouse gas emissions, socioeconomic situations, and atmospheric concentrations used in climate modeling. SSP 5-8.5 represents a global "unabated" scenario and SSP 2-4.5 represents a lower, "middle of the road", emission scenario.
"Very hot" temperature	95 th percentile maximum daily temperature reported in degrees.
Vulnerable populations	Populations more likely to experience adverse impacts from exposure to climate hazards because of demographics factors (e.g., race, gender), socioeconomic status, and life- or livelihood-sustaining needs (e.g., dependence on electricity for critical medical care).
3-day precipitation	Largest total precipitation gotten over the course of three consecutive days. The value is calculated for a given time period (e.g., season or year).



Executive Summary

Climate change is already affecting Pennsylvania. From intense storms and floods to air quality emergencies, climate change is influencing weather events and is posing serious economic, health, and equity impacts across the Commonwealth. The Pennsylvania Climate Change Act (Act 70 of 2008) requires the Department of Environmental Protection to update the Climate Impacts Assessment and Climate Action Plan regularly. This report provides this update of the Climate Impacts Assessment for 2024 and reviews current scientific findings and climate projections to identify relative risks which can be used to inform priority adaptation needs in the Climate Action Plan. This report is not a comprehensive or prescriptive assessment of all potential climate risks and impacts to Pennsylvania.

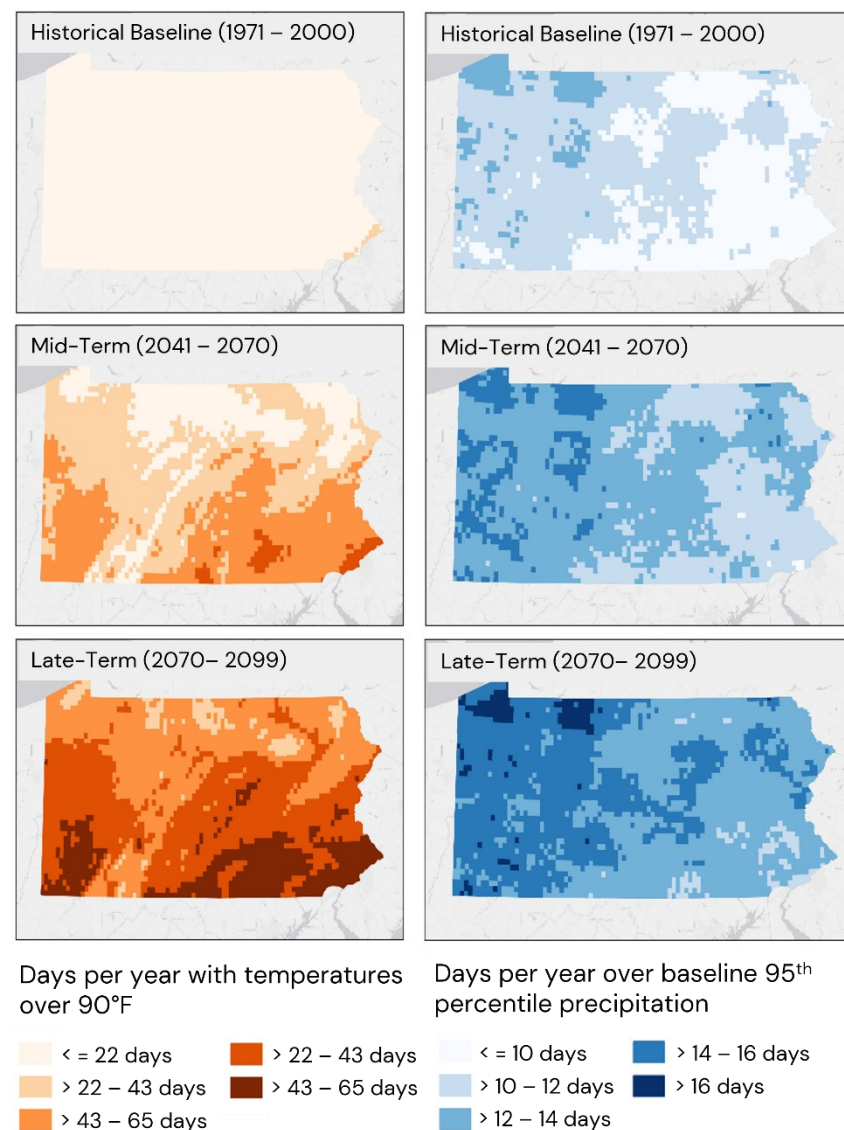
Projected Climate Changes

The 2024 Climate Impacts Assessment presents climate projections based on the latest available downscaled climate model data. These projections have been updated from prior versions of this report, and the situation for Pennsylvania remains the same: Pennsylvania is expected to get hotter with dangerous heat waves and droughts while at the same time experiencing more intense storms and damaging flooding. There will also be changes along its coastlines, including those of the Delaware Valley Estuary and Lake Erie.¹ Many impacts will be felt statewide, while other hazards will impact regions

By mid-century, key expected changes compared to a historical 1971–2000 baseline of climate conditions include:

- The average annual temperature statewide is rising, and is expected to increase by 6.7°F (3.7°C).
- There will be more frequent and intense extreme heat events. For example, temperatures are expected to reach at least 90°F on 36 days per year, up from the five (5) days during the historical baseline period (see **Figure 1**). The number of days reaching temperatures above 95°F and 100°F will become more frequent as well.
- Increasing temperatures will continue to alter the growing season and increase the number of days that people need to cool their homes and workspaces, but will also decrease the number of days that people will need to use heating.
- Pennsylvania is expected to receive more total average rainfall, occurring in less frequent but heavier rain events. Extreme rainfall events are projected to increase in magnitude, frequency, and intensity (**Figure 1**) and drought conditions are also expected to occur more often.
- Tidally-influenced flooding is expected to increase in the Delaware Estuary Coastal Zone due to sea level rise and storm surge from more intense storm events.
- Lake Erie is also expected to undergo significant changes in water level, coastal erosion, and water temperature.
- Increasing average temperatures and extreme heat events could affect nearly every aspect of life in the Commonwealth, from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment.

Figure 1. Observed and projected annual days with temperatures above 90°F (left) and “very heavy” precipitation (right)



Temperature and precipitation projections based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5-8.5.

Key Terms

Risk—The chance a climate hazard will cause harm. Risk is a function of the likelihood of an adverse climate impact occurring and the severity of its consequences (e.g., Risk = Likelihood x Consequence).

Climate hazard—Changes or events related to global climate change. Climate hazards can be discrete (e.g., severe storms) or ongoing (e.g., increasing average temperatures).

Impact—The effect of a climate hazard.

Likelihood—The probability or expected frequency a climate hazard is expected to occur.

Consequence—A measure of the severity of impacts from a climate hazard.

EJ areas—A geographic area characterized by increased pollution burden, and sensitive or vulnerable populations based on demographic and environmental data. EJ areas in Pennsylvania are defined at the census block group level based on more than 30 environmental, health, and socioeconomic indicators.

Risk Assessment Approach

This Impacts Assessment evaluates the likelihood and consequences of six climate hazards:

- Increasing average temperatures
- Heavy precipitation and inland flooding
- Heat waves
- Landslides
- Sea level rise
- Severe tropical and extra-tropical cyclones.

The assessment focuses on how climate change is impacting hazards at mid-century and end-of-century at the state level and takes into consideration regional variations (e.g., urban or rural,

proximity to waterways), as well as the economic, health, and equity considerations of these impacts. The assessment examines the severity of consequences in the following categories:

- Human health
- Environmental justice and equity
- Agriculture
- Recreation and tourism
- Other economic activity
- Forests, ecosystems, and wildlife
- Built infrastructure

The Impacts Assessment also includes an analysis of environmental justice (EJ) and equity considerations as climate change can impose a disproportionate burden on the most vulnerable communities and populations in society. The assessment evaluates impacts within Department of Environmental Protection (DEP) defined EJ areas which include more than 30 environmental, health, and socioeconomic indicators to evaluate a range of factors that could drive differential or inequitable distribution of climate impacts in communities across the state.

Climate Risk Assessment Results

The risk assessment revealed several key findings:

- Flooding is currently the highest-risk hazard facing Pennsylvania, and flood risks are projected to increase. At the same time, risks from increasing average temperatures and heat waves could rise to be as high as flooding is today by mid-century.
- Flooding from heavy rain events affects built infrastructure, human health, and agriculture, with ripple effects throughout the economy.
- Heat waves will become increasingly common and will create particular health and economic risks for vulnerable populations,

including low-wealth and low-income populations, the elderly, pregnant people, people with certain mental health conditions, outdoor workers, and those with cardiovascular conditions. These risks will be particularly acute in areas subject to the urban heat island effect and for populations without access to air conditioning.

- Landslides and sea level rise pose relatively low risks statewide but can cause severe impacts in the locations where they occur. For example, sea level rise in the Delaware Estuary could drastically change the estuary’s ecology and threaten the built infrastructure near the tidal zone. Landslides cutting off critical transportation routes can have severe consequences, particularly in rural areas.
- Severe tropical storms, flooding, and landslides already pose risks, and these could become more likely or severe in the future. Pennsylvania has an opportunity to build on its existing hazard mitigation practices for these risks.
- Climate change will not affect all Pennsylvanians equally. Some may be more at risk because of their location, socioeconomic status, housing situation, health vulnerabilities, or other factors. Pennsylvania should also take care that these inequitable impacts are addressed and that adaptation efforts do not inadvertently exacerbate inequities.
- For gradual onset climate changes, such as rising average temperature, Pennsylvania has an opportunity not only to reduce potential harm, but also to capitalize on potential positive changes. This is particularly true for rising average temperature, which could enable the cultivation of warmer-weather crops during an extended growing season, expansion of the warm-weather recreation and tourism economy, and reduced wintertime heating energy demand.

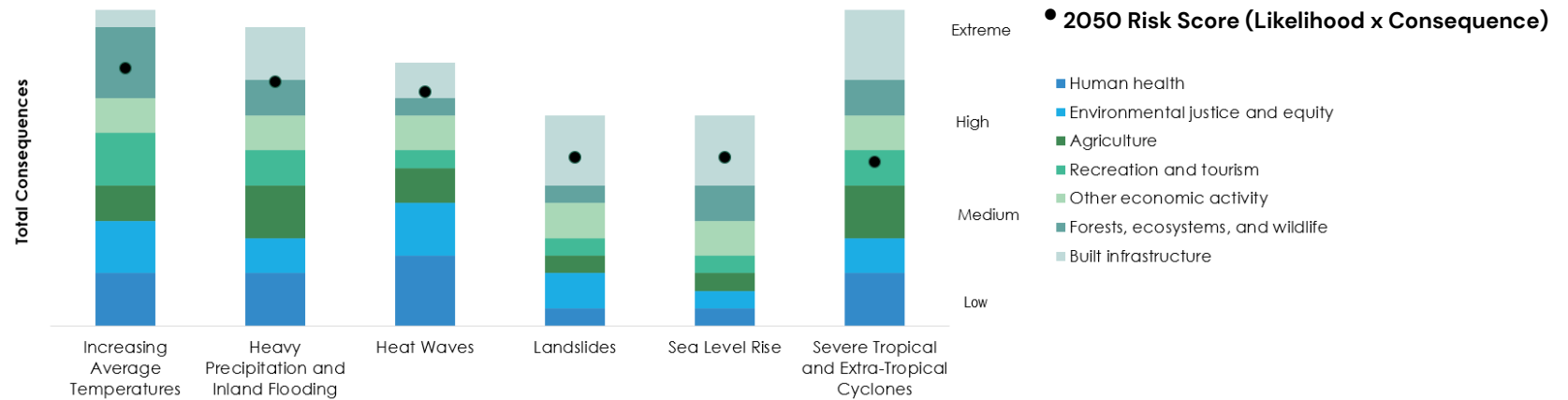
Climate Impact Spotlights

New for the 2024 Climate Impacts Assessment are spotlights on key issues affecting the Commonwealth. Climate change induced changes such as severity of storms, floods, winds, heat, and increased frequency of landslides and sinkholes are likely to have cascading effects. The three spotlights, summarized in **Table 2**, describe some of these cascading effects on human health and the built environment.

Table 2. Key issue spotlight summaries

Hazard	Threat	Differential Impacts
Flooding impacts to air quality and health		
Flooding poses a threat to human health	<ul style="list-style-type: none"> • Deep and quickly moving flood waters • Cascading impacts to air quality and health • Disease from contaminated drinking water or other sources 	EJ communities have higher flood risks
Heat impacts to occupational exposure and public health		
Air pollution, increasing extreme heat events, and extended heat waves can stress the human body and cause long-term harm to the heart and lungs	<ul style="list-style-type: none"> • Dehydration, heat cramps, heat exhaustion, heatstroke, and hyperthermia. • Accidental injury, particularly in outdoor workplace 	<ul style="list-style-type: none"> • Outdoor workers (27% of Pennsylvania’s workforce) are more exposed • People over the age of 65 are more at risk • Pregnant people and fetuses are more vulnerable
Climate change impacts to energy resilience		
More extreme weather will make power outages more frequent, widespread, and disruptive	<ul style="list-style-type: none"> • Physical damage to grid infrastructure • High temperatures may overload the grid and cause blackouts • Power outages occurring at the same time as extreme heat or cold can expose individuals to climate hazards 	Low-income communities are disproportionately impacted and experience more frequent blackouts

Figure 2. Total consequences by hazard (sorted lowest to highest overall risk)



Economic Opportunities

The impacts of climate change may also provide positive opportunities for Pennsylvania. Climate adaptation and mitigation investments may also represent an opportunity to drive economic growth and equity in the Commonwealth.

- In agriculture, farmers can explore new streams of income by situating renewable energy installations, such as solar arrays, on less productive farm property and by taking advantage of the federal investments in carbon sequestration. Farmers may benefit from some additional crop yields and more agricultural jobs that come from a longer growing season.
- Communities can build outdoor recreation opportunities as climate change increases the length of the warm-weather season. Investment in green spaces can create jobs for locals to manage green projects in their area while increasing equitable access to nature, improving stormwater management, and reducing the urban heat island effect.

- Transitioning to low-carbon energy sources can provide research and development jobs while providing new streams of income for property owners hosting clean energy projects. These adaptation measures can lower energy costs to residents and businesses.

As Pennsylvania invests in projects to adapt to climate change, an emphasis on equity is necessary to ensure that adaptation benefits reach the most vulnerable communities.

Conclusions and Recommendations

Increasing average temperatures and heavy precipitation and inland flooding emerged as the two highest-risk hazards by mid-century. Both hazards could affect the entire state and all sectors (**Figure 1** and **Figure 2**). Increasing temperatures have the highest consequences for human health and for environmental justice and equity, especially in urban areas. Heavy precipitation and flooding could also have severe consequences for human health, agriculture, and built infrastructure, with populations, farms, and infrastructure located in or near floodplains particularly at risk.

Climate hazards can affect human health, alter the built environment, and limit access to care and resources such as electricity that individuals have come to rely on. The direct and indirect impacts of climate hazards do not dissipate after a hazardous event but continue to have far reaching impacts long after the fact.

Climate change does not affect all Pennsylvanians equally, and this was a focus throughout this risk assessment. Some communities may be more vulnerable to impacts because of their location, and some populations may be more at risk because of housing, health, socioeconomic, or other factors. Certain populations have greater physical exposure to risks (e.g., outdoor workers may be more exposed to heat waves) or have limitations on their ability to manage consequences if they occur (e.g., low-wealth may hinder ability to pay for air conditioning and low-wealth communities may not have equal capacity to apply for resilience-building grants). Consequences of historical discriminatory practices in BIPOC (Black, Indigenous, and people of color) communities (e.g., redlining, disinvestment) remain manifest today, with BIPOC communities disproportionately living in housing that is particularly susceptible to climate hazards.

Climate risks and related impacts in Pennsylvania could be severe, potentially causing increased infrastructure disruptions, higher risks

to public health, economic impacts, and other changes, unless actions are taken by the Commonwealth to avoid and reduce the consequences of climate change.

As Pennsylvania works to respond to climate change, it has an opportunity to take advantage of adaptations to adapt and build new industries and workforces. These opportunities may take the form of shifts in agricultural practices, built environment projects that revitalize communities, or building renewable energy infrastructure to power a green transition. Pennsylvania can use this as a chance to reinvest in communities that are the most vulnerable to climate change and that have been previously overlooked in development. Such an investment would mirror nationwide efforts under the Justice40 initiative to ensure that 40 percent of federal investments responding to climate change are dedicated to such communities.²

Climate risks will continue to grow and change beyond mid-century. Although this assessment focuses on the likelihood and consequences of each hazard in the mid-century time horizon, Pennsylvania must also consider risks for infrastructure and other planning processes that require assumptions about conditions in the late 21st century and beyond.



CHAPTER 1

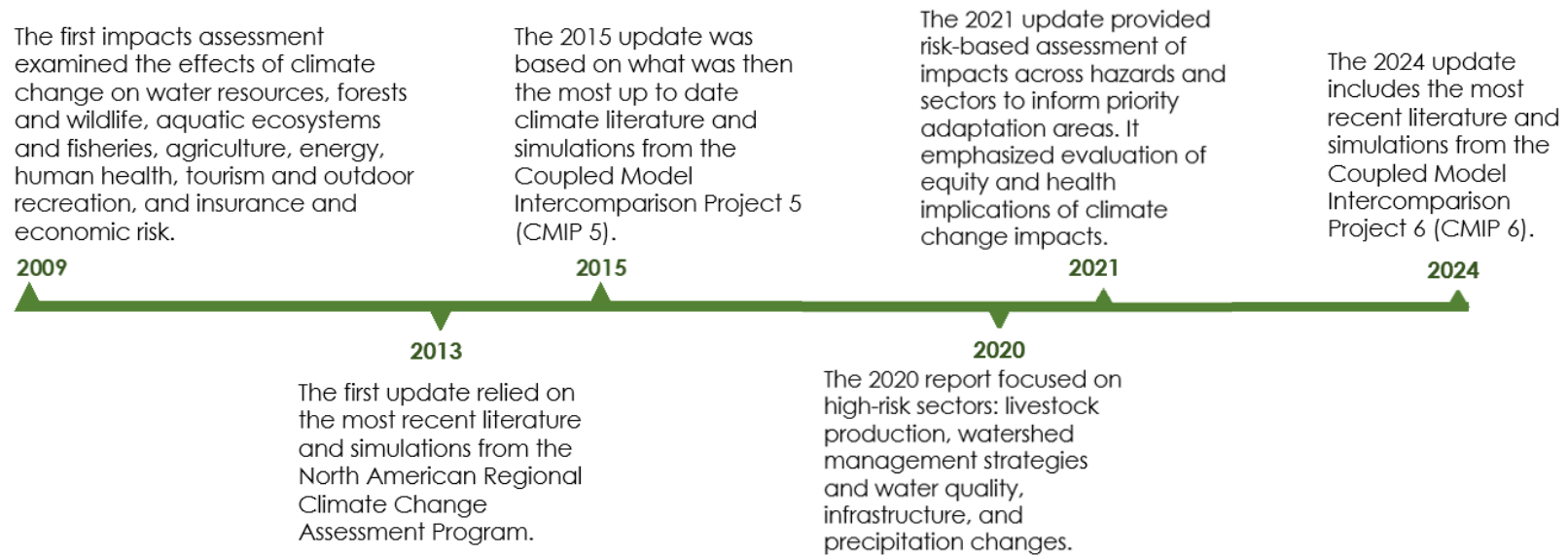
Introduction

1.1 Purpose and Objectives

The Pennsylvania Climate Change Act (Act 70 of 2008) requires Pennsylvania to improve its understanding of, and approach to, addressing and adapting to the causes and impacts of climate change. The Act requires the Pennsylvania Department of Environmental Protection (DEP) to update the Pennsylvania Climate Impacts Assessment (Impacts Assessment) and Climate Action Plan (CAP) regularly. Impacts assessments provide an understanding of the state of the science concerning the range of significant climate change hazards facing Pennsylvania, such as flood events and increasing temperatures. **Figure 3** summarizes the impacts assessments completed and in progress.

Climate change impacts create a variety of risks across sectors, resources, and populations. The 2024 Impacts Assessment is designed as a risk-based assessment to directly inform the CAP by helping decision makers identify meaningful and prioritized adaptation actions.

Figure 3. Timeline of Pennsylvania Climate Impacts Assessments



This Impacts Assessment presents impacts by hazard (e.g., increasing average temperatures, sea level rise) rather than by sector, as was done in past impacts assessments. Each hazard is then broken down by consequence category to allow for easier prioritization and comparison between different climate risks. The consequence categories in this assessment align with the sectors specified in Act 70 and key concepts addressed in the CAP:

- Human health
- Environmental justice and equity
- Agriculture
- Recreation and tourism
- Other economic activity
- Forests, ecosystems, and wildlife
- Built infrastructure

To evaluate the environmental justice and equity impacts for each hazard, this 2024 Impacts Assessment includes analysis that seeks to answer two key questions:

- What populations may be most vulnerable to climate hazards?
- To what extent are climate changes projected to affect communities that are already overburdened with environmental, economic, health, or other concerns?

Finally, in this 2024 Impacts Assessment, the assessments include supplemental discussion and analysis of three spotlight issues that have been relatively less understood or under-studied in previous iterations of the Impacts Assessment: Flooding, Air Quality and Health impacts; Heat and Public Health; and Climate Change and Energy Resilience.



Scope of Impacts Assessment

This Impacts Assessment focuses on impacts of climate change that occur within the borders of Pennsylvania; however, climate changes outside of our borders can still have effects within the Commonwealth. These are discussed in Section 2.9 and highlighted in call-out boxes or throughout the Impacts Assessment as appropriate.

Overall, the Impacts Assessment's risk-based method produces a prioritized list of risks and impacts. It also identifies the relative timing and severity of expected impacts. These outputs directly inform priority adaptation strategies in the CAP and the lead times needed for adaptation.

1.2 Scope

The Impacts Assessment and risk assessment ratings focus on mid-century (2050) risks at the state level, with discussion of regional variations (e.g., urban or rural, proximity to waterways), populations, industries, or other areas disproportionately affected. Although risks are evaluated and rated from present-day to mid-century, the assessment also describes potential impacts through the 21st century and provides climate projections for late in the 21st century (2090).

The Impacts Assessment evaluates risks posed by climate change for the following hazards:

- Increasing average temperatures
- Heavy precipitation and inland flooding
- Heat waves
- Landslides
- Sea level rise
- Severe tropical and extra-tropical cyclones

The six selected hazards represent the hazards expected to affect the Commonwealth most significantly. Other hazards noted in previous impacts assessments (short-term drought, saltwater intrusion, sinkholes, snowstorms and snow cover, and stormwater management) are folded into the selected hazards where appropriate but are not covered in depth.

The glossary in **Table 1** defines the key terms used throughout the report. [APPENDIX A](#) provides more details on the risk assessment process and the approach to analyzing environmental justice and equity impacts. [APPENDIX B](#) provides the full detailed risk assessment, with detailed evaluations of impacts by hazard and consequence type. Finally, [APPENDIX C](#) provides additional information on the climate data analysis, including detailed methodology and additional data.



CHAPTER 2

Expected Climate Changes in Pennsylvania

2.1 Key Findings

The climate projections presented in this chapter could have significant impacts across the Commonwealth that are discussed at length in the remainder of this document.

The latest climate projections reinforce conclusions from prior impacts assessments that Pennsylvania is expected to continue to experience an impactful **increase in both temperature and serious precipitation events** over the coming decades. The critical increases in average temperatures will translate to **more frequent and dangerous heat events**, such as the heat waves experienced in the summer of 2023. Precipitation patterns are also expected to change, resulting in **periods of drought** as well as more frequent or **extreme heavy rain events**, which can cause more frequent and extreme flooding. **Coastal flooding** will also continue to increase in Pennsylvania's coastal areas, both in the Delaware River and Estuary and along Lake Erie.

2.2 Overview of Key Updates

The 2024 Pennsylvania Climate Impacts Assessment is based on updated climate projections that leverage the latest Global Climate Model (GCM) data for the state of Pennsylvania. These present updated climate projections based on the latest available downscaled climate model data. These projections are calculated using the Localized Constructed Analogs Version 2 (LOCA2) downscaled Coupled Model Intercomparison Project Phase 6 (CMIP6) Global Climate Models, which includes daily temperature and precipitation projections for 23 model simulations at a 6 km by 6 km spatial resolution. The 23-model ensemble was used to reduce uncertainty by aggregating the projections from all individual models into one projection. This assessment presents results from two Shared Socioeconomic Pathway (SSP) scenarios (SSP 2-4.5 and SSP 5-8.5, see box at right) to represent the range of possible climate futures. For simplicity and to take a risk-averse approach, maps and some figures show projections from only the SSP 5-8.5 scenario (unless otherwise noted), but projections from the range of scenarios are provided throughout the report. With this information, Pennsylvania can prepare for all possible climate events that may affect the Commonwealth. Full results from both SSP scenarios are included in [APPENDIX C](#).

This assessment suggests that Pennsylvania is expected to continue to experience an impactful increase in both temperature and serious precipitation events. Temperature projections indicate that Pennsylvania will see a critical increase in average annual temperature as well as increasing frequency and intensity of dangerous heat events. Precipitation projections show that the Commonwealth will see a significant increase in average annual precipitation. Extreme precipitation events and drought events will also increase due to rainfall falling in fewer but more extreme events.

Introduction to CMIP6 and Shared Socio-Economic Pathways (SSPs)

This report uses data from the latest global climate model projections, known as the Coupled Model Intercomparison Project phase 6 (CMIP6). The CMIP6 projections use future greenhouse gas emission scenarios known as Shared Socioeconomic Pathways (SSPs). The SSPs are the new global standard set of climate model emission pathways as of 2022, replacing the Representative Concentration Pathways (RCPs) readers may be familiar with. The SSPs are future narratives that reflect different socioeconomic development strategies and climate policies that may be undertaken globally. SSPs are based on a comprehensive assessment of the literature on future socioeconomic development as well as expert judgment. This report utilized two SSPs to represent the range of possible climate futures:

- **SSP 2-4.5: A “middle of the road” emissions scenario** where CO₂ emissions are maintained at current-day levels until approximately 2050 and then decline to near zero by 2100. This scenario limits warming to 3°C.
- **SSP 5-8.5: An “unabated” emissions scenario** where CO₂ emissions continue to increase until late into the 21st century when CO₂ emissions begin to level off. In this scenario, warming exceeds 4°C.

This updated iteration of the Pennsylvania Impacts Assessment uses the recently published CMIP6 data to project a range of temperature and precipitation variables. All methods for variable calculation were kept constant with the previous iteration of the Assessment to allow for direct comparability between projections.

The updated CMIP6 projections demonstrate strong spatial alignment with the previous CMIP5 projections, and state-wide temperature and precipitation averages are almost identical between the two datasets. Research indicates that the CMIP6 models better project a range of precipitation variables, particularly those that capture extremes.



Climate Change Beyond 2100

Given that climate change is influenced by a multitude of factors, including greenhouse gas emissions, natural variability, and human actions, Global Climate Models currently only project out to the year 2100. Projecting beyond the year 2100 introduces greater uncertainty due to the inherent complexity of the Earth's climate system, as well as the uncertainty surrounding future emissions scenarios and societal responses to climate change.

As such, the Pennsylvania Climate Impacts Assessment only models climate change through 2100; however, the climatological trends discussed throughout the report are expected to continue far beyond the turn of the century. Beyond this time horizon, the Earth will likely see continued warming, increased sea level rise, and heightened intensity and frequency of extreme events.

The updated climate model analysis shows very similar projections for overall increases in average annual temperature and precipitation when compared to the 2021 assessment (see text box, bottom right).

The 2024 Impacts Assessment includes updated projections for more detailed climate variables and thresholds pertaining to key sectors and impacts. For example, projections are provided below for cooling and heating degree days (measures of energy use), days above extreme heat thresholds relevant for public health and agriculture, growing degree days, extreme precipitation, and more.

APPENDIX C gives details on the data sources and methods used for projections.

2.3 Temperature Changes

2.3.1 Key Findings

Temperatures are already rising and will continue to rise rapidly in Pennsylvania. Although temperatures will continue to be variable year-to-year, average annual temperature statewide is expected to increase by 6.7°F (3.7°C) by mid-century and 10.4°F (5.8°C) by end-of-century from a historical baseline time period of 1971–2000. Average annual temperature has already risen approximately 1.2°F from 2000 to 2023.

Increasing average temperatures will cause more frequent and intense dangerous heat events such as hot days or heat waves. For example, days per year where temperatures reach at least 90°F are expected to increase from five (5) days at baseline to 23–36 days by mid-century and 40–70 days by end-of-century, depending on SSP scenario. Some parts of the state could experience over 75 days over 90°F by mid-century. For context, from June–September 2023,

Impacts Assessment Mid-Century Projections: 2021 versus 2024 Impacts Assessments

	2021	2024
Average annual temperature	+5.9°F	+6.7°F
Average annual precipitation	+8%	+9%

Projections are statewide averages for a mid-century time period of 2041–2070 vs. a historical baseline time period of 1971–2000.

This impacts assessment shows increases in the expected rise of temperature and precipitation by mid-century. These changes are due to updates in climate data and models from the integration of the latest projections through CMIP6.

Harrisburg experienced 19 days over 90°F.³ Days over 95°F are projected to increase from an average of 0.6 days over 1971–2000 to 11 days by mid-century and 34 by end-of-century.

Increasing temperatures will alter the growing season across the Commonwealth and increase cooling degree days. Heating degree days will also decrease.

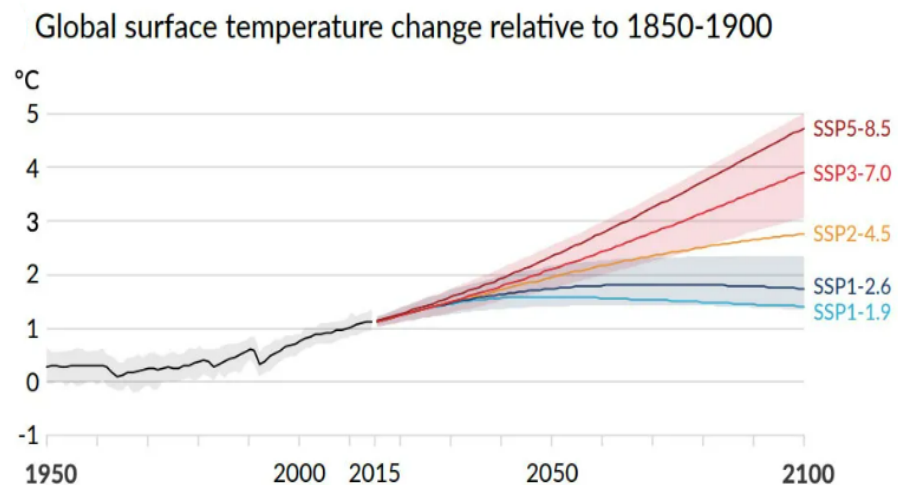
2.3.2 Detailed Projections

Projected values reported below for temperature and precipitation are presented for up to three future time periods, which represent the average values over 2016–2045 (present context), 2041–2070 (mid-century), and 2070–2099 (end-of-century). Values within each time period are compared to a baseline period of 1971–2000. Projections are statewide averages of the 50th percentile of the 23 climate models.

The projections reported are based on SSP 2–4.5 and SSP 5–8.5. As shown in **Figure 4**, all emissions scenarios project similar changes in average temperature through 2050, but temperature changes and other climate change effects vary more by the end-of-century and beyond depending on global emissions.

For Pennsylvania, mid-century climate projections do not vary widely between SSP 2–4.5 and SSP 5–8.5 (see **Figure 5**). End-of-century projections are where differences between emission scenarios become pronounced. For example, average annual temperature statewide is expected to rise 9.3°F (5.2°C) by end-of-century under SSP 5–8.5, but only 5.5°F (3.1°C) under SSP 2–4.5—this is similar to the SSP 5–8.5 projections for mid-century. Projections for all variables under SSP 2–4.5 are provided in [APPENDIX C](#).

Figure 4. Comparison of projected global average surface temperature change



Five different SSP scenarios including SSP 5–8.5 (high fossil-fuel development scenario) and SSP 1–1.9 (lowest emissions scenario most closely reflecting a 1.5C target under the Paris Agreement). SSP 2–4.5 is the mid-level emissions scenario. Source: IPCC Sixth Assessment Report.

Temperatures are likely to increase substantially across the Commonwealth throughout this century. Across the state, annual average temperatures are projected to increase by 5.1°F (2.8°C)–6.7°F (3.7°C) by mid-century and 6.2°F (3.4°C)–10.4°F (5.8°C) by the end-of-century, depending on emissions scenario.

Across global climate models, a consensus exists that as global greenhouse gas emissions rise, average temperatures will increase. The magnitude of increase varies by climate model and depends on how each model captures future concentrations of greenhouse gases in the atmosphere, climate sensitivities, and natural climate variability. These differences account for the uncertainty associated with climate models.

Figure 5. Mid-century and end-of-century projections for key climate indicators under SSP 2-4.5 and SSP 5-8.5. Percentiles show the range across the 23-model ensemble

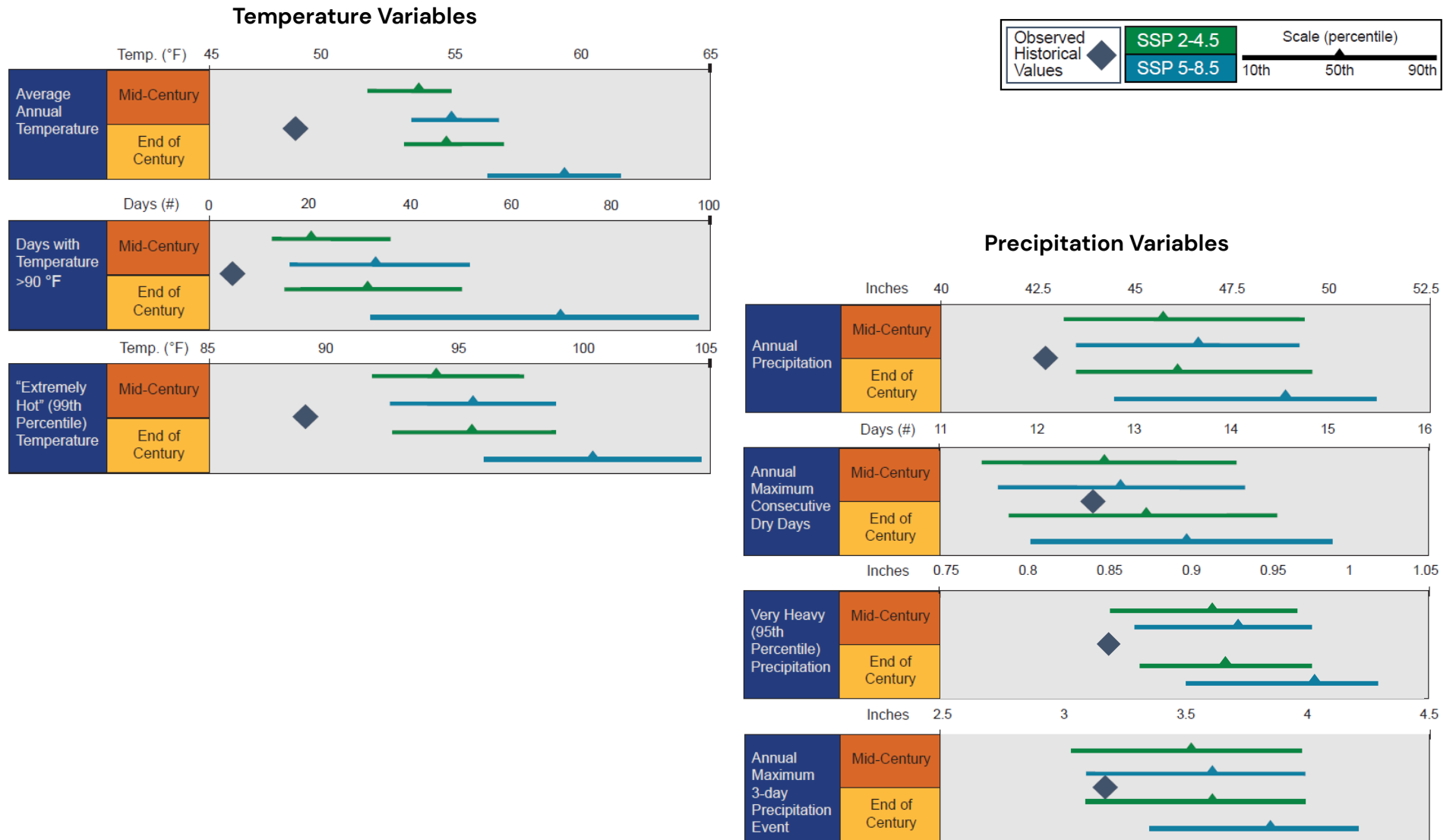
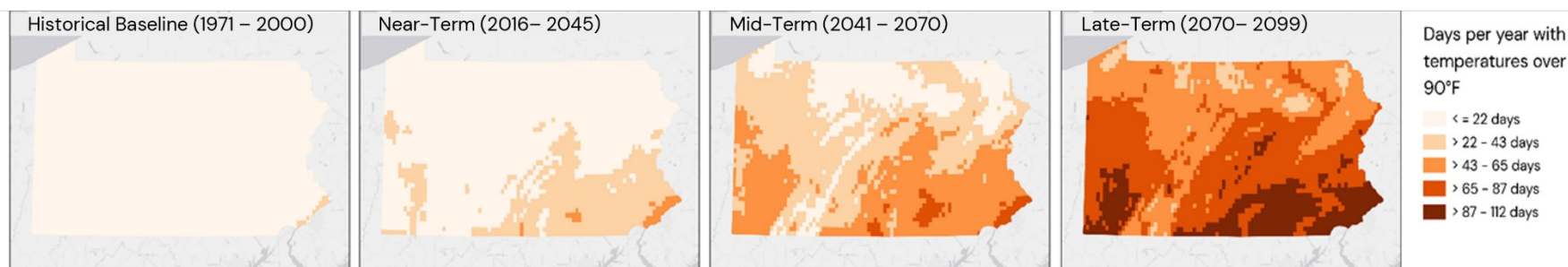
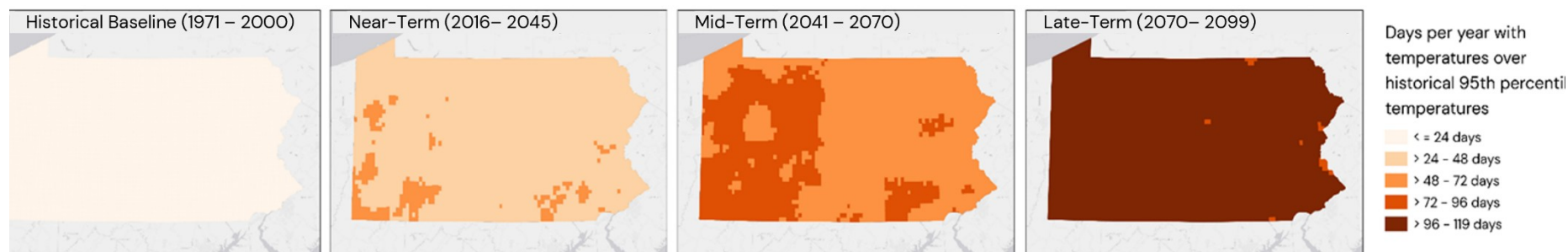


Figure 6. Observed and projected annual days with temperatures above 90°F



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5–8.5. The legend shows the full range of observed and projected values divided into equal increments.

Figure 7. Observed and projected annual days with "very hot" temperatures



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5–8.5. The "very hot" threshold varies by grid cell, based on the 95th percentile of observed days' maximum temperature. The legend shows the full range of observed and projected values divided into equal increments.

As the climate changes, so will the frequency and severity of extreme temperatures.

The temperature of very hot days is projected to increase as well as the number of annual occurrences of historical very hot days. Similarly, "extremely hot" days are days with temperatures greater than 99 percent of all days in the baseline period of record. Heat waves are approximated by the annual number of days above 90°F and 95°F as well as the number of consecutive days above 90°F and 95°F. The projections for number of days above 90°F is shown on maps in **Figure 6**. Extreme heat events are projected to occur more

often and become more severe; very hot days, extremely hot days, and heat waves will all increase in frequency. "Very hot" days are days experiencing 95th percentile maximum daily temperatures, or temperatures greater than 95 percent of all days in the baseline period of record, shown in **Figure 7**.

Although the average temperature trends upward, inter-annual temperature variability will continue to increase and warming overall temperatures does not preclude the possibility of extremely cold weather events. For example, in December 2022, a Polar Vortex with freezing temperatures was followed by record breaking warmth during

the first week of January 2023.⁴ Pennsylvania will continue to experience temperature fluctuations as the climate warms.

Average Temperatures

Average temperatures are projected to increase from historical levels across the Commonwealth. From 1971–2000, the baseline average annual daily temperature was 48.3°F (9.1°C). For all months, average daily temperatures are projected to increase by 4.8 to 8.5°F (2.7 to 4.6°C) mid-century and 7.9 to 13.5°F (4.3 to 7.4°C) by the end-of-century, with greatest warming in the summer season. Average monthly high temperatures will also increase. The southern corners of the state are projected to experience the highest temperatures in both the near and long-term, while the northwest could see the greatest change.

Frequency and Severity of Hot Days

Hot days, where temperatures exceed 90°F or even 95°F are expected to become more common in Pennsylvania. From 1971 to 2000, on average across the state, there were six days above 90°F per year.⁵ This number is projected to increase throughout the century. highlights the map of observed and projected days above 90°F across the Commonwealth. By mid-century, Pennsylvania is expected to experience 23 days per year with temperatures over 90°F under SSP 2–4.5 and 36 days per year with temperatures over 90°F under the high “unabated” emissions scenario, SSP 5–8.5. Warmer areas will see closer to 63–77 days. By end-of-century, the state is projected to experience an average of 34–70 days per year with temperatures exceeding 90°F. Compared to the historical baseline (1971–2000), these future projections represent an increase of approximately 300%–530% by mid-century and 500%–1,100% increase by end-of-century.

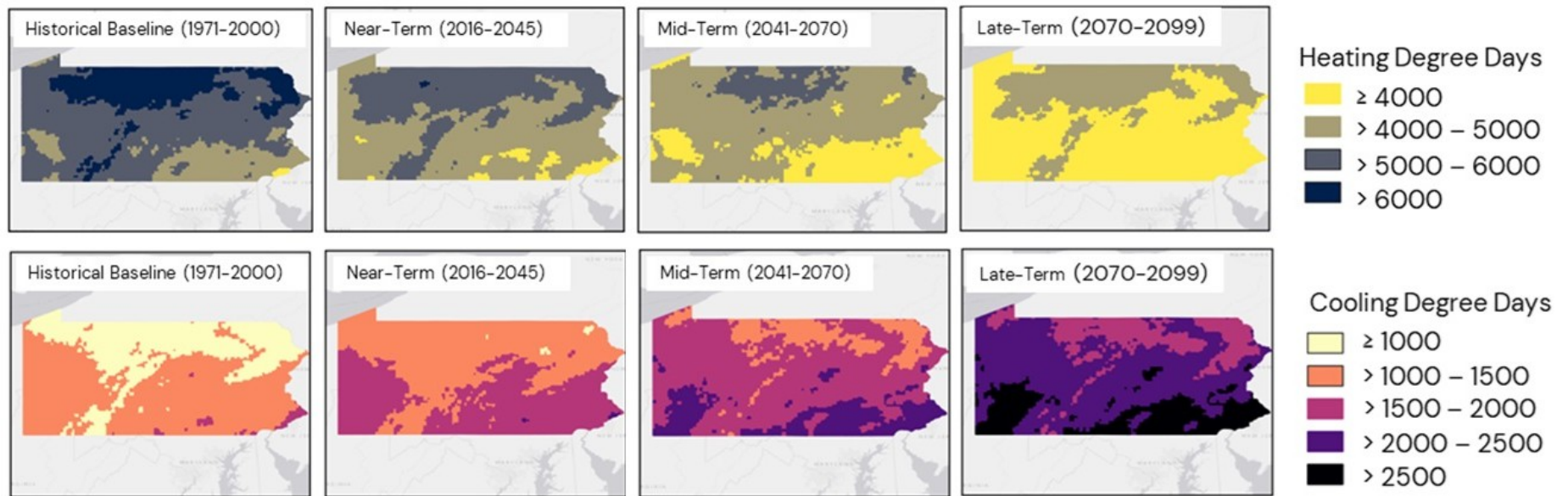
Pennsylvania is also expected to experience a similar trend in annual numbers of days where temperatures exceed 95°F. While historically

rare (less than once per year, on average), days above 95°F are projected to occur about 5–11 times per year by mid-century and 9–34 times per year by end-of-century, depending on emissions scenario. Under a high-emissions scenario, the warmest parts of the state could experience up to 36 days above 95°F by 2050.

In addition to an increase in the frequency of hot days, days classified as “very hot”, where temperatures are above 95 percent of all days in the period of record (85.2°F), and “extremely hot”, where temperatures are above 99 percent of all days in the period of record (89.0°F), will also rise. And, as temperatures rise, what we consider to be “very hot” and “extremely hot” will also shift. By mid-century, the “very hot” temperature threshold is projected to be 92°F, and by end-of-century, 96.5°F. By mid-century, the “very hot” temperature threshold is projected to be 92°F, and by end-of-century, 96.5°F. Under a “middle of the road” emissions scenario, the “very hot” threshold would reach 92°F by the end of the century. Similar to “very hot” days, “extremely hot” days (which occur less than 1% of the time) will also be substantially hotter. “Extremely hot” days are projected to be days >95.9°F by mid-century and days >100.7°F by end-of-century. At the end of the century, Pennsylvania temperatures will feel like those of present-day northeast Arkansas.⁶ With limited emissions, the end-of-century “extremely hot” threshold could be contained to 96°F.

Besides an increase in extreme temperature (“very hot” and “extremely hot”) thresholds, the number of days experiencing historical extreme temperature thresholds is projected to increase. **Figure 7** shows a map of observed and projected days with historical “very hot” temperatures across the Commonwealth. Particularly in the southwestern region of the state, by mid-century, the number of days experiencing historical “very hot” temperatures (on average 85.2°F across the state) is projected to be at least 71 days.

Figure 8. Observed and projected average annual cooling and heating degree days



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5–8.5. The full range of observed and projected values is shown divided into equal increments.

Warm Nights

In addition to high daytime temperatures, the Commonwealth may also see higher nighttime temperatures. A key threshold for infrastructure and human health cooling relief is when nighttime temperatures are above 68°F. The number of nights with minimum temperatures above 68°F is projected to increase from an average of four (4) days (1971–2000) to 26 days by mid-century and 55 days by the end-of-century.

Heating and Cooling Needs

Another indicator of Pennsylvania’s warming climate is the change in heating degree days and cooling degree days. Heating and cooling

degree days are indicative of energy needed to heat and cool buildings, respectively.⁷

As temperatures increase, heating degree days generally decrease, and cooling degree days increase because cooling homes requires more energy and heating homes becomes less needed. Urban areas are expected to see higher impacts of extreme heat due to the urban heat island effect, and Philadelphia is already identified as the county most prone to extreme heat.⁸ Increased cooling needs will put strain on grid reliability, that if unaddressed, would contribute to severe impacts on human health. More information in energy grid resilience can be found in [CHAPTER 4](#) and, additional details on the impacts of extreme heat are provided in [APPENDIX C](#).

Calculating Heating and Cooling Degree Days

Both heating and cooling degree days relate to the energy demand for heating and cooling, and are calculated based on the deviation of the average daily temperature from 65°F. To reflect the fact that it takes more energy to heat or cool a building when average daily temperature is further from a comfortable living temperature, heating and cooling degree days increase in value as the daily temperature moves further from 65°F.

For example, a day with an average temperature of 70°F is counted as having five (5) cooling degree days and a day with an average temperature of 60°F is counted as having five (5) heating degree days. The calculations for heating degree days and cooling degree days sum the total number of heating and cooling degree days, respectively, throughout the year.

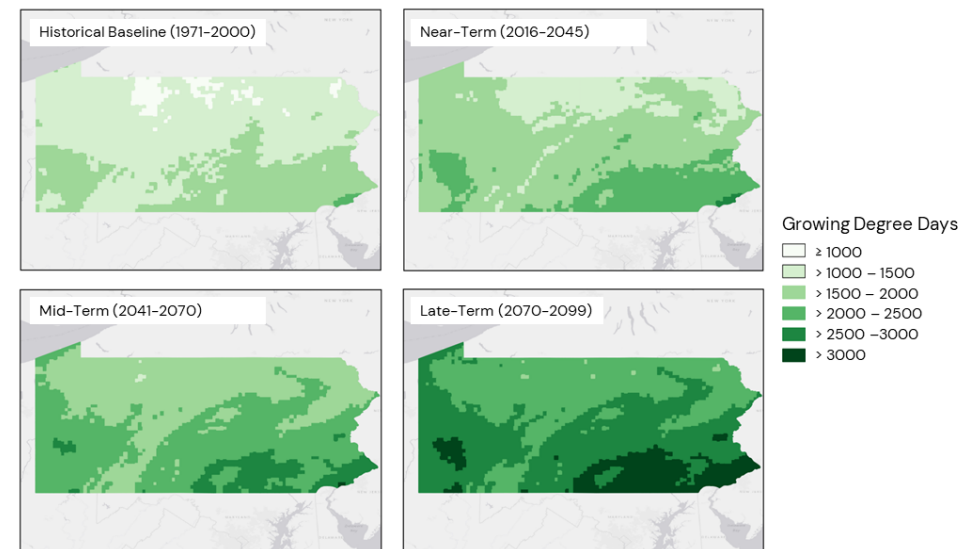
Annual total heating degree days are anticipated to decrease by 13% by mid-century and 25% by end-of-century compared to the historical baseline. However, by mid-century, annual total cooling degree days are projected to increase by 7% (SSP 2–4.5) to almost 68% (SSP 5–8.5). By the end of the century, annual total degree days could increase by up to 285%. **Figure 8** illustrates the shift in heating and cooling degree days in Pennsylvania.

Growing Season

Increasing temperatures will also alter the growing season across the Commonwealth. Growing degree days are a heat unit that can help indicate how temperature may impact (e.g., facilitate or impede) different crops and pests' development.⁹ Growing degree days are a good indicator for the length of the growing season, but they are not a direct correlation.

Growing degree days are increasing across the state (indicative of a longer growing season) but the magnitude of growing degree days varies by region (see **Figure 9**). Growing degree days are historically highest in the southeastern corner of the state, which will continue to experience the highest number of growing degree days by mid-century.

Figure 9. Observed and projected average annual growing degree days



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5–8.5. The full range of observed and projected values is shown divided into equal increments.

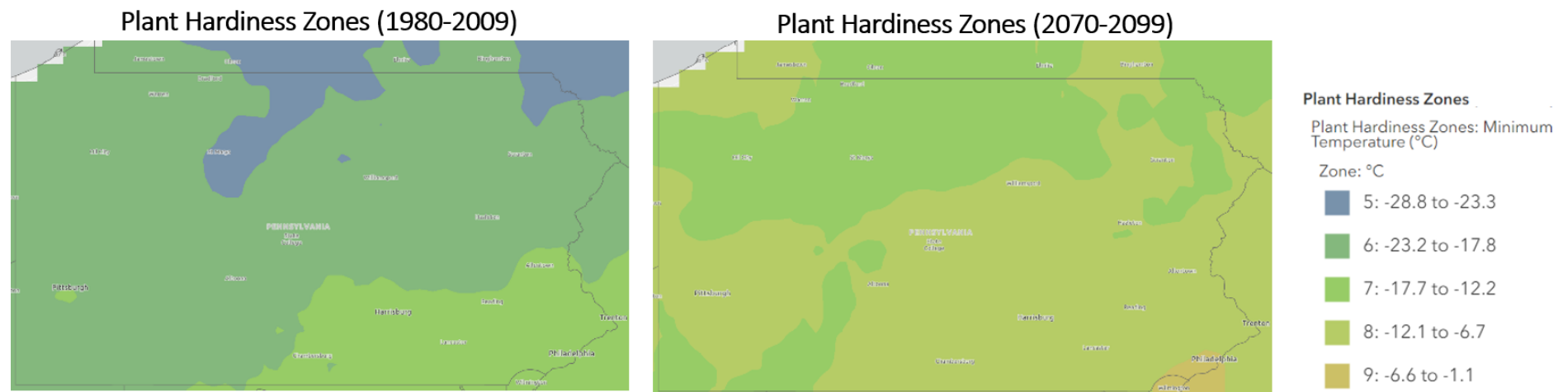
Calculating Growing Degree Days

Growing degree days are calculated based on the difference between the average daily temperature and a certain temperature threshold. Here, that threshold is 50°F, a standard temperature at which many crops grow best. For example, a day with an average temperature of 56°F is counted as having six growing degree days while a day with an average temperature of 53°F is counted as having three growing degree days. The calculation is set up to reflect the fact that a day with a higher average temperature has more hours of the day above the 50°F growth threshold than a day with a lower average temperature. The calculation of the growing season is based on the sum of all growing degree days throughout the year.

On average, the state is projected to see a 34% increase in growing degree days by mid-century (see **Table 3**). By end-of-century, growing degree days are projected to increase by 57%. Figure 11 on page 20 visualizes how monthly cumulative growing degree days are projected to increase across all time periods analyzed.

Similarly, increasing temperatures will decrease the intensity of winter and allow plants that are less cold-resilient to grow in Pennsylvania. Plant Hardiness Zones indicate the extent of winter stress that plants experience due to cold temperatures. These zones are based on the average annual extreme minimum temperatures and are used by horticulturists to evaluate the cold hardiness of plants. In Pennsylvania, the coldest Plant Hardiness Zone is expected to shift from being in the -28.8°C (-19.8°F) to -23.3°C (-9.9°F) range to the -17.7°C (-0.14°F) to -12.2°C (10.0°F) range by the end-of-century (Figure 10).¹⁰

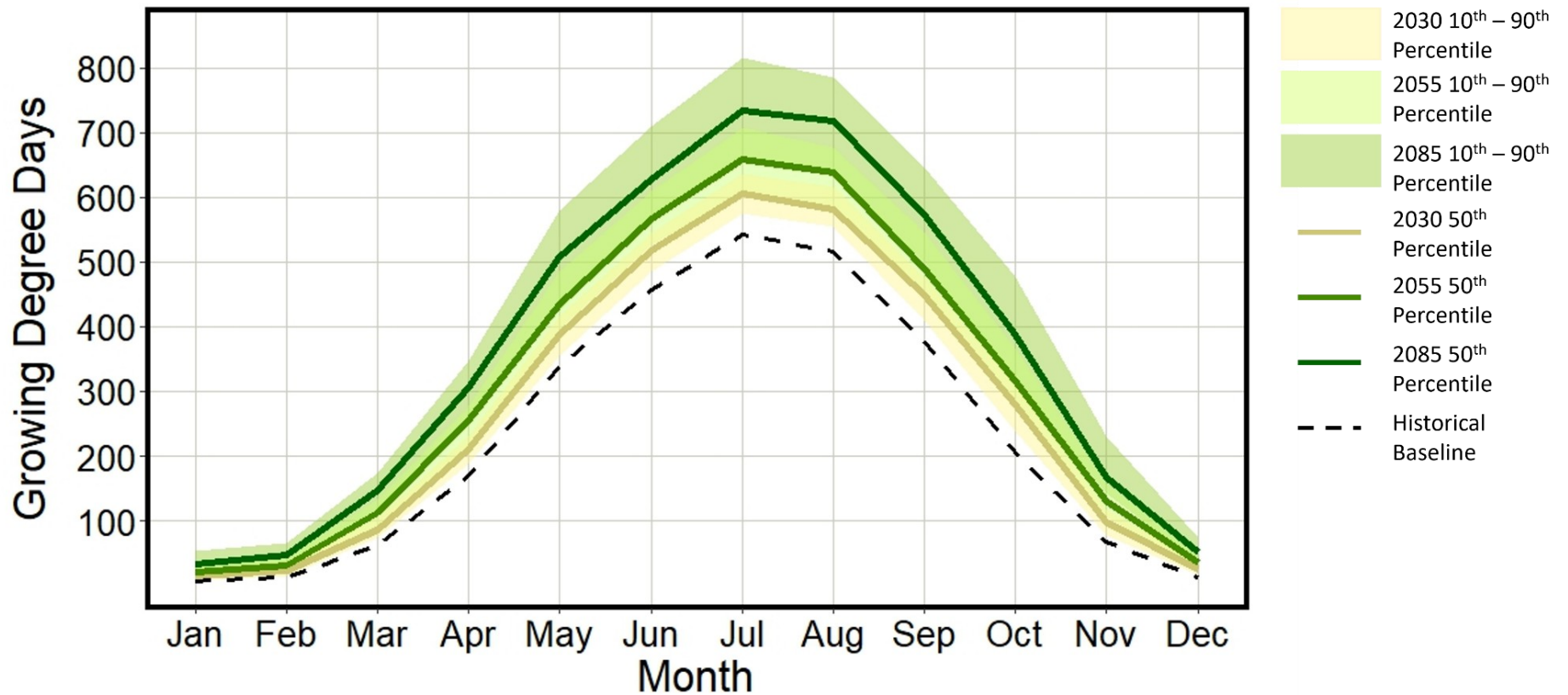
Figure 10. Historic plant hardiness (left) from 1980–2009, and projected future plant hardiness zones from 2070–2099 (right) based on RCP8.5 projections



Source: USDA Plant Hardiness Zones – Office of Sustainability and Climate Zones

Observed and Projected Temperature Data

Figure 11. Observed and projected average monthly cumulative growing degree days



Based on 23-model ensemble of LOCA downscaled data, SSP 5-8.5. Values for 2025 represent all years 2011-2040, those for 2055 represent 2041-2070, and those for 2085 represent 2070-2099. Values are statewide averages.

Table 3 Summarizes statewide average projections for temperature variables under SSP 5–8.5. Projections under the lower SPP 2–4.5 emission scenario are provided in [APPENDIX C](#). The statewide average for the 10th to 90th percentile range is included to illustrate the spread in projections and highlight the range of possible outcomes.

Table 3. Statewide average observed and projected temperature variables (SSP 5–8.5)

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Average annual temperature (°F)	48.3	52.0 (50.7 – 53.3)	3.7	54.9 (53.1 – 56.6)	6.6	58.7 (56.0 – 61.6)	10.4
Average annual minimum temperature (°F)	37.6	41.4 (40.2 – 42.7)	3.7	44.0 (42.6 – 45.9)	6.7	47.6 (45.5 – 51.0)	10.5
Average annual maximum temperature (°F)	59.0	62.6 (61.2 – 63.8)	3.7	65.7 (63.7 – 67.2)	6.4	69.5 (66.4 – 72.2)	10.0
Heating degree days (degree days)	5,569.1	4,830.5 (4,578.9 – 5,060.9)	-738.6	4,830.8 (4,425.1 – 5,217.7)	-1,672.3	4,137 (3,389.9 – 4,440.0)	-2,366.1
Cooling degree days (degree days)	1,096.4	1,446.2 (1,283.3 – 1,592.5)	349.8	1,194.7 (910.5 – 1,460.0)	716.4	1,843.7 (1,266.7 – 2,331.3)	1,365.5
“Very hot” (95 th percentile) temperature (°F)	85.2	88.9 (87.1 – 90.8)	3.5	92 (89.0 – 94.9)	6.8	96.5 (92.3 – 100.3)	11.3
Days with temperature above “very hot” baseline temperature (°F)	19.6	44.9 (32.5 – 57.5)	25.1	70.6 (46.6 – 86.8)	49.8	104.8 (68.4 – 129.4)	83.9
“Extremely hot” (99 th percentile) temperature(°F)	89.0	92.6 (90.5 – 94.8)	3.6	95.9 (92.8 – 98.5)	6.9	100.6 (96.1 – 104.4)	11.6
Days above baseline “extremely hot” temperature	6.2	19.5 (10.7 – 29.7)	11.8	38.0 (20.0 – 57.0)	30.9	74.8 (39.8 – 102.6)	67.3
Days with temperature >90°F	6.1	18.5 (10.9 – 27.4)	11.2	35.9 (18.7 – 52.5)	30.4	69.8 (36.7 – 97.2)	63.9
Days with temperature >95°F	0.8	4.1 (1.4 – 7.4)	2.8	11.2 (4.1 – 20.6)	10.6	33.6 (11.4 – 58.3)	32.8
Days with temperature >100°F	0.0	0.5 (0.1 – 1.0)	0.4	2.0 (0.4 – 4.3)	2.1	9.8 (2.1 – 24.2)	9.9

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Days with low temperature > 68°F	4.9	13.7 (9.4 – 18.1)	8.6	25.7 (16.4 – 35.6)	23.2	54.6 (31.0 – 78.8)	51.5
Consecutive days above 90°F	2.3	5.1 (3.1 – 7.4)	2.6	8.8 (5.3– 15.2)	6.5	19.3 (9.1 – 36.8)	17.0
Consecutive days above 95°F	0.4	1.6 (0.6 – 2.8)	1.1	3.4 (1.7 – 6.2)	3.0	8.3 (3.7 – 16.3)	7.9
Growing degree days (degree days)	1,375.6	1,754.3 (1,593.4 – 1,904.2)	378.7	3,687.7 (3,316.6 – 3,916.7)	920.3	4,282.8 (3,656.4 – 4,771.8)	1,565.8

2.4 Precipitation Changes

2.4.1 Key Findings

While climate models generally agree that temperature will increase over the century, there is less consensus on how precipitation will change because it is more difficult to model. Limitations in statistical downscaling techniques make it difficult to project extreme precipitation values. The updated CMIP6 data represents an improvement in precipitation projections when compared to CMIP5, especially those that model precipitation extremes. CMIP6 uses a better historical training dataset that preserves heavy precipitation, as well as an improved methodology for capturing extreme precipitation events. As such, especially within the SSP 5–8.5 projections, modeled future precipitation is slightly higher in the updated CMIP6 projections than was previously seen in the CMIP5 projections. Nonetheless, there remains uncertainty in precipitation projections that should be considered in climate resilience planning that addresses precipitation changes.^{11,12}

Based on the available modeling, **in the coming century the Commonwealth will see an increase in average annual precipitation, extreme precipitation events, and droughts**, as both “very heavy” precipitation events and consecutive dry days increase. Pennsylvania could experience a marked increase in total average rainfall, occurring in less frequent but much more severe rain events. Precipitation changes could also include more precipitation falling as rain rather than snow,¹³ which could affect flooding and other hazards.¹⁴

2.4.2 Detailed Projections

Like temperature projections, precipitation projections are reported by the 10th, 50th, and 90th percentile of the future precipitation variables’ distribution to capture the uncertainty associated with the range of potential values. Despite limitations, climate models help to provide insight into the potential changes in precipitation that Pennsylvania may experience in the coming decades and can help inform more effective climate resilience planning.

Average Precipitation

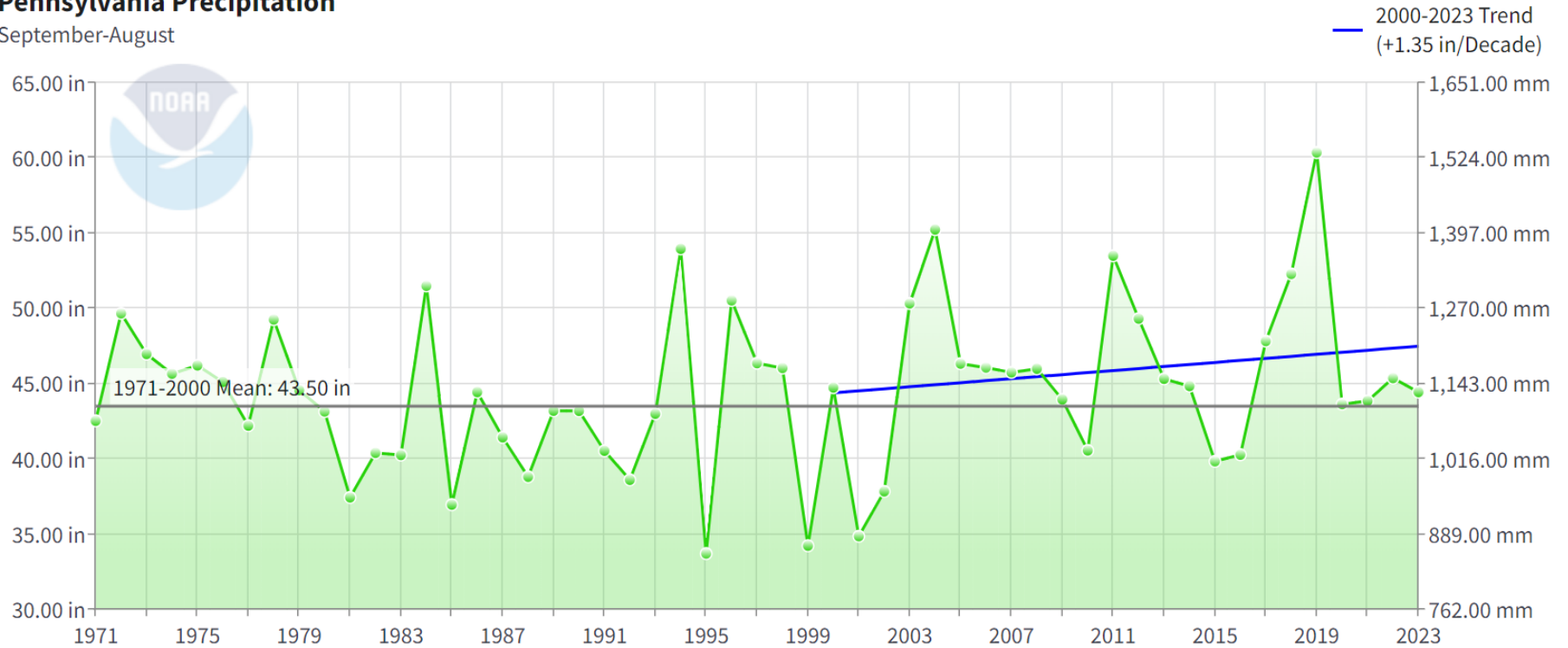
In the past several decades, precipitation in Pennsylvania has already been increasing. Between 2000 and 2023, Pennsylvania experienced an increase in annual precipitation of approximately 2.51 inches compared to the 1971–2000 period.¹⁵ (see **Figure 12** on the next page).¹⁶ June, October and December saw the greatest increases in precipitation.

Annual average precipitation is projected to continue to increase. Historically, average annual precipitation was 43 inches (1,090 mm). Pennsylvania will likely experience a small (8–9%) increase in annual precipitation by mid-century and slightly greater (8–13%) increase by end-of-century compared to the observed historical baseline (1971–2000). The mid-century projection is essentially the same as that from the 2021 assessment.¹⁷ Average annual precipitation is projected to increase to 47 inches (about 1,195 mm) by mid-century under both a “middle of the road” and a high-emissions scenario. Average annual precipitation is expected to reach 47–49 inches (1,191–1,241 mm) by end-of-century, depending on emissions scenario.

Figure 12. Annual precipitation in Pennsylvania

Pennsylvania Precipitation

September-August

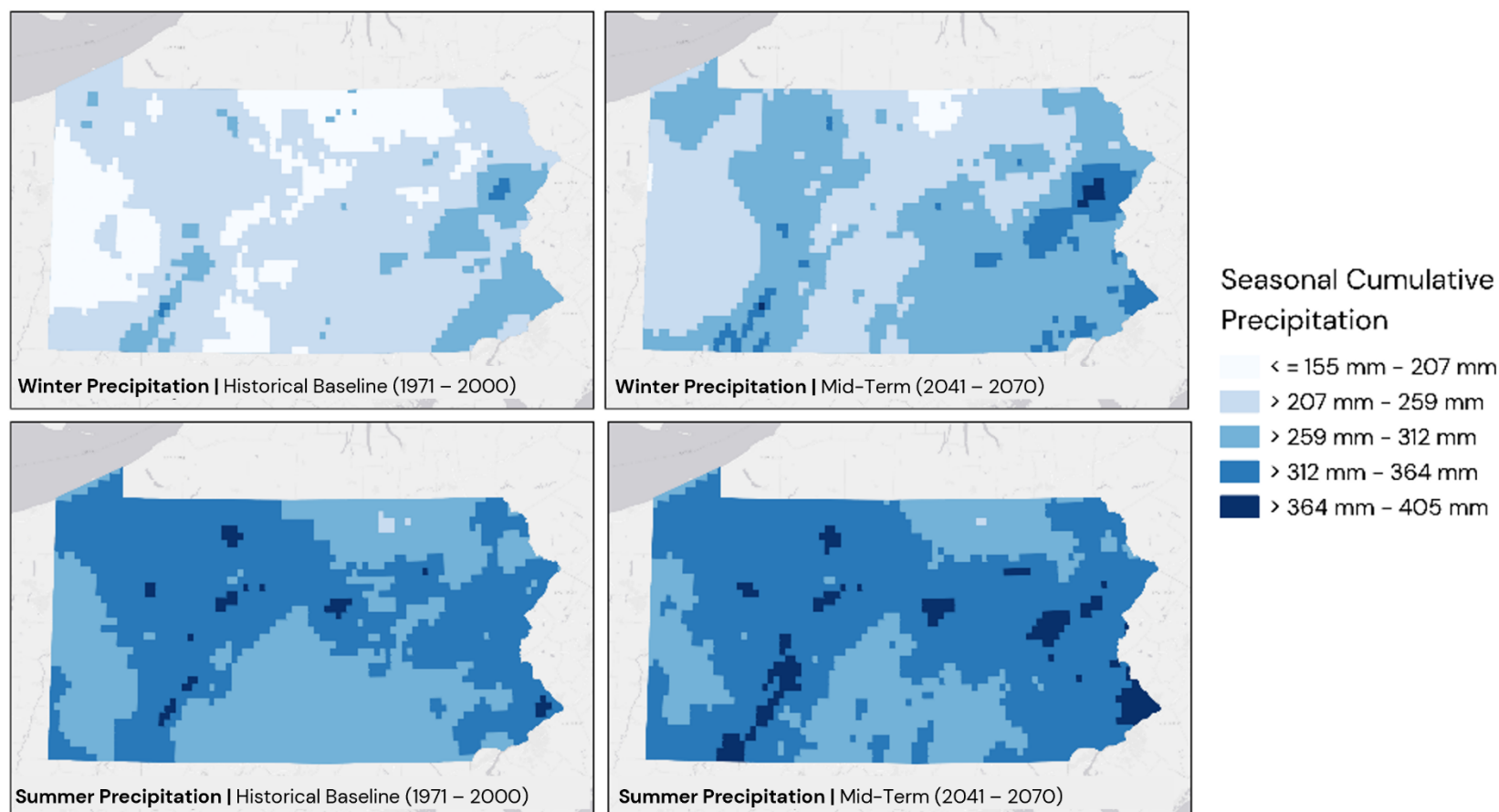


The 1971-2000 mean of 42.5 inches is shown in addition to the trend from 2000 to 2023. Source: National Centers for Environmental Information. Climate at a Glance – Statewide Time Series.

Monthly precipitation patterns are also projected to shift slightly over the century. Most increases in precipitation will occur in the winter and spring, with future precipitation conditions remaining similar to historic patterns during summer and fall (see **Figure 13**). This seasonal pattern of projected precipitation change is

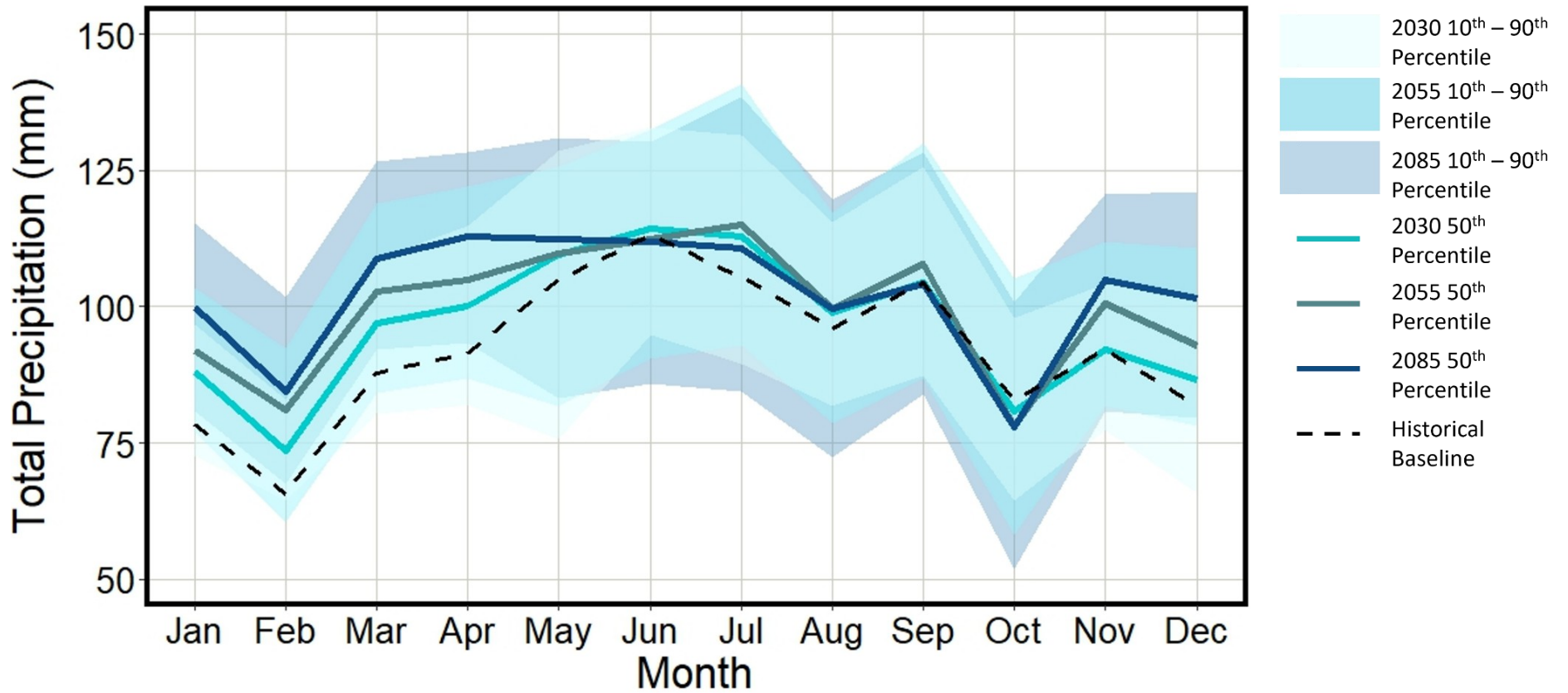
consistent with numerous past studies for the Commonwealth.^{18,19,20} The range in monthly total precipitation values shown across models indicates the variability and uncertainty in precipitation projections (see **Figure 14** on the next page).

Figure 13. Observed and projected winter and summer seasonal cumulative precipitation



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5-8.5. The legend shows the full range of observed and projected values divided into equal increments.

Figure 14. Statewide observed and projected average monthly precipitation



Based on 23-model ensemble of LOCA downscaled data, SSP 5-8.5. Values for 2025 represent all years 2011-2040, values for 2055 represent all years 2041-2070, and values for 2085 represent all years 2070-2099.

Extreme Precipitation

Consistent with findings from prior assessments,^{21,22} extreme rainfall events are projected to increase in magnitude, frequency, and intensity as the century progresses. The statewide average amount of rainfall that falls during “very heavy” precipitation events (which are heavier than 95% of the days with precipitation per year) is projected to rise from 0.85 inch (21.5 mm) (historical baseline) to 0.92 inch (23.3 mm) by mid-century and to 0.98 inch (24.9 mm) by end-of-century. These projections represent 9% and 15% increases respectively and are consistent across emissions scenarios. Existing climate models may not capture all the extremes of precipitation events, and so events may have even higher intensity than established in this report.²³

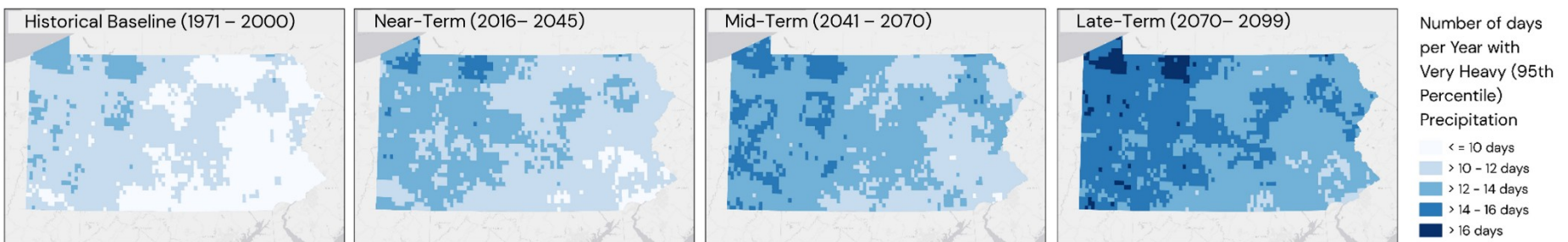
The amount of rainfall during “extremely heavy” precipitation events (which are heavier than 99% of the days with precipitation per year) is also projected to rise from 1.4 inches (36.4 mm) in the historical baseline to 1.6 inch (40.5 mm) and 1.7 inch (43.3 mm) by mid-century

and end-of-century respectively. This is a 21% increase by mid-century and 32% increase by end-of-century.

Finally, the magnitude of precipitation during longer rain events will also increase. The annual maximum amount of precipitation during an annual 3-day precipitation event is projected to increase by 0.4 inches by mid-century and 0.6 inches by end-of-century. Overall, climate projections show a consistent and notable increase in the amount of rainfall during extreme precipitation events.

Extreme rainfall events are also projected to become more frequent; the number of days with historical “very heavy” (21.5 mm on average statewide) and historical “extremely heavy” (36.4 mm) precipitation days are projected to rise. Pennsylvania is projected to experience over two more days (21% increase) with observed baseline “very heavy” precipitation amounts and over one more day (43% increase) with historical “extremely heavy” precipitation amounts by mid-century (compared to baseline). By end-of-century, the Commonwealth will see over three more days (33% increase) with observed historical “very heavy” precipitation amounts and nearly

Figure 15. Observed and projected annual days with “very heavy” precipitation



Based on 50th percentile of 23-model ensemble of LOCA downscaled data, SSP 5–8.5. The “very heavy” threshold varies by grid cell, based on the 95th percentile of observed rainy days. The full range of observed and projected values is shown divided into equal increments.

two more days (74% increase) with observed baseline “extremely heavy” precipitation amounts. The number of days with “very heavy” precipitation will increase across the State (see **Figure 15**). The southeastern corner of Pennsylvania will continue to experience the highest number of days with very heavy precipitation throughout the century.

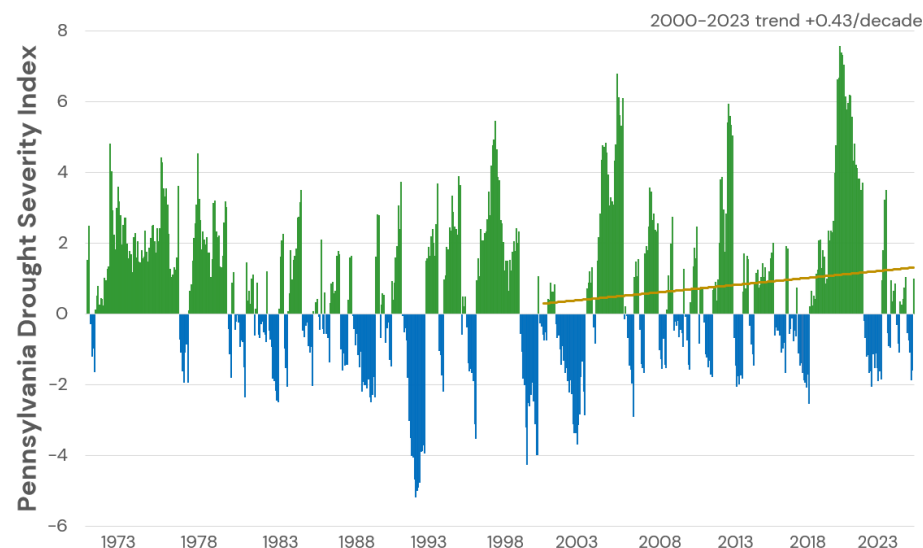
This change is already occurring. Historical weather data show that over 80% of Cooperative Observer Program sites surveyed by the state climatologist are seeing an increase in heavy rain events in the 2010s when compared to the 1980s (see **Figure 16**).²⁴

Climate model projections suggest that these changes will only be exacerbated in the future. For example, the number of days with more than three (3) inches of rainfall is projected to increase by from an average of 0.15 days to 0.25 days by mid-century and 0.31 by end-of-century (compared to baseline and depending on emissions scenario). Such a rain event is therefore 60% more likely to occur by mid-century and 97% more likely to occur by end-of-century.

Pennsylvania will continue to experience an increase in more serious rain events. Sudden, short, and heavy rainfall events, known as cloudbursts, are often responsible for flash flooding.²⁵ Climate change is expected to **increase the intensity and frequency of cloudburst events**.^{26,27,28} These events result in significant impacts (i.e., flooding), but are not well captured in many climate models. The models used here attempt to capture precipitation events at daily resolution rather than hourly or sub-daily resolutions. Greater research on the change in frequency and intensity in cloudbursts over the coming century is needed.^{29,30}

Extreme precipitation events are likely to exacerbate flood risk. Flood is already the highest-risk climate hazard facing the Commonwealth, and 27 of Pennsylvania’s 67 counties experience an average of one or more flood events per year. Recently, major flood

Figure 16. Pennsylvania Palmer Drought Severity Index for 1971–2023



Source: National Centers for Environmental Information. Climate at a Glance Statewide Time Series.

events have impacted in Pennsylvania in 2011, 2014, 2017, 2018, and 2021.³¹ Increased extreme precipitation events are expected to lead to at least minor increases in runoff and flooding for all of Pennsylvania by mid-century while major increases in runoff are expected in the eastern half of the Commonwealth in the same time period.³²

Drought Conditions

While average and extreme precipitation is projected to increase, a slight increase in drought conditions is also probable. Details surrounding future drought conditions, for example duration and intensity of drought events, remain uncertain, but changes in future precipitation and temperature are expected to exacerbate

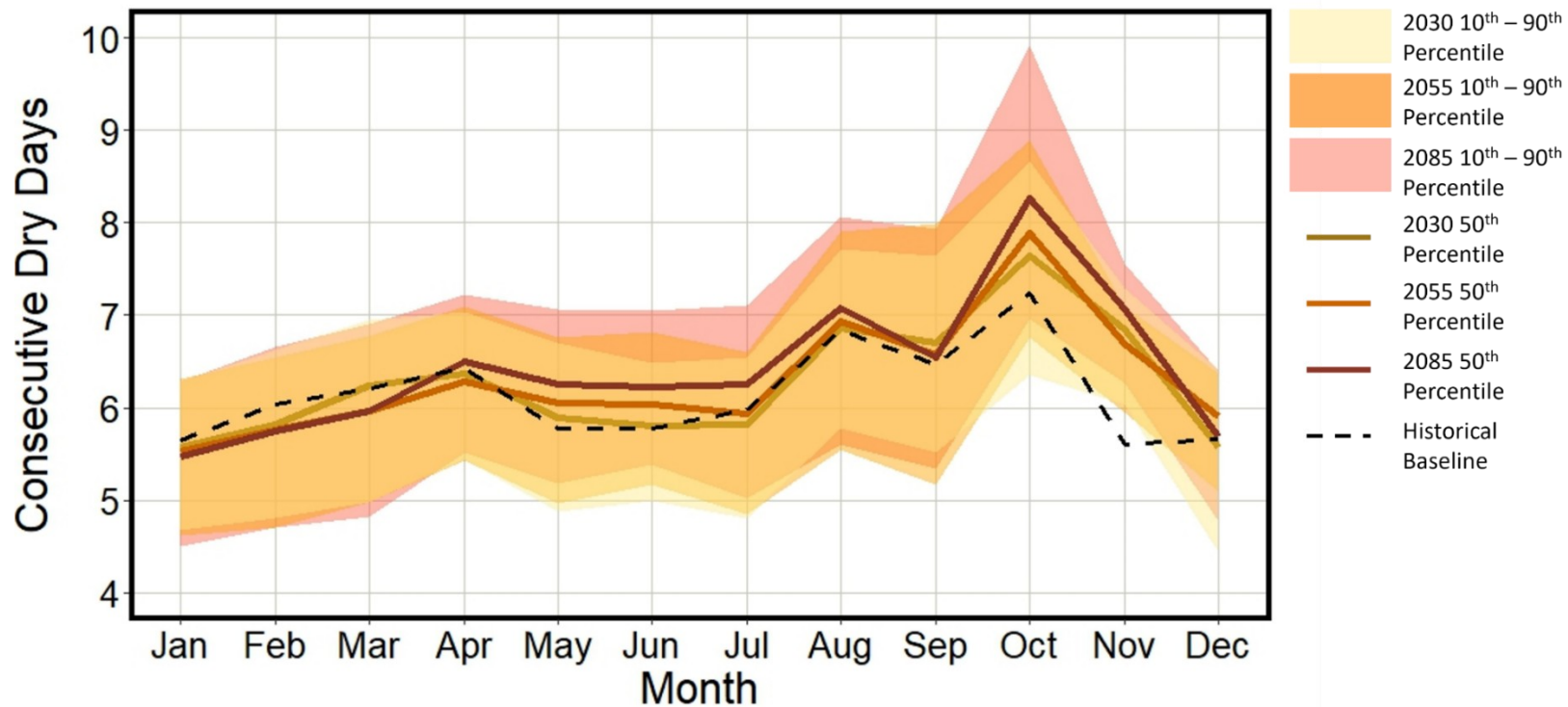
drought.³³ Overall, changes in precipitation events will create **wetter winters and springs and drier falls** in the Commonwealth.

The number of days without rain will increase 3% by mid-century and 8% by end-of-century. These findings of fewer rainy days and longer periods without rain are consistent with prior Climate Impacts Assessments.^{34,35} Average monthly consecutive dry days in Pennsylvania are projected to increase in the late summer and fall months (see **Figure 17**). The month of October shows the largest increase in consecutive dry days for every projection scenario.

Average monthly consecutive dry days are not projected to change significantly from historical conditions in the winter and spring.

Drought conditions have declined in recent decades but persist despite more overall precipitation, according to measurements using the Palmer Drought Severity Index.³⁶ This is a standardized index used to understand the intensity and duration of long-term drought conditions.³⁷ **Figure 16** shows Pennsylvania's drought trends from January 1971 to December 2023 and highlights a trend toward increased precipitation. It also highlights that drought conditions continue to occur even with a trend toward greater precipitation.

Figure 17. Statewide observed and projected average monthly consecutive dry days



Based on 23-model ensemble of LOCA downscaled data, SSP 5-8.5. Values for 2025 represent all years 2011-2040, values for 2055 represent all years 2041-2070, and values for 2085 represent all years 2070-2099.

Observed and Projected Precipitation Data

Understanding precipitation projections is complicated given all the variability behind precipitation and how it manifests. **Table 4** summarizes statewide average projections for precipitation

variables under SSP 5-8.5. Projections under the lower SSP 2-4.5 emission scenario are provided in [APPENDIX C](#). The average for the 10th and 90th percentile range is included to illustrate the spread in projections and highlight the range of possible conditions.

Table 4. Statewide average observed and projected precipitation variables

Precipitation Variable	Baseline (1971– 2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change
Annual precipitation (inches)	42.9	44.8 (41.8 – 47.3)	5.4%	46.8 (43.4 – 49.3)	9.0%	48.3 (44.2 – 51.0)	12.5%
Days with rainfall > 3 inches (days)	0.2	0.2 (0.1 – 0.3)	37.9%	0.2 (0.1 – 0.4)	60.7%	0.3 (0.1 – 0.5)	97.4%
Annual maximum consecutive dry days (days)	12.6	12.8 (11.5 – 14.1)	2.6%	12.9 (11.6 – 14.1)	3.0%	13.5 (11.9 – 15.0)	7.7%
“Very heavy” (95 th percentile) precipitation (inches)	0.8	0.9 (0.8 – 0.9)	5.3%	0.9 (0.9 – 1.0)	9.1%	1.0 (0.9 – 1.0)	15.1%
Days with precipitation above baseline “very heavy” precipitation (days)	10.5	11.7 (10.2 – 13.1)	12.5%	12.7 (10.7 – 14.0)	21.1%	13.9 (11.7 – 15.5)	32.9%
“Extremely heavy” (99 th percentile) precipitation (inches)	1.4	1.5 (1.4 – 1.6)	7.1%	1.6 (1.5 – 1.7)	11.3%	1.7 (1.5 – 1.8)	18.7%
Days with precipitation above baseline “extremely heavy” precipitation (days)	2.4	3.0 (2.3 – 3.7)	26.1%	3.5 (2.6 – 4.3)	43.4%	4.2 (3.0 – 5.2)	74.0%
Annual maximum 3-day precipitation event (inches)	3.2	3.4 (3.0 – 3.8)	8.2%	3.6 (3.1 – 4.0)	12.8%	3.8 (3.3 – 4.2)	19.91%

Note: Projections are based a 23-model ensemble of LOCA downscaled data, SSP 5–8.5. Values reported are the median for the 23-model ensemble, as well as the 10th and 90th percentile values across models.

2.5 Coastal Changes

2.5.1 Coastline Changes along the Delaware River and Estuary

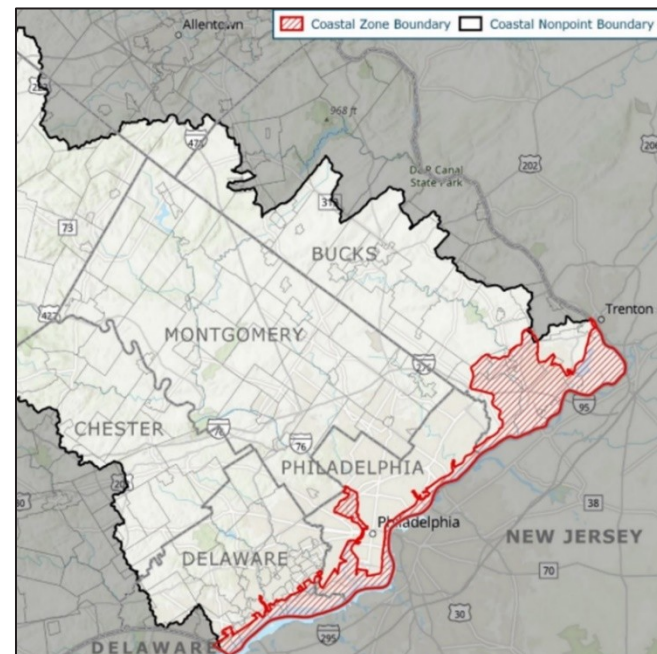
Pennsylvania has a small 56-mile coastline along the Delaware Estuary, as seen in **Figure 18**. This coastline spans from Morrisville, PA to Marcus Hook, PA.³⁸ Storm surge has previously led to coastal flooding from the Delaware River and forced interstate closures.³⁹ Rising sea levels are expected to exacerbate this risk. Because of land subsidence in the Mid-Atlantic region, local sea level rise is projected to be approximately 0.06 inch per year greater than the global average.⁴⁰ In an intermediate-high sea level rise scenario, water levels are expected to rise by 1.4 feet by mid-century, and 5.0 feet by the end of the century.⁴¹ The intermediate-high scenario has a 2% change of occurring or being exceeded.⁴² **Figure 19** on the next page highlights sea level rise scenarios in the Delaware Estuary Coastal Zone over the course of the century, including the intermediate-high scenario shown in orange. While Philadelphia saw approximately eight days of tidal flooding in a year early this decade, it is likely to see 74 days of tidal flooding by mid-century.⁴³ Higher sea level exposes more of Pennsylvania's population to flooding.

As the coastline experiences a rise in sea level, the abutting tidal wetlands may be inundated.⁴⁴ Already, Pennsylvania's coastline varies with the large tidal fluctuations in the Delaware River and Chesapeake Bay. Sea level rise will exacerbate these fluctuations. While Pennsylvania's coastal area is relatively limited, sea level rise threatens the ecosystem and low-lying facilities and properties in the Delaware Estuary Coastal Zone.

For example, almost 1,000 people in Philadelphia would be immediately impacted by the two feet of sea level rise expected by

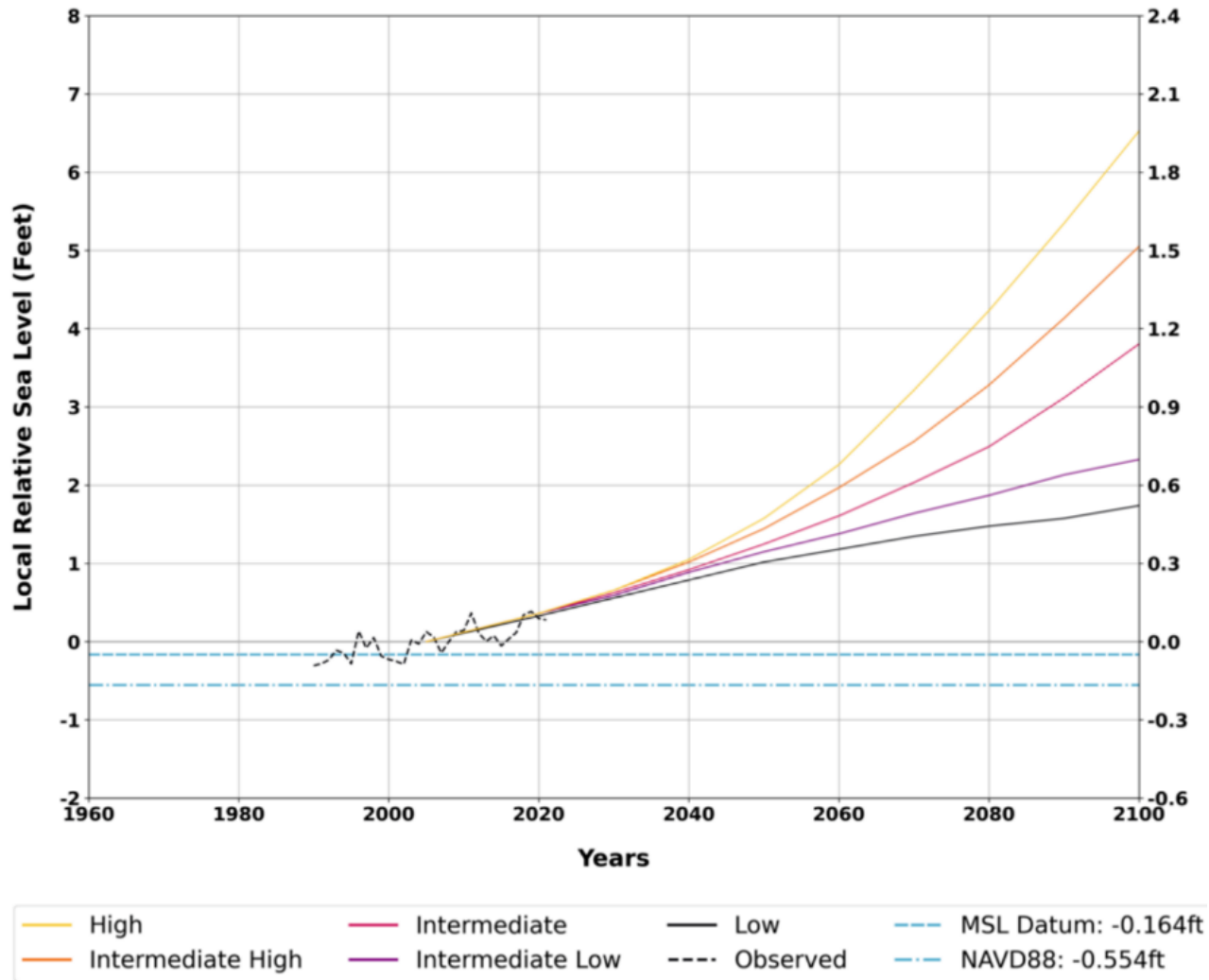
2060, and the almost 6,000 that live within four feet would also see higher flood risk by mid-century. A flood reaching four feet above sea level rise would affect about \$686 million in property value.⁴⁵ Storm surge or other extreme flooding is likely to reach nine feet above sea level by the end of the century. Such a flood would affect about 38,000 individuals and \$3.4 billion in property value.^{46,47} **Figure 20** and **Figure 21** on a following page highlight the change in areas that may be inundated under a five-foot rise in sea level. Additionally, sea level rise is expected to result in salinity increases throughout the Delaware Estuary, which will affect ecosystems and drinking water supplies. The consequences of sea level rise are further discussed in **APPENDIX B** (see pg. 92).

Figure 18. Delaware Estuary Coastal Zone map



Source: Pennsylvania DEP.

Figure 19. Sea level rise scenarios for the Philadelphia tide gauge



Source: NOAA Tides and Currents. <https://tidesandcurrents.noaa.gov>

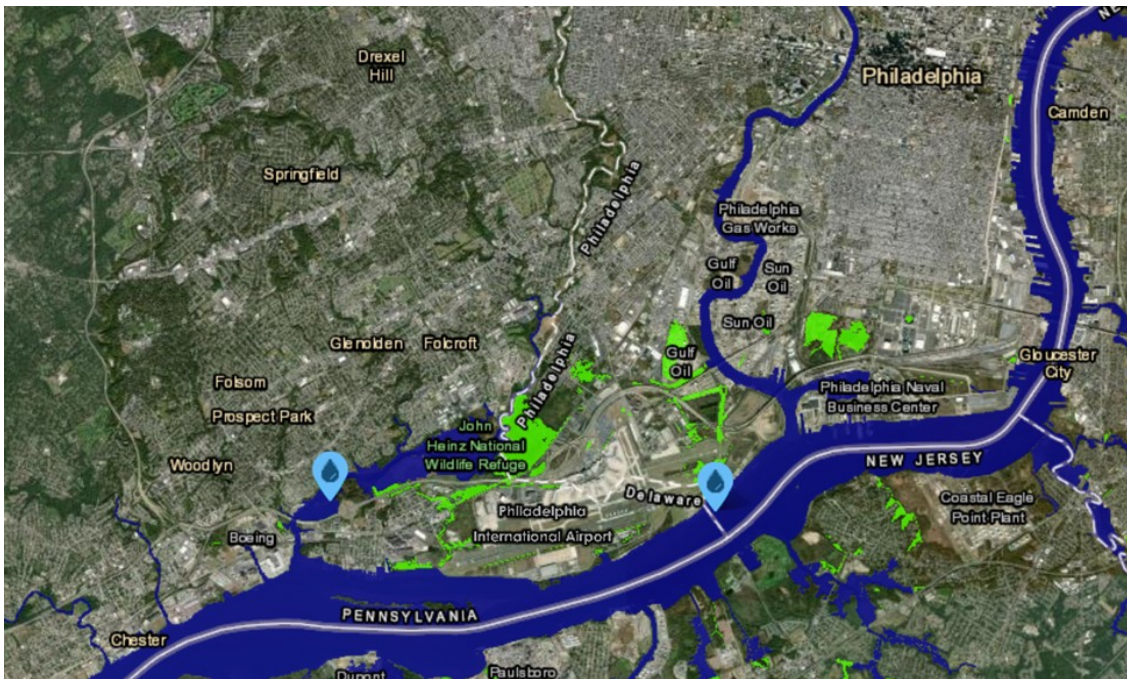


Figure 20. Current areas at risk from tidal flooding

Areas shaded in lime green represent low-lying areas currently at risk from flooding and dark blue areas describe existing water bodies. Source: NOAA Sea Level Rise Viewer. <https://coast.noaa.gov/slr/>

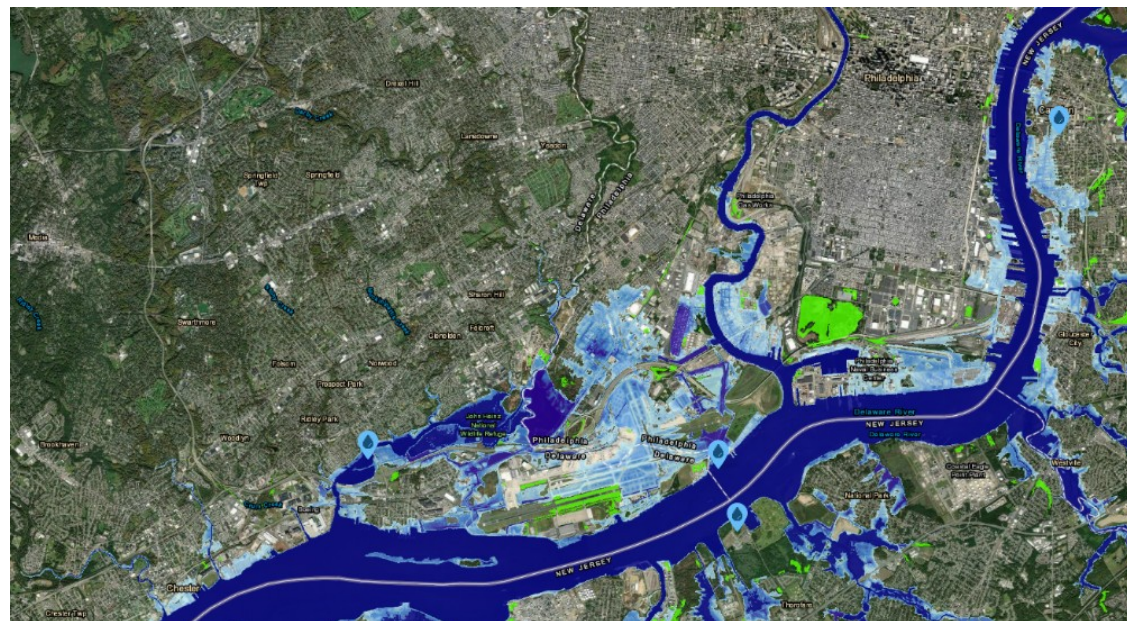


Figure 21. Areas at risk from tidal flooding from a 5-foot rise in sea levels

Areas shaded in lime green represent low-lying areas currently at risk from flooding, dark blue areas describe existing water bodies, and light blue areas highlight inundated areas with 5ft sea level rise. Source: NOAA Sea Level Rise Viewer. <https://coast.noaa.gov/slr/>

2.5.2 Coastline Changes along Lake Erie

Pennsylvania also has a 64-mile coastline along Lake Erie (highlighted in **Figure 22**). Lake Erie is projected to experience significantly higher variability in water levels under a changing climate.⁴⁸ Warmer temperatures and increased extreme precipitation events are anticipated to have substantial effect on Lake Erie.

Warmer temperatures will increase evapotranspiration, which in turn is projected to lower levels in Lake Erie in some years or months.⁴⁹ However, at other points, increased average precipitation and greater extreme precipitation events are projected to raise water levels.⁵⁰ For example, as a result of increased rain, Lake Erie hit its highest ever water level in June 2019.⁵¹ Lake Erie's water levels are expected to continue fluctuating in the decades to come.

Climate change is also projected to affect water quality and increase erosion. Warming temperatures will result in higher lake water temperatures and increased frequency of extreme precipitation events will drive greater runoff into the lake. Combined warmer waters and increased runoff will boost the likelihood of *E. coli* and algal blooms, compromising water quality and threatening human and ecosystem health.⁵² Additionally, as winter temperatures become less severe, each of the Great Lakes will be covered by less ice, leading to higher concentrations of suspended solids that contribute to algal blooms.^{53,54} Higher inter-basin connectivity from increased storms and winds in the area will increase the concentration of suspended solids in Lake Erie.⁵⁵ Although the deeper waters of eastern Lake Erie have been less affected than western Lake Erie, harmful algal blooms have grown more common near the Pennsylvania shoreline in recent years, posing public health concerns.⁵⁶ Algal blooms such as these are expected to become more frequent and severe with climate change.

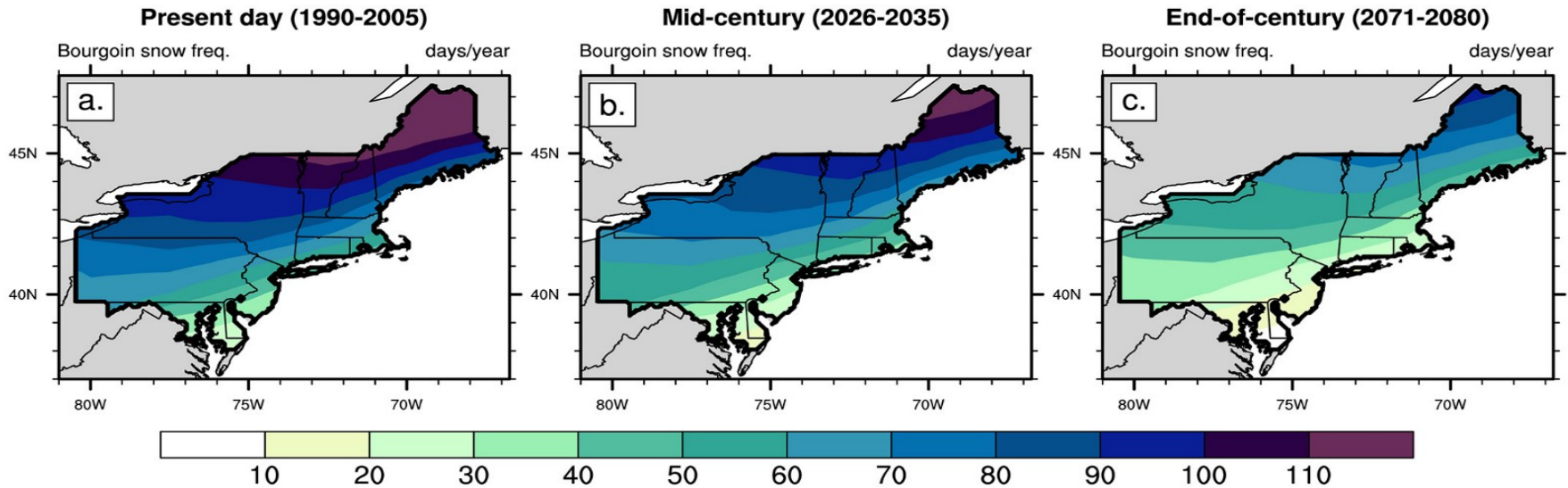
Figure 22. Lake Erie Watershed.



Increased runoff is also anticipated to cause greater bluff instability as runoff erodes the bluff face.⁵⁷ With lower ice coverage the ice dunes that typically protect the Presque Isle's beaches will experience greater erosion.⁵⁸ Coastal erosion rates are also expected to increase as the Lake's coastlines are impacted more frequently by severe storms.⁵⁹

Warmer temperatures will also alter snow patterns. In the winter, warmer water and a lack of surface ice on the lake will likely result in an increase in lake effect snow events in the short-term.^{60,61} Lake Erie is anticipated to experience significant overall change from climate change.

Figure 23. Average number of days per year where snowfall could occur, present-day, mid-century, and end-of-century



Values for present day represent all years 1990–2005, values for mid-century represent all years 2026–2035, and values for end-of-century represent all years 2071–2080.

Source: Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

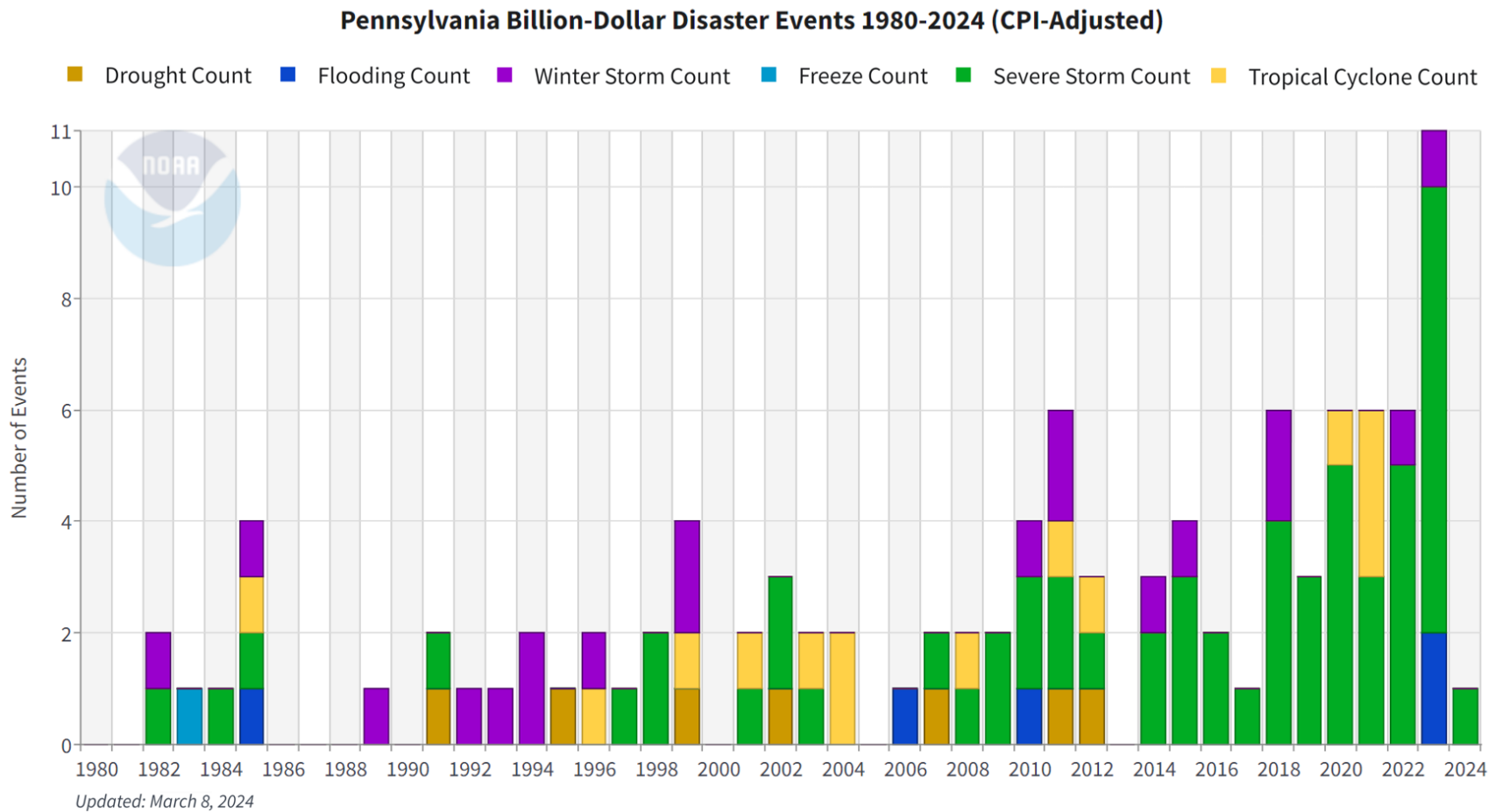
2.6 Extreme Weather Events

Extreme weather events will continue to have severe impacts on Pennsylvania as climate change increases the intensity of extreme weather events. In the literature, a consensus highlights that extreme storms are expected to be stronger and lead to heavier rains. Cumulative precipitation from storms is expected to increase.⁶² There is also consensus in the literature that, globally, the proportion of very intense (i.e., Category 4–5) tropical cyclones will increase.⁶³ For the North Atlantic region specifically, various modeling results are mixed, but the median projected change is a decrease in the overall frequency of tropical cyclones and an increase in the frequency of Category 4–5 tropical cyclones.⁶⁴

While severe non-tropical rain events are anticipated to become more likely,⁶⁵ snowstorms are projected to decrease in frequency.^{66,67} Smaller storms rather than major storms are forecasted to comprise

the majority of this reduction.⁶⁸ **Figure 23** highlights the projected decrease in days in which snow events can occur. Increasing temperature may also decrease the severity of average weather in winter and reduce the amount of total precipitation that falls as snow.⁶⁹ When snow storms do occur, they may be more extreme due to changes in global temperature gradients that affect the path of the jet stream.⁷⁰ As mentioned in the previous section (Coastline Changes along Lake Erie), lake effect snow events are projected to increase in the short-term.^{71,72} In the long-term, however, as winter temperatures warm significantly, lake effect snow events will decrease.^{73,74} From 2000 to 2023, 65 “billion-dollar” disaster events occurred in Pennsylvania because of tropical cyclones, severe storms, and winter storms. **Figure 24** highlights the change in the number of billion-dollar disaster events over the last 43 years. Heavy rains, flooding and damages from wind are significant driver of damage during these events.

Figure 24. Billion-dollar extreme weather events in Pennsylvania 1980–February 2024



Source: NOAA National Centers for Environmental Information. 2023. Billion-Dollar Weather and Climate Disasters: Time Series. <https://www.ncdc.noaa.gov/billions/time-series>

2.7 Landslides and Sinkholes

Currently, landslides and sinkholes are serious hazards in the Commonwealth that affect transportation networks and buildings and create serious health and safety concerns.⁷⁵ The effect of climate change on the location, quantity, frequency, and severity of landslides remains uncertain, though climate change is expected to increase the rate of sinkhole formation as extreme precipitation is forecasted to increase.

Projections also indicate that an increase in the frequency and intensity of severe precipitation events could increase landslide risk, because heavy rainfall is a key cause of certain types of landslide events.^{76,77} Significant uncertainty, however, is associated with these projections.⁷⁸

Due to Pennsylvania's geology, soil texture, precipitation, and rate of human development, regions of the state have a moderate to very high sinkhole susceptibility.⁷⁹ Sinkhole development is caused by changes in the groundwater table (i.e., water input into or extraction from the ground), soil disturbance, concentrated water flow, high intensity but short duration storms, erosion, and heavy surface loads.^{80,81,82} Activities and conditions that may drive these mechanisms include the thawing of frozen ground, groundwater pumping, land use practices, construction, drought, declining water levels, mining, pipe leakage, water impoundments (i.e., basins, ponds, reservoirs), runoff, and drilling.^{83,84} Models predicting urban development and future precipitation in Pennsylvania suggest that southeastern Pennsylvania will remain a hotspot for sinkholes and the projected increase in extreme precipitation will increase the rate of sinkhole formation in this area of the Commonwealth.⁸⁵

Drought and groundwater table decline have both been linked to climate change, and are significant drivers of sinkhole

development.^{86,87} With projected increases in the occurrence of drought and low summer groundwater levels in the coming century, proper groundwater management may become necessary to mitigate the increasing risk of sinkholes. More state level research delineating how different types of sinkholes respond to changes in environmental conditions is needed to understand how climate change may impact on the interlocking mechanisms that cause sinkhole development in Pennsylvania.

2.8 Climate Change Attribution Science and Extreme Weather in Pennsylvania

Climate attribution is the process of discerning whether, and to what extent, human versus natural influences are responsible for observed changes in the Earth's climate system and the extent to which extreme weather events might be influenced by climate change.⁸⁸ Advances in climate attribution science, largely due to improvements in computer models and data collection, have reframed how climate change can be attributed to extreme weather events. For many years, climate scientists were able to capture general trends on a global basis—the change in global average temperatures being one such example. Increasingly, attribution science is able to address the extent to which specific extreme weather events might have been influenced by human-induced climate change.

2.8.1 Current State of Attribution Science

The process of determining attribution around extreme weather typically uses one of two approaches.⁸⁹ The *risk-based approach* seeks to statistically address whether the likelihood of certain types of extreme weather events (their frequency, intensity, location or some combination) has been influenced by human activity through

a changing climate. The second approach, the *storyline approach*, relies on analysis of physical factors such as air circulation patterns and sea surface temperature to determine causal relationships between physical conditions and extreme events.^{90,91} These physical conditions can then be linked to human factors and attributed to climate change.

Both the risk-based and storyline methods of attribution science rely heavily on computer models of climate processes. These computer models generate “counterfactuals” – simulated histories of Earth’s climate system with and without human activity.⁹² These counterfactuals are used to evaluate the likelihood of specific kinds of events occurring (in the risk-based approach) or the likelihood of certain Earth-system conditions prevailing (in the storyline approach) without human influence over the climate. Improvements in computational capability and ability to downscale climate models to very specific areas have both contributed to the increased understanding of the influence of human activity on extreme weather events.⁹³

While attribution science has improved in recent years, it is important to understand what these studies can and cannot say regarding extreme weather events, and the major sources of uncertainty involved in attributional studies. While risk-based and storyline attribution studies use similar methods, they yield different kinds of conclusions.^{94,95} Risk-based analysis is focused on likelihoods and not specific events – these attributional studies can speak to the increased risk of certain kinds of extreme weather as the climate continues to change but a risk-based study cannot determine whether or to what extent a specific event was influenced by human activity. Storyline analysis, very much like an investigation, is focused on the circumstances surrounding specific extreme weather events. A storyline analysis can suggest whether or to what extent a specific event was influenced by human-induced climatic

conditions but cannot directly speak to the likelihood of these types of events occurring in the future.

Like all analysis of complex systems such as the global climate, both risk-based and storyline attributional studies involve uncertainty.⁹⁶ Major sources of uncertainty include the data that are used to construct counterfactual climate models, since these data have been gathered over a period of over a century using very different methods. Climate models themselves also involve uncertainty since scientists are still learning fundamental information about the Earth’s climate system. The quality of the modeled counterfactuals themselves can be hard to determine since those counterfactuals involve climate histories that did not actually happen.⁹⁷

2.8.2 Attribution of Extreme Weather in Pennsylvania

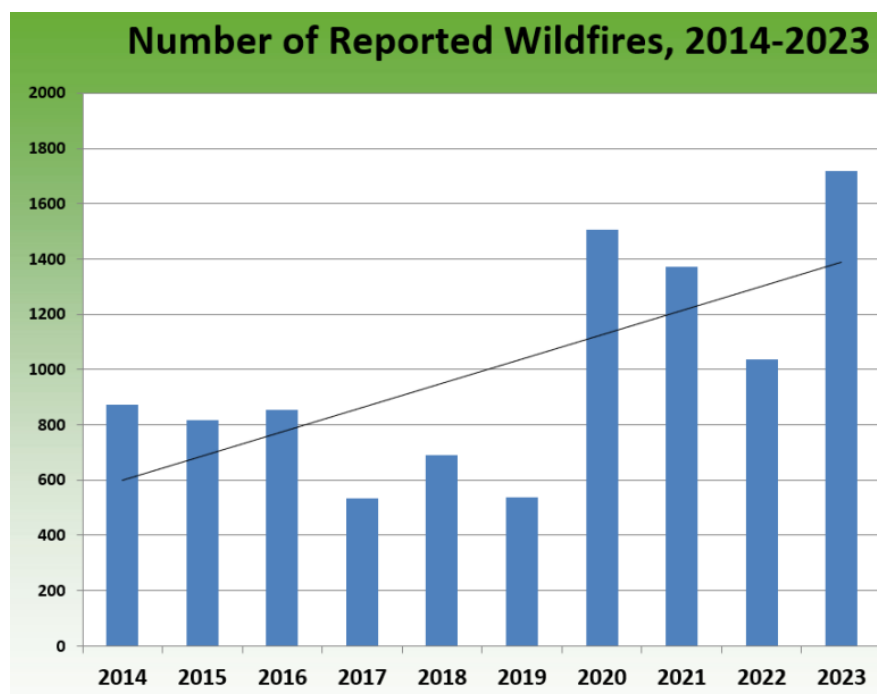
This Impacts Assessment highlights extreme precipitation events and flooding, along with heat waves and extremely hot summer days as two climate risks that are particularly important for Pennsylvania. While Pennsylvania itself is a relatively small area for the purposes of extreme weather attribution studies (because of the state’s numerous climate zones and challenges in downscaling large-scale climate models), a number of extreme weather attribution studies covering the eastern and northeastern U.S. have suggested that human factors are a contributor to the risk of extreme precipitation/flooding events and extreme heat.^{98,99} Human-induced climate change is likely to increase the risk of very hot weather in the summertime in the northeastern U.S. (including Pennsylvania), and therefore increases the risk of seeing the kinds of heat extremes that Pennsylvania experienced during the summer of 2023. Cities such

as Philadelphia, Harrisburg, and Allentown experienced heat events during the summer of 2023 that one analysis judged to be twice as likely as they would have been in the absence of climate change.¹⁰⁰

Risk-based attributional studies, while not based around specific events, have suggested that flooding events in Pennsylvania are likely to become more frequent and more severe amid a changing climate.¹⁰¹ Studies specific to Pennsylvania, based on downscaled climate models and hydrometeorological models, have suggested that flooding hazards (severity of flood damage) and exposure (the geographic areas prone to flooding) are both increasing with a changing climate, with a large number of cities and boroughs in Pennsylvania likely to be affected.

Wildfires are not considered a major direct climate risk for Pennsylvania, but the number of non-disastrous wildfires has been rising over the last several decades. More than 1,000 wildfires were reported each year from 2020–2023,¹⁰² and Pennsylvania’s Department of Conservation and Natural Resources (DCNR) reports that the trend of fires has increased since 2014 (**Figure 25**). This is close to double the average number of wildfires seen each year since 1990.¹⁰³ Extreme wildfire events occurring outside the Commonwealth also cause impacts in Pennsylvania. The summer of 2023 brought degraded air quality to many areas of Pennsylvania because of the spread of wildfires in Canada. Extreme weather attribution analysis has suggested that the conditions under which these wildfires developed and spread have become twice as likely to prevail under a changing climate.¹⁰⁴

Figure 25. Number of wildfires reported in Pennsylvania



Source: PA DCNR

2.9 Climate Change Impacts Outside of Pennsylvania

Climate change is a global phenomenon with highly local impacts. This study focuses on the impacts of climate variables within the boundaries of Pennsylvania. However, it is important to remember that Pennsylvania exists within an interconnected natural and socioeconomic network and **climatic changes outside the borders could have impacts within the Commonwealth.**

For example, In the summer of 2023, smoke from wildfires in northern Ontario and Quebec, Canada, traveled south and caused air quality

impacts across Pennsylvania and surrounding states. An unprecedented drought led to significant dry fuel available to burn, sparked by lightning. An unusual wind pattern pushed the smoke southward into Pennsylvania and other Northeast states. A similar event occurred in 2021 due to fires from the American West. Scientists say that climate change is making conditions like heat and drought that led to these wildfires more likely. During these wildfire smoke events, air quality alerts were triggered, outdoor recreation activities were canceled, sporting events were postponed, and outdoor worker productivity was reduced causing impacts to the economy. The poor air quality also exacerbated asthma and other respiratory illnesses for vulnerable populations including the elderly and small children. Though unquantified for these events, studies show that wildfire smoke can have mental health impacts, particularly when the smoke is chronic and persistent.¹⁰⁵

Health impacts that prevent people from working may cause workforce implications for which small businesses may be particularly vulnerable. Overall, the human health and economic impacts have the potential to be significant. In Canada, smoke originating from fires farther away has been estimated to directly cause hundreds of premature deaths and the economic valuation of those health impacts has been estimated in the billions.¹⁰⁶ These impacts have equity implications as well; one study found that increased risks of respiratory admissions from wildfire smoke were significantly higher for women than for men and for black people than white people.¹⁰⁷ This difference may be due to the different rates of underlying health issues for different demographics.¹⁰⁸ Although the extreme wildfire events may not yet occur within the Commonwealth, Pennsylvania communities will have to cope with the impacts.

Furthermore, Pennsylvania is a transportation hub for a significant amount of goods and passengers and is home to several major

interstate highways and railroad lines. Climate change impacts on transportation infrastructure outside Pennsylvania could have ramifications within Pennsylvania, affecting the broader supply chains for food and other goods. Stable prices and food security could be at risk if Pennsylvania is unable to import from surrounding states due to climate impacts on infrastructure. For instance, a major hurricane event could force closures at east coast ports, limiting imported bulk goods from abroad and increasing the price of staple foods for communities in the Commonwealth. Impacts would likely be more severe for Pennsylvanians living without grocery stores nearby or who face financial, mobility, or housing-related barriers to food access.

Climate impacts to other states and countries may also create climate refugee populations looking for safe-havens, and Pennsylvania could see change in migration patterns in the future as other areas of the U.S. directly experience extreme heat, storms, wildfires, floods, or other extreme weather events. Even if these climate hazards do not impact Pennsylvania directly, the hazards may force people to migrate. For example, sea level rise along the coasts of neighboring states may cause populations to move inland to Pennsylvania seeking higher land that is less vulnerable to this impact. Communities along the New Jersey, Delaware, and Maryland coasts may be particularly at risk and see Pennsylvania's higher elevation as a safe place to relocate without the risk of inundation due to sea level rise.

Recognizing the interconnected nature of climate impacts across scales is important to ensuring Pennsylvania can be resilient to a range of conditions and changes, regardless of where they occur.



CHAPTER 3

Risk Assessment Overview

3.1 Key Findings and Overall Climate Risks

This chapter presents an overview of key findings from the risk assessment. The comprehensive results can be found in [APPENDIX B](#), and an overview of the approach to evaluate impacts and risks is found in [APPENDIX A](#).

Overall, this assessment finds that the projected climate changes detailed in [CHAPTER 2](#) could have significant impacts to Pennsylvania's people, environment, infrastructure, and economy. Key findings include:

- **Increasing average temperatures and heavy precipitation and inland flooding** emerged as the two highest-risk hazards by mid-century, and could have harmful effects across the entire state and all sectors.
 - Increasing temperatures have the highest consequences for human health and environmental justice and equity, especially in urban areas.
 - Extreme precipitation events and flooding could also have severe consequences to human health, agriculture, and built infrastructure, with populations, farms, and infrastructure located in or near floodplains at particular risk.
- Heat waves will become increasingly common and will create health and economic risks for vulnerable populations, including low-wealth populations, the elderly, pregnant people, people with

certain mental illnesses, outdoor workers, and those with cardiovascular conditions. These risks will be particularly acute in areas subject to the urban heat island effect.

- All hazards; especially heat waves, increasing temperatures, and flooding, could affect public health negatively. For example, higher temperatures mean more days with hazardous heat conditions or reduced air quality, and increased risk of heat-related illness and, indirectly, vector-borne illness. Flooding increases the risks of direct injury from flood waters and of illness caused by contaminated water.
- Climate change will not affect all Pennsylvanians equally. Some may be more at risk because of their location, income, housing, health, or other factors. As Pennsylvania works to reduce its climate risks, it should also address these inequitable impacts and ensure that adaptation efforts do not worsen them.
- Landslides and sea level rise pose relatively low risks statewide but can cause severe impacts in the locations where they occur. For example, sea level rise in the Delaware Estuary could drastically change its ecology and threaten the built infrastructure near the tidal zone. Landslides can have severe consequences if they cut off critical transportation routes, particularly in rural areas of Southwest Pennsylvania.
- For changes that will come on gradually, such as rising temperature, Pennsylvania has an opportunity not only to reduce potential harm, but also to capitalize on potential positive changes. This is particularly true for rising average temperature, which could allow for warmer-weather crops, expanded warm-weather recreation and tourism, and lower wintertime heating energy demand.

3.1.1 Overall Impacts by Category

Human Health

One of the largest climate-related threats to human health in Pennsylvania is heat waves, which cause mortality and morbidity and are projected to increase significantly. Relatedly, increasing average temperatures will likely contribute to worsened air quality and encourage the spread of vector-borne diseases. As with heat waves, severe cyclones and heavy precipitation are expected to increase and can both directly and indirectly cause mortality and morbidity.

Key Potential Consequences from Heavy Precipitation and Flooding

- Flood damage to homes, businesses, and critical energy and transportation infrastructure, particularly those located in floodplains
- Health risks from injury from flood waters or water quality contamination
- Agricultural impacts including increased risk of runoff, erosion, and nutrient leaching, and greater challenges to timing of crop planning
- Wide-ranging economic impacts, from disruptions to recreation and tourism to infrastructure service disruptions
- Disproportionate impacts in vulnerable communities

Key Potential Consequences from Increasing Average Temperatures

- Increase in health and safety risks, such as more days with hazardous heat conditions for outdoor workers and reduced air quality from higher ground-level ozone and increased pollen
- Potential increased energy burden for low-wealth households
- Gradual shifts in growing seasons, suitable habitat range, and ecosystems
- Increase in pests, invasive species, and diseases (e.g., Lyme disease)
- Change in outdoor recreational opportunities (e.g., severe reduction in snow- and ice-based winter recreation and tourism)

Environmental Justice and Equity

The greatest climate-related risks to human health (i.e., increasing temperatures/heat waves and severe storms/heavy precipitation) are expected to disproportionately impact communities in Pennsylvania that are within EJ areas and thus, are already overburdened by hazards and other structural disadvantages. Sea level rise is not expected to disproportionately impact these populations from a statewide perspective. However, those along the Delaware River who live in affordable housing, which has been found to have a higher risk compared to standard housing, may be more sensitive and less able to adapt to coastal flooding.

Agriculture

The agricultural sector is expected to be impacted mostly by increasing average temperatures, as well as increased flooding from severe cyclones and other heavy precipitation events. Increasing temperatures will shift growing seasons and plant hardiness zones, and increased flooding will cause runoff, erosion, and challenges with the timing of crop planting or harvesting. Temperature and precipitation shifts will also change the range for pests and diseases, exposing new threats to the interlinked environmental, animal, and human health systems. Heat waves will also cause stress to livestock, in addition to crops, and threaten agricultural workers' health and productivity.

Recreation and Tourism

Recreation and tourism in the Commonwealth will be most impacted by increasing average temperatures, which are expected to negatively impact snow and ice-based recreation and have the potential to contribute to harmful algal blooms that discourage

fishing and other freshwater-based recreation. High temperatures can also exacerbate air quality concerns and make active outdoor recreation more difficult. Although the warm-weather season is expected to lengthen, warm-weather activities can have a mixed impact given the potential increase in the spring and fall and decrease during heat waves in the summer. Increases in the severity of cyclones and other heavy precipitation events will likely cause disruptions at Philadelphia International Airport and closures of state parks and forests.

Other Economic Activity

Increasing temperatures can cause fatal stress to forests and thus negatively impact the forest products industry, which employs 10% of Pennsylvania's manufacturing workforce. Heat waves will likely decrease the productivity of workers who engage in physical activity outdoors. Cyclones can temporarily disrupt economic activity, with significant consequences for the energy sector and small businesses dependent on electricity. Additionally, flooding impacts on transportation networks and power supplies can have downstream consequences on other sectors.

Forests, Ecosystems, and Wildlife

Increasing average temperatures are expected to shift suitable habitat for tree species to higher latitudes and elevations, which may have a neutral effect given that species at the southern extent of their range in Pennsylvania would have less suitable habitat, whereas those at the northern extent would have more. Longer growing seasons may increase overall growth rates; however, this may be offset by increased mortality in stressed forest species.

Built Infrastructure – Energy, Transportation, and Other

Climate change can stress infrastructure as it begins to experience conditions it may not have been designed to withstand. Increasing average temperatures, including heat waves, will increase energy usage for cooling in the summer, potentially straining the grid. In contrast, heating needs are expected to decrease in the winter. Higher temperatures will also impact the service life of buildings and possibly increase maintenance costs. More frequent heat waves and more severe flooding events can cause costly transportation network disruptions. Severe cyclones and other heavy precipitation events can cause damage to all building types (residential, commercial, and industrial) and overwhelm urban stormwater and wastewater management systems.

3.1.2 Risk Assessment Results Overview

Risks from all the analyzed hazards are expected to increase from the present-day through 2050 by varying degrees. The Commonwealth subsequently needs to plan for more significant and complex climate risks. These results are intended to help understand relative risk and inform priority adaptation strategies in the CAP. They are not a comprehensive or prescriptive assessment of all potential risks to Pennsylvania.

Table 5 and **Figure 26** summarize the overall risks at present and by 2050. As seen in **Table 5**, flooding is currently the highest-risk hazard facing Pennsylvania, but risks from increasing average temperatures and heat waves could rise to be as high as flooding is today by mid-century. Flooding from extreme rain events affects built infrastructure, human health, and agriculture, with ripple effects throughout the economy. Increasing average temperatures will likely

affect nearly every aspect of life in the Commonwealth, from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment.

Figure 26. Overall summary risk matrix (2050)

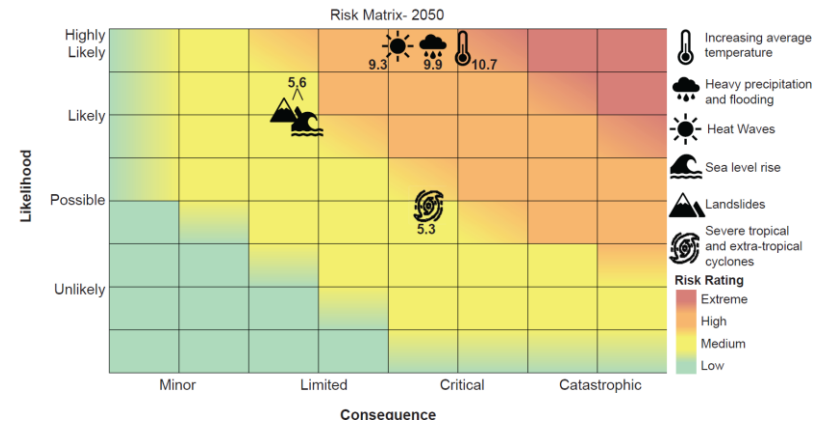


Table 5. Overall risk assessment results

	Climate Hazard	Current Risk Rating (Score)	2050 Risk Rating (Score)
1	Increasing average temperatures	Medium (5.3)	High (10.7)
2	Heavy precipitation and inland flooding	High (9.9)	High (9.9)
3	Heat waves	Medium (4.7)	High (9.3)
4	Landslides	Medium (5.6)	Medium (5.6)
5	Sea level rise	Low (1.9)	Medium (5.6)
6	Severe tropical and extra-tropical cyclones	Medium (5.3)	Medium (5.3)

Finally, **Figure 27** and **Figure 28** show the overall risk for each hazard and consequence category. The maximum possible overall risk rating is 16. Priority climate risks per consequence category can help identify adaptation priorities for the CAP per sector. The values

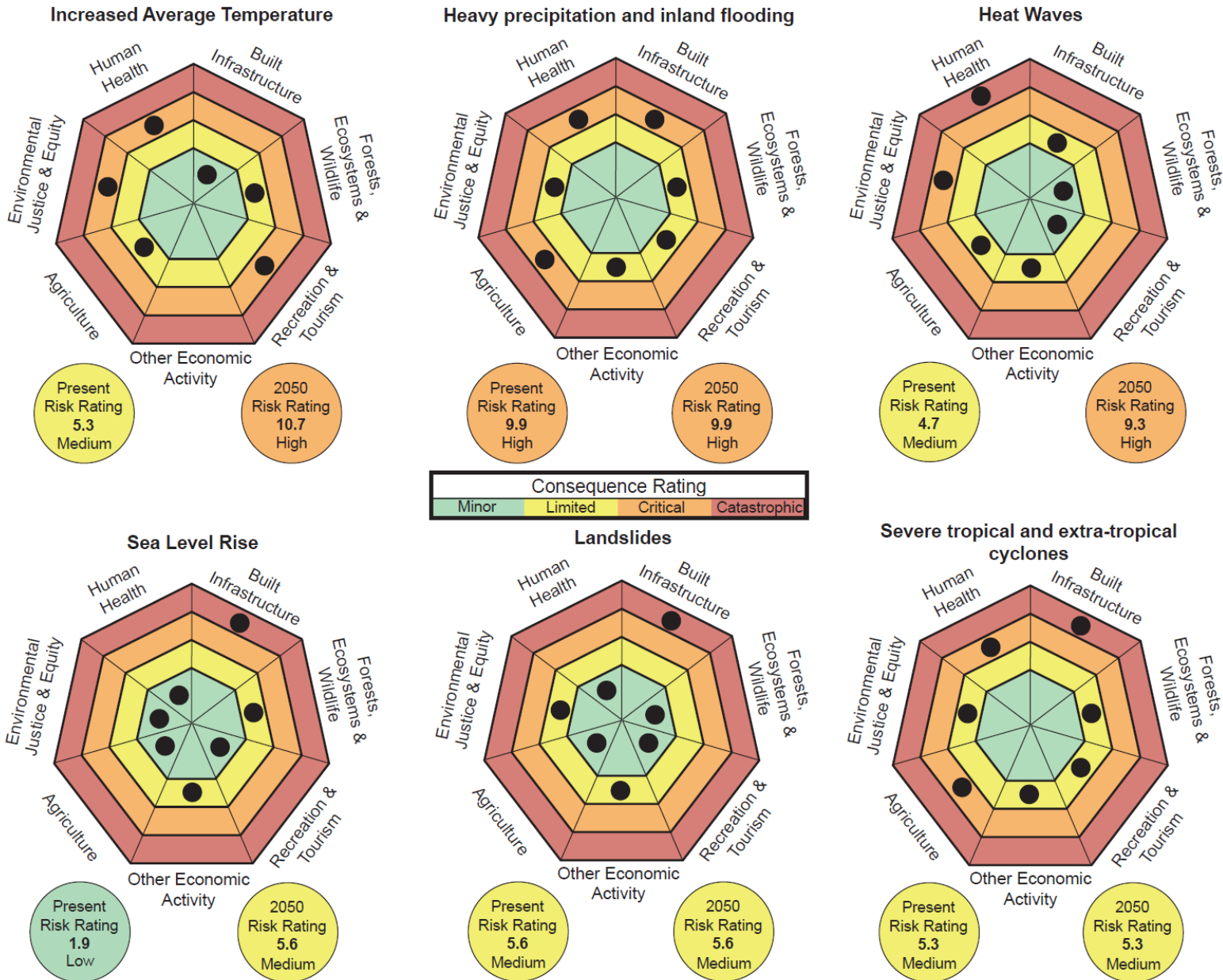
represent the product of the 2050 likelihood rating and the individual consequence score, and reflect the key findings mentioned earlier. For more information on how the risk score was calculated, see [APPENDIX A](#).

Figure 27. Total risks by hazard and sector (scores within the table are hazard likelihood rating × consequence rating)

		IMPACT CATEGORY						
		Human Health	Environmental Justice and Equity	Agriculture	Recreation and Tourism	Other Economic Activity	Forests, Ecosystems, and Wildlife	Built Infrastructure
CLIMATE HAZARD	Increasing average temperatures	12	12	8	12	8	16	4
	Heavy Precipitation and Flooding	12	8	12	8	8	8	12
	Heat Waves	16	12	8	4	8	4	8
	Landslides	3	6	3	3	6	3	12
	Severe tropical and Extra-tropical cyclones	6	4	6	4	4	4	8
	Sea Level Rise	3	3	3	3	6	6	12

Legend			
Low Risk	Medium Risk	High Risk	Extreme Risk

Figure 28. Summary of consequences and risks by hazard



Impacts to human health are one of the greatest risks, especially related to extreme heat. Increasing average temperatures and heat waves are projected to increase heat-related illnesses or deaths, allergies, violent crimes, and anxiety and mood disorders. Populations at greater risk from these heat-related hazards include the elderly, young children, low-income communities, pregnant people, individuals with cardiovascular disease, unhoused populations, and outdoor workers. Nights where temperatures remain above 68°F can be dangerous for human health as the body may not be able to cool down from the heat stress of the day. This deprives the body of a much-needed relief and could add additional physiological strain, increasing the risk of heat-related health impacts.¹⁰⁹ Flooding and severe cyclones can also have severe health impacts as critical services are disrupted and conditions are more hazardous. **Figure 29** summarizes the health impacts of climate change. The impacts to human health of natural disasters and extreme weather events are felt more strongly among racial and ethnic minority populations as minority populations have a higher mortality rate from these events.¹¹⁰

Key Terms: Additional key terms are included in Table 1. Glossary of key terms.

Risk – The chance a climate hazard will cause harm. Risk is a function of both the likelihood of an adverse climate impact occurring and the severity of its consequences (i.e., Risk = Likelihood x Consequence).

Climate hazard – Changes or events related to global climate change. Climate hazards can be discrete (e.g., severe storms) or ongoing (e.g., increasing average temperatures).

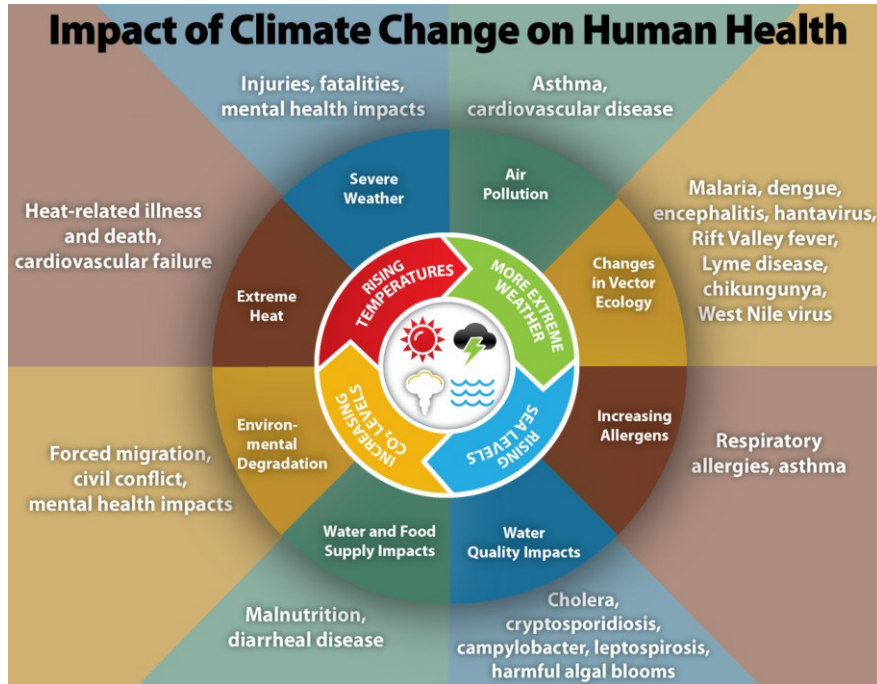
Impact – The effect of a climate hazard.

Likelihood – The probability that a climate hazard will occur or its expected frequency.

Consequence – A measure of the severity of impacts from a climate hazard.

Environmental Justice (EJ) areas – A geographic area characterized by increased pollution burden, and sensitive or vulnerable populations based on demographic and environmental data. EJ areas in Pennsylvania are defined at the census block group level based on more than 30 environmental, health, and socioeconomic indicators.

Figure 29. Impacts of climate change on physical, mental, and community health



Source: U.S. Climate Resilience Toolkit, Impact of Climate Change on Human Health <https://toolkit.climate.gov/image/505>

As reflected in **Figure 29**, consequence categories face significant and varying risks from different hazards. For example, forests, ecosystems, and wildlife face extreme risk from increasing temperatures but medium risk from heat waves. Ecosystems are generally more sensitive to long-term changes rather than short-term extreme events. On the other hand, the agricultural sector faces similar risks from increasing temperatures and heat waves. Livestock and crops are susceptible to heat stress from both increasing average temperatures, especially in the summer, and heat waves. For built infrastructure, landslides, sea level rise, and

severe tropical and extra-tropical cyclones received catastrophic individual consequence ratings. However, the likelihood of these events differs. When factoring in likelihood, landslides, sea level rise, and heavy precipitation and flooding (which received a critical consequence rating) emerge as extreme risks to built infrastructure.

In **APPENDIX B**, risk summaries by hazard are presented in order from the highest to lowest overall risk:

- Increasing Average Temperatures
- Heavy Precipitation and Inland Flooding
- Heat Waves
- Landslides
- Sea Level Rise
- Severe Tropical and Extra-Tropical Cyclones

Each summary includes an overview, a summary risk matrix, a summary table of scores and high-level justifications, followed by a more detailed description of each likelihood and consequence rating. The information presented in the risk summaries is derived from prior impacts assessments and updated with any new literature or information available since the 2021 Impacts Assessment was completed. These summaries describe the risks to the Commonwealth from each climate hazard. While the likelihoods associated with climate hazards vary, the dangers posed by each are evident. To reduce these impacts on Pennsylvania, the Commonwealth must act to address priority adaptation needs.

3.2 Approach Overview

The Impacts Assessment applies a risk-based method that evaluates both the relative likelihood and consequences of key climate hazards across sectors. Based on the previous Impacts Assessment, the risk assessment focuses on six primary climate hazards expected to affect the Commonwealth:

- Increasing average temperatures
- Heavy precipitation and inland flooding
- Heat waves
- Landslides
- Sea level rise
- Severe tropical and extra-tropical cyclones

The process for analyzing and evaluating each hazard is shown in **Figure 30**. The likelihood of each hazard occurring is evaluated on a scale of one to four **and the severity of each consequence is also evaluated on a scale of one to four for the following categories:**

- Human health
- Environmental justice and equity
- Agriculture
- Recreation and tourism
- Other economic activity
- Forests, ecosystems, and wildlife
- Built infrastructure

Based on the product of its likelihood and consequence scores, each hazard then receives an overall risk rating per the matrix in **Table 6**. Therefore, two hazards with similarly high consequence scores could

have significantly different risk ratings if the likelihood scores are different. The likelihood and consequence rating scales, among other methodological details, can be found in [APPENDIX A](#).

The assessment assumes that there have been no adaptation actions or policy changes to capture the “business-as-usual” risk. Thus, the results indicate where Pennsylvania has an opportunity to reduce risk, recognizing that some hazards or specific impacts may be easier to address than others.

Table 6. Risk rating matrix and scoring rubric

Likelihood	Consequence				Risk Score	Rating
	Minor	Limited	Critical	Catas-trophic	(low end inclusive)	
Highly Likely	4	8	12	16	12+	Extreme
Likely	3	6	9	12	6–11.9	High
Possible	2	4	6	8	3–5.9	Medium
Unlikely	1	2	3	4	1–2.9	Low

While all types of consequences have the potential to impact populations living in EJ areas, impacts in those areas are also specifically described in the environmental justice and equity consequences section for each hazard in [APPENDIX B](#).

To quantitatively and geospatially evaluate potential environmental justice and equity consequences, the Impacts Assessment uses Pennsylvania EJ areas identified from PennEnviroScreen. An EJ area is any community facing EJ issues, which are based on more than 30 environmental, health, and socioeconomic indicators. EJ areas serve as a proxy for already overburdened areas. This indicator does

not capture all impacts on overburdened populations (e.g., it does not capture impacts on overburdened populations not located in EJ areas). Nonetheless, it is valuable to begin examining structural disadvantages, and this assessment also draws on other information to supplement where possible given its limitations. **Figure 31** shows where EJ areas (at the block group level) are located across the Commonwealth, featuring inset maps of Philadelphia and Pittsburgh where higher population density makes block group shading less legible in the statewide map.

This analysis is not a comprehensive bottom-up assessment. While based solidly on evidence from past Impact Assessments, recent literature, and updated climate projections,¹¹¹ the decision-centered approach recognizes uncertainty and emphasizes practicality. Rather than aiming for a perfect characterization of risk, this approach focuses on gathering information at a sufficient level of detail to enable prioritizing the adaptation actions that can be taken to reduce risks. Further, it provides the foundation for PA DEP to easily revisit the results of the assessment as priorities or circumstances change.

Figure 30. Risk assessment overview

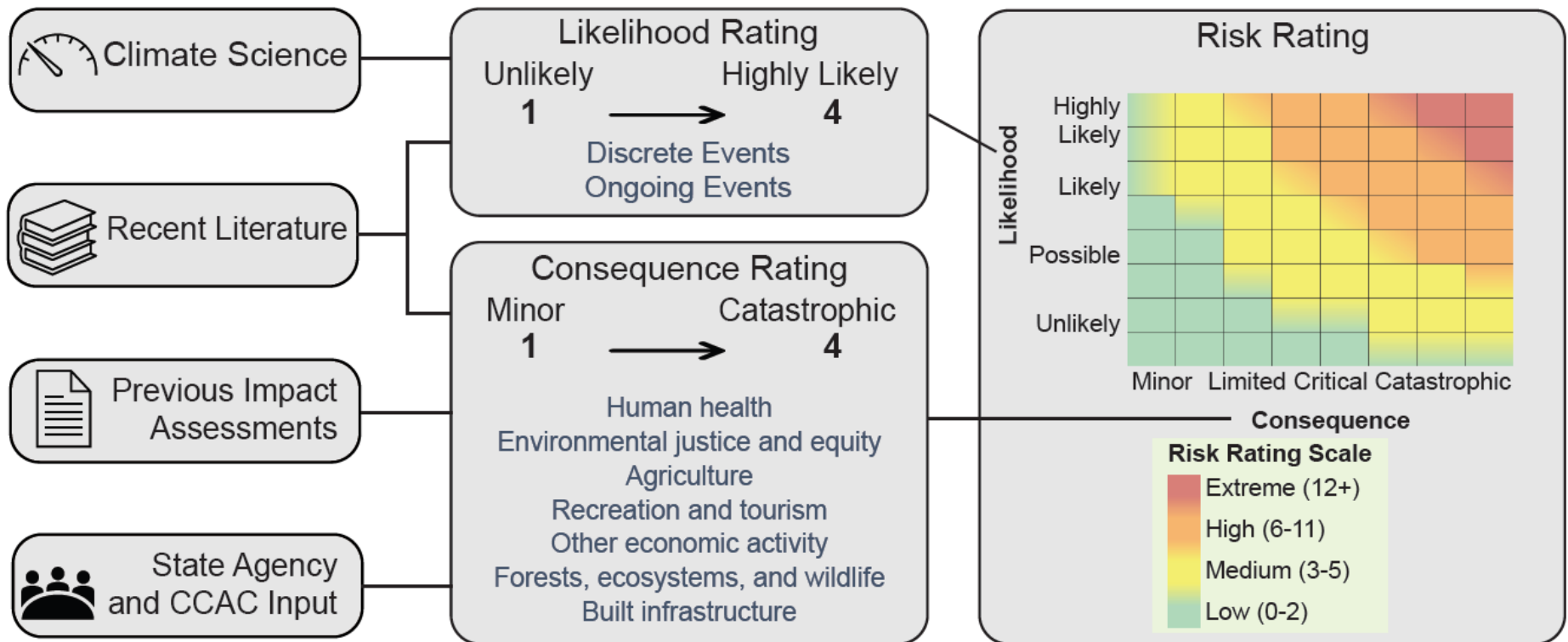
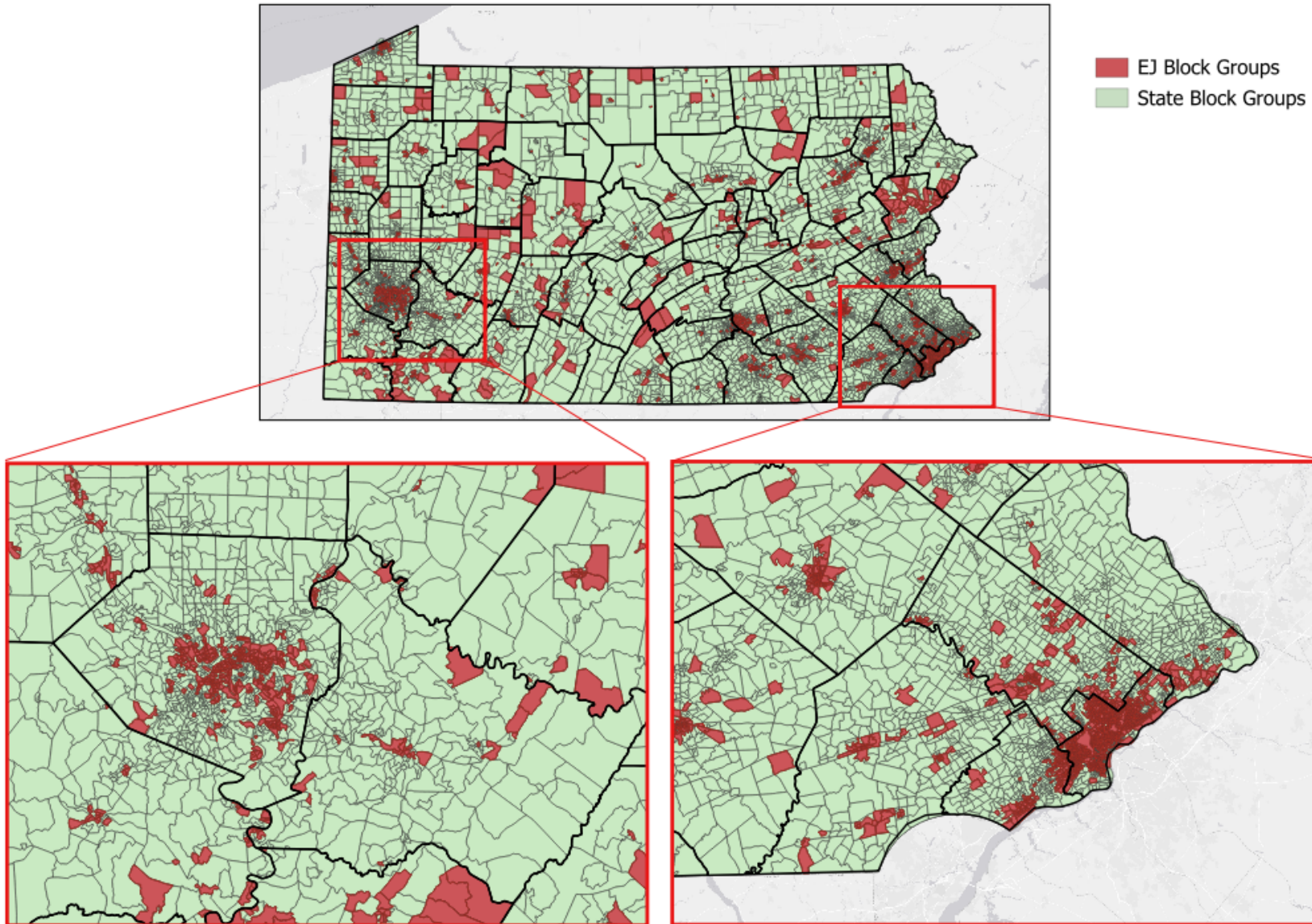


Figure 31. Environmental Justice census block groups in Pennsylvania



APPENDIX B provides a thorough, structured description of the risks of climate changes across Pennsylvania, spanning hazards and key consequence categories. This chapter provides additional analysis and discussion of three spotlight issues that have been relatively less understood or under-studied in previous iterations of the Impacts Assessment: 1) **Flooding Impacts to Air Quality and Health**; 2) **Heat Impacts to Occupational Exposure and Public Health**; and 3) **Climate Change Impacts to Energy Resilience**.

4.1 Flooding Impacts to Air Quality and Health

Between 2010 and 2022, Pennsylvania recorded 663 unique flood and flash flood events. During this time, the counties with the most recorded flood events are in the southwest, southeast, and northeast parts of the state.¹¹² Flash flood events are expected to become more frequent in the Commonwealth due to climate change. Climate change projections suggest that the risk of flooding in Pennsylvania will increase in coastal regions due to sea level rise.

4.1.1 Health Impacts of Flooding

Flood events pose an acute risk to human health, at both the community and individual levels.

Direct impacts on human health include:^{113,114}

- Drowning or serious injury due to slips, falls, and cuts from debris carried by floodwater.
- Bites or stings from displaced insects and animals.
- Hypothermia following prolonged exposure to cold water.
- Negative mental health effects, including exacerbated mood disorders (i.e., anxiety, depression, etc.), substance use, and post-disaster trauma.

Indirect impacts on health include.^{115,116,117,118,119}

- Malnutrition, dehydration, and gastrointestinal distress due to food and water scarcity.
- Water-borne diseases, such as legionellosis, E. coli, and cryptosporidiosis due to contaminated drinking water stores. The risk for contamination is particularly high in unregulated private drinking water sources.
- Skin infections from exposure to contaminated floodwaters.
- Respiratory conditions, due to mold and contaminant exposure.
- Mosquito-borne diseases, due to the standing water breeding grounds created by flooding.
- Inhibited access to hospitals and pharmacies due to flooded or damaged infrastructure.
- Exposure to runoff from contaminated hazardous waste sites.
- Exposure to coal ash from flooding of unprotected coal ash impoundments.

Infrastructural impacts on health include:¹²⁰

- Flooding and damage to roads, bridges, and healthcare facilities, which may inhibit access to necessary health services.
- Damage to sewer, septic, and water supply systems, which can contaminate water with harmful chemicals and pathogens and limit access to safe drinking water.
- Spread of water-borne diseases due to contaminated water supply from sewage overflow and post-flooding standing water. Although Pennsylvania has been a leader in implementing green stormwater infrastructure, most stormwater and combined (storm and sanitary) sewers were not designed for the flows projected with climate change.
- Roadway disruptions and building damage during a flood, which may cause driving collisions or limit emergency services access.
- Damage to public transit, which can inhibit evacuation capacity, particularly for vulnerable communities.
- Power outages can cause injury, reduce access to life saving medical equipment, and cause refrigerated foods to spoil, that if eaten can cause illness.

4.1.2 Indoor Air Quality

Damage to buildings during and after flood events can contaminate indoor air with toxins including carbon monoxide, lead, asbestos, and mold and mildew spores (**Figure 32**).

Lead & Asbestos

Asbestos was a standard material used in building construction until the 1970s, and asbestos mining in the U.S. continued through 2002.¹²¹ Lead-based wall paint was standard until 1978.¹²² Asbestos becomes friable if it is exposed to water or moisture and it releases dangerous asbestos fibers into the air. Similarly, water exposure can cause paint to peel, creating inhalable lead dust.

Figure 32. Effects of flooding on indoor air quality (IAQ) and health

Effects of Flooding on Indoor Air	Resulting Health Effects
Power outages may necessitate generator use, which produces carbon monoxide	• Exposure to carbon monoxide can cause brain damage or death.
Water damage can cause lead paint to peel, creating lead dust	• Lead exposure in children may result in broad cognitive impairment.
Water makes asbestos friable and releases asbestos fibers	• Asbestos exposure can result in mesothelioma, lung cancer, asbestosis, and other lung diseases.
Post-flood moisture supports the growth of mold and mildew	• Mold spores can exacerbate respiratory conditions (i.e. asthma) and lead to coughing, wheezing, and difficulty breathing.

Exposure to asbestos can incur asbestosis, the scarring of lung tissue when breathing asbestos fibers; pleural disease, a group of lung conditions that affect the tissue surrounding the lungs and chest cavity; lung cancer; and mesothelioma, a rare form of cancer that impacts the lung, chest, abdominal cavity, or membranes surrounding internal organs.¹²³ Lead exposure can incur damage to the brain and nervous system, leading to stunted growth and development, learning and

behavioral challenges, and hearing and speech impairments.¹²⁴ Children are particularly at risk of these effects.

Carbon Monoxide

Carbon monoxide is an odorless poisonous gas that can cause headaches, nausea, and dizziness, serious tissue damage, and death.¹²⁵ Floods may result in power outages, necessitating the use of backup generators. Generators produce carbon monoxide, and users are at risk of carbon monoxide poisoning without proper ventilation.

While carbon monoxide poisoning is a threat to everyone, young children, elderly people, and those with lung or heart conditions are more susceptible to carbon monoxide poisoning. As young people breathe faster, they could inhale more of the toxic fumes per pound than others.¹²⁶ The negative effects of carbon monoxide may affect those over 65 years of age more since they are more likely to be suffering from multiple health problems and their bodies are also less able to deal with oxygen deprivation.^{127,128} People with chronic heart disease, a history of anemia, and breathing problems are also more likely to get sick from exposure to carbon monoxide. These health conditions are disproportionately present within low-wealth populations.^{129,130}

Mold & Mildew

The moisture left after flooding supports mold and mildew growth, and the released spores impact IAQ and health.^{131,132,133,134} Exposure exacerbates respiratory conditions and increases the risk of children developing asthma, allergies, infections, and bronchitis (**Figure 32**).¹³⁵ Older adults and those with compromised immune systems and existing lung conditions, for example, former coal miners with Black Lung, are also particularly at risk.^{136,137} Symptoms of mold exposure include eye irritation, sinusitis, headaches, dizziness, or fatigue.

4.1.3 Vulnerability and Climate Justice

When residential buildings are damaged, those that lack the ability to evacuate, who cannot afford relocation, or who are tasked with cleaning and remediating flooded homes are at heightened risk of harmful, flood-related exposures. Elderly populations are particularly vulnerable to carbon monoxide poisoning due to a decreased capacity to manage oxygen deprivation and an increased likelihood of preexisting conditions, both of which can exacerbate carbon monoxide poisoning.¹³⁸ Low-wealth communities may lack the resources to pay for professional remediation services, prolonging their exposure. A lack of adequate adult education exacerbates this issue as individuals may not be aware of practices such as using N-95 or other respiratory protection while mud mucking homes and may hold the common misperception that bleach adequately addresses mold resulting from flooding. Socially vulnerable populations are more likely to reside in flood-prone areas.¹³⁹ These populations may lack access to a vehicle or reliable transportation, another key vulnerability if evacuation is required. Accordingly, older age, lower socioeconomic status, racial and ethnic minority status, and non-U.S. citizenship are significant risk factors for post-flood related harm.¹⁴⁰ Other vulnerabilities include language barriers to understanding remediation and cleaning guidance, the cost of flood insurance, and access to federal funding for post-flood recovery efforts.

Across the U.S., low-income and low-wealth populations are more likely to live in inland flood zones.¹⁴¹ In Pennsylvania, EJ areas are found in coastal areas along the Delaware River and Lake Erie. **Figure 33** shows flood risk and EJ areas based on DEP's EJ areas data.¹⁴² **Figure 34** shows flood events by PA county, and EJ areas.¹⁴³ Across Pennsylvania, EJ areas are about 1.2 times as exposed to flood risk. Across the Commonwealth, 5.2% of Pennsylvania is located within a

Federal Emergency Management Agency (FEMA) 100-year floodplain, whereas 6.2% of EJ areas sit within the 100-year floodplain.

Over half of all EJ areas are within the five Pennsylvania counties that experienced the largest number of flood events from 2010–2022. Over three-quarters of EJ areas are within or bordering counties that have had higher frequencies (54+) flood events from 2010 to 2022, as shown in **Figure 34**. All counties in Pennsylvania with more frequent flood events (54+ from 2010 to 2022) contain at least one EJ area. Across the Commonwealth, EJ areas face higher flood risks than non-EJ areas.

Figure 33. Flood risk and EJ areas

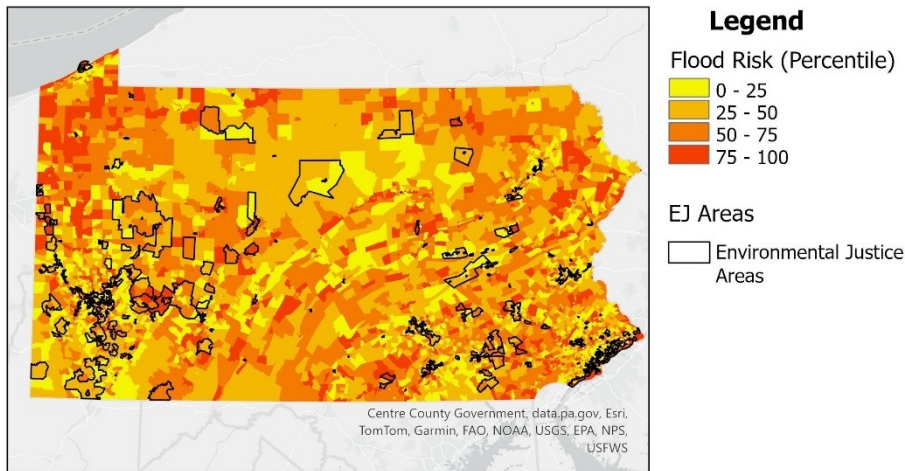
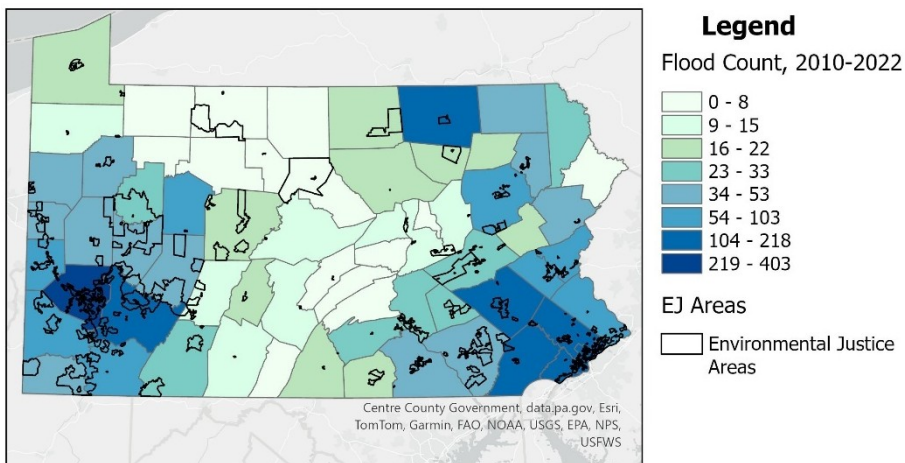


Figure 34. Flood count by county and EJ areas



Did you know? Flooding in areas with industrial sites can expose nearby communities to higher levels of contaminants. Contaminants from industrial sites can include asbestos, lead paint in buildings, as well as contaminated soil. Chemicals stored on site, including fuels, could be at risk of spilling during flood events. A study of six U.S. cities conducted in 2022, identified 679 relic industrial sites (out of use since at least 2009) at risk of flooding. The study includes the following cities and their urban areas: Providence, Rhode Island; Houston, Texas; Philadelphia, Pennsylvania; Portland, Oregon; New Orleans, Louisiana; and Minneapolis, Minnesota. There are 14,000 Philadelphians whose houses are flood-prone who live in close proximity (at the block level) of industrial relic sites. These at-risk areas tend to be disproportionately inhabited by socially vulnerable groups including minority and low-income households.

Approximately 43% of Philadelphia Census Block Groups are classified as Environmental Justice Areas. The study does not indicate whether the industrial sites and impacted communities reside in EJ areas as defined by Pennsylvania Department of Environmental Protection.

Housing Justice

Resource inequities, lack of transportation, physical disabilities, or lack of alternate shelter all contribute to some residents remaining in flood-damaged housing during and after a flood. Sheltering in place during flood conditions increases exposure to poor IAQ and the associated health effects as described above.

As flooding becomes increasingly frequent and severe, managed retreat offers a promising solution for at-risk communities. Managed retreat entails the intentional and coordinated movement of people, housing, and infrastructure from hazard-prone areas. However, given the long-term and complicated logistics of this approach, a failed attempt may leave communities worse off. Large-scale urban renewal was attempted in Eastwick, a flood-prone community in southwest Philadelphia, from the 1950s to 1980s. But White flight depleted demand for homes in the neighborhood, and the 4,000 demolished homes were replaced with only 500 new ones. The neighborhood became burdened by more environmental injustices in the following decades, including landfills and repeated floods.¹⁴⁴

Major disaster recovery programs in the U.S. identify greatest need based on the extent of physical damage to residences. Those who can prove they owned things that were destroyed, including homes, are able to receive recovery funds.¹⁴⁵ Thus, low-income homeowners receive less repair assistance.¹⁴⁶ This approach results in more assistance being provided to those who had more to begin with, amplifying existing wealth disparities.¹⁴⁷ This approach fails to consider the needs of socially vulnerable populations, including renters.¹⁴⁸ Renters in Pennsylvania make up nearly 50% of households in EJ areas and under 30% in non-EJ areas, on average.¹⁴⁹ Although rental homes make up 30% of households in Pennsylvania, less than 25% of homes that received FEMA Hazard Mitigation Assistance funding were rental properties between 1994 and 2019.¹⁵⁰ Rental

housing tends to take longer to recover post-flooding and renters are less likely to return to their original places of residence after a flood due to displacement.¹⁵¹ The lack of investment in renter communities could impact their ability to recover after a flood event.

Finally, flooding has particularly disproportionate impacts on people without adequate housing including those experiencing homelessness. As extreme precipitation events become more intense, unhoused populations become more exposed to fast-moving floodwaters, and their belongings are more likely to become wet and damaged. Wearing wet clothing for long periods of time can lead to health impacts such as hypothermia or wound infection.¹⁵² Emergency shelters in Philadelphia have already observed these types of impacts.¹⁵³

Housing justice —the “idea that everyone deserves safe, affordable, and health-promoting housing regardless of race, income, gender, ethnicity, ability, and more”—is a critical approach to mitigate these inequitable exposures and impacts. Housing justice initiatives may provide vulnerable populations with temporary safe housing during and after a flood event, cleaning and remediation services, and assistance with permanent relocation outside of the floodplain. These solutions may include rent control, public housing, and access to housing recovery programs.¹⁵⁴

4.2 Heat Impacts to Occupational Exposure and Public Health

As climate change steadily increases ambient temperatures and the number of annual high heat days, the impact of heat on human health is a growing concern. In some parts of Pennsylvania, the annual number of days over 90°F is projected to surpass 77 days per year by 2050, significantly more than the statewide historic average of six days per year.

4.2.1 Health Impacts Overview

Heat is the deadliest climate hazard. In the United States, approximately 1,220 people die from extreme heat each year.¹⁵⁵ Indirect heat-related injuries, illnesses, and fatalities are not included in this number. Extreme heat leads to cellular damage and inadequate blood flow to organs, and these effects underlie the direct impacts of heat exposure, including dehydration, heat cramps, heat exhaustion, heatstroke, and hyperthermia. Children, elderly populations, and pregnant people are particularly at risk. Additional, indirect impacts include the following:

- Increased risk of accidental injury due to dizziness, fatigue, sweaty palms, or fogged-up safety glasses in jobs that require protective gear.¹⁵⁶
- Elevated incidence of food and water-borne disease due to heat creating favorable conditions for bacteria.

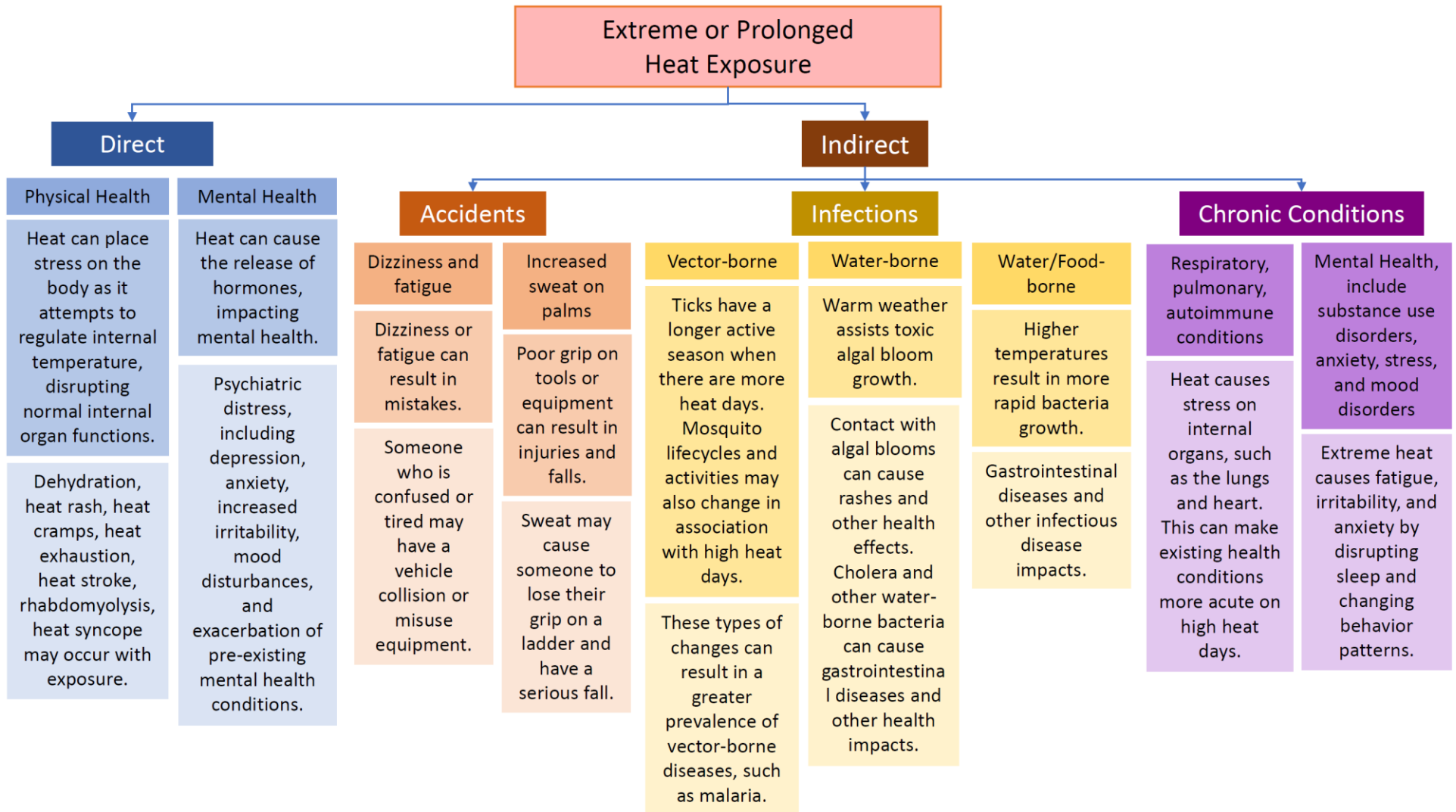
Did you know? In communities affected by major storms, terms like “Sandy Cough,” “Katrina Cough,” and “Long Island Cough,” are used to describe symptoms that appear following a major storm event. These coughs are associated with poor indoor air quality and exposure to air pollutants following storm events, including the post-storm reconstruction and clean-up.

Hurricane Sandy, the second costliest storm in U.S. history, made landfall in New York and New Jersey in 2011 and caused extensive flooding, which resulted in environmental conditions that increased the risk of lower respiratory symptoms. Evidence indicates that Sandy-related exposure led to an increase in emergency department visits for respiratory conditions immediately following the superstorm. One study found that one-third of study participants reported post-Sandy lower respiratory disease with exposure to clean-up and reconstruction in 2011, increasing the risk for lower respiratory disease. Participants of this study previously had exposure to the World Trade Center Disaster in 2001. Sandy also resulted in four reported fatal cases of carbon monoxide poisoning in Pennsylvania.

- Exacerbation of chronic conditions, including respiratory or cardiovascular diseases due to a reduction in low-cost outdoor physical activity options.
- Mental health stress, including exacerbated mood disorders and heightened suicide rates.^{157,158}

Figure 35 depicts the different ways in which high or prolonged heat can affect human health. People who work outdoors are disproportionately exposed to extreme heat and are at higher risk of suffering the associated health effects.

Figure 35. Heat impacts on health



4.2.2 Air Pollution

Air pollution poses an acute risk to health.¹⁵⁹ In 2019, outdoor air pollution is estimated to have caused 4.2 million premature deaths globally.¹⁶⁰ In Pennsylvania, poor air quality can be attributed to industrial facilities, electricity generation, vehicle exhaust, and chemical solvents from within the state and beyond the borders. Out-of-state sources include global ozone concentrations and wildfire smoke. Within the state, junkyard and tire fires in Philadelphia (seven between [June 2022](#) and [August 2023](#)) also contributed to poor air quality, triggering city-wide emergencies and stay-at-home orders.^{161,162,163}

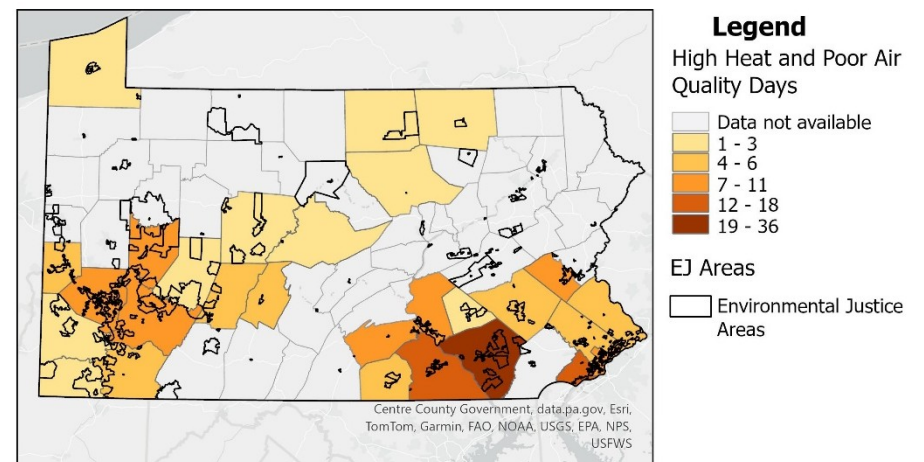
Air pollution is associated with a wide range of health effects including increased hospitalization and mortality in individuals with heart disease or chronic obstructive pulmonary disorder (COPD); exacerbated respiratory conditions, including asthma and bronchitis; lung tissue inflammation; reduced lung function; increased risk of heart attacks and heart failure; and long-term cancer risk and immune system suppression. The primary components of air pollution include particulate matter (dust from vehicle exhaust, construction activity, wildfire smoke, and more), ozone, nitrogen dioxide, sulfur dioxide, and volatile organic compounds. These components can cause blood vessel inflammation and disrupt the autonomic nervous system.¹⁶⁴

High temperatures and air pollution often coincide as they share some of the same underlying drivers.¹⁶⁵ Ozone levels increase in the presence of light (UV rays from the sun), so that sunny days tend to be the ones with poor air quality. Fossil fuel electricity production and construction both peak in the summer as well. The combination of poor air quality and heat on health results in worse health outcomes than either poor air quality or heat alone.¹⁶⁶ Heat exposure and air pollution causes cell damage which can exacerbate preexisting health

conditions. The combination of heat-induced cell damage and dehydration alongside air pollution-induced inflammation and restricted blood flow results in compounded biological disruption and health effects.

Figure 36. Pennsylvania counties experiencing high heat and moderate or unhealthy air quality days overlaid with 2023 EJ areas

In 2022, 26 counties in Pennsylvania experienced high heat days that



overlapped with poor air quality days (**Figure 36** and **Figure 49**).¹⁶⁷ Of these high heat days, 26% were also classified as moderate or unhealthy air quality days, 13% of moderate or unhealthy air quality days were also classified as high heat days. Philadelphia County had the greatest number of high heat days and Lancaster County had the greatest number of moderate and unhealthy air quality days. Available air quality and high heat information by county is included in **Table 20**.

4.2.3 Occupational Hazards

As heat waves increase due to climate change, outdoor workers will be increasingly at risk of related illness.¹⁶⁸ Exposure to heat, direct sun,

and humidity are concerns for workers in unventilated and outdoor workspaces, particularly those who are 65 years or older, overweight, have preexisting cardiovascular conditions, who take certain medications, as well as individuals unacclimated to full days in excessive heat.¹⁶⁹ Approximately 10% of Pennsylvania’s workforce is 65 or older and as of 2023, approximately 1.6 million Pennsylvanians (27%) work outdoors.^{170,171} The transportation, warehousing, agriculture, forestry, fishing, hunting, mining, quarrying, and oil and gas extraction sectors require outdoor work with a significant proportion of industry employees over age 55.¹⁷²

From 2000–2010 in the U.S., heat-related deaths occurred the most in outdoor environments. Further, the Workers Compensation Research Institute (WCRI) recently found that there are increases in the frequency of injuries by 5–8% per county on a day when the outside temperature surpasses 90°. Even at temperatures ranging from 75–90° in the Northeast, there is a 3–4% increase in the number of injuries.¹⁷³ Workers with high rates of outdoor exposure include those in agricultural, construction, landscaping and grounds keeping, mail and package delivery, and highway maintenance work, as well as recreational personnel, oil and gas well operators, and first responders.^{174,175} The risk of heat-related death was 35 times higher in the agriculture sector and 13 times higher in construction, as compared to all other industries.¹⁷⁶

An estimated 1,050 injuries and illnesses due to heat exposure in Pennsylvania were reported to the Bureau of Labor Statistics between 2011 and 2020 (see **Table 7**). There was a significant spike in the number of reported injuries and illnesses due to heat exposure in 2014 (as shown in **Table 7**), however it is unclear what caused this increase. In 2021, 26 deaths in Pennsylvania could be attributed to excess heat. This number includes those who were exposed to heat through outdoor work and through other work activities.¹⁷⁷

New workers are at increased risk of illness due to outdoor heat exposure, with almost half of heat-related fatalities occurring on a worker’s first day on the job, and 73% of heat-related deaths occurring during a worker’s first week.¹⁷⁸ There are two types of workplace injuries caused by heat: direct and indirect. Indirect injuries occur when heat impacts a worker’s perception, motor, or cognitive abilities, leading to accidents. For instance, a worker may faint, fall off a ladder and break his or her leg but this injury would likely be reported as a broken bone instead of a heat-related illness. Therefore, the actual number of heat-related illnesses, injuries, and fatalities among outdoor workers is likely underreported, as these cases are often documented as heart attacks or other illnesses or injuries indirectly caused by heat exposure.¹⁷⁹

Table 7. Worker illness and injuries due to heat exposure in Pennsylvania

Year	Injuries or Illnesses Count
2011	90
2012	40
2013	130
2014	410
2015	90
2016	30
2017	30
2018	80
2019	100
2020	50

Source: Databases, Tables & Calculators by Subject (bls.gov)

4.2.4 Social and Occupational Vulnerability

According to the U.S. Census Bureau, almost 25% of the U.S. population is socially vulnerable to extreme heat.¹⁸⁰ Socioeconomic status, race and ethnicity, region, housing, incarceration, underlying health conditions, and citizenship status all impact vulnerability.¹⁸¹

Several factors underlie these disparities. Racial and ethnic minorities and low-income populations are less likely to have air conditioning than other groups. Preexisting chronic health conditions are more prevalent among BIPOC and low-income populations due to reduced access to health care, education, generational wealth, and other factors exacerbated by systemic racism. People with lower educational attainment are more likely to work high-risk jobs, and racial and ethnic minorities are disproportionately represented in the outdoor labor force.¹⁸² Low-income and low-wealth groups additionally have reduced access to healthy food and increased exposure to chronic stress. The confluence of these factors puts these populations at heightened risk of acute and chronic health conditions and renders them more vulnerable to heat-related illness.^{183,184,185,186}

Outdoor workers in urban areas, regardless of their socioeconomic or demographic background, are at particular risk of poor health outcomes as they are more likely to be exposed to high temperatures in combination with unhealthy air quality.¹⁸⁷ Urban centers tend to be especially hot due to the heat island effect (gray infrastructure absorbing and re-emitting heat) and their minimal tree cover. Intra-urban heat islands are often linked to demographic factors such as income and race.¹⁸⁸ On average, low-income blocks have less tree cover than high-income blocks. In the Northeast region of the U.S., low-income blocks have up to 30% less tree cover and are 7.2°F hotter than higher income counterparts.¹⁸⁹ Daytime temperatures in urban areas are about 1–7°F higher than outlying areas and nighttime temperatures are about 2–5°F higher.¹⁹⁰

Formerly redlined neighborhoods have ongoing vulnerability, with some neighborhoods experience temperatures 22°F hotter than others. Redlining can be defined as a discriminatory practice that consists of the systematic denial of services such as mortgages, insurance, loans, and other financial services to residents in certain areas, based on their race or identity.¹⁹¹ Communities in historically redlined neighborhoods are disproportionately low-income with majority racial and ethnic minority populations.^{192,193} Philadelphia is one example of a city where communities in historically redlined neighborhoods are experiencing more extreme high temperatures, though this is a common phenomenon in urban areas across the United States.

Pennsylvania's rural areas are economically vulnerable, with aging populations that experience higher rates of unemployment and lower incomes.¹⁹⁴ Across the United States, people in rural areas often lack adequate access to health and healthcare.¹⁹⁵ Over 25% of Pennsylvania's rural populations live in federally designated Health Professional Shortage Areas.¹⁹⁶ These areas will also be disproportionately burdened by the cost of climate change related damage. Estimates project that rural Pennsylvania will spend nearly 60% more per capita on cooling centers by 2040 compared to the statewide average, and that costs will reach \$5,990 per capita by 2040 for climate-responsive infrastructure (roads and bridge repairs, landslide prevention, and cooling centers).¹⁹⁷

Incarcerated populations may be at a heightened risk of heat related illness. In 2023, approximately 39,000 individuals were incarcerated within the Pennsylvania Department of Corrections (DOC). Black Pennsylvanians are six times more likely than White Pennsylvanians to be housed within the DOC and are more likely to represent the socially vulnerable to extreme heat, including a prevalence of preexisting chronic health conditions. In 2023, the DOC reported that of the 24 state correctional institutions, 15 facilities are air-conditioned, but nine facilities had only partial air-conditioning. During periods of

extreme heat, the DOC provides additional water and ice, circulates air with fans, and limits outside recreation and work. Additionally, staff are trained to recognize symptoms and provide treatment for heat related illnesses. According to review of DOC medical records over the past 10+ years, there have been no deaths among the incarcerated population due to heat related illnesses. Note that this information does not include data from county jails, federal prisons, or youth detention centers.

Agricultural workers are four times more likely than workers in other industries to experience heat-related illness and are 35 times more likely to die due to heat exposure. Migrant and immigrant workers in the U.S. are particularly vulnerable to heat-related illness, injury, and mortality as these groups are more likely to work in these roles.¹⁹⁸ In 2017, approximately 75% of agricultural workers in Pennsylvania were foreign-born and approximately half of Pennsylvania agricultural workers were undocumented.¹⁹⁹ Migrant workers are less likely to have health insurance, leading to worse health outcomes.

Protecting against heat illness, injury, and mortality can take a variety of forms, including policy, infrastructure, and social interventions. Notably, social cohesion (the connectedness among members of a community) may have a protective effect against heat-related mortality as it encourages support, organizing, and sharing of resources.²⁰⁰ While it has not been studied, strong social ties may benefit vulnerable outdoor workers by encouraging conversation around heat-related symptoms and protective resources, such as water and shade. Supporting community building and access to cooling centers may also improve health outcomes.²⁰¹ Climate planners, employers, and local governments can better support outdoor workers by fostering social cohesion and providing precautionary guidance for working in high heat.

4.2.5 Labor Policies and Guidelines

Expanded health and safety protections will improve conditions for at-risk workers and communities in EJ areas.

In 2022, the Occupational Safety and Health Administration (OSHA) launched the National Emphasis Program (NEP) for Outdoor and Indoor Heat-Related Hazards, initiating inspections and outreach to reduce heat hazards in high-risk work environments.²⁰² Engineering controls include air conditioning, ventilation, insulation of hot surfaces, and the use of mechanical equipment to reduce manual labor. Administrative controls are recommended when engineering controls are not sufficient. These include mandatory rest breaks in cooler areas, shorter shifts for unacclimatized workers, scheduling work at cooler times of the day, and monitoring employees for heat stress. Cooling personal protective equipment (PPE) is also recommended. Some PPE, such as respirators and hard hats, can increase the risk of heat-related illness and employers should account for this risk.²⁰³ As part of the NEP, the U.S. Department of Labor strongly recommends that states adopt the initiatives laid out in the state plans which, as of November 2023, Pennsylvania has yet to do.²⁰⁴

Pennsylvania requires employers to provide drinking water to employees and requires non-residential facilities to use mechanical ventilation such as fans or air conditioning when indoor temperatures exceed 90°F.^{205,206} However, these regulations may not provide sufficient protection from high humidity and strenuous workload. OSHA recommends the use of wet bulb globe temperature (WBGT) monitors to measure workplace environmental heat for both indoor and outdoor workplaces.²⁰⁷ Heat indexes may be used if WBGT monitors are unavailable. The National Institute for Occupational Safety and Health (NIOSH) encourages workplaces to create acclimation plans to reduce heat-related health risks for workers. These plans gradually increase workers' exposure to

high temperatures over a multi week period to improve tolerance and reduce risk.²⁰⁸

The Pennsylvania Department of Labor and Industry offers [Pennsylvania Training for Health and Safety \(PATHS\)](#), which provides no-fee health and safety resources for Pennsylvania employers and employees. The Department also runs the [PA Workplace Safety Committee Certification Program](#), which encourages workplaces to create safety committees. Besides the General Safety Law, which applies to Pennsylvania's public sector employees, private sector workplace safety measures are generally not enforced by the State, as they fall under OSHA's jurisdiction.²⁰⁹ The Pennsylvania Legislature could work with the Department of Labor and Industry to create state-level legal protections and requirements for workplace health and safety to protect workers from exposure to dangerous conditions that will increase as climate change progresses.

Protective Policies for Pregnant Workers

The Pregnant Workers Fairness Act (PWFA) requires that pregnant workers are provided reasonable accommodations.²¹⁰ PWFA does not explicitly refer to heat exposure, and accommodations for heat-exposed pregnant workers should be established given that pregnant people are particularly vulnerable to heat-related illness.²¹¹ The [updated NIOSH guidelines](#) on occupational heat exposure addresses pregnancy and can be used as a reference for formulating these accommodations.²¹²

State policy could be strengthened by requiring the use of onsite temperature measurement, providing appropriate heat-risk controls in alignment with the NEP, and outlining accommodations for vulnerable employees including elderly workers, pregnant, workers, and those with preexisting conditions. Workplace safety standards could also be expanded to include those that are not sufficiently protected by existing state and Federal statutes.

Protective Policies for Incarcerated Populations

Prisons and prison factories are not subject to the Fair Labor Standards Act or most OSHA requirements, as incarcerated workers are generally not defined as employees.²¹³ Thus, incarcerated workers are denied workplace protections, the right to refuse to work, and the right to unionize.²¹⁴ The Pennsylvania legislature and DOC can strengthen health and safety requirements in state facilities.^{215,216} The Pennsylvania DOC requires that temperatures in DOC-owned facilities should be maintained at 67°F in the winter and 75°F in the summer, but this does not extend to "areas that are not heated or cooled and areas with unique environmental needs."²¹⁷ While this policy does state that hazards, including extreme temperatures, should be limited or controlled, it could be expanded to include the OSHA guidance for monitoring and reducing exposure to hazardous heat conditions.

Protective Policies for Migrant and Immigrant Workers

If provided at all, training and safety materials may not be accessible due to language barriers.²¹⁸ While undocumented workers are granted protections under OSHA, they are less likely to report their employers for noncompliance for fear of deportation and other retaliatory actions. In 2023, the U.S. Department of Labor signed a memorandum allowing OSHA to provide visas to non-U.S. citizens during workplace safety investigations, which will make it less risky for workers to report unsafe conditions.²¹⁹ Pennsylvania can support this effort by expanding resources for immigrants, whistleblower protection laws, and requiring workplaces to provide training in languages spoken by workers.

4.3 Climate Change Impacts to Energy Resilience

Weather events are one of the leading causes of electrical outages across the United States. As climate change drives increasingly extreme weather, outages are likely to become more frequent, widespread, and disruptive. Understanding the electrical grid's sensitivity to climate hazards as well as the sensitivity of Pennsylvania communities to associated outages, is critical for building resilience across the Commonwealth.

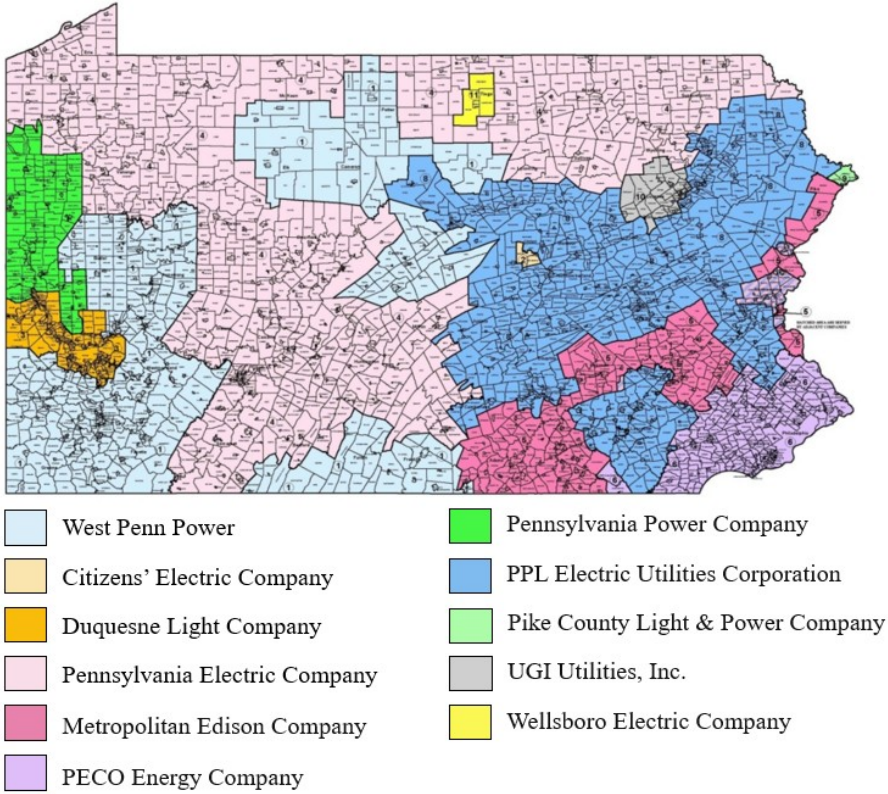
Between 2000 and 2021, about 83% of reported major outages in the U.S. were attributed to weather-related events.²²⁰ These events can leave thousands without electricity for days to weeks at a time. Elderly populations and those who rely on refrigerated medicines are particularly vulnerable during power outages. In many large-scale outages, outdated equipment and a lack of climate resilient design left the power grid vulnerable to failure. For example, in August 2003, 55 million people throughout southern and central Ontario and eight U.S. states were left without power for up to four days. This was due to an alarm system software bug that left operators unaware of the need to redistribute load after extreme heat conditions caused overloaded transmission lines to droop into foliage. The event was the largest of its kind in the northeastern U.S. and caused nearly 100 fatalities.²²¹ In 2021, heavy rainfall and strong winds from Hurricane Ida caused damage to power lines from fallen trees. This event left about 46,000 Pennsylvania Power and Light (PPL) Electric Utilities customers without power across the Commonwealth.²²² Throughout 2021, over 177,000 Pennsylvanian utilities customers were impacted by major outage events.²²³ These blackouts disrupt essential daily operations for households, businesses, and communities, incurring significant economic and public health consequences.

Pennsylvania Energy Landscape

Most of Pennsylvania's electricity is provided by private companies that are publicly regulated. The Pennsylvania Public Utility Commission (PAPUC) regulates the 11 Investor-Owned Utility (IOU) companies that provide energy transmission and distribution to the state (**Figure 37**).²²⁴ Power generation in Pennsylvania comes from a variety of sources and companies, including but not limited to the 11 IOUs. The majority of the state's energy comes from natural gas generation (62.3%), with other generation from nuclear (33.2%), renewables (2.4%), and coal (1.9%), as of 2023.²²⁵

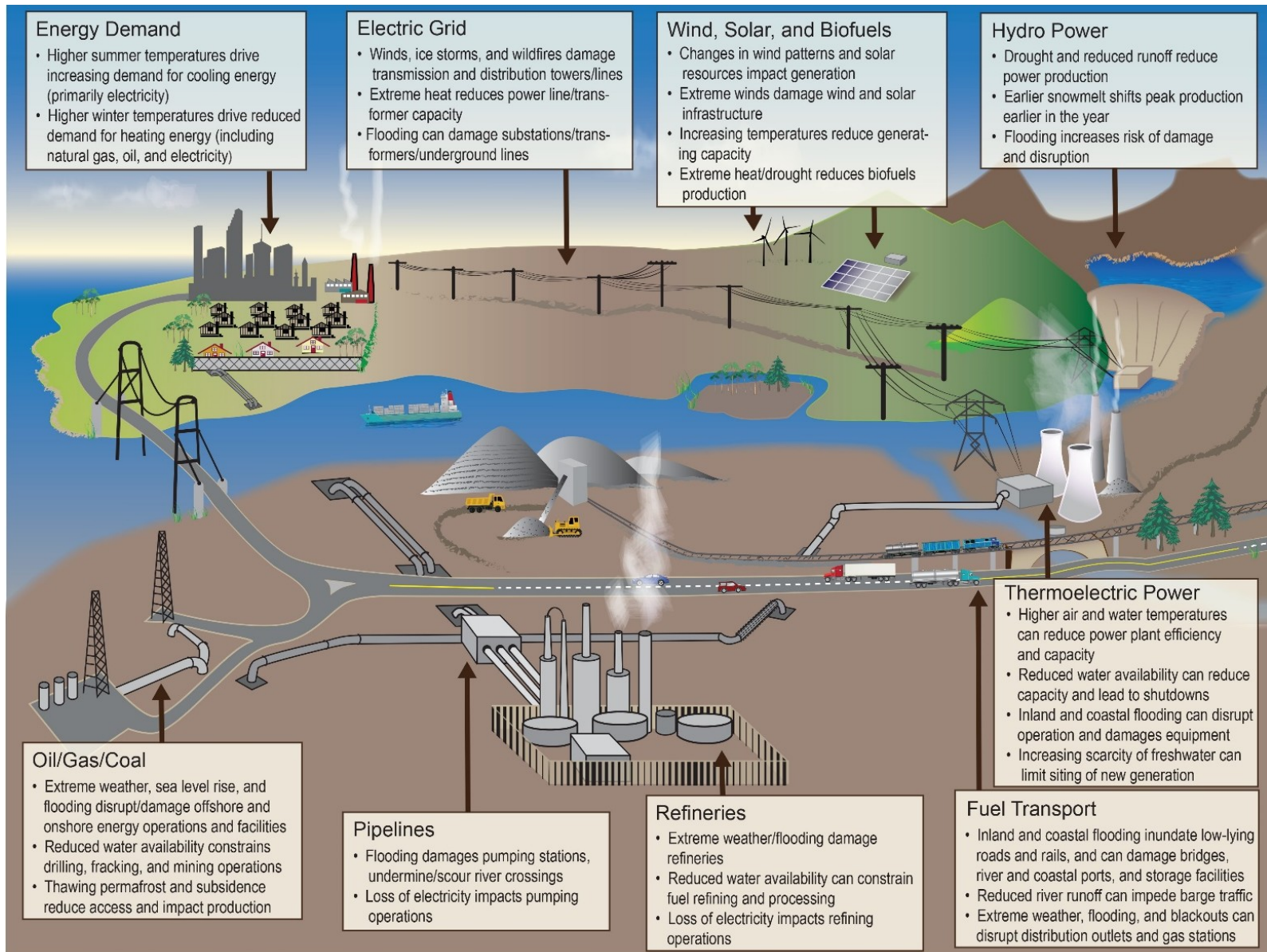
While PAPUC-directed grid resilience measures are currently limited, some utilities have received federal funding for resilience measures. Through the Bipartisan Infrastructure Law, PECO won \$100 million to relocate flood-prone substation assets and create a microgrid with battery storage to support its storm response center; PPL Electric won \$50 million for grid automation to predict failure and reduce outages; and Duquesne Light won \$20 million to increase its transmission capacity.²²⁶ **Figure 38** summarizes the interactions between climate change and the energy system.

Figure 37. A map showing the operating territory of Pennsylvania's 11 Investor-Owned Utilities companies



Source: Pennsylvania Public Utility Commission, 2021.
<https://www.puc.pa.gov/media/1604/epo-report2021.pdf>

Figure 38. Summary of how climate change impacts energy systems



Source: Fourth National Climate Assessment, 2018.

Hazard Analysis

Different climate hazards affect electrical infrastructure in different ways. Sensitivity of individual assets and sub-assets can vary widely depending on their design specifications, presence or absence of existing resilience measures, age and condition, and the nature and function of the asset. The following presents a high-level summary of the potential impact of climate hazards on utility infrastructure for each of the hazards included in the Climate Impacts Assessment.

Increasing Average Temperatures & Heatwaves

Overall, if temperatures exceed the safe operating ratings of assets, assets can become more prone to failure, experience damage that shortens their lifespan, or create hazardous conditions (such as line sag) that can increase the chances of outages. Periods of high heat can raise the temperature of water bodies used for cooling of thermal generation powerplants. If water temperatures become too high, plant operations may need to cease or be reduced for regulatory compliance. Nuclear generation plants operate at much higher power generation capacity than other types of powerplants; a loss in operations of a single nuclear plant has the potential to impact the grid more than other types of generation.

Flooding, Extreme Precipitation, and Sea Level Rise

While some assets can withstand the effects of water exposure, many electrical assets, such as transformers, can be highly sensitive to water and experience severe damage or failure if inundated. Flooding can also cause corrosion and structural damage through direct contact with water, scouring, or damage from vegetation or debris contact. Nuclear generation plants have a particularly high-level of consequence of failure; flooding and sea level rise, if severe enough, can damage a plant causing a reduction in capacity

and impacts to the grid, or in worst case scenarios, potential radiation contamination.

Severe Tropical and Extra-Tropical Cyclones

The high winds associated with tropical and extra-tropical cyclones have the potential to impact sensitive electrical assets if their wind ratings are exceeded or if blown debris or vegetation (such as fallen trees) collide with and damage equipment, which has historically been a significant challenge for Pennsylvania.²²⁷ Nuclear generation plants have a particularly high-level of consequence of failure; severe tropical and extra-tropical cyclones, if severe enough, can damage a plant causing a reduction in capacity and impacts to the grid, or in worst case scenarios, potential radiation contamination. The precipitation associated with these storms can also carry the same risks associated with flooding if the precipitation is severe enough to cause pooling of water or raise the levels of lakes, rivers, and streams.

Landslides and Sinkholes

Landslides and sinkholes pose a high potential impact to most electrical assets (except overhead conductors). If impacted, all electrical assets face a high risk of extreme damage, leading to outages. Landslides and sinkholes can compromise the structural integrity of assets and also cause debris or other structures to collide with and damage electrical equipment.

Potential Impacts to the Energy System

Potential impact is the potential for negative outcomes in the event of climate hazard exposure and is a result of the combination of sensitivity (the degree to which assets could be negatively affected by climate hazard exposures) and consequence (the potential for impacts to sensitive assets to result in negative outcomes for the utility's system, customers, or staff). **Table 9** through **Table 12** present potential impact

scores for different types of grid assets and are built on general assumptions about electrical infrastructure in Pennsylvania. These scores are informed by the rubric presented in **Table 8**. Further analysis on the sensitivities and consequences of each utility's unique assets, as well as an examination of individual asset exposure, is needed to provide a more detailed analysis of vulnerability.

Table 8. Potential impact rubric

Potential Impact Score	Description
LOW	<i>LOW SENSITIVITY & LOW CONSEQUENCE</i> <i>The asset faces low to minimal potential adverse impacts when exposed to a hazard and if adverse impacts were to occur, the resulting consequences are minimal.</i>
MEDIUM	<i>LOW-MEDIUM SENSITIVITY & LOW-MEDIUM CONSEQUENCE</i> <i>The asset may experience potential adverse impacts when exposed to a hazard and if adverse impacts were to occur, the resulting consequences are minimal to moderate.</i>
HIGH	<i>MEDIUM-HIGH SENSITIVITY & MEDIUM-HIGH CONSEQUENCE</i> <i>The asset moderate may be subject to increased risk of major and/or sudden failure in the event of hazard exposure, the resulting consequences are severe.</i>

Table 9. Transmission asset potential impact

Asset	Increasing Average Temperatures & Heatwaves	Flooding, Heavy Precipitation, Sea Level Rise	Severe Tropical and Extra-Tropical Cyclones	Landslides and Sinkholes
<i>Line Structures (Poles/Towers)</i>	LOW	HIGH	HIGH	HIGH
<i>Overhead Conductors</i>	HIGH	MEDIUM	MEDIUM	LOW
<i>Underground Conductors</i>	MEDIUM	MEDIUM	LOW	HIGH

Table 10. Distribution asset potential impact

Asset	Increasing Average Temperatures & Heatwaves	Flooding, Heavy Precipitation, Sea Level Rise	Severe Tropical and Extra-Tropical Cyclones	Landslides and Sinkholes
<i>Line Structures (Poles/Towers)</i>	LOW	MEDIUM	HIGH	HIGH
<i>Overhead Conductors</i>	MEDIUM	MEDIUM	MEDIUM	LOW
<i>Underground Conductors</i>	LOW	MEDIUM	LOW	HIGH
<i>Pad Mount Transformers</i>	HIGH	HIGH	MEDIUM	HIGH
<i>Pole Top Transformers</i>	HIGH	LOW	LOW	HIGH

Table 11. Substation asset potential impact

Asset	Increasing Average Temperatures & Heatwaves	Flooding, Heavy Precipitation, Sea Level Rise	Severe Tropical and Extra-Tropical Cyclones	Landslides and Sinkholes
<i>Substation Transformers</i>	HIGH	HIGH	MEDIUM	HIGH
<i>Circuit Breakers</i>	MEDIUM	HIGH	LOW	HIGH
<i>Protection & Control Systems</i>	MEDIUM	HIGH	MEDIUM	HIGH
<i>Instrument Transformers</i>	MEDIUM	HIGH	LOW	HIGH
<i>Control Room</i>	MEDIUM	HIGH	HIGH	HIGH

Table 12. Generation potential impact

Generation Type	Increasing Average Temperatures & Heatwaves	Flooding, Heavy Precipitation, Sea Level Rise	Severe Tropical and Extra-Tropical Cyclones	Landslides and Sinkholes
<i>Hydro</i>	MEDIUM ²²⁸	MEDIUM	LOW	HIGH
<i>Gas</i>	MEDIUM	MEDIUM	LOW	HIGH
<i>Coal</i>	MEDIUM	MEDIUM	LOW	HIGH
<i>Nuclear</i>	HIGH	HIGH	MEDIUM	HIGH
<i>Solar</i>	LOW	LOW	LOW	HIGH

4.3.1 Health and Equity: The Importance of Safe, Reliable Energy

Reliable energy utilities are a crucial component of public health and safety, and disrupted service broadly threatens the safety and well-being of impacted groups. Low-wealth communities are disproportionately impacted and experience more frequent blackouts than non-low-wealth groups, despite paying proportionally three times more of their income for energy services.²²⁹ This vulnerability persists as these communities have a lower ability to pay for infrastructural improvements through rate increases.²³⁰ Other at-risk groups include the following:²³¹

- **Children** are at increased risk of exposure to carbon monoxide poisoning due to improper generator use.
- **Non-English literate populations** may not understand emergency response messaging in English and thus may not be sufficiently prepared for inclement weather or know how to access resources.
- **Racial and ethnic minorities** are disproportionately at risk of experiencing increased crime rates and heightened mental health effects.
- **Older adults** are more likely to depend upon medical equipment and are prone to heightened mental health impacts.
- **Rural populations** are at higher risk of prolonged outages.
- **Healthcare Workers** are impacted by stressed health care systems and experience extreme burnout and fatigue in power crises.

Direct Health & Safety Impacts

Power outages can leave households without heating or cooling capacity during periods of extreme temperatures. Prolonged exposure to extreme heat drives heat-related illness, including heat stroke, and may exacerbate cardiovascular and respiratory conditions.²³² Rising temperatures further increase the risk of power outages. Power losses may negatively impact those that rely on refrigerated medications. This vulnerability is exacerbated by infrastructural features of at-risk neighborhoods (e.g. minimal tree cover, fewer green spaces, more exposed asphalt, history of redlining and neighborhood disinvestment resulting in an aging housing stock) that trap heat and raise temperatures.²³³ Furthermore, while many households still utilize gas or oil furnaces, many of these systems require electricity to operate. Outages pose a risk to those who wholly or partially dependent upon electricity for heat in the winter months. Without heating, these groups can be exposed to extremely cold temperatures and related illness, including hypothermia and exacerbated cardiovascular conditions.²³⁴

EJ areas have reduced access to energy distribution technology, and this contributes to their disproportionate vulnerability during power outages. For example, solar panels can help support a microgrid or may provide emergency power when connected to battery storage. But solar panels are not equitably accessible, and they are primarily installed in majority Non-Hispanic White households with nearly double the national average household income.²³⁵

Power outages increase incidence of carbon monoxide poisoning, particularly among children and elderly populations, and lead to a spike in emergency department visits.²³⁶ This is primarily due to the necessitated use of indoor charcoal and gasoline-powered generators.²³⁷ Racial and ethnic minority groups are also at heightened risk as these groups are significantly less likely to have heard relevant

public health warnings about CO poisoning and reportedly choose to place generators indoors for fear of theft.²³⁸

Outages can also have adverse impacts on mental health. The stress of food perishing and diminished access to basic utilities, appliances, and social connection can lead to anxiety, depression, social isolation, and other exacerbated mood disorders.²³⁹ Power outages may also pose safety hazards to impacted communities. For example, downed wires or poles may cause infrastructural damage and may directly injure or pose electrical hazards to passersby. There is some research suggesting that extended power outages are also associated with inequitable upticks in crime.²⁴⁰ Outages also may force schools and other institutions to temporarily close. This disproportionately affects families that depend on school as a form of childcare and low-wealth communities are thus inequitably impacted.²⁴¹

Health Systems & Care Delivery

Outages broadly burden health systems and impact healthcare delivery.²⁴² Hospitals are only required to maintain backup generators that allow highly critical units to run uninterrupted through emergencies. Hospitals are not required to have sufficient standby power resources to preserve comprehensive operations.²⁴³ Thus, when energy utilities fail, it temporarily reduces available hospital services and impacts quality of care. Affected services may include blood banks, transfusion services, human tissue storage, pharmaceutical storage and dispensary, morgue and lab functioning, diagnostic tools (e.g., radiological equipment), and more.²⁴⁴ Power outages also may result in sweeping appointment cancellations.²⁴⁵ Any procedures that are not imminently life-threatening may be impacted. Outages thus delay routine screenings and lead to reproductive care clinic closures, obstacles that may incur

life-altering detriment to patients.²⁴⁶ These effects disproportionately burden those with hourly-wage jobs, as these groups may be less able to attend a rescheduled appointment.

Power interruptions also dangerously impact healthcare delivery beyond the clinical setting. As private citizens often lack backup generators, outages may imminently endanger the life of individuals who depend upon power-dependent medical equipment, including dialysis or sleep apnea machines, ventilators, or electric wheelchairs.²⁴⁷ Prolonged power outages also may render refrigerated medications unusable, posing a risk to those who rely on these treatments.

Economic Effects & Incurred Costs

Power outages, especially during extreme weather events, amplify existing inequities within low-wealth populations. When faced with a major outage event, low-wealth households struggle to keep up with the initial costs associated with outages and the long-term impacts of disrupted businesses, transportation, and damaged property. Costs associated with power outages can vary depending on the duration and severity of the event. These costs can include replenishing a refrigerator of spoiled food and buying flashlights, batteries, portable chargers, nonperishables, bottled water, and other emergency supplies. In some cases, people may need to temporarily relocate to a hotel outside of the impacted area. Costs associated with outages and related extreme weather events can be an immense burden on households, ranging from hundreds to thousands of dollars, depending on the severity of the damage.

National assessments suggest that the annual, cumulative cost of power interruptions ranges from \$22 billion to \$135 billion dollars annually, with an estimated average of approximately \$79 billion.²⁴⁸ Commercial utilities customers bear the brunt of this financial burden

and represent 72% (\$57 billion) of national, annual outage-associated costs. Industrial customers are also significantly impacted, with an estimated 26% (\$20 billion) share of this cost. Residential customers are estimated to account for 2% (\$2 billion) of this burden.²⁴⁹

Transportation systems rely on electricity for safety. For airports, subways, or train systems, outages can cause failure of signals and control systems or cease the ability to operate electric-powered vehicles (i.e., trains, electric cars, people-movers, electric buses) leading to delays, cancellations, or complete system disruptions for communities. These disruptions can compound the challenge of economic recovery in the hours, days, and months following a major outage. For example, the collapse of a major transportation corridor due to a power failure can impede traffic flow and stall freight movement over a broader region. Pennsylvania is a major conduit for freight and goods transportation, and outages in the Commonwealth can have ripple effects across the region. Similarly, outages in neighboring states may have an impact on the economy in Pennsylvania. These impacts can have more intense effects on areas where public transportation access is already limited.²⁵⁰ Lack of suitable transportation also drives reluctance to evacuate before hurricanes or forecasted flooding and may present a barrier to post-disaster recovery, potentially compounding the impacts of a hazard event.²⁵¹ This disproportionately impacts low-income populations who may be more dependent upon public transit options.

Specific recommendations on how Pennsylvania can support energy resilience can be found in the adaptation strategies section of the CAP. To ensure that these recommendations prioritize health and equity in building resilience, close considerations should be paid to prioritize the historically vulnerable populations that are discussed in this section.



CHAPTER 5

Economic Opportunities

Some of Pennsylvania's top economic sectors face significant impacts from climate change. The need to accelerate climate adaptation and mitigation investments comes with the opportunity to drive economic growth in Pennsylvania and improve economic opportunities for communities in EJ areas. This section looks at some of Pennsylvania's top industries, the new opportunities being brought to these sectors by climate adaptation, and the EJ issues that make focusing these opportunities in vulnerable communities indispensable.

The 2024 Pennsylvania CAP provides additional information on costs and benefits of specific prioritized climate change mitigation and adaptation strategies.

5.1 Climate Adaptation and Economic Opportunities

Climate change will continue to put more people and greater value, in the form of infrastructure and housing, in the path of weather disasters such as floods, hurricanes and heat waves. The potential economic impacts of climate change in Pennsylvania are described in [Chapter 3](#) and detailed even further in [APPENDIX B](#).

The worsening impacts of climate change increase the need for industries, agencies, and communities to harden or otherwise

protect infrastructure from these events, turn to alternative sources of energy, implement carbon sequestration technologies, and adopt other climate change adaptation and mitigation strategies. A 2023 study by the Center for Climate Integrity estimates that Pennsylvania's municipal governments would need to spend \$15.47 billion by 2040, or nearly \$1 billion a year, to protect residents from extreme heat, heavy precipitation events, and rising sea levels under a moderate climate change scenario.²⁵² Adaptation measures are crucial to increasing the resilience of communities and economies to damaging events.

While adaptation measures require up-front spending, they also present an opportunity to make smart investments and introduce climate-forward policy to support the Commonwealth's economy and increase equity in EJ communities. Adaptation projects provide long-term investments and economic opportunities for communities. These projects will also create various new jobs for the construction, operation, and maintenance of climate-resilient infrastructure, presenting a potential opportunity to expand job training programs across the state. The need for these opportunities is already much higher in EJ areas, where communities are already more vulnerable to climate change impacts. In many cases, these communities have faced historical disinvestment and prolonged inaction, making the transition to a more resilient future even more difficult. The following sections provide additional information on economic opportunities within each sector associated with the need for climate change mitigation and adaptation solutions.

5.2 Agriculture

The agricultural sector is an integral part of the Commonwealth's economy. The direct economic output of the sector totals \$81.5 billion, including industries involved in the production and processing of crops, animals, forestry products, landscaping, and horticultural services, agriculture-related support services, and food manufacturing.²⁵³ Increasing average temperatures are expected to have varying impacts on agricultural operations. While some fruits and vegetables may experience an extended growing season, potentially providing higher yield for those crops, climate change impacts can threaten the stability of other crops. Some common agricultural climate impacts can be mitigated to provide more environmental benefit as well as contribute economic benefits. For example, increased flow and runoff concentration from precipitation events can create greater challenges for nutrient management methods. Techniques used to mitigate stormwater runoff, such as riparian buffer zones and retention ponds, can create co-benefits by increasing the population and biodiversity of local pollinators, and providing wildlife habitat, water accessibility, erosion control, and other ecosystem services. These ecosystem services can improve crop yield and quality, enhancing output and generating related economic benefits.

Greenhouse gas mitigation techniques also provide opportunities for farmers to set up additional streams of income. Renewable energy installations, such as solar arrays, can be sited on less productive farm property through land leases. Solar developers can set up lease agreements with landowners allowing the company to install raised panels on the selected portion of land. These agreements contribute to the Commonwealth's renewable energy goals while providing new

income opportunities for farmers. For example, one Pennsylvania solar developer provides land leases ranging between \$1,500 and \$2,500 per acre per year.²⁵⁵

Climate change increases the frequency of extreme weather events, greatly impacting the operations of farm workers. Farm workers face substantial risk in the form of income losses incurred from missed days of work due to extreme weather, and unsafe working conditions due to extreme heat. Higher temperatures can also cause greater dermal absorption of pesticides and can facilitate the transformation of pesticides into more toxic and degrading compounds. Climate change also enables agricultural pests to expand their range, which may lead agricultural employers to apply increasing amounts of pesticides. Many hired crop workers are foreign-born people from Mexico and Central America that face linguistic isolation, poverty, and poor healthcare access, leaving them more vulnerable to climate impacts and impeding their ability to transition to different work. Adaptive farming practices are crucial to ensuring resilience and increasing worker safety in the wake of these changes. These practices include crop rotation, nutrient management, and integrated pest management. Practices like nutrient management maximize crop-nitrogen uptake and help mitigate greenhouse gas emissions from agriculture. Transitioning to regenerative farming systems, which increase plant and soil health, can decrease pest damage, and improve the soil's ability to store carbon, thus reducing the need for pesticide use as well as the associated costs and health impacts to farm workers. Currently, the growth of climate resilient practices is being supported by the U.S. Department of Agriculture's (USDA) investments into climate-smart commodities. Climate-smart commodities are any agricultural commodity that is produced using agricultural (farming, ranching or forestry) practices that reduce

Managing Risk

Some farmers have already identified opportunities to maintain their sales in the wake of changing growing conditions. For example, a farm in New Park faces significant losses due to frequent, heavy rain during the fall season, compromising sales from common weekend attractions such as corn mazes and apple picking.²⁵⁴ To manage this risk, the owner of the farm has chosen other crops to incorporate into the growing season. The latest crop, lavender, is drought resistant and was planted on a field with particularly thin and dry soil. The lavender starts to bloom in June, attracting pollinators to the farm and extending the agritourism season. These activities also require additional labor to implement, potentially creating new employment opportunities.

greenhouse gas emissions or sequester carbon.²⁵⁶ In 2022, USDA began investing a pledged \$1 billion into selected pilot projects that create market opportunities for U.S. agricultural and forestry products that use climate-smart practices and include innovative, cost-effective ways to measure and verify greenhouse gas benefits.²⁵⁷ Many of these pilot projects also promote equitable partnerships by collaborating with smaller underserved farmers and indigenous communities.²⁵⁸

Alternative farming practices, such as Controlled Environment Agriculture, can also potentially provide solutions to climate change driven impacts to farm worker health and safety. Controlled Environment Agriculture (CEA) is a sustainable approach to farming that involves producing crops within a climate-controlled structure, offering increased biosecurity and year-round production without pesticides or herbicides.²⁶⁰ CEA has a growing industry in Pennsylvania, that is focused on improving the Commonwealth's food system resilience by producing crops typically supplemented by out-of-state agriculture. CEA requires additional energy and management to operate, bringing new, indoor agriculture job opportunities. While Pennsylvania is gaining traction as an advantageous geography for CEA operators, utilities access and zoning challenges must be improved to ensure agricultural workers can access emerging indoor job opportunities in the wake of extreme heat.²⁶¹

5.3 Outdoor Recreation

Outdoor recreation added \$17 billion to Pennsylvania's gross domestic product in 2022, producing more than 164,000 jobs, more than a 7% increase from 2021.²⁶² Climate impacts to outdoor recreation can vary. Rising temperatures can extend the warm-weather season (air quality permitting), while the opportunity for winter outdoor recreation can also be negatively impacted by rising temperatures. How these impacts affect communities across the Commonwealth can vary. As outdoor recreation that relies on snow and ice declines, some communities and regions will need to adjust to support alternatives.

Regardless, the demand for outdoor recreation is expected to increase as the warm-weather season becomes longer. Climate resilient improvements to infrastructure can be multifunctional, producing improved outcomes for Pennsylvania's recreational sector. For example, traditional ("gray") stormwater infrastructure can be replaced or supplemented with "green" stormwater infrastructure in the form of stormwater parks and rain gardens. This can greatly increase valuable recreation space and have other economic benefits for the surrounding area. Transportation infrastructure can also incorporate green stormwater aspects or additional connections such as pedestrian or bicycle routes. Focusing on alternative transportation improvements in urban communities can provide more connectivity and potentially give pedestrians access to stores and other commercial areas now available through the pathways provided by green infrastructure. The creation of these spaces requires workers that can build, perform maintenance on, and monitor the living stormwater systems once the area is in use. These projects can bring many new jobs to the

Maximizing Benefits and Revitalizing Public Space

In Lancaster, the City redeveloped Brandon Park with a host of green infrastructure features, including over 23,000 square feet of bioretention and infiltration practices (with a drainage area of 132,400 square feet) and over 30,000 square feet of permeable pavement (with a drainage area of 48,300 square feet).²⁵⁹ The park includes basketball courts, playgrounds and new public art sculptures. The integrated stormwater infrastructure across parks in Lancaster provides an estimated \$661,000 in reduced pumping and treatment costs per year, not to mention additional amenity benefits provided to the community.

areas they are sited in, while also providing long-term benefits for locals.

One example of green investment is DCNR's [Conservation Landscapes](#) program. In this program, eight large regions throughout Pennsylvania are working together to drive strategic investment and actions around sustainability, conservation, community revitalization, and recreational projects. These collaborations are found in regions where there are strong natural assets, local readiness and buy-in, and state-level investment and support.²⁶³ In addition, small parcels of land in densely populated developed areas can build climate change resilience. The landscape conservation approach extends beyond political boundaries and supports broader climate goals.

Natural areas, parks, and trails provide opportunities for locals to stay active and healthy, potentially avoiding health care costs. One study found that there is a much higher return on money spent maintaining park trails through avoided health care costs, estimating \$3 in avoided healthcare costs for every \$1 spent.²⁶⁴ These benefits are often scarce for communities in EJ areas as many urban communities lack access to green space and healthy waterways that can also provide resilience to climate hazards such as flooding. Green spaces may also reduce the impact of the heat island effect. In particular, BIPOC and low-wealth communities are more likely to live in nature deprived areas.²⁶⁵ There is an opportunity to maximize benefits in EJ communities by considering the comprehensive needs of green infrastructure projects. This can include job training for locals to gain additional skills for green projects in their area and low-wealth communities considering where projects may be needed the most to enhance stormwater management, connectivity, and access to outdoor recreation space.

Enhanced green space can also boost property values, benefiting homeowners. However, care must be taken to make enhancements in a way that avoids displacing low-wealth residents, such as by pairing enhancements to natural areas with affordable housing and equity programs.

5.4 Energy Production & Transition

Pennsylvania is the second largest net supplier of total energy to other states.²⁶⁶ With the Commonwealth's expansive impact in the energy sector, there is an opportunity for the state to become a regional clean energy provider and clean energy sources will be crucial for mitigating climate impacts. Investment and growth in Pennsylvania's clean energy production and energy adaptation are necessary for greenhouse gas mitigation pathways. Clean energy projects can provide more research and development opportunities and jobs while reducing greenhouse gas emissions and lowering energy costs to residents and businesses. These projects can also provide new streams of income for property owners hosting clean energy projects. For example, Pennsylvanian solar projects also provide significant impacts and benefits to the populations and communities surrounding them. A study from 2020 found the 235 planned solar projects in Pennsylvania could create 5,991 direct jobs in construction, interconnection, and advertising work.²⁶⁷ Once in operation, the projects could generate a one-time, temporary economic output of \$1.8 billion and around \$83.3 million in economic output annually once the facilities are operating.

Expanding Resilience in Underserved Communities

Across 40 different New York City Housing Authority buildings, Community Power delivers guaranteed electricity bill savings of 20% to 500 low- to moderate-income households through its 1.2 MW project. This project leverages the power of partnerships, working across nonprofits, community-based organizations, mission-driven financiers, an energy cooperative, the nation's largest public housing entity, a solar installer, and a utility.

Preexisting programs in the Commonwealth help to boost incentives for residents and community partners to transition to clean energy and from new energy projects. This includes funding alternative energy generation projects on top of available federal credits.²⁶⁸ These investments help to drive future energy transition, as fossil fuels become less efficient in comparison. Renewable energy and storage are becoming cost-competitive with fossil fuel generation, even without subsidies. For example, one study found that about ¾ of the U.S. coal fleet is now more expensive to operate than it would be to build and operate new solar and wind energy farms.²⁶⁹ Recent research also suggests that new natural gas plants could be a risky investment, given continuing improvements in the cost and performance of clean energy technologies.²⁷⁰ The opportunities for the Pennsylvania economy can also be seen in workforce shifts. The low-carbon economy is emerging as a major U.S. employer, though disruptions in the sustainable energy supply chain during the COVID-19 lockdown threatened that progress.²⁷¹ In 2019, zero-emissions generation, like solar and wind, was responsible for about 544,000 jobs in the U.S., more than twice as many as the 214,000 jobs in fossil fuel generation.²⁷²

Equitable transition is key to ensuring that these benefits reach the most vulnerable populations. Without the proper job training, historically marginalized communities and linguistically isolated citizens with limited educational attainment will struggle to transition to jobs in the emerging low-carbon sector. Workers in the fossil fuel industry also face preexisting inequities that are necessary to address simultaneously to clean energy transition.²⁷³ Alongside access barriers in jobs, clean energy projects and infrastructure are not equitably distributed throughout the population due to other social and economic barriers such as income and location. One study found that majority-Black communities install 69% less rooftop solar than other neighborhoods that have the same level of income; less than half of U.S. community solar projects include low-income households.²⁷⁴ Low-income, rural households face the highest energy burden in the country, spending 9% of household income on energy bills compared to the national average of 3.3%. Energy efficiency upgrades such as adding insulation and sealing air leaks can reduce rural energy burdens by as much as 25%, translating into more than \$475 in annual savings for rural households. Addressing the needs of isolated and financially distressed communities to make clean energy improvements requires targeted programming and funding. With this comes the opportunity to improve the economic mobility and living conditions of many in EJ areas while supporting equitable climate adaptation strategies.

5.5 Potential Housing Pricing Impacts

Housing prices may experience shifts and changes due to climate change; for example, areas with an increased rate of damaging events are becoming less attractive. Extreme weather or climate events also damage infrastructure and parks, limiting the amenities in the area creating additional economic and social losses. Climate change is also increasing the cost of maintaining homes, both in the case of responding to a damaging event and making climate adaptation or mitigation improvements to the home. Climate-resilient home improvements and neighborhood improvements can not only avoid substantial costs but can potentially appreciate the value of homes. For example, one study looking at the impact of adaptation projects on housing prices in New York City and Miami-Dade County (FL) found that having natural green infrastructural adaptation projects within a 400-meter proximity is associated with a housing price appreciation by 2.7% in New York City and 9.7% in Miami-Dade County.²⁷⁵

Damaging events are expected to increase insurance rates and even potentially cause policy non-renewals as insurers change how climate change is factored into premiums.²⁷⁶ To combat rising flood insurance, communities can participate in Community Rating System (CRS) and earn National Flood Insurance Program rate discounts of 5%–45%. For CRS communities, flood insurance premium rates are discounted to reflect the reduced flood risk resulting from the community's efforts to advance several flood damage reduction and preparedness goals including stormwater management and the advancement of public information.²⁷⁷

Sustainable Infrastructure and Affordable Housing

The Silver Gardens Apartments in Albuquerque, New Mexico is a Smart Growth project that combined revitalization, affordable housing solutions, and energy-efficient infrastructure. Designed with community input, it includes a rooftop solar installation and fuel-efficient transportation options. Construction also strategically and safely placed unsuitable soils from the former brownfield underneath clean soil on the site avoiding fuel costs for moving the soils off-site.²⁷⁸

Many communities within EJ areas face the highest burden as they are more likely to live in these impacted areas, have aged housing in need of repairs, cannot move out of the area as easily and sometimes must move even further into affected areas.²⁷⁹ Low-wealth and low-income households particularly struggle to make the home improvements necessary for climate adaptation. In many cases, historical disinvestment and redlining discouraged lenders from providing home loans and other investments in urban neighborhoods where there were a high presence of recent immigrants and BIPOC. Redlining was a discriminatory practice of denying people access to credit and other financial services by labeling the area they live in as high-risk.²⁸⁰ Many urban neighborhoods and areas with larger populations of Black people were redlined by mortgage lenders. Although the 1969 Fair Housing Act outlawed racially motivated redlining, the long-term impacts of these practices still affect these communities today. Overcoming these historical impacts is important to ensuring that communities in EJ areas can make necessary adaptation moves and experience the associated economic benefits. Programming, resources, and financial support will be necessary to empower citizens to make changes and avoid a displacement of low-wealth populations through gentrification.

6.1 Adaptation Priorities

Climate changes will be severe in Pennsylvania, but the Commonwealth can take actions to avoid and reduce the impacts of climate change. Based on the risk assessment, the following represent priority considerations for climate adaptation, including consideration of programs, policies, infrastructure, or other changes that may be necessary to reduce risks:

- Reduce extreme heat risks to human health, particularly for vulnerable populations
- Support key sectors in the transition to a warmer climate, including agriculture, recreation and tourism, and forests, ecosystems, and wildlife
- Reduce flood risks to infrastructure and communities and increase their ability to cope and recover from the impacts of flood events
- Increase utility resilience to climate hazards with special consideration of outage impacts to vulnerable populations
- Help low-wealth households cope with potential increased energy burden
- Enhance tropical storm and landslide risk mitigation

Notably, implementing adaptation measures should be informed by this list but also consider the lead time needed for effective adaptation to these risks and those identified as lower priorities. For example, though sea level rise impacts to infrastructure may have a relatively lower risk rating than heat waves, they could get significantly worse by end-of-century and beyond, and climate change mitigation and adaptation work needs to begin soon.

6.2 Opportunities to use Mitigation and Adaptation Strategies for Economic Benefits

Strategies to prevent or address the impacts of climate change, such as greenhouse gas mitigation through renewable energy installations and riparian buffer zones and retention ponds used to mitigate stormwater runoff, can offer economic opportunities in their establishment and long-term operation. Projects such as the construction of a solar array or a stormwater park require workers to carry out the initial establishment of the project, operation and maintenance. This can provide new job opportunities as the demand for renewable energy and green infrastructure grows. These benefits are most needed in communities located in EJ areas. These benefits are most needed in communities located in EJ areas and for communities whose economies are in transition due to changes in the energy production landscape. In these communities, citizens are often more vulnerable to climate change impacts and may lack the resources to recover. Focusing programming and funding to boost hazard mitigation projects in EJ areas can potentially boost access to more equitable solutions. Extending employment opportunities to

these communities will ensure that the Commonwealth moves toward sustainability and resilience together.

6.3 Equity Considerations

In addition, a key theme across this risk assessment has been that climate change will not affect all Pennsylvanians equally. Some may be more vulnerable to impacts due to their location, income, housing, or other factors discussed within each hazard profile. For example, certain populations may have greater physical exposure to risks (e.g., construction workers may be more exposed to heat waves), or limitations to their ability to manage consequences if they occur (e.g., income or wealth may impact ability to pay for air conditioning).

Disproportionate impacts are often not random. Consequences of historical discriminatory practices in BIPOC communities (e.g., redlining, systemic disinvestment) manifest today with BIPOC communities disproportionately in housing that is particularly susceptible to deterioration by heat waves.

As Pennsylvania works to reduce its climate risks, care needs to be taken that these inequitable impacts are addressed, and that adaptation efforts do not inadvertently exacerbate existing inequities.

6.4 Continued Research Needs

This Impacts Assessment evaluates Pennsylvania's climate change impacts in terms of relative risk ratings to inform adaptation priorities. The risk assessment focused at a high level, and additional detail and quantification of risks could be incorporated over time.

In addition, there remain open research questions around several important risk factors in the state, particularly related to heavy precipitation and flood risk. Remaining open research questions include: what is the main driver of flooding in Pennsylvania; what are the uncertainties around precipitation projections, which are most decision-relevant, and what changes in observations, data analysis or modeling have the greatest potential to reduce those uncertainties?

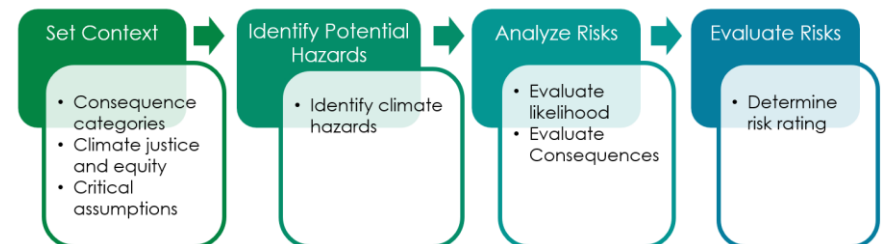
Managing deep uncertainty in projections of precipitation extremes in local-level adaptation decision-making is critical. Local-level decisions about adaptation measures (e.g., sewer capacity upgrades to manage flooding and health concerns) made by municipalities, cities, and states can impact urban infrastructure. Those decisions can hinge on estimates of future precipitation extremes, and infrastructure failures are often driven by heavy precipitation. However, there may be significant gaps between the resolution of data (e.g., projections and models) ideally used for stormwater infrastructure management decision-making modeling and the resolution of data available. Additionally, there is deep uncertainty in current flood hazard projections. As such, decision-making must use an approach that accounts for deep and dynamic uncertainties.

Pennsylvania faces significant climate risks in the coming century. While uncertainties regarding climate projections and opportunities to better understand climate trends exist, overwhelming evidence demonstrates the imperative that Pennsylvania act to reduce the consequences of climate change by mid-century and beyond. The adaptation priorities described above are a starting point for reducing priority risks.

Introduction

The risk assessment methodology is consistent with the International Organization for Standardization (ISO) 31000 Risk Management standard, a framework for managing a broad array of risks including climate risks. This is a risk-based approach to assessing and prioritizing climate impacts. The risk assessment evaluates the likelihood that a climate hazard will occur and the magnitude of its consequences. The risk assessment prioritizes impacts that are reasonably likely to occur within mid-century timeframe, likely to result in potentially major or catastrophic consequences, and have adequate information to evaluate risk. The four major steps included in the standard ISO risk assessment process are included in **Figure 39**.

Figure 39. Risk assessment process



Step 1—Set Context

The first step of a risk assessment is to establish the critical context and focus areas for the assessment.

Consequence Categories

The risk assessment will focus on consequences in the following categories. These categories cover all sectors specified in Act 70, with additional attention to impacts to built infrastructure and environmental justice and equity, which are emerging as key potential cross-cutting consequence areas related to the other sectors:

- Human health
- Environmental justice and equity
- Economy
- Agriculture
- Recreation and tourism
- Other economic activity
- Forests, ecosystems, and wildlife
- Built infrastructure

Approach to Climate Justice and Equity

The Impacts Assessment focuses on improving understanding of the equity impacts of climate change in the Commonwealth. The assessment seeks to answer two key questions:

- What populations may be most vulnerable to climate hazards?
- To what extent are climate changes projected to affect communities that are already overburdened?

Key Terms

Exposed areas—Geographic areas projected to be affected by climate change based on climate change projections.

Vulnerable populations—Populations more likely to experience adverse impacts from being exposed to climate hazards, such as due to factors such as demographics (e.g., race, gender), socioeconomic status, and life- or livelihood-sustaining needs (e.g., dependence on electricity for critical medical care).

EJ areas—Shorthand for “Environmental Justice census tracts,” which have high environmental risk as indicated by data on over 30 different EJ indicators such as socioeconomic status, sensitivity to environmental hazards, and level of exposure to environmental hazards and is defined in [DEP’s EJ Policy](#).²⁸¹

Overburdened populations—“Minority, low-income, tribal, or indigenous populations or geographic locations ... that potentially experience disproportionate environmental harms and risks.”²⁸² EJ areas are used in this assessment as a proxy for locations where populations are already overburdened by hazards and other structural disadvantages.

Overburdened Populations

The environmental justice and equity consequence ratings for each hazard are based on the degree to which areas most exposed to climate impacts also have a high percentage of overburdened individuals, based on spatial analysis of overlap between exposed areas and EJ areas at the census block group level.

EJ areas are used as a proxy for locations where populations are already overburdened by hazards and other structural

disadvantages. These areas are commonly used by DEP and other state agencies for similar purposes.

EJ areas cannot capture all characteristics of historically marginalized, burdened, or underserved populations (e.g., the areas draw defined lines of EJ locations, are based on percentiles, and are based on thresholds from two indicator variables). Nonetheless, they support an approach to identify where climate change impacts could be falling disproportionately to EJ communities.

Vulnerable Populations

The environmental justice and equity consequence sections in this assessment also dive deeper into the nuances of what drives risks of each hazard, identifying specific populations that may be more vulnerable to certain climate changes, and noting where additional factors critical to equity analysis come into play. For example:

- In rural areas where there are several critical roads to support the economy (e.g., for individuals to get to work, or for agricultural centers to receive and send supplies), landslide exposure may be particularly key as consequences of a road being damaged would be severe.
- People who do not speak English may face barriers related to accessing social or health services, making those groups more at-risk to climate hazards such as increased frequency of extreme heat conditions.
- Poverty may reduce a person's capacity to handle significant changes (e.g., temporary loss of work or damage to housing) that may be associated with climate risks.

Other Critical Assumptions

Risks were assessed under the assumption that Pennsylvania's present-day population, demographics, and economy would continue into 2050 and beyond. Though this assumption does not provide a fully accurate picture of climate change's impacts to Pennsylvania in 2050, the approach allows the assessment to isolate climate change as the variable of interest. For example, expected population growth in Pennsylvania's urban areas could increase the extent to which Pennsylvanians are exposed to the urban heat island effect.²⁸³ Similarly, significant population growth in the southeast region by mid-century could also increase the sensitivity of the region to coastal storm surges as a result of sea level rise and increased cyclone severity.²⁸⁴ However, the extent to which Pennsylvania's demographic and economic makeup will change is dynamic. Attempting to predict and control for all future shifts unrelated to climate change is impractical, and as a result was excluded for the risk assessment.

Step 2—Identify Potential Hazards

The second step is to identify and select potential hazards for detailed risk evaluation. [CHAPTER 3](#) summarizes expected impacts of climate change by sector in Pennsylvania, as described in previous iterations of the Impacts Assessment. The six focus hazards identified (increasing average temperatures, heat waves, heavy precipitation and inland flooding, landslides, sea level rise, and severe tropical and extra-tropical cyclones) represent the primary hazards expected to affect the Commonwealth drawn from previous impacts assessments. The 2024 Impacts Assessment focuses on updates to the expected impacts from the selected hazards based on the latest science, with priority given to providing additional information about impacts on equity and human health.

Step 3—Analyze Risks

Risk is a function of the likelihood and consequences of a hazard. The approach to evaluating each of these for the selected hazards is described below.

Likelihood

To assess likelihood, the analysis draws on exposure information available in previous Impact Assessments and the latest available projections. Then, the annual probability, or chance of each hazard event occurring in a given year, is evaluated using the scale to the right. Likelihood is evaluated for a baseline and mid-century (e.g., 2040–2059) time frame. Projected changes beyond mid-century and beyond the end of the century are described qualitatively.

The Pennsylvania All-Hazard Mitigation Planning Standard Operating Guide describes the likelihood of hazard events occurring in terms of their frequency. “Probability of occurrence” estimates can then be used by community officials to inform and assess future development and risks. **Table 13** builds on this guide and describes climate hazards’ likelihood in terms of their probability of occurring in a given year. Discrete hazards are those related to individual extreme events (e.g., a heat wave) that occur over a relatively short period of time (e.g., days or weeks). Ongoing risks are those related to gradual changes in climate occurring over many years (e.g., higher average temperatures or sea level rise); they may include critical thresholds which, if reached or surpassed, engender particular risks (e.g., X feet of sea level rise). Critical thresholds are defined tipping points at which significant impacts occur.

Table 13. Likelihood rating scale

Rating	Criteria for Discrete Hazards	Criteria for Ongoing Hazards
Highly Likely	4 Greater than 90% annual probability	Risk is very likely (greater than 90%) to cross critical threshold by the 2050s.
Likely	3 Between 50% and 90% annual probability	Risk is likely (greater than 66%) to cross critical threshold by the 2050s. It would be surprising if this did not happen.
Possible	2 Between 1% and 49.9% annual probability	Risk is just as likely as not to cross critical threshold by the 2050s.

The rating scale for discrete hazards (i.e., individual events like heat waves or storms) is consistent with the Pennsylvania All-Hazard Mitigation Planning Standard Operating Guide²⁸⁵ and the Pennsylvania Emergency Management Agency (PEMA) Hazard Mitigation Plan.²⁸⁶ To expand the rating scale to accommodate the more gradual or ongoing nature of some hazards (e.g., higher average temperatures, sea level rise), DEP and ICF expanded the rating scale as shown above in the rightmost column, consistent with how the Fifth National Climate Assessment and Intergovernmental Panel on Climate Change defines likelihood of climate changes.^{287,288} A comparison of the different likelihood scales and terminology are shown in **Table 14**. The critical thresholds for ongoing hazards (e.g., increasing average temperatures) are based on likely projections for mid-century.

Table 14. Comparison of scales of likelihood: PEMA Hazard Mitigation Plan, NCA4, and IPCC

PEMA Hazard Mitigation Plan		NCA5		IPCC	
Term	Likelihood	Term	Likelihood	Term	Likelihood
Highly likely	90-100% annual probability	Very likely	≥9 in 10 (90%)	Virtually certain	99-100%
				Very likely	90-100% probability
Likely	50-90% annual probability	Likely	≥2 in 3 (66%)	Likely	66-100% probability
Possible	1-49.9% annual probability	As likely as not	= 1 in 3 to 2 in 3 (33-66%)	About as likely as not	33-66% probability
		Unlikely	≤1 in 3 (33%)	Unlikely	0-33% probability
Unlikely	0-1% annual probability	Very unlikely	≤ 1 in 10 (10%)	Very unlikely	0-10% probability
				Exceptionally unlikely	0-1% probability

Consequences

DEP and ICF applied a consequence rating scale to assess the severity of impacts for key consequence categories and indicated the rationale behind the ratings. After updating climate science projections, DEP and ICF sought input from Penn State University (PSU) experts and key community partners to complement information on the consequences of each climate risk as described in the 2015 and 2018 impacts assessments, and then

to rate the consequences using the scale. The proposed consequence rating scale is in **Table 16**.

This scale was developed through review of the Pennsylvania All-Hazard Mitigation Planning Standard Operating Guide (striving for consistency where possible, such as in the overall 1-4 rating scale and the criteria for several types of impacts) and expanding on this guidance as needed to fit additional consequence categories for the Climate Impacts Assessment. The metrics to define each category are intended to ensure consistency and comparability across risk scenarios. The thresholds to indicate different levels of consequence (e.g., critical vs. catastrophic) are not identical for all consequence categories, because the types of priority impacts in each category are different (e.g., impacts to human health vs. infrastructure). The scale was applied to expected consequences from the climate hazards at the state scale by mid-century. It evaluates consequences from individual discrete hazard events, and the cumulative impacts of ongoing hazards.

Using the scale, the overall consequence score is compiled as an average of the five consequence category ratings. The overall risk assessment results also emphasize the disaggregated nine consequence ratings. Finally, while the climate change risk assessment is focused on evaluating negative consequences of the hazards (in order to inform adaptation priorities), the assessment includes information on positive impacts or opportunities that may arise (see [CHAPTER 5](#)).

Confidence Ratings

Recognizing that the availability and quality of data sources for evaluating climate hazards varies, each likelihood and consequence rating is assigned a confidence rating. The confidence rating

indicates the strength, consistency, and makeup of the knowledge base used to inform the likelihood and consequence ratings:

- **High confidence**—Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement.
- **Medium confidence**—Several sources of high-quality independent evidence, with some degree of agreement.
- **Low confidence**—Varying amounts and quality of evidence and/or little agreement between experts; or assessment made only using expert judgment.

Step 4—Evaluate Risks

To compute a total risk score and corresponding risk rating for each climate hazard, the likelihood score and overall consequence score are multiplied together. A risk matrix and scoring rubric are then used to determine total risk as shown in **Table 15**.

Table 15. Risk rating matrix and rating rubric

Likelihood	Consequence				Risk Score	Rating
	Minor	Limited	Critical	Catastrophic	(low end inclusive)	
Highly Likely	4	8	12	16	12+	Extreme
Likely	3	6	9	12	6 – 11.9	High
Possible	2	4	6	8	3 – 5.9	Medium
Unlikely	1	2	3	4	1 – 2.9	Low

Table 16. Consequence rating scale

Scale	Human Health	Environmental Justice & Equity	Economy			Forests, Ecosystems, and Wildlife	Built Infrastructure
			Agriculture	Recreation and Tourism	Other Economic Activity		
4 Catastrophic	1000+ people potentially affected; over tens of deaths or injuries possible; long duration of impact	Percent of population in EJ areas that is exposed is > 2x the average percent of population exposed statewide	<ul style="list-style-type: none"> Severe, disruption to multiple industries and employment lasting months to years Over \$1 billion in potential annual losses 	<ul style="list-style-type: none"> Severe disruption to multiple seasons or employment Over \$1 billion in potential annual losses 	<ul style="list-style-type: none"> Severe disruption to multiple industries and employment lasting months to years Over \$1 billion in potential annual losses 	Irreversible damage to a significant natural asset	Over 50% of infrastructure in the area damaged, destroyed or shut down; long-duration impact for critical facilities (30+ days) or potential for at least impact across >50% of the state
3 Critical	100-1000 people affected; multiple deaths, sicknesses, or injuries possible; moderate to long duration of impact	Percent of population in EJ areas that is exposed is 1.5-2x the average percent of population exposed statewide	<ul style="list-style-type: none"> Moderate, disruption to multiple industries and employment; or severe impacts to one industry lasting months to years \$100 million to \$1 billion in potential annual losses 	<ul style="list-style-type: none"> Severe disruption to one season or employment \$100 million to \$1 billion in potential annual losses 	<ul style="list-style-type: none"> Moderate, disruption to multiple industries and employment; or severe impacts to one industry lasting months to years \$100 million to \$1 billion in potential annual losses 	<ul style="list-style-type: none"> Widespread damage to a natural asset Recovery would take years to decades 	More than 25% of infrastructure in affected area damaged or destroyed; complete shutdown of critical facilities for more than one week, or potential for at least moderate impact across > 25% of the state
2 Limited	10-100 people affected; minor injuries only; brief to moderate duration of impact	Percent of population in EJ areas that is exposed is 1-1.5x the average percent of population exposed statewide	<ul style="list-style-type: none"> Moderate, weeks-to months-long disruption to multiple industries and employment; or severe short-term impacts to one industry \$10 million to \$100 million in potential annual losses 	<ul style="list-style-type: none"> Moderate disruption to multiple seasons or employment; or severe weeks-long disruption to one season \$10 million to \$100 million in potential annual losses 	<ul style="list-style-type: none"> Moderate, weeks-to months-long disruption to multiple industries and employment; or severe short-term impacts to one industry \$10 million to \$100 million in potential annual losses 	<ul style="list-style-type: none"> Localized, significant damage to a natural asset Recovery would take years to decades 	More than 10% of infrastructure in affected area damaged or destroyed; complete shutdown of critical facilities for more than one day
1 Minor	Very low potential for health impacts; very few injuries, if any; brief duration of impact	Percent of exposed population in EJ areas is equal to or less than the average percent of population exposed statewide	<ul style="list-style-type: none"> Moderate-to-minor disruption to industries and employment Or < \$10 million in potential annual losses 	<ul style="list-style-type: none"> Moderate disruption to one season or employment Less than \$10 million in potential annual losses 	<ul style="list-style-type: none"> Moderate-to-minor disruption to industries and employment Or < \$10 million in potential annual losses 	<ul style="list-style-type: none"> Localized, moderate damage to a natural asset Recovery would take months to years 	Only minor property damage; temporary shutdown of critical facilities

For each hazard, this section presents a detailed description of the hazard, expected impacts across sectors, and the evidence base for the relative likelihood and consequence ratings. Hazards are presented in order from highest to lowest overall risk score. Use the links below to jump to a particular hazard:

- [Increasing Average Temperatures](#)
- [Heavy Precipitation and Inland Flooding](#)
- [Heat Waves](#)
- [Landslides](#)
- [Sea Level Rise](#)
- [Severe Tropical and Extra-Tropical Cyclones](#)

Increasing Average Temperatures

Overview

On average, the state is expected to experience an increase of 6.7°F (3.7°C) in average annual temperature by mid-century under the SSP 5–8.5 scenario. The effect of these increasing average temperatures will be felt throughout the Commonwealth and across sectors. In particular, human health, winter recreation and tourism, and forests, ecosystems, and wildlife are expected to face higher levels of risk. The occurrence of heat-related illness and death is projected to increase. Outdoor recreation that relies on snow and ice may no longer be possible after mid-century, though would likely be replaced by other forms of recreation. Species may experience range shifts or even local extirpation due to sensitivity to temperature and a decrease in suitable habitat.

Overall, average temperatures will increase from a medium to high risk by mid-century. **Table 17** summarizes the likelihood and consequence ratings. **Figure 40** illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings. Overall, the likelihood of increasing average annual temperatures is high, particularly after mid-century.

Figure 40. Increasing average temperatures risk matrix

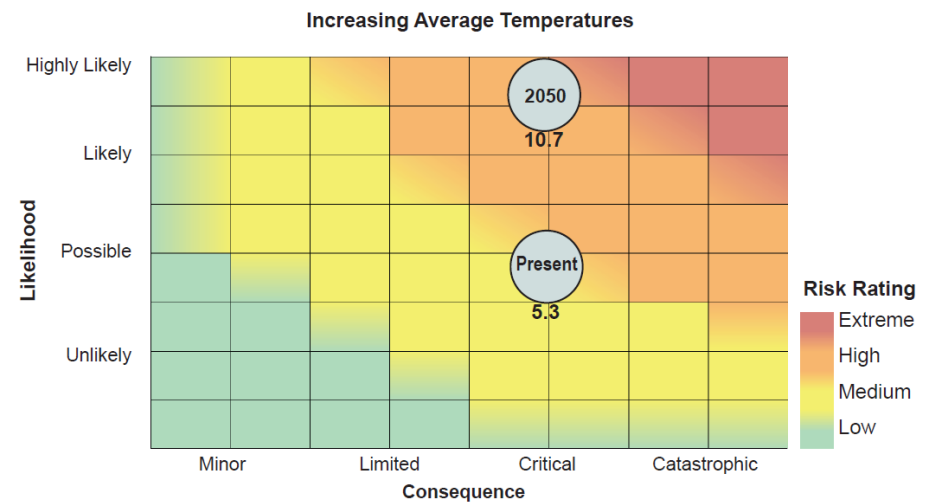


Table 17. Increasing average temperature statewide risk summary

Timeframe or Sector	Rating	Justification Notes	Confidence	Differential Impacts
Likelihood (details on pg. 96)				
Current	2	The state has experienced long-term change of more than 1.8°F (1°C) increase since 1905.	High	Southeastern PA historically experiences the highest temperatures.
Mid-century	4	Climate models project 4.9–8.3°F (2.7–4.6°C) increase by mid-century under the SSP 5–8.5 scenario.	High	Southeastern and southwestern PA will experience the highest temperatures, while northwestern PA will experience the greatest change in temperature.
Beyond 2050		By the end-of-century under the SSP 5–8.5 scenario, average temperatures in the state are projected to increase by 7.7–13.3°F (4.3–7.4°C). Average temperature will continue to increase beyond 2100 without greenhouse gas mitigation.		Same as above.
Consequences (details on pg. 96)				
Human health	3	Increased heat-related mortality. Decreased cold-related mortality. Increased prevalence of diseases (e.g., Lyme disease).	High	Vulnerable populations (e.g., the elderly, those with cardiovascular disease or respiratory conditions, outdoor workers, and populations with limited access to air conditioning) experience higher risk to heat-related illness and death.
Environmental justice and equity	3	EJ areas are approximately 1.8 times as exposed to high numbers of days >90°F than the state overall.	High	See above.
Economy: Agriculture	2	Increased livestock heat stress. Decreased dairy industry productivity. Positive and negative impacts to crops.	Medium	Animal husbandry is expected to face more severe impacts from increased temperatures than crops.
Economy: Recreation and tourism	3	Severe disruption to snow- and ice-based winter recreation and tourism.	High	While winter recreation is expected to suffer, spring and fall recreation and summer water-based recreation may see increased demand.
Economy: Other	2	Increased energy demand. Decreased timber supply due to forest die-back.	Medium	

Timeframe or Sector	Rating	Justification Notes	Confidence	Differential Impacts
Forests, ecosystems, and wildlife	4	Local extirpation for certain species lacking suitable habitat. Increase in pests and invasive species. Decreased water quality.	Medium	Species that require cooler climates are at greater risk than those suited to warmer climates. Specialist species with specific habitat requirements are also more vulnerable to habitat changes.
Built Infrastructure	1	Low infrastructure vulnerability. Increased cooling demand. More frequent mandatory capacity decreases. Reduced efficiency of energy infrastructure.	High	Managers should consider increased temperatures in planning and operations for built infrastructure that serves populations at greater risk to heat stress.

Overall Risk

Current	5.3	Medium	High
2050s	10.7	High	High

Potential Opportunities

- Use of biofuels to reduce reliance on fossil fuels poses an economic opportunity for the agricultural sector in Pennsylvania, with crops such as perennial shrub willow, perennial grasses, and annual sorghum and winter rye as potential biomass crop candidates
- Increase in soil health and in the development of healthier products for people and buildings with the use of biomaterials from agriculture that sequester carbon
- Longer growing seasons and higher temperatures may provide opportunities to grow new, warmer-weather crops (e.g., soybeans, peaches)
- Increase in use of silvopasture for livestock operations, which reduces heat stress among other benefits
- Increase in participation in spring and fall recreation (e.g., biking, golfing) and summer water-based recreation
- Increase in suitable habitat for species at the northern extent of their range in Pennsylvania
- Decline in wintertime heating energy demand and costs

Likelihood

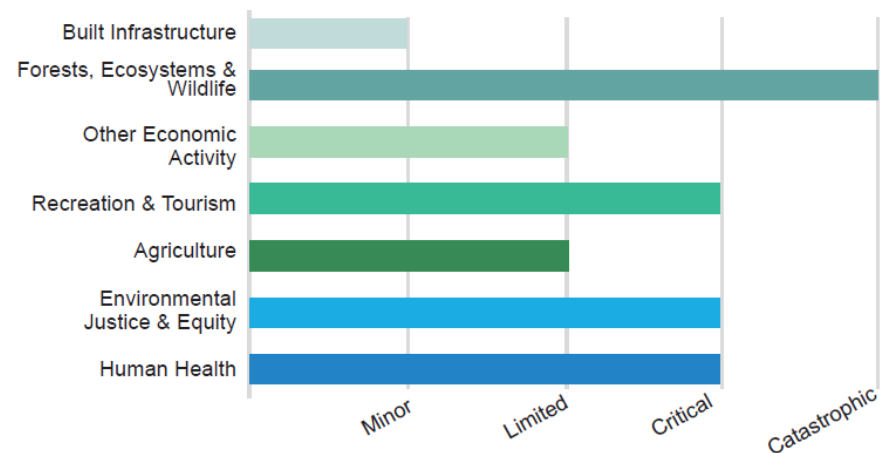
Among projections for climate hazards, those for increasing average temperatures have among the highest certainty. The National Climate Assessment gives very high confidence²⁸⁹ to the statement that warming over the continental United States is higher than the global average, and high confidence²⁹⁰ to the statement that “recent record-setting years may be “common” in the next few decades.”²⁹¹ Much larger rises are projected by end-of-century (2071–2100): 4.6°–8.1°F (2.5°–4.5°C) in a lower emissions scenario (SSP 2–4.5) and 7.7°–13.3°F (4.3°–7.4°C) in the higher emissions scenario (SSP 5–8.5). Given such strong confidence in projections and the intensity of the increases, increasing average temperatures merits a likelihood rating of four.

Note that the projected increases in temperature are similar across emission scenarios (e.g., SSP 2–4.5 and SSP 5–8.5) through mid-century. After 2050, there is more divergence between scenarios, with greater increases in temperature occurring under the SSP 5–8.5 scenario.

Consequences

Projected increases in average temperatures would mean that recent record-high average temperatures become normal in the next few decades. This carries consequences across sectors, as discussed below. **Figure 41** summarizes the overall consequence ratings statewide for increasing average temperatures – highest consequences are in forests, ecosystems, and wildlife.

Figure 41. Increasing average temperatures consequences



Human Health

Rating: 3

Increased temperatures will increase heat-related mortality and morbidity but reduce cold-related mortality and morbidity. Currently, cold-related mortality is higher than heat-related mortality. The literature is divided on whether increasing temperatures will cause a net positive or negative effect in the future but is clear that heat-related deaths will increase.^{292,293,294,295} Even small increases from seasonal average temperature can result in higher death rates.²⁹⁶ Between 2000 and 2022, Pennsylvania has experienced 66 extreme cold and chill episodes and 40 extreme heat episodes. Cold episodes have resulted in four direct deaths and heat episodes have resulted in 92 deaths.²⁹⁷ These are based on the limited definitions of extreme cold and heat events in the National Weather Services’ Storm Events database, which may not capture all extreme cold or extreme events hazardous to human health. For example, the Pennsylvania Department of Health has estimated that

between 2018 and 2022 Pennsylvania experienced 1,165 hospitalizations and 6,487 emergency department visits for heat-related illness.

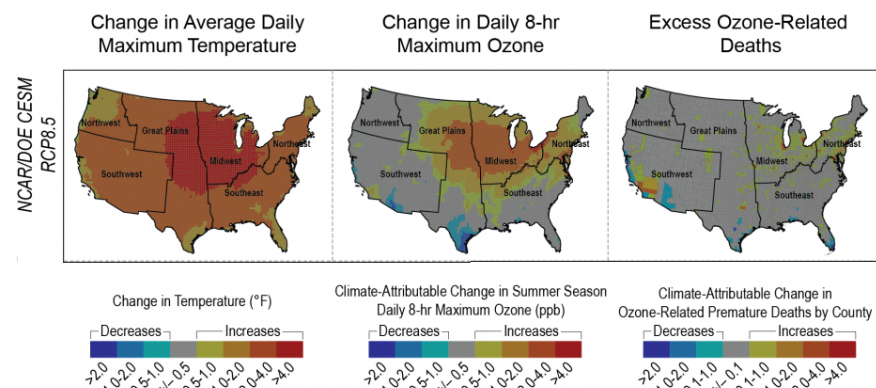
Dramatic increases in the heat index in the Northeast²⁹⁸ are also projected to make working, walking, and exercising outdoors more difficult certain times a year, and may create hazardous conditions for being outside.^{299,300} More information can be found in section 4.2. However, the risk of mortality from extreme heat events has been decreasing, as more and more households install air conditioning.

The elderly, pregnant people, those with cardiovascular disease, outdoor workers, and populations with limited access to air conditioning experience higher risk to heat-related illness and death.

When high temperatures extend into the night, the health risk increases. With night temperatures above 68°F, the human body cannot cool down from the high temperatures of the day. Warm nights add to the physiological strain from a hot day instead of releasing it, making the risk of heat-related health concerns much higher.³⁰¹ Even without a heat wave, warm nights may also disrupt the normal sleep cycle, thereby causing damage to the immune system and increasing the risk of cardiovascular disease, chronic illness, and more.³⁰² Increased temperatures also reduce air quality through increased ground-level ozone and particulate matter (PM 2.5), as well as increased allergen levels.^{303,304} Higher temperatures can increase the rate at which ozone is formed and increase the prevalence of pollutants that act as precursors to ozone.³⁰⁵ Warmer temperatures are also projected to raise pollen production, allergenicity, distribution, and seasonal timing. Combined, increased ground-level ozone and allergens will decrease air quality. Poor air

quality has been linked with medical emergencies, acute respiratory symptoms, exacerbated maternal heat stress for pregnant people, and premature deaths.^{306,307} As shown in **Figure 42**, projected increases in ozone from climate-attributable temperature change are likely to contribute to an increase in premature deaths in Pennsylvania. Increased levels in PM 2.5 are also expected contribute to an annual increase of premature deaths in the Northeast (specifically, 400 more deaths among people ages 65 and older, relative to a 1986–2005 baseline, with 2°C of warming).³⁰⁸ Additionally, increased allergens will also lead to more individuals experiencing allergies.³⁰⁹ Higher pollen production and longer pollen season could also increase asthma episodes.³¹⁰

Figure 42. Projected premature deaths from changes in ozone



Projected change in average daily maximum temperature, daily 8-hour maximum ozone, and excess ozone-related premature deaths in the United States in 2030. This study was based on RCP 8.5.³¹¹

Increased temperatures may contribute to the development of harmful algal blooms on Lake Erie and other water bodies, which can be a health hazard if people or pets come in contact with or ingest the toxic algae.³¹²

Climate change also could affect the distribution and prevalence of vector-borne diseases (e.g., Lyme disease and West Nile Virus) and air-borne infectious diseases. For example, warmer winters could increase the rates of Lyme disease. Already, Pennsylvania experiences the most Lyme diseases cases in the country partly as a result of increased winter temperatures and the westward expansion of tick populations that carry Lyme disease.^{313, 314} Higher temperatures could also lead to increases in the prevalence of mosquito-borne illnesses.³¹⁵ Warm summers and milder winters could lengthen these diseases transmission seasons. Finally, a more temperate Commonwealth may allow for greater movement of southern disease carrying species northward, like the lone star tick,³¹⁶ Gulf Coast tick,³¹⁷ and the Asian tiger mosquito.³¹⁸ In 2022, Pennsylvania identified gulf coast ticks for the first time³¹⁹ and reported its first human case of Heartland virus,³²⁰ an arbovirus transmitted by the lone star tick.

Violence is also projected to increase as a result of climate change. Increased temperatures have a significant positive effect on criminal behavior.^{321,322} Violent crimes are projected to increase as a result of warmer temperatures, including murder, rape, and aggravated assault.^{323,324}

Human health impacts may be exacerbated in areas where populations experiencing heat-related impacts have less ability to adapt (e.g., low-income individuals that cannot afford air conditioning or need to take public transportation or walk). Additionally, heat impacts may be more significant in certain urban areas. The urban heat island effect, which can raise local daytime temperatures by 1-7°F and nighttime temperatures by 2-5°F, happens in areas with significant amounts of paved surfaces and buildings which reflect heat and low concentrations of greenery.³²⁵

As a result, urban areas are projected to experience greater rates of mortality from heat events.³²⁶

Environmental Justice and Equity

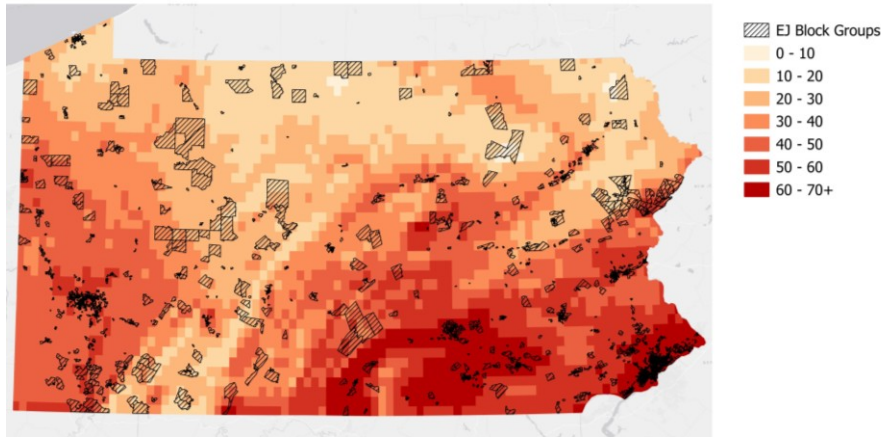
Rating: 3

EJ areas are more likely to experience days above 90°F compared to the state average. For example, EJ locations are 1.9 times more likely to be in the top one-fifth of census blocks with days above 90°F compared to non-EJ census blocks.

Although populations in EJ areas constitute less than a third of the statewide population, over half of all people in the state exposed to highly frequent heat days are those of EJ areas. BIPOC and those living below the poverty line are disproportionately exposed to urban heat island intensity in 169 of the largest U.S. cities, which includes Philadelphia and Pittsburgh.³²⁷

Figure 43 shows the number of days with temperatures >90°F projected to occur across the state by mid-century, overlaid with state EJ areas. This indicator is useful for capturing the general areas where temperatures are projected to most frequently be very hot, and therefore where vulnerable populations may be most at risk. However, the indicator does not capture localized urban heat island (UHI) effects in cities, where temperatures may be even hotter than the downscaled averages projected in local areas with fewer trees and less green space³²⁸ that can otherwise absorb heat and provide shade.

Figure 43. Projected annual number of days with temperatures over 90°F in 2050, with EJ block groups



Risks of heat-related illness and mortality will increase with warmer average temperatures. Populations most at risk will likely be those that disproportionately lack access to the key methods of adapting to this risk – such as using air conditioning indoors (price may be a barrier), staying in the shade outside (outdoor work and financial constraints may be a barrier), and drawing on support networks (seniors living alone may be especially vulnerable).³²⁹

A City of Philadelphia heat report found that average surface temperatures are up to 22°F hotter in some neighborhoods than others. Low-income and minority residents are more likely to live in these neighborhoods.^{330,331} The expected causes of hotter surface temperatures are limited green space and tree canopy, more exposed dark surfaces (e.g., asphalt), and aging housing stock due to a history of redlining and disinvestment. Residents interviewed for the study also indicated limited access and awareness of City

cooling centers and a need for better air conditioning and fans at home to stay cool.

Economy

Agriculture

Rating: 2

Increasing average temperatures will have both positive and negative impacts on crops in Pennsylvania. Warmer temperatures mean longer frost-free and growing seasons (see map of projected growing degree days and Plant Hardiness Zones in **Figure 9** and **Figure 10**). For example, soybean crops are expected to experience increased yields due to longer frost-free and growing seasons and higher concentrations of atmospheric carbon dioxide.³³² Other crops such as peaches, could also see an expansion in growing season and yield; Pennsylvania's current peach production has a value of approximately \$20 million annually.³³³ However, corn, which is Pennsylvania's crop with the highest agricultural sales, is projected to experience decreased yields due to hotter summers. Increased temperatures are also projected to harm corn crops by allowing pests such as corn earworm to increase their populations.³³⁴

Livestock and dairy farming will be negatively impacted overall due to increased heat stress experienced by the animals (and subsequent decreased meat and milk yields), increased energy and capital expenditures to reduce heat stress, and lower-quality forage material.³³⁵ However, poultry farms are expected to double in size by 2050 as Pennsylvania becomes a better alternative to the climate of southern states.³³⁶

Increased temperatures may encourage a shift to using silvopasture for livestock operations, which integrates trees, foraging, and grazing on the same plot of land. This practice reduces heat stress, increases forage and reduces feed cost, increases carbon sequestration, captures more runoff/nutrients, and provides alternate income source via nuts or fruits.³³⁷

Recreation and Tourism

Rating: 3

Climate change is expected to greatly impact snow and ice-based recreation for the worse and may affect the types of recreation that people choose to pursue in each season. The state's downhill ski and snowboard resorts are not expected to be economically viable past mid-century. Particularly in southern Pennsylvania, snow cover to support cross-country skiing and snowmobiling has been declining and is projected to decline further by 20–40% by the middle of the century and 40–80% by the end of the century.³³⁸

Water-based recreation may experience increased demand, though the impact is expected to be small. A national study found that climate and participation in water-based recreation do not have a strong relationship. Decreased snowpack and earlier snowmelt may lead to diminished water levels later in the summer.³³⁹ Other outdoor, warm-weather leisure (e.g., biking, golfing) is expected to experience an increase in activity during spring and fall and a decrease during the hottest days of summer.

Hunting and fishing in Pennsylvania will also be altered. Cold-water fishing (e.g., trout) may no longer be supported. This impact could be particularly severe in southeastern and northwestern Pennsylvania. However, the Pennsylvania Fish and Boat Commission conducts an extensive annual trout stocking program that may help

support trout populations under changing conditions.³⁴⁰ Increased drought conditions may increase the risk of wildfire, affecting hunting and other outdoor recreation.³⁴¹

Increased temperatures may also contribute to the development of harmful algal blooms on Lake Erie and other inland lakes, which could discourage recreation and fishing due to health concerns to both humans and fish.

Other Economic Activity

Rating: 2

Pennsylvania is a major energy-producing state in the U.S., largely due to natural gas production, and the energy sector will have to manage demand transitions that accompany climate change. Warming is likely to increase demand for cooling during summer months, and this increase is likely to be larger than any decline in wintertime heating energy consumption (i.e., an overall increase in annual energy demand).

The forest products industry might see a reduction in supply as large areas begin to die back due to climate-induced stress and may need to make substantial investments in artificial regeneration. The industry has an estimated direct economic impact of \$21.5 billion and employs 10% of Pennsylvania's manufacturing workforce.³⁴²

Forest, Ecosystems, and Wildlife

Rating: 4

As temperatures increase, suitable habitat for tree species will shift to higher latitudes and elevations. This will present a decrease in suitable habitat available for species that currently have the southern extent of their range in Pennsylvania or are found primarily at high latitudes

Example economic impacts of increasing average temperatures

The economic impacts of increasing average temperatures are likely to be felt in tandem with extreme heat. The mean annual temperature in Pennsylvania has increased approximately two degrees Fahrenheit over the last century but has recently been increasing at a faster rate.³⁴⁸

Agricultural Impacts

The agricultural industry in Pennsylvania generates approximately \$132.5 billion in total economic impact each year and supports 593,600 jobs.³⁴⁹

Increasing average temperatures may lengthen growing periods, but an increase in the number of hot days will negatively impact yields (see heat waves).

Farmers may also have to deal with costs such as additional frost concerns (cold snaps occurring during an earlier growing season may damage crops). Longer growing seasons may result in more generations of pests, whereas historically farmers only have been concerned with two generations, a spray of a third round of pesticide would increase costs.³⁵⁰

Increasing atmospheric CO₂ concentrations may decrease livestock forage productivity, protein content, and digestibility. These, and other, impacts may increase prices of purchased feed, maintenance costs for livestock, and changes in price for meat.³⁵¹

About 58% of Pennsylvania is covered by forests, which face challenges from invasive species and disease.³⁵² As average temperature increases, the mix of tree species within forests may also change, opening up the way for new diseases and pests. The spread and severity of insect outbreaks, pathogens, and invasive plant species are expected to intensify with continued warming trends.³⁵³

Recreational Impacts

In Pennsylvania outdoor recreation generates \$17 billion in gross domestic product and sustains more than 164,000 direct jobs.³⁵⁴ Increases in average temperature will have different impacts on seasonal recreational activities. Outdoor activities in fall and spring may increase as the weather stays warmer for longer. Summer activities may be curtailed as temperatures approach dangerous levels. Winter activities may suffer in some areas (with a decline in skiing and snowmobiling),³⁵⁵ however lake effect snowfall in northwestern PA is likely to increase.³⁵⁶ There is not yet a clear picture of the aggregate impacts at a state level, but there are likely to be significant changes, and winners and losers in various industries.

(e.g., American beech, bigtooth aspen, chokecherry, eastern hemlock, quaking aspen, yellow birch), and will present an increase in suitable habitat available for species that are currently at the northern extent of their range in Pennsylvania (e.g., shortleaf pine, black hickory, black oak, black walnut, blackgum, flowering dogwood, pignut hickory, scarlet oak).^{343,344} Additionally, longer growing seasons and higher temperatures, among other climate-related factors, may increase overall forest growth rates; however, this may be offset by increased mortality in stressed forest species.

Some plant and animal species will experience increased stress due to changes such as decreases in suitable habitat area and habitat fragmentation, increases in the prevalence of pests and invasive species, and disruptions to the timing of natural cycles such as migration, emergence from dormancy or hibernation, and leaf development and blooming.³⁴⁵ Species composition is likely to change as a result of these stressors. Specialist species with specific habitat needs may not survive the habitat changes. Generalist species, however, will be better able to adapt to changing climates and habitats.³⁴⁶ Rising temperatures and shifts in weather patterns affect bird's ability to find food and reproduce, impacting local populations. In Pennsylvania, 80 species of bird face moderate to high vulnerability to these impacts.³⁴⁷

Winter stream temperatures have shown warming trends, which presents both positive and negative outcomes for fish communities. Riverine ecosystems may shift as some fish populations that depend on a cold-water habitat become lose habitat.³⁵⁷ In the tidal freshwater portion of the Delaware Estuary, increased water temperatures will decrease the solubility of oxygen while increasing respiration rates, both of which lead to decreased dissolved oxygen concentration and decreased water quality.

Higher evapotranspiration rates from increased temperatures will make wetlands more dependent on the protection from nearby trees and forests. Urbanization or logging activities that occur around wetlands will have a larger impact on wetland degradation.³⁵⁸

Increased temperatures may also contribute to the development of harmful algal blooms on Lake Erie, which exposes many aquatic or coastal dwelling species to toxins, affecting the health of the ecosystem.

Built Infrastructure

Rating: 1

The trend of increasing temperatures will require infrastructure managers to undertake adaptation in planning and operations. The “tropicalization” of the climate (i.e., increased heat and moisture) will decrease the service life of building and roofing materials and increase maintenance costs for built infrastructure.³⁵⁹

As for energy infrastructure, increased temperatures simultaneously increase demand for cooling and require power grid operators to reduce operable capacity on electric generation facilities and electric transmission lines to avoid heat-related damage. Electrical and electronic equipment in unconditioned or outdoor spaces have shorter service lives and are subject to a greater chance of thermal overload or reduced efficiency.³⁶⁰ Extreme heat will also reduce efficiency of energy generation in solar photovoltaic (PV) panels, especially when temperatures exceed 77°F.^{361,362} However, rooftop solar can reduce the cooling energy needs of buildings and help reduce peak demand.³⁶³ Increased water temperatures could decrease the availability of water that would be used for power plant cooling.

In addition, warmer temperatures can affect the chemical composition of drinking water by impacting source water ecosystems. Water treatment is also temperature dependent. Increased temperatures will require water treatment facilities to modify their operations to account for this.³⁶⁴

Heavy Precipitation and Inland Flooding

Overview

Flood events are recognized as the costliest weather hazards in Pennsylvania.³⁶⁵ From 1996 to 2018, flooding caused approximately \$1.025 billion in property damage, 31 fatalities, and 107 injuries. Flash flooding from stormwater runoff specifically caused approximately \$2.156 billion in property damage, 58 fatalities, and 52 injuries. In the 1996–2018 time period, inland riverine floods and localized flash floods together generated 79% of the property damage of all weather-related impacts in the state, though they only caused 12% and 7% respectively of all fatalities and injuries related to weather events.³⁶⁶

In Pennsylvania’s 2018 Hazard Mitigation Plan, the “flood, flash flood, and ice jam” hazard – which considers multiple types of flooding including 1%- and 0.2%-annual chance (1-in-100 and 1-in-500-year return periods, respectively) floodplain risks – received the highest-risk factor ranking of all hazards assessed.³⁶⁷

Costs associated with infrastructure damage and increased risks to agricultural production and human health are particularly significant.³⁶⁸ **Figure 44** illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence rating. **Table 18** summarizes the statewide likelihood and consequences of heavy precipitation and inland flooding in Pennsylvania.

Figure 44. Heavy precipitation and inland flooding risk matrix

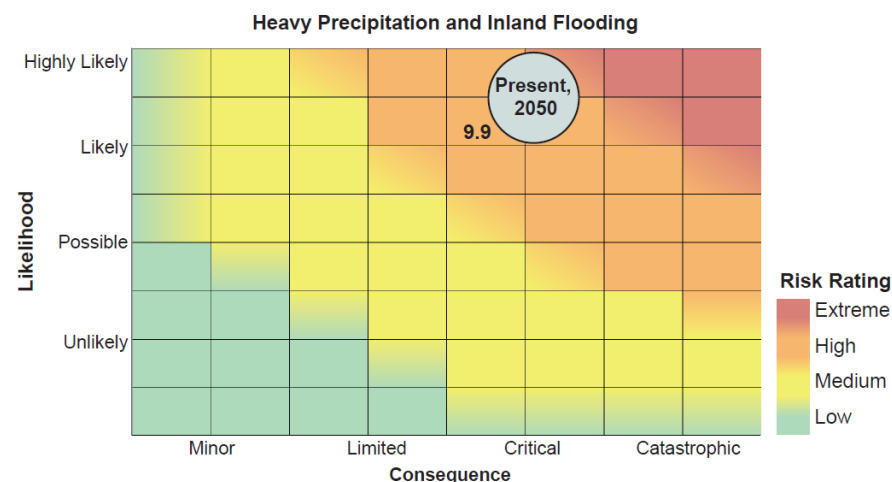


Table 18. Heavy precipitation and inland flooding statewide risk summary

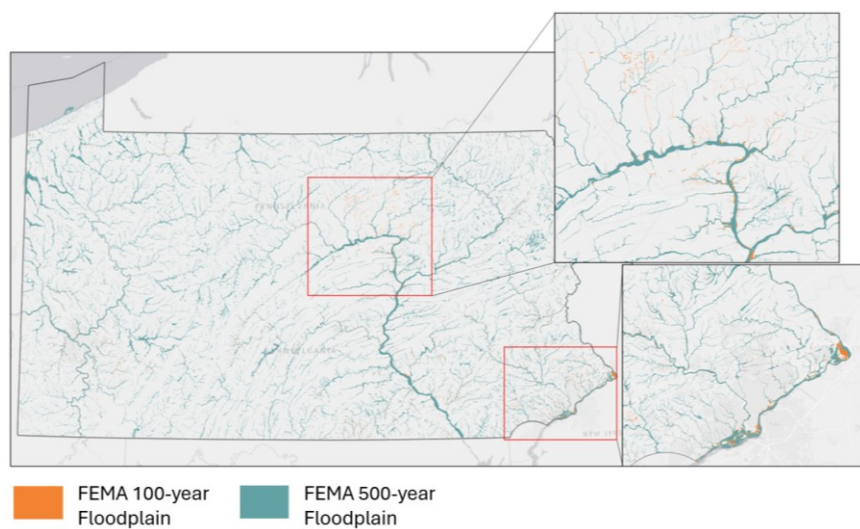
Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood (details on pg. 106)				
Current	4	There are 24 counties that regularly experience one flood event per year.	High	Areas in FEMA 100- and 500-year floodplains or adjacent to water bodies or areas with high urban stormwater runoff may be most at risk.
Mid-century	4	Average annual precipitation, precipitation variability, and flooding are projected to increase by mid-century, potentially increasing the frequency and severity of floods.	Medium	Same as current differential impacts.
Beyond 2050		Precipitation changes are expected to continue well beyond mid-century.		
Consequences (details on pg. 107)				
Human health	3	Risk of direct injury from flood waters or health impacts from water quality contamination.	High	Certain populations may be disproportionately exposed to and have greater barriers to managing flood impacts. For example, homeless and low-income individuals, people who work outside (e.g., agricultural or construction sector), and BIPOC communities that have historically been disinvested in (e.g., older infrastructure) may be more at risk to impacts.
Environmental justice and equity	2	EJ areas slightly overrepresented in high-risk floodplains compared to the state overall.	Medium	Vulnerable populations may face greater challenges in managing flood impacts. Also see above.
Economy: Agriculture	3	Increased runoff, erosion, and nutrient leaching. Greater challenges in timing of crop planting.	High	See above.

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Economy: Recreation and tourism	2	State parks and forests have experienced significant impacts from flooding and heavy precipitation events (e.g., closure, infrastructure damages, decreased water quality).	Medium	See above.
Economy: Other	2	Significant damage to infrastructure, with broad downstream economic impacts. Represents the most expensive weather hazard in the state.	Medium	See above.
Forests, ecosystems, and wildlife	2	Increased hydrological variability may impact wetland and stream ecosystems. Increased pathogen loads and eutrophication and algal bloom risks.	High	See above.
Built Infrastructure	3	Increasing risk of flood damages to homes, small businesses, and major energy and transportation assets. Infrastructure in floodplains is particularly at risk.	High	See above.
Overall Risk				
Current	9.9	High risk	High	
2050s	9.9	High risk	Medium	
Potential Opportunities				
<ul style="list-style-type: none"> Invest in more agricultural best management practices to reduce the shock of acute storm events Invest in healthy soils in agricultural land. One percent of organic matter in the top 6 inches of soil would hold approximately 27,000 gallons of water per acre 				

Likelihood

Data on past events indicates that from 1950 to 2017, 24 counties experienced, on average, at least one flood event per year (“flood event” as defined by NOAA/NCEI), and disaster declarations in the state caused by flood events outnumbered those caused by other hazards.³⁶⁹ And from 1953 to 2023 of the 63 Presidential Disaster and Emergency Declarations that affected the Commonwealth, 26 (41%) were flood events.³⁷⁰ These flood events have occurred across the state, including in, though not limited to, areas defined as FEMA floodplains (see **Figure 45**).

Figure 45. FEMA 100- and 500-year floodplains in Pennsylvania



Data source: FEMA

The occurrence of heavy precipitation events and associated inland flooding impacts is projected to significantly increase due to climate change. In general, Pennsylvania is expected to see greater

precipitation variability, which translates to more frequent and intense occurrence of both heavy precipitation events and very low precipitation conditions. The degree of change is likely to vary across the state; projected variability is also uncertain because of the significant natural variability of precipitation.³⁷¹

Averages of statewide observed and projected precipitation data demonstrate this statewide trend of increased variability (more local information would be needed for local-level nuance). Mid-century (2041–2070) modeled conditions are compared to baseline observed data (1971–2000).

- By mid-century, the number of days with more rainfall than currently occurs on “very heavy” (95th percentile) rainfall days is projected to increase 21%, from 11 days to 13 days. The amount of precipitation falling on those days is also projected to increase 9%.
- Notably, these numbers speak to events that all happen relatively infrequently but are projected to occur more often in the future.

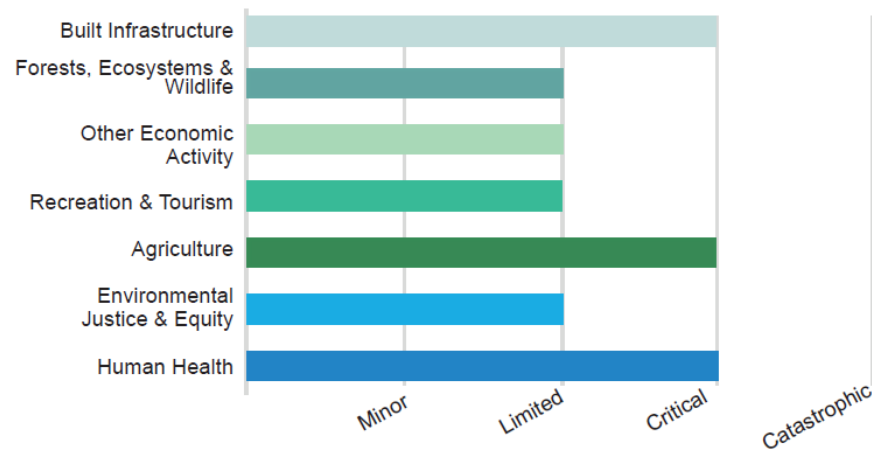
This Assessment evaluates the likelihood of damaging flood events, which are already occurring regularly and incurring significant damages, as detailed in the 2020 Impacts Assessment and 2018 Hazard Mitigation Plan. Notably, as more intense precipitation events become more common, the occurrence of extreme flood events – such as today’s 1% annual chance floods (or 1-in-100-year floods) and 0.2% annual chance floods (or 1-in-500-year floods) – may as well. The increase in intense precipitation events is likely to increase the number of people exposed to flooding each year by 5–10% in 2050.³⁷² Accounting for population growth, the total number of people exposed to flooding in Pennsylvania is expected to increase 25–75%.³⁷³ Due to uncertainty around localized projections of future intense precipitation conditions, the likelihood of specific types of

future flood events (e.g., 1-in-500 year floods) occurring is difficult to quantify; nonetheless, projections of increased occurrence of intense precipitation events by end-of-century suggest associated intense flood events will likely increase as well. Decision makers will need to work with assumptions of deep uncertainty to manage potential increases in extreme flood events.

Consequences

Flood events are recognized as the costliest weather hazards in Pennsylvania. As shown in **Figure 46**, increased risks to human health and agricultural production and costs associated with infrastructure damage are particularly significant.³⁷⁴

Figure 46. Consequences of heavy precipitation and inland flooding



Human Health

Rating: 3

Intense precipitation and inland flooding can cause significant human health risks, particularly related to flash flood events and water pollution.

In the historical context, Pennsylvania has experienced extreme floods frequently, and the deadliest among those events have been caused by extreme precipitation.³⁷⁵ Heavy precipitation can result in hazardous road conditions and reduced visibility, which can cause automobile accidents.³⁷⁶ Data on births that occurred under flood conditions indicates flood exposure has been linked to hazardous birthing outcomes.^{377,378} For events between 1959 and 2005, “Pennsylvania ranked 2nd, 10th, and 14th in the U.S. in the frequency of flash flood-related fatalities, injuries, and casualties, respectively”; during this period, a flash flood in 1977 and a flood caused by Tropical Storm Agnes in 1972 resulted in more than 50 fatalities.³⁷⁹ More recently, in July 2023, seven people in Bucks County drowned in a flash flood.³⁸⁰

Climate change can also potentially worsen water quality through a combination of weather changes and pollutant emissions; lower water quality may affect health through contact during outdoor recreation, or if drinking water is affected. Individuals who consume contaminated water may experience gastrointestinal illnesses.³⁸¹ Post-flood event health consequences may include the remobilization and redistribution of pollutants³⁸² such as coal ash,³⁸³ physical safety risks related to standing flood water or limited access to critical services (e.g., due to transportation damages),^{384,385} respiratory risks related to reduced IAQ (e.g., because of mold);^{386,387} and mental health impacts.³⁸⁸

Impacts of flooding, such as redistribution of materials, will vary based on the type of land flooded. For example, flooding of industrial or brownfields areas can distribute hazardous materials widely; storage tanks can float, tip, and rupture, and pipelines and contaminated soils can be scoured out and exposed.³⁸⁹ Flooding of agricultural lands could spread contaminants from animal waste.

Pennsylvania's aging infrastructure exacerbates health impacts from stormwater runoff. Unlike newer cities, many cities in Pennsylvania have combined stormwater and wastewater sewer systems. In what is known as a combined sewer overflow (CSO), so much stormwater accumulates in a sewer system that it exceeds the infrastructure capacity and overflows into the environment, bringing the untreated wastewater with it. Pennsylvania is considered to have the largest incidence of CSO events in the country and has 152 communities that regularly experience CSOs.³⁹⁰

Additional information on flooding impacts to health can be found in section 4.1.

Environmental Justice and Equity

Rating: 2

Spatial analysis of areas located in FEMA 100-year and 500-year floodplains indicates that, in percentage of land cover, EJ areas are slightly overrepresented in high-risk flood zones compared to the state overall.

Nearly 5.2% of Pennsylvania land and 6.2% of Pennsylvania EJ areas are located in FEMA 100-year floodplains, and 5.5% of Pennsylvania land and 6.8% of Pennsylvania EJ areas are located in FEMA 500-year floodplains. These statistics indicate a slightly greater percentage of EJ areas are exposed to 100- and 500-year flooding

compared to the state on average (about 1.2 times as exposed). This matches national statistics showing low-income and low-wealth populations as a higher percent of inhabitants of flood zones in inland areas.³⁹¹

This land area-based spatial analysis is limited in its ability to fully capture potential inequities in flooding risk – for example:

- Statistics on individuals who live or work in each floodplain are not captured, such as the number of people, how vulnerable they are to flood impacts, and their base level of adaptive capacity.
- Information about buildings and structures in each area is not considered (e.g., if buildings located in floodplains have flood-proofing measures, making residents less vulnerable).
- Low-wealth or marginalized individuals living in Census tracts not classified as EJ areas are not captured by this analysis.
- There are individuals who live in EJ areas but are *not* overburdened.
- Populations known to face greater vulnerabilities to and obstacles in managing flood impacts may not all be captured by the EJ areas indicator because it is based solely on income and racial and ethnic identity (e.g., individuals who are elderly or experiencing homelessness).
- Data on past flood costs is not included. Rural communities in Pennsylvania have seen some of the highest per capita property losses related to flooding, on average, within the state.

Additional considerations are needed to further contextualize potential EJ and equity risks, including potential infrastructure underinvestment, flood inequalities often present in urban areas, and existing work to prevent flood inequities.

Riverine and coastal flooding challenges are likely to be exacerbated by existing underinvestment in stormwater management or flood protection infrastructure³⁹² – a cycle that may leave poorest populations in most at-risk locations due to financial obstacles to leaving for higher ground. This cycle can increase peoples’ vulnerability to flood risk, such as:³⁹³

- Demographics (e.g., older age, minority race or ethnicity)
- English as a second language
- Low-income or wealth
- Food insecurity
- Mobility (e.g., access to vehicles and/or public transportation)
- Having their home or place of business located in a floodplain
- Lack of flood insurance
- Lack of business security
- Proximity to toxic sites or hazardous facilities

A range of flood consequences may be related to those indicators – such as impacts to employment (e.g., if someone’s business is closed), food security (e.g., if crops are lost due to flooding), housing (e.g., if someone’s home is damaged by flooding), emergency management (e.g., language and platform accessibility of communications), or access to services (e.g., education, healthcare, emergency management).³⁹⁴ Immigration status and English-speaking ability may also create barriers to accessing assistance during and after flood events.

Analysis of equity and urban flood risks by the U.S. Water Alliance, informed in part by the Philadelphia Urban Flooding Bootcamp Team, describes how vulnerable or marginalized communities may face barriers to social and economic opportunities, or to living in a healthy environment.³⁹⁵ The analysis identifies five key types of flooding

inequities often experienced in urban environments: “1) Historical development practices placed low-wealth people and BIPOC communities in flood-prone areas, 2) Infrastructure in economically distressed communities is often in worse condition, 3) Poverty intersects with flood vulnerability, 4) Social and environmental factors also leave some populations more vulnerable, and 5) Climate change is leading to migration that exacerbates existing flooding inequities”. It also identifies five priority actions to support equitable resilience to urban flooding: “1) Use data to identify risks, assets, and community vulnerabilities, 2) Commit to ongoing and meaningful community engagement, 3) Set a proactive vision and build strategic alignment, 4) Fully incorporate equity into resilience planning processes, and 5) Target investments in vulnerable communities”.³⁹⁶

Ongoing work in Philadelphia is highlighted as an example of Priority Action 4 in the Water Alliance analysis. Philadelphia’s Flood Risk Management Task Force, in place since 2015, works to coordinate resources and manage flooding across different neighborhoods, and in 2020 has piloted a community-led task force to make the voices of interested parties and leaders in the community central in the planning, decision-making, and communications processes.³⁹⁷ Additionally, projects in three low-income neighborhoods—Lancaster, York, and Harrisburg—are currently targeting the issue of polluted urban and suburban runoff, a “leading source of stream pollution in Pennsylvania” known to cause nuisance flooding and threaten drinking water. Community volunteers are working with the projects’ sponsors, DEP, and the Chesapeake Bay Foundation to design and implement mitigation measures in their neighborhoods, from planting street trees to putting together rain gardens.³⁹⁸

Economy

Agriculture

Rating: 3

The primary impacts to crop and livestock agriculture from extreme precipitation are increased flooding risks including augmented runoff, erosion, and nutrient leaching, as well as challenges in timing of crop planting or harvesting. In particular, heavier precipitation and higher temperatures are causing earlier snowmelt, which increases the risk of springtime flooding that can delay planting and reduce yields.³⁹⁹ Any kind of severe flooding can cause crop, equipment, and livestock losses or damage. Though many practices (e.g., no-till management and soil conservation) to reduce runoff rates have been successfully implemented in recent years in Pennsylvania, flooding remains a challenge, and current conservation practices may not protect against more frequent and intense extreme precipitation events.

Areas in Pennsylvania experienced excessive rain twice in 2021. Floods in July were brought by a 100-year storm, while the remnants of Hurricane Ida flooded counties along the Delaware River in the first days of September.^{400,401} The USDA designated ten Pennsylvania counties as natural disaster areas and provided funding to support impacts of livestock death, feed and grazing losses, and crop loss.^{402,403} High precipitation has historically cut crop production levels by limiting the ability to harvest crops while allowing mold and disease to affect waterlogged crops.

Extreme precipitation events tend to affect entire regions rather than isolated farms, which can cause volatility in local prices due to

sudden reductions in commodity or supply availability (e.g., grain, which is critical to the dairy industry).

Crop management practices may be challenged by increased frequency and intensity of extreme precipitation events – in particular, the increased runoff and flow concentration associated with this hazard. These impacts could challenge nutrient management methods by increasing nutrient losses prior to plant growth and uptake and could also create vulnerabilities in structural management practices and traditional crop management strategies such as conservative crop rotations and contour farming. Crop residue and no-till soil management may cease to provide suitable erosion management strategies with the increase in extreme precipitation.⁴⁰⁴ Similarly, pasture management for livestock farming may be impacted by more runoff and intense flows, especially in locations that are already regularly wet, poorly drained, and sloped. Crops commonly used for biofuels such as miscanthus, shrub willow and switchgrass may benefit from warmer and wetter spring conditions and can serve as natural riparian buffers for sensitive parts of the landscape.

Indirect effects of heavy precipitation events could also include reducing effectiveness of strategies to manage the spread of pollution, nutrients, and sediments across waterways and agricultural and urban landscapes.

Costs associated with crop impacts from flooding and heavy precipitation are significant. Extreme precipitation is estimated to have caused 26% of all Pennsylvania's crop losses from 1989–2021, mostly affecting corn, soybeans, and apples.⁴⁰⁵ The overarching trend is that insurance payment totals increased throughout that period.⁴⁰⁶ The agricultural sub-sector of crop and animal production generated about \$9.2 Billion USD; this figure represents

approximately 10% of the total economic output from the agricultural sector, and the crop and animal production sub-sector also provides about 29% of the total direct employment in the agricultural sector.⁴⁰⁷

Recreation and Tourism

Rating: 2

State parks and state forests across Pennsylvania have been experiencing significant impacts from flooding and heavy precipitation events. For example:

- In June 2023, heavy precipitation caused flash flooding with inundation up to five feet in southeastern Pennsylvania. Roads were closed and airline flights were canceled across the eastern seaboard.⁴⁰⁸
- In 2021, officials closed 14 state parks and seven state forests to campers and hikers out of concern that heavy precipitation from the remnants of Hurricane Ida would cause significant flooding that could be unsafe for recreationists.⁴⁰⁹
- Heavy precipitation in December 2020, falling as rain due to high temperatures, caused flooding and fast river currents in the Delaware River corridor, leading the National Park Service to close travel on and access to the river in the Delaware Water Gap National Recreation Area.⁴¹⁰
- An extended period of heavy precipitation in July 2018 forced multiple state parks as well as Hershey Park and Knoebels Amusement Park to close for several days due to flooding.^{411,412}
- In August 2013, intense storms in Southwestern Pennsylvania led to flooding that forced a variety of recreation areas including

boat launches, beaches, and campgrounds to close; many of the closures restricted recreation spaces over the Labor Day holiday.⁴¹³

- “Torrential” rains and flooding in eastern and central Pennsylvania from Tropical Storm Lee (September 2011) forced closures of several recreation areas including World End State Park, Bald Eagle State Park, and parts of the Canal Towpath, and eight other state parks reported damage from the storm (much of it due to flooding). Several of these areas had also been impacted by flooding in January 2010.⁴¹⁴

Potential effects of climate change and pollution on water quality may increase risks of outdoor recreation where people could come into contact with dirtier or more polluted water.⁴¹⁵ In 2022, there were 1,263 acres of recreational lakes deemed too impaired for use as a result of agricultural and urban runoff.⁴¹⁶

Additionally, increased flooding will impact planning and investments, where recreation can occur, and ultimately which projects receive grant funding (for more information, see DCNR Climate Change Adaptation Plan).⁴¹⁷

Increased frequency and intensity of flooding and stormwater runoff may result in impacts to infrastructure and recreational and ecological resources (high risk). Infrastructure potentially at risk includes trails and recreational amenities; transportation assets such as bridges and roads; buildings; dams; and cultural and historical resources.⁴¹⁸ If trails or recreational amenities are impacted by severe weather or rain events and need to close down for repair, that could put increased pressure on other recreational resources.⁴¹⁹

Other Economic Activity

Rating: 2

Due to the interconnectedness of Pennsylvania's economic sectors, impacts of flooding on assets or infrastructure in one sector may have downstream effects on other sectors. For example, localized flooding of and damage to rail assets could disrupt access to workplaces or recreation spaces. Additionally, local power blackouts caused by flood damage to energy infrastructure could impact those reliant on that power supply.⁴³⁷ Depending on the region and asset(s) impacted, consequences may vary significantly. Example economic impacts of flooding are described in the box at right.⁴³⁸

Forest, Ecosystems, and Wildlife

Rating: 2

More intense rainfall projections are already beginning to manifest in Pennsylvania. More extreme streamflow associated with intense rainfall is already occurring across much of the state, except for the southwest quadrant. Four of the top 10 wettest years on record have occurred since 2000 and the top two have occurred since 2010.⁴³⁹ This risk is projected to continue to increase under climate change, and bank erosion is therefore expected to become an increasingly large concern for the state. More broadly, greater hydrological variability, including more intense and less predictable floods and extreme streamflow, could have significant long-term impacts on wetland and stream communities.⁴⁴⁰

Rainfall and runoff events are the primary weather drivers of nonpoint pollution; increased frequency, intensity, and variability of these events could have negative impacts on both rural and

Example economic impacts of flooding

Pennsylvania is one of the most flood-prone states, with an estimated 86,000 miles of streams and rivers, the most in the continental U.S. 2018 was Pennsylvania's wettest year on record with 63.97 inches of annual rainfall.^{420,421}

Flooding along Rivers

From 1991 to 2012, Pennsylvania saw a 71% increase in heavy rainfall events of two or more inches.⁴²²

Flash floods in 2019 and 2023 from between four and seven inches of precipitation led to multiple fatalities and necessitated water rescues.^{423,424} In 2021, flooding events caused by 5–10 inches of rain that fell as the remnants of Hurricane Ida led to record streamflow in 19 locations.⁴²⁵ There were several fatalities as a result of this flooding event.⁴²⁶

A heavy rain event from August 10–15, 2018 led to severe flash flooding in counties along the Delaware and Susquehanna Rivers and their tributaries. This flooding resulted in an estimated nearly \$62.8 million in total recovery costs for with the governor requested for disaster relief in 16 counties.⁴²⁷

In early 2018 in Western PA, several rainstorms resulted in flash flooding and landslides resulting in closed roads. Landslide and rain damage in April 2018 resulted in \$14.6 million in Pittsburgh and Allegheny County.^{428,429,430,431}

Wettest Year on Record (2018)

PEMA estimated 2018's severe weather to have caused approximately \$125 million in damage to public infrastructure due to flooding and landslides. Nearly half of damages were not covered by federal disaster aid, imposing strain on local, county, and PA's budgets.⁴³²

Rural Impacts

Roughly 6.5% of PA's population lives in floodplains (roughly 374,000 housing units on 5.6% of PA's land mass). The population living in floodplains tends to be older and less financially well off.

FEMA, under the Biggert–Waters Flood Insurance Reform Act of 2012, requires "actuarial" rates for flood insurance to address budget shortfalls from storm damage, resulting in sharp, short-term premium increases, especially previously subsidized rates. An expected 25% increase in National Flood Insurance Program premiums would yield a 6.6% short-term loss in property value.⁴³³

Heavy rain and flooding in 2019 were expected to negatively impact PA farmers' corn and soybean yields and record rains continued from 2018 into 2019. In Pennsylvania, rain makes steady planting nearly impossible, making scheduling of pest management and harvest difficult. Nationally, heavy rains and flooding delayed the start of soybean planting by 34% by acreage.^{434,435, 436}

urban ecosystems and wildlife. Increased flooding and runoff associated with heavy rain events may affect water quality through increasing pathogen loads (e.g., through runoff from livestock farms, sewer overflows, and resuspension of pathogens in river sediments due to water turbulence in intense storms) and increasing risks of eutrophication and harmful algal blooms (e.g., due to greater nutrient availability from runoff).^{441,442}

Hydraulic fracturing or “fracking” is currently underway in many parts of Pennsylvania, particularly in southwest and northeast Pennsylvania in the Marcellus Shale.⁴⁴³ Laws such as Act 13⁴⁴⁴ govern safe management of potentially toxic spills and runoff from fracking operations that can occur with heavy flooding.⁴⁴⁵ Additionally, there are municipal waste landfills and other waste facilities located across Pennsylvania,⁴⁴⁶ which could potentially leach contaminants during flood events if not properly managed.

Further, wetter soil in mountains could contribute to flash flooding during spring storms that coincide with snowmelt.

Additionally, water levels in the Great Lakes, including Lake Erie, are primarily driven by rainfall. Warmer temperatures and greater precipitation variability may lead to more precipitation falling as rain instead of snow, and warmer winters may lead the Lake to be frozen for less time, which could accelerate erosion and cause more flooding. However, warmer temperatures will also increase evaporation, and precipitation variability will likely cause record lows as well as record highs.⁴⁴⁷

Built Infrastructure

Rating: 3

The greatest impacts that flooding is expected to have in Pennsylvania are on infrastructure systems. Flood-related damages are likely to be localized but intense (e.g., flooding alone may cause a local blackout but is unlikely to bring down a full regional power grid). However, if key infrastructure is damaged that may have broader downstream effects (e.g., damage to transportation infrastructure could lead to broader disruptions to the economy). Costs related to these damages are significant; for example, FEMA paid \$1.23 billion to National Flood Insurance Program (NFIP) policyholders in Pennsylvania between 2000 and 2020.⁴⁴⁸ NFIP insurance is available to businesses and property owners and renters; in high flood-risk areas, businesses and homes must have flood insurance if they have mortgages from government-backed lenders.⁴⁴⁹ On a higher scale, Pennsylvania is the second most-at-risk state for flood damage. One study has found that the state holds \$1.2 billion in possible damage costs.⁴⁵⁰ Another found that the cost to adapt storm drainage capacity to avoid sewage overflows and flooding could reach \$7.8 billion and the cost to reinforce bridges could reach \$268 million.⁴⁵¹

Both rural and urban infrastructure face significant increasing flooding risk, though likely with differential risks and vulnerabilities across regions and demographics. For example, an evaluation of per capita property losses due to flooding found many of the higher losses were experienced in rural counties in Pennsylvania.⁴⁵²

Infrastructure at greatest risk of flooding are structures located in flood zones, though structures not in flood zones (e.g., underground pipelines) may be at significant risk as well. Significant portions of

transportation and energy infrastructure in Pennsylvania may be susceptible to direct flooding damage, especially in the southwestern region where heavy precipitation events may bring compounding flood and landslide risks. For example, transportation infrastructure (e.g., bridges, roads, railways) may be vulnerable to disruption from flooding, debris, or landslides. And extreme rainfall represents one of the largest risks to pipelines—including many underground—carrying various power products (e.g., natural gas, crude oil, petroleum). However, recent severe storms (e.g., Hurricane Ida and Hurricane Irene) and flooding events indicate that local electricity infrastructure may be more susceptible to heavy rainfall hazards than the regional bulk power grid.⁴⁵³

Greater frequency and intensity of intense rainfall events will also challenge urban stormwater and wastewater management systems, which could lead to combined outflows detrimental to water quality. Stormwater retrofits may be somewhat adapted to reduce or withstand impacts to some extent, and nature-based solutions may also increase adaptive capacity (this strategy is currently being implemented in Philadelphia, for example).⁴⁵⁴

Issues such as storm sewer backup may lead to groundwater flooding, which may cause infrastructure damages (e.g., related to water infiltration into building basements) or spring overflow. Many state and local actors are evaluating adaptation measures such as increasing sewers' capacity and developing projections to better estimate future loading and overflow potential, to prevent sewage release events, and manage higher flow amounts.⁴⁵⁵ Pennsylvania's counties have some of the highest occurrences of combined sewage overflows of any in the country.⁴⁵⁶

Additionally, a potential increase in area located within the 1% annual chance (1-in-100 year) floodplain by end-of-century would put

significantly more infrastructure at risk to flood impacts. A comparison of the number of state-owned or leased facilities located in the current 1% annual chance floodplain to the number located in the projected end-of-century floodplain in Delaware, Allegheny, and Lycoming counties highlights this risk. The comparison identified a nearly 500% increase in the number of vulnerable structures, with replacement value of structures in the future floodplain over \$92 Billion.⁴⁵⁷

Notably, increased temperatures affect the Palmer soil index and reduce the moisture absorption of the soil, which can in turn increase the likelihood of flash flooding occurring.⁴⁵⁸

Various flood protection efforts are underway, described in detail in the Pennsylvania State Hazard Mitigation Plan.

Heat Waves

Overview

Heat waves will increase from a medium to a high risk by mid-century. **Figure 47** illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

Heat waves are a discrete hazard. Currently, cities in Pennsylvania experience roughly 5–6 excessive heat event days per year. The frequency of such days is projected to increase about tenfold by mid-century, leading to over a month’s worth of extreme heat day events. Across the state, on average the annual number of days experiencing temperatures above 95°F is expected to increase by 4–21 days by the mid-century and 12–59 days by the end-of-century. Similarly, the number of consecutive days experiencing temperatures above 95°F is expected to increase by 2–6 days by the mid-century and 4–16 days by the end-of-century. Additionally, across the state, the number of days above the baseline time period’s 99th percentile temperature (90.1°F on average across the state, though it varies by grid cell) is projected to range from 20–57 days by the mid-century and 40–103 days by the end-of-century. The ranges provided above refer to the 10th–90th percentile projections under SSP 5–8.5.

This will impact the entire state and all sectors, but will have the highest consequences for human health, especially in urban areas. Heat waves create the risk of heat illness and death. **Table 19** summarizes the statewide likelihood and consequences of heat waves in Pennsylvania.

Figure 47. Heat waves risk matrix

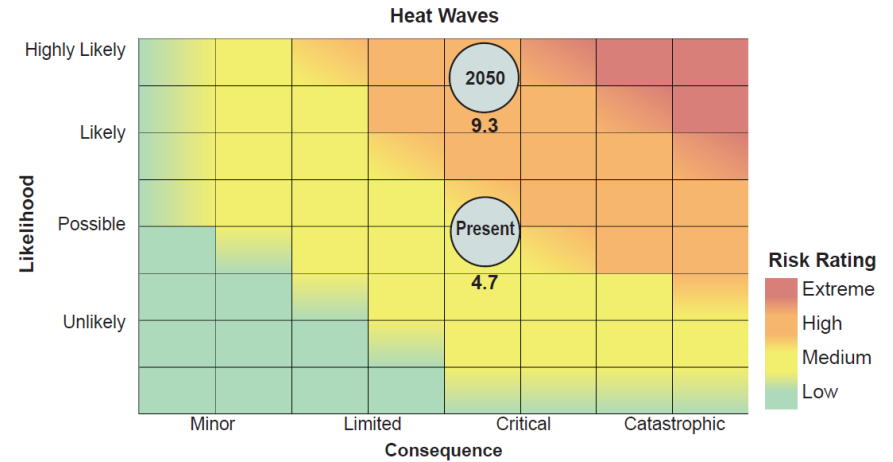


Table 19. Heat waves statewide risk summary

Timeframe or Category	Rating	Notes	Confidence	Differential Impacts
Likelihood (details on pg. 118)				
Current	2	Currently, Pennsylvania experiences, on average, about six days per year that are “extremely hot.”	High	No significant geographic differences in observed high temperature days.
Mid-century	4	By mid-century, Pennsylvania is expected to experience over 38 “extremely hot” days per year.	High	Southwestern PA will experience more days with high temperatures than other regions of the state.
Beyond 2050		Temperatures are expected to continue increasing beyond 2050 without significant greenhouse gas reductions. On a business-as-usual emission trajectory (SSP 5-8.5), Pennsylvania could experience over 75 “extremely hot” days annually.		
Consequences (details on pg. 118)				
Human health	4	Increased heat-related mortality and morbidity.	High	The elderly, those with cardiovascular disease, those with certain mental health illnesses, outdoor workers, pregnant people, and populations with limited access to air conditioning experience higher risk to heat-related illness and death.
Environmental justice and equity	3	EJ areas are projected to experience a disproportionate increase in exposure to heat stress compared to the state overall.	Medium	Lower-income populations have higher vulnerability to heat stress and less access to adaptive measures such as natural infrastructure (e.g., shade trees around a home), good insulation, and air conditioning. More broadly, vulnerable populations include those with: outdoor jobs, housing with less insulation/ access to natural infrastructure/ air conditioning, decreased access to quality healthcare, and populations living in densely populated urban areas experiencing UHI effects.

Timeframe or Category	Rating	Notes	Confidence	Differential Impacts
Economy: Agriculture	2	Decreased production (e.g., of milk). Animal illness/death. Decreased crop yields.	Medium	
Economy: Recreation and tourism	1	Decreased time spent participating in outdoor leisure.	Medium	
Economy: Other	2	Increased demand for cooling. Heat-related damage to energy infrastructure.	Medium	
Forests, ecosystems, and wildlife	1	Increased stress on species experiencing decreasing habitat suitability.	Low	This applies particularly to species that are more suited to colder habitats.
Built Infrastructure	2	Increased energy demand and decreased energy capacity. Stress on public water suppliers and utilities. Exacerbate negative impacts of the UHI effect.	Medium	
Overall Risk				
Current	4.7	Medium risk	High	
2050s	9.3	High risk	High	
Potential Opportunities				
Increase in utilization of silvopasture for livestock operations, which reduces heat stress among other benefits				

Likelihood

Additionally, there is high confidence⁴⁵⁹ that “heatwaves have become more common and severe.”⁴⁶⁰ While currently, the state experiences about six days per year on average that are “extremely hot” (the baseline 99th percentile temperature or approximately 90.1°F), that number will increase to over 38 days by mid-century, with a potential range of about 20 to 57 days.

Risks of heat waves are higher in urban areas due to the UHI effect. Given the high confidence of such projections and the high projected occurrence of excessive heat event days, heat waves merited a likelihood rating of four for the mid-century timeframe. The current timeframe received a likelihood rating of two, since heat waves do occur currently, but only happen about 5–6 days per year.

Consequences

Figure 48 summarizes the overall consequence ratings statewide for heat waves—highest consequences are in human health and in environmental justice and equity.

Human Health

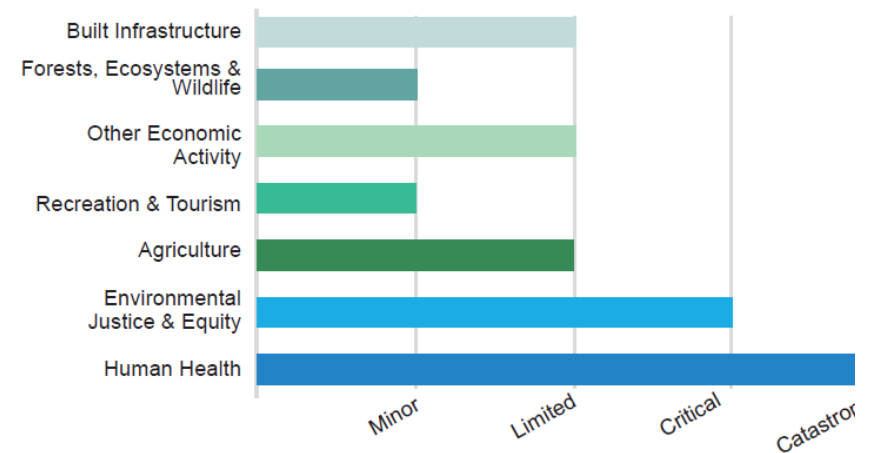
Rating: 4

Heat wave events will cause heat-related mortality and morbidity. Extreme heat is responsible for the most weather-related deaths in the United States.⁴⁶¹ and climate change has been attributed to an average of 37% of heat-related deaths across the globe.⁴⁶² In Pennsylvania, the Center for Disease Control (CDC) reports that a total of 97 people died from heat-related deaths between the years

of 2016–2020,⁴⁶³ but this is likely an undercount of deaths attributable to heat.⁴⁶⁴

By impeding the body’s ability to thermoregulate, exposure to high temperatures can cause conditions like heat exhaustion, dehydration, heat rash, heat stroke, and heat cramps, which for more severe conditions can lead to death if left untreated.^{465,466} When heat is a contributing cause of death (rather than the underlying cause), it is most commonly for cardiovascular diseases like ischemic heart disease and hypertension, alcohol poisoning, and drug overdoses.⁴⁶⁷ Very high outdoor temperatures have also been shown to increase the occurrence of three potentially life-threatening conditions for people with type 2 diabetes.⁴⁶⁸ However, the risk of mortality from extreme heat events has been decreasing, as more and more households are installing air conditioning.

Figure 48. Heat wave consequences



Underlying health conditions, age, race, limited access to air conditioning, outdoor employment (e.g., farm labor or logging), and living in urban areas can all increase risk to heat-related health conditions.^{469,470,471} Specifically, young children and the elderly are at heightened risk of morbidity or mortality.⁴⁷² Individuals with preexisting psychiatric illnesses and those who are socially isolated are also at high risk during heat waves.^{473,474} Heat can also contribute to death for individuals suffering from certain mental health conditions that change risk perception and understanding of exposure to extreme heat.⁴⁷⁵

Pregnant people and their fetuses are at greater risk from extreme heat as their capacity to thermoregulate is compromised.⁴⁷⁶ Exposure to extreme temperatures could affect multiple birth outcomes including length of gestation, birth weight, stillbirth, and neonatal stress.⁴⁷⁷ Exposure to extreme heat that occurs in all stages of pregnancy contributes to the risk of preterm birth, and in so doing increases the risk of morbidity and mortality.^{478,479} Preterm birth is a leading cause of morbidity and mortality in newborns.⁴⁸⁰

For outdoor workers, the OSHA cautions that worker heat protection measures should be taken if temperatures exceed 91°F, or if temperatures come near that threshold and people are working outside in direct sunlight and/or without wind to cool them down.⁴⁸¹ There is evidence that extreme heat can lead to higher rates of occupational injuries for both outdoor and indoor activities, even those not directly related to heat such as falls, slips, and trips.⁴⁸² Beyond work, walking and exercising outdoors will also become more hazardous.⁴⁸³

Direct and indirect mental health impacts from climate-related events are not as well documented or studied as physical health impacts. A recent literature review found mood disorders, feelings of anger and frustration, and increased anxiety are all associated with heat stress and discomfort.⁴⁸⁴ Heat stress can also affect the ability of children to learn and retain information and adults to be able to work productively.⁴⁸⁵ Extreme heat is also associated with increased rates of suicide and contributes to heightened aggression, hostility, and violence.⁴⁸⁶ Violent crimes are expected to increase as a result of extreme heat events.⁴⁸⁷

Human health impacts may be exacerbated in areas where EJ populations experiencing heat-related impacts have less ability to adapt (e.g., low-income individuals who cannot afford to purchase air conditioning or take time off work on high heat days).

Figure 49. Pennsylvania Counties Experiencing High Temperature and Moderate to Unhealthy Air Quality Days

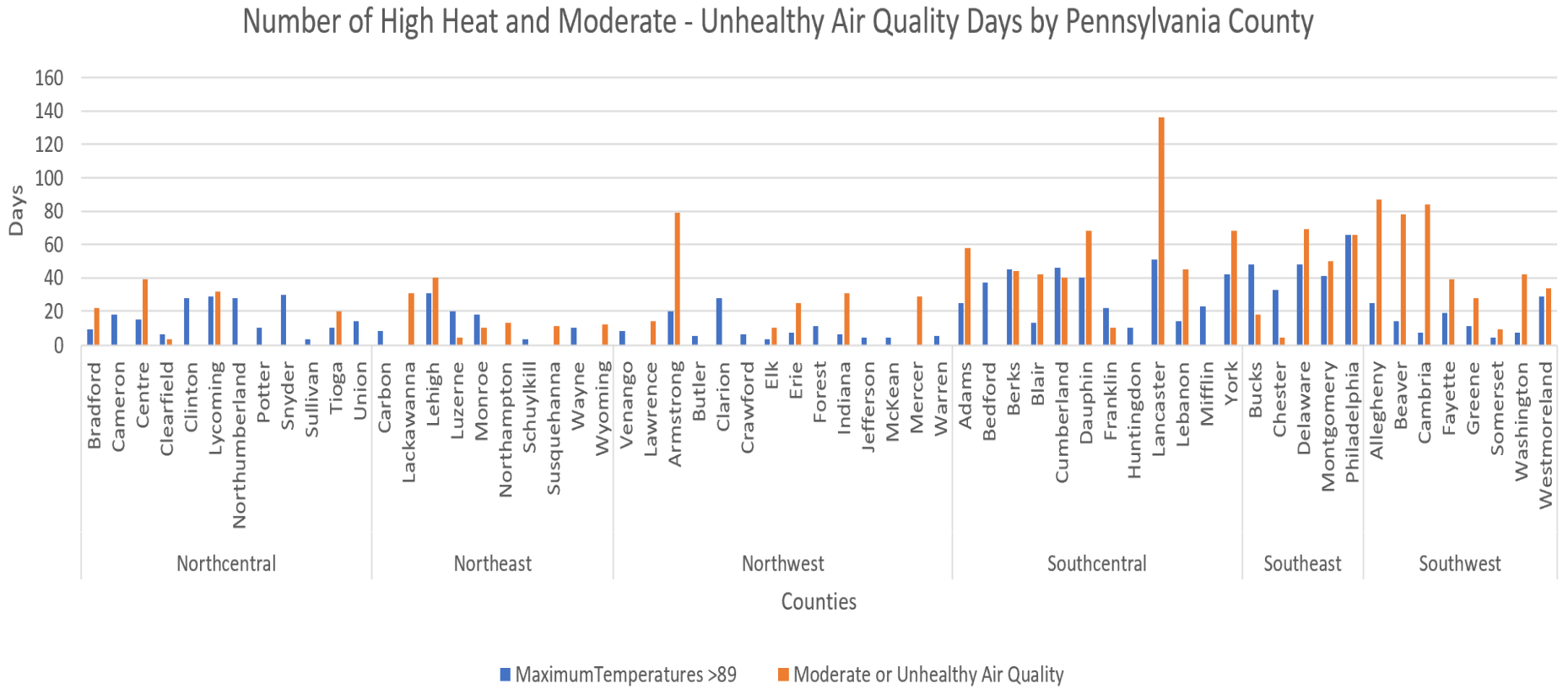


Table 20. Heat and low air quality days by county

County	Combined High Heat and Air Quality Days	Maximum Temperatures at or above 90°F	Moderate or Unhealthy Air Quality	% High Temp with Poor Air Quality	% Poor Air Quality with High Temp
Adams	6	25	58	24%	10%
Allegheny	9	25	87	36%	10%
Armstrong	7	20	79	35%	9%
Beaver	5	14	78	36%	6%
Bedford	NA	37	NA		
Berks	4	45	44	9%	9%
Blair	5	13	42	38%	12%
Bradford	1	9	22	11%	5%
Bucks	4	48	18	8%	22%
Butler	NA	5	NA		
Cambria	5	7	84	71%	6%
Cameron	NA	18	NA		
Carbon	NA	8	NA		
Centre	3	15	39	20%	8%
Chester	NA	33	4		
Clarion	NA	28	NA		
Clearfield	1	6	3	17%	33%
Clinton	NA	28	NA		
Crawford	NA	6	NA		
Cumberland	7	46	40	15%	18%
Dauphin	11	40	68	28%	16%
Delaware	18	48	69	38%	26%
Elk	NA	3	10		
Erie	2	7	25	29%	8%
Fayette	5	19	39	26%	13%
Forest	NA	11	NA		
Franklin	NA	22	10		
Greene	3	11	28	27%	11%
Huntingdon	NA	10	NA		
Indiana	1	6	31	17%	3%

County	Combined High Heat and Air Quality Days	Maximum Temperatures at or above 90°F	Moderate or Unhealthy Air Quality	% High Temp with Poor Air Quality	% Poor Air Quality with High Temp
Jefferson	NA	4	NA		
Lackawanna	NA	NA	31		
Lancaster	36	51	136	71%	26%
Lawrence	NA	NA	14		
Lebanon	3	14	45	21%	7%
Lehigh	7	31	40	23%	18%
Luzerne	NA	20	4		
Lycoming	3	29	32	10%	9%
McKean	NA	4	NA		
Mercer	NA	NA	29		
Mifflin	NA	23	NA		
Monroe	NA	18	10		
Montgomery	4	41	50	10%	8%
Northampton	NA	NA	13		
Northumberland	NA	28	NA		
Philadelphia	8	66	66	12%	12%
Potter	NA	10	NA		
Schuylkill	NA	3	NA		
Snyder	NA	30	NA		
Somerset	NA	4	9		
Sullivan	NA	3	NA		
Susquehanna	NA	NA	11		
Tioga	1	10	20	10%	5%
Union	NA	14	NA		
Venango	NA	8	NA		
Warren	NA	5	NA		
Washington	2	7	42	29%	5%
Wayne	NA	10	NA		
Westmoreland	9	29	34	31%	26%
Wyoming	NA	NA	12		
York	15	42	68	36%	22%

Environmental Justice and Equity

Rating: 3

As shown in **Figure 43**, the number of hot days across the state is projected to increase, and populations in EJ areas are projected to disproportionately experience the most days with hot temperatures. For example, EJ locations are 1.9 times more likely to be in the top one-fifth of census blocks with days above 90°F compared to non-EJ census blocks. This aligns with studies showing that minority populations and those living below the poverty line are disproportionately exposed to UHI intensity in 169 of the largest U.S. cities, including Philadelphia and Pittsburgh.⁴⁸⁸

Consequences of historical practices of redlining, building substandard housing in BIPOC communities, and intentionally disinvesting in BIPOC communities manifest today as inequities where BIPOC communities are disproportionately in older or substandard housing that is particularly susceptible to deterioration by heat waves. Studies in many different parts of the United States show that EJ areas are likely to experience more frequent and prolonged blackouts, making communities living or working in EJ areas more vulnerable to heat-related health impacts.^{489,490} Adverse conditions include less tree cover, and darker, more flat roofs compared to other neighborhoods.⁴⁹¹

The elderly, those with cardiovascular disease, and populations with limited access to air conditioning experience higher risk to heat-related illness and death. Other at-risk populations include children playing outside, seniors living alone, construction workers, and athletes.⁴⁹² Climate change may further widen total compensation inequality because heat-related workplace safety risks are distributed to more impact lower-income occupations.⁴⁹³

From 2008 to 2017, extreme heat played a larger role in mortality, and this effect was more pronounced for older adults, men, and non-Hispanic Black individuals.⁴⁹⁴ Simultaneously, Black and African American people are 40% more likely than others to live in areas that have the highest projected increases in extreme temperature related mortality.⁴⁹⁵ Low-income and Hispanic or Latinx populations also live in areas that will experience strongest increases in temperature.⁴⁹⁶ Without mitigation, the projected increase in extreme heat may widen health disparities.

Access to air conditioning is a key adaptation strategy for decreasing excess heat deaths and illness. Indeed, the rate of heat-related mortality has decreased over the 20th century and largely after 1960, due to air conditioning becoming more available and prevalent. It is therefore important that low-income residents who cannot afford air conditioning have access to publicly available cooling shelters or other assistance installing or accessing air conditioning. A survey of Philadelphia residents found the majority of respondents were not aware of or have limited access to City cooling centers. Although 84% of respondents have air conditioning, 77% indicated a need for better air conditioning and fans at home to stay cool.⁴⁹⁷

Historically, some of the hardest-hit counties with respect to extreme weather events such as extreme heat are also among the poorest counties in the state. The Philadelphia Heat Vulnerability Index, which combines heat data with information on population, age, income, language, educational attainment, race and ethnicity, social isolation, and health, shows that BIPOC residents and low-income residents are more likely to live in the hottest neighborhoods (up to 22°F hotter), making climate change heat risk both a public health issue and “an issue of racial and social equity.”⁴⁹⁸

The expected causes of hotter temperatures in these neighborhoods are limited green space and tree canopy, more exposed dark surfaces (e.g., asphalt), and aging housing stock due to a history of redlining and disinvestment.

Economy

Agriculture

Rating: 2

As described in the section on increasing average temperatures above, livestock are likely to suffer from heat stress as temperatures rise over the coming decades. This will be exacerbated during extreme heat events, and farmers will have to spend more on energy for cooling or other adaptive measures to reduce livestock stress and mortality.

Increased temperatures may encourage a shift to using silvopasture for livestock operations, which integrates trees, foraging, and grazing on the same plot of land. This practice reduces heat stress, increases forage, and reduces feed cost, increases carbon sequestration, captures more runoff/nutrients, and provides alternate income source via nuts or fruits.⁴⁹⁹

Crops can also experience heat stress from a heat wave, which may decrease yields. Depending on the timing of the heat wave, significant life stages or milestones can be disrupted. More irrigation may be necessary during a heat wave to minimize impacts to crops.^{500,501}

Extreme heat also threatens worker safety and health as described under the human health section (see pg. 118) and in section 4.2. Time spent working outdoors generally declines above 85°F for agriculture

workers. In a study of U.S. agricultural workers, climate change at its current pace is projected to double crop worker heat risk by mid-century and triple by the end of the century, absent extensive restructuring of agricultural labor.⁵⁰²

Recreation and Tourism

Rating: 1

The amount of time spent participating in outdoor leisure drops when daytime high temperatures exceed 100°F. Such hot days are expected to increase in frequency in Pennsylvania due to climate change. By mid-century, the number of days exceeding 100°F is expected to increase by 1–12 days.

Extreme heat could add additional pressure to natural and man-made water features (e.g., lakes, rivers, city pools) used for recreation and an escape from the heat. Additional water features may be necessary in urban areas to meet demand for cooling spaces.⁵⁰³

Other Economic Activity

Rating: 2

Productivity of sectors that depend on workers who engage in physical outdoor activity may decrease, given that work capacity decreases by 25% at 90°F and by 70% at 110°F.⁵⁰⁴ Pennsylvania is expected to see a 0.5–2% loss from worker productivity decreases due to heat stress by 2050.⁵⁰⁵

Example of economic impacts: heat waves

While the economic impacts of heat waves are hard to monetize, significant impacts are expected.

Vulnerable Populations

Nationally, heat is the leading cause of weather-related deaths over the last 30 years. In Pennsylvania, statistics show that between 2008 and 2018 PA has recorded at least two deaths per year except in 2014 and 2017. The high point occurred in 2011 with 36 heat-related deaths.⁵⁰⁶

More than 310,000 people in PA are especially vulnerable to extreme heat (over 65, under five, or living below the poverty line).⁵⁰⁷

Increasing temperatures later in the year require air conditioning units to be installed in schools. The necessary upgrades are estimated to cost the state \$1.23 billion. Similarly, expanding and operating cooling centers will cost \$78.8 million.⁵⁰⁸

Agricultural Impacts

With rising heat come longer growing seasons, but potentially lower yields. Research suggests negative correlation between maximum daily temperature and corn yield—heat waves could negatively impact corn, and other crop, losses.⁵⁰⁹

Apples, sweet corn, grapes, and dairy production could all see negative impacts, as extreme heat impacts growth and production.⁵¹⁰

One study suggests that above a critical temperature threshold of 77 degrees Fahrenheit, dairy milk production may drop by up to 22%. This type of decline could inflict as much as \$480 million in direct and indirect economic costs.⁵¹¹

Infrastructure Investments

Adapting road and urban infrastructure is expected to cost around \$3 billion.⁵¹²

Forest, Ecosystems, and Wildlife

Rating: 1

Increasing average temperatures represent a greater risk to forests, ecosystems, and wildlife than intermittent heat waves, as the former carries the potential to change the amount and location of suitable habitat. However, extreme heat can lead to heat stress and death, particularly among species that are at the southern end of their range in Pennsylvania (i.e., are more suited to colder, northern habitats).

Built Infrastructure

Rating: 2

Extreme heat can stress infrastructure, including pavement, electrical and mechanical equipment, and energy infrastructure (generation, transmission, and distribution). This stress can lead to increased deterioration rates and maintenance costs and, in severe cases, infrastructure failures.

In the energy sector, increased temperatures simultaneously increase demand for cooling and require power grid operators to reduce operable capacity on electric generation facilities and electric transmission lines to avoid heat-related damage. Electrical and electronic equipment in unconditioned or outdoor spaces have shorter service lives and are subject to greater chance of thermal overload or reduced efficiency.⁵¹³ Power outages are possible if the system is overloaded.

Transportation infrastructure is also at risk and can lead to costly disruptions when affected. For example, roadways will become more pliable, experience greater wear and tear, and be more susceptible to buckling under extreme heat conditions.⁵¹⁴ Excessive heat can

also cause metal train tracks to expand and cause overhead wires that power the trains to sag and potentially get tangled. To reduce these risks of power issues and potential track damages, Southeast Pennsylvania Transportation Authority (SEPTA) limits train and trolley speeds between five and 10 miles per hour when temperatures hit above 90°F.⁵¹⁵

Areas with a higher concentration of built infrastructure and hard surfaces (i.e., urban areas) experience higher surface and air temperatures than their rural counterparts—this is known as the UHI. This can exacerbate the negative impacts of heat waves and

increase the stress on the occupants and infrastructure of cities. The “tropicalization” of the climate (i.e., increased heat and moisture) will decrease the service life of building and roofing materials, increase demand for cooling, and increase maintenance costs for built infrastructure.⁵¹⁶

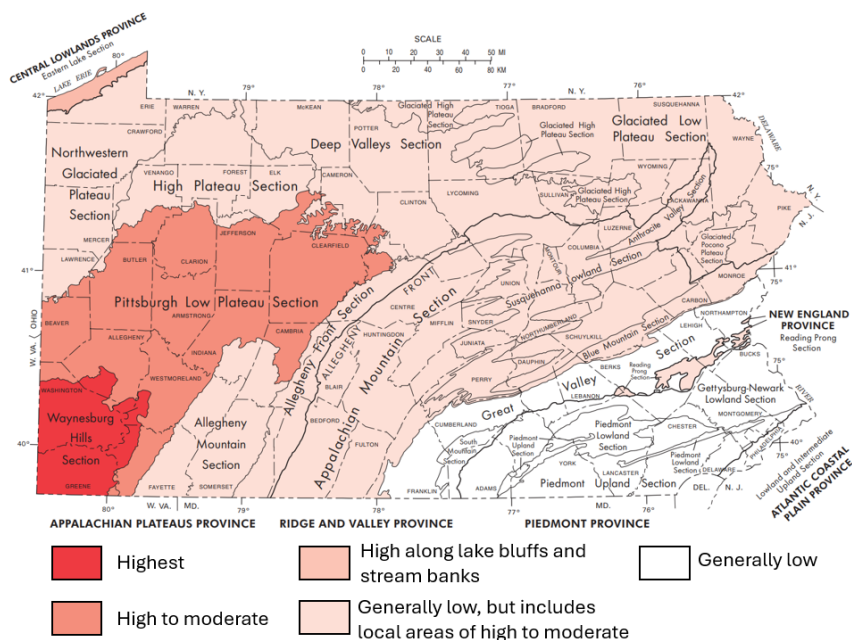
Public water suppliers and utilities could also face increased stress from increased water usage, water intake levels, and salinity concerns near the southeastern and northwestern portions of the state.⁵¹⁷

Landslides

Overview

Landslides can occur across Pennsylvania. As shown in **Figure 50**, they occur most often in the southwestern region, though other regions may have significant landslide hazards as well—and this region may expand.⁵¹⁸ As landslides become more common around the state, areas in Pennsylvania with a history of coal extraction have a higher likelihood of landslides.⁵¹⁹

Figure 50. Physiographic information and landslide susceptibility in Pennsylvania



Source: Delano and Wilshusen, 2001.

Higher average and extreme precipitation may increase soil water saturation, which can destabilize soil and increase the risk of landslide occurrence.⁵²⁰ Seasonal distribution of precipitation is also important; extreme events can trigger landslides at any time of year, while precipitation accumulated over time poses less of an issue if vegetation is incrementally taking up soil moisture to grow.⁵²¹

Temperature is also relevant to landslide risk. For example, one component of the extreme landslide occurrences in 2018 was warm weather. In early 2018, the ground never froze in the Pittsburgh area, leading to more infiltration, and further, most precipitation fell as rain (not snow), and the snow that fell melted rapidly. Historically, most precipitation in February has normally fallen as snow, which melts slowly or sublimates; nearly continuous rain in February 2018 overwhelmed soil moisture capacity, causing slope failures.

With climate change, average annual cumulative precipitation is projected to slightly increase, and precipitation variability is projected to increase as well, which may lead to greater frequency and intensity of heavy rainfall events. Average temperatures are also projected to warm due to climate change, which may increase the amount of precipitation that falls as rain. Depending on non-climate variables (e.g., current landslide risk, land use), risks of landslides may increase at some locations corresponding to these precipitation and temperature trends.

The greatest consequences of concern for landslides are damages to built infrastructure and associated economic impacts, as well as human health and safety impacts. Infrastructure damages are often severe after landslides, with varying consequences. The amount of resources (e.g., time, money) needed to repair these damages can also vary greatly.

Historically, landslides have tended to have greatest impacts when they disrupt transportation or energy infrastructure; the degree of downstream impacts (e.g., on the agricultural sector, or human health, if a highway is damaged) varies depending on factors such as the type of damage, the criticality of the asset/infrastructure, and the location of the landslide. For example, a landslide that damages a rural section of highway while cars are traveling on it could cause injuries or fatalities, while a landslide that breaks an electric transmission line could impact electricity end-users (e.g., homes, buildings like hospitals, farms with irrigation systems that run on electricity). **Figure 51** plots the overall current and mid-century risk ratings for landslides. While landslide likelihood may increase with greater precipitation variability, not enough evidence exists to change the current likelihood (and therefore risk) rating.

Table 21 summarizes the statewide likelihood and consequences of landslides in Pennsylvania.

Figure 51. Landslides risk matrix

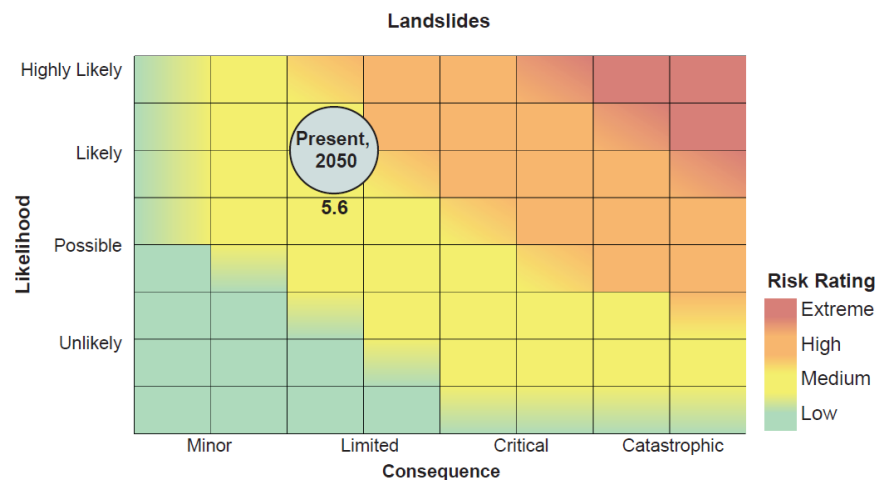


Table 21. Landslide statewide risk summary

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood (details on pg. 129)				
Current	3	The PA HMP identifies landslides of any magnitude as “highly likely” (over 90% probability) to occur any given year. More severe landslides like those analyzed in this scenario would be less likely.	High	In general, southwestern locations and populations are more exposed; there are also other localized areas with high vulnerability.
Mid-century	3	Landslide probability may increase with greater precipitation variability, though not enough evidence exists to change current likelihood rating.	Medium	Same as current.
Beyond 2050		These trends are expected continue as precipitation variability increases beyond 2050.		Same as current.
Consequences (details on pg. 130)				
Human health	1	Limited direct health impacts are expected, with some potential for indirect health impacts (e.g., due to infrastructure disruption).	Medium	Health risks may be particularly significant for low-income individuals with homes in high-risk areas or reliant on infrastructure (e.g., public transit) in high-risk areas to access jobs and income.
Environmental justice and equity	2	EJ areas 1.17x as exposed to high landslide risk compared to the state overall.	Medium	Rural townships with low tax base and many miles of roads, which may be severely affected by landslides in some areas and may not be captured in the EJ areas.
Economy: Agriculture	1	Localized impacts unless critical infrastructure is severely damaged.	High	Severe economic disruptions may disproportionately impact low-income populations. Additionally, rural townships may be particularly impacted, and not captured by the EJ areas analysis.
Economy: Recreation and tourism	1	Few consequences expected.	Medium	See Economy: Agriculture.

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Economy: Other	2	Localized impacts unless critical infrastructure is severely damaged.	High	See Economy: Agriculture.
Forests, ecosystems, and wildlife	1	Few consequences expected.	Medium	N/A
Built Infrastructure	4	Direct damages to energy or transportation infrastructure with downstream impacts that are relatively localized, but significant.	High	See Economy: Agriculture.
Overall Risk				
Current	5.6	Medium risk		High
2050s	5.6	Medium risk		High
Potential Opportunities				
None identified.				

Likelihood

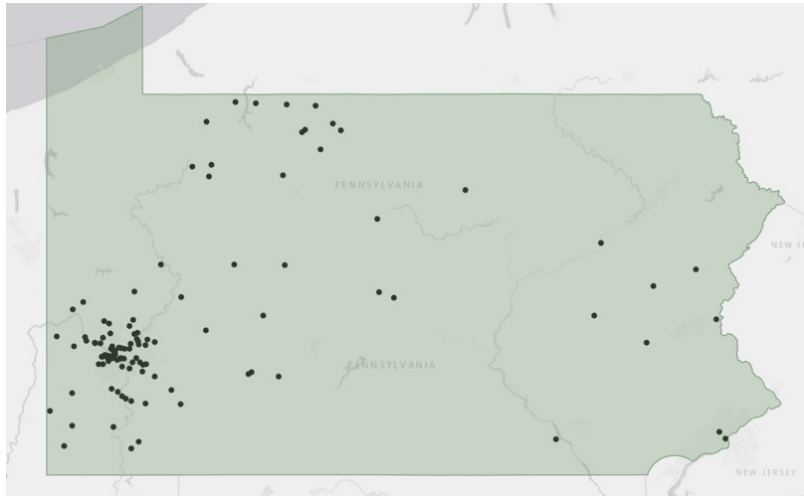
Landslides of any magnitude are currently highly likely (>90% annual probability) to occur in Pennsylvania, and with less than six hours of warning time, but are anticipated to have minor impacts, negligible spatial extent, and short duration.⁵²² However, this assessment focuses on potential occurrences and impacts of more severe landslides, which are relatively less likely to occur. For example, while the Hazard Mitigation Plan analysis is based on any landslide occurring (e.g., even those with minimal impacts to built infrastructure and no human impacts), this assessment is focused on the subset of more extreme but lower probability events (e.g., a landslide causing significant damages to infrastructure, with potentially significant downstream economic or natural systems impacts, or human injuries or fatalities).

Literature on climate change and landslide risk⁵²³ finds that greater frequency and intensity of heavy rainfall events, which are known to trigger landslide events, may lead to greater landslide risk in Pennsylvania. However, causes of landslides are multivariate and complex, and there is significant uncertainty around how and to what degree landslide risk may change due to climate change.

As shown in **Figure 50**, approximately 48% of land in Pennsylvania currently has high rates of landslide incidence or susceptibility, with risk primarily concentrated in the southwestern region. Historical occurrences of landslides in Pennsylvania depict a similar risk region (**Figure 52**),⁵²⁴ though slides have occurred in eastern PA.

Though the likelihood of landslides occurring may increase by 2050, due to projected increased frequency and intensity of precipitation, the likelihood of a landslide occurring at any given

Figure 52. Historical incidence of landslides



Source: U.S. Landslide Inventory (USGS, N.d.).

location, and the change in that likelihood, is uncertain and will vary significantly due to non-climate variables such as land use and physiography. As a result, there is not enough evidence to change the current likelihood rating for 2050.

Consequences

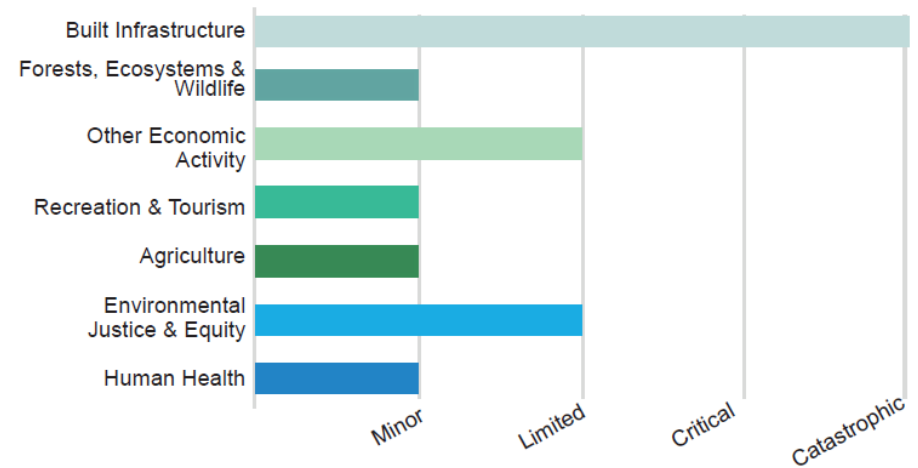
Historically observed landslides have been concentrated primarily in Southwestern Pennsylvania; susceptibility in other regions is limited, and areas with high susceptibility are relatively smaller. Locations of past landslide occurrence of landslides are often indicative of future high-risk areas.^{525,526} Additionally, there are several large landslides that have not been active in recent history but could become active,

with major consequences (e.g., damming a large river or damaging an interstate highway) if unknown thresholds are reached.⁵²⁷

For the most part, human injuries and fatalities have been limited, though they can occur if people are in the debris flow zone when a slide occurs. The greater impact is damage to infrastructure (e.g., highways, buildings, utility facilities).

Figure 53 summarizes the overall consequence ratings statewide for landslides— highest consequences are in environmental justice and equity, other economic activity, and built infrastructure.

Figure 53. Landslide consequences



Human Health

Rating: 1

Direct human health impacts from historical landslides have been limited, with nearly all of the few injuries and fatalities recorded occurring due to vehicle impacts from landslides along highways. Notably, greater human impacts on land (e.g., cutting into rock to build highways) tend to cause more landslides and cause more humans to be impacted than by naturally occurring events.⁵²⁸

Landslides can indirectly affect health if they disrupt infrastructure critical to supplying commodities and services that people rely on (e.g., energy infrastructure, electricity lines, transportation infrastructure needed to deliver medicine or roads critical to fast ambulance travel,⁵²⁹ or water or wastewater systems and treatment facilities), accessing places of employment (e.g., road or rail infrastructure), or otherwise allowing economic function and revenue generation.^{530,531} Individuals may also lose their homes to landslides, with significant financial and health and safety consequences. Further, rare events such as a pipeline rupture due to landslide can have major consequences, as indicated by several past events with liquid and gas fuels: one polluted drinking water in the Allegheny River for multiple days, and the other caused an explosion and loss of a house.⁵³² Finally, landslides have the potential to negatively impact drinking water quality if sediment is introduced into water bodies.⁵³³

Environmental Justice and Equity

Rating: 2

As shown in **Figure 54**, spatial analysis of regions with high landslide incidence rates and susceptibility finds that EJ areas do not demonstrate spatial correlation with areas of landslide potential.

However, communities in EJ areas may nonetheless experience disproportionate impacts of landslides when they occur. For example:⁵³⁴

- Lack of homeowners' insurance coverage for landslide damage and low values of homes in EJ areas can increase landslide impacts in these areas.
- Total loss of home is common when repair cost estimates almost always exceed value of home.
- Low tax base in low-income areas challenges government response for roadway and other infrastructure repair.
- Poor maintenance of drains and roadways can contribute to increasing hazard through ineffective water management.

Other factors that may increase individuals' vulnerability to impacts from landslides may include location and infrastructure needed to access employment. For example, in urban areas, large populations dependent on public transportation could be impacted if it is damaged (though it might be repaired faster with public pressure), while in more rural areas, smaller populations might be more severely impacted by loss of critical roads if there are fewer travel routes to begin with.

Downstream economic impacts

PA Department of Agriculture staff noted that, depending on the location, size and frequency of landslide occurrences, food supply chain disruptions could be significant.

damage to crops, livestock, or materials (e.g., stored feed, equipment).⁵³⁵

Additionally, many agricultural services rely on commodities being delivered, and delivery could be disrupted if transportation infrastructure is damaged by landslides. For example, damage to local transportation infrastructure could prevent trucks carrying milk and feed from getting to or from a farm.⁵³⁶

Recreation and Tourism

Rating: 1

Minimal research is available on landslide impacts to recreation and tourism. However, it is possible that landslides could temporarily affect recreation and tourism—if, for example, landslide damages to transportation infrastructure hindered access to recreation destinations.

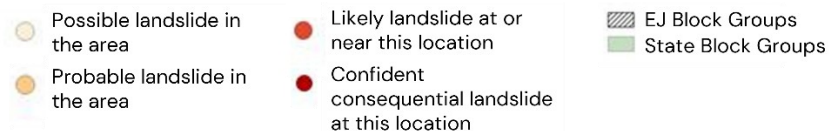
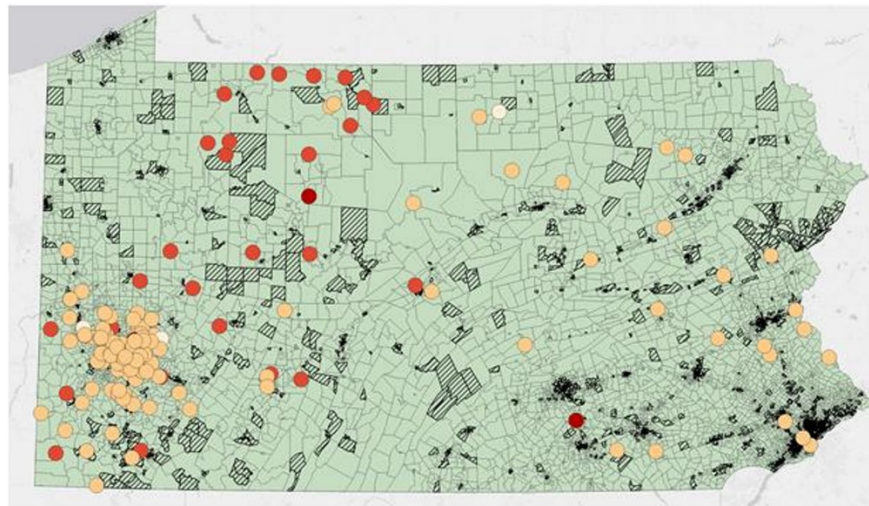
Other Economic Activity

Rating: 2

Given the geography of Pennsylvania, with both the Appalachian and Allegheny Mountain ranges, landslides cause significant annual impacts and damages to both infrastructure and personal property. The total cost of protecting against landslides is projected to reach \$935 million.⁵³⁷ Much of Pennsylvania is susceptible to landslides, with 4.49 million people, 6,021 critical facilities, and nearly

Figure 54. Areas of landslide potential with EJ block groups

Landslide data source: USGS-- Version 2 of the National Landslide Inventory (NLSIV2)



Economy

Agriculture

Rating: 1

Disruptions to commerce and supply chains or physical damage to agricultural land due to landslides could impact the agricultural industry. A landslide occurring on agricultural land would have the most intense and direct impacts, including displacement of or

\$950 billion in exposed building infrastructure.⁵³⁸ “Backyard” landslides (landslides on private property), common in western PA are usually repaired incompletely or not at all, costing upwards of several thousand dollars to stabilize and repair a landslide affecting two or three properties. With repair costs exceeding the value of most properties in this area, abandonment is a frequent solution.⁵³⁹

Economic sectors reliant on infrastructure (e.g., the energy sector), particularly in Southwest Pennsylvania, may be impacted by infrastructure damages from landslide occurrences. This risk may

Example economic impacts of landslides

Given the geography of Pennsylvania, with both the Appalachian and Allegheny Mountain ranges, landslides cause significant annual impacts and damages to both infrastructure and personal property.

Transportation and Natural Gas Infrastructure

Large portions of the Pennsylvania roadway network run through mountainous terrain and are continually at risk. In three counties alone (Beaver, Allegheny, and Lawrence), Pennsylvania Department of Transportation (PennDOT) crews fix roughly 15 sites of varying size per year, but during that same period, 30–40 new slides occur. Beyond cost, repair crews often cannot keep up with the pace of slides.⁵⁴⁰

Many of Pennsylvania’s natural gas pipelines also stretch across areas susceptible to landslides. Since between early 2018 and mid-2019, at least six pipeline explosions occurred because of landslides in Appalachia.⁵⁴¹

Historic Damages

In a typical year, PennDOT budgets about \$30 million for flooding and landslide damage. In 2018 alone, PennDOT spent about \$127 million fixing damage from flooding and landslides.⁵⁴²

increase in the future, as heavy precipitation events, which are projected to become more frequent and intense, are associated with increased landslide potential.^{543,544}

Large portions of the Pennsylvania roadway network run through mountainous terrain and are continually at risk. The economic effects of major delays in transportation and commuting time for large areas could be significant. For example, business could be cut off from historic customer traffic, and school buses, commuters, and delivery times could be affected by road closures. Short-term delays frequently occur due to landslides along major routes, but they are normally managed within a day or two; long-term road or lane closures could cause delays and loss of access for years.⁵⁴⁵

Forest, Ecosystems, and Wildlife

Rating: 1

Landslides have minimal impacts on forests, ecosystems, and wildlife.

Landslides may impact land topography, including forest cover and river, stream, and groundwater flow, as well as physical habitats and the ecosystems and wildlife they support. For example, movement of sediment into a river could reduce water quality and impact fish habitat, or a large land movement could strip vegetation (e.g., from a forested hillside).⁵⁴⁶

Landslide impacts on surface water ecosystems are largely unknown, but in most cases likely short-lived. For example, a landslide could increase sediment in a stream, potentially temporarily damming the stream. Ecosystems impacts could also be a downstream consequence of larger infrastructure failures (e.g., if a pipeline or storage tank were damaged, and contents spilled out).⁵⁴⁷

Built Infrastructure

Rating: 4

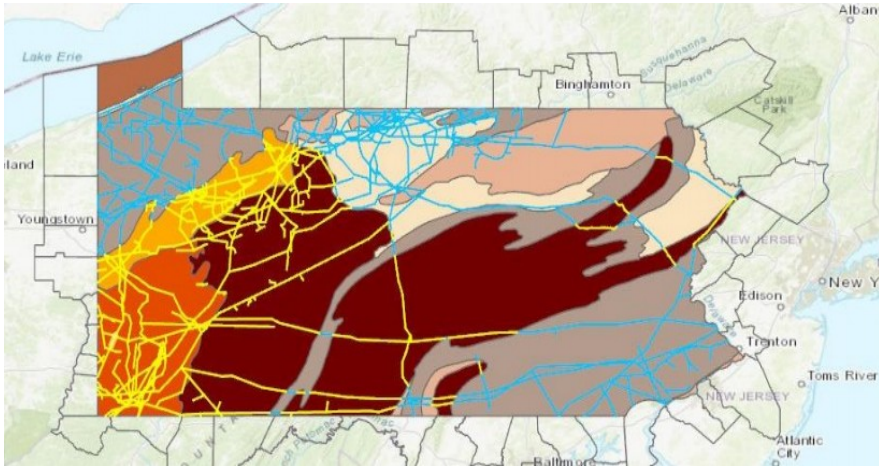
Though records of damage costs are limited, those that exist are significant. In Allegheny County, for example—one of the eight southwestern counties identified as most at-risk—the costs to remediate landslides continues to increase. PennDOT data indicates landslide damage repairs in Allegheny cost between 2016 and 2019, the costs exceeded \$45 million in total. During this same time period, based on National Oceanic and Atmospheric Administration data, Pennsylvania experienced the rainiest two-year, three-year and four-year periods on record. Studies have predicted that greater frequency and intensity of heavy precipitation events may increase landslide potential.⁵⁴⁸ High impacts have occurred more recently as well: the Pittsburgh area saw “record” landslides and associated costs in 2018, and the mayor noted the City was “already five times over budget for landslide remediation by mid-April” of that year, with damages to homes, roads, and vehicles.⁵⁴⁹

If landslides impact major highways where federal or state funds become available, repairs can be fast, so that damages are relatively localized and temporary. However, impacts to other roads and homes may be long-lasting, if difficult to enumerate. For most state or local roads, repairs are often deferred for multiple years, or sometimes permanently, due to budget constraints. PennDOT District 11, for example, has a large backlog of landslide repairs. And there are hundreds of locations in Allegheny County where roadway repairs are waiting on funding or have been abandoned because they are not expected to ever be funded. If a municipality loses access to a road that is a link in emergency transportation routes or a significant commuter route, many peoples’ daily lives and certain individuals’ health may be impacted.⁵⁵⁰

Energy and transportation systems infrastructure (e.g., natural gas pipeline, or highway), particularly in Southwestern Pennsylvania, may be particularly vulnerable to disruption from landslide events. Landslides have been known to cover rail track and shut down train traffic for two days.⁵⁵¹ Due to infrastructure interdependencies, landslides that cause service disruptions or transportation and shipping impacts could indirectly have many downstream impacts. For example, damage to the transportation system could impact fuel deliveries, which could lead to service interruptions (e.g., electrical blackouts), and these could in turn impact power supply to other industries (e.g., loss of power for water pumps could lead to stormwater outflow or interruptions at wastewater treatment plants).⁵⁵²

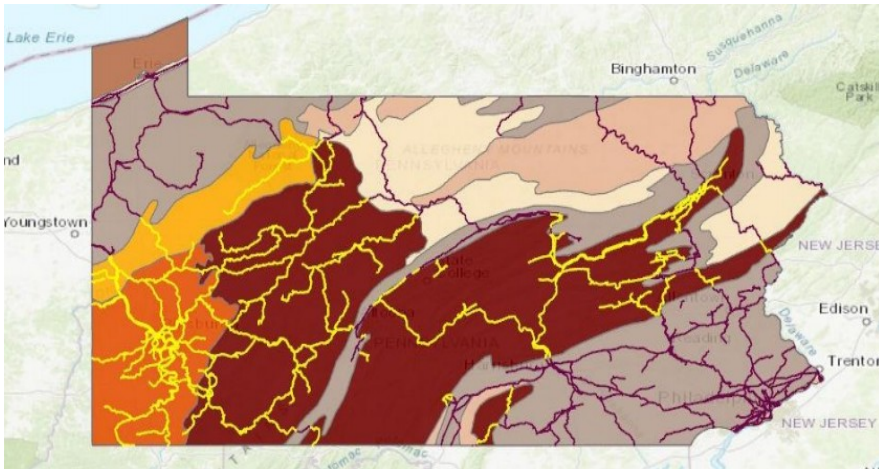
Landslide risk maps developed for the 2020 Impacts Assessment show natural gas (**Figure 55**), railway (**Figure 56**) and electrical (**Figure 57**) infrastructure located in landslide hazard zones. Of the infrastructure studied, nearly 50% of miles of electric transmission lines and natural gas pipelines, 41% of electric substations, and 55% of railroad miles are in landslide hazard zones.⁵⁵³

Figure 55. Natural gas pipelines in landslide hazard areas



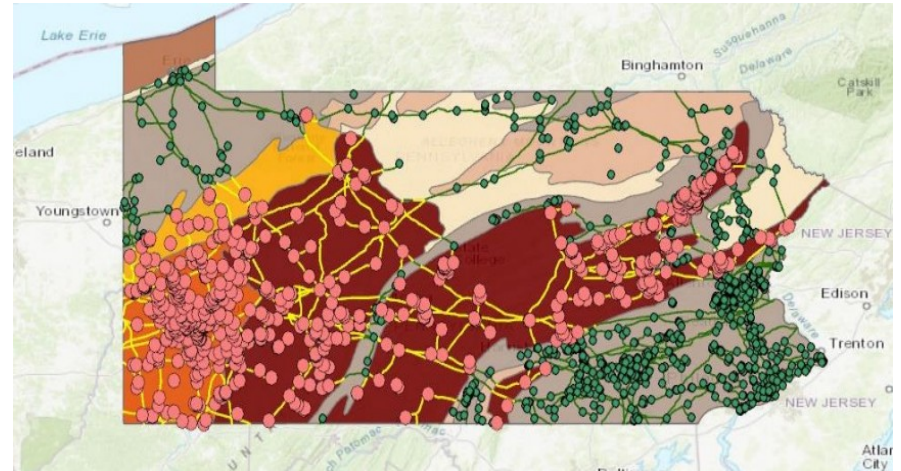
Natural gas pipelines in landslide hazard areas (yellow lines) and pipelines outside landslide hazard areas (blue lines). Source: DEP, 2020 Climate Impacts Assessment

Figure 56. Railroads in landslide hazard areas



Railroads in landslide hazard areas (yellow lines) and outside landslide hazard area (purple lines). Source: DEP, 2020 Climate Impacts Assessment.

Figure 57. Electrical infrastructure in landslide areas



Electric power substations and transmission lines (red dots) and support towers for transmission lines (yellow lines) in landslide hazard areas, and substations and transmission lines outside landslide hazard areas (green dots and lines). Source: DEP, 2020 Climate Impacts Assessment

Sea Level Rise

Overview

Sea level rise (SLR) is expected to increase risks to freshwater tidal wetlands and fauna and exacerbate flooding. SLR has the potential to add to the existing stresses on southeastern Pennsylvania’s freshwater tidal ecosystems. Additionally, SLR is projected to increase water levels and the salinity of inland rivers, including the Delaware and Schuylkill rivers that run through Philadelphia.⁵⁵⁴ As a result, storm surges will cause increased flooding in Philadelphia and the surrounding region, and could permanently inundate some low-lying areas.⁵⁵⁵ Moreover, increased salinity in rivers will mean that water used by municipalities and industries in and near Philadelphia will be too salty for many present-day applications and threatening drinking water supplies.⁵⁵⁶ In Pennsylvania more broadly, SLR mainly threatens built infrastructure as well as forest, ecosystems, and wildlife along the state’s coastline and tidally-influenced rivers. However, SLR will have relatively minor consequences in Pennsylvania overall and will be a low risk for the state. **Figure 58** illustrates the overall risk rating in present-day and 2050 based on the likelihood and consequence ratings.

Table 22 summarizes the statewide likelihood and consequences of SLR in Pennsylvania

Figure 58. Sea level rise risk matrix

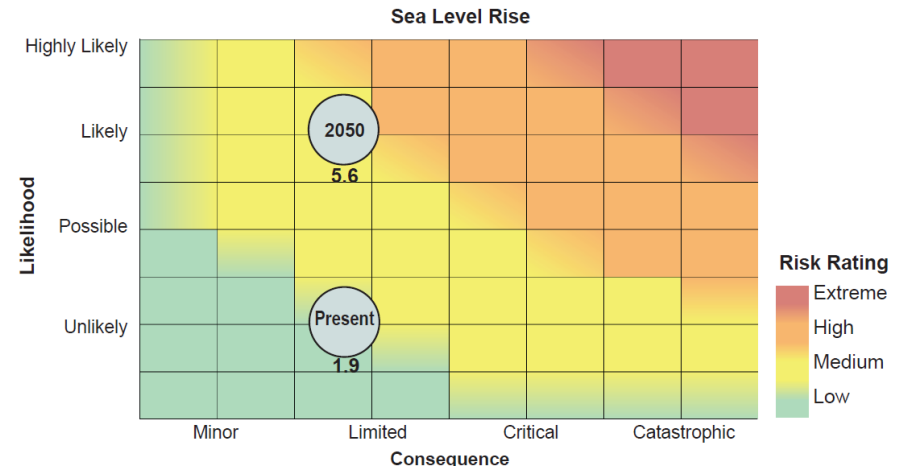


Table 22. Sea level rise statewide risk summary

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood (details on pg. 139)				
Current	1	SLR is increasing but has not neared the critical threshold of two feet of SLR, which is the critical threshold given this is a likely and significant increase.	High	The Delaware Estuary is currently experiencing the most significant impacts of SLR.
Mid-century	3	SLR will increase and is likely to approach 1.5 feet by mid-century.	High	The broader region of the Delaware River Valley is projected to be at risk. The Delaware Estuary will also continue to face severe impacts.
Beyond 2050		NOAA projects SLR of 1.8 to 6.5 feet by the end of the century.	High	Same as mid-century.
Consequences (details on pg. 139)				
Human health	1	Possible saltwater intrusion in water wells, thought impacts on drinking water safety are not expected.	High	Communities that receive water from rivers in the Delaware Estuary may experience reduced water quality.
Environmental justice and equity	1	Not projected to experience disproportionate exposure to SLR-driven flooding.	Medium	People living in lower-elevation areas are more likely to experience impacts from SLR.
Economy: Agriculture	1	Not expected to be severely affected.	High	NA
Economy: Recreation and tourism	1	Not expected to be severely affected.	High	Philadelphia International Airport could be flooded during storms.
Economy: Other	2	Millions of dollars in repairs and improvements costs from damage to water infrastructure.	High	Industries receiving water from rivers in the Delaware Estuary will have to cope with saltier water.

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Forests, ecosystems, and wildlife	2	Possible inundation of wetlands. Tidal freshwater flora and fauna threatened by rising water levels and increased water salinity.	High	The location of the state's small coastline makes southeastern Pennsylvania near the Delaware Estuary vulnerable to SLR.
Built Infrastructure	4	Inundated or increased flooding of infrastructure and river-adjacent areas, particularly wastewater treatment plants.	High	Southeastern Pennsylvania, particularly Philadelphia, will see greater flooding, as river levels rise.
Overall Risk				
Current	1.9	Low risk	High	
2050s	5.6	Medium risk	High	
Potential Opportunities				
Opportunities for the development of improved water treatment. Higher water levels might also open greater shipping opportunities.				

Likelihood

Over the next 30 years, there is very high confidence that coastal sea levels along the contiguous US Coasts are expected to rise about 11 inches. SLR is expected to increase faster along the Mid-Atlantic and Northeast coasts than globally as described in the coastal change section.⁵⁵⁷ The range of change varies depending on the trajectory of greenhouse gas emissions. SLR is expected to reach 1-1.7 feet by mid-century and 1.8-6.5 feet by end-of-century.⁵⁵⁸ This range represents intermediate low to intermediate-high SLR scenarios. Even in the low SLR scenario, water levels will increase by one foot by 2050 and 1.8 feet by the end of the century. In a high-emissions scenario, sea levels in the Philadelphia area could rise by 1.6 feet by 2050 and 6.5 feet by 2100.

Consequences

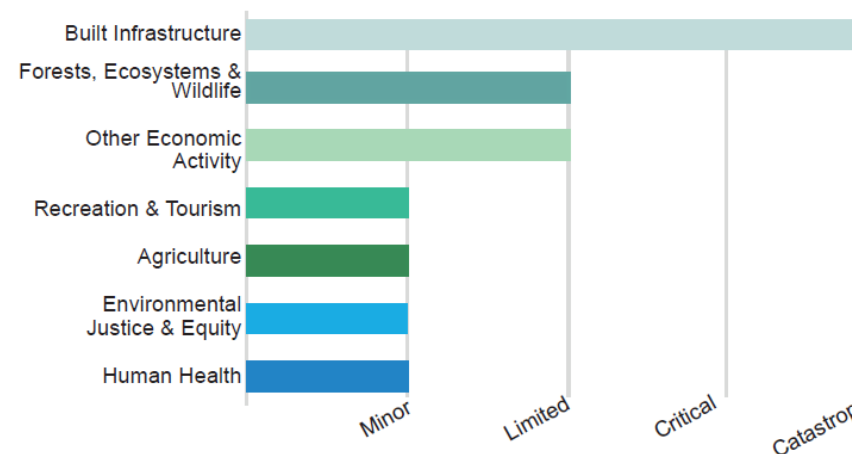
Figure 59 summarizes the overall consequence ratings statewide for SLR —highest consequences are in the other economic activity category and the forests, ecosystems, and wildlife category.

Human Health

Rating: 1

SLR will have a minimal impact on human health. However, SLR has the potential to reduce water quality which could be a threat to long-term public health if not addressed. Given a two to eight-foot rise in sea level, the salt front would move 10 to 25 miles further upriver in years with high drought.⁵⁵⁹ Philadelphia and other municipalities in the region would face impacts to their drinking water supply with only a 2.4-foot rise in sea level, which is possible

Figure 59. Sea level rise consequences



by mid-century and likely by the end of the century.⁵⁶⁰ Additionally, water wells may experience increase salinity if they are near areas where groundwater sources are facing salt water intrusion. Lower water quality could increase health issues if greater investments in water treatment are not made. Additionally, with SLR, coastal storm surges might be greater during cyclone events. Subsequently, health risks outlined in Section 4.1 could be exacerbated by SLR.

Environmental Justice and Equity

Rating: 1

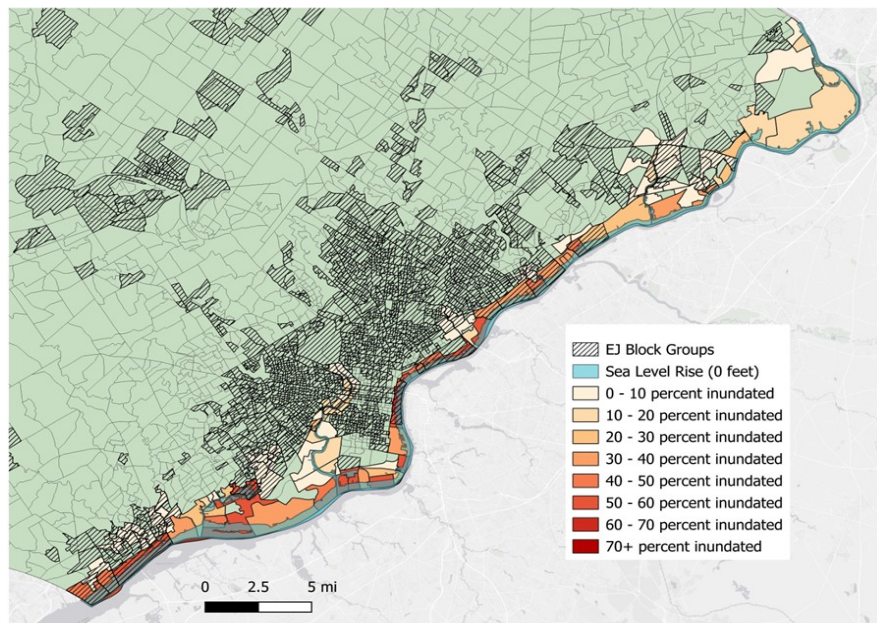
Spatial analysis (see **Figure 60**) indicates coastal EJ areas are not projected to be disproportionately exposed to five feet of SLR-driven flooding. This analysis shows the percent of census blocks inundated from zero and five feet of SLR; black cross-hatching indicates EJ areas. About 20% of coastal EJ census blocks are projected to experience flooding under two feet SLR. This flooding statistic does not differ significantly from the 21% of total

area of *all* coastal communities that is projected to experience flooding under two feet SLR. Additionally, the total number of people projected to experience inundation under the two feet SLR scenario is relatively lower than that exposed to other climate hazards, given the smaller size of coastal populations in Pennsylvania.

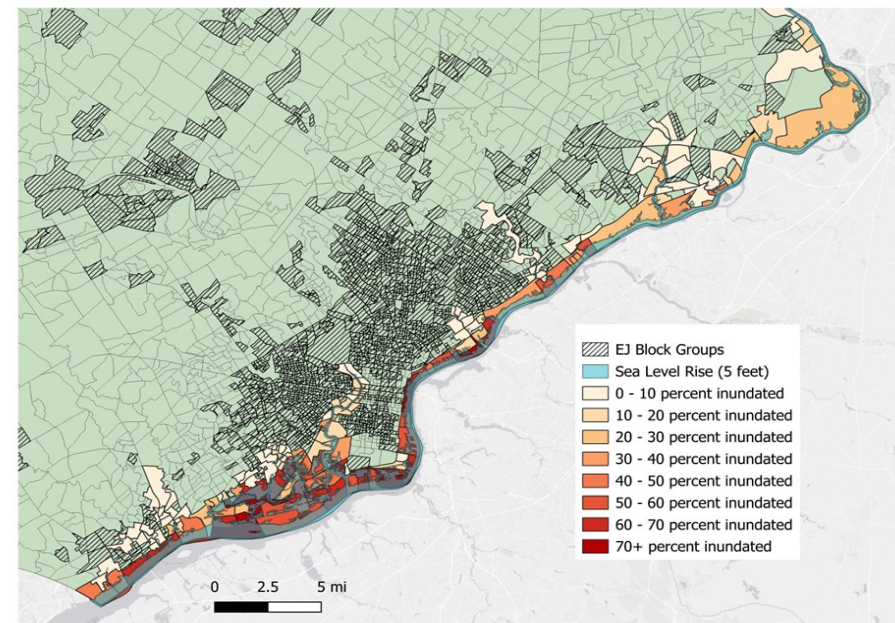
Area-based findings on coastal flood exposure offer limited nuance regarding population-level flood risk. For example, this analysis does not reflect the distribution of residences within a block group (e.g., proximity to the coast or flooded areas, density of homes in an area).

Figure 60. Percent of land mass inundated with 0 feet (left) and 5 feet (right) of water increase. EJ census block groups are shown with black cross-hatching

Percent Land Mass Inundated with 0 Feet Sea Level Rise (Present)



Percent Land Mass Inundated with 5 Feet Sea Level Rise (2100)



As such, findings from this analysis may not fully capture on-the-ground disparities in flood risk.

Indeed, certain populations may be disproportionately vulnerable to or impacted by this hazard. For example, as described under the Heavy Precipitation and Inland Flooding section (see pg. 103), many flooding inequities prevalent in urban areas often place low-income people and BIPOC communities at higher risk.⁵⁶¹ Those who live in economically distressed communities or in substandard housing may have a greater sensitivity to SLR driven from flooding events. Affordable housing units have been found to face much higher risk from SLR than standard housing in Pennsylvania.⁵⁶² They may experience greater impacts from SLR related flooding and be less able to recover as a result of limited access to resources.

Economy

Agriculture

Rating: 1

SLR does not appear to threaten Pennsylvania agriculture. As a result, it will have minor impacts on the sector.

Recreation and Tourism

Rating: 1

This hazard will have minor impacts on the sector. The overall impact of SLR will be minimal on recreation and tourism. However, SLR will increase key tourism infrastructure's vulnerability to flooding. The Federal Aviation Administration has designated the Philadelphia International Airport as in danger: with only two feet of SLR, the airport would be exposed to flooding.⁵⁶³ The electricity system of the airport is particularly at risk as critical utilities are often

underground.⁵⁶⁴ During a Category 1 storm or a 100-year flood, 10 to 11 terminals and hangers (out of 12) and five to 18 terminals (out of 20) would be inundated with two feet of SLR. Repairs from storm damage with two feet of SLR could be significant. However, overall SLR is not expected to have significant consequences for recreation and tourism in Pennsylvania.

Other Economic Activity

Rating: 2

Overall, consequences will be limited in this category. However, changes in the salinity of the freshwaters in rivers surrounding the Delaware Estuary will have significant impacts on the municipalities and industries that rely on those waters. For example, cities and companies that rely on the Schuylkill River near Philadelphia will be forced to adapt as the river's waters become too salty for many applications.⁵⁶⁵ Brackish waters would be especially present during dry periods.⁵⁶⁶ The use of brackish water threatens to damage equipment, raise water treatment costs, and force a shift in water supplies.⁵⁶⁷ Replacing damaged equipment and water treatment infrastructure could cost tens of millions of dollars over time, and thus the cost of inaction is moderate. Overall, the consequences will be experienced only in water infrastructure in the Delaware Estuary. SLR could have severe economic implications when combined with extra-tropical and tropical cyclones. Flooding associated with coastal storm surges amplified by SLR is projected to threaten thousands of jobs and properties. Example economic impacts of SLR are described in the box on the next page.

Example economic impacts of sea level rise

SLR has, and will continue, to inundate Pennsylvania with flooding. These damages can cost Pennsylvania billions of dollars but will center around Philadelphia.

Sea Level Rise Implications

Philadelphia's airport is built on what used to be a network of islands in the Delaware River (built with an elevation of just 8.3 feet). The airport's location is one of the City's most vulnerable areas to SLR.⁵⁶⁸ The airport's ongoing \$6.2 billion expansion, to be completed in phases through 2025, lengthening two of the airport's four runways and building a fifth runway along the Delaware River, includes SLR such as filling 135 acres of floodplain and building 11 acres on stormwater basins.^{569,570}

In the Delaware River Basin, some 147,000 jobs and \$20.4 billion in residential property values could be affected by the combined impact of SLR, storm surge and flooding.⁵⁷¹ The portion of that damage attributable to SLR alone is unknown, though the estimated cost to the state for all sea level related costs is \$547 million.⁵⁷²

Forest, Ecosystems, and Wildlife

Rating: 2

SLR threatens the ecology of Pennsylvania's portion of the Delaware Estuary. Specifically, the upper Delaware Estuary is projected to experience a modest change in salinity as a result of climate change.^{573,574} Increased salinity is projected to cause a change in habitat for the fauna that live in these waters. As the estuary's water levels rise and increase in salinity, marine species will likely advance up the estuary and freshwater species will retreat resulting in a significant shift in the makeup of the estuary's ecology.⁵⁷⁵ Fish populations and other marine species that need lower salinity levels may be threatened. Specifically, oysters and mussels may be imperiled.^{576,577} Tidal wetlands may also be damaged by SLR and changes in salinity levels as plant species are unable to adapt to higher water levels, saltier water, or frequent inundation.⁵⁷⁸

By mid-century, coastal wetlands are also projected to experience severe, localized damage. SLR may result in the drowning of tidal and nontidal wetlands on Pennsylvania's southeastern coast.⁵⁷⁹ Development in southeastern Pennsylvania may hinder tidal flora and fauna from migrating horizontally to escape ecosystem changes.⁵⁸⁰ Ultimately, SLR may stress or destroy freshwater tidal ecosystems.⁵⁸¹ Wetlands are a unique resource for Pennsylvania and face significant devastation.

Built Infrastructure

Rating: 4

Though Pennsylvania has a small coastline, SLR will increase river levels. As a result, the frequency, exposure, and severity of flooding in southeastern Pennsylvania is expected to grow. SLR will exacerbate the consequences of extreme precipitation and flooding outlined in the "Precipitation and Inland Flooding" hazard section. While exposure will remain limited in mid-century, the number of facilities and homes at risk at the end-of-century will dramatically increase.⁵⁸² With a four-foot rise in sea level, 2,515 homes worth an estimated \$686 million dollars and 63 miles of roads will be at risk in Pennsylvania.⁵⁸³ These damages will be concentrated in the Philadelphia region. Overall, SLR will have a localized impact in southeastern Pennsylvania but will result in significant damage when combined with storms.

Severe Tropical and Extra-Tropical Cyclones

Overview

Tropical cyclones include events such as tropical storms, tropical depressions, and hurricanes, while extra-tropical cyclones encompass events like nor'easters.⁵⁸⁴ Severe tropical and extra-tropical cyclones will result in significant flooding and winds that threaten Pennsylvania as well as clusters of landslides and sinkholes. Additionally, tropical cyclones also cause tornadoes, while extra-tropical cyclones result in winter storms that bring severe weather (i.e., hail, tornadoes). Tropical and extra-tropical cyclones are the main driver of annual extreme precipitation in the Northeastern United States.⁵⁸⁵ As a result, the consequences of flooding and extreme rainfall outlined in the "Precipitation and Inland Flooding" hazard section also apply to cyclones.

Tropical and extra-tropical cyclones are projected to have significant consequences for human health, the energy sector, and built infrastructure. Stronger cyclones are expected to endanger individuals as high winds damage buildings and flooding causes accidents. Significant destruction and harm follow cyclone events as seen with Hurricane Ida, Hurricane Sandy, Hurricane Irene, and Tropical Storm Lee. For example, 16,000 homes and businesses were damaged during Tropical Storm Lee, which resulted in over \$2 billion dollars in damages.⁵⁸⁶

Figure 61 illustrates the current and 2050 overall risk rating based on the likelihood and consequence ratings.

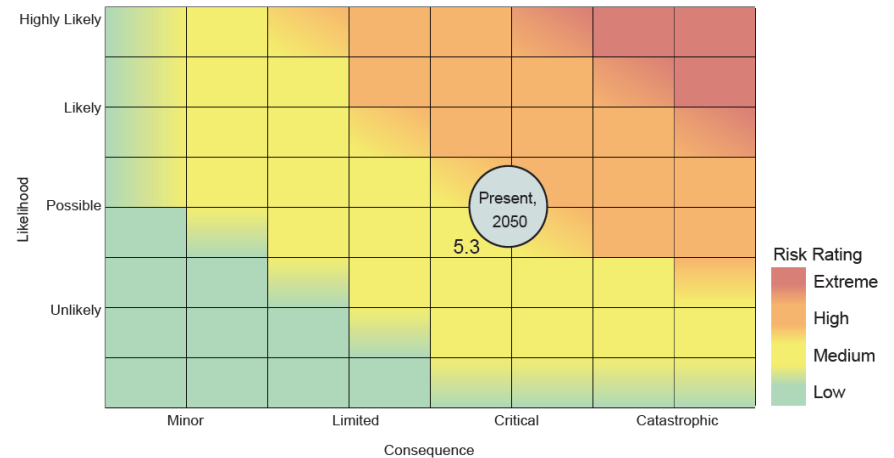


Figure 61. Tropical and extra-tropical cyclones risk matrix

Table 23 summarizes the statewide likelihood and consequences of tropical and extra-tropical cyclones in Pennsylvania.

Table 23. Tropical and extra-tropical cyclones statewide risk summary

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood (details on pg. 146)				
Current	2	Extra-tropical cyclones have become more frequent. Tropical cyclones have not increased in frequency.	High	
Mid-century	2	Extra-tropical cyclones frequency is expected to grow. Tropical cyclones will become more intense, but not necessarily more frequent.	Medium	
Beyond 2050		These trends, including increase in severe tropical cyclone intensity and extra-tropical cyclone frequency, are expected to continue well beyond 2050.	Medium	
Consequence (details on pg. 146)				
Human health	3	Potential for dozens of people severely injured.	High	Individuals who live in low-lying areas or who face serious dangers to their health during power outages.
Environmental justice and equity	2	Slight over-representation of EJ areas in the FEMA 500-year floodplain.	High	Individuals more sensitive to extreme flooding and with less access to resources to recover from a storm event. This may include individuals with higher social vulnerability such as those who are low-income.
Economy: Agriculture	3	Potential for severe crop damage.	Medium	NA
Economy: Recreation and tourism	2	Damage to the Philadelphia International Airport and recreation sites in the state. Disruptions to state parks and forests.	Medium	Southeastern Pennsylvania may be hit more severely as flooding is exacerbated by SLR.
Economy: Other (e.g., energy)	2	Short-term disruptions to energy delivery in the natural gas and petroleum sectors.	High	Southeastern Pennsylvania may be hit more severely as flooding is exacerbated by SLR.

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Forests, ecosystems, and wildlife	2	Damage to state forests and other ecosystems from high winds.	Medium	NA
Built Infrastructure	4	Transportation and local electricity infrastructure could be severely hit.	High	Southeastern Pennsylvania may be hit severely where flooding is exacerbated because of the region's proximity to the coast.
Overall Risk				
Current	4.8	Medium risk	Medium	
2050s	4.8	Medium risk	Medium	
Potential Opportunities				
<ul style="list-style-type: none"> Investments in healthy soils in agricultural land and best management practices reduce the shock of an acute storm event. After tropical and extra-tropical cyclones, communities often experience a boom in construction and car sales as individuals seek to replace lost property. 				

Likelihood

Tropical and extra-tropical cyclones are possible each year. For example, eight tropical and extra-tropical cyclones passing through Pennsylvania since 2000.⁵⁸⁷ Climate change will have differing effects on cyclones and extra-tropical cyclones events. Overall, a building consensus in the literature anticipates that individual storms' strength and level of precipitation will increase.⁵⁸⁸ The literature indicates that an increase in the severity of tropical cyclones is almost certain. However, the impacts of climate change on the frequency of tropical and extra-tropical storms will differ. The frequency of tropical storms is not projected to change.⁵⁸⁹ No consensus has been reached on whether there has been a demonstrated trend in a change in tropical cyclones' likelihood.⁵⁹⁰ On the other hand, extra-tropical cyclones are expected to increase in frequency. Overall, there is a high degree of uncertainty in how both tropical and extra-tropical cyclones will change in likelihood.

Consequences

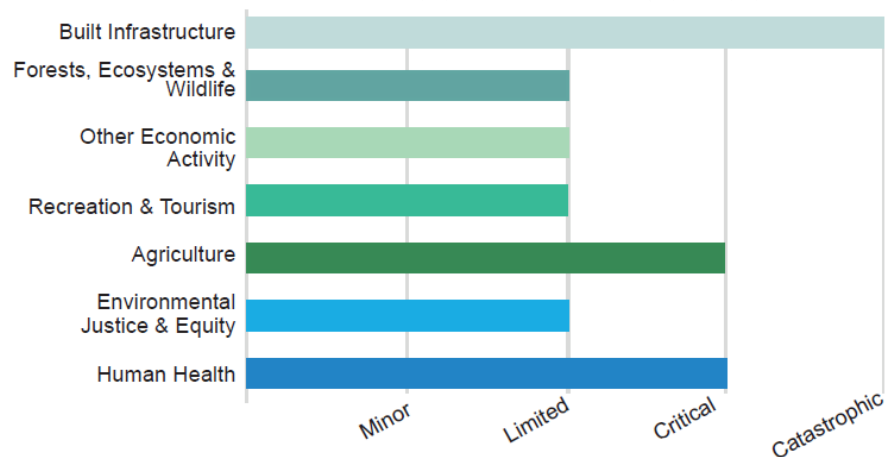
Figure 62 summarizes the overall consequence ratings statewide for tropical and extra-tropical cyclones—highest consequences are in human health, environmental justice and equity, agriculture, and built infrastructure.

Human Health

Rating: 3

The health impacts of severe cyclones are limited but can be severe. Flooding during tropical and extra-tropical cyclones poses

Figure 62. Tropical and extra-tropical cyclones consequences



significant dangers to human health. These extreme storms can result in significant mortality, especially as storms' strength intensifies. Cyclones can directly cause injuries and death from drowning and trauma sustained during the event. They can also contribute to a higher risk of certain health issues, such as preterm birth.⁵⁹¹ Additionally, severe cyclone events can have significant mental health impacts. Trauma of the event, loss of resources, and economic and social consequences can lead to stress and anxiety, post-traumatic stress disorder, and depression.⁵⁹²

During cyclone events, risks to human health depend mainly on exposure and vulnerability rather than on changes in storms' intensity. Exposure is driven by living in areas that are low-lying or adjacent to waterbodies and thus more prone to severe flooding. Individuals may also be more vulnerable if they face a serious health risk if the power is shut off, such as those who are elderly or have certain medical conditions.

In addition, cyclones threaten to disrupt critical services to human health such as telecommunications, water, wastewater, emergency services, and transportation infrastructure. Loss or interruption of these services can result in serious harm and mortality.⁵⁹³ A large number of people would face risk of harm and dozens of people in the Commonwealth could experience harm during or after a cyclone event because of hazardous conditions created by the event. For example, disruption of electricity and inability to refrigerate food can result in foodborne diarrheal illnesses if individuals consume spoiled foods.⁵⁹⁴ Death from electrocution from fallen power lines, carbon monoxide poisoning, candle-started fires, and car accidents can all also be indirectly caused by severe cyclones.⁵⁹⁵ Heavy rain and winds can reduce visibility while driving and cause other hazardous road conditions which can also result in greater car accidents.

Finally, winter extra-tropical cyclones can be dangerous because of snow accumulation, winds, and freezing temperatures.⁵⁹⁶ Resulting health risks include frostbite and hypothermia.⁵⁹⁷

Environmental Justice and Equity

Rating: 2

Many of the same EJ and equity concerns raised in the “Precipitation and Inland Flooding” hazard section apply to cyclone events. Cyclones will threaten those in low-lying areas, as these extreme storm events exacerbate flooding. EJ areas are slightly overrepresented in FEMA 500-year floodplains compared to the state average (1.2 times as exposed). Affordable housing is also expected to see a 792% increase in exposure to coastal flood. This is the largest predicted increase in affordable housing exposure for any coastal state.⁵⁹⁸

Beyond being slightly overrepresented in terms of exposure, communities with a high percentage of low-income individuals are more at-risk of facing serious consequences after an extreme storm. Low-income households are more likely to lack the resources to recover quickly from an extreme cyclone, and to reside in substandard housing, which increases the risk of mold, mildew, poor IAQ, and damage after intense rain and wind during storms.^{599,600} Similarly, areas with a high percentage of low-income individuals are more likely to have less climate resilient infrastructure.⁶⁰¹

Economy

Agriculture

Rating: 3

Rainfall during tropical cyclones and extra-tropical cyclones will parallel many of the consequences of extreme precipitation on agriculture discussed in the “Precipitation and Inland Flooding” hazard section. Heavy precipitation during extreme weather events will increase risks associated with flooding such as augmented runoff, erosion, and nutrient leaching.

In 2021, the remnants of Hurricane Ida caused excessive rain in Pennsylvania, and the USDA recognized the significant impact from this event on Pennsylvania agriculture.⁶⁰² Four counties received a disaster designation to support recovery in response to livestock death, feed and grazing losses, and crop losses.⁶⁰³

Recreation and Tourism

Rating: 2

Cyclones and extra-cyclones will have limited consequences for recreation and tourism. Though the consequences appear mild,

extreme storms could damage the Philadelphia International Airport when combined with other climate stressors like SLR, as discussed in the “Sea Level Rise” hazard section. For example, a two-foot rise in sea level in conjunction with a Category 1 storm would inundate 25% of the airport’s supporting infrastructure and 42% of the airport’s terminals and hangars.⁶⁰⁴ Like with other infrastructure, cyclones could damage recreation and tourism facilities in the state. For example, in the aftermath of Hurricane Irene, the National Park Service had to remove fallen trees and debris, repair minor road damage, and clear culverts.⁶⁰⁵ State parks and forests have also experienced significant disruptions from cyclones that have reduced tourism opportunities and resulted in lost revenue for the state.⁶⁰⁶ Overall, cyclone impacts to this sector are limited.

Other Economic Activity

Rating: 2

Cyclones will likely temporarily disrupt economic activity. The consequences are significant for the energy sector and for small businesses dependent on electricity. Business and government activity may be disrupted as teleworking employees may not be able to connect to the internet. Flooding during storms can disrupt fuel delivery services such as natural gas compressor stations, petroleum product pipelines, and pumping stations for crude oil. Refineries are also at risk during extreme flooding and blackout events caused by cyclones. Similarly, extreme rainfall during severe storms is a main cause of pipeline damage.⁶⁰⁷ Additionally, high winds and precipitation associated with severe storms disrupts electricity delivery which impacts communities and small businesses. Storms force stores, restaurants, and other businesses to close. During Hurricane Irene and Hurricane Sandy, electric

service was down for four to eight days.⁶⁰⁸ Blackouts during Hurricane Irene affected 700,000 people, while outages during Hurricane Sandy affected 1.2 million Pennsylvanians. In 2021, Hurricane Ida left over 100,000 customers at least temporarily without power.⁶⁰⁹ Monetary losses related to Hurricane Ida were estimated to be over \$117 million in Pennsylvania.⁶¹⁰ Extreme storms temporarily disrupt energy delivery services and hurt business revenue.

Extra-tropical storms that take the form of storms have similarly challenged the state’s electricity infrastructure. Pennsylvania has an average of five major winter storms per year and has had the fifth most weather-related outages of any state from 2000 to 2021.^{611,612} A winter storm in 2022, caused a blackout affecting 100,000 people,⁶¹³ and winter storms Riley and Quinn caused 11,770 total outage cases in 2018.⁶¹⁴

Examples of the economic impacts of severe tropical storms are described in the box on the next page.

Example of economic impacts: severe tropical storms

Tropical storms have inundated Pennsylvania with heavy rains and caused record flooding. These damages have cost the Commonwealth millions of dollars and several deaths.

2021 Hurricane Season: Hurricane Ida

The remnants of Hurricane Ida hit Pennsylvania on August 31st, triggering a Presidential disaster declaration for eight counties. Over \$100 million was sustained in housing damages.⁶¹⁵ The average household in Pennsylvania received \$4,600 in assistance to recover from Hurricane Ida.⁶¹⁶

2018 Hurricane Season: Hurricane Florence and Tropical Storm Gordon

Tropical Storm Gordon dumped rain throughout PA and, on September 9th, set the record as the second-wettest day ever recorded at the Pittsburgh airport, yielding 3.73 inches of rain.⁶¹⁷ Allegheny County declared a State of Emergency due to this event. Numerous roads were closed due to high water and localized flooding.⁶¹⁸ On September 16-17, 2018, Hurricane Florence dumped three to four inches of rain along and just east of the Appalachians. Florence made 2018 the wettest year ever for Pennsylvania.⁶¹⁹

2020 Hurricane Season: Tropical Storm Isaias

In August 2020, Tropical Storm Isaias caused considerable inland flooding in PA. Estimated damage costs associated with the storm total more than \$27.6 million and two dead.^{620,621}

2011 Hurricane Season: Irene and Tropical Storm Lee

Tropical storm Lee caused considerable damage from record flooding across the Northeast. Tropical Storm Lee cost Pennsylvania \$67.9 million in flooding and landslide costs and seven deaths.^{622,623} Hurricane Irene also caused torrential rainfall and flooding across the Northeast. Separately, PennDOT estimated that Hurricane Irene cost the Department \$18.5 million in damages. Combined, \$86.4 million in public damages resulted from the 2011 hurricane season in Pennsylvania.⁶²⁴

Forest, Ecosystems, and Wildlife

Rating: 2

The evidence exploring severe storms' effect on forests, ecosystems, and wildlife is limited. Pennsylvania DCNR reports significant increases in wind damage in the state's forests and other ecosystems in recent years. Both heavy precipitation and high winds can stress trees.⁶²⁵ These stressors can make trees more susceptible to pests and disease, and ultimately cause a decline in the tree's health and lead to mortality.⁶²⁶ If this trend continues, it could lead to increasingly significant damage to natural assets that increase the time needed for habitats to recover.

Built Infrastructure

Rating: 4

Cyclones' consequences to the built infrastructure will be severe but limited. Extreme weather will exacerbate many of the consequences of flooding on infrastructure discussed in the "Precipitation and Inland Flooding" hazard section. Coastal storm surges have a massive potential to harm Pennsylvania's infrastructure systems, especially in the Philadelphia region. Storm surge flooding threatens transportation systems and water treatment facilities.

The combined effect of high winds and heavy precipitation during cyclone events also puts local electricity infrastructure at a high risk of failure or damage. High winds alone during a hurricane event have the potential to damage power plants and transmission infrastructure. As a result, communities may be left in the dark for extended periods of time after storms and may not be able to get the goods they need like natural gas or gasoline. Water treatment plants in Pennsylvania also often rely on grid electricity, and a power

outage can limit the amount of clean water available in the short-term.⁶²⁷ Even if not facing an outage, communities may experience bursts of power outages. Equipment may become unreliable as a result. Additionally, high winds can damage building materials and lower these materials' expected lifetimes.

The consequences of extreme storms will vary as counties' preparedness ranges. In Philadelphia alone, a single more intense hurricane could cost between \$20 million and \$900 million, depending on the severity of flooding and strength of wind gusts.⁶²⁸ Cyclones have the potential to result in significant damage and a complete shutdown of critical infrastructure. Overall, cyclones pose a substantial risk to the Commonwealth's built infrastructure.

Data and Projection Methods

The updated projections presented in this report are based on temperature and precipitation projections from an ensemble of 23 climate models, downscaled to a 1/16th degree grid (or approximately six km square grid) using the Localized Constructed Analogs (LOCA) method.⁶²⁹ This represents the same underlying dataset used in the Fifth National Climate Assessment.⁶³⁰

The 23 models included in the ensemble are:

- ACCESS-CM2
- ACCESS-ESM1-5
- AWI-CM-1-1-MR
- BCC-CSM2-MR
- CanESM5
- CNRM-CM6-1
- CNRM-ESM2-1
- EC-Earth3
- EC-Earth3-Veg
- MPI-ESM1-2-HR
- MRI-ESM2-0
- NorESM2-MM
- FGOALS-g3
- GFDL-CM4
- GFDL-ESM4
- HadGEM3-GC31-LL
- INM-CM4-8
- INM-CM5-0
- IPSL-CM6A-LR
- KACE-1-0-G
- MIROC6
- MPI-ESM1-2-LR
- NorESM2-LM

Projected values represent the averages over three time periods: 2016–2045 (early-century/present context), 2041–2070 (mid-century), and 2070–2099 (end-of-century).

Projected values reported represent the 50th percentile of the 23 climate models. The report and figures below also provide the 10th and 90th percentile range across models. Projected values are calculated by determining the change between modeled future and modeled baseline values and adding that change to the observed baseline. Future change is presented relative to a 1971–2000 historical baseline. All values and percentiles are calculated for each model and grid cell, then averaged across grid cells where applicable (or presented in map form).

Historical data were drawn from a 1/16th degree gridded reanalysis dataset, which uses meteorological station data across continental United States. Historical conditions represent the average over the 1971–2000 baseline.

Present context and mid-century projections assume a global “unabated” greenhouse gas representative concentration pathway where there are no new emission reduction actions (SSP 5–8.5). This

“unabated” emissions pathway is relatively similar to the “middle of the road” pathway (SSP 2–4.5) through 2050, at which point the difference between the two scenarios becomes greater. Late-century projections are provided for both a “middle of the road”-emissions pathway (SSP 2–4.5) and high-emissions pathway (SSP 5–8.5) to capture the potential range of outcomes depending on global greenhouse gas emissions over this century.

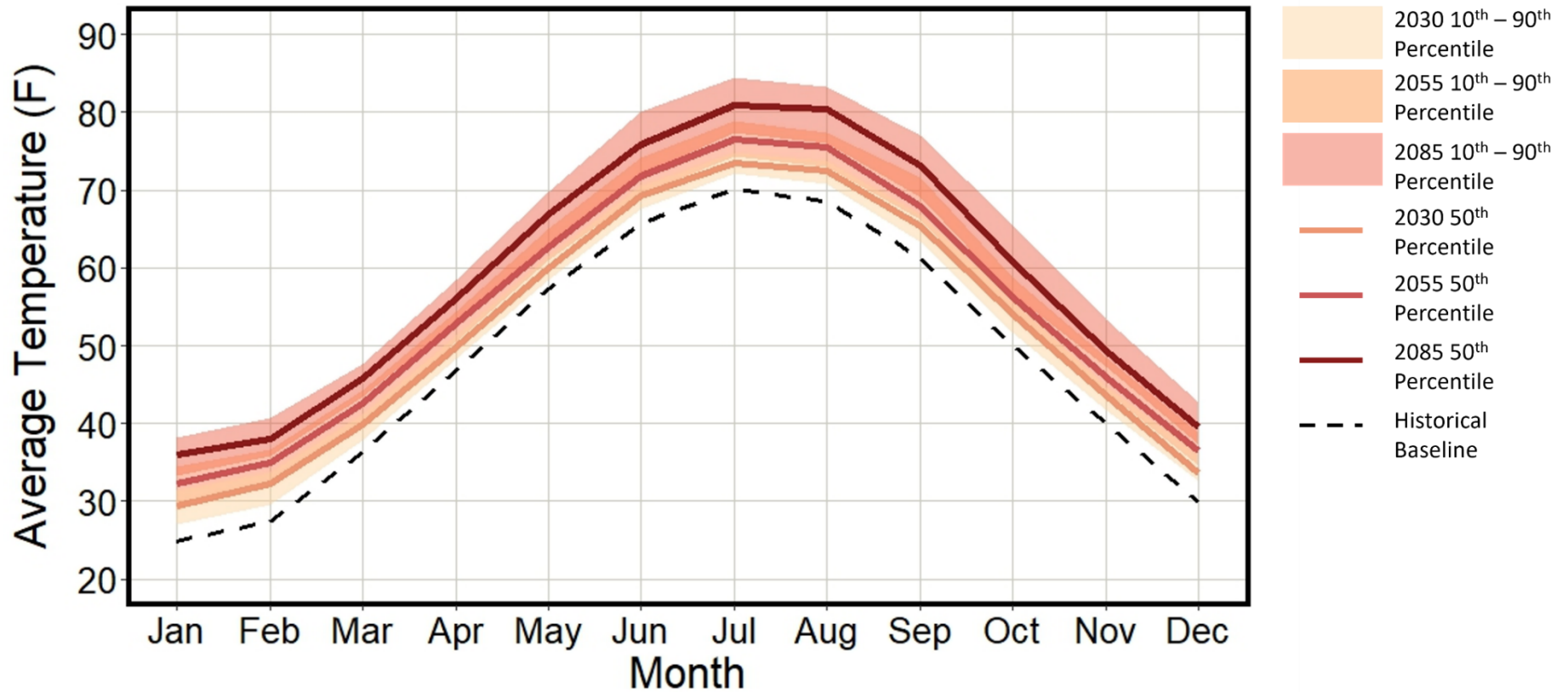
Because each value provided in this report is generated by averaging the 10th, 50th, or 90th percentile outputs from 23 models across the geography of Pennsylvania, these values are estimates of future conditions, but are not intended to be used as precise projections. Additionally, the projections may not reflect extreme scenarios that are plausible but projected by a minority of models.

The following figures and tables supplement the findings provided in the main body of the report.

Additional Projection Data

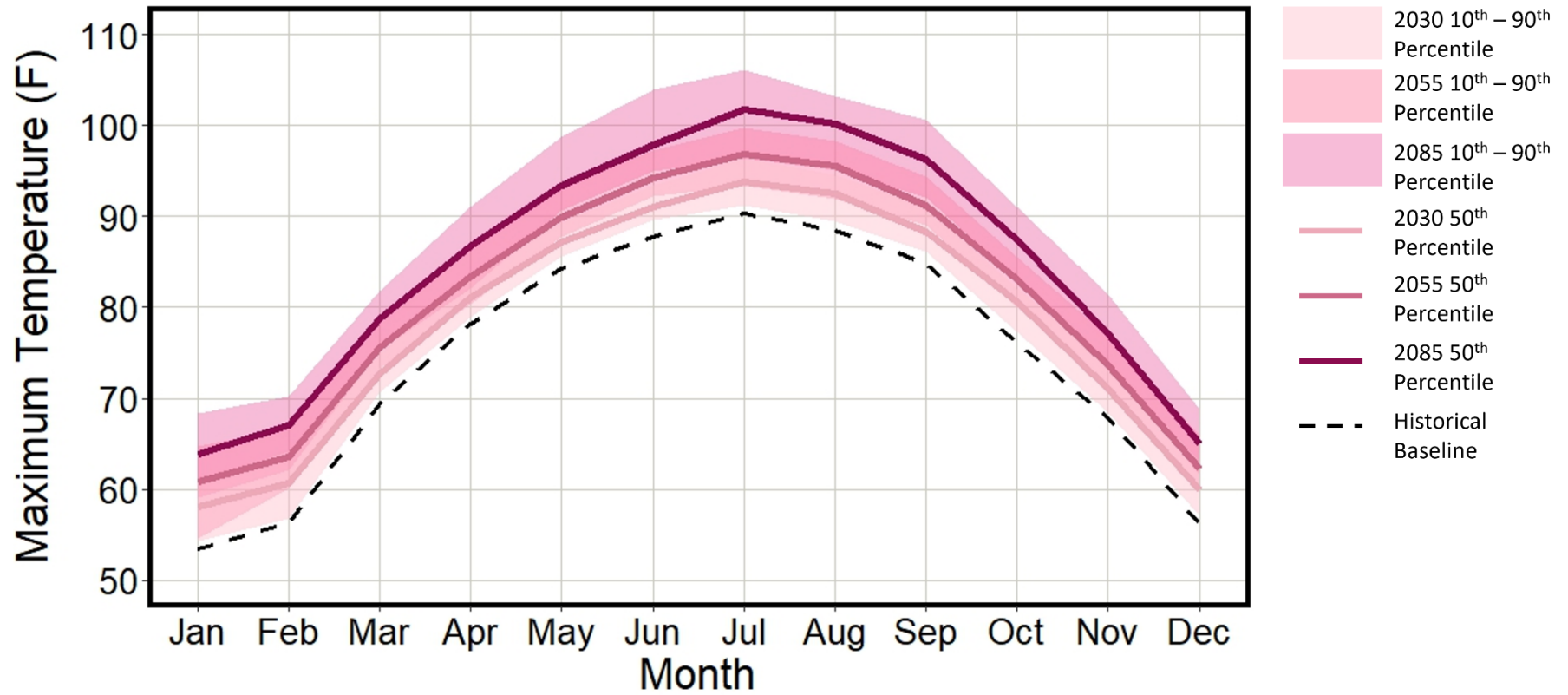
Monthly and County-Wide Temperature Projections

Figure 63. Statewide average observed and projected monthly average temperatures



Based on a 23-model ensemble of LOCA downscaled data, SSP 5-8.5. Values for 2030 represent all years 2011-2040, those for 2055 represent 2041-2070, and those for 2085 represent 2070-2099.

Figure 64. Statewide average observed and projected monthly maximum temperatures



Based on 23-model ensemble of LOCA downscaled data, SSP 5-8.5. Values for 2025 represent all years 2011-2040, those for 2055 represent 2041-2070, and those for 2085 represent 2070-2099. Values are statewide averages.

Table 24. County-wide average observed and projected annual average temperature (°F)

County	Observed	Near Term	Mid-Century	End-of-Century	County	Observed	Near Term	Mid-Century	End-of-Century	County	Observed	Near Term	Mid-Century	End-of-Century
	(1971–2000)	(2016–2040)	(2041–2070)	(2070–2099)		(1971–2000)	(2016–2040)	(2041–2070)	(2070–2099)		(1971–2000)	(2016–2040)	(2041–2070)	(2070–2099)
Adams	51.8	54.9	58.1	61.8	Elk	44.7	48.3	51.4	55.2	Montour	49.3	52.6	56.1	59.8
Allegheny	51.4	54.5	58.0	61.7	Erie	47.5	51.1	54.6	58.4	Northampton	50.4	53.7	57.0	60.5
Armstrong	48.8	52.0	55.2	59.0	Fayette	49.7	53.1	56.1	59.8	Northumberland	49.4	52.7	56.0	59.7
Beaver	50.6	53.8	57.0	60.7	Forest	45.7	49.1	52.3	56.0	Perry	50.4	53.8	56.9	60.5
Bedford	49.6	52.6	56.0	59.7	Franklin	51.5	54.7	58.2	62.0	Philadelphia	54.9	58.1	61.4	65.1
Berks	50.8	54.0	57.2	60.9	Fulton	50.1	53.1	56.3	60.0	Pike	46.7	50.0	53.4	57.1
Blair	48.4	51.6	55.1	58.9	Greene	50.2	53.6	56.5	60.2	Potter	44.4	47.8	51.1	54.9
Bradford	45.9	49.3	52.7	56.5	Huntingdon	49.8	52.8	56.2	59.9	Schuylkill	48.6	51.8	55.1	58.7
Bucks	52.2	55.4	58.6	62.1	Indiana	48.9	52.4	55.6	59.3	Snyder	49.7	52.8	56.0	59.7
Butler	48.6	51.9	55.2	58.9	Jefferson	47.1	50.5	53.8	57.5	Somerset	46.8	50.5	53.4	57.2
Cambria	47.4	50.8	54.1	58.0	Juniata	50.0	53.0	56.3	60.1	Sullivan	45.6	49.0	52.4	56.1
Cameron	45.1	48.4	51.6	55.2	Lackawanna	46.8	50.3	54.1	57.7	Susquehanna	45.4	49.1	52.2	55.9
Carbon	47.5	50.9	54.3	57.7	Lancaster	52.3	55.6	59.0	62.9	Tioga	44.5	47.8	51.1	54.9
Centre	47.6	50.9	54.1	57.9	Lawrence	49.1	52.4	55.7	59.4	Union	49.5	52.5	56.0	59.7
Chester	52.3	55.5	58.6	62.4	Lebanon	51.3	54.6	58.2	62.2	Venango	46.9	50.2	53.4	57.0
Clarion	47.3	50.6	53.7	57.4	Lehigh	50.6	53.8	57.2	60.9	Warren	45.6	49.1	52.6	56.4
Clearfield	46.6	50.1	53.4	57.1	Luzerne	47.2	50.9	54.3	57.9	Washington	50.4	53.9	56.9	60.6
Clinton	46.5	49.6	52.8	56.5	Lycoming	47.0	50.1	53.6	57.4	Wayne	44.9	48.4	52.0	55.6
Columbia	48.3	51.4	55.0	58.7	McKean	43.9	47.6	50.8	54.6	Westmoreland	49.6	53.2	56.4	60.2
Crawford	46.7	50.2	53.5	57.3	Mercer	48.4	51.8	55.3	59.1	Wyoming	46.9	50.2	53.9	57.6
Cumberland	51.6	54.8	58.4	62.1	Mifflin	49.3	52.4	55.6	59.4	York	52.4	55.8	59.1	63.0
Dauphin	51.3	54.6	58.0	61.8	Monroe	47.8	51.0	54.5	58.1					
Delaware	54.8	57.7	61.5	65.1	Montgomery	52.2	55.6	58.6	62.3					

Projections under SSP 2-4.5

Table 25. Statewide average observed and projected precipitation (SSP 2-4.5)

Precipitation Variable	Baseline (1971– 2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10th–90th Percentile)	50th Percentile Percent Change	Projected Value (10th–90th Percentile)	50th Percentile Percent Change	Projected Value (10th–90th Percentile)	50th Percentile Percent Change
Annual precipitation (inches)	42.9	45.1 (42.3 – 47.4)	6.1%	46.1 (43.0 – 48.9)	7.8%	46.3 (43.4 – 49.5)	7.9%
Days with rainfall > 3 inches (days)	0.2	0.2 (0.1 – 0.3)	40.2%	0.2 (0.1 – 0.4)	45.9%	0.2 (0.1 – 0.4)	59.0%
Annual maximum consecutive dry days (days)	12.6	12.7 (11.4 – 13.9)	0.7%	12.8 (11.5 – 14.1)	1.8%	13.1 (11.7 – 14.5)	4.0%
“Very heavy” (95 th percentile) precipitation (inches)	0.8	0.9 (0.8 – 0.9)	4.9%	0.7 (0.6 – 0.7)	7.5%	0.7 (0.6 – 0.7)	7.6%
Days with precipitation above baseline “very heavy” precipitation (days)	10.5	11.6 (10.1 – 13)	11.8%	21.0 (18.7 – 23.0)	13.2%	21.1 (19.1 – 23.4)	13.4%
“Extremely heavy” (99 th percentile) precipitation (inches)	1.4	1.5 (1.4 – 1.6)	6.8%	1.3 (1.2 – 1.4)	9.0%	1.3 (1.2 – 1.4)	10.9%
Days with precipitation above baseline “extremely heavy” precipitation (days)	2.4	3.0 (2.2 – 3.7)	25.2%	5.3 (4.2 – 6.2)	29.9%	5.6 (4.5 – 6.5)	35.9%
Annual maximum 3-day precipitation event (inches)	3.2	3.4 (3.0 – 3.8)	9.2%	3.5 (3.0 – 3.9)	9.7%	3.6 (3.1 – 4.0)	12.6%

Note: Projections are based a 23-model ensemble of LOCA downscaled data, SSP 2-4.5. Values reported are the median for the 23-model ensemble, as well as the 10th and 90th percentile values across models.

Table 26. Statewide average observed and projected temperature variables (SSP 2-4.5)

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Average annual temperature (°F)	48.3	51.7 (50.6 – 52.7)	3.4	53.5 (51.8 – 54.9)	5.2	54.6 (52.9 – 56.4)	6.3
Average annual minimum temperature (°F)	37.6	41.0 (39.9 – 42.2)	3.2	64.4 (62.3 – 65.5)	5.5	65.3 (63.4 – 67.1)	6.4
Average annual maximum temperature (°F)	59	62.4 (61.2 – 63.5)	3.6	42.6 (41.2 – 44.2)	4.9	43.8 (42.2 – 45.9)	6.1
Heating degree days (degree days)	5,569.1	4,649.2 (4,649.7 – 5,083.8)	-919.9	5,189.2 (4,804.3 – 5,486.6)	-1,313.9	4,902.7 (4,303.9 – 5,268.8)	-1,600.4
Cooling degree days (degree days)	1,096.4	1,416.4 (1,271.3 – 1,559.0)	320	974.9 (768.9 – 1,193.6)	496.6	1,162.3 (859.4 – 1,399.4)	684.0
“Very hot” (95th percentile) temperature (°F)	85.2	88.8 (87.1 – 91.0)	3.2	90.1 (88.1 – 92.7)	4.9	91.8 (88.9 – 94.4)	6.6
Days with temperature above “very hot” baseline temperature (°F)	19.6	42.9 (30.6 – 56.5)	22.0	56.0 (37.7 – 71.8)	36.6	67.8 (43.8 – 88.4)	48.3
“Extremely hot” (99th percentile) temperature(°F)	89	92.8 (91.2 – 94.8)	3.4	94.0 (92.0 – 97.2)	5.1	95.8 (93.0 – 98.3)	6.8
Days above baseline “extremely hot” temperature	6.2	19.5 (11.9 – 30.6)	9.9	25.0 (14.8 – 41.8)	19.2	35.9 (18.5 – 55.0)	30.1
Days with temperature >90°F	6.1	18.6 (11.3 – 28.5)	9.9	23.0 (14.2 – 37.6)	18.0	33.6 (17.9 – 50.3)	28.5
Days with temperature >95°F	0.8	4.3 (1.9 – 7.6)	2.5	5.8 (2.7 – 12.9)	5.2	10.0 (3.7 – 19.2)	9.4
Days with temperature >100°F	0.0	0.5 (0.1 – 1.0)	0.4	0.9 (0.2 – 2.3)	0.9	1.7 (0.4 – 4.2)	1.7
Days with low temperature > 68°F	4.9	12.9 (8.9 – 17.4)	7.5	17.8 (10.9 – 25)	14.1	23.8 (14.1 – 34.1)	20.1
Consecutive days above 90°F	2.4	5.2 (3.5 – 7.6)	2.3	6.1 (4.3 – 11.1)	3.9	8.3 (5.3 – 13.5)	6.0

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Consecutive days above 95°F	0.4	1.7 (0.8 – 2.8)	1.1	2.3 (1.2 – 4.9)	1.9	3.3 (1.6 – 5.8)	2.9
Growing degree days (degree days)	1,375.6	1,716.3 (1,578.2 – 1,862.1)	340.7	3,429.0 (3,116.3 – 3,662.4)	696.6	3,632.4 (3,279.6 – 3,932)	899.9

Projections under SSP 5–8.5

Table 27. Statewide average observed and projected precipitation variables (SSP 5–8.5)

Precipitation Variable	Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change
Annual precipitation (inches)	42.9	44.8 (41.8 – 47.3)	5.4%	46.8 (43.4 – 49.3)	9.0%	48.3 (44.2 – 51.0)	12.5%
Days with rainfall > 3 inches (days)	0.2	0.2 (0.1 – 0.3)	37.9%	0.2 (0.1 – 0.4)	60.7%	0.3 (0.1 – 0.5)	97.4%
Annual maximum consecutive dry days (days)	12.6	12.8 (11.5 – 14.1)	2.6%	12.9 (11.6 – 14.1)	3.0%	13.5 (11.9 – 15.0)	7.7%
“Very heavy” (95 th percentile) precipitation (inches)	0.8	0.9 (0.8 – 0.9)	5.3%	0.9 (0.9 – 1.0)	9.1%	1.0 (0.9 – 1.0)	15.1%
Days with precipitation above baseline “very heavy” precipitation (days)	10.5	11.7 (10.2 – 13.1)	12.5%	12.7 (10.7 – 14.0)	21.1%	13.9 (11.7 – 15.5)	32.9%
“Extremely heavy” (99 th percentile) precipitation (inches)	1.4	1.5 (1.4 – 1.6)	7.1%	1.6 (1.5 – 1.7)	11.3%	1.7 (1.5 – 1.8)	18.7%

Precipitation Variable	Baseline (1971– 2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Percent Change
Days with precipitation above baseline “extremely heavy” precipitation (days)	2.4	3.0 (2.3 – 3.7)	26.1%	3.5 (2.6 – 4.3)	43.4%	4.2 (3.0 – 5.2)	74.0%
Annual maximum 3-day precipitation event (inches)	3.2	3.4 (3.0 – 3.8)	8.2%	3.6 (3.1 – 4.0)	12.8%	3.8 (3.3 – 4.2)	19.91%

Note: Projections are based a 23-model ensemble of LOCA downscaled data, SSP 5–8.5. Values reported are the median for the 23-model ensemble, as well as the 10th and 90th percentile values across models.

Table 28. Statewide average observed and projected temperature variables (SSP 5–8.5)

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Average annual temperature (°F)	48.3	52.0 (50.7 – 53.3)	3.7	54.9 (53.1 – 56.6)	6.6	58.7 (56.0 – 61.6)	10.4
Average annual minimum temperature (°F)	37.6	41.4 (40.2 – 42.7)	3.7	44.0 (42.6 – 45.9)	6.7	47.6 (45.5 – 51.0)	10.5
Average annual maximum temperature (°F)	59.0	62.6 (61.2 – 63.8)	3.7	65.7 (63.7 – 67.2)	6.4	69.5 (66.4 – 72.2)	10.0
Heating degree days (degree days)	5,569.1	4,830.5 (4,578.9 – 5,060.9)	-738.6	4,830.8 (4,425.1 – 5,217.7)	-1,672.3	4,137 (3,389.9 – 4,440.0)	-2,366.1
Cooling degree days (degree days)	1,096.4	1,446.2 (1,283.3 – 1,592.5)	349.8	1,194.7 (910.5 – 1,460.0)	716.4	1,843.7 (1,266.7 – 2,331.3)	1,365.5
“Very hot” (95th percentile) temperature (°F)	85.2	88.9 (87.1 – 90.8)	3.5	92 (89.0 – 94.9)	6.8	96.5 (92.3 – 100.3)	11.3
Days with temperature above “very hot” baseline temperature (°F)	19.6	44.9 (32.5 – 57.5)	25.1	70.6 (46.6 – 86.8)	49.8	104.8 (68.4 – 129.4)	83.9
“Extremely hot” (99th percentile) temperature(°F)	89.0	92.6 (90.5 – 94.8)	3.6	95.9 (92.8 – 98.5)	6.9	100.6 (96.1 – 104.4)	11.6
Days above baseline “extremely hot” temperature	6.2	19.5 (10.7 – 29.7)	11.8	38.0 (20.0 – 57.0)	30.9	74.8 (39.8 – 102.6)	67.3
Days with temperature >90°F	6.1	18.5 (10.9 – 27.4)	11.2	35.9 (18.7 – 52.5)	30.4	69.8 (36.7 – 97.2)	63.9
Days with temperature >95°F	0.8	4.1 (1.4 – 7.4)	2.8	11.2 (4.1 – 20.6)	10.6	33.6 (11.4 – 58.3)	32.8
Days with temperature >100°F	0.0	0.5 (0.1 – 1.0)	0.4	2.0 (0.4 – 4.3)	2.1	9.8 (2.1 – 24.2)	9.9

Temperature Variable	Observed Baseline (1971–2000)	Near Term (2016–2040)		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change	Projected Value (10 th –90 th Percentile)	50 th Percentile Absolute Change
Days with low temperature > 68°F	4.9	13.7 (9.4 – 18.1)	8.6	25.7 (16.4 – 35.6)	23.2	54.6 (31.0 – 78.8)	51.5
Consecutive days above 90°F	2.3	5.1 (3.1 – 7.4)	2.6	8.8 (5.3 – 15.2)	6.5	19.3 (9.1 – 36.8)	17.0
Consecutive days above 95°F	0.4	1.6 (0.6 – 2.8)	1.1	3.4 (1.7 – 6.2)	3.0	8.3 (3.7 – 16.3)	7.9
Growing degree days (degree days)	1,375.6	1,754.3 (1,593.4 – 1,904.2)	378.7	3,687.7 (3,316.6 – 3,916.7)	920.3	4,282.8 (3,656.4 – 4,771.8)	1,565.8

Endnotes

¹ Rebekah Frankson et al., “Pennsylvania State Climate Summary 2022,” NOAA Technical Report NESDIS 150-PA (NOAA/NESDIS, 2022), <https://statesummaries.ncics.org/chapter/pa>.

² The White House, “Justice40: A Whole of Government Initiative” (Washington, DC: Accessed March 2024), <https://www.whitehouse.gov/environmentaljustice/justice40/>.

³ NWS, “Climatological Report (monthly),” (January 1, 2024), <https://forecast.weather.gov/product.php?site=CTP&issuedby=MDT&product=CLM&format=CI&version=4&glossary=0>

⁴ NASA Earth Observatory, “Weather Whiplash,” (NASA, January 4, 2023), <https://earthobservatory.nasa.gov/images/150797/weather-whiplash>.

⁵ Days above 90, 95, 100, 105°F are days when the daily high temperature reaches or exceeds those thresholds.

⁶ Matthew C. Fitzpatrick and Robert R. Dunn, “Contemporary Climatic Analogs for 540 North American Urban Areas in the Late 21st Century,” *Nature Communications*, 10, no. 1: (February 12, 2019) 61, <https://doi.org/10.1038/s41467-019-08540-3>.

⁷ “Units and Calculators Explained: Degree-Days,” U.S. Energy Information Administration (EIA), (August 2023), <https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php>

⁸ Pennsylvania Emergency Management Agency (PEMA), “Commonwealth of Pennsylvania: 2023 Hazard Mitigation Plan”, (PEMA, 2023), <https://www.pema.pa.gov/Mitigation/Planning/Documents/2023%20Hazard%20Mitigation%20Plan.pdf>

⁹ Zachary Curtis, Brittany Clark, and Zachary Larson, “Understanding Growing Degree Days,” PennState Extension (February 14, 2023), <https://extension.psu.edu/understanding-growing-degree-days>.

¹⁰ USDA. Office of Sustainability and Climate, “App: Climate Change Pressures in the 21st Century,” (ArcGIS StoryMaps, July 26, 2022), <https://storymaps.arcgis.com/stories/9ee0cc0a070c409cbde0e3a1d87a487c>.

¹¹ Tania Lopez-Cantu, Andreas F. Prein, and Constantine Samaras, “Uncertainties in Future U.S. Extreme Precipitation From Downscaled Climate Projections,” *Geophysical Research Letters* 47, no. 9 (2020): e2019GL086797, <https://doi.org/10.1029/2019GL086797>.

¹² Jared W. Oyler and Robert E. Nicholas, “Time of Observation Adjustments to Daily Station Precipitation May Introduce Undesired Statistical Issues,” *International Journal of Climatology* 38, no. S1 (2018): e364–77, <https://doi.org/10.1002/joc.5377>.

¹³ PEMA. Landslide. Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan. (PEMA: 2023), Retrieved from: <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>

¹⁴ Pennsylvania Department of Environmental Protection, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP: April 2020), <https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

¹⁵ National Centers for Environmental Information, “Climate at a Glance Statewide Time Series,” n.d., <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series>.

¹⁶ National Centers for Environmental Information, “Climate at a Glance Statewide Time Series,” n.d., <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series>.

¹⁷ PA DEP, “Pennsylvania Climate Impacts Assessment 2021,” (Pennsylvania Department of Environmental Protection, May 2021), <https://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=3667348&DocName=PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%202021.PDF>.

- ¹⁸ James Shortle et al., “Pennsylvania Climate Impacts Assessment,” (Pennsylvania Department of Environmental Protection, June 29, 2009), [https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252\[1\].pdf](https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252[1].pdf).
- ¹⁹ Andrew Ross et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania Department of Environmental Protection, October 2013), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=6806&DocName=PA%20DEP%20CLIMATE%20IMPACT%20ASSESSMENT%20UPDATE.PDF>.
- ²⁰ James Shortle et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania State University, May 2015), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF>.
- ²¹ James Shortle et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania State University, May 2015), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF>.
- ²² Andrew Ross et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania Department of Environmental Protection, October 2013), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=6806&DocName=PA%20DEP%20CLIMATE%20IMPACT%20ASSESSMENT%20UPDATE.PDF>.
- ²³ Kunkel, K.E., et al., “Incorporation of the Effects of Future Anthropogenically Forced Climate Change in Intensity–Duration–Frequency Design Values: Final Report,” North Carolina Institute for Climate Studies, (North Carolina State University, 2020).
- ²⁴ Kyle Imhoff, “Heavy Rain Events in Pennsylvania, Appendix A,” Research completed by Kyle Imhoff, Pennsylvania State Climatologist, Penn State University and analyzed by Jeff Jumper, State Meteorologist, Pennsylvania Emergency Management Agency.
- ²⁵ Pennsylvania Department of Transportation (PennDOT) and Michael Baker International, “Phase 1: PennDOT Extreme Weather Vulnerability Study,” (PennDOT, April 2017), <http://s3.amazonaws.com/tmp-map/climate/doc/StudyReport-PaVulnerabilityStudy-ver040317.pdf>.
- ²⁶ S. Westra et al., “Future Changes to the Intensity and Frequency of Short-Duration Extreme Rainfall,” *Reviews of Geophysics* 52, no. 3 (2014): 522–55, <https://doi.org/10.1002/2014RG000464>.
- ²⁷ Elizabeth J. Kendon et al., “Heavier Summer Downpours with Climate Change Revealed by Weather Forecast Resolution Model,” *Nature Climate Change* 4, no. 7 (July 2014): 570–76, <https://doi.org/10.1038/nclimate2258>.
- ²⁸ Andreas F. Prein et al., “The Future Intensification of Hourly Precipitation Extremes,” *Nature Climate Change* 7, no. 1 (January 2017): 48–52, <https://doi.org/10.1038/nclimate3168>.
- ²⁹ Bernice Rosenzweig et al., “Developing Knowledge Systems for Urban Resilience to Cloudburst Rain Events,” *Environmental Science & Policy* 99 (September 1, 2019): 150–59, <https://doi.org/10.1016/j.envsci.2019.05.020>.
- ³⁰ S. Westra et al., “Future Changes to the Intensity and Frequency of Short-Duration Extreme Rainfall,” *Reviews of Geophysics* 52, no. 3 (2014): 522–55, <https://doi.org/10.1002/2014RG000464>.
- ³¹ PEMA “Flood, Flash Flood, Ice Jam,” in *Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan*, (PEMA 2023), <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>
- ³² PEMA, “Flood, Flash Flood, Ice Jam,” (PEMA, 2023).
- ³³ Payton, E.A., A.O. Pinson, T. Asefa, L.E. Condon, L.-A.L. Dupigny-Giroux, B.L. Harding, J. Kiang, D.H. Lee, S.A. McAfee, J.M. Pflug, I. Rangwala, H.J. Tanana, and D.B. Wright, “Ch. 4. Water,” In: *Fifth National Climate Assessment*. Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. (U.S. Global Change Research Program, Washington, DC, USA, 2023), <https://doi.org/10.7930/NCA5.2023.CH4>
- ³⁴ James Shortle et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania State University, May 2015), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF>.
- ³⁵ Andrew Ross et al., “Pennsylvania Climate Impacts Assessment Update,” (Pennsylvania Department of Environmental Protection, October 2013), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=6806&DocName=PA%20DEP%20CLIMATE%20IMPACT%20ASSESSMENT%20UPDATE.PDF>.
- ³⁶ National Centers for Environmental Information, “Climate at a Glance Statewide Time Series,” n.d., <https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series>.
- ³⁷ National Centers for Environmental Information, “Climate at a Glance Statewide Time Series,” n.d.,

<https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/statewide/time-series>.

³⁸ James Shortle et al., "Pennsylvania Climate Impacts Assessment Update," (Pennsylvania State University, May 2015), <http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF>.

³⁹ ABC News, "Flooding Leaves Part of Philadelphia's Penn's Landing under Water; I-95 Exit Closed," 6abc Philadelphia, (October 29, 2021), <https://6abc.com/delaware-river-flooding-flood-waters-tidal-philadelphia-high-water/11181144/>.

⁴⁰ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁴¹ U.S. Army Corps of Engineers (USACE), "Sea Level Tracker," n.d., https://climate.sec.usace.army.mil/slr_app/.

⁴² City of Philadelphia, Office of Sustainability, Staff expertise (January 2024).

⁴³ NASA, "Projected Flooding | Flooding Analysis Tool," NASA Sea Level Change Team, n.d., <https://sealevel.nasa.gov/flooding-analysis-tool/projected-flooding>.

⁴⁴ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁴⁵ Climate Central, "Pennsylvania and the Surging Sea," in *Surging Seas: Sea level rise analysis by Climate Central*, n.d., <https://sealevel.climatecentral.org/research/reports/pennsylvania-and-the-surging-sea>.

⁴⁶ NOAA, "Sea Level Rise in Philadelphia County, PA | NOAA Coastal County Snapshots," National Oceanic and Atmospheric Administration (NOAA), n.d., <https://coast.noaa.gov/snapshots>.

⁴⁷ Climate Central, "Pennsylvania and the Surging Sea," in *Surging Seas: Sea level rise analysis by Climate Central*, n.d., <https://sealevel.climatecentral.org/research/reports/pennsylvania-and-the-surging-sea>.

⁴⁸ Drew Gronewold and Richard B. Rood, "Climate Change Sends Great Lakes Water Levels Seesawing," (Scientific American, June 8, 2019), <https://www.scientificamerican.com/article/climate-change-sends-great-lakes-water-levels-seesawing/>.

⁴⁹ Anthony M. Foyle, "The Lake Erie Bluff Coast of Pennsylvania: A State of Knowledge Report on Coastal Change Patterns, Processes, and Management," (Pennsylvania Great Lakes WALTeR, January 2018), <https://pawalter.psu.edu/sites/default/files/resources/SOK%20Complete%20Report%20Final%20%282018%29.pdf>.

⁵⁰ Drew Gronewold and Richard B. Rood, "Climate Change Sends Great Lakes Water Levels Seesawing," (Scientific American, June 8, 2019), <https://www.scientificamerican.com/article/climate-change-sends-great-lakes-water-levels-seesawing/>.

⁵¹ USACE, "Lake Erie Water Levels," (U.S. Army Corps of Engineers (USACE), accessed September 15, 2023), <https://lre-wm.usace.army.mil/ForecastData/BulletinGraphics/MBOGLWL-erie.pdf>.

⁵² PA DEP, "What Are HABs?" <https://www.dep.pa.gov:443/Business/Water/HABs/Pages>.

⁵³ Pengfei Xue et al., "Climate Projections over the Great Lakes Region: Using Two-Way Coupling of a Regional Climate Model with a 3-D Lake Model," *Geoscientific Model Development* 15, no. 11 (June 9, 2022): 4425–46, <https://doi.org/10.5194/gmd-15-4425-2022>.

⁵⁴ Aidin Jabbari et al., "Increases in Great Lake Winds and Extreme Events Facilitate Interbasin Coupling and Reduce Water Quality in Lake Erie," *Scientific Reports* 11, no. 1 (March 11, 2021): 5733, <https://doi.org/10.1038/s41598-021-84961-9>.

⁵⁵ Donald Scavia et al., "St. Clair-Detroit River System: Phosphorus Mass Balance and Implications for Lake Erie Load Reduction, Monitoring, and Climate Change," *Journal of Great Lakes Research* 45, no. 1 (February 1, 2019): 40–49, <https://doi.org/10.1016/j.jglr.2018.11.008>.

⁵⁶ PA DEP, "What Are HABs?" <https://www.dep.pa.gov:443/Business/Water/HABs/Pages>.

⁵⁷ Decker, Tom, "Lake Erie Bluffs and the Effects of Erosion," (PA DEP, 2022), <https://www.dep.pa.gov/OurCommonWealth/Pages/Article.aspx?post=101>.

⁵⁸ Buckler, Kathleen, "Presque Isle Spring Beach Walk Shows Significant Erosion," (USACE, 2016), <https://www.lrb.usace.army.mil/Media/News-Stories/Article/710731/presque-isle-spring-beach-walk-shows-significant-erosion/>.

⁵⁹ Foyle, "The Lake Erie Bluff Coast of Pennsylvania: A State of Knowledge Report on Coastal Change Patterns, Processes, and Management."

⁶⁰ Tom Di Liberto, "The paradox of lake effect snow: global warming could bring the Great Lakes more of it, at least for a while | NOAA Climate.gov," (NOAA Climate.gov,

January 11, 2017), <http://www.climate.gov/news-features/event-tracker/paradox-lake-effect-snow-global-warming-could-bring-great-lakes-more-it>.

⁶¹ As air temperatures increase, the cold air that drives the lake-effect will also warm. As a result, in the long-term, lake-effect snow events have the potential to decrease in frequency.

⁶² C. M. Zarzycki, "Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms," *Geophysical Research Letters* 45, no. 21 (2018): 12,067–12,075, <https://doi.org/10.1029/2018GLO79820>.

⁶³ Thomas Knutson et al., "Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming," *Bulletin of the American Meteorological Society* 101, no. 3 (March 1, 2020): E303–22, <https://doi.org/10.1175/BAMS-D-18-0194.1>.

⁶⁴ Thomas Knutson et al., "Tropical Cyclones and Climate Change Assessment: Part II: Projected Response to Anthropogenic Warming," *Bulletin of the American Meteorological Society* 101, no. 3 (March 1, 2020): E303–22, <https://doi.org/10.1175/BAMS-D-18-0194.1>.

⁶⁵ James Shortle et al., "Pennsylvania Climate Impacts Assessment," (Pennsylvania Department of Environmental Protection, June 29, 2009), [https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252\[1\].pdf](https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252[1].pdf).

⁶⁶ C. M. Zarzycki, "Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms," *Geophysical Research Letters* 45, no. 21 (2018): 12,067–12,075, <https://doi.org/10.1029/2018GLO79820>.

⁶⁷ Walker S. Ashley, Alex M. Haberlie, and Vittorio A. Gensini, "Reduced Frequency and Size of Late-Twenty-First-Century Snowstorms over North America," *Nature Climate Change* 10, no. 6 (June 2020): 539–44, <https://doi.org/10.1038/s41558-020-0774-4>.

⁶⁸ C. M. Zarzycki, "Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms," *Geophysical Research Letters* 45, no. 21 (2018): 12,067–12,075, <https://doi.org/10.1029/2018GLO79820>

⁶⁹ C. M. Zarzycki, "Projecting Changes in Societally Impactful Northeastern U.S. Snowstorms," *Geophysical Research Letters* 45, no. 21 (2018): 12,067–12,075, <https://doi.org/10.1029/2018GLO79820>.

⁷⁰ City of Philadelphia, Office of Sustainability, Staff expertise, January 2024.

⁷¹ Tom Di Liberto, "The paradox of lake effect snow: global warming could bring the Great Lakes more of it, at least for a while | NOAA Climate.gov," (NOAA Climate.gov, January 11, 2017), <http://www.climate.gov/news-features/event-tracker/paradox-lake-effect-snow-global-warming-could-bring-great-lakes-more-it>.

⁷² Kenneth E. Kunkel, Nancy E. Westcott, and David A. R. Kristovich, "Assessment of Potential Effects of Climate Change on Heavy Lake-Effect Snowstorms Near Lake Erie," *Journal of Great Lakes Research* 28, no. 4 (January 1, 2002): 521–36, [https://doi.org/10.1016/S0380-1330\(02\)70603-5](https://doi.org/10.1016/S0380-1330(02)70603-5).

⁷³ Tom Di Liberto, "The paradox of lake effect snow: global warming could bring the Great Lakes more of it, at least for a while | NOAA Climate.gov," (NOAA Climate.gov, January 11, 2017), <http://www.climate.gov/news-features/event-tracker/paradox-lake-effect-snow-global-warming-could-bring-great-lakes-more-it>.

⁷⁴ Kunkel, Westcott, and Kristovich, "Assessment of Potential Effects of Climate Change on Heavy Lake-Effect Snowstorms Near Lake Erie."

⁷⁵ Pennsylvania Department of Conservation and Natural Resources Bureau of Geological Survey, "Landslides," (PA DEP, 2020), <https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/>

⁷⁶ Gariano, S. L. and F. Guzzetti, "Landslides in a changing climate," *Earth-Science Reviews*, 162 (2016), p. 227–252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁷⁷ Haque, U, et al., "The human cost of global warming: Deadly landslides and their triggers (1995–2014)". *Science of the Total Environment* (2019), <https://doi.org/10.1016/j.scitotenv.2019.03.415>

⁷⁸ Gariano, S. L. and F. Guzzetti, "Landslides in a changing climate," *Earth-Science Reviews*, 162 (2016), p. 227–252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁷⁹ Wood NJ, Doctor DH, et al., "Current and future sinkhole susceptibility in karst and pseudokarst areas of the conterminous United States". *Front. Earth Sci* (2023), <https://doi.org/10.3389/feart.2023.1207689>

⁸⁰ Gutiérrez, F., "Sinkhole Hazards," Oxford Research Encyclopedia of Natural Hazard Science (2016), <https://oxfordre.com/naturalhazardscience/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-40>.

⁸¹ PA DEP, "Sinkholes", <https://www.dep.pa.gov/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx>

⁸² Wood NJ, Doctor DH, et al., "Current and future sinkhole susceptibility in karst and pseudokarst areas of the conterminous United States". *Front. Earth Sci* (2023), <https://doi.org/10.3389/feart.2023.1207689>

⁸³ Gutiérrez, F., "Sinkhole Hazards," Oxford Research Encyclopedia of Natural Hazard Science (2016),

<https://oxfordre.com/naturalhazardscience/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-40>.

⁸⁴ PA DEP, "Sinkholes", <https://www.dep.pa.gov/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx>

⁸⁵ Wood NJ, Doctor DH, et al., "Current and future sinkhole susceptibility in karst and pseudokarst areas of the conterminous United States". *Front. Earth Sci* (2023), <https://doi.org/10.3389/feart.2023.1207689>

⁸⁶ Gutiérrez, F., "Sinkhole Hazards," Oxford Research Encyclopedia of Natural Hazard Science (2016), <https://oxfordre.com/naturalhazardscience/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-40>.

⁸⁷ PA DEP, "What Causes a Sinkhole," Accessed November 22, 2023, <https://www.dep.pa.gov:443/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx>.

⁸⁸ Stephen Ornes, "How Does Climate Change Influence Extreme Weather? Impact Attribution Research Seeks Answers," *Proceedings of the National Academy of Sciences* 115, no. 33 (August 14, 2018): 8232–35, <https://doi.org/10.1073/pnas.1811393115>.

⁸⁹ Jonathan Haskett, "Is That Climate Change? The Science of Extreme Event Attribution," (Congressional Research Service, June 1, 2023), <https://crsreports.congress.gov/product/pdf/R/R47583>.

⁹⁰ Kevin E. Trenberth, John T. Fasullo, and Theodore G. Shepherd, "Attribution of Climate Extreme Events," *Nature Climate Change* 5, no. 8 (August 2015): 725–30, <https://doi.org/10.1038/nclimate2657>.

⁹¹ Jonathan Haskett, "Is That Climate Change? The Science of Extreme Event Attribution," (Congressional Research Service, June 1, 2023), <https://crsreports.congress.gov/product/pdf/R/R47583>.

⁹² Stephen Ornes, "How Does Climate Change Influence Extreme Weather? Impact Attribution Research Seeks Answers," *Proceedings of the National Academy of Sciences* 115, no. 33 (August 14, 2018): 8232–35, <https://doi.org/10.1073/pnas.1811393115>.

⁹³ Jonathan Haskett, "Is That Climate Change? The Science of Extreme Event Attribution," (Congressional Research Service, June 1, 2023), <https://crsreports.congress.gov/product/pdf/R/R47583>.

⁹⁴ Cheng Qian et al., "An Updated Review of Event Attribution Approaches," *Journal of Meteorological Research* 36, no. 2 (April 1, 2022): 227–38, <https://doi.org/10.1007/s13351-022-1192-5>.

⁹⁵ Laura García-Portela and Douglas Maraun, "Overstating the Effects of Anthropogenic Climate Change? A Critical Assessment of Attribution Methods

in *Climate Science*," *European Journal for Philosophy of Science* 13, no. 1 (2023): 17, <https://doi.org/10.1007/s13194-023-00516-x>.

⁹⁶ Jonathan Haskett, "Is That Climate Change? The Science of Extreme Event Attribution," (Congressional Research Service, June 1, 2023), <https://crsreports.congress.gov/product/pdf/R/R47583>.

⁹⁷ Stephen Ornes, "How Does Climate Change Influence Extreme Weather? Impact Attribution Research Seeks Answers," *Proceedings of the National Academy of Sciences* 115, no. 33 (August 14, 2018): 8232–35, <https://doi.org/10.1073/pnas.1811393115>.

⁹⁸ M. Zachariah et al., "Extreme Heat in North America, Europe and China in July 2023 Made Much More Likely by Climate Change," (Report, July 25, 2023), <https://doi.org/10.25561/105549>.

⁹⁹ Climate Central, "Climate Shift Index," (Climate Central, accessed September 27, 2023), <https://www.climatecentral.org/tools/climate-shift-index>.

¹⁰⁰ Climate Central, "Climate Shift Index," (Climate Central, accessed September 27, 2023), <https://www.climatecentral.org/tools/climate-shift-index>.

¹⁰¹ Sanjib Sharma et al., "Regional Flood Risk Projections under Climate Change," *Journal of Hydrometeorology*, June 17, 2021, <https://doi.org/10.1175/JHM-D-20-0238.1>.

¹⁰² Pennsylvania Bureau of Forestry, "2022 Annual Report: Wildland Fire Program", <https://www.dcnr.pa.gov/Communities/Wildfire/Pages/default.aspx>

¹⁰³ Pennsylvania Bureau of Forestry, "Pennsylvania Wildfire Statistics 1913–2022," <https://www.dcnr.pa.gov/Communities/Wildfire/Pages/default.aspx>

¹⁰⁴ M. Zachariah et al., "Extreme Heat in North America, Europe and China in July 2023 Made Much More Likely by Climate Change," (Report, July 25, 2023), <https://doi.org/10.25561/105549>.

¹⁰⁵ Eisenman, D. and Galway, L., "The mental health and well-being effects of wildfire smoke: a scoping review," (BMC Public Health, 2022), doi: 10.1186/s12889-022-14662-z

¹⁰⁶ Carlyn J. Matz et al., "Health Impact Analysis of PM2.5 from Wildfire Smoke in Canada (2013–2015, 2017–2018)," *Science of The Total Environment* 725 (July 2020): 138506, <https://doi.org/10.1016/j.scitotenv.2020.138506>.

¹⁰⁷ B. Ford et al., "Future Fire Impacts on Smoke Concentrations, Visibility, and Health in the Contiguous United States," *GeoHealth* 2, no. 8 (August 2018): 229–47, <https://doi.org/10.1029/2018GH000144>.

- ¹⁰⁸ Kim, et al., “National Health Statistics Report,” (CDC, April 2021), <https://www.cdc.gov/nchs/data/nhsr/nhsr154-508.pdf>
- ¹⁰⁹ Bhatia, A. and Choi-Schagrin, W., “Why Record-Breaking Overnight Temperatures Are So Concerning,” (New York Times, 2021), <https://www.nytimes.com/2021/07/09/upshot/record-breaking-hot-weather-at-night-deaths.html>
- ¹¹⁰ Sharpe, J. Danielle, and Amy F. Wolkin, “The Epidemiology and Geographic Patterns of Natural Disaster and Extreme Weather Mortality by Race and Ethnicity, United States, 1999–2018,” *Public Health Reports* 137, no. 6 (November 2022): 1118–25.
- ¹¹¹ Updated climate projections are based on the latest available science described in Chapter 2.
- ¹¹² National Centers for Environmental Information, “Storm Events Database,” (NOAA, accessed October 17, 2023), <https://www.ncdc.noaa.gov/stormevents/>.
- ¹¹³ CDC, “Flood Waters or Standing Waters” in *Water, Sanitation, & Hygiene (WASH)-related Emergencies & Outbreaks*, (Center for Disease Control and Prevention, updated November 30, 2022). <https://www.cdc.gov/healthywater/emergency/extreme-weather/floods-standingwater.html>.
- ¹¹⁴ Nikunj Makwana, “Disaster and its impact on mental health: A narrative review,” *Journal of Family Medicine and Primary Care* 8, no. 10 (October 31, 2019): 3090 – 3095, https://doi.org/10.4103/jfmpc.jfmpc_893_19.
- ¹¹⁵ Weiwei Du et al., “Health impacts of floods,” *Prehospital and Disaster Medicine*, 25, no. 3 (June, 2010): 265 – 272. <https://doi.org/20586021/>
- ¹¹⁶ CDC, “Floodwater After a Disaster or Emergency,” in *Natural Disasters and Severe Weather*, (Centers for Disease Control and Prevention, updated August 30, 2023), <https://www.cdc.gov/disasters/floods/floodsafety.html>.
- ¹¹⁷ Paterson, David L, Hugh Wright, and Patrick N A Harris, “Health Risks of Flood Disasters,” *Clinical Infectious Diseases* 67, no. 9 (October 15, 2018): 1450–54, <https://doi.org/10.1093/cid/ciy227>.
- ¹¹⁸ Lynch, Victoria D., and Jeffrey Shaman, “Waterborne Infectious Diseases Associated with Exposure to Tropical Cyclonic Storms, United States, 1996–2018,” *Emerging Infectious Diseases Journal* 29, no. 8 (August 2023), <https://doi.org/10.3201/eid2908.221906>.
- ¹¹⁹ Lydersen, Kari, et al., “Cracking down on coal ash: Tough talk and tough choices,” (Energy News Network, August 2022), <https://energynews.us/2022/08/24/cracking-down-on-coal-ash-tough-talk-and-tough-choices/>
- ¹²⁰ Pytel, Brandon, “Why flood resilience is key to public health,” *American Flood Coalition*, (December 6, 2021), <https://floodcoalition.org/2021/12/flood-resilience-is-key-to-public-health/>.
- ¹²¹ CDC, “Where is Asbestos Found?” Environmental Health and Medicine Education, Agency for Toxic Substances and Disease Registry (updated May 19, 2023), https://www.atsdr.cdc.gov/csem/asbestos/where_is_asbestos_found.html.
- ¹²² CDC, “Lead in Paint,” (updated December 16, 2022) <https://www.cdc.gov/nceh/lead/prevention/sources/paint.htm>.
- ¹²³ CDC, “Health Effects of Asbestos,” Agency for Toxic Substances and Disease Registry (updated November 3, 2016), https://www.atsdr.cdc.gov/asbestos/health_effects_asbestos.html.
- ¹²⁴ CDC, “Health Effects of Lead Exposure,” Childhood Lead Poisoning Prevention (updated September 2, 2022), Centers for Disease Control and Prevention. <https://www.cdc.gov/nceh/lead/prevention/health-effects.htm>.
- ¹²⁵ Mayo Clinic, “Carbon monoxide poisoning,” Symptoms and causes, (Mayo Clinic, accessed April 6, 2016), <https://www.mayoclinic.org/diseases-conditions/carbon-monoxide/symptoms-causes/syc-20370642>.
- ¹²⁶ American Academy of Pediatrics, “Carbon Monoxide Poisoning: How to Protect Your Family,” *Healthy Children*, (AAP, December 2022), <https://www.healthychildren.org/English/safety-prevention/all-around/Pages/How-to-Prevent-Carbon-Monoxide-Poisoning.aspx>
- ¹²⁷ CDC, “Percent of U.S. Adults 55 and Over with Chronic Conditions,” (CDC, 2015), https://www.cdc.gov/nchs/health_policy/adult_chronic_conditions.htm
- ¹²⁸ Mehli, R., “Management of Hypoxia in Older Aged People—An Overview,” (iCliniq, September 2023), <https://www.icliniq.com/articles/geriatric-health/management-of-hypoxia-in-older-aged-people>
- ¹²⁹ Abdalla, et al., “Trends in Cardiovascular Disease Prevalence by Income Level in the United States,” *Health Policy* (September 2020), <https://doi.org/10.1001/jamanetworkopen.2020.18150>
- ¹³⁰ Gaffney et, al., “Socioeconomic Inequality in Respiratory Health in the US From 1959 to 2018,” *JAMA Intern Med* (May 2021), doi:10.1001/jamainternmed.2021.2441
- ¹³¹ Parham Azimi, et al., “Respiratory health harms often follow flooding: Taking these steps can help,” *Harvard Health Publishing*, (Harvard Medical School, November 9, 2022), <https://www.health.harvard.edu/blog/respiratory-health-harms-often-follow-flooding-taking-these-steps-can-help-202211092848>.

- ¹³² Climate Central, "After the Storm: Damp, Moldy Homes," (Climate Central, accessed October 23, 2023), <https://www.climatecentral.org/climate-matters/after-the-storm-damp-moldy-homes-2023>
- ¹³³ National Center for Environmental Health, "Flood Safety Tips," (CDC, updated March 27, 2023), <https://www.cdc.gov/nceh/features/flood-safety/index.html>
- ¹³⁴ Kathryn Lane et al., "Health Effects of Coastal Storms and Flooding in Urban Areas: A Review and Vulnerability Assessment," *Journal of Environmental and Public Health*, 13 (May 30, 2013): 13., <https://www.hindawi.com/journals/jep/2013/913064/>
- ¹³⁵ Illinois Department of Public Health, "Mold and Your Health," (Illinois DPH, accessed December 13, 2023), <https://dph.illinois.gov/topics-services/environmental-health-protection/toxicology/indoor-air-quality-healthy-homes/mold-your-health.html>.
- ¹³⁶ American Lung Association, "Floods and Water Damage," (updated November 2, 2023), <https://www.lung.org/clean-air/emergencies-and-natural-disasters/floods-and-water-damage>.
- ¹³⁷ CDC, "Basic Facts about Mold and Dampness," (Reviewed November 2022), <https://www.cdc.gov/mold/faqs.htm>.
- ¹³⁸ Medline Plus, "Aging Changes in the Lungs," in *MedlinePlus Medical Encyclopedia* (Accessed January 29, 2024), <https://medlineplus.gov/ency/article/004011.htm>.
- ¹³⁹ Eric Tate et al., "Flood exposure and social vulnerability in the United States," *Natural Hazards*, 106 (January 4, 2021): 435 – 457. <https://doi.org/10.1007/s11069-020-04470-2>.
- ¹⁴⁰ Timothy W. Collins, et al., "South East Hispanic Health Disparities After a Flood Disaster: Results of a Population-Based Survey of Individuals Experiencing Home Site Damage in El Paso (Texas, USA)," *Journal of Immigrant Minority Health*, 15 (April 21, 2012): 415 – 426, <https://doi.org/10.1007/s10903-012-9626-2>.
- ¹⁴¹ Yi Qiang, "Disparities of population exposed to flood hazards in the United States," *Journal of Environmental Management*, 232 (2019): 295 – 304, <https://www.sciencedirect.com/science/article/abs/pii/S0301479718313057>.
- ¹⁴² PA DEP, Environmental Justice Map (accessed November 7, 2023), <https://gis.dep.pa.gov/PennEnviroScreen/>.
- ¹⁴³ National Centers for Environmental Information, "Storm Events Database," (NOAA, accessed October 17, 2023), <https://www.ncdc.noaa.gov/stormevents/>.
- ¹⁴⁴ Hurdle, Jon, "As Water Rise, a Community Must Decide: Do We Stay or Go?" *Yale Environment 360* (September 28, 2023), <https://e360.yale.edu/features/chronic-flooding-eastwick-philadelphia>.
- ¹⁴⁵ Rebecca Hersher and Kellerman, Ryan, "Why FEMA Aid Is Unavailable To Many Who Need It The Most," All Things Considered, National Public Radio, WHYY (June 29, 2021), <https://www.npr.org/2021/06/29/1004347023/why-fema-aid-is-unavailable-to-many-who-need-it-the-most>.
- ¹⁴⁶ Rebecca Hersher and Kellerman, Ryan, "Why FEMA Aid Is Unavailable To Many Who Need It The Most," All Things Considered, National Public Radio, WHYY (June 29, 2021), <https://www.npr.org/2021/06/29/1004347023/why-fema-aid-is-unavailable-to-many-who-need-it-the-most>.
- ¹⁴⁷ Howell, Junia, and James R. Elliott, "As Disaster Costs Rise, So Does Inequality," *Socius: Sociological Research for a Dynamic World* 4 (2018), <https://doi.org/10.1177/2378023118816795>.
- ¹⁴⁸ Wilson, Bradley, Eric Tate, and Christopher T. Emrich, "Flood Recovery Outcomes and Disaster Assistance Barriers for Vulnerable Populations," *Frontiers in Water* 3 (2021), <https://doi.org/10.3389/frwa.2021.752307>.
- ¹⁴⁹ United States Census Bureau, "Explore Census Data," (US Census Bureau, accessed December 13, 2023), <https://data.census.gov/table?q=DPO4>. Data on occupancy (renter/owner) is available by census tract. Calculated percentages of renter-occupied housing do not include unoccupied units.
- ¹⁵⁰ FEMA, "Hazard Mitigation Assistance Mitigated Properties," (FEMA, December 13, 2023), <https://www.fema.gov/openfema-data-page/hazard-mitigation-assistance-mitigated-properties-v3>.
- ¹⁵¹ Wilson, Bradley, Eric Tate, and Christopher T. Emrich, "Flood Recovery Outcomes and Disaster Assistance Barriers for Vulnerable Populations," *Frontiers in Water* 3 (2021), <https://doi.org/10.3389/frwa.2021.752307>.
- ¹⁵² Schmidt, Sophia, "Heavy rain, floods, and heat: How climate change makes life tougher for unhoused people in the Philly area," (WHYY, December 2023), <https://whyy.org/articles/climate-change-unhoused-people-homelessness/>
- ¹⁵³ Schmidt, Sophia, "Heavy rain, floods, and heat: How climate change makes life tougher for unhoused people in the Philly area," (WHYY, December 2023), <https://whyy.org/articles/climate-change-unhoused-people-homelessness/>
- ¹⁵⁴ Soken-Huberty, Emmaline, "Housing Justice 101: Definitions, Examples, Learning Opportunities," (Human Rights Careers, April 16, 2023), <https://www.humanrightscarers.com/issues/housing-justice-101-definitions-examples-learning-opportunities/>.
- ¹⁵⁵ CDC, "Extreme Heat | Natural Disasters and Severe Weather," (CDC, October 19, 2023), <https://www.cdc.gov/disasters/extremeheat/index.html>.
- ¹⁵⁶ CDC, "NIOSH Heat Stress Topic Page," (CDC, September 1, 2023), <https://www.cdc.gov/niosh/topics/heatstress/default.html>.

¹⁵⁷ American Psychiatric Association, “Extreme Heat Can Take a Toll on Mental Health,” *Psychiatry* (July 20, 2023), <https://www.psychiatry.org/news-room/apa-blogs/extreme-heat-can-take-a-toll-on-mental-health>.

¹⁵⁸ Rony, Mousataq Karim Khan, and Hasnat M. Alamgir, “High Temperatures on Mental Health: Recognizing the Association and the Need for Proactive Strategies—A Perspective,” *Health Science Reports* 6, no. 12 (December 4, 2023): e1729, <https://doi.org/10.1002/hsr2.1729>.

¹⁵⁹ World Health Organization, “Ambient (Outdoor) Air Pollution,” (WHO, December 19, 2022), [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health).

¹⁶⁰ World Health Organization, “Ambient (Outdoor) Air Pollution,” (WHO, December 19, 2022), [https://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health).

¹⁶¹ Schmidt, Sophia, “After a Junkyard Fire Pollutes Philly with Smoke, City Has Few Avenues for Accountability,” *WHYY* (November 18, 2021),

<https://whyy.org/articles/after-a-junkyard-fire-pollutes-philly-with-smoke-city-has-few-avenues-for-accountability/>.

¹⁶² 6abc, “Junkyard fire in Philadelphia’s Parkside section under investigation,” (6ABC, Aug 15, 2023), <https://6abc.com/philadelphia-pa-fire-today-junkyard-parkside/13653311/>

¹⁶³ Rinde, Meir, “An accounting of the many, many junkyard fires in Philadelphia over the past 12 months,” *BillyPenn* at *WHYY* (June 2, 2023).

¹⁶⁴ US EPA, “Clinical Outcomes Related to Particulate Matter Exposure and Cardiovascular Disease,” *Overviews and Factsheets* (September 17, 2021), <https://www.epa.gov/air-research/clinical-outcomes-related-particulate-matter-exposure-and-cardiovascular-disease>.

¹⁶⁵ Schnell, Jordan L., and Michael J. Prather, “Co-Occurrence of Extremes in Surface Ozone, Particulate Matter, and Temperature over Eastern North America,” *Proceedings of the National Academy of Sciences* 114, no. 11 (February 17, 2017): 2854–59, <https://doi.org/10.1073/pnas.1614453114>.

¹⁶⁶ Rahman, Md Mostafijur, Rob McConnell, Hannah Schlaerth, Joseph Ko, Sam Silva, Frederick W. Lurmann, Lawrence Palinkas, et al., “The Effects of Coexposure to Extremes of Heat and Particulate Air Pollution on Mortality in California: Implications for Climate Change,” *American Journal of Respiratory and Critical Care Medicine* 206, no. 9: (June 2022) 1117–27, <https://doi.org/10.1164/rccm.202204-0657OC>.

¹⁶⁷ Note that data for air quality and temperature was not available for all counties on all dates.

¹⁶⁸ The White House, “FACT SHEET: Biden Administration Mobilizes to Protect Workers and Communities from Extreme Heat,” (The White House, September 20, 2021), <https://www.whitehouse.gov/briefing-room/statements-releases/2021/09/20/fact-sheet-biden-administration-mobilizes-to-protect-workers-and-communities-from-extreme-heat/>.

¹⁶⁹ CDC, “NIOSH Heat Stress Topic Page,” (Centers for Disease Control and Prevention, September 1, 2023), <https://www.cdc.gov/niosh/topics/heatstress/default.html>.

¹⁷⁰ United States Census Bureau, “Explore Census Data,” Accessed December 13, 2023, <https://data.census.gov/table/ACSDPIY2022.DPO3?q=Pennsylvania%20Employment>.

¹⁷¹ Bureau of Labor Statistics, “Occupational Employment and Wage Statistics,” Accessed December 13, 2023, <https://data.bls.gov/oes/#/geoOcc/Multiple%20occupations%20for%20one%20geographical%20area>.

¹⁷² Center for Workforce Information and Analysis, “Older Workers by Industry,” (Accessed December 13, 2023), <https://www.workstats.dli.pa.gov/dashboards/Pages/workers-age-by-industry-and-area.aspx>.

¹⁷³ Negrusa, Sebastian, Oleysa Fomenko, and Vennela Thumula. “Impact of Heat on the Frequency of Work-Related Injuries,” *Workers Compensation Research Institute WC-24-18* (May 2024).

¹⁷⁴ Bureau of Labor Statistics, “Civilian Occupations Required to Spend the Most Time Outdoors in 2020,” *The Economics Daily* (June 25, 2020), <https://www.bls.gov/opub/ted/2021/civilian-occupations-required-to-spend-the-most-time-outdoors-in-2020.htm>.

¹⁷⁵ OSHA, “Heat Hazard Prevention,” (Occupational Safety and Health Administration, accessed December 13, 2023), <https://www.osha.gov/heat-exposure>.

¹⁷⁶ Gubernot, Diane M., G. Brooke Anderson, and Katherine L. Hunting, “Characterizing Occupational Heat-Related Mortality in the United States, 2000–2010: An Analysis Using the Census of Fatal Occupational Injuries Database,” *American Journal of Industrial Medicine* 58, no. 2 (February 2015): 203–11, <https://doi.org/10.1002%2Fajim.22381>

¹⁷⁷ CDC, “QuickStats: Age-Adjusted Rates of Death Involving Exposure to Excessive Heat Among States with the Highest Numbers of Deaths — National Vital Statistics System, United States, 2021,” *MMWR. Morbidity and Mortality Weekly Report* 72 (2023), <https://doi.org/10.15585/mmwr.mm7235a7>.

- ¹⁷⁸ Arbury, Sheila, Brenda Jacklitsch, Opeyemi Farquah, Michael Hodgson, Glenn Lamson, Heather Martin, and Audrey Profitt, "Heat Illness and Death among Workers – United States, 2012–2013," (August 8, 2014), <https://pubmed.ncbi.nlm.nih.gov/25102413/>.
- ¹⁷⁹ OSHA, "Inspection Guidance for Heat Related Hazards," (September 1, 2021).
- ¹⁸⁰ US Census Bureau, "New Community Resilience Estimates For Heat Identify Areas Socially Vulnerable to Extreme Heat," (US Census Bureau, June 11, 2023), <https://www.census.gov/library/stories/2023/07/almost-a-quarter-of-population-vulnerable-to-rising-heat.html>
- ¹⁸¹ Gronlund, Carina J., "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: A Review," *Current Epidemiology Reports* 1, no. 3 (September 1, 2014): 165–73. <https://doi.org/10.1007/s40471-014-0014-4>.
- ¹⁸² Tustin, Aaron W., Dawn L. Cannon, Sheila B. Arbury, Richard J. Thomas, and Michael J. Hodgson "Risk Factors for Heat-Related Illness in U.S. Workers: An OSHA Case Series," *Journal of Occupational and Environmental Medicine* 60, no. 8 (August 2018): e383–89. <https://doi.org/10.1097/JOM.0000000000001365>.
- ¹⁸³ Marmot, Michael, "The Influence of Income On Health: Views Of An Epidemiologist," *Health Affairs* 21, no. 2 (2002): 31–46. <https://doi.org/10.1377/hlthaff.21.2.31>.
- ¹⁸⁴ National Academies of Sciences, Engineering, and Medicine; Health and Medicine Division; Board on Population Health and Public Health Practice; Committee on Community-Based Solutions to Promote Health Equity in the United States, and James N. Weinstein, *Communities in Action: Pathways to Health Equity*, Edited by Alina Baciu, Yamrot Negussie, and Amy Geller (National Academy of Sciences, 2017), <https://www.ncbi.nlm.nih.gov/books/NBK425844/>.
- ¹⁸⁵ Joint Economic Committee Democrats , "The Mounting Costs of Extreme Heat – The Mounting Costs of Extreme Heat – United States Joint Economic Committee," (Senate, August 10, 2023), <https://www.jec.senate.gov/public/index.cfm/democrats/reports?ID=BOOBEEAF-B86E-4B3D-8639-AF8FD98926CA>
- ¹⁸⁶ Behrer, A. P., R. J. Park, G. Wagner, C. M. Golja, and D. W. Keith, "Heat Has Larger Impacts on Labor in Poorer Areas," *Environmental Research Communications* 3, no. 9 (September 2021): 095001, <https://doi.org/10.1088/2515-7620/abffa3>.
- ¹⁸⁷ Gronlund, Carina J., "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: A Review," *Current Epidemiology Reports* 1, no. 3 (September 1, 2014): 165–73, <https://doi.org/10.1007/s40471-014-0014-4>.
- ¹⁸⁸ US Environmental Protection Agency (EPA), "Heat Islands and Equity," Overviews and Factsheets, (EPA, November 6, 2019), <https://www.epa.gov/heatislands/heat-islands-and-equity>.
- ¹⁸⁹ David Nowak, Erica Spotswood, Charlotte K. Stanley, and Stefan Leyk, "The Tree Cover and Temperature Disparity in US Urbanized Areas: Quantifying the Association with Income across 5,723 Communities," *PLOS ONE* 16, no. 4 (April 28, 2021): e0249715, <https://doi.org/10.1371/journal.pone.0249715>.
- ¹⁹⁰ US Environmental Protection Agency (EPA), "Heat Islands and Equity," Overviews and Factsheets, (EPA, November 6, 2019), <https://www.epa.gov/heatislands/heat-islands-and-equity>.
- ¹⁹¹ Legal Information Institute, "Redlining," (Cornell Law School, n.d.), <https://www.law.cornell.edu/wex/redlining>
- ¹⁹² Schinasi, Leah H., Chahita Kanungo, Zachary Christman, Sharrelle Barber, Loni Tabb, and Irene Headen, "Associations Between Historical Redlining and Present-Day Heat Vulnerability Housing and Land Cover Characteristics in Philadelphia, PA," *Journal of Urban Health: Bulletin of the New York Academy of Medicine* 99, no. 1 (February 2022): 134–45. <https://doi.org/10.1007/s11524-021-00602-6>.
- ¹⁹³ City of Philadelphia Office of Sustainability, "Beat the Heat Hunting Park: A Community Heat Relief Plan," (2019), https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf.
- ¹⁹⁴ Rural Health Information Hub, "Rural Health for Pennsylvania Overview," (August 11, 2023), <https://www.ruralhealthinfo.org/states/pennsylvania>.
- ¹⁹⁵ Boyle, Patrick, "Rural Americans Find Little Escape from Climate Change," *Association of American Medical Colleges* (June 13, 2023), <https://www.aamc.org/news/rural-americans-find-little-escape-climate-change>.
- ¹⁹⁶ Pennsylvania Office of Rural Health, "About Rural Health | Rural Health Care Challenges | Rural Pennsylvania Demographics," (Pennsylvania Office of Rural Health, accessed December 13, 2023), <https://www.porh.psu.edu/about/about-rural-health/>.
- ¹⁹⁷ Center for Climate Integrity, "Pennsylvania's Looming Climate Crisis: The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise," (Center for Climate Integrity, 2023), <https://climateintegrity.org/uploads/media/Pennsylvania-ClimateCostStudy-2023.pdf>.
- ¹⁹⁸ Moyce, Sally C., and Marc Schenker, "Occupational Exposures and Health Outcomes Among Immigrants in the USA," *Current Environmental Health*

Reports 4, no. 3 (September 2017): 349–54. <https://doi.org/10.1007/s40572-017-0152-1>.

¹⁹⁹ Pennsylvania Department of Agriculture, “Fast Facts on the Role of Foreign-Born Workers in the Hired Farmworker Labor Force,” (Pennsylvania Department of Agriculture, accessed November 7, 2023),

²⁰⁰ CDC, “Extreme Heat | Natural Disasters and Severe Weather,” (CDC, October 19, 2023), <https://www.cdc.gov/disasters/extremeheat/index.html>.

²⁰¹ Baussan, Danielle, “Social Cohesion: The Secret Weapon in the Fight For Equitable Climate Resilience,” (Center for American Progress, May 2015), <https://www.americanprogress.org/wp-content/uploads/sites/2/2015/05/SocialCohesion-report-summary.pdf>.

²⁰² OSHA, “National Emphasis Program – Outdoor and Indoor Heat-Related Hazards,” (April 8, 2022), CPL O3-00-024.

²⁰³ Pennsylvania Code: Rules and Regulations (Accessed December 13, 2023), <https://www.pacodeandbulletin.gov/Display/pacode?file=/secure/pacode/data/O28/chapter705/s705.26.html&d=reduce>.

²⁰⁴ Pennsylvania Department of Corrections, “Racial Disparities,” (Accessed December 13, 2023), <https://dashboard.cor.pa.gov/us-pa/narratives/racial-disparities/1>.

²⁰⁵ Pennsylvania Code: Rules and Regulations (Accessed December 13, 2023), https://www.law.cornell.edu/state_regulations/pennsylvania.html.

²⁰⁶ 28 Pa. Code Chapter 705, Physical Plant Standards, (Accessed December 18, 2023), <https://www.pacodeandbulletin.gov/Display/pacode?file=/secure/pacode/data/O28/chapter705/s705.26.html&d=reduce>.

²⁰⁷ OSHA, “Heat Hazard Prevention,” (Occupational Safety and Health Administration, accessed December 13, 2023), <https://www.osha.gov/heat-exposure/hazards>.

²⁰⁸ CDC, “Heat Stress Acclimatization,” (CDC, June 6, 2018), <https://www.cdc.gov/niosh/topics/heatstress/acclima.html>.

²⁰⁹ Department of Labor & Industry, “General Safety,” (Accessed December 13, 2023), <https://www.dli.pa.gov:443/Individuals/Labor-Management-Relations/bois/Pages/General-Safety.aspx>.

²¹⁰ U.S. Equal Employment Opportunity Commission, “What You Should Know About the Pregnant Workers Fairness Act,” (2023), <https://www.eeoc.gov/wysk/what-you-should-know-about-pregnant-workers-fairness-act>.

²¹¹ CDC, “Heat and Pregnant Women,” (CDC, Last reviewed August 2022), https://www.cdc.gov/disasters/extremeheat/heat_and_pregnant_women.html

²¹² U.S. Department of Health and Human Services, Public Health Service, “Criteria for a Recommended Standard: Occupational Exposure to Heat and Hot Environments – Revised Criteria 2016,” (Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, February 1, 2016), <https://doi.org/10.26616/NIOSH-PUB2016106>.

²¹³ Haupton, Megan, “The Health and Safety of Incarcerated Workers: OSHA’s Applicability in the Prison Context,” (American Bar, June 20, 2023), https://www.americanbar.org/content/dam/aba/publications/aba_journal_of_labor_employment_law/v37/no-1/jlel-37-1-5.pdf.

²¹⁴ ACLU, “Captive Labor: Exploitation of Incarcerated Workers,” *American Civil Liberties Union* (June 15, 2022), <https://www.aclu.org/news/human-rights/captive-labor-exploitation-of-incarcerated-workers>.

²¹⁵ Clark, Roger A., “1975.5,” (Occupational Safety and Health Administration, December 16, 1992), <https://www.osha.gov/laws-regs/standardinterpretations/1992-12-16-1>.

²¹⁶ Belkin, Jacob, “Extreme Heat Protections Should Include Incarcerated Workers,” *Climate Law Blog* (September 24, 2021), <https://blogs.law.columbia.edu/climatechange/2021/09/24/extreme-heat-protections-should-include-incarcerated-workers/>.

²¹⁷ Pennsylvania Department of Corrections, “Policy Statement,” (Pennsylvania Department of Corrections, November 20, 2023), <https://www.cor.pa.gov/About%20Us/Documents/DOC%20Policies/15.01.01%20Safety.pdf>.

²¹⁸ Quandt, Sara A., Kristen L. Kucera, Courtney Haynes, Bradley G. Klein, Ricky Langley, Michael Agnew, Jeffrey L. Levin, Timothy Howard, and Maury A. Nussbaum, “Occupational Health Outcomes for Workers in the Agriculture, Forestry and Fishing Sector: Implications for Immigrant Workers in the Southeastern US,” *American Journal of Industrial Medicine* 56, no. 8 (August 2013): 940–59. <https://doi.org/10.1002/ajim.22170>.

²¹⁹ U.S. Department of Labor, “READOUT: US Department of Labor Expands OSHA’s Ability to Protect All Workers by Certifying Special Visa Applications to Ensure Effective Enforcement,” (U.S. Department of Labor, February 13, 2023), <https://www.osha.gov/news/newsreleases/readout/O2132023>.

²²⁰ Climate Central, “Surging Power Outages and Climate Change,” (Climate Central Report, 2022), <https://www.climatecentral.org/climate-matters/surging-weather-related-power-outages>

²²¹ U.S. Department of Energy, “August 2003 Blackout Report,” (DOE, August 2003).

- ²²² PennLive, "Tens of Thousands in PA Without Power Due to Ida," (PennLive, September 1, 2021), <https://www.pennlive.com/weather/2021/09/tens-of-thousands-in-pa-without-power-due-to-ida.html>
- ²²³ Pennsylvania Public Utility Commission, "Electric Distribution Company Emergency Preparedness and Operations Plan (EPO) 2017," (Pennsylvania Public Utility Commission, 2017), https://www.puc.pa.gov/General/publications_reports/pdf/EPO_2017.pdf, 20.
- ²²⁴ Pennsylvania Public Utility Commission, "Electric Distribution Company Emergency Preparedness and Operations Plan (EPO) 2017," (Pennsylvania Public Utility Commission, 2017), https://www.puc.pa.gov/General/publications_reports/pdf/EPO_2017.pdf, 20.
- ²²⁵ U.S. Energy Information Administration, "Energy Data for Pennsylvania," (U.S. EIA, accessed November 6, 2023), <https://www.eia.gov/state/data.php?sid=PA>.
- ²²⁶ Sophia Schmidt, "Pennsylvania Receives Federal Dollars for Building a Climate-Ready Electric Grid," (WHYY, accessed November 6, 2023), <https://whyy.org/articles/pa-federal-dollars-building-climate-ready-electric-grid/>.
- ²²⁷ Pennsylvania Public Utility Commission, "Pennsylvania Electric Reliability Report 2021," (Pennsylvania Public Utility Commission, 2021), <https://www.puc.pa.gov/filing-resources/reports/electric-service-reliability-report/>
- ²²⁸ While increasing temperatures and heatwaves do not always coincide with drought, they can increase the possibility of drought conditions, which can reduce the levels of water bodies that feed hydroelectric powerplants creating conditions that may reduce plant operations or cease them entirely.
- ²²⁹ ACEEE, "Report: Low-Income Households, Communities of Color Face High Energy Burden," (ACEEE, September 10, 2020), <https://www.aceee.org/press-release/2020/09/report-low-income-households-communities-color-face-high-energy-burden>
- ²³⁰ Macmillan, M., Wilson, K. M., Baik, S., Carvallo, J. P., Dubey, A., & Holland, C. A., "Shedding light on the economic costs of long-duration power outages: A review of resilience assessment methods and strategies," *Energy Research & Social Science*, 99: (2023), 103055. <https://doi.org/10.1016/j.erss.2023.103055>
- ²³¹ Andresen, Adam, Liza Kurtz, David Hondula, Sara Meerow, and Melanie Gall, "Understanding the Social Impacts of Power Outages in North America: A Systematic Review," *Environmental Research Letters* 18, no. 5 (2023), <https://doi.org/10.1088/1748-9326/acc7b9>.
- ²³² WHO, "Heat and Health," (World Health Organization, June 1, 2018), <https://www.who.int/news-room/fact-sheets/detail/climate-change-heat-and-health>.
- ²³³ City of Philadelphia, "Philadelphia Historic Preservation Task Force Report: HP R7," (July 19, 2019).
- ²³⁴ Seltnerich, Nate, "Between Extremes: Health Effects of Heat and Cold," *Environmental Health Perspectives* 123, no. 11 (2015): A275–A279. Accessed November 3, 2023, <https://doi.org/10.1289/ehp.123-A275>.
- ²³⁵ Forrester, S., et al., "Residential Solar-Adopter Income and Demographic Trends: November 2022 Update," (Lawrence Berkely National Laboratory, November 2022), https://eta-publications.lbl.gov/sites/default/files/solar-adopter_income_trends_nov_2022.pdf.
- ²³⁶ Andresen, Adam, Liza Kurtz, David Hondula, Sara Meerow, and Melanie Gall, "Understanding the Social Impacts of Power Outages in North America: A Systematic Review."
- ²³⁷ Casey, J. A., Fukurai, M., Hernández, D., Balsari, S., & Kiang, M. V., "Power Outages and Community Health: a Narrative Review," *Current Environmental Health Reports*, 7, no. 4 (2020): 371–383, <https://doi.org/10.1007/s40572-020-00295-0>
- ²³⁸ Casey, J. A., Fukurai, M., Hernández, D., Balsari, S., & Kiang, M. V., "Power Outages and Community Health: a Narrative Review," *Current Environmental Health Reports*, 7, no. 4 (2020): 371–383, <https://doi.org/10.1007/s40572-020-00295-0>
- ²³⁹ Adelphi Psych Medicine Clinic, "Surprising Effects of Power Outages on Mental Health," (Adelphi Psych Medicine Clinic, October 4, 2017), <https://adelphipsych.sg/surprising-effects-of-power-outages-on-mental-health>.
- ²⁴⁰ Andresen, Adam, Liza Kurtz, David Hondula, Sara Meerow, and Melanie Gall, "Understanding the Social Impacts of Power Outages in North America."
- ²⁴¹ Nuamah, Sally, Ryan Good, Ariel Bierbaum, and Elaine Simon, "School Closures Always Hurt. They Hurt Even More Now," *EducationWeek* (June 8, 2020), <https://www.edweek.org/leadership/opinion-school-closures-always-hurt-they-hurt-even-more-now/2020/06>.
- ²⁴² U.S. Federal Emergency Management Agency (FEMA) & Assistant Secretary for Preparedness and Response (ASPR), "Healthcare Facilities and Power Outages," (Washington, D.C.: FEMA & ASPR, 2019),

<https://www.fema.gov/sites/default/files/2020-07/healthcare-facilities-and-power-outages.pdf>

²⁴³ U.S. Federal Emergency Management Agency (FEMA) & Assistant Secretary for Preparedness and Response (ASPR), "Healthcare Facilities and Power Outages," (Washington, D.C.: FEMA & ASPR, 2019), <https://www.fema.gov/sites/default/files/2020-07/healthcare-facilities-and-power-outages.pdf>

²⁴⁴ U.S. Federal Emergency Management Agency (FEMA) & Assistant Secretary for Preparedness and Response (ASPR), "Healthcare Facilities and Power Outages," (Washington, D.C.: FEMA & ASPR, 2019), <https://www.fema.gov/sites/default/files/2020-07/healthcare-facilities-and-power-outages.pdf>

²⁴⁵ Taylor, Mariah, "Power Outage Downs Florida Hospital Computers, Appointments Rescheduled," Becker's Hospital Review (September 12, 2023), <https://www.beckershospitalreview.com/care-coordination/power-outage-downs-florida-hospital-computers-appointments-rescheduled.html>.

²⁴⁶ Solis, Marie, "Texas's Power Outage Sparked a Reproductive Health Care Crisis," (Fortune, February 26, 2021), <https://fortune.com/2021/02/26/texas-power-outage-planned-parenthood-texas-whole-womans-health-reproductive-health-care/>.

²⁴⁷ Solis, Marie, "Texas's Power Outage Sparked a Reproductive Health Care Crisis," (Fortune, February 26, 2021), <https://fortune.com/2021/02/26/texas-power-outage-planned-parenthood-texas-whole-womans-health-reproductive-health-care/>.

²⁴⁸ Hamachi LaCommare, Kristina, and Joseph H. Eto, "Cost of Power Interruptions to Electricity Consumers in the United States (US)," *Energy* 31, no. 12 (2006): 1845-1855. <https://doi.org/10.1016/j.energy.2006.02.008>.

²⁴⁹ Hamachi LaCommare, Kristina, and Joseph H. Eto, "Understanding the Cost of Power Interruptions to U.S. Electricity Consumers," *Energy Analysis Department - Ernest Orlando Lawrence Berkeley National Laboratory*, (2004), <https://www.energy.gov/oe/articles/understanding-cost-power-interruptions-us-electricity-consumers>.

²⁵⁰ Urban Institute, "The Unequal Commute," (Urban Institute, October 6, 2020), <https://www.urban.org/features/unequal-commute>.

²⁵¹ Stough, L. M., Sharp, A. N., Resch, J. A., Decker, C., & Wilker, N., "Barriers to the long-term recovery of individuals with disabilities following a disaster," *Disasters*, 40, no.3 (2015): 387-410.

²⁵² Center for Climate Integrity, "Pennsylvania's Looming Climate Cost Crisis: The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise," (Center for Climate Integrity, July 2023).

²⁵³ Econsult Solutions, Team Pennsylvania, and the Pennsylvania Department of Agriculture, "The Economic Impact of Agriculture in Pennsylvania: 2021 Update," (2020).

²⁵⁴ McDevitt, Rachel, "Climate Challenges propts Pa. farmers to adapt crops and businesses," (NPR, November 2022), <https://stateimpact.npr.org/pennsylvania/2022/11/07/climate-change-prompts-pa-farmers-to-adapt-crops-and-businesses/>

²⁵⁵ Shelby Bradford, "Pa. group pitches farms on solar model that keeps farmland usable, takes up less space," (State Impact NPR, July 2023).

²⁵⁶ USDA, "Climate-Smart Agriculture and Forestry," <https://www.farmers.gov/conservation/climate-smart>.

²⁵⁷ USDA, "USDA to Invest \$1 Billion in Climate Smart Commodities, Expanding Markets, Strengthening Rural America," (USDA, retrieved November 16, 2023), <https://www.usda.gov/media/press-releases/2022/02/07/usda-invest-1-billion-climate-smart-commodities-expanding-markets>

²⁵⁸ USDA, "A Greener World," Partnerships For Climate-Smart Commodities, (USDA, retrieved November 16, 2023), https://publicdashboards.dl.usda.gov/t/FPAC_PUB/views/PartnershipsForClimate-SmartCommodities/ProjectDetail?%3Aembed=y&%3AisGuestRedirectFromVizportal=y

²⁵⁹ Environmental Protection Agency, "The Economic Benefits of Green Infrastructure. A Case Study of Lancaster, PA," (EPA, February 2014), https://www.epa.gov/sites/default/files/2015-10/documents/cnt-lancaster-report-508_1.pdf

²⁶⁰ Center for Advanced Agriculture and Sustainability, "Center for Advanced Agriculture and Sustainability," (Harrisburg University, accessed January 29, 2024).

²⁶¹ Pennsylvania Advanced Agriculture Cross-Sector Collaborative "Controlled Environment Agriculture," (Pennsylvania Advanced Agriculture Cross-Sector Collaborative, accessed January 29, 2024), <https://www.paagcollab.org/controlled-environment-agriculture>.

²⁶² U.S. Bureau of Economic Analysis, "Outdoor Recreation Satellite Account, U.S. and States, 2022- Pennsylvania," (BEA, 2022), <https://apps.bea.gov/data/special-topics/orsa/summary-sheets/ORSA%20-%20Pennsylvania.pdf>

- ²⁶³ PA DCNR, "Conservation Landscapes," (PA DCNR, accessed April 2024), <https://www.dcnr.pa.gov/Communities/ConservationLandscapes/Pages/default.aspx>
- ²⁶⁴ Guijing Wang et al., "A Cost Benefit Analysis of Physical Activity using bike/pedestrian trails," *Health Promot Pract.*, 6 no.2 (2005 Apr):174–9, doi: 10.1177/1524839903260687.
- ²⁶⁵ Center for American Progress, "*The Nature Gap: Confronting Racial and Economic Disparities in the Destruction and Protection of Our Planet*," (CAP, July 2020), [The-Nature-Gap.pdf](https://www.americanprogressaction.org/wp-content/uploads/2020/07/The-Nature-Gap.pdf)
- ²⁶⁶ U.S. Energy Information Administration, "*Pennsylvania State Profile*," (EIA, accessed November 15, 2023).
- ²⁶⁷ PennState Center for Economic and Community Impact, "Potential Economic Impact of Community Solar in Pennsylvania," (PennState, 2020), https://aese.psu.edu/research/centers/cecd/publications/economic-impact/economic-impact-of-community-solar_sept-2020_psu-cecd.pdf
- ²⁶⁸ PA DEP, "Energy Efficiency Incentives," <https://www.dep.pa.gov/Citizens/Energy/EnergyEfficiencyandConservation/Pages/Incentives-Fact-Sheet-PA-PUC-Electric-Choice.aspx>.
- ²⁶⁹ Saha, D. and Jaeger, J., "America's New Climate Economy: A Comprehensive Guide to the Economic Benefits of Climate Policy in the United States," (WRI, accessed July 2020), <https://www.wri.org/research/americas-new-climate-economy-comprehensive-guide-economic-benefits-climate-policy-united>.
- ²⁷⁰ Dyson, M., Teplin, C., Engel, A., & Glazer, G., "The Growing Market for Clean Energy Portfolios," (Rocky Mountain Institute, 2019), <https://rmi.org/insight/clean-energy-portfolios-pipelines-and-plants>.
- ²⁷¹ Johns Hopkins School of Advanced International Studies, "How COVID-19 Disrupted the Renewable Energy Transition – and How the World Can Get Back on Track", (December 2022), <https://energy.sais.jhu.edu/articles/how-covid-19-disrupted-renewable-energy-transition/>.
- ²⁷² Johns Hopkins School of Advanced International Studies, "How COVID-19 Disrupted the Renewable Energy Transition – and How the World Can Get Back on Track", (December 2022), <https://energy.sais.jhu.edu/articles/how-covid-19-disrupted-renewable-energy-transition/>.
- ²⁷³ Pennsylvania Department of Environmental Protection, "Pennsylvania Clean Energy Program Plan 2023–2025," (accessed November 15, 2023).
- ²⁷⁴ Sunter et al., "Racial Disparities in Exposure to Air Pollution in the United States," *Environmental Research* (2020).
- ²⁷⁵ Seung Kyum Kim, "*The Economic Effects of Climate Change Adaptation Measures: Evidence from Miami-Dade County and New York City*," *Environmental Research* (May 2019), https://www.jchs.harvard.edu/sites/default/files/harvard_jchs_kim_economic_effects_climate_change_adaptation_2019.pdf
- ²⁷⁶ Axios, "Insurance prices in Philadelphia could rise due to flooding, high winds – Axios," (Axios, 12 Oct. 2023), <https://www.axios.com/local/philadelphia/2023/10/12/insurance-prices-premiums-pennsylvania>.
- ²⁷⁷ Federal Emergency Management Agency, "Community Rating System," (FEMA, March 2023), https://www.fema.gov/sites/default/files/documents/fema_crs-brochure_032023.pdf.
- ²⁷⁸ U.S. Environmental Protection Agency, "2011 Smart Growth Achievement Awards," (accessed November 7, 2023).
- ²⁷⁹ U.S. Department of Housing and Urban Development, "HUD's Climate Action Plan," (accessed May 12, 2023).
- ²⁸⁰ Rose, Jonathan, "Redlining," (Federal Reserve History, June 2, 2023), <https://www.federalreservehistory.org/essays/redlining>.
- ²⁸¹ Pennsylvania DEP, "Environmental Justice Policy," <https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/Policy-Revision.aspx>.
- ²⁸² EPA, "EJ 2020 Glossary," (EPA, 2020), <https://www.epa.gov/environmentaljustice/ej-2020-glossary>
- ²⁸³ The Center for Rural Pennsylvania, "Pennsylvania Population Projections 2010–2040, (2014), https://www.rural.palegislature.us/documents/reports/Population_Projections_Report.pdf
- ²⁸⁴ The Center for Rural Pennsylvania, "Pennsylvania Population Projections 2010–2040, (2014), https://www.rural.palegislature.us/documents/reports/Population_Projections_Report.pdf
- ²⁸⁵ PEMA, "Pennsylvania Hazard Mitigation Plan: Standard Operating Guide," (PEMA, 2020), <https://www.pema.pa.gov/Mitigation/Planning/Documents/All-Hazard-Mitigation-Planning-Standard-Operating-Guide.pdf>
- ²⁸⁶ Pennsylvania Emergency Management Agency, "Landslide" in *Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan*, (PEMA, 2023), <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>

²⁸⁷ Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, *Fifth National Climate Assessment*, (USGCRP 2003), <https://doi.org/10.7930/NCA5.2023>

²⁸⁸ Intergovernmental Panel on Climate Change, "Chapter 1" in *Fifth Assessment Report – Climate Change 2013: The Physical Science Basis*, (2017). <https://www.ipcc.ch/report/ar5/wg1/>

²⁸⁹ Very high confidence denotes "Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus."

²⁹⁰ High confidence denotes "Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus."

²⁹¹ Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner, "Temperature changes in the United States", in *Climate Science Special Report: Fourth National Climate Assessment*, Volume I. (U.S. Global Change Research Program, 2017), pp. 185–206, doi:10.7930/JON29V45.

²⁹² Carina J. Gronlund, Kyle P. Sullivan, Yonathan Kefelegn, Lorraine Cameron, Marie S. O'Neill, "Climate change and temperature extremes: A review of heat- and cold-related morbidity and mortality concerns of municipalities", *Maturitas* 114(2018): 54–59, <https://doi.org/10.1016/j.maturitas.2018.06.002>

²⁹³ Veronika Huber, "Will climate change bring benefits from reduced cold-related mortality? Insights from the latest epidemiological research. *Real Climate*," (*Real Climate*, 2018) <http://www.realclimate.org/index.php/archives/2018/06/will-climate-change-bring-benefits-from-reduced-cold-related-mortality-insights-from-the-latest-epidemiological-research/>

²⁹⁴ Gerardo Sanchez Martinez, Julio Diaz, Hans Hooyberghs, Dirk Lauwaet, Koen De Ridder, Cristina Linares, Rocio Carmona, Cristina Ortiz, Vladimir Kendrovski, Dovile Adamonyte, "Cold-related mortality vs heat-related mortality in a changing climate: A case study in Vilnius (Lithuania)," *Environ Res.* 166 (2018): 384–393, doi: 10.1016/j.envres.2018.06.001

²⁹⁵ Centers for Disease Control and Prevention, "Temperature Extremes," (CDC, October 2020), https://www.cdc.gov/climateandhealth/effects/temperature_extremes.htm

²⁹⁶ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>

²⁹⁷ Pennsylvania Emergency Management Agency, "Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan," (PEMA, 2023), <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>

²⁹⁸ The heat index is a measure of temperature and relative humidity. One study projected that days in which the heat index was especially dangerous are projected to quadruple in the Northeast. Dahl, K., et al., 2019. Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. In *Environmental Research Communications*. <https://doi.org/10.1088/2515-7620/ab27cf>

²⁹⁹ Dahl, K., et al., "Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century," In *Environmental Research Communications* (2019). <https://doi.org/10.1088/2515-7620/ab27cf>

³⁰⁰ The National Weather Service issues heat advisories in Pennsylvania when the heat is 100–104°F. When the heat index reaches 100°F, the National Weather Service alerts individuals that prolonged exposure or strenuous activity is dangerous or extremely dangerous. National Weather Service. 2020. Heat. <https://www.weather.gov/bgm/heat>

³⁰¹ Bhatia, A. and Choi-Schagrin, W., "Why Record-Breaking Overnight Temperatures Are So Concerning," (New York Times, 2021), <https://www.nytimes.com/2021/07/09/upshot/record-breaking-hot-weather-at-night-deaths.html>

³⁰² UNC Gillings School of Global Public Health, "Risk of death rises as climate change causes nighttime temperatures to climb," (UNC, 2021), <https://sph.unc.edu/sph-news/risk-of-death-rises-as-climate-change-causes-nighttime-temperatures-to-climb/>

³⁰³ U. S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Chapter 3: Air Quality Impacts" (USGCRP, 2016), <https://health2016.globalchange.gov/>

³⁰⁴ Neal L. Fann et al., "Associations Between Simulated Future Changes in Climate, Air Quality, and Human Health," *JAMA Network Open* 4, no. 1 (January 4, 2021): e2032064, <https://doi.org/10.1001/jamanetworkopen.2020.32064>.

³⁰⁵ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>

³⁰⁶ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>

- ³⁰⁷ Keuhn and McCormick, "Heat Exposure and Maternal Health in the Face of Climate Change", *International Journal of Environmental Research and Public Health* (2017), <https://doi.org/10.3390/ijerph14080853>
- ³⁰⁸ EPA, "Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts," (U.S. Environmental Protection Agency, September 2021), https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.
- ³⁰⁹ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>
- ³¹⁰ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>
- ³¹¹ U.S. Global Change Research Program, "The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment," (USGCRP, 2016), <https://health2016.globalchange.gov/>
- ³¹² Centers for Disease Control and Prevention, "Summary Report – One Health Harmful Algal Bloom System (OHHABS), United States, 2021," (CDC, September 12, 2023), <https://www.cdc.gov/habs/data/2021-ohhabs-data-summary.html>.
- ³¹³ Pennsylvania DEP, "Climate Change in Pennsylvania" (DEP, 2020), <http://www.depgis.state.pa.us/ClimateChange/index.html>.
- ³¹⁴ Lucy Gilbert, "The Impacts of Climate Change on Ticks and Tick-Borne Disease Risk," *Annual Review of Entomology* 66, no. 1 (2021): 373–88, <https://doi.org/10.1146/annurev-ento-052720-094533>.
- ³¹⁵ Pennsylvania DEP, "Climate Change in Pennsylvania" (DEP, 2020), <http://www.depgis.state.pa.us/ClimateChange/index.html>.
- ³¹⁶ Ram K. Raghavan et al., "Current and Future Distribution of the Lone Star Tick, *Amblyomma Americanum* (L.) (Acari: Ixodidae) in North America," *PLOS ONE* 14, no. 1 (January 2, 2019): e0209082, <https://doi.org/10.1371/journal.pone.0209082>.
- ³¹⁷ Abdelghafar Alkische and A. Townsend Peterson, "Climate Change Influences on the Geographic Distributional Potential of the Spotted Fever Vectors *Amblyomma Maculatum* and *Dermacentor Andersoni*," *PeerJ* 10 (May 3, 2022): e13279, <https://doi.org/10.7717/peerj.13279>.
- ³¹⁸ Pennsylvania DEP, "Climate Change in Pennsylvania" (DEP, 2020), <http://www.depgis.state.pa.us/ClimateChange/index.html>.
- ³¹⁹ Pennsylvania Department of Health, "Emerging Tickborne Diseases in Pennsylvania," (DOH, August 26, 2022), <https://www.health.pa.gov/topics/Documents/HAN/2022-658-8-26-ADV-Tickborne.pdf>.
- ³²⁰ Pennsylvania Department of Health, "Lyme Disease and Other Tickborne Diseases in Pennsylvania," (DOH, April 13, 2023), <https://www.health.pa.gov/topics/Documents/HAN/2023-690-4-13-Lyme.pdf>.
- ³²¹ Ranson, M., "Crime, weather, and climate change," In *Journal of Environmental Economics and Management*, 67, no. 3(2014): p274–302. <https://doi.org/10.1016/j.jeem.2013.11.008>
- ³²² Cianconi et al., "The impact of climate change on mental health: A systematic descriptive review," *Front Psychiatry*, 11 no. 74(2020), <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/>
- ³²³ Ranson, M., "Crime, weather, and climate change," In *Journal of Environmental Economics and Management*, 67, no. 3(2014): p274–302. <https://doi.org/10.1016/j.jeem.2013.11.008>.
- ³²⁴ Ranson, 2014; Heilmann, K., Kahn, M., "The Urban Crime and Heat Gradient in High and Low Poverty Areas," (National Bureau of Economic Research, 2019). <https://www1050.nber.org/papers/w25961.ack>.
- ³²⁵ U.S. Environmental Protection Agency, "Heat Island Effect," (EPA, 2020), <https://www.epa.gov/heatislands>
- ³²⁶ Wu, J. et al., « Estimation and uncertainty analysis of impacts of future heat waves on mortality in the eastern United States," *Environmental Health Perspectives*. 122(2014): 10–16. <https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1306670>
- ³²⁷ Hsu, Angel, Glenn Sheriff, Tirthankar Chakraborty, and Diego Manya, "Disproportionate Exposure to Urban Heat Island Intensity across Major US Cities," *Nature Communications* 12, no. 1 (May 25, 2021): 2721, <https://doi.org/10.1038/s41467-021-22799-5>.
- ³²⁸ City of Philadelphia Office of Sustainability, "Beat the Heat Hunting Park: A Community Heat Relief Plan," (2019), https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf.
- ³²⁹ Maxwell, K., S. Julius, A. Grambsch, A. Kosmal, L. Larson, and N. Sonti, "Built Environment, Urban Systems, and Cities," In *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. (U.S. Global Change Research Program, 2018), p. 438–478, doi: 10.7930/NCA4.2018.CH11
- ³³⁰ Hsu, Angel, Glenn Sheriff, Tirthankar Chakraborty, and Diego Manya, "Disproportionate Exposure to Urban Heat Island Intensity across Major US

Cities," *Nature Communications* 12, no. 1 (May 25, 2021): 2721, <https://doi.org/10.1038/s41467-021-22799-5>.

³³¹ City of Philadelphia Office of Sustainability, "Beat the Heat Hunting Park: A Community Heat Relief Plan," (2019), https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf.

³³² U.S. EPA, "What Climate Change Means for Pennsylvania," (EPA, August 2016), 430-F-16-O40, <https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf>

³³³ Penn State Extension, "Peach Production," (PennState, 2017), <https://www.fishandboat.com/Fish/Stocking/Pages/default.aspx>

³³⁴ U.S. EPA, "What Climate Change Means for Pennsylvania," (EPA, August 2016), <https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf>

³³⁵ U.S. EPA, "What Climate Change Means for Pennsylvania," (EPA, August 2016), <https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf>

³³⁶ Environment & Natural Resources Institute, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>.

³³⁷ Pennsylvania Department of Agriculture, Department staff expertise, November 2020.

³³⁸ Wobus, Cameron, Eric E. Small, Heather Hosterman, David Mills, Justin Stein, Matthew Rissing, Russell Jones, et al., "Projected Climate Change Impacts on Skiing and Snowmobiling: A Case Study of the United States," *Global Environmental Change* 45 (July 1, 2017): 1-14. <https://doi.org/10.1016/j.gloenvcha.2017.04.006>.

³³⁹ Drought.gov, "Recreation and Tourism," n.d., <https://www.drought.gov/sectors/recreation-and-tourism>.

³⁴⁰ Pennsylvania Fish and Boat Commission, "Fish Stocking," (2020), <https://www.fishandboat.com/Fish/Stocking/Pages/default.aspx>

³⁴¹ Drought.gov, "Recreation and Tourism," n.d., <https://www.drought.gov/sectors/recreation-and-tourism>.

³⁴² Pennsylvania Department of Agriculture. "State of the Forest Products Industry in Pennsylvania," (2020).

³⁴³ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015).

<https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

³⁴⁴ Pennsylvania Department of Conservation and Natural Resources, "Climate Change Adaptation and Mitigation Plan," (2018).

³⁴⁵ Pennsylvania Department of Conservation and Natural Resources, "Climate Change Adaptation and Mitigation Plan," (2018).

³⁴⁶ Pennsylvania DCNR, Bureau of Forestry, Department staff expertise, November 2020.

³⁴⁷ National Audubon Society, "Survival by Degrees: 389 Bird Species on the Brink. How Climate Change Will Affect Birds in Pennsylvania," (Audubon, 2021).

³⁴⁸ NOAA National Center for Environmental Information, "State Climate Summaries: Pennsylvania," <https://statesummaries.ncics.org/chapter/pa/>.

³⁴⁹ PA Department of Agriculture (DOA), "The Economic Impact of Agriculture in Pennsylvania: 2021 Update," (DOA, 2021).

³⁵⁰ NPR, "A Few More Bad Apples: As the Climate Changes, Fruit Growing Does, Too," (NPR, 2018), <https://www.npr.org/sections/thesalt/2018/08/01/634135514/a-few-more-bad-apples-as-the-climate-changes-fruit-growing-does-too>.

³⁵¹ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

³⁵² PennState Extension, "Forest Management and Timber Harvesting in Pennsylvania" (PennState, 2019), <https://extension.psu.edu/forest-management-and-timber-harvesting-in-pennsylvania>

³⁵³ USDA, "Assessment of Forest Sector Carbon Stocks and Mitigation Potential for State Forests of Pennsylvania," (USDA, 2018), https://www.climatehubs.usda.gov/sites/default/files/PA_ForestCarbon_MainReport.pdf

³⁵⁴ U.S. Bureau of Economic Analysis, "Outdoor Recreation Satellite Account, U.S. and States, 2022- Pennsylvania," (BEA, 2022).

³⁵⁵ Pittsburgh Post-Gazette, "How climate change will affect Pennsylvania," (2012), <https://www.post-gazette.com/news/environment/2012/04/22/How-climate-change-will-affect-Pennsylvania/stories/201204220205>

³⁵⁶ Climate Central, “On Thin Ice: How Climate Change is Shaping Winter Recreation,” (Central Climate, 2020), <https://www.climatecentral.org/news/report-on-thin-ice-climate-change-shaping-winter-recreation>.

³⁵⁷ Hendricks, Karen, “In Pa., Climate Change Threatens the State Tree, Bird and Fish. Work Is under Way to Help the Native Species,” StateImpact Pennsylvania (May 8, 2023), <https://stateimpact.npr.org/pennsylvania/2023/05/08/in-pa-climate-change-threatens-the-state-tree-bird-and-fish-work-is-under-way-to-help-the-native-species/>.

³⁵⁸ Schuette, Scott, “Climate Change Vulnerability of Select Plant Species in Pennsylvania,” (Western Pennsylvania Conservancy, September 30, 2022), <https://doi.org/10.13140/RG.2.2.29962.54720>.

³⁵⁹ Pennsylvania Department of General Services, Department staff expertise, November 2020.

³⁶⁰ Pennsylvania Department of General Services, Department staff expertise, November 2020.

³⁶¹ Jacob Marsh. “How hot do solar panels get? Effect of temperature on solar performance,” (Energy Sage, July 2020), <https://news.energysage.com/solar-panel-temperature-overheating/>.

³⁶² Kerry B. Burke, “The reliability of distributed solar in critical peak demand: A capital value assessment,” *Renewable Energy* 68(2014): 103–110. <https://doi.org/10.1016/j.renene.2014.01.042>.

³⁶³ F. Salamanca, M. Georgescu, A. Mahalov, M. Moustauoui & A. Martilli, “Citywide Impacts of Cool Roof and Rooftop Solar Photovoltaic Deployment on Near-Surface Air Temperature and Cooling Energy Demand,” *Boundary-Layer Meteorology* 161(2016): 203–221. <https://doi.org/10.1007/s10546-016-0160-y>.

³⁶⁴ Philadelphia Water Department, “Climate-Resilient Planning and Design Guidance: Building Our Future Today,” (Philadelphia Water Department, January 2022), <https://water.phila.gov/pool/files/climate-resilient-guidance.pdf>.

³⁶⁵ Pennsylvania Emergency Management Agency, “Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan,” (PEMA, 2023), <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>

³⁶⁶ PA DEP, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP, 2020), p. 108, <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>.

³⁶⁷ Pennsylvania Emergency Management Agency, “Risk Assessment,” in Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan, (PEMA, 2018), <https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

³⁶⁸ PA DEP, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>.

³⁶⁹ Pennsylvania Emergency Management Agency, “Risk Assessment,” in Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan, (PEMA, 2018), <https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

³⁷⁰ Pennsylvania Emergency Management Agency, “Risk Assessment,” in Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan, (PEMA, 2018), <https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

³⁷¹ PA DEP, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>.

³⁷² Wing, Oliver E. J., William Lehman, Paul D. Bates, Christopher C. Sampson, Niall Quinn, Andrew M. Smith, Jeffrey C. Neal, Jeremy R. Porter, and Carolyn Kousky, “Inequitable Patterns of US Flood Risk in the Anthropocene,” *Nature Climate Change* 12, no. 2 (February 2022): 156–62. <https://doi.org/10.1038/s41558-021-01265-6>

³⁷³ Wing, Oliver E. J., William Lehman, Paul D. Bates, Christopher C. Sampson, Niall Quinn, Andrew M. Smith, Jeffrey C. Neal, Jeremy R. Porter, and Carolyn Kousky, “Inequitable Patterns of US Flood Risk in the Anthropocene,” *Nature Climate Change* 12, no. 2 (February 2022): 156–62. <https://doi.org/10.1038/s41558-021-01265-6>

³⁷⁴ PA DEP, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>.

ogy/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf

³⁷⁵ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf>.

³⁷⁶ Bell, J et al., "Ch. 4: Impacts of Extreme Events on Human Health" in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*, (U.S. Global Change Research Program, 2016) 99–128, <http://dx.doi.org/10.7930/JOBZ63ZV>

³⁷⁷ Tong, V. T., M. E. Zotti, and J. Hsia, "Impact of the Red River catastrophic flood on women giving birth in North Dakota, 1994–2000," *Maternal and Child Health Journal*, 15 (2011), 281–288, doi:10.1007/s10995-010-0576-9.

³⁷⁸ Xiong, X. et al., "Exposure to Hurricane Katrina, post-traumatic stress disorder and birth outcomes," *The American Journal of the Medical Sciences*, 336 (2008), 111–115, doi:10.1097/MAJ.0b013e318180f21c.

³⁷⁹ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf>

³⁸⁰ 6abc, "Roads Reopen after Devastating Flash Flood in Bucks County That Left Seven People Dead," (6abc Philadelphia, August 2, 2023), <https://6abc.com/bucks-county-flood-flash-deaths-upper-makefield-road-closures-lower/13588010/>.

³⁸¹ Lane, K. et al., "Health effects of coastal storms and flooding in urban areas: A review and vulnerability assessment," *Journal of Environmental and Public Health* (2013), <http://dx.doi.org/10.1155/2013/913064>

³⁸² Sarah E. Crawford et al., "Remobilization of Pollutants during Extreme Flood Events Poses Severe Risks to Human and Environmental Health," *Journal of Hazardous Materials* 421 (January 5, 2022): 126691, <https://doi.org/10.1016/j.jhazmat.2021.126691>.

³⁸³ Noor A. Aly et al., "Environmental Impacts of Hurricane Florence Flooding in Eastern North Carolina: Temporal Analysis of Contaminant Distribution and Potential Human Health Risks," *Journal of Exposure Science & Environmental Epidemiology* 31, no. 5 (September 2021): 810–22, <https://doi.org/10.1038/s41370-021-00325-5>.

³⁸⁴ FEMA, "Critical Facilities and Higher Standards," https://www.fema.gov/media-library-data/1436818953164-4f8f6fc191d26a924f67911c5eaa6848/FPM_1_Page_CriticalFacilities.pdf

³⁸⁵ Ready.gov, "Floods," (2020), <https://www.ready.gov/floods>

³⁸⁶ Berkeley La, "Dampness and Mold from Severe Storms and Flooding," (2020), <https://iaqscience.lbl.gov/cc-dampness>

³⁸⁷ U.S. Environmental Protection Agency, "Flood Cleanup: Protecting Indoor Air Quality," (EPA, 2015), <https://www.epa.gov/sites/production/files/2015-09/documents/floods.pdf>

³⁸⁸ Stanke, C., Murray, V., Amlôt, R., Nurse, J., and R. Williams, "The effects of flooding on mental health: Outcomes and recommendations from a review of the literature," *PLOS Currents*, 4 (2012), May 30, DOI: 10.1371/4f9f1fa9c3cae.

³⁸⁹ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

³⁹⁰ Rhea, Danielle, "What are Combined Sewer Overflows?" (PennState Extension, updated January 22, 2024), <https://extension.psu.edu/what-are-combined-sewer-overflows#:~:text=Pennsylvania%20is%20considered%20to%20have%20the%20largest%20CSO,Pennsylvania%20including%20Pittsburgh%2C%20Philadelphia%2C%20and%20Harrisburg%20experience%20CSOs>.

³⁹¹ Qiang, Yi, "Disparities of Population Exposed to Flood Hazards in the United States," *Journal of Environmental Management* 232 (February 2019): 295–304, <https://doi.org/10.1016/j.jenvman.2018.11.039>.

³⁹² Russek, Karl, "Building Community Capacity at the Intersection of Water, Equity, and Climate Change," (The Water Center at Penn, 2020), <https://watercenter.sas.upenn.edu/building-community-capacity-at-the-intersection-of-water-equity-and-climate-change/>

³⁹³ National Association for the Advancement of Colored People, "Equity in Building Resilience in Adaptation Planning," (NAACP, 2016), https://www.naacp.org/wp-content/uploads/2016/04/Equity_in_Resilience_Building_Climate_Adaptation_Indicators_FINAL.pdf

³⁹⁴ NAACP, "Equity in Building Resilience in Adaptation Planning," (2016).

³⁹⁵ U.S. Water Alliance, "Water Rising: Equitable Approaches to Urban Planning," (2020), www.uswateralliance.org/sites/uswateralliance.org/files/publications/Final_US_WA_Water%20Rising_0.pdf

- ³⁹⁶ U.S. Water Alliance, "Water Rising: Equitable Approaches to Urban Planning," (2020), www.uswateralliance.org/sites/uswateralliance.org/files/publications/Final_US_WA_Water%20Rising_O.pdf
- ³⁹⁷ U.S. Water Alliance, "Water Rising: Equitable Approaches to Urban Planning," (2020), www.uswateralliance.org/sites/uswateralliance.org/files/publications/Final_US_WA_Water%20Rising_O.pdf
- ³⁹⁸ Chesapeake Bay Foundation, "Environmental Justice Projects Take Hold," <https://www.cbf.org/about-cbf/locations/pennsylvania/whats-up-in-pennsylvania/environmental-justice-projects-take-hold.html>
- ³⁹⁹ Rebekah Frankson et al., "Pennsylvania State Climate Summary 2022," NOAA Technical Report NESDIS 150-PA (NOAA/NESDIS, 2022), <https://statesummaries.ncics.org/chapter/pa>.
- ⁴⁰⁰ NBC10 First Alert Weather, "'100-Year Flood' Leads to Water Rescues in Bucks County, NJ," (NBC10 Philadelphia, July 12, 2021), <https://www.nbcphiladelphia.com/weather/stories-weather/first-alert-strong-storms-monday/2876555/>.
- ⁴⁰¹ Bucks County, PA, "Ida Brings Heavy Rains to All of Bucks, River Flooding Remains a Threat," (Accessed November 1, 2023), <https://buckscounty.gov/CivicAlerts.aspx?AID=190>.
- ⁴⁰² USDA Farm Agency, "Disaster Designation Information," <https://fsa.usda.gov/programs-and-services/disaster-assistance-program/disaster-designation-information/index>.
- ⁴⁰³ USDA, "USDA Offers Disaster Assistance to Farmers and Livestock Producers in Pennsylvania Impacted by Hurricane Ida," September 30, 2021, <https://fsa.usda.gov/state-offices/Pennsylvania/news-releases/2021/usda-offers-disaster-assistance-to-farmers-and-livestock-producers-in-pennsylvania-impacted-by-hurricane-ida>.
- ⁴⁰⁴ Cai, X., et al., "Impacts of climate change on agricultural water management: a review," (Wiley Interdisciplinary Reviews Water, 2015), doi:10.1002/wat2.1089
- ⁴⁰⁵ Kukal, Meetpal, Kyle Alexander Imhoff, and Suat Irmak, "Crop Loss and Climate-Risk in Pennsylvania," (PSU, March 9, 2023), <https://extension.psu.edu/crop-loss-and-climate-risk-in-pennsylvania>.
- ⁴⁰⁶ Southwest Climate Hub, "Agricultural Risk," (Southwest Climate Hub, accessed September 14, 2023), <https://swclimatehub.info/rma/rma-data-viewer.html>.
- ⁴⁰⁷ Pennsylvania Department of Agriculture, "Pennsylvania Agriculture: A Look at the Economic Impact and Future Trends," (2018), https://www.agriculture.pa.gov/Documents/PennsylvaniaAgriculture_EconomicImpactFutureTrends.pdf
- ⁴⁰⁸ AP News, "Heavy Rains Swamp Northeast Again as Flash Flooding Claims at Least 5 Lives in Pennsylvania | AP News," <https://apnews.com/article/flash-flooding-pennsylvania-deaths-c0b3fc0c9c3e40b4cd33c8dc0ad50c14>.
- ⁴⁰⁹ Schneck, Marcus, "Flood Worries from Ida Lead to Closure of State Park, State Forest Campsites," (PennLive, September 1, 2021), <https://www.pennlive.com/weather/2021/09/flood-worries-from-ida-lead-to-closure-of-state-park-state-forest-campsites.html>
- ⁴¹⁰ Pierce, P., "Flooding closes recreation areas as holiday weekend under way," (2013), <https://archive.triblive.com/local/westmoreland/flooding-closes-recreation-areas-as-holiday-weekend-under-way/>
- ⁴¹¹ Schneck, Marcus, "Flooding damage minor in Pennsylvania's state parks and forests," (PennLive, January 30, 2019), https://www.pennlive.com/wildaboutpa/2018/07/flooding_damage_minor_in_penns.html.
- ⁴¹² The Associated Press, "5 days of heavy rain bring flood waters, prompt evacuations," (*Herald Mail Media*, July 28, 2018), https://www.heraldmillmedia.com/news/tri_state/pennsylvania/5-days-of-heavy-rain-bring-flood-waters-prompt-evacuations/article_59671c28-9003-11e8-b1c1-072ffa1adfb.html
- ⁴¹³ Pierce, P., "Flooding closes recreation areas as holiday weekend under way," (2013), <https://archive.triblive.com/local/westmoreland/flooding-closes-recreation-areas-as-holiday-weekend-under-way/>
- ⁴¹⁴ Pennsylvania DCNR, "Tropical Storm Lee leaves state parks awash in central, eastern Pa.," (DCNR, 2014), <http://www.apps.dcnr.state.pa.us/news/resource/res2011/11-0914-spdamagelee.aspx>
- ⁴¹⁵ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015). <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.
- ⁴¹⁶ Pennsylvania Department of Environmental Protection, "2022 Pennsylvania Integrated Water Quality Report," (DEP, July 8, 2022), <https://storymaps.arcgis.com/stories/b9746eec807f48d99decd3a583eede12>

- ⁴¹⁷ Pennsylvania DCNR, "Climate Change Adaptation and Mitigation Plan," (DCNR, 2018), <https://www.dcnr.pa.gov/Conservation/ClimateChange/Pages/default.aspx>.
- ⁴¹⁸ Pennsylvania DCNR, "Climate Change Adaptation and Mitigation Plan," (DCNR, 2018), <https://www.dcnr.pa.gov/Conservation/ClimateChange/Pages/default.aspx>.
- ⁴¹⁹ Pennsylvania DCNR, Office of Policy and Planning, Department staff expertise, November 2020.
- ⁴²⁰ Fowler et al., "Flood Mitigation for Pennsylvania's Rural Communities: Community-Scale Impact of Federal Policies," (Center for Rural Pennsylvania, 2018), <https://www.rural.palegislature.us/documents/reports/Flood-Mitigation-2017.pdf>
- ⁴²¹ National Weather Service (NWS), "2018 in Context: Record Precipitation across Pennsylvania. National Oceanic and Atmospheric Administration," <https://www.weather.gov/ctp/RecordPrecip2018>.
- ⁴²² Fowler et al., "Flood Mitigation for Pennsylvania's Rural Communities: Community-Scale Impact of Federal Policies," (Center for Rural Pennsylvania, 2018), <https://www.rural.palegislature.us/documents/reports/Flood-Mitigation-2017.pdf>
- ⁴²³ FloodList, "USA – Deadly Flash Floods Hit Pennsylvania," (FloodList, accessed November 21, 2023), <https://floodlist.com/america/usa/flash-floods-pennsylvania-july-2019>.
- ⁴²⁴ The Independent, "Five Dead and Two Kids Missing after Cars Swept Away in Pennsylvania Flash Flooding," (Independent, July 17, 2023), <https://www.independent.co.uk/climate-change/news/pennsylvania-flooding-bucks-county-dead-b2376208.html>.
- ⁴²⁵ Pennsylvania Water Science Center, "USGS Releases Products Documenting Effects of Hurricane Ida | U.S. Geological Survey," (USGS, accessed November 21, 2023). <https://www.usgs.gov/centers/pennsylvania-water-science-center/news/usgs-releases-products-documenting-effects-hurricane>.
- ⁴²⁶ FloodList, "USA – Over 40 Killed in Floods After Storm Ida Dumps Record Rainfall in New York and New Jersey," (FloodList, accessed November 21, 2023), <https://floodlist.com/america/usa/floods-hurricane-ida-newyork-newjersey-pennsylvania-september-2021>.
- ⁴²⁷ Pennsylvania Media, "Governor Wolf Requests Federal Aid for Severe Storms in August," (PA Media, 2018), <https://www.media.pa.gov/Pages/PEMA-Details.aspx?newsid=85>
- ⁴²⁸ PennDOT, "PennDOT Estimates over \$105M in Flood, Slide Damages," (PennDOT, 2018), <https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165>
- ⁴²⁹ Post-Gazette, "Flooding shuts down many local roads; some school districts close," (Post-Gazette, January 12, 2018), <https://www.post-gazette.com/local/region/2018/01/12/TRAFFIC-Flooding-closes-pittsburgh-roads-Mon-Wharf-roadwork/stories/201801120139>
- ⁴³⁰ David Templeton, "Precipitation rates raising the potential for flooding," (Post-Gazette, April 15, 2018), <https://www.post-gazette.com/local/city/2018/04/15/Rain-raising-concern-National-Weather-Service-landslide-flooding/stories/201804150192>
- ⁴³¹ Post-Gazette, "Rainstorms cause damage, flooding throughout region," (Post-Gazette, February 15, 2018), <https://www.post-gazette.com/local/region/2018/02/15/Rainstorms-cause-damage-flooding-throughout-region-Allegheny-Beaver-Washington-Westmoreland/stories/201802150227>
- ⁴³² Pennsylvania Department of Environmental Protection, "Climate Change in PA", <https://www.depgis.state.pa.us/ClimateChange/index.html>
- ⁴³³ Fowler et al., "Flood Mitigation for Pennsylvania's Rural Communities: Community-Scale Impact of Federal Policies," (Center for Rural Pennsylvania, 2018), <https://www.rural.palegislature.us/documents/reports/Flood-Mitigation-2017.pdf>
- ⁴³⁴ Pennsylvania Real-Time News, "For Pa. farmers, year of record rain a 'big nuisance,'" (PennLive, 2019), <https://www.pennlive.com/news/2019/06/for-pa-farmers-year-of-record-rain-often-a-big-nuisance.html>
- ⁴³⁵ Post-Gazette.com, "For farmers in Pa. and beyond, heavy rain has turned planting into erratic waiting game" (Post-Gazette, June 1, 2019), <https://www.post-gazette.com/business/pittsburgh-company-news/2019/06/01/As-rains-thrash-the-Midwest-AccuWeather-lowers-expectations-for-corn-and-soybeans/stories/201906010024>
- ⁴³⁶ Federal Reserve Bank of St. Louis, "Crop Prices and Flooding: Will 2019 Be a Repeat of 1993?" (June 6, 2019), <https://www.stlouisfed.org/on-the-economy/2019/june/crop-prices-flooding-2019-repeat-1993>
- ⁴³⁷ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁴³⁸ Post-Gazette.com, "For farmers in Pa. and beyond, heavy rain has turned planting into erratic waiting game" (Post-Gazette, June 1, 2019), <https://www.post-gazette.com/business/pittsburgh-company-news/2019/06/01/As-rains-thrash-the-Midwest-AccuWeather-lowers-expectations-for-corn-and-soybeans/stories/201906010024>

⁴³⁹ US Department of Commerce, NOAA, "2018 in Context: Record Precipitation," NOAA's National Weather Service, <https://www.weather.gov/ctp/RecordPrecip2018>.

⁴⁴⁰ Pennsylvania State University, "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁴⁴¹ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015). <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁴⁴² PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁴⁴³ Amico, C., DeBelius, D., Detrow, S. and M. Stiles, "Shale Play: Natural Gas Drilling in Pennsylvania," (StateImpact Pennsylvania, 2011), <http://stateimpact.npr.org/pennsylvania/drilling/>

⁴⁴⁴ DEP, "Act 13 Frequently Asked Questions," (DEP, 2020), <https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/Act13/Pages/Act-13-FAQ.aspx>

⁴⁴⁵ Mall, A., "Big storms and fracking: what's at stake?" (Natural Resources Defense Council, 2012), <https://www.nrdc.org/experts/amy-mall/big-storms-and-fracking-whats-stake>

⁴⁴⁶ DEP, "Municipal Waste Landfills and Resource Recovery Facilities," (DEP, 2020), <https://www.dep.pa.gov/Business/Land/Waste/SolidWaste/MunicipalWaste/MunicipalWastePermitting/Pages/MW-Landfills-and-Resource-Recovery-Facilities.aspx>

⁴⁴⁷ Cosier, Susan, "Great Lakes Levels Are Rising – a Sign of Things to Come?" (NRDC, 2019), <https://www.nrdc.org/stories/great-lakes-levels-are-rising-sign-things-come>

⁴⁴⁸ Epstein, Jenna, Carolyn Kousky, and Zoe Linder-Baptie, "The National Flood Insurance Program in Pennsylvania," (2021).

⁴⁴⁹ FEMA, "Flood Insurance," (FEMA, 2020), <https://www.fema.gov/flood-insurance>

⁴⁵⁰ First Street Foundation, "The 4th National Risk Assessment: Climbing Commercial Closures," (First Street Foundation, Arup, December 13, 2021). <https://assets.firststreet.org/uploads/2021/11/The-4th-National-Risk-Assessment-Climbing-Commercial-Closures.pdf>.

^v Center for Climate Integrity, "Cost Crisis," <https://climateintegrity.org/uploads/media/Pennsylvania-ClimateCostStudy-2023.pdf>.

⁴⁵² PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁴⁵³ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁴⁵⁴ The Nature Conservancy, "Natural Solutions to Stormwater Pollution," <https://www.nature.org/en-us/about-us/where-we-work/united-states/pennsylvania/stories-in-pennsylvania/natural-solutions-to-stormwater/>

⁴⁵⁵ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁴⁵⁶ Pennsylvania State Council of the American Society of Civil Engineers, "2022 Report Card for Pennsylvania's Infrastructure," (ASCE, November 15, 2022), <https://infrastructurereportcard.org/wp-content/uploads/2016/10/PA-Report-Card-2022.pdf>

⁴⁵⁷ Pennsylvania Emergency Management Agency, "Risk Assessment," in Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan, (PEMA, 2018), <https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

- ⁴⁵⁸ Pennsylvania Office of Water Programs, Department staff expertise, November 2020.
- ⁴⁵⁹ High confidence denotes “Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus,” The full list of models included in this analysis is included in Appendix C.
- ⁴⁶⁰ Crimmins, A.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, *Fifth National Climate Assessment*, (USGCRP 2003), <https://doi.org/10.7930/NCA5.2023>
- ⁴⁶¹ Davis et al., “Changing heat-related mortality in the United States,” *Environmental Health Perspectives*. 111 (2003): 1712–1718. <https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336>
- ⁴⁶² A. M. Vicedo-Cabrera et al., “The Burden of Heat-Related Mortality Attributable to Recent Human-Induced Climate Change,” *Nature Climate Change* 11, no. 6 (June 2021): 492–500, <https://doi.org/10.1038/s41558-021-01058-x>.
- ⁴⁶³ “National Environmental Public Health Tracking Network Data Explorer,” (National Center for Health Statistics, accessed September 15, 2023), <https://ephtracking.cdc.gov/DataExplorer>.
- ⁴⁶⁴ Kate R. Weinberger et al., “Estimating the Number of Excess Deaths Attributable to Heat in 297 United States Counties,” *Environmental Epidemiology* 4, no. 3 (June 2020): e096, <https://doi.org/10.1097/EE9.000000000000096>.
- ⁴⁶⁵ Davis et al., “Changing heat-related mortality in the United States,” *Environmental Health Perspectives*. 111 (2003): 1712–1718. <https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336>
- ⁴⁶⁶ Kuehn, L., and McCormick, S., “Heat Exposure and Maternal Health in the Face of Climate Change,” *International journal of environmental research and public health*, 14, no. 8 (2017): 853. <https://doi.org/10.3390/ijerph14080853>
- ⁴⁶⁷ Vaidyanathan et al., “Heat-Related Deaths – United States, 2004–2018,” Centers for Disease Control and Prevention Morbidity and Mortality Weekly Report (MMWR) 69 (2020): 729–734. <https://www.cdc.gov/mmwr/volumes/69/wr/mm6924a1.htm>
- ⁴⁶⁸ Kacie Bogar et al., “Climate Change and Ambient Temperature Extremes: Association With Serious Hypoglycemia, Diabetic Ketoacidosis, and Sudden Cardiac Arrest/Ventricular Arrhythmia in People With Type 2 Diabetes,” *Diabetes Care* 45, no. 11 (October 7, 2022): e171–73, <https://doi.org/10.2337/dc22-1161>.
- ⁴⁶⁹ Davis et al., “Changing heat-related mortality in the United States,” *Environmental Health Perspectives*. 111 (2003): 1712–1718. <https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336>
- ⁴⁷⁰ Pennsylvania Department of Agriculture, November 2020, Department staff expertise.
- ⁴⁷¹ Vaidyanathan et al., “Heat-Related Deaths – United States, 2004–2018,” Centers for Disease Control and Prevention Morbidity and Mortality Weekly Report (MMWR) 69 (2020): 729–734. <https://www.cdc.gov/mmwr/volumes/69/wr/mm6924a1.htm>
- ⁴⁷² U.S. Global Change Research Program, “The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” (USGCRP, 2016), <https://health2016.globalchange.gov/>
- ⁴⁷³ Bouchama, A et al., “Prognostic Factors in Heat Wave-Related Deaths,” *Journal of the American Medical Association Internal Medicine* 167, no. 20 (2007): 2170–2176. <https://pubmed.ncbi.nlm.nih.gov/17698676/>
- ⁴⁷⁴ U.S. Global Change Research Program, “The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment,” (USGCRP, 2016), <https://health2016.globalchange.gov/>
- ⁴⁷⁵ Vaidyanathan et al., “Heat-Related Deaths – United States, 2004–2018,” Centers for Disease Control and Prevention Morbidity and Mortality Weekly Report (MMWR) 69 (2020): 729–734. <https://www.cdc.gov/mmwr/volumes/69/wr/mm6924a1.htm>
- ⁴⁷⁶ Kuehn, L., and McCormick, S., “Heat Exposure and Maternal Health in the Face of Climate Change,” *International journal of environmental research and public health*, 14, no. 8 (2017): 853. <https://doi.org/10.3390/ijerph14080853>
- ⁴⁷⁷ Kuehn, L., and McCormick, S., “Heat Exposure and Maternal Health in the Face of Climate Change,” *International journal of environmental research and public health*, 14, no. 8 (2017): 853. <https://doi.org/10.3390/ijerph14080853>
- ⁴⁷⁸ Ha, et al., “Ambient Temperature and Early Delivery of Singleton Pregnancies,” *Environmental Health Perspectives* (2017), <https://doi.org/10.1289/EHP97>
- ⁴⁷⁹ Veenema, et al., “Climate Change-Related Environmental Exposures and Perinatal and Maternal Health Outcomes” in the U.S. *International Journal of Environmental Research and Public Health* (2023), <https://doi.org/10.3390/ijerph20031662>.
- ⁴⁸⁰ Manuck, et al., “Preterm Neonatal Morbidity and Mortality by Gestational Age: A Contemporary Cohort,” *American Journal of Obstetrics and Gynecology* (2016), <https://doi.org/10.1016/j.ajog.2016.01.004>.

- ⁴⁸¹ U.S. Department of Labor, Occupational Safety and Health Administration, "Protective Measures to Take at Each Risk Level," https://www.osha.gov/SLTC/heatillness/heat_index/protective_low.html#:~:text=Most%20people%20can%20work%20safely,close%20to%20the%20work%20area.
- ⁴⁸² Jisung Park, Nora M. C. Pankratz, and A. Behrer, "Temperature, Workplace Safety, and Labor Market Inequality," *SSRN Electronic Journal* (2021), <https://doi.org/10.2139/ssrn.3892588>.
- ⁴⁸³ Dahl, K., et al., "Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century," In *Environmental Research Communications* (2019), <https://doi.org/10.1088/2515-7620/ab27cf>
- ⁴⁸⁴ Cianconi et al., "The impact of climate change on mental health: A systematic descriptive review," *Front Psychiatry*. 11, 74 (2020), <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/>
- ⁴⁸⁵ Cianconi et al., "The impact of climate change on mental health: A systematic descriptive review," *Front Psychiatry*. 11, 74 (2020), <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/>
- ⁴⁸⁶ Cianconi et al., "The impact of climate change on mental health: A systematic descriptive review," *Front Psychiatry*. 11, 74 (2020), <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/>
- ⁴⁸⁷ Ranson, M., "Crime, weather, and climate change," In *Journal of Environmental Economics and Management*, 67, no. 3 (2014): 274–302. <https://doi.org/10.1016/j.jeem.2013.11.008>
- ⁴⁸⁸ Hsu, Angel, Glenn Sheriff, Tirthankar Chakraborty, and Diego Manya, "Disproportionate Exposure to Urban Heat Island Intensity across Major US Cities," *Nature Communications* 12, no. 1 (May 25, 2021): 2721, <https://doi.org/10.1038/s41467-021-22799-5>.
- ⁴⁸⁹ Marcotullio, et al., "Local power outages, heat, and community characteristics in New York City," *Sustainable Cities and Society* (December 2023), <https://doi.org/10.1016/j.scs.2023.104932>
- ⁴⁹⁰ Bhattacharyya, et al., "A data-driven approach to quantify disparities in power outages," *Sci Rep.* (2023), <https://doi.org/10.1038/s41598-023-34186-9>
- ⁴⁹¹ Hsu, Angel, Glenn Sheriff, Tirthankar Chakraborty, and Diego Manya, "Disproportionate Exposure to Urban Heat Island Intensity across Major US Cities," *Nature Communications* 12, no. 1 (2021): 2721. <https://doi.org/10.1038/s41467-021-22799-5>
- ⁴⁹² Maxwell et al., "Built Environment, Urban Systems, and Cities" in *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment* (USGCRP, 2018), DOI:10.7930/NCA4.2018.CH11
- ⁴⁹³ Park, Jisung, Nora M. C. Pankratz, and A. Behrer, "Temperature, Workplace Safety, and Labor Market Inequality," *SSRN Electronic Journal* (2021), <https://doi.org/10.2139/ssrn.3892588>.
- ⁴⁹⁴ Khatana, Sameed Ahmed M., Rachel M. Werner, and Peter W. Groeneveld, "Association of Extreme Heat With All-Cause Mortality in the Contiguous US, 2008–2017," *JAMA Network Open* 5, no. 5 (May 19, 2022): e2212957, <https://doi.org/10.1001/jamanetworkopen.2022.12957>.
- ⁴⁹⁵ EPA, "Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts," (U.S. Environmental Protection Agency, September 2021), https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.
- ⁴⁹⁶ EPA, "Climate Change and Social Vulnerability in the United States: A Focus on Six Impacts," (U.S. Environmental Protection Agency, September 2021), https://www.epa.gov/system/files/documents/2021-09/climate-vulnerability_september-2021_508.pdf.
- ⁴⁹⁷ City of Philadelphia Office of Sustainability, "Beat the Heat Hunting Park: A Community Heat Relief Plan," (2019), https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf.
- ⁴⁹⁸ City of Philadelphia Office of Sustainability, "Beat the Heat Hunting Park: A Community Heat Relief Plan," (2019), https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf.
- ⁴⁹⁹ Pennsylvania Department of Agriculture, Department staff expertise, November 2020.
- ⁵⁰⁰ Pennsylvania Emergency Management Agency, Department staff expertise, November 2020.
- ⁵⁰¹ Pennsylvania Department of Environmental Protection, Office of Water Programs, Department staff expertise, November 2020.
- ⁵⁰² Michelle Tigchelaar, David S. Battisti, and June T. Spector, "Work Adaptations Insufficient to Address Growing Heat Risk for U.S. Agricultural Workers," *Environmental Research Letters: ERL [Web Site]* 15, no. 9 (September 2020): 094035, <https://doi.org/10.1088/1748-9326/ab86f4>.
- ⁵⁰³ Pennsylvania DCNR, Office of Policy and Planning, Department staff expertise, November 2020.
- ⁵⁰⁴ Josh Foster et al., "An Advanced Empirical Model for Quantifying the Impact of Heat and Climate Change on Human Physical Work Capacity," *International Journal of Biometeorology* 65, no. 7 (July 2021): 1215–29, <https://doi.org/10.1007/s00484-021-02105-0>.

⁵⁰⁵ “Extreme Heat: The Economic and Social Consequences for the United States,” (Adrienne–Arsht Rockefeller Foundation Resilience Center, August 2021), <https://www.atlanticcouncil.org/in-depth-research-reports/report/extreme-heat-the-economic-and-social-consequences-for-the-united-states/>.

⁵⁰⁶ PennLive, “Heat stroke tops list of weather–related deaths,” (PennLive, 2019), <https://www.pennlive.com/news/2019/07/heat-stroke-tops-list-of-weather-related-deaths.html>

⁵⁰⁷ States at Risk, “America’s Preparedness Report Card 2015: Pennsylvania,” (States at Risk, 2015), https://reportcard.statesatrisk.org/report-card/pennsylvania/extreme_heat_grade

⁵⁰⁸ Center for Climate Integrity, “Pennsylvania’s Looming Climate Cost Crisis: The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise,” (Center for Climate Integrity, July 2023).

⁵⁰⁹ CropProphet, “Heat Waves and Corn Yield”, (CropProphet, 2019), <https://www.cropprophet.com/heat-waves-and-corn-yield-timing-matters/>

⁵¹⁰ Pittsburg Post–Gazette, “How climate change will affect Pennsylvania,” (Pittsburg Post–Gazette, 2012), <https://www.post-gazette.com/news/environment/2012/04/22/How-climate-change-will-affect-Pennsylvania/stories/201204220205>

⁵¹¹ University of Maryland, “Economic Impacts of Climate Change on Pennsylvania,” (UMD, 2008), <http://cier.umd.edu/climateadaptation/Pennsylvania%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf>

⁵¹² University of Maryland, “Economic Impacts of Climate Change on Pennsylvania,” (UMD, 2008), <http://cier.umd.edu/climateadaptation/Pennsylvania%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf>

⁵¹³ Pennsylvania Department of General Services, Department staff expertise, November 2020.

⁵¹⁴ Pennsylvania Emergency Management Agency, Department staff expertise November 2020.

⁵¹⁵ WHYY, “SEPTA Monitoring Effects on Rail Systems as Heat Wave Continues,” WHYY (July 25, 2022), <https://whyy.org/articles/philadelphia-heatwave-2022-septa-service-disruptions/>.

⁵¹⁶ Pennsylvania Department of General Services, Department staff expertise, November 2020.

⁵¹⁷ Pennsylvania Department of Environmental Protection, Office of Water Programs, Department staff expertise, November 2020.

⁵¹⁸ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵¹⁹ City of Pittsburgh, “Resilient Pittsburgh,” (City of Pittsburgh, 2016), https://apps.pittsburghpa.gov/cis/PRA2016_Final_version.pdf.

⁵²⁰ Gariano, S. L. and F. Guzzetti, “Landslides in a changing climate,” *Earth–Science Reviews*, 162 (2016), p. 227–252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁵²¹ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵²² Pennsylvania Emergency Management Agency, “Risk Assessment,” in *Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan*, (PEMA, 2018), <https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

⁵²³ Gariano, S. L. and F. Guzzetti, “Landslides in a changing climate,” *Earth–Science Reviews*, 162 (2016), p. 227–252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁵²⁴ U.S. Geological Survey (USGS), “U.S. Landslide Inventory,” <https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=ae120962f459434b8c904b456c82669d>

⁵²⁵ Pennsylvania Department of Conservation and Natural Resources (DCNR), N.d., “Landslides,” <https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx>

⁵²⁶ Delano, H. L., and J.P. Wilshusen, “Landslides in Pennsylvania: Pennsylvania Geological Survey,” 4th ser., Educational Series 9 (2001), http://elibrary.dcnr.pa.gov/GetDocument?docId=1752504&DocName=ES9_Landslides_Pa.pdf#

⁵²⁷ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵²⁸ Pennsylvania Department of Conservation and Natural Resources (DCNR), N.d., “Landslides,” <https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx>

⁵²⁹ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵³⁰ PA DEP, “Pennsylvania Climate Change Impacts Assessment Update,” (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technol>

ogy/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf

⁵³¹ Center for Disease Control, "Landslides and Mudslides," (CDC, 2018) <https://www.cdc.gov/disasters/landslides.html>

⁵³² Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵³³ Geertsema, M., Highland, L., and Vaugeouis, L., "Chapter 31: Environmental Impact of Landslides," In: *Landslides – Disaster Risk Reduction*. (Springer, 2009), DOI:10.1007/978-3-540-69970-5_31

⁵³⁴ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵³⁵ Food and Agriculture Organization of the United Nations, "Landslides," (2020), [http://www.fao.org/emergencies/emergency-types/landslides/en/?page=3&ipp=10&no_cache=1&tx_dynalist_pil\[par\]=YToxOntzOjE6lkwiO3M6MToiMCI7fQ==](http://www.fao.org/emergencies/emergency-types/landslides/en/?page=3&ipp=10&no_cache=1&tx_dynalist_pil[par]=YToxOntzOjE6lkwiO3M6MToiMCI7fQ==)

⁵³⁶ Pennsylvania Department of Agriculture, Department staff expertise, November 2020.

⁵³⁷ Center for Climate Integrity, "Pennsylvania's Looming Climate Cost Crisis: The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise," (Center for Climate Integrity, July 2023).

⁵³⁸ Pennsylvania Emergency Management Agency, "Landslide" in *Commonwealth of Pennsylvania 2023 Hazard Mitigation Plan*, (PEMA, 2023), <https://www.pema.pa.gov/Mitigation/Planning/Pages/default.aspx>

⁵³⁹ Pennsylvania Department of Conservation and Natural Resources, n.d. Landslides. <https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx>

⁵⁴⁰ The Times, "PennDot faces uphill battle in fixing local landslides," (The Times, 2018), <https://www.timesonline.com/news/20181101/penndot-faces-uphill-battle-in-fixing-local-landslides>

⁵⁴¹ E&E News, "Landslides, explosions spark fear in pipeline country," (E&E News, 2019), <https://www.eenews.net/stories/1060472727>

⁵⁴² TRIBLIVE, "Landslide costs add to PennDOT's funding challenges," (TRIBLIVE, 2019), <https://triblive.com/local/regional/landslide-costs-add-to-penndots-funding-challenges/>

⁵⁴³ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf>

⁵⁴⁴ Gariano, S. L. and F. Guzzetti, "Landslides in a changing climate," *Earth-Science Reviews*, 162 (2016), p. 227-252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁵⁴⁵ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵⁴⁶ Geertsema, M., Highland, L., and Vaugeouis, L., "Chapter 31: Environmental Impact of Landslides," In: *Landslides – Disaster Risk Reduction*. (Springer, 2009), DOI:10.1007/978-3-540-69970-5_31

⁵⁴⁷ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵⁴⁸ Gariano, S. L. and F. Guzzetti, "Landslides in a changing climate," *Earth-Science Reviews*, 162 (2016), p. 227-252. <https://www.sciencedirect.com/science/article/pii/S0012825216302458>.

⁵⁴⁹ Pennsylvania Emergency Management Agency, "Risk Assessment," in *Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan*, (PEMA, 2018),

<https://www.pema.pa.gov/Mitigation/Planning/Documents/PA%202019%20SHMP%20Update.pdf>.

⁵⁵⁰ Pennsylvania DCNR, Bureau of Geological Survey, Department staff expertise, November 2020.

⁵⁵¹ City of Pittsburgh, "Resilient Pittsburgh," (City of Pittsburgh, 2016), https://apps.pittsburghpa.gov/cis/PRA2016_Final_version.pdf.

⁵⁵² PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf>

⁵⁵³ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessment Update.pdf>

⁵⁵⁴ City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015), <https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁵⁵⁵ City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015),

<https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁵⁵⁶ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁵⁷ May, C.L., M.S. Osler, H.F. Stockdon, P.L. Barnard, J.A. Callahan, R.C. Collini, C.M. Ferreira, J. Finzi Hart, E.E. Lentz, T.B. Mahoney, W. Sweet, D. Walker, and C.P. Weaver, "Coastal effects," In: *Fifth National Climate* (U.S. Global Change Research Program, 2023), <https://doi.org/10.7930/NCA5.2023.CH9>

⁵⁵⁸ NOAA, "Relative Sea Level Trend: Annual Mean Relative Sea Level Since 1960 and Regional Scenarios," (NOAA, 2022), https://tidesandcurrents.noaa.gov/sltrends/sltrends_station.shtml?id=8545240

⁵⁵⁹ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁶⁰ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁶¹ U.S. Water Alliance, "Water Rising: Equitable Approaches to Urban Planning," (2020), www.uswateralliance.org/sites/uswateralliance.org/files/publications/Final_US_WA_Water%20Rising_O.pdf

⁵⁶² Buchanan, Maya K, Scott Kulp, Lara Cushing, Rachel Morello-Frosch, Todd Nedwick, and Benjamin Strauss, "Sea Level Rise and Coastal Flooding Threaten Affordable Housing," *Environmental Research Letters* 15, no. 12 (December 1, 2020): 124020. <https://doi.org/10.1088/1748-9326/abb266>.

⁵⁶³ City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015), <https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁵⁶⁴ Griggs, Gary, "Coastal Airports and Rising Sea Levels," *Journal of Coastal Research* 36, no. 5 (June 26, 2020): 1079-92, <https://doi.org/10.2112/JCOASTRES-D-20A-00004.1>.

⁵⁶⁵ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁶⁶ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁶⁷ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁶⁸ Frank Kummer, "As climate changes and seas rise, Philadelphia International Airport is in the crosshairs," (Philadelphia Inquirer, September 17, 2019), <https://www.inquirer.com/science/climate/philadelphia-international-airport-climate-change-sea-level-rise-flooding-delaware-river-20190917.html>

⁵⁶⁹ Frank Kummer, "As climate changes and seas rise, Philadelphia International Airport is in the crosshairs," (Philadelphia Inquirer, September 17, 2019), <https://www.inquirer.com/science/climate/philadelphia-international-airport-climate-change-sea-level-rise-flooding-delaware-river-20190917.html>

⁵⁷⁰ Linda Loyd, "Airport expansion estimate up \$1.2B," (Philadelphia Inquirer, October 2011), https://www.inquirer.com/philly/insights/in_money/20111007_Airport_expansion_estimate_up__1_2B.html#:~:text=The%20long-range%20expansion%20of%20Philadelphia%20airport%20is%20now,Aviation%20Administration%20unveiled%20the%20proposal%20in%20May%202010

⁵⁷¹ University of Pennsylvania, "Climate Change: Impacts and Responses in the Delaware River Basin", (UPenn, 2008), https://planning-org-uploaded-media.s3.amazonaws.com/legacy_resources/awards/studentprojects/2009/pdf/climatechangedelaware.pdf

⁵⁷² Center for Climate Integrity, "Pennsylvania's Looming Climate Cost Crisis: The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise," (Center for Climate Integrity, July 2023).

⁵⁷³ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁵⁷⁴ Ross, A.C., Najjar, R.G., Li, M., Mann, M.E., Ford, S.E., Katz, B., "Sea-level rise and other influences on decadal-scale variations of salinity in a coastal plain estuary," *Estuarine Coastal and Shelf Science* 157 (2015), 79-92.

⁵⁷⁵ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁷⁶ Delaware Valley Regional Planning Commission, "Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania," (Delaware Valley Regional Planning Commission, June 2004).

⁵⁷⁷ Partnership for the Delaware Estuary, "Living Resources" in *Technical Report for the Delaware Estuary and Basin*, (Partnership for the Delaware Estuary, 2017), <https://www.delawareestuary.org/wp-content/uploads/2018/01/TREB-2017-complete.pdf>

⁵⁷⁸ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁵⁷⁹ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁵⁸⁰ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁵⁸¹ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>. PSU. 2015 IA.

⁵⁸² City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015), <https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁵⁸³ Climate Central, "Surging Seas Risk Finder," (Climate Central, 2020), https://riskfinder.climatecentral.org/state/pennsylvania.us?comparisonType=county&forecastType=NOAA2017_int_p50&level=2&unit=ft

⁵⁸⁴ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁵⁸⁵ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

[ogy/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf](http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf)

⁵⁸⁶ National Weather Service, "Fourth Anniversary of the Flooding from Tropical Storm Lee," (NWS, 2015), <https://www.weather.gov/ctp/TSLeeFlooding#:~:text=In%20Pennsylvania%2C%20over%2016%2C000%20homes,lee%20are%20over%20%242%20billion.>

⁵⁸⁷ NOAA National Hurricane Center, "Historical Hurricanes Tracks," (NOAA, 2020), <https://oceanservice.noaa.gov/news/historical-hurricanes/>

⁵⁸⁸ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015), <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁵⁸⁹ Lemcke-Stampone, M., et al., "Chapter 18: Northeast" in *Fourth National Climate Assessment*, (U.S. Global Change Research Program, 2018), <https://nca2018.globalchange.gov/chapter/18/>

⁵⁹⁰ Lemcke-Stampone, M., et al., "Chapter 18: Northeast" in *Fourth National Climate Assessment*, (U.S. Global Change Research Program, 2018), <https://nca2018.globalchange.gov/chapter/18/>

⁵⁹¹ Shengzhi Sun et al., "Tropical Cyclones and Risk of Preterm Birth: A Retrospective Analysis of 20 Million Births across 378 US Counties," *Environment International* 140 (July 2020): 105825, <https://doi.org/10.1016/j.envint.2020.105825>.

⁵⁹² Dodgen, D., D. Donato, N. Kelly, et al., "Mental Health and Well-Being" in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. (U.S. Global Change Research Program, 2016), 217–246. <http://dx.doi.org/10.7930/JOTX3C9H>

⁵⁹³ Bell, J et al., "Impacts of Extreme Events on Human Health" " in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. (U.S. Global Change Research Program, 2016), 99–128. <http://dx.doi.org/10.7930/JOBZ63ZV>

⁵⁹⁴ Lin, S., B. A. Fletcher, M. Luo, R. Chinery, and S. A. Hwang, "Health impact in New York City during the Northeastern blackout of 2003," *Public Health Reports*, 126 (2011), 384–93.

⁵⁹⁵ McKinney, N., Houser, C., Meyer-Arendt, K., "Direct and indirect mortality in Florida during the 2004 hurricane season," *Int J Biometeorol* 55 (2011), 533–546. <https://doi.org/10.1007/s00484-010-0370-9>

⁵⁹⁶ Bell, J et al., "Impacts of Extreme Events on Human Health" " in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. (U.S. Global Change Research Program, 2016), 99–128. <http://dx.doi.org/10.7930/JOBZ63ZV>

⁵⁹⁷ Bell, J et al., "Impacts of Extreme Events on Human Health" " in *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment*. (U.S. Global Change Research Program, 2016), 99–128. <http://dx.doi.org/10.7930/JOBZ63ZV>

⁵⁹⁸ Buchanan, Maya K, Scott Kulp, Lara Cushing, Rachel Morello-Frosch, Todd Nedwick, and Benjamin Strauss, "Sea Level Rise and Coastal Flooding Threaten Affordable Housing," *Environmental Research Letters* 15, no. 12 (December 1, 2020): 124020, <https://doi.org/10.1088/1748-9326/abb266>.

⁵⁹⁹ Urban Sustainability Directors Network (USDN) and Raimi Associates, "Equitable Community-driven Climate Preparedness Planning," (USDN, 2017), 46. https://www.usdn.org/uploads/cms/documents/usdn_guide_to_equitable_community-driven_climate_preparedness-_high_res.pdf

⁶⁰⁰ Clifton, R., Majumder, B., and Kelly, C., "Equitable and Just Hurricane and Disaster Preparedness Amid COVID-19," (Center for American Progress, 2020), <https://www.americanprogress.org/issues/green/reports/2020/09/30/490964/equitable-just-hurricane-disaster-preparedness-amid-covid-19/>

⁶⁰¹ Clifton, R., Majumder, B., and Kelly, C., "Equitable and Just Hurricane and Disaster Preparedness Amid COVID-19," (Center for American Progress, 2020), <https://www.americanprogress.org/issues/green/reports/2020/09/30/490964/equitable-just-hurricane-disaster-preparedness-amid-covid-19/>

⁶⁰² USDA Farm Service Agency, "USDA Offers Disaster Assistance to Farmers and Livestock Producers in Pennsylvania Impacted by Hurricane Ida," (USDA, Sept 30), <https://fsa.usda.gov/state-offices/Pennsylvania/news-releases/2021/usda-offers-disaster-assistance-to-farmers-and-livestock-producers-in-pennsylvania-impacted-by-hurricane-ida>.

⁶⁰³ USDA Farm Service Agency, "USDA Offers Disaster Assistance to Farmers and Livestock Producers in Pennsylvania Impacted by Hurricane Ida," (USDA, Sept 30), <https://fsa.usda.gov/state-offices/Pennsylvania/news-releases/2021/usda-offers-disaster-assistance-to-farmers-and-livestock-producers-in-pennsylvania-impacted-by-hurricane-ida>.

⁶⁰⁴ City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015), <https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁶⁰⁵ Nordeen, D., "Delaware Water Gap News," (National Park Service, 2011), <https://www.nps.gov/dewa/learn/news/storm-damage-assessment-and-cleanup-continue.htm>

⁶⁰⁶ Schneck, Marcus, "Flood Worries from Ida Lead to Closure of State Park, State Forest Campsites," (PennLive, September 1, 202), <https://www.pennlive.com/weather/2021/09/flood-worries-from-ida-lead-to-closure-of-state-park-state-forest-campsites.html>.

⁶⁰⁷ PA DEP, "Pennsylvania Climate Change Impacts Assessment Update," (PA DEP, 2020), <http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf>

⁶⁰⁸ Pennsylvania State University. "Pennsylvania Climate Impacts Assessment Update," (PA DEP, 2015). <https://greenport.pa.gov/elibrary//GetDocument?docId=5002&DocName=2015%20PENNSYLVANIA%20CLIMATE%20IMPACTS%20ASSESSMENT%20UPDATE.PDF%20>.

⁶⁰⁹ Ron, Southwick, "Tens of Thousands in Pa. without Power Due to Ida," (PennLive, September 1, 2021), <https://www.pennlive.com/weather/2021/09/tens-of-thousands-in-pa-without-power-due-to-ida.html>.

⁶¹⁰ National Centers for Environmental Information, "September 2021 National Climate Report," (NCEI, October 2021), <https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202109>.

⁶¹¹ City of Pittsburgh, "Resilient Pittsburgh," (City of Pittsburgh, 2016), https://apps.pittsburghpa.gov/cis/PRA2016_Final_version.pdf.

⁶¹² Climate Central, "Surging Weather-Related Power Outages," (Climate Central, September 14, 2022), <https://www.climatecentral.org/climate-matters/surging-weather-related-power-outages>.

⁶¹³ McDevitt, Rachel, "Pa. Lawmakers Hear Challenges to Electric Grid Reliability; Experts Call for Clear Policy," (StateImpact Pennsylvania, March 2, 2023), <https://stateimpact.npr.org/pennsylvania/2023/03/02/pennsylvania-electric-grid-reliability/>.

⁶¹⁴ Bureau of Technical Utility Services, "Summary Report on the Response of the Electric Distribution Companies Affected by Winter Storms Riley & Quinn," (Pennsylvania Public Utility Commission, March 2019),

https://www.puc.pa.gov/Electric/pdf/Winter_Storm_Riley_Quinn_Report_2019.pdf.

⁶¹⁵ Justine McDaniel and Julia Terruso, "After Ida Destroyed Hundreds of Pa. Homes and Caused More than \$100 Million in Damage, Residents Await Disaster Relief," (The Inquirer, September 8, 2021), <https://www.inquirer.com/news/pennsylvania/hurricane-ida-damage-cost-pennsylvania-20210908.html>.

⁶¹⁶ Kenny Cooper, Emily Rizzo, and Sophia Schmidt, "One Year after Hurricane Ida, Pa. Residents Are Still Paying the Price," (WHYY, September 1, 2022), <https://whyy.org/articles/pennsylvania-hurricane-ida-one-year-anniversary/>.

⁶¹⁷ Childs, Jan, "Tropical Storm Isaias' Aftermath: At Least 12 Dead in Eastern U.S., Millions Left Without Power. Jan Wesner Childs," (The Weather Channel, August 06, 2020), <https://weather.com/storms/hurricane/news/2020-08-05-isaias-damage-impacts-power-outages-flooding-carolina-northeast>

⁶¹⁸ Esri. "A Recap of the Wettest Year on Record in Allegheny County", <https://www.arcgis.com/apps/Cascade/index.html?appid=8834fd8de2954613941caa0553c6adfa>

⁶¹⁹ National Weather Service, "2018 in Context: Record Precipitation across Pennsylvania," National Oceanic and Atmospheric Administration, <https://www.weather.gov/ctp/RecordPrecip2018>

⁶²⁰ Brian Myszkowski and Christopher Dornblaser, "Wolf seeks federal relief funds for Isaias damage in nine PA counties," (Pocono Record, October 6, 2020), <https://www.poconorecord.com/story/news/2020/10/05/gov-wolf-seeks-out-isaias-relief-funds-nine-pa-counties/3631225001/>

⁶²¹ Childs, Jan, "Tropical Storm Isaias' Aftermath: At Least 12 Dead in Eastern U.S., Millions Left Without Power. Jan Wesner Childs," (The Weather Channel, August 06, 2020), <https://weather.com/storms/hurricane/news/2020-08-05-isaias-damage-impacts-power-outages-flooding-carolina-northeast>

⁶²² Pennsylvania Department of Transportation, "PENNDOT Estimates over \$105M in Flood, Slide Damages," (PennDOT, 2018), <https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165>

⁶²³ NWS, "4th Anniversary of the Flooding from Tropical Storm Lee," (NWS, 2015), <https://www.weather.gov/ctp/TSLeeFlooding>

⁶²⁴ Pennsylvania Department of Transportation, "PENNDOT Estimates over \$105M in Flood, Slide Damages," (PennDOT, 2018), <https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165>

⁶²⁵ DCNR, "Forests Insects and Diseases," (DCNR, 2020), <https://www.dcnr.pa.gov/Conservation/ForestsAndTrees/InsectsAndDiseases/pages/default.aspx>

⁶²⁶ DCNR, "Forests Insects and Diseases," (DCNR, 2020), <https://www.dcnr.pa.gov/Conservation/ForestsAndTrees/InsectsAndDiseases/pages/default.aspx>

⁶²⁷ Liu, Ran, and Christopher A. Graf, "Planning for Resilient Drinking Water Systems: Case Studies From Pennsylvania," *Journal AWWA* 113, no. 2 (2021): 22–32, <https://doi.org/10.1002/awwa.1668>.

⁶²⁸ City of Philadelphia Mayor's Office of Sustainability and ICF International, "Toward a Climate-Ready Philadelphia," (City of Philadelphia, 2015), <https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf>.

⁶²⁹ Pierce, D., Cayan, D., and B. Thrasher, "Statistical Downscaling Using Localized Constructed Analogs (LOCA)," *Journal of Hydrometeorology*, 15, no. 6 (2014), p. 2558–2585, <https://doi.org/10.1175/JHM-D-14-0082.1>.

⁶³⁰ Basile, S., A.R. Crimmins, C.W. Avery, B.D. Hamlington, and K.E. Kunkel, "Appendix 3. Scenarios and datasets," in *Fifth National Climate Assessment*, (U.S. Global Change Research Program, 2023), <https://doi.org/10.7930/NCA5.2023.A3>