Pennsylvania Climate Impacts Assessment 2021

Cover Photo(s) TBD

December 15, 2020

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

Pennsylvania Climate Impacts Assessment 2021

Draft Final

December 15, 2020

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Acknowledgements and Disclaimer

This material is based upon work supported by the United States Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE), under the State Energy Program Award Number EE0008293. This report and the analyses contained within it were prepared by the Pennsylvania Department of Environmental Protection (DEP) with support from ICF. The results and discussion in this report reflect the views of DEP.

This report was prepared in response to the Pennsylvania Climate Change Act (Act 70 of 2008), which requires the DEP to prepare a climate change impacts assessment. Revisions to the Impacts Assessment are required every three years. The Pennsylvania Climate Change Advisory Committee (CCAC) provided input and feedback to the DEP and ICF for the preparation of this assessment. The CCAC is composed of 18 members plus 3 “ex Officio members.” This 2021 Impacts Assessment Update is the fifth iteration of the Pennsylvania Climate Impacts Assessment and builds on the work the commonwealth has already done. Different than years past, this 2021 Update offers a risk-based approach to assess risks and prioritize adaptation needs.

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1 EXECUTIVE SUMMARY

Climate change is already affecting Pennsylvania from more severe heat waves to significant flood events. Under Act 70, the Pennsylvania Climate Change Act, the Department of Environmental Protection (DEP) is required to develop an updated Impacts Assessment (IA) and Climate Action Plan (CAP) every three years. The 2021 Impacts Assessment provides an update on the state of the science and identifies relative risks to inform priority adaptation needs that may be considered when developing the CAP; it is not a comprehensive or prescriptive assessment of all potential risks and impacts to Pennsylvania.

1.1 Expected Climate Changes in Pennsylvania

The 2021 IA presents updated climate projections based on the latest available downscaled climate model data. Overall, the latest projections are in line with what has been presented in previous IAs: Pennsylvania is expected to get warmer and wetter, as well as experience changes on its coastlines (including the Delaware Valley Estuary and Lake Erie).

Key expected changes compared to a 1971-2000 baseline include:

- Although temperatures will continue to be variable year-to-year, the **average temperature is trending upward.** Average annual temperature statewide is expected to increase by 5.9°F (3.3°C) by mid-century.
- Increasing average temperatures will cause **more frequent and intense extreme heat events** such as hot days or heat waves. For example, days per year where temperatures reach at least 90°F is expected to increase from 5 to 37 days.
- Increasing temperatures will **alter the growing season** across the Commonwealth and **increase cooling degree-days** (while decreasing heating degree-days).
- **Extreme rainfall events are projected to increase** in magnitude, frequency, and intensity.
- Consecutive dry days are projected to increase, indicating **more potential for drought conditions**.
- On average, Pennsylvania could see **more total rainfall**, but occurring in more spaced out heavy rain events.
- Most **increases in precipitation will occur in the winter and spring** months.
- An increase in **tidally-influenced flooding** is expected in the Delaware Estuary coastal zone.
- Significant changes related to **lake levels, coastal erosion, and water temperatures** are expected in Lake Erie.

Figure 1 shows the projected increase in average annual number days with temperatures above 90°F, which is most significant in the southeast and southwest regions of Pennsylvania. Figure 2 shows the change in number of days with an extreme rainfall, which is most significant in the southeast region of Pennsylvania.

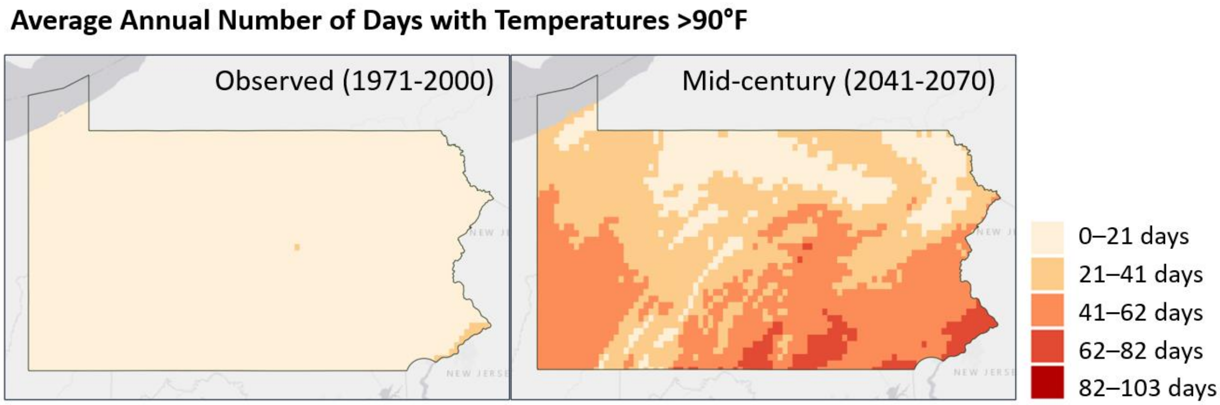


Figure 1. Observed and projected annual numbers of days with temperatures above 90°F.

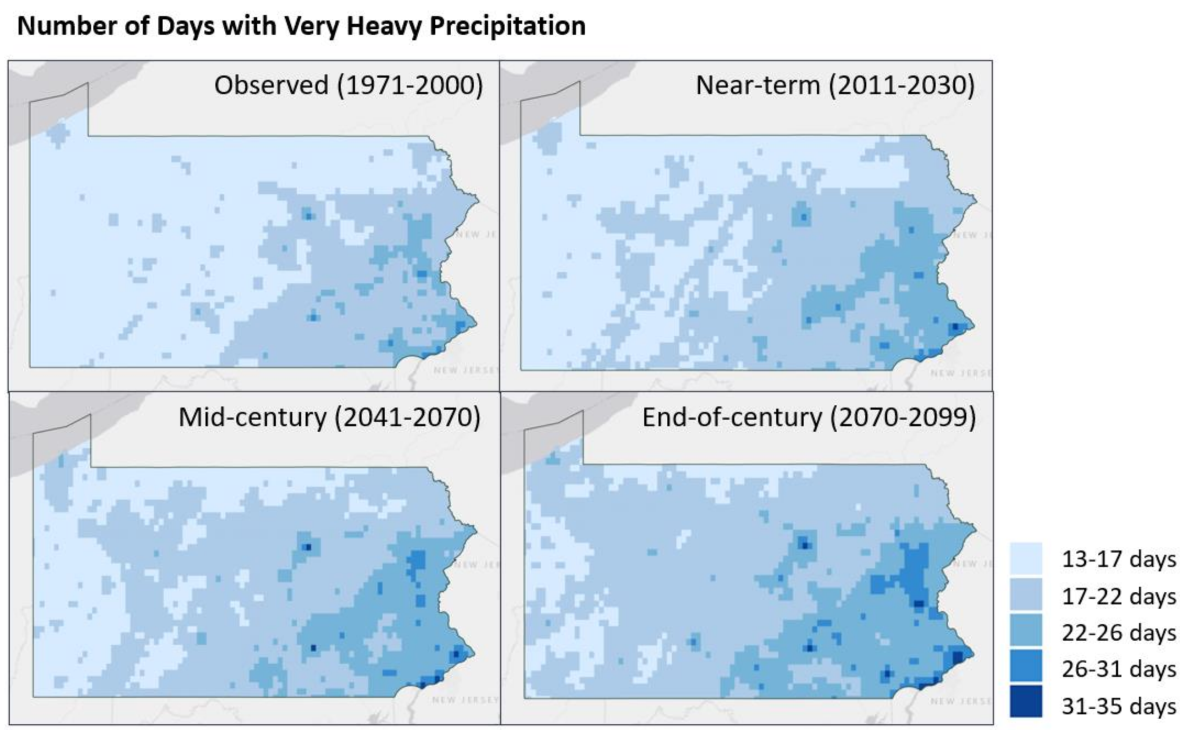


Figure 2. Observed and projected annual number of days with historically "very heavy" precipitation. The "very heavy" threshold varies by grid cell, based on the 95th percentile of observed rainy days.

1.2 Climate Risk Assessment Approach Overview

The IA applies a risk-based method by evaluating the relative likelihood and consequences of key climate hazards, across sectors. Based on the previous IAs, the risk assessment focuses on six primary climate hazards expected to affect the Commonwealth:

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

The IA 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, as appropriate. The likelihood of each hazard occurring is evaluated on a 1-4 scale and the severity of each consequence category is also evaluated on a 1-4 scale across several categories, including:

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

Each hazard then receives an overall risk rating, based on the product of its likelihood and consequence scores, per the matrix in Table 1.

Key Terms

Risk – The chance a climate hazard with cause harm. Risk is a function of the likelihood of an adverse climate impact occurring and the severity of its consequences.

Climate Hazard – Climate related events or indicators, such as temperature and precipitation. Climate hazards can be discrete (e.g., heat wave) or ongoing (e.g., increasing average temperature)

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 – Short for PA Environmental Justice Areas, this includes any census tract where ≥ 20% of individuals live in poverty, and/or ≥ 30% is minority. Populations in these areas are also referred to as EJ populations and EJ communities.

Table 1. Risk Rating Matrix

Likelihood	Consequence			
	Minor (1)	**Limited (2)**	**Critical (3)**	**Catastrophic (4)**
Highly Likely (4)	Medium	High	Extreme	Extreme
Likely (3)	Medium	High	High	Extreme
Possible (2)	Low	Medium	High	High
Unlikely (1)	Low	Low	Medium	Medium

Also new to the 2021 IA is an explicit analysis and consideration of environmental justice and equity. The assessment seeks to answer two key questions:

- Identifying vulnerable communities – Which communities will disproportionately bear the impacts of climate changes?
- Identifying overburdened communities – To what extent are climate changes affecting certain communities that are already disproportionately burdened with environmental, economic, health, or other concerns?

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

This analysis is not a comprehensive bottom-up assessment. While based solidly on evidence from past IAs and updated climate projections[1], 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 facilitate prioritization of adaptation actions that can be taken to reduce risks. Further, it provides the foundation for DEP to easily revisit the results of the assessment as needed as priorities or circumstances change.

1.3 Climate Risk Assessment Results

The risk assessment revealed several key findings:

- **Increasing average temperatures pose the greatest overall risk to Pennsylvania.** Average temperatures affect nearly every aspect of life in the Commonwealth, from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment. Some key potential consequences, if the risk is unmitigated, include:
    - Increased vulnerability to heat-related illness and mortality risks, especially for EJ communities
    - Potential increased energy burden for low-income 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)
- Heat waves will become an increasingly common event, and create a particular health and economic risk for vulnerable populations, including the low-income, elderly, and those with cardiovascular conditions. These risks will be particularly acute in urban areas subject to the urban heat island effect.
- **Flood risks to infrastructure is another priority risk**, whether caused by heavy rain, riverine flooding, stormwater flooding, tropical storms, or sea level rise. Impacts to built infrastructure have ripple effects throughout the economy.
- **Landslides and sea level rise pose relatively low risks statewide, but can cause severe impacts where they occur.** For example, sea level rise in the Delaware estuary could drastically change the makeup of the estuary's ecology and also threaten built infrastructure near the tidal zone. Landslides can have severe consequences if they cut of critical transportation routes, particularly in rural areas.

[1] Updated climate projections are based on the latest available science.

- **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. 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.
- Several of these hazards—especially flooding, severe tropical storms, and landslides—already pose risks today, and could become more likely or severe in the future. Pennsylvania has an opportunity to build on its existing hazard mitigation practices for these risks.
- The gradual nature of many of these changes, however, also creates an **opportunity for the Commonwealth to not only reduce potential harms, but also capitalize on potential positive changes** (e.g., ability to grow new crops). This is particularly true for increasing average temperatures and sea level rise.
- **Risks will continue to grow beyond 2050.** These risk ratings focus on the likelihood and consequences of each hazard by 2050, but all will continue to change after that. Pennsylvania will need to consider longer-term risks for infrastructure and other long-range planning processes that require assumptions about conditions in the late 21st century or beyond.

Climate change impacts are dynamic; the Commonwealth needs to plan for more significant and more complex impacts in the future. 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 2 summarizes the overall risks for 2050. **Increasing average temperatures** and **heat waves** emerged as the two highest risk hazards. Both hazards will impact the entire state and all sectors but will have the highest consequences for human health and environmental justice and equity, especially in urban areas. The long-term warming trend will also have significant negative impacts on winter recreation and tourism and the health of forests, ecosystems, and wildlife.

Both of these hazards and **sea level rise** also had the greatest change in risk score from present day to 2050.

Table 2. Overall Risk Assessment Results

	Climate Hazard	Current Risk Rating	2050 Risk Rating
1	**Increasing average temperatures**	Medium	High
2	**Heat waves**	Medium	High
3	**Heavy precipitation and inland flooding**	Medium	Medium
3	**Landslides**	Medium	Medium
3	**Sea level rise**	Low	Medium
6	**Severe tropical and extra-tropical cyclones**	Medium	Medium

Figure 3 breaks down the consequence ratings per category for each of the hazards, which are presented from left to right by descending overall risk score. The size of the color bar corresponds to the severity of the rating per category. **Increasing average temperatures** and **heavy precipitation and inland flooding** had the most significant consequences overall. The size of each bar indicates the relative severity of each consequence type. For example, human health consequences are greatest for heat waves, heavy precipitation and inland flooding, increasing average temperatures, and severe tropical and extra-tropical cyclones.

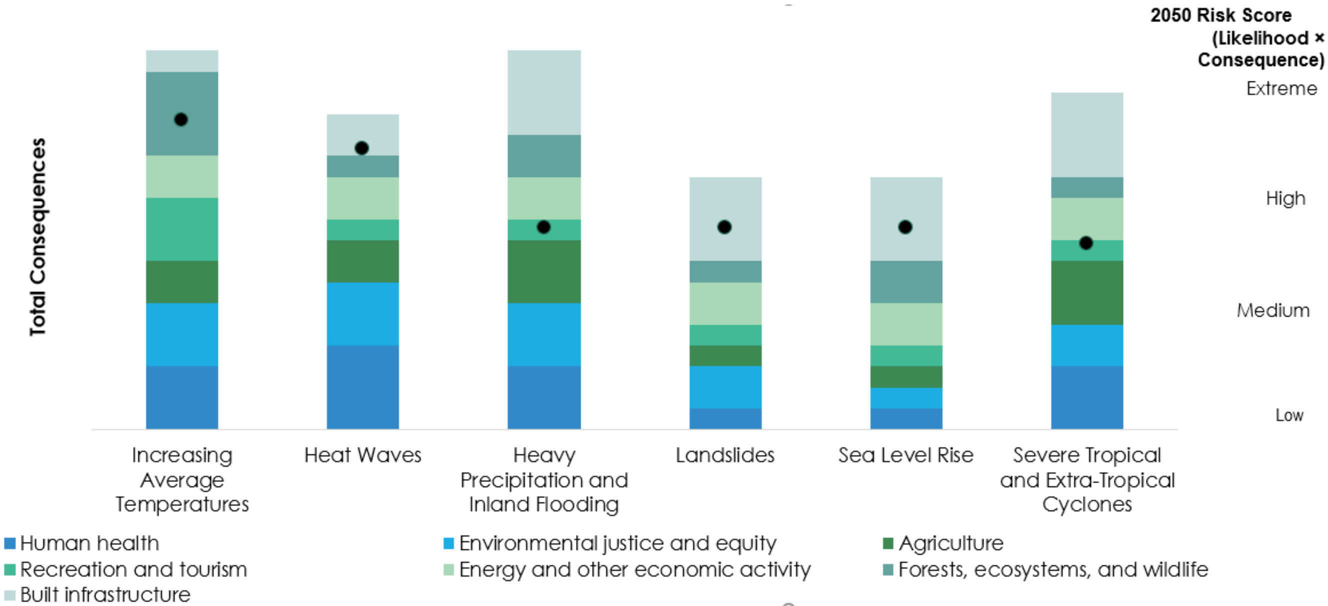


Figure 3. Total Consequences and Risks by Hazard.

In addition, a key theme across this risk assessment is 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 more exposed to heat waves, low-elevation houses more exposed to flood risk) and limitations to their ability to manage consequences if they occur (e.g., being able to purchase an air conditioner on short notice, or being able to read heat safety emergency communications). Consequences of historical discriminatory practices in communities of color (e.g., redlining, systemic disinvestment) manifest today with communities of color 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.

2 INTRODUCTION

2.1 Purpose and objectives

Act 70 of 2008, the Pennsylvania Climate Change Act, requires Pennsylvania to improve its understanding of, and approach to, addressing and adapting to the causes and impacts of climate change. More specifically, the Act requires the Department of Environmental Protection (DEP) to update the Pennsylvania Impacts Assessment (IA) and Climate Action Plan (CAP) every three years. Figure 4 shows a timeline of the IAs completed since 2009. These IAs focus on providing an updated "state of the science" understanding of the range of significant climate change hazards facing Pennsylvania, such as flood events and increasing temperatures. Figure 4 summarizes the IAs completed and in progress.

Key Terms

Climate Hazard – Changes or events related to global climate change that could potentially cause harm, such as increasing temperatures or flooding.

Impact – The effect of a climate hazard.

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

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

Risk – The chance a climate hazard will cause harm. Risk is a function of the likelihood of a climate hazard occurring and the severity of its consequences.

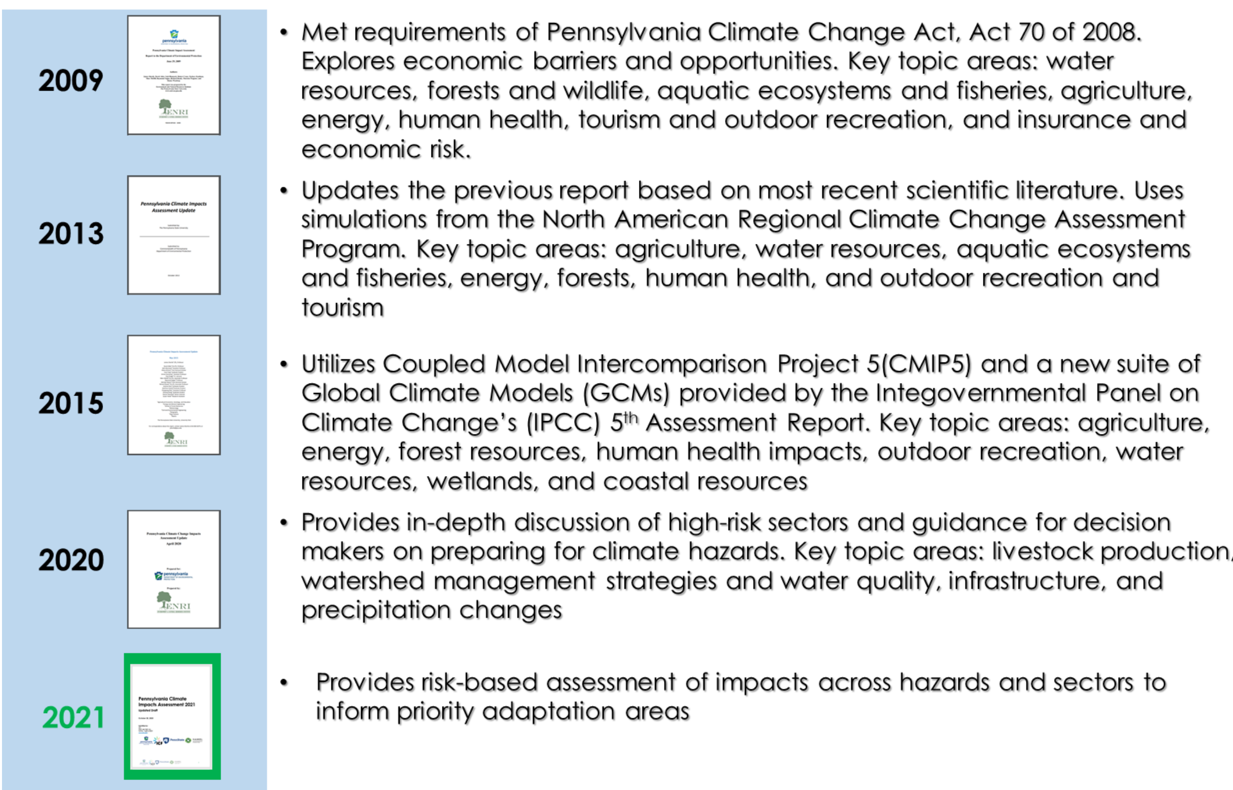


Figure 4. Timeline of Pennsylvania Impact Assessments

Climate change impacts create a variety of risks across sectors, resources, and populations. The 2021 IA is redesigned as a risk-based assessment to directly inform the CAP and help decision-makers identify meaningful and prioritized adaptation actions. See Section 4.1 and Appendix B for details on the risk assessment process.

This IA presents impacts by hazard (e.g. increasing average temperatures, sea level rise) rather than by sector, as was done in past IAs. 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
- Energy and other economic activity
- Forests, ecosystems, and wildlife
- Built infrastructure

Also new to the 2021 IA is an explicit analysis and consideration of environmental justice and equity for each of the hazards included in the risk assessment. The assessment seeks to answer two key questions:

- **Identifying vulnerable communities** – Which communities will disproportionately bear the impacts of climate changes?
- **Identifying overburdened communities** – To what extent are climate changes affecting certain communities that are already disproportionately burdened with environmental, economic, health, or other concerns?

Appendix B provides additional details on the approach to analyzing environmental justice and equity impacts.

This 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.

2.2 Scope

The IA 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, as appropriate. Although risks are evaluated and rated from present-day to mid-century, the IA also describes potential impacts through the 21st century and provides climate projections for late in the 21st century (2090).

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

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

Building on the findings of the previous IAs, a list of key climate hazards and impacts were compiled in Table 13 (see Appendix B). The six selected hazards ultimately represent the primary hazards expected to affect the Commonwealth. Other hazards noted in previous IAs are acknowledged where appropriate, but are not covered in depth, including short-term drought, saltwater intrusion, sinkholes, and stormwater management.

3 EXPECTED CLIMATE CHANGES IN PENNSYLVANIA

3.1 Overview of Key Changes

The 2021 IA presents updated climate projections based on the latest available downscaled climate model data. The projections below are based on a 32-model ensemble from the *Localized Constructed Analogs* (LOCA) dataset, which provides projections on a 1/16th degree grid (see Appendix C for details on the data sources and methods used for climate projections).

Overall, the latest projections are in line with what has been presented in previous IAs: Pennsylvania is expected to get warmer and wetter. Temperature projections indicate that Pennsylvania will see an increase in average annual temperature as well as increasing frequency and intensity of hot, very hot, and extremely hot days. Precipitation projections show that the Commonwealth will see an increase in average annual precipitation, extreme precipitation events, and drought due to more extreme, but less frequent precipitation patterns. The updated climate model analysis shows very similar projections for overall increases in average annual temperature and precipitation (see box).

Quick Comparison: Projections from the 2015 IA vs. 2021 IA

	2015 IA	2021 IA
Average annual temperature	+5.4°F	+5.9°F
Average annual precipitation	+8%	+8%

All projections are statewide averages for a mid-century time period of 2041-2070 vs. a baseline time period of 1971-2000.

New in the 2021 IA are 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.

3.2 Temperature and Precipitation Changes

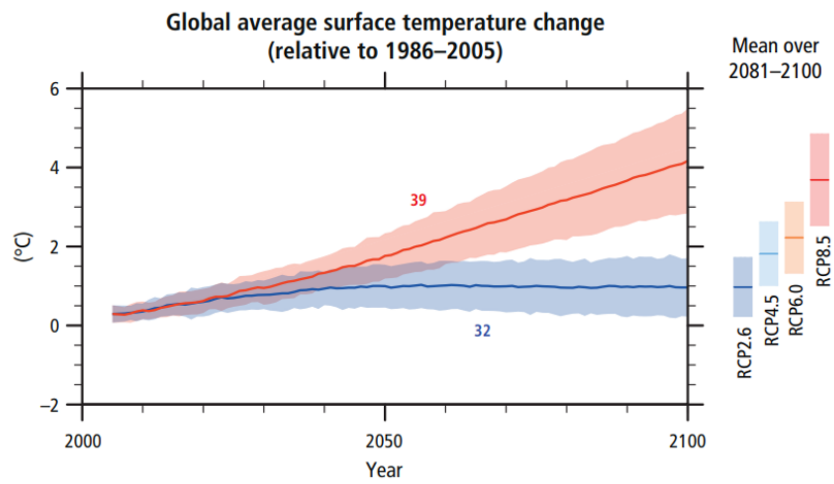
Projected values reported below for both temperature and precipitation represent the averages over three time periods: 2011–2040 (present context), 2041-2070 (mid-century), and 2070-2099 (end-of-century), compared to a baseline period of 1971-2000. All projections represent a statewide average of the 50th percentile of the 32 climate models. The statewide average for the 10th and 90th percentile range across models is also included in Table 3 and Table 4 to illustrate the spread in model projections and highlight the range of possible outcomes.

Key Terms

Representative Concentration Pathways (RCP) –Scenarios of projected GHG emissions and atmospheric concentrations used in climate modeling

See **Appendix A** for specific definitions of climate variables.

The projections reported in the tables and narrative below are based on RCP 8.5 as it represents a global "baseline" scenario without additional efforts to reduce emissions taken. As shown in Figure 5, all emissions scenarios (bookended by RCP 8.5 and RCP 2.6) 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. Temperature projections reported under RCP 4.5, a lower emissions scenario, are included in Appendix C for additional context.



Climate Changes Beyond 2100

Climate change is a dynamic process, and events taking place today can affect the atmosphere for decades into the future. While most readily available climate change projections go through the end of the 21st century, the climate will continue to change well beyond 2100. Exactly how depends on a range of factors, including global greenhouse gas emissions over the next several decades.

Figure 5. Comparison of Projected Global Average Surface Temperature Change between RCP 8.5 (baseline emissions scenario) and RCP 2.6 (lowest emissions scenario). RCP 4.5 is the next lowest emissions scenario compared to RCP 2.6. Source: IPCC Climate Change 2014 Synthesis Report.

In Pennsylvania, for example, projected average annual temperature is expected to rise 9.3°F (5.2°C) by end-of-century under RCP 8.5, but only 5.5°F (3.1°C) under RCP 4.5. See Appendix C for more details on the data sources and methods used for climate projections as well as end-of-century projections under RCP 4.5, a lower emissions scenario.

3.2.1 Temperature

Key Temperature Findings

- Although temperatures will continue to be variable year-to-year, the average is trending upward. Average annual temperature statewide is expected to increase by 5.9°F (3.3°C) by mid-century.
- Increasing average temperatures will cause more frequent and intense extreme heat events such as hot days or heat waves. For example, days per year where temperatures reach at least 90°F is expected to increase from 5 to 37 days.
- Increasing temperatures will alter the growing season across the Commonwealth and increase cooling degree-days (while decreasing heating degree-days).

Across the Commonwealth, temperatures are projected to substantially increase this century. 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.

Overall, Pennsylvania is projected to see higher average temperatures over the course of the next several decades. On average across the state, annual average temperatures are projected to increase by about 5.9°F (3.3°C) by mid-century and 9.4°F (5.2°C) by the end-of-century.

As the climate changes, so will the frequency and severity of extreme temperatures. 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. 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 experiencing 99th percentile maximum daily temperatures. Heat waves are represented 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.

Notably, while the average temperature trends upward, interannual temperature variability will continue; extremely cold temperatures are still very possible. For example, though Pennsylvania has been warming the past decade, the 2017-2018 Polar Vortex created extremely cold conditions for multiple weeks in the State. 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, as shown in Figure 6 and Figure 7. Across all months, average daily temperatures are projected to increase by 4.0-8.0°F (2.2-4.5°C) mid-century and 6.4-12.4°F (3.6-3.9°C) by the end-of-century, with greatest warming in the summer season (see Figure 50 and Figure 51 in Appendix C for observed and projected average daily average and maximum temperatures for each month). 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 (see Figure 7).

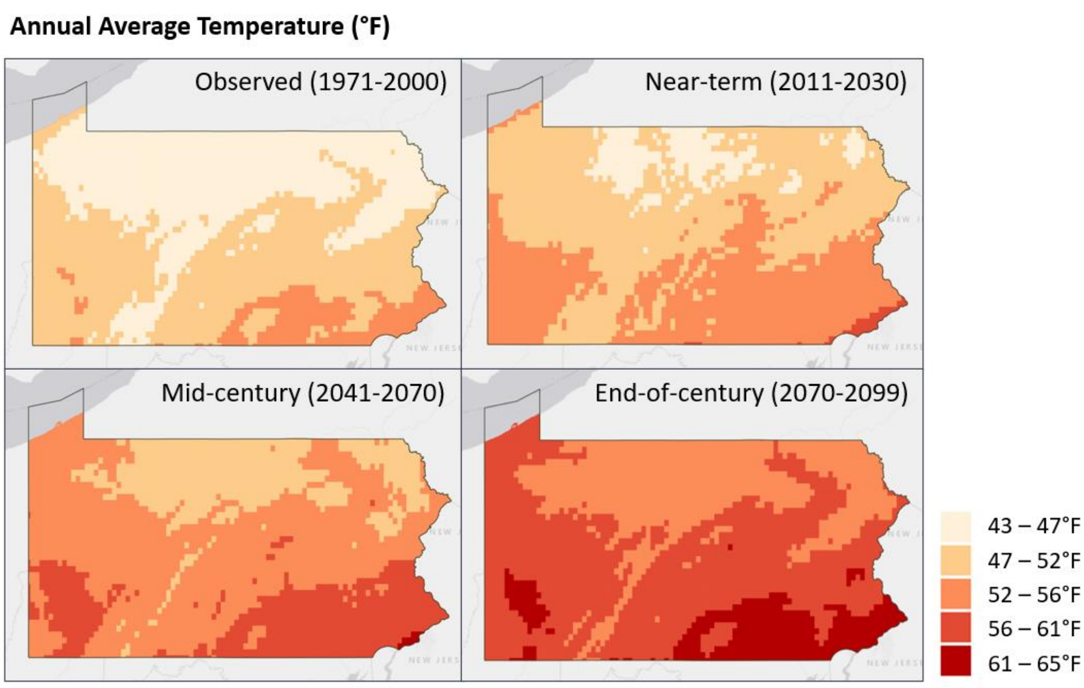


Figure 6. Observed and projected annual average temperatures in Pennsylvania (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). Legend range was selected to include full range of observed and projected values divided into equal increments.

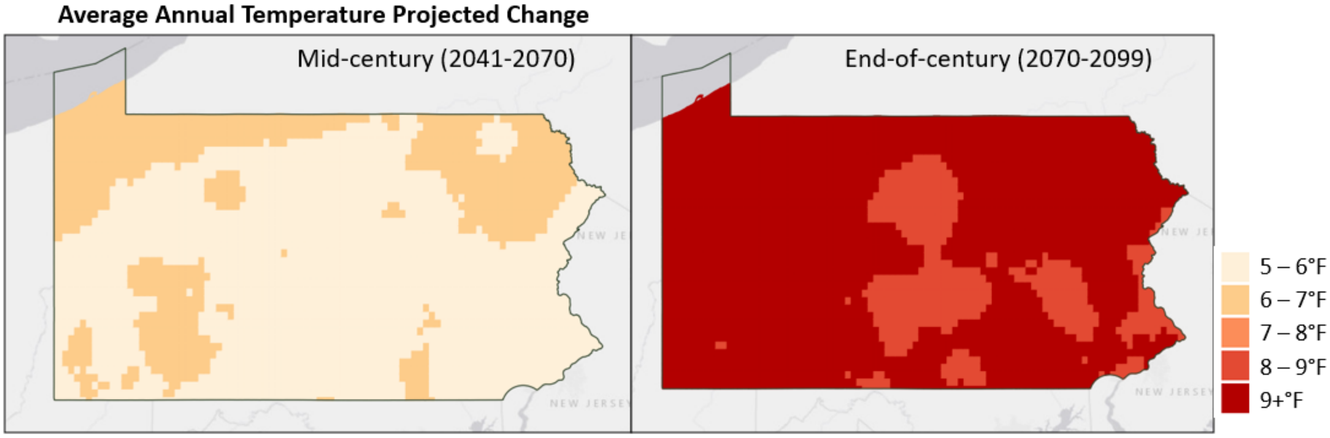


Figure 7. Projected change in average annual temperature relative to the historic period (1971-2000) (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5).

Increased Number and Temperature of Hot Days

The Commonwealth is expected to see an increase in the frequency and intensity of hot days.

From 1971 to 2000, on average across the state, there were 5 days above 90°F per year.[2] By mid-century, there are projected to be 31 days with temperatures over 90°F per year (see Figure 1) on average across the state, and over 60 days in several areas. And by end-of-century, the state is projected to experience an average of 66 days per year with temperatures exceeding 90°F. Compared to the baseline, these future projections represent a 630% increase by mid-century and nearly a 1,200% 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 rare historically (less than once per year, on average), days above 95°F are projected to occur about 12 times per year by mid-century and 31 times per year by end-of-century.

In addition to high daytime temperatures, the Commonwealth could also see more days where nighttime temperatures do not fall below 68°F – a key threshold for infrastructure and human health cooling relief. The number of days with minimum temperatures above 68°F is projected to increase from an average of 3.6 days (baseline) to 25 days by mid-century and 48 days by the end-of-century.

[2] Days above 90, 95, 100, 105°F indicate days where the daily high temperature reaches or exceeds those temperature thresholds.

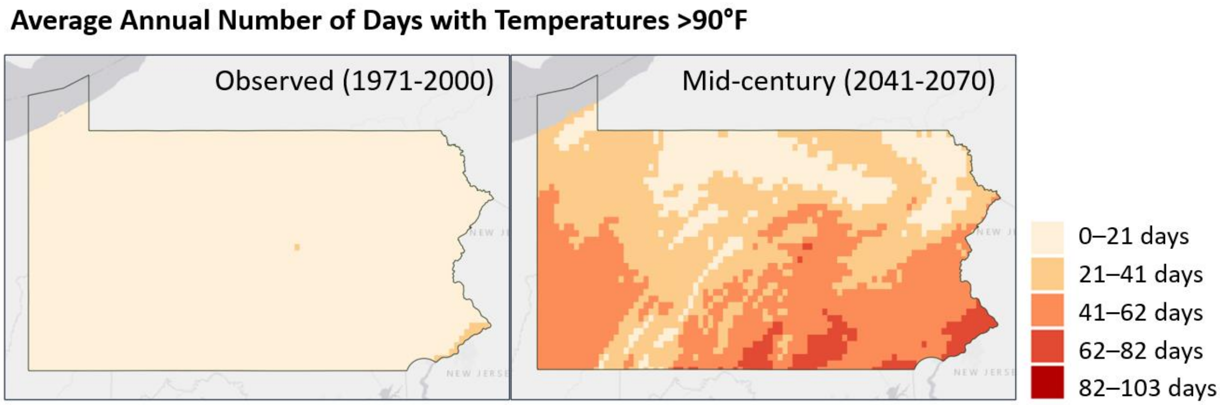


Figure 8. Observed and projected annual numbers of days with temperatures above 90°F (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). Legend range was selected to include full range of observed and projected values divided into equal increments.

The projected increase in temperature can also be expressed in the temperature ranges that define hot days. In addition to an increase in frequency of hot days shown in Figure 1, the temperature range that defines "very hot" and "extremely hot" days will also rise. Even the interpretation of "very hot" is likely to shift over time. For example, historically, "very hot" days (which are defined as occurring less than 5 percent of the time) on average in Pennsylvania, have been any temperature above 85.4°F. By mid-century, the "very hot" temperature threshold is projected to be 92.5°F, and by end-of-century, 96.6°F. Similarly, "extremely hot" days (which occur less than 1 percent of the time) will also be substantially hotter. Historically (1971-2000), "extremely hot" days were, on average across the state, days with temperatures > 90.1°F; "extremely hot" days are projected to be days > 97.6°F by mid-century and days >101.6°F by end-of-century.

Besides increasing extreme temperature ("very hot" and "extremely hot") thresholds, the number of days experiencing historical extreme temperature thresholds is projected to increase. Figure 9 highlights the map of observed and projected days with historical "very hot" (95th percentile) temperatures across the Commonwealth. Particularly in the south-western region of the state, by mid-century, the number of days experiencing historical "very hot" temperatures (on average 85.4°F across the state) is projected to be at least 70 days.

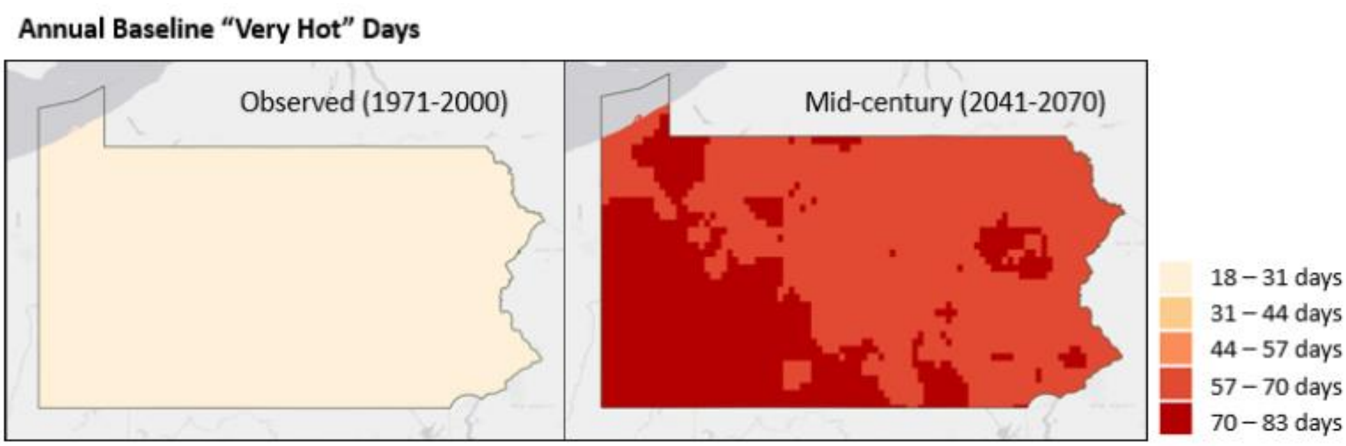


Figure 9. Observed and projected annual occurrences of historical "very hot" temperature days (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). The "very

hot" threshold varies by grid cell, based on the 5th percentile of observed days' maximum temperature. Legend range was selected to include full range of observed and projected values divided into equal increments.

Another indicator of Pennsylvania's warming climate is the change in heating degree days (HDD), cooling degree days (CDD), and growing degree days (GDD). Heating and cooling degree days are indicative of energy needed to heat and cool buildings, respectively.[3] As temperatures increase, heating degree days generally go down while cooling degree days go up.

Annual total heating degree days are anticipated to decrease by 22% by mid-century and 33% by end-of-century compared to the baseline. On the other hand, annual total cooling degree days are projected to increase by almost 150% by mid-century and by 260% by end-of-century. Figure 10 demonstrates the shift in heating and cooling degree days in Pennsylvania.

[3] U.S. Energy Information Administration (EIA). 2020. "Units and calculators explained: Degree days." https://www.eia.gov/energyexplained/units-and-calculators/degree-days.php.

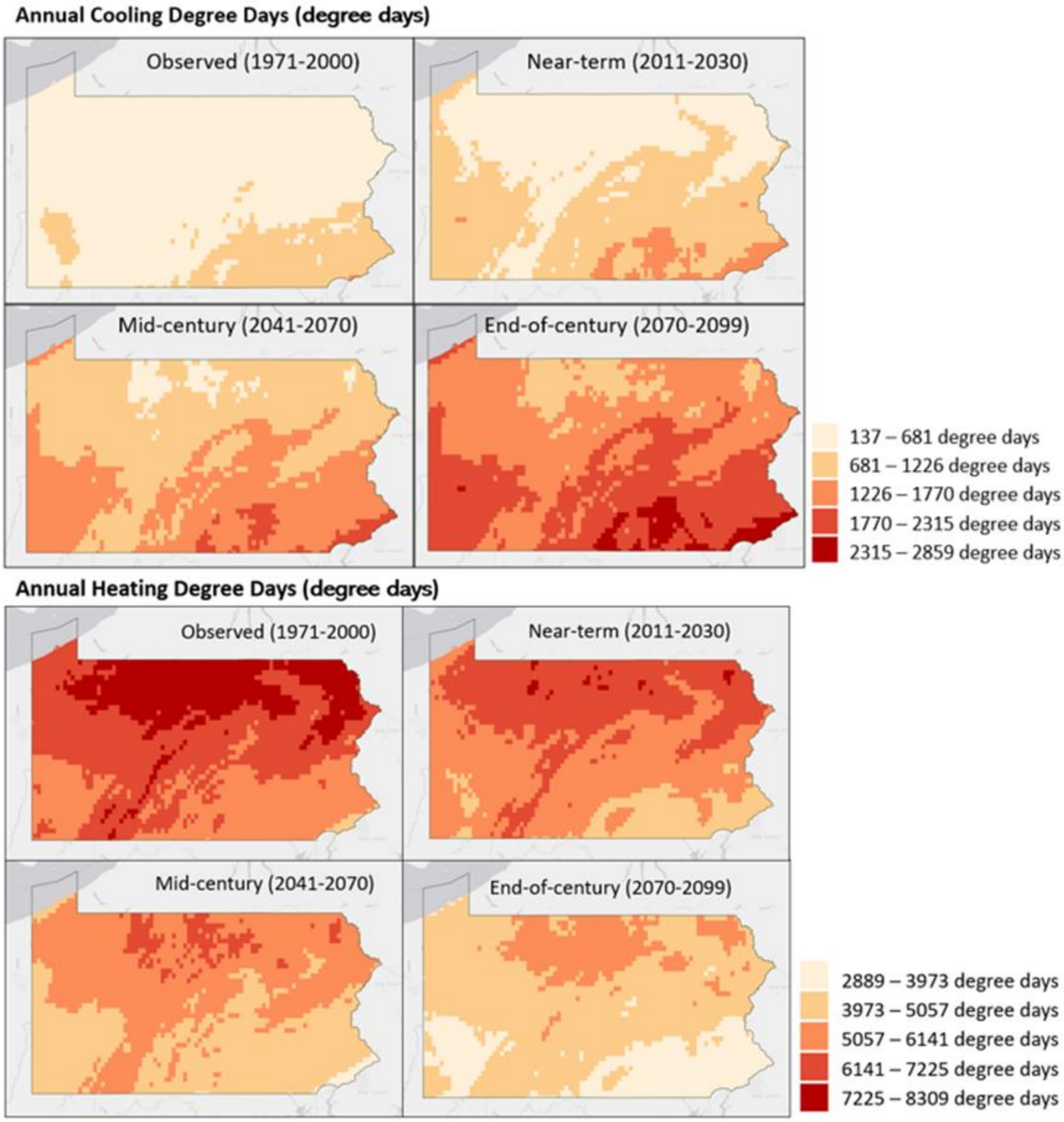


Figure 10. Observed and projected annual cooling and heating degree days (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). Legend range was selected to include full range of observed and projected values divided into equal increments.

Increasing temperatures will 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.[4] Growing degree days are measured here as the annual number of degree days where the average temperature is greater than 50°F. 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, but the magnitude of growing degree days varies by region (see Figure 11). 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. On average, the

[4] PennState Extension. 2020. "Understanding Growing Degree Days." https://extension.psu.edu/understanding-growing-degree-days.

state is projected to see a 50% increase in growing degree days by mid-century (see Figure 11). By end-of-century, growing degree days are projected to increase by 81%. Figure 12 visualizes how monthly cumulative growing degree days are project to increase across all time periods analyzed.

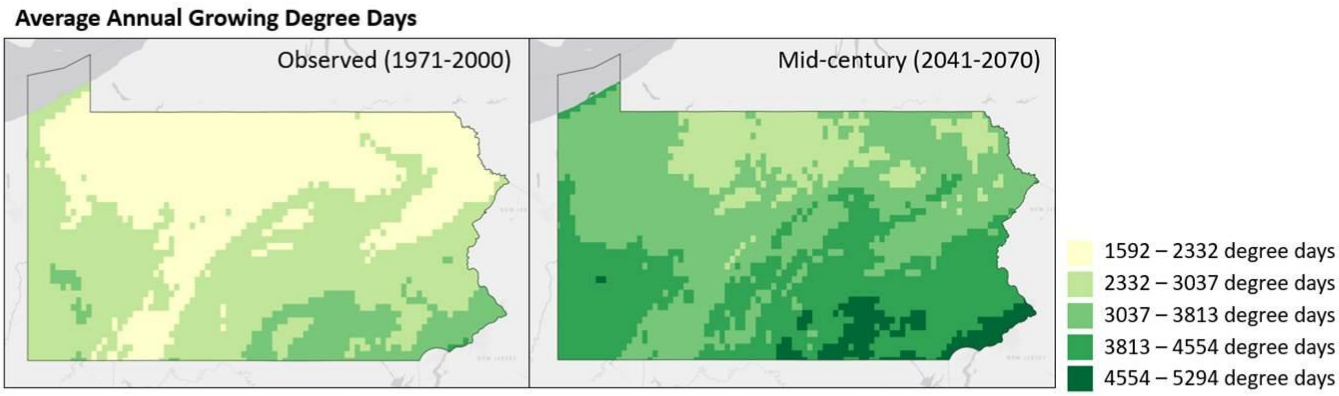


Figure 11. Observed and projected average annual growing degree days (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). Legend range was selected to include full range of observed and projected values divided into equal increments.

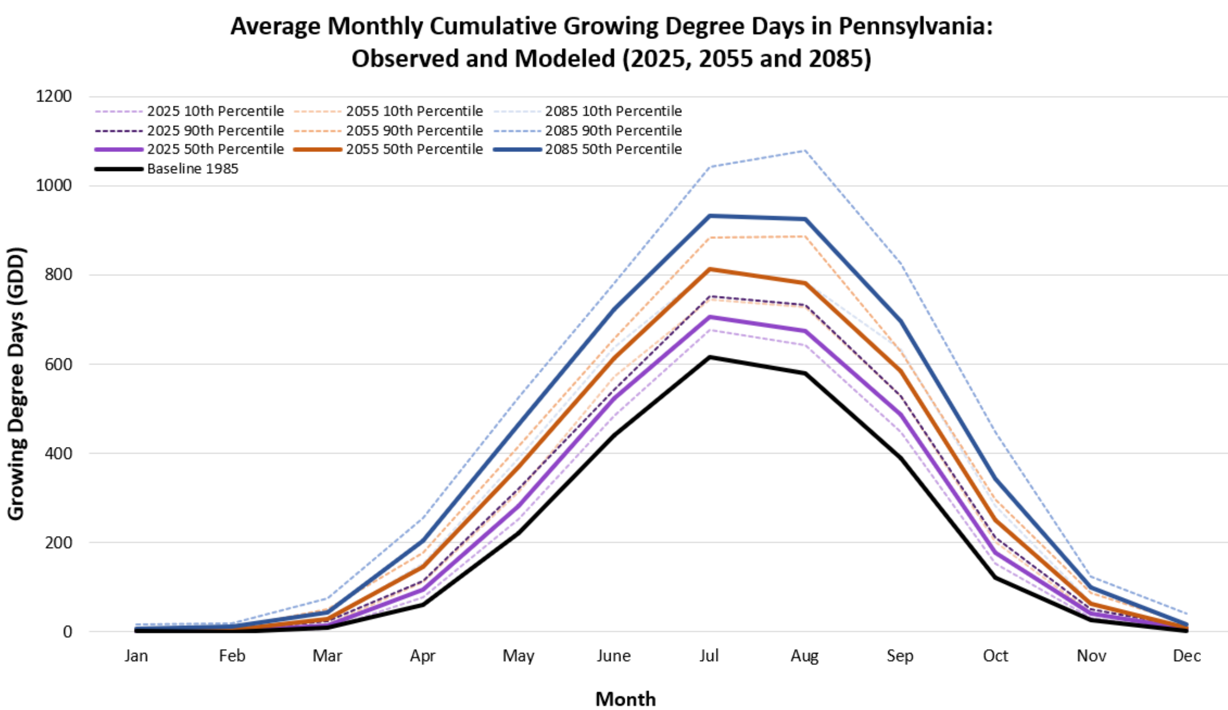


Figure 12. Statewide average observed and projected average monthly cumulative Growing Degree Days (based on 32-model ensemble of LOCA downscaled data, RCP 8.5) Solid lines represent 50th percentile model outputs, and narrower dotted lines represent 10th percentile and 90th percentile model outputs. 2025 values represent all years 2011-2040, 2055 represents 2041-2070, and 2085 represents 2070-2099.

Summary Table: Observed and Projected Temperature Data

Table 3 summarizes statewide average projections for multiple temperature variables under RCP 8.5. Additional data on projections under RCP 4.5 are available in Appendix C.

Table 3. Statewide average observed and projected temperature variables. Projections are based a 32-model ensemble of LOCA downscaled data, RCP 8.5. Values reported are the median value (bold) across the 32-model ensemble, as well as the 10th and 90th percentile values across models.

	Observed Baseline (1971–2000)	**Mid-Century (2041–2070)**		**End-of-Century (2070–2099)**	
		Projected Value (10th – 90th Percentile Range)	50th Percentile Absolute Change	Projected Value (10th – 90th Percentile Range)	50th Percentile Absolute Change
Average annual temperature (°F)	48.3	**54.1** (52.7 - 55.9)	5.9	**57.6** (54.9 – 60.0)	9.4
Average annual minimum temperature (°F)	37.6	**43.4** (42.1 - 45.2)	5.9	**46.8** (44.5 - 49.3)	9.2
Average annual maximum temperature (°F)	58.9	**64.9** (63.1 - 66.9)	6.0	**68.2** (65.7 - 71.3)	9.3
Heating Degree Days (degree days)	6,600	**5,1655** (4,695 – 5,503)	-1,435	**4,430** (3,848 – 4,978)	-2,170
Cooling degree days (degree days)	483	**1,185** (959 – 1,432)	703	**1,722** (1,283 – 2,274)	1239
"Very hot" (95th percentile) temperature (°F)	85.4	**92.5** (89.9 - 96.6)	7.1	**96.7** (92.1 - 103.5)	11.2
Days with temperature above baseline "very hot" temperature (°F)	18.3	**69.7** (51.1 - 80.1)	51.4	**98.6** (71.2 - 114.2)	80.3
"Extremely hot" (99th percentile) temperature(°F)	90.1	**97.6** (94.7 - 103.2)	7.5	**101.6** (96.6 - 107.9)	11.5
Days above baseline "extremely hot" temperature	3.7	**35.1** (19.7 - 50.3)	31.4	**65.1** (34.3 - 87.9)	61.4
Days with temperature >90°F	5.1	**37.0** (22.0 - 51.2)	31.9	**65.5** (35.8 - 89.0)	60.5

Days with temperature >95°F	0.6	**12.1** (5.1 - 26.9)	11.5	**31.1** (10.0 - 62.0)	30.5
Days with low temperature > 68°F	3.6	**25.0** (18.6 - 36.5)	21.4	**47.7** (30.6 - 72.4)	44.1
Consecutive days above 90°F	1.4	**6.2** (1.8 - 12)	4.8	**11.4** (4.6 - 27.2)	10.0
Consecutive days above 95°F	0.1	**2.4** (0.2 - 5.3)	2.3	**4.9** (1.2 - 13.7)	4.8
Growing Degree Days (degree days)	2,472	**3,698** (3,351 – 4,033)	1,226	**4,482** (3,865 – 5,145)	2,010

3.2.2 Precipitation

Key Precipitation Findings

- Extreme rainfall events are projected to increase in magnitude, frequency, and intensity.
- Consecutive dry days are projected to increase.
- Overall, Pennsylvania could see more total rainfall, but occurring in more spaced out heavy rain events.
- Most increases in precipitation will occur in the winter and spring months.

In the coming century, precipitation patterns will change across the Commonwealth. While climate models generally agree that temperature will increase over the century, there is less consensus in 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 LOCA method was developed to improve models' ability to capture extreme rainfall events; however, the LOCA method remains limited in its capacity to project changes in extreme precipitation in variables like rainfall intensity.[5,6] For example, significant differences across datasets (e.g., precipitation observation data taken at different times at different observation stations, leading to temporal misalignment for observations assumed between stations) lead to significant uncertainty in projections based on those observed data – uncertainty that should be taken into account in climate resilience planning.[7]

[5] Pierce, D., Cayan, D., and Thrasher, B. 2014. "Statistical Downscaling Using Localized Constructed Analogs (LOCA)." *Journal of Hydrometeorology* 15 (6): 2558–85. https://doi.org/10.1175/JHM-D-14-0082.1.
[6] Lopez-Cantu, T., Prein, A. F., and Samaras, C. 2020. "Uncertainties in Future U.S. Extreme Precipitation From Downscaled Climate Projections." Geophysical Research Letters 47 (9). https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL086797; Oyler, J. and Nicholas, R.E. 2017. "Time of observation adjustments to daily station precipitation may introduce undesired statistical issues." International Journal of Climatology 38 (S1). https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.5377

[7] Lopez-Cantu, T., Prein, A. F., and Samaras, C. 2020. "Uncertainties in Future U.S. Extreme Precipitation From Downscaled Climate Projections." Geophysical Research Letters 47 (9).

Like temperature projections, precipitation projections are reported by the 10th, 50th, and 90th percentile of the future precipitation variables' distribution in order to capture the uncertainty associated with the range of potential values. Table 4 provides these projections averaged across Pennsylvania. Despite limitations, climate models help to provide insight into the potential changes in precipitation that Pennsylvania may experience in the coming decades. Overall, climate models project that the Commonwealth will see an increase in average annual precipitation, extreme precipitation events, as well as drought as both "very heavy" precipitation events and consecutive dry days are projected to increase. In other words, Pennsylvania could see more rainfall overall, but occurring in more spaced out heavy rain events.

Increased Average Precipitation

Overall, annual average precipitation is anticipated to increase over the century. As shown in Table 4, Pennsylvania will likely experience a small (8%) increase in annual precipitation by mid-century and slightly greater (12%) 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 2015 assessment.[8] Historically, average annual precipitation was 44 inches (1,105 mm). Average annual precipitation is projected to increase to 47 inches (1,198 mm) by mid-century, and to 49 inches (1,232 mm) by end-of-century.

Monthly precipitation patterns are also projected to shift slightly over the century. As shown in Figure 14, most increases in precipitation will occur in the winter and spring months, with future precipitations conditions remaining similar to historic patterns during summer and fall months. This seasonal pattern of projected precipitation change is consistent with numerous past studies for the Commonwealth.[9] The range in monthly total precipitation values across models shown in Figure 13 indicates the variability and uncertainty in precipitation projections.

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https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2019GL086797; Oyler, J. and Nicholas, R.E. 2017. "Time of observation adjustments to daily station precipitation may introduce undesired statistical issues." International Journal of Climatology 38 (S1). https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.5377

[8] Pennsylvania State University (PSU). 2015. "Pennsylvania Climate Impacts Assessment Update (IA).

[9] Shortle et al., 2009 IA; Ross et al., 2013 IA; PSU, 2015 IA.

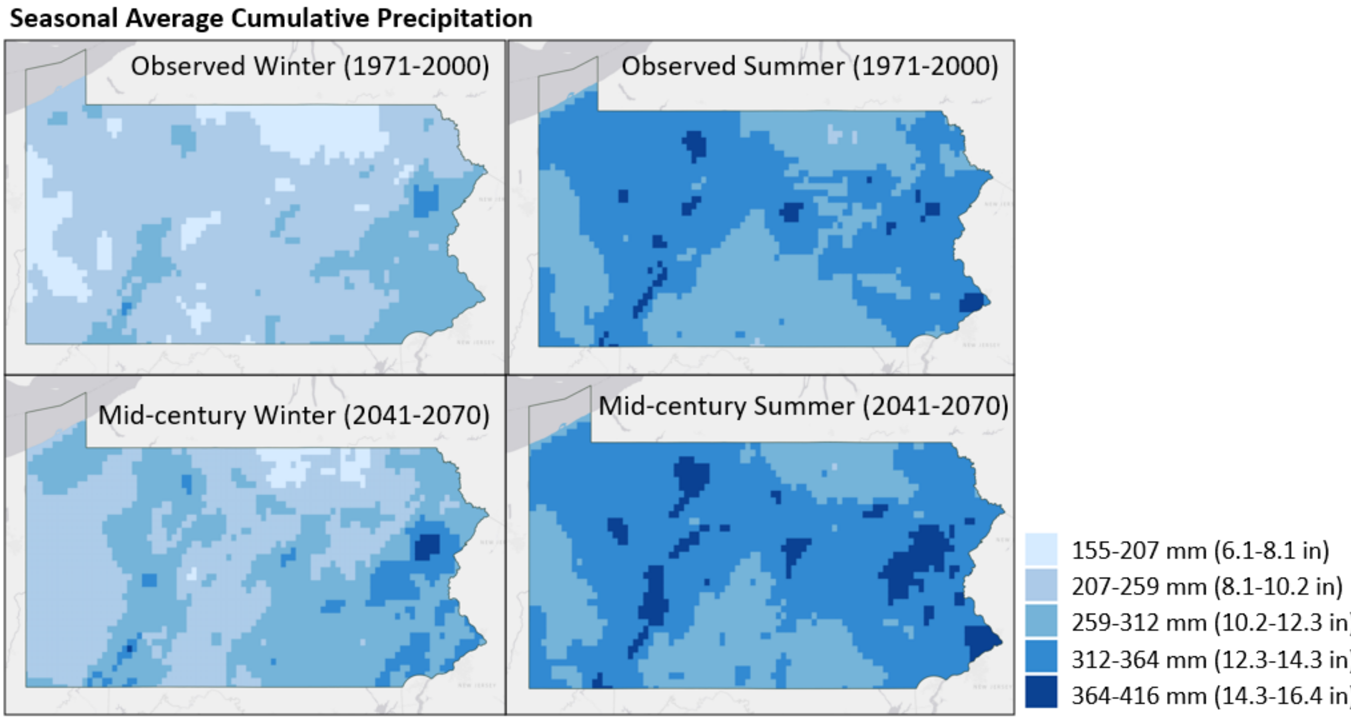

Figure 13. Observed and projected winter and summer seasonal cumulative precipitation (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). Legend range was selected to include full range of observed and projected values divided into equal increments.

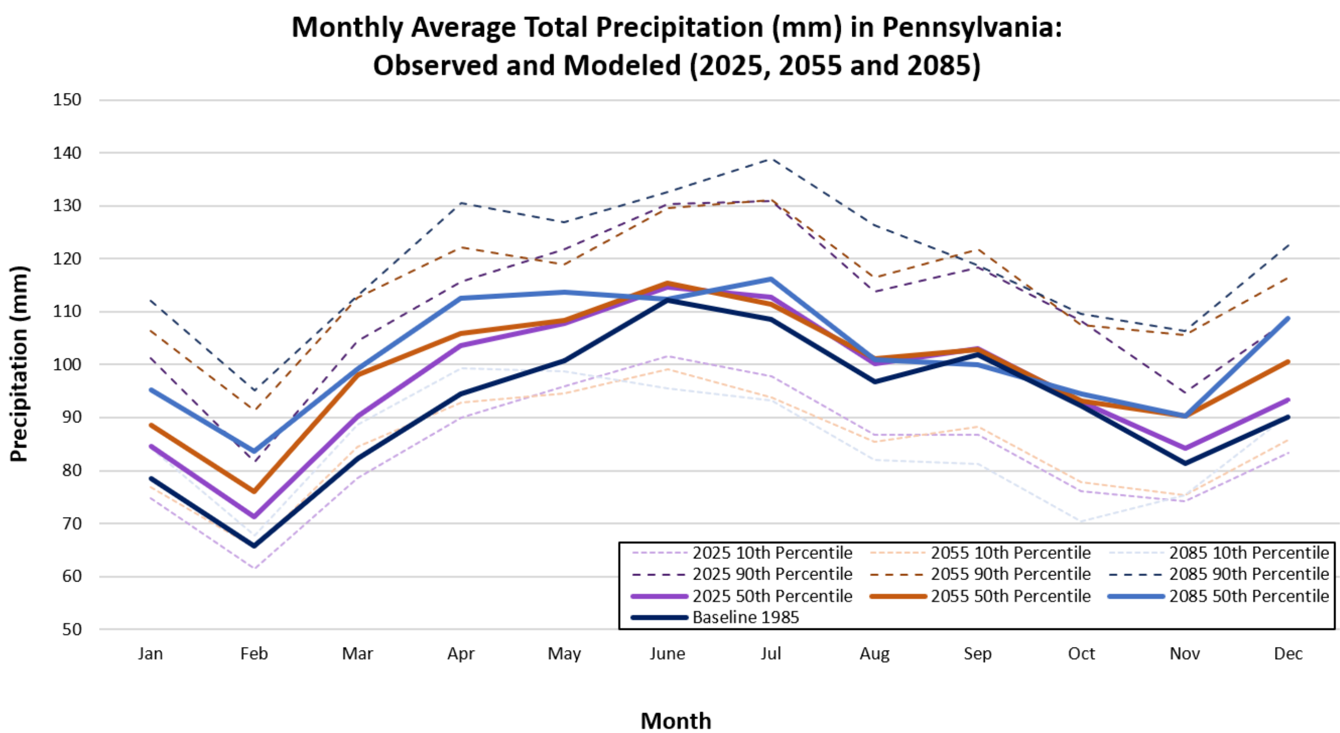

Figure 14. Statewide average observed and projected average monthly total precipitation (mm) (based on 32-model ensemble of LOCA downscaled data, RCP 8.5). Solid lines represent 50th percentile model outputs, and narrower dotted lines represent 10th percentile and 90th

percentile model outputs. 2025 values represent all years 2011-2040, 2055 represents 2041-2070, and 2085 represents 2070-2099.

Increased Extreme Precipitation

Consistent with findings from prior assessments,[10,11] extreme rainfall events are projected to increase in magnitude, frequency, and intensity as the century progresses.

As is presented in Table 4, the statewide average amount of rainfall that falls during "very heavy" precipitation events (which occur less than 5 percent of the time) is projected to rise from 0.7 in (17.2 mm (historical baseline) to 0.8 in (19.3 mm) by mid-century and to 0.8 (20.3 mm) by end-of-century. These represent 12% and 18% increases respectively. The amount of rainfall during "extremely heavy" precipitation events (which occur less than 1% of the time) is also projected to rise – a 13% increase by mid-century and 20% increase by end-of-century. Rainfall during "extremely heavy" precipitation events will increase from 30.2 mm (1.2 in) (historical baseline) to 34.1 mm (1.3 in) and 36.1 mm (1.4 in) by mid-century and end-of-century respectively. 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 11% by mid-century and 16% 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" (17.2 mm on average statewide) and historical "extremely heavy" (30.4 mm) precipitation amounts is projected to rise. Pennsylvania is projected to experience 24% more days with observed baseline "very heavy" precipitation amounts and 42% more days with historical "extremely heavy" precipitation amounts by mid-century (compared to baseline). By end-of-century, the Commonwealth will see 36% more days with observed historical "very heavy" precipitation amounts and 67% more days with observed baseline "extremely heavy" precipitation amounts. The number of days with "very heavy" precipitation will increase across the State (see Figure 2). 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. Pennsylvania weather data shows that over 80 percent of cooperative observer program (COOP) sites surveyed by the state climatologist are seeing an increase in heavy rain events in the 2010s when compared to the 1980s.[12]

Additionally, the number of days with more than 3 inches of rainfall is projected to increase by 52% by mid-century and 93% by end-of-century (compared to baseline). Historically, on average statewide, Pennsylvania has experienced less than one day per year with more than 3

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[10] Shortle, J., Abler, D., Blumsack, S., Crane, R., Kaufman, Z., McDill, M., Najjar, R., Ready, R., Wagener, T., and D. Wardrop. 2009. "Pennsylvania Climate Impact Assessment." *Pennsylvania Department of Environmental Protection (DEP).* *http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252%5B1%5D.pdf*

[11] Ross, A., Benson, C., Abler, D., Wardrop, D., Shortle, J., McDill, M., Rydzik, M., Najjar, R., Ready, R., Blumsack, S., and T. Wagener. 2013. "Pennsylvania Climate Impacts Assessment Update." *PA DEP*. http://www.depgreenport.state.pa.us/elibrary/GetDocument?docId=6806&DocName=PA%20DEP%20CLIMATE%20IMPACT%20ASSESSMENT%20UPDATE.PDF%20

[12] Imhoff, K. 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.

inches of rainfall and the number of days by mid- and end-of-century is projected to remain less than one day per year as shown in Table 4.

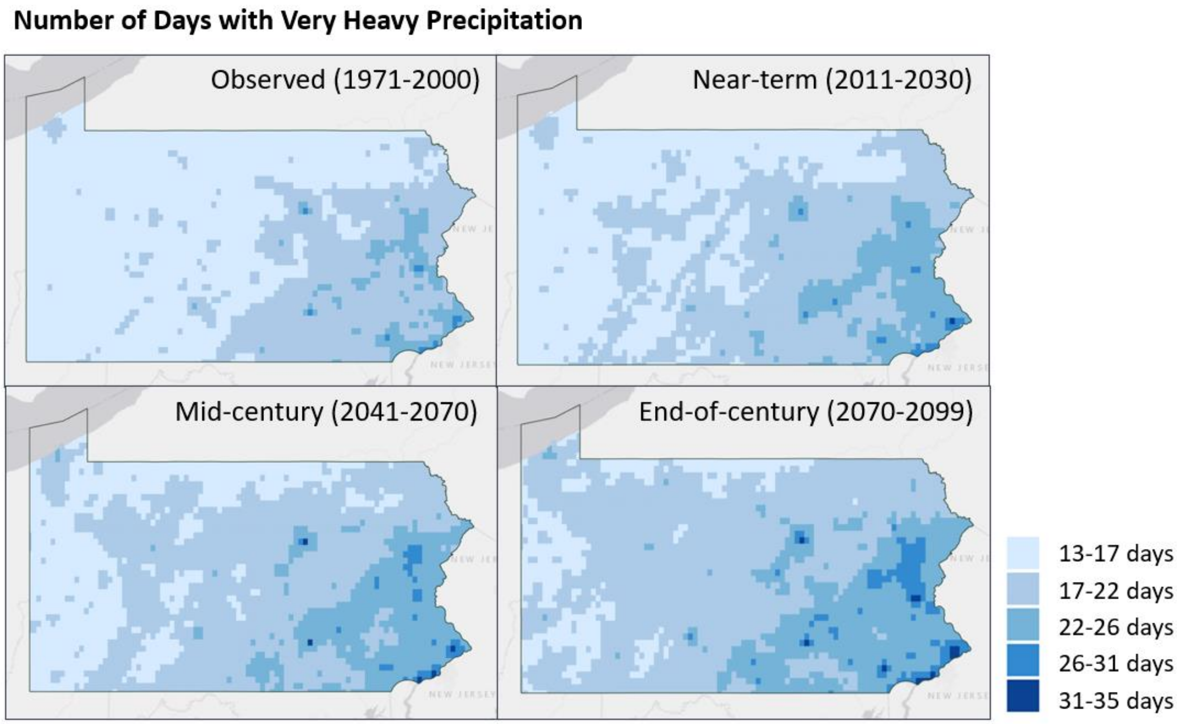

Figure 15. Observed and projected annual number of days with historically "very heavy" precipitation (based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5). The "very heavy" threshold varies by grid cell, based on the 95th percentile of observed rainy days. Legend range was selected to include full range of observed and projected values divided into equal increments.

Finally, Pennsylvania will continue to experience an increase in more intense rain events. Sudden, short, and heavy rainfall events are known as cloudbursts and are often responsible for flash flooding. Pennsylvania experiences noticeable flash flooding as noted in research conducted by PennDOT.[13] Climate change is expected to increase the intensity and frequency of cloudburst events.[14,15,16] These events result in significant impacts (e.g., flooding), but are not currently 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

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[13] Pennsylvania Department of Transportation and Michael Baker International. 2017. "Phase 1: PennDOT Extreme Weather Vulnerability Study." http://s3.amazonaws.com/tmp-map/climate/doc/StudyReport-PaVulnerabilityStudy-ver040317.pdf. P. 16.

[14] Westra, S., Fowler, H.J., Evans, J.P., Alexander, L.V., Berg, P., Johnson, F., Kendon, E.J., Lenderink, G., and N.M. Roberts. 2014. "Future Changes to the Intensity and Frequency of Short-Duration Extreme Rainfall." *Review of Geophysics*, 52, no. 3, p. 522-555. https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1002/2014RG000464.

[15] Kendon, E.J., Roberts, N.M., Fowler, H.J., Roberts, M.J., Chan, S.C., and C.A. Senior. 2014. "Heavier summer downpours with climate change revealed by weather forecast resolution model." *Nature Climate Change*, 4, p. 570-576. https://www.nature.com/articles/nclimate2258.

[16] Prein, A.F., Rasmussen, R.M., Ikeda, K., Liu, C., Clark, M.P., and G.J. Holland. 2017. "The Future Intensification of Hourly Precipitation Extremes." *Nature Climate Change*, 7, p. 48-52. https://www.nature.com/articles/nclimate3168?cookies=accepted

research on the change in frequency and intensity in cloudbursts over the coming century is needed.[17,18]

Increased Drought Conditions

While average and extreme precipitation is projected to increase, a slight increase in drought conditions is also probable. The extent of drought conditions remains uncertain, but higher temperatures are projected to increase evaporative demand and thus reduce water availability.[19] The number of days without rain will rise over the century. The annual maximum in consecutive dry days is projected to increase from 12.5 days historically to 13.4 days by mid-century and 13.9 days by end-of-century. This increase represents a 7% increase by mid-century and 11% increase by end-of-century. These findings of fewer rainy days and longer periods without rain are consistent with prior assessments.[20] As shown in Figure 16, average monthly consecutive dry days in Pennsylvania are projected to increase in the late summer and fall months. Average monthly consecutive dry days are not projected to change significantly from historical conditions in the winter and spring. Overall, changes in precipitation events will create wetter winters and springs and drier falls in the Commonwealth.

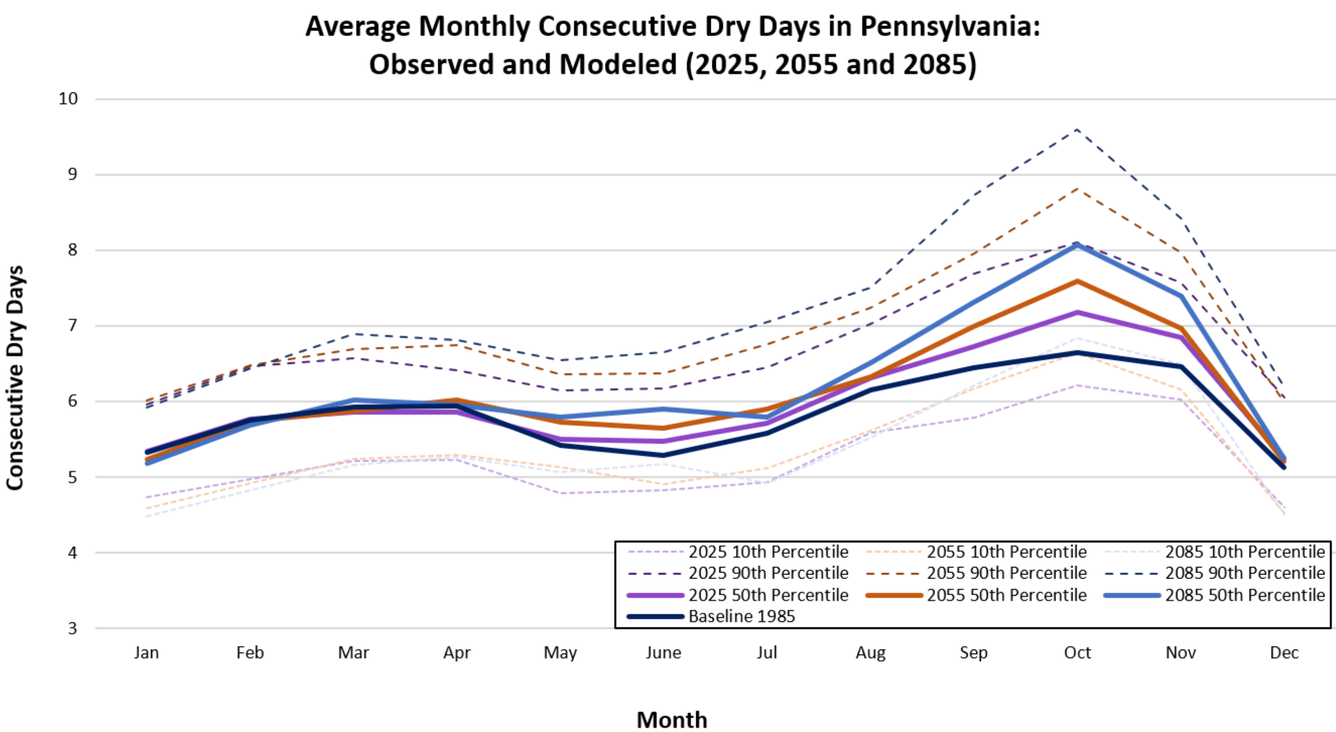

Figure 16. Statewide average observed and projected average monthly consecutive dry days (based on 32-model ensemble of LOCA downscaled data, RCP 8.5). Solid lines represent 50th percentile model outputs, and narrower dotted lines represent 10th percentile and 90th

[17] Rosenzweig, B., Ruddell, B., McPhillips, L., Hobbins, R., McPhearson, T. Cheng, Z., Chang, H., Kim, Y. 2019. "Developing Knowledge Systems for Urban Resilience to Cloudburst Rain Events." *Environmental Science and Policy*, 99, p. 150-159. https://www.sciencedirect.com/science/article/abs/pii/S1462901118310876.
[18] Westra et al., 2014. "Future Changes to the Intensity and Frequency of Short-Duration Extreme Rainfall."
[19] U.S. Global Change Research Program. 2018. Chapter 18: Northeast. Fourth National Climate Assessment. P. 270. https://nca2018.globalchange.gov/chapter/18/
[20] Shortle et al., 2009 IA; Ross et al., 2013 IA.

percentile model outputs. 2025 values represent all years 2011-2040, 2055 represents 2041-2070, and 2085 represents 2070-2099.

Summary Table: Observed and Projected Precipitation Data

Table 4 summarizes statewide average projections for multiple precipitation variables under RCP 8.5. Additional data on projections under RCP 4.5 are available in Appendix C.

Table 4. Statewide average observed and projected precipitation variables. Projections are based a 32-model ensemble of LOCA downscaled data, RCP 8.5. Values reported are the median value (bold) across the 32-model ensemble, as well as the 10th and 90th percentile values across models.

	Baseline (1971–2000)	Mid-Century (2041–2070)		End-of-Century (2070–2099)	
		Projected Value	% Change	Projected Value	% Change
Annual Precipitation (in)	43.5	**47.1** (44.2 - 49.7)	8.4%	**48.5** (44.7 - 51.4)	11.5%
Days with rainfall > 3 inches (days)	0.1	**0.1** (0.0 - 0.2)	51.6%	**0.1** (0.1 - 0.2)	93.3%
Annual Maximum Consecutive Dry Days (days)	12.5	**13.4** (12.2 - 14.8)	7.2%	**13.9** (12.6 - 15.6)	11.3%
"Very heavy" (95th percentile) precipitation (in)	0.7	**0.8** (0.7 - 0.8)	12.1%	**0.8** (0.7 - 0.9)	17.7%
Days with precipitation above baseline "very heavy" precipitation (days)	12.4	**15.4** (13.6 - 17.4)	24.5%	**16.8** (14.5 - 18.8)	36.2%
"Extremely heavy" (99th percentile) precipitation (in)	1.2	**1.3** (1.2 - 1.4)	13.1%	**1.4** (1.3 - 1.5)	19.8%
Days with precipitation above baseline "extremely heavy" precipitation (days)	2.5	**3.5** (2.9- 4.3)	41.9%	**4.2** (3.3 - 5.0)	68.5%
Annual Maximum 3 -Day Precipitation Event (in)	2.4	**2.6** (2.3 - 3)	11.2%	**2.8** (2.3 - 3.1)	16.3%

3.3 Coastal Changes

3.3.1 Coastline along the Delaware Estuary

Pennsylvania has a small 56-mile coastline along the Delaware estuary as seen in Figure 17. This coastline spans from Morrisville, PA to Marcus Hook, PA.[21] Because of land subsidence in the Mid-Atlantic region, local sea level rise is projected to be approximately 0.06 in/yr greater than the global average.[22] In an intermediate sea level rise scenario, water levels are expected to rise by 2.1 feet by mid-century, and 4.7 feet by the end of the century.[23] Figure 18 below highlights sea level rise scenario in the Delaware Estuary Coastal Zone over the course of the century, including the intermediate scenario.

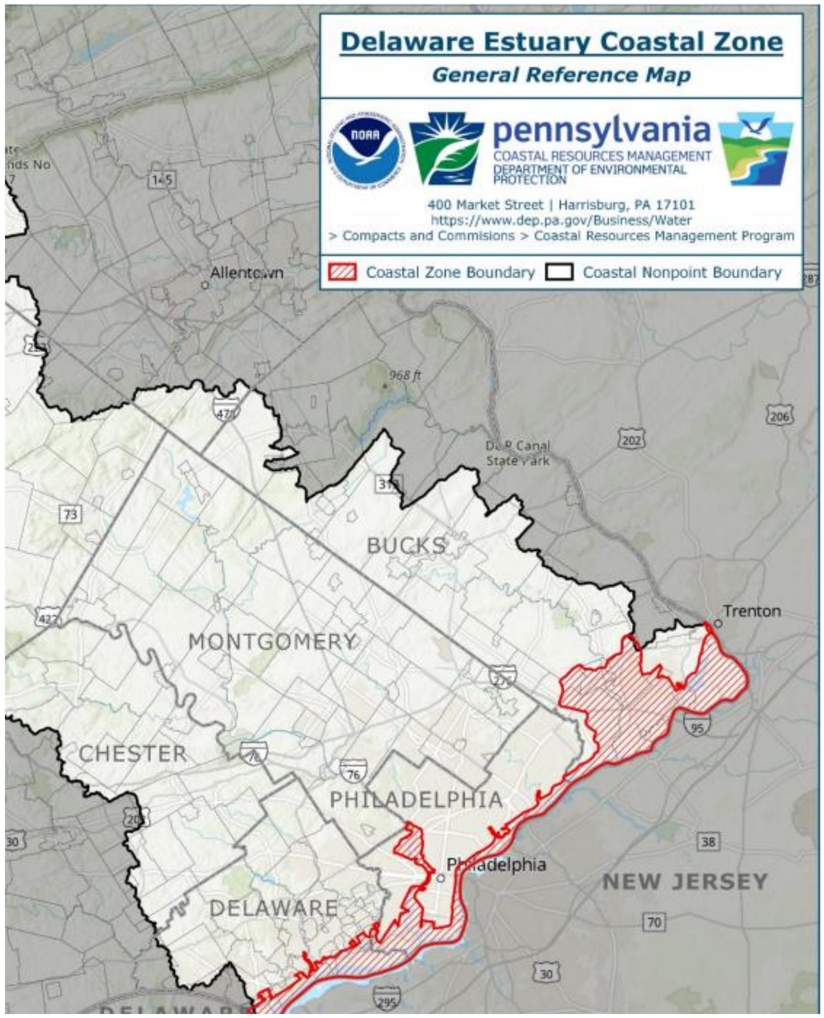

Figure 17. Delaware Estuary Coastal Zone.

As the coastline experiences a rise in sea level, the abutting tidal wetlands may be inundated.[24] 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. Figure 19 and Figure 20 highlight the change in areas that may be inundated under a 3-foot rise in sea level.

[21] PSU. 2015 IA.
[22] Delaware Valley Regional Planning Commission (DVRPC). 2004. Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania. https://www.dvrpc.org/Products/04037
[23] U.S. Army Corps of Engineers (USACE). 2019. Sea Level Change Curve Calculator. http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html
[24] DVRPC. 2004.

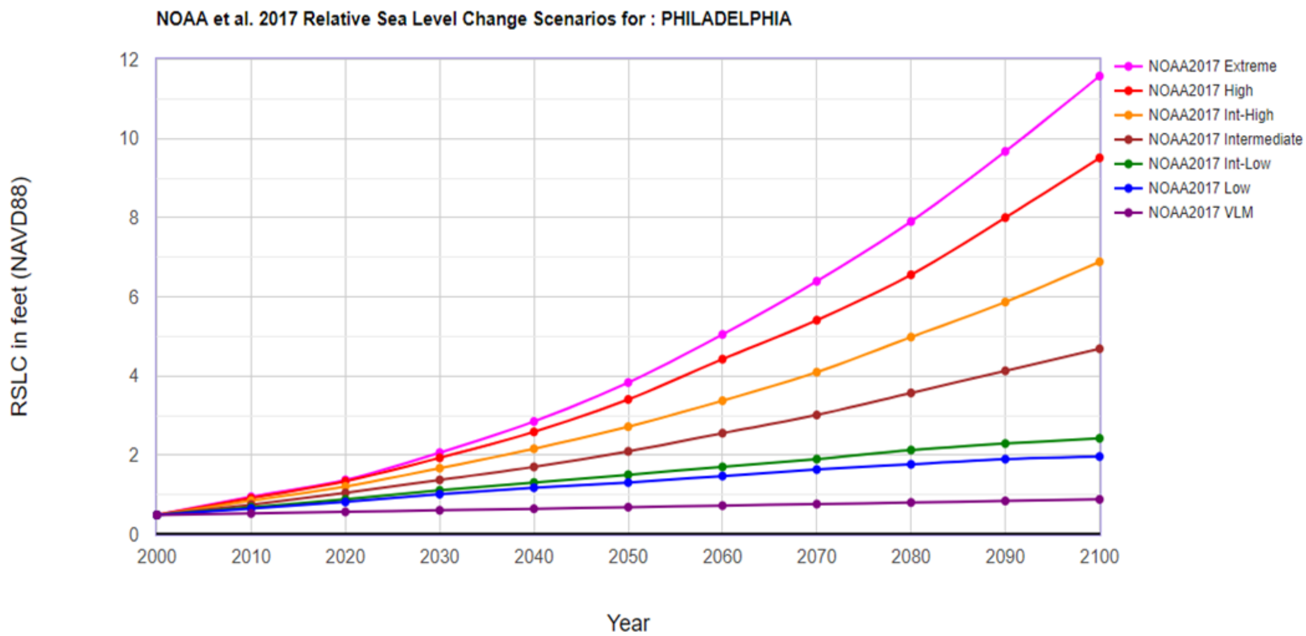

Figure 18. Sea level rise scenarios for Philadelphia tide gauge.

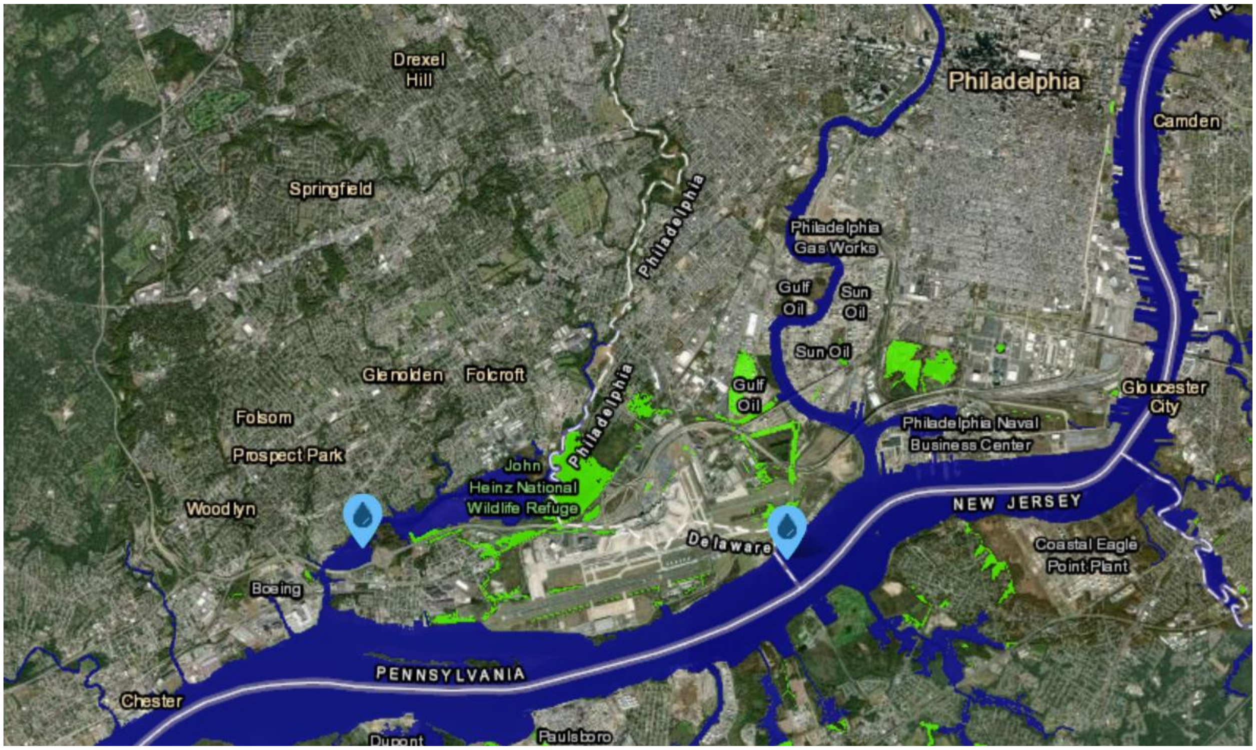

Figure 19. Current inundation threat. Areas shaded in lime green represent low-lying areas, dark blue areas describe existing water bodies, and light blue areas highlight inundated areas.[25]

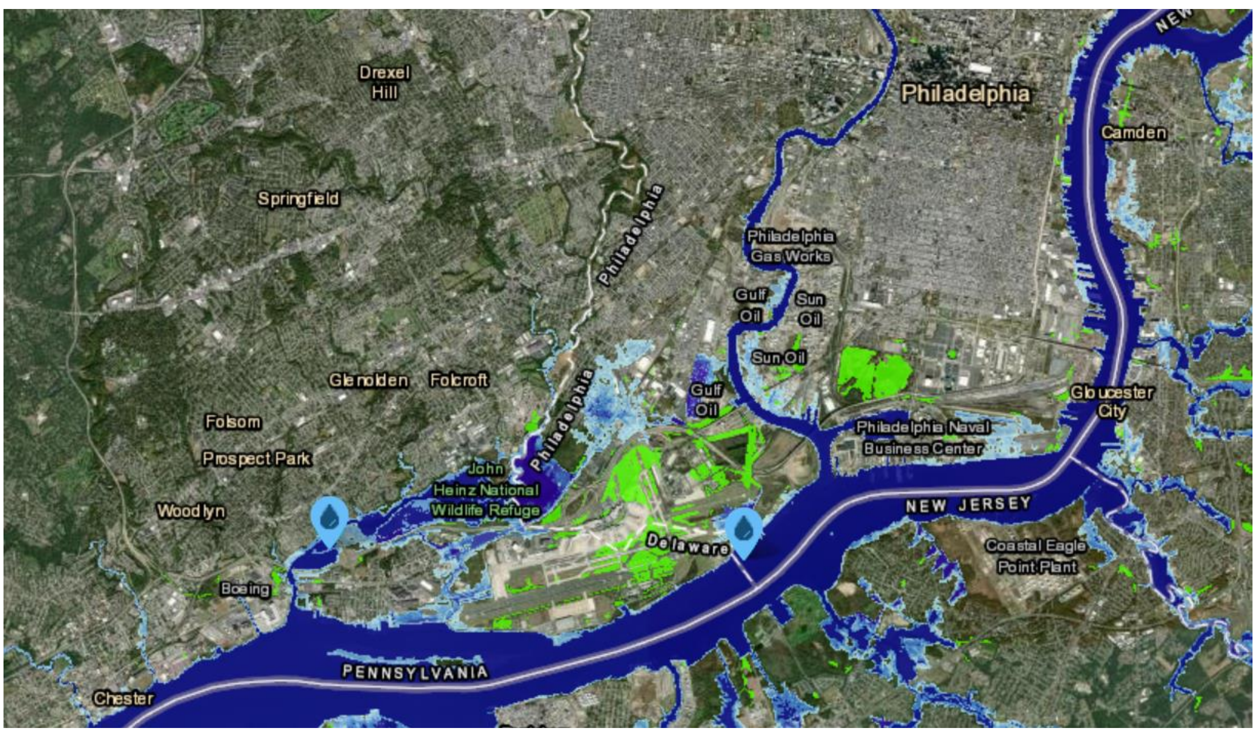

Figure 20. Modeled inundation from a 3-foot rise in sea levels. Areas shaded in lime green represent low-lying areas, dark blue areas describe existing water bodies, and light blue areas highlight inundated areas.[26]

3.3.2 Coastline along Lake Erie

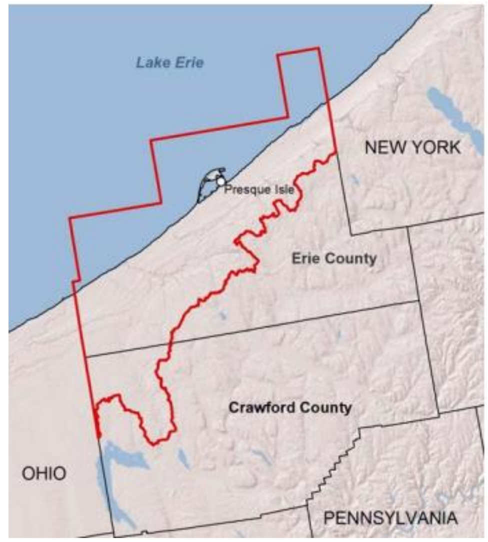

Figure 21. Lake Erie watershed.

Pennsylvania also has a 64-mile coastline along Lake Erie as highlighted in Figure 21. 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.[27] As winter temperatures become less severe, Lake Erie will be covered by less ice, and ice dunes that typically protect the Presque Isle's beaches will experience greater erosion.[28] Climate change will also result in higher lake water temperatures and greater runoff from the increased frequency of extreme precipitation events.[29] Combined warmer waters and increased runoff will boost the likelihood of e-coli and algal blooms.[30] In the summer of 2014, Lake Erie experienced a harmful algal bloom in its western basin. Algal bloom such as these are expected to become more frequent with climate change. Increased runoff is also anticipated to cause greater bluff instability as runoff erodes the bluff face.[31] Climate change is also projected to increase coastal erosion rates as the Lake's coastlines are impacted more frequently by severe storms.[32] Lake Erie is anticipated to experience significant changes as a result of climate change.

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[25] U.S. National Oceanic and Atmospheric Administration (NOAA). N.d. Sea Level Rise Viewer. https://coast.noaa.gov/slr/.

[26] U.S. National Oceanic and Atmospheric Administration (NOAA). N.d. Sea Level Rise Viewer. https://coast.noaa.gov/slr/.

[27] Foyle, A. 2018. The Lake Erie Bluff Coast of Pennsylvania: A State of Knowledge Report on Coastal Change Patterns, Processes and Management. https://seagrant.psu.edu/sites/default/files/PA%20Sea%20Grant%20Lake%20Erie%20Bluff%20Coast%20of%20PA%20a%20State%20of%20Knowledge%20Report%20on%20Coastal%20Change%20Patters%2C%20Processes%2C%20and%20Management%202018.pdf

[28] Sea Grant Pennsylvania. Climate Impacts to Erie. http://seagrant.psu.edu/topics/erie-climate-change/projects/climate-impacts-erie#:~:text=When%20precipitation%20does%20occur%20in,Lake%20doesn't%20freeze%20over.

[29] Sea Grant Pennsylvania. Climate Impacts to Erie. http://seagrant.psu.edu/topics/erie-climate-change/projects/climate-impacts-erie#:~:text=When%20precipitation%20does%20occur%20in,Lake%20doesn't%20freeze%20over.

[30] Sea Grant Pennsylvania. Climate Impacts to Erie. http://seagrant.psu.edu/topics/erie-climate-change/projects/climate-impacts-erie#:~:text=When%20precipitation%20does%20occur%20in,Lake%20doesn't%20freeze%20over.

[31] Sea Grant Pennsylvania. Climate Impacts to Erie. http://seagrant.psu.edu/topics/erie-climate-change/projects/climate-impacts-erie#:~:text=When%20precipitation%20does%20occur%20in,Lake%20doesn't%20freeze%20over.

[32] Foyle, A. 2018. The Lake Erie Bluff Coast of Pennsylvania: A State of Knowledge Report on Coastal Change Patterns, Processes and Management. https://seagrant.psu.edu/sites/default/files/PA%20Sea%20Grant%20Lake%20Erie%20Bluff%20Coast%20of%20PA%20a%20State%20of%20Knowledge%20Report%20on%20Coastal%20Change%20Patters%2C%20Processes%2C%20and%20Management%202018.pdf

3.4 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. The literature does not expect that climate change will impact the frequency of tropical cyclones or major winter cyclones.[33] While severe non-tropical rain events are anticipated to become more likely,[34] snowstorms are projected to decrease in frequency. [35] Increasing temperature may also decrease the severity of winter weather.[36] Overall, climate change is projected to alter the frequency and intensity of extreme weather events.

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[33] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms. Geophysical Research Letters 45, 12,067-012,075.

[34] PSU. 2015 IA.

[35] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms. Geophysical Research Letters 45, 12,067-012,075.

[36] Pennsylvania Department of Environmental Protection (DEP). 2020. "Pennsylvania Climate Change Impacts Assessment Update (IA). http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf.

4 RISK ASSESSMENT OVERVIEW

4.1 Approach Overview

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

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

The process for analyzing and evaluating each hazard is shown in Figure 22. The likelihood of each hazard occurring is evaluated on a 1-4 scale and the severity of each consequence category is also evaluated on a 1-4 scale across several categories, including:

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

Each hazard then receives an overall risk rating, based on the product of its likelihood and consequence scores, per the matrix in Table 5. The likelihood and consequence rating scales, among other methodological details, can be found in Appendix B.

Key Terms

Risk – The chance a climate hazard with cause harm. Risk is a function of the likelihood of an adverse climate impact occurring and the severity of its consequences.

Climate Hazard – Climate related events or indicators, such as temperature and precipitation. Climate hazards can be discrete (e.g., heat wave) or ongoing (e.g., increasing average temperature).

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 – Short for PA Environmental Justice Areas, this includes any census tract or block group where ≥ 20% of individuals live in poverty, and/or ≥ 30% is minority. Populations in these areas are also sometimes referred to as EJ populations and EJ communities.

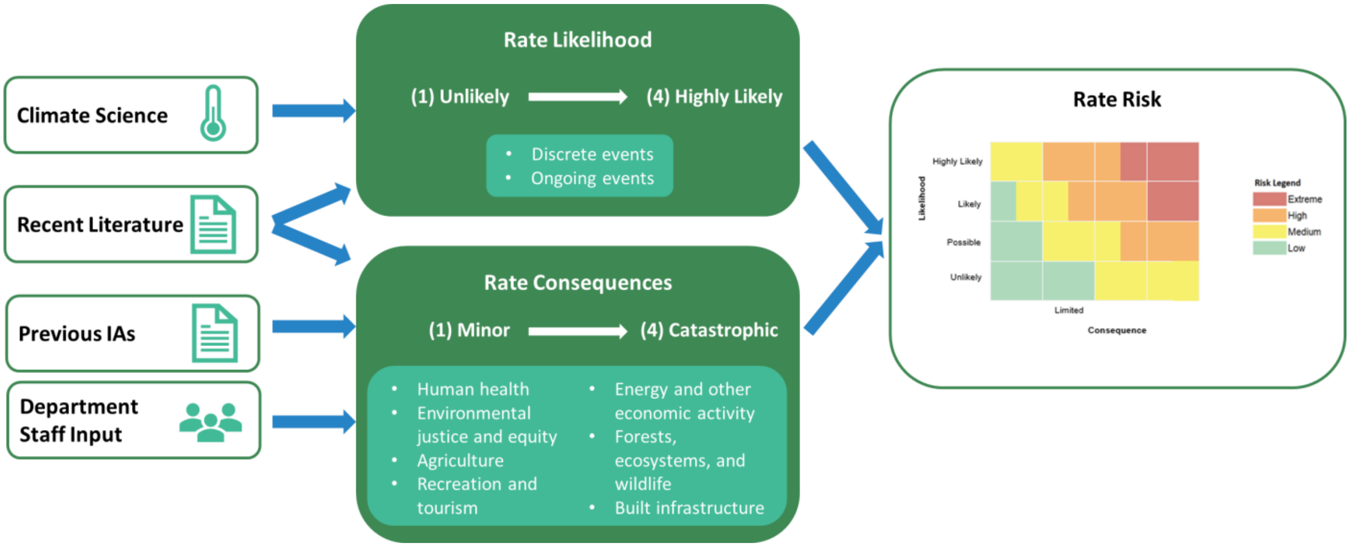

Figure 22. Risk assessment process overview.

Table 5. Risk Rating Matrix and Scoring Rubric

Likelihood	Consequence			
	Minor	Limited	Critical	Catastrophic
Highly Likely	4	8	12	16
Likely	3	6	9	12
Possible	2	4	6	8
Unlikely	1	2	3	4

Risk Score	Rating
(low end inclusive)	
12+	Extreme
6 - 9	High
3 - 4	Medium
1 - 2	Low

To evaluate environmental justice and equity, Pennsylvania Environmental Justice Areas are used to represent already disadvantaged populations. An EJ area is any census tract or block group where 20 percent or more individuals live in poverty, and/or 30 percent or more of the population is minority.[37] EJ areas serve as an indicator of locations that are overburdened by environmental hazards and other structural disadvantages. This indicator does not capture all impacts to overburdened populations (for example, it does not capture impacts to overburdened populations not located in EJ areas). Nonetheless, it is a valuable indicator to begin study of structural disadvantages, and this assessment draws on other information to supplement it where possible given its limitations.

Figure 23 shows where EJ areas (at the block group level) are located across the Commonwealth, with a zoomed-in focus on Philadelphia and Pittsburgh where higher population density makes block group shading less legible in the state map. See Appendix B - Approach to Climate Justice and Equity for additional details.

[37] Pennsylvania Office of Environmental Justice (OEJ). N.d. "PA Environmental Justice Areas." https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx

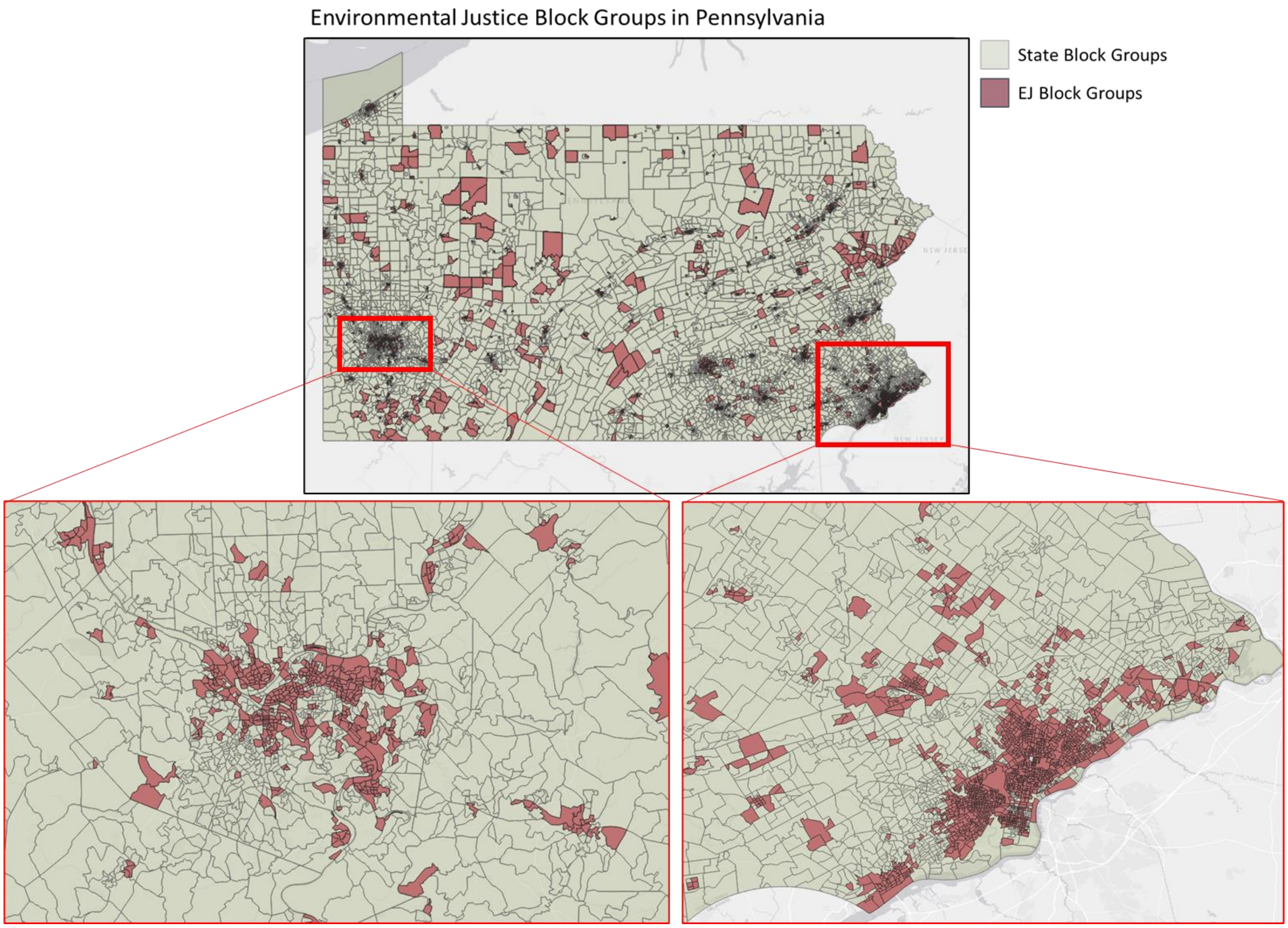

Figure 23. Environmental Justice block groups in Pennsylvania, overlaid on a map of all state Census block groups[38]

This assessment is focused on evaluating the direct impacts in Pennsylvania from each of the six hazards. However, the Commonwealth could be affected by the ripple effects of national or global climate changes beyond its borders, which could increase the severity of impacts. For example, a major hurricane or flood event occurring elsewhere in the U.S. could affect supply chains for key goods and services.

The assessment assumes no adaptation actions or policy changes to capture the "business as usual" risk. **The results therefore indicate where Pennsylvania has an opportunity to reduce risk**, recognizing that some hazards or specific impacts may be easier to address than others.

This analysis is not a comprehensive bottom-up assessment. While based solidly on evidence from past IAs, recent literature, and updated climate projections,[39] 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 facilitate prioritization of adaptation actions that can be taken to reduce risks. Further,

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[38] Pennsylvania Office of Environmental Justice (OEJ). N.d. "PA Environmental Justice Areas." https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx

[39] Updated climate projections are based on the latest available science.

it provides the foundation for DEP to easily revisit the results of the assessment as needed as priorities or circumstances change.

See Appendix B for further details on the risk assessment methodology.

4.2 Key Findings and Overall Climate Risks

The risk assessment revealed several key findings:

- **Increasing average temperatures pose the greatest overall risk to Pennsylvania.** Average temperatures affect nearly every aspect of life in the Commonwealth, from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment. Some key potential consequences, if the risk is unmitigated, include:
    - Increased vulnerability to heat-related illness and mortality risks, especially for EJ communities
    - Potential increased energy burden for low-income 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)
- Heat waves will become an increasingly common event and create a particular health and economic risk for vulnerable populations, including the low-income, elderly, and those with cardiovascular conditions. These risks will be particularly acute in urban areas subject to the heat island effect.
- **Flood risks to infrastructure is another priority risk**, whether caused by heavy rain, riverine flooding, stormwater flooding, tropical storms, or sea level rise. Impacts to built infrastructure have ripple effects throughout the economy.
- Landslides and sea level rise pose relatively low risks statewide but can cause severe impacts in the locations where they occur.
- **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. 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.
- Several of these hazards—especially flooding, severe tropical storms, and landslides—already pose risks today, and could become more likely or severe in the future. Pennsylvania has an opportunity to build on its existing hazard mitigation practices for these risks.
- The gradual nature of many of these changes, however, also creates an **opportunity for the Commonwealth to not only reduce potential harms, but also capitalize on potential positive changes** (e.g., ability to grow new crops). This is particularly true for increasing average temperatures and sea level rise.
- **Risks will continue to grow beyond 2050.** These risk ratings focus on the likelihood and consequences of each hazard by 2050, but all will continue to change after that. Pennsylvania will need to consider longer-term risks for infrastructure and other long-range planning processes that require assumptions about conditions in the late 21st century or beyond.

Climate change impacts are dynamic; overall, the Commonwealth needs to plan for more significant and more complex impacts in the future. 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 6 and Figure 24 summarize the overall risks for 2050. The total risk scores are a product of the likelihood and average consequence scores for each hazard. **Increasing average temperatures** and **heat waves** emerged as the two highest priority risks. Both hazards will impact the entire state and all sectors but will have the highest consequences for human health and environmental justice and equity, especially in urban areas. The long-term warming trend will also have significant negative impacts on winter recreation and tourism and the health of forests, ecosystems, and wildlife.

Both of these hazards and **sea level rise** also had the greatest change in risk score from present day to 2050.

Table 6. 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	**Heat waves**	Medium (4.7)	High (9.3)
3	**Heavy precipitation and inland flooding**	Medium (5.6)	Medium (5.6)
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 (4.8)	Medium (4.8)

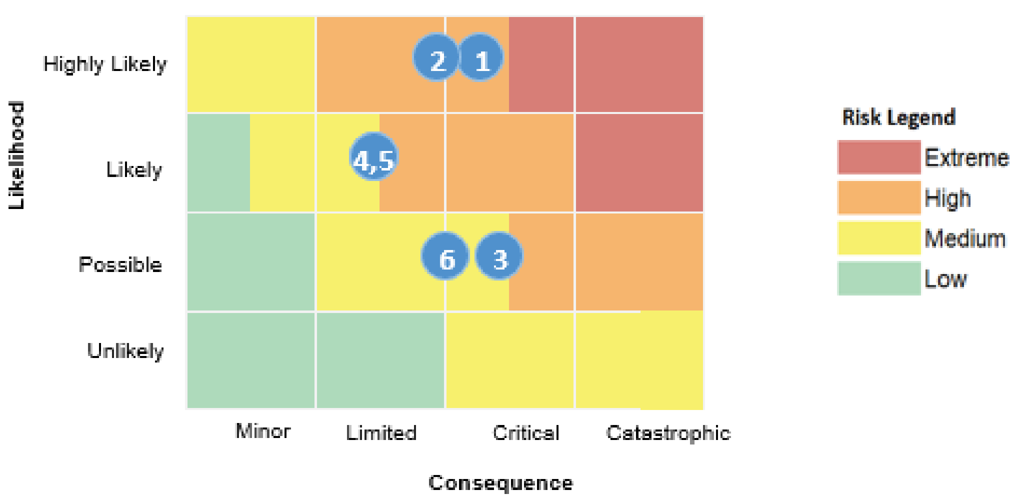

Figure 24. Overall Summary Risk Matrix.

Figure 25 breaks down the consequence ratings per category for each of the hazards, which are presented from left to right by descending overall risk score. The size of the color bar corresponds to the severity of the rating per category. **Increasing average temperatures** and **heavy precipitation and inland flooding** had the most significant consequences overall.

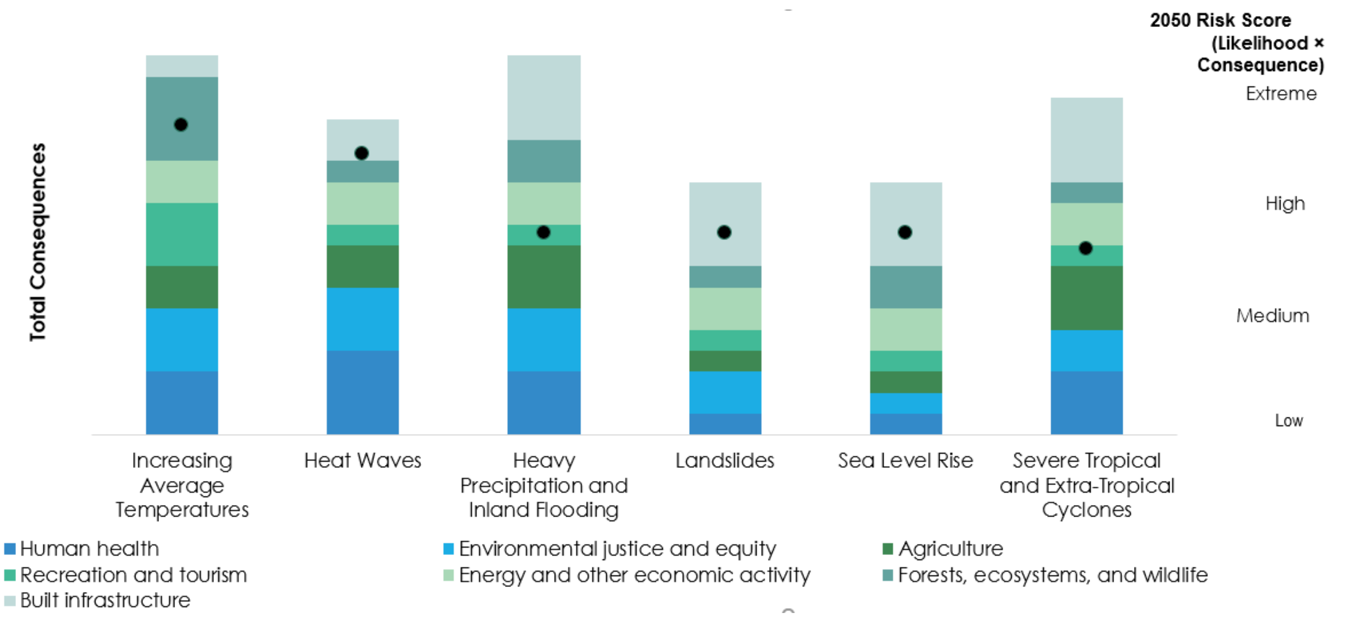

Figure 25. Total Consequences and Risks by Hazard.

Finally, Figure 26 illustrates the overall risk for each hazard and consequence category priority climate risks per consequence category to help prioritize 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.

	Human health	Environmental justice and equity	Agriculture	Recreation and tourism	Energy and other economic activity	Forests, ecosystems, and wildlife	Built infrastructure
Increasing average temperatures	12	12	8	12	8	16	4
Heat waves	16	12	8	4	8	4	8
Heavy precipitation and inland flooding	6	6	6	2	4	4	8
Landslides	3	6	3	3	6	3	12
Sea level rise	3	3	3	3	6	6	12
Severe tropical and extra-tropical cyclones	6	4	6	2	4	2	8

Figure 26. Overall Summary Risk Matrix (2050 likelihood x individual consequences)

The following sections provide detailed risk summaries by hazard, presented in order from the highest to lowest overall risk:

5.1 Increasing Average Temperatures

5.2 Heat Waves

5.3 Heavy Precipitation and Inland Flooding

5.4 Landslides

5.5 Sea Level Rise

5.6 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. Most of the information presented in the risk summaries is derived from the 2015 and 2020 IAs.

5 RISK ASSESSMENT DETAILS

5.1 Increasing Average Temperatures

5.1.1 Overview

On average, the state is expected to experience an increase of 5.9°F (3.3°C) in average annual temperature by mid-century under the RCP8.5 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 7 summarizes the likelihood and consequence ratings. Figure 27 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.

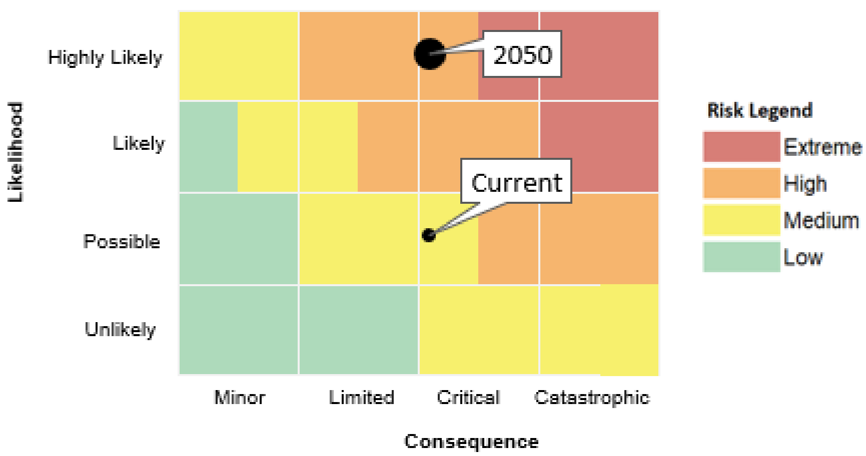

Figure 27. Increasing Average Temperatures Risk Matrix

Table 7 summarizes the statewide likelihood and consequences of increased average temperatures in Pennsylvania.

Table 7. Increasing Average Temperature Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.1.2)**	**Confidence**	**Differential Impacts**
Current	2	The state has experienced long-term change of more than1.8°F (1°C) increase since 1905.	High	Southeastern PA historically experiences the highest temperatures.

2020-2050	4	Climate models project 4.4-7.6°F (2.4-4.2°C) increase by mid-century under the RCP8.5 scenario.	High	Southeastern and Southwestern PA will experience the highest temperatures, while northwestern PA will experience the greatest change in temperature from present day.
Beyond 2050	By the end-of-century under the RCP8.5 scenario, average temperatures in the state are projected to increase by 6.6-11.8°F (3.7-6.5°C). Average temperature will continue to increase beyond 2100 without greenhouse gas (GHG) mitigation.			Same as above
Consequences				
Category	**Rating**	**Justification Notes (details in 5.1.3)**	**Confidence**	**Differential Impacts**
Human health	3	• Increased heat-related mortality • Decreased cold-related mortality • Increased prevalence of diseases (e.g., Lyme disease)	High	The elderly, those with cardiovascular disease, outdoor workers, and populations with limited access to air conditioning experience higher risk to heat-related illness and death.
Environmental justice and equity	3	• Significantly disproportional impacts to EJ areas overall • EJ communities may be more vulnerable to heat-related illness and mortality risks	High	See justification
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	

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 facing higher vulnerability to heat stress.
Overall Risk		**Risk Score**	**Confidence**	
	Current	**5.3 (Medium)**	High	
	2050s	**10.7 (High)**	High	

Potential Opportunities

There are also some potential opportunities associated with increasing temperatures, including:

- **Decline in wintertime heating energy demand and costs**
- **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 spring and fall recreation (e.g., biking, golfing) and summer water-based recreation participation**
- **Increase in suitable habitat available for species that are currently at the northern extent of their range in Pennsylvania**
- **Longer growing seasons and higher temperatures, among other climate-related factors, may provide opportunities to grow new, warmer-weather crops**
- **Increase in utilization of silvopasture for livestock operations, which reduces heat stress among other benefits**

5.1.2 Likelihood

Among projections for climate hazards, those for increasing average temperatures have among the highest certainty. Projected increases in average temperatures are statistically significant – meaning that more than half of climate models show a statistically significant change, and more than two-thirds agree on the sign of the change.[40] The National Climate

[40] Vose, R.S., D.R. Easterling, K.E. Kunkel, A.N. LeGrande, and M.F. Wehner. 2017. "Temperature changes in the United States." In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, D.C., USA, p. 185-206, doi: 10.7930/J0N29V45.

Assessment gives very high confidence[41] to the statement that annual average temperature in the United States is projected to rise, and high confidence[42] to the statement that "recent record-setting years may be "common" in the next few decades."[43] Much larger rises are projected by end-of-century (2071–2100): 3.4°–7.6°F (1.9°–4.2°C) in a lower scenario (RCP4.5) and 6.6°–11.8°F (3.7°–6.5°C) in the higher scenario (RCP8.5). Given such strong confidence in projections and the intensity of the increases, increasing average temperatures merits a likelihood rating of 4.

Note that the projected increases in temperature are similar across emission scenarios (e.g., RCP4.5 and RCP8.5) through mid-century. After 2050, there is more divergence between scenarios, with greater increases in temperature occurring under the RCP 8.5 scenario.

5.1.3 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 28 summarizes the overall consequence ratings statewide for increasing average temperatures – highest consequences are in forests, ecosystems, and wildlife. These consequence ratings are also in Table 7.

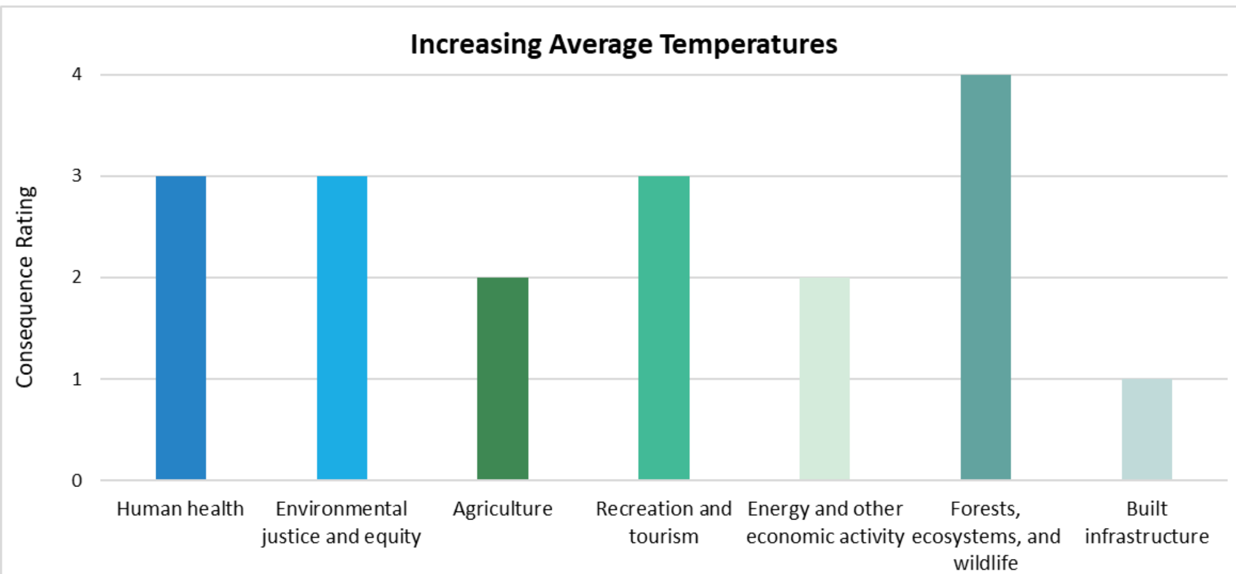

Figure 28. Increasing Average Temperatures Consequences

Human health: 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

[41] Very high confidence denotes "Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus."
[42] High confidence denotes "Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus."
[43] Vose et al., 2017. "Temperature changes in the United States."

or negative effect in the future but is clear that heat-related deaths will increase.[44,45,46,47] The risk of mortality from extreme heat events has been decreasing, as more and more households are installing air conditioning.

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

Increased temperatures may also result in worsened air quality due to increased allergen levels, though increased ground-level ozone creation is the strongest link between climate change and decreased air quality.

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.

While there is overall consensus that climate change could affect the distribution and prevalence of vector-borne diseases (e.g., Lyme Disease and West Nile Virus) and air-borne infectious diseases, there is not clear consensus on whether these changes will manifest in Pennsylvania.

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 to purchase A/C or take time off work on high heat days).

Environmental justice and equity: 3

Risks of heat-related illness and mortality will increase with warmer average temperatures. Populations most at risk will likely be communities 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).[48]

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

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[44] Carina J. Gronlund, Kyle P. Sullivan, Yonathan Kefelegn, Lorraine Cameron, Marie S. O'Neill. 2018. Climate change and temperature extremes: A review of heat- and cold-related morbidity and mortality concerns of municipalities. Maturitas 114: 54-59. https://doi.org/10.1016/j.maturitas.2018.06.002

[45] Veronika Huber. 2018. Will climate change bring benefits from reduced cold-related mortality? Insights from the latest epidemiological research. Real Climate. 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/

[46] Gerardo Sanchez Martinez, Julio Diaz, Hans Hooyberghs, Dirk Lauwaet, Koen De Ridder, Cristina Linares, Rocio Carmona, Cristina Ortiz, Vladimir Kendrovski, Dovile Adamonyte. 2018. Cold-related mortality vs heat-related mortality in a changing climate: A case study in Vilnius (Lithuania). Environ Res. 166:384-393. doi: 10.1016/j.envres.2018.06.001

[47] Centers for Disease Control and Prevention. October 2020. Temperature Extremes. https://www.cdc.gov/climateandhealth/effects/temperature_extremes.htm

[48] Maxwell, K., S. Julius, A. Grambsch, A. Kosmal, L. Larson, and N. Sonti. 2018. "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, Washington, D.C., USA, p. 438–478. doi: 10.7930/NCA4.2018.CH11

live in these neighborhoods.[49] 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.

Analysis of population by Census Block Group and regions experiencing the most frequent (top 20%) heat days (> 90˚F) across the state, indicates that a greater proportion of people living in EJ communities is expected to experience highly frequent days > 90˚F than that statewide. Moreover, although EJ communities constitute under a third of the State's total population, over half of all people in the Commonwealth experiencing highly frequent heat day exposure are members of EJ communities.

Figure 29 visualizes the number of days with temperatures >90˚F projected to occur across the state by mid-century. 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 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 space[50] that can otherwise absorb heat and provide shade.

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[49] City of Philadelphia. 2019. Beat the Heat Hunting Park: A Community Heat Relief Plan. https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf

[50] City of Philadelphia Office of Sustainability. 2019. "Beat the Heat Hunting Park: A Community Heat Relief Plan." https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf

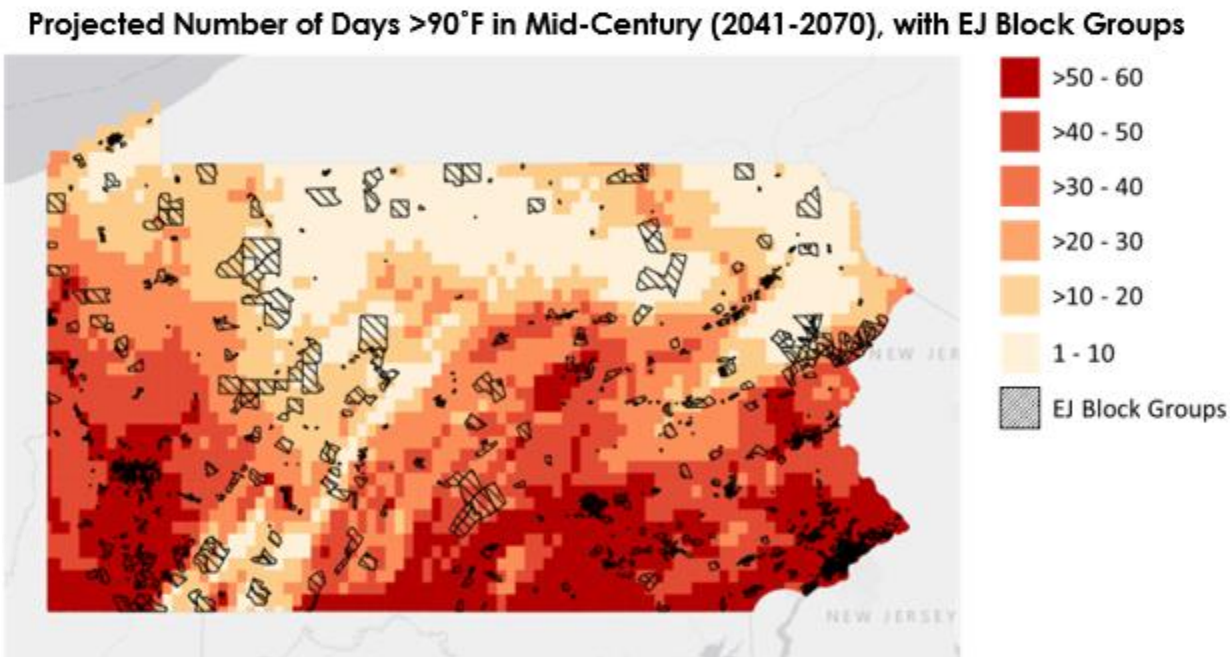

Figure 29. Projected annual number of days with temperatures over 90°F expected to occur by census block in 2050, with overlay of environmental justice (EJ) census block groups. Population data source: https://www.census.gov/data/developers/data-sets/acs-5year.html.

Economy

Agriculture: 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 in Figure 11). Soybean crops are expected to experience increased yields due to longer frost-free and growing seasons and higher concentrations of atmospheric carbon dioxide.[51] However, corn, which is Pennsylvania's most important crop, 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.[52]

For crops grown indoors, there will be less heating needed during winter but more cooling during summer, and the net effect on annual energy use is currently unclear.

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[51] U.S. EPA. August 2016. What Climate Change Means for Pennsylvania. EPA 430-F-16-040. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf

[52] U.S. EPA. August 2016. What Climate Change Means for Pennsylvania. EPA 430-F-16-040. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf

Livestock and dairy farming will be negatively impacted overall due to increased heat stress experienced by the animals (and subsequent decreased milk yields), increased energy and capital expenditures to mitigate heat stress, and lower-quality forage material.[53]

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.[54]

Recreation and tourism: 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 20-60%.

Finally, due to a longer warm season, 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. 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.

The types of fishing that are viable in Pennsylvania will also be altered. Trout fishing, which is cold-water fishing, may no longer be supported. This impact will be particularly severe in southeastern and northwestern Pennsylvania.

Increased temperatures may also contribute to the development of Harmful Algal Blooms on Lake Erie, which could discourage recreation and fishing on Lake Erie due to health concerns to both humans and fish.

Energy and other economic activity: 2

Pennsylvania is a major energy-producing state in the US, largely due to natural gas production. 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.[55] Example economic impacts of increasing average temperatures are described below.[56]

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[53] U.S. EPA. August 2016. What Climate Change Means for Pennsylvania. EPA 430-F-16-040. https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf

[54] Pennsylvania Department of Agriculture. November 2020. Department staff expertise.

[55] Pennsylvania Department of Agriculture. 2020. State of the Forest Products Industry in Pennsylvania.

[56] NPR, 2018. A Few More Bad Apples: As the Climate Changes, Fruit Growing Does, Too. Retrieved from: https://www.npr.org/sections/thesalt/2018/08/01/634135514/a-few-more-bad-apples-as-the-climate-

1

Example Economic Impacts: Increasing Average Temperatures

The economic impacts of increasing average temperatures are likely to be felt in tandem to extreme heat. The mean annual temperature in Pennsylvania has increased approximately 2 degrees Fahrenheit over the last century but is increasing at a faster pace.[1]

Agricultural Impacts

The agricultural industry in Pennsylvania generates approximately $135.7 billion in total economic impact each year and supports 579,000 jobs.[2]

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 to be concerned with two generations, a spray of a third round of pesticide would increase costs.[3]

Increasing atmospheric CO_2 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.[4]

About 58 percent of Pennsylvania is covered by forests, which face challenges from invasive species and disease.[5] 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.[6]

Recreational Impacts

In Pennsylvania outdoor recreation generates $29.1 billion in consumer spending, $1.9 billion in state and local tax revenue and sustains 251,000 direct jobs.[7]

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changes-fruit-growing-does-too; Pittsburgh Post-Gazette, 2012. How climate change will affect Pennsylvania. Retrieved from: https://www.post-gazette.com/news/environment/2012/04/22/How-climate-change-will-affect-Pennsylvania/stories/201204220205; NOAA National Center for Environmental Information, n.d. State Climate Summaries: Pennsylvania. Retrieved from: https://statesummaries.ncics.org/chapter/pa/; Climate Central, 2020. On Thin Ice: How Climate Change is Shaping Winter Recreation. Retrieved from: https://www.climatecentral.org/news/report-on-thin-ice-climate-change-shaping-winter-recreation; PA Department of Environmental Protection (DEP), 2020. Pennsylvania Climate Change Impacts Assessment Update. Retrieved from: http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/ClimateChange/2020ClimateChangeImpactsAssessmentUpdate.pdf; USDA, 2018. Assessment of Forest Sector Carbon Stocks and Mitigation Potential for State Forests of Pennsylvania. Retrieved from: https://www.climatehubs.usda.gov/sites/default/files/PA_ForestCarbon_MainReport.pdf; PennState Extension, 2019. Forest Management and Timber Harvesting in Pennsylvania. Retrieved from: https://extension.psu.edu/forest-management-and-timber-harvesting-in-pennsylvania; PA Wilds Center, 2017. Pennsylvania – 5th in Nation in Outdoor Recreation Consumer Spending. Retrieved from: https://www.pawildscenter.org/studies-reports/#:~:text=In%20Pennsylvania%2C%20outdoor%20recreation%20generates,for%20spending%20on%20outdoor%20recreation; PA Department of Agriculture (DOA), 2018. Pennsylvania Agriculture: a look at the economic impact and future trends. Retrieved from: https://www.agriculture.pa.gov/Documents/PennsylvaniaAgriculture_EconomicImpactFutureTrends.pdf

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)[8], however lake effect snowfall in north western PA is likely to increase.[9] 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.

Sources: Sources: [1] NOAA National Centers for Environmental Information, n.d.; [2] PA DOA, 2018;[3] NPR, 2018; [4] PA DEP, 2020; [5] PennState Extension, 2019; [6] USDA, 2018; [7] PA Wilds Center, 2017; [8] Pittsburgh Post-Gazette, 2012; [9] Climate Central, 2020

Forest, ecosystems, and wildlife: 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 (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).[57,58] 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.

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.[59] 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.[60]

Winter stream temperatures have shown warming trends, which presents both positive and negative outcomes for fish communities. In the tidal freshwater portion of the Delaware estuary, increased water temperatures decreased the solubility of oxygen while increasing respiration rates, both of which lead to decreased dissolved oxygen concentration and decreased water quality.

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.

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[57] PSU. 2015 IA.

[58] Pennsylvania Department of Conservation and Natural Resources (DCNR). 2018. Climate Change Adaptation and Mitigation Plan.

[59] Pennsylvania DCNR. 2018. Climate Change Adaptation and Mitigation Plan.

[60] Pennsylvania DCNR. November 2020. Department staff expertise.

Built infrastructure: 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.[61]

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.[62] Extreme heat will also reduce efficiency of energy generation in solar PV panels, especially when temperatures exceed 77°F.[63,64] However, rooftop solar can reduce the cooling energy needs of buildings and help reduce peak demand.[65]

In addition, warmer water temperatures could decrease the availability of water that would be used for power plant cooling.

[61] Pennsylvania Department of General Services. November 2020. Department staff expertise.

[62] Pennsylvania Department of General Services. November 2020. Department staff expertise.

[63] Jacob Marsh. July 2020. How hot do solar panels get? Effect of temperature on solar performance. Energy Sage. https://news.energysage.com/solar-panel-temperature-overheating/

[64] Kerry B. Burke. 2014. The reliability of distributed solar in critical peak demand: A capital value assessment. Renewable Energy 68: 103-110. https://doi.org/10.1016/j.renene.2014.01.042

[65] F. Salamanca, M. Georgescu, A. Mahalov, M. Moustaoui & A. Martilli. 2016. Citywide Impacts of Cool Roof and Rooftop Solar Photovoltaic Deployment on Near-Surface Air Temperature and Cooling Energy Demand. Boundary-Layer Meteorology 161:203–221. https://doi.org/10.1007/s10546-016-0160-y

5.2 Heat Waves

5.2.1 Overview

Heat waves will increase from a medium to a high risk by mid-century. Table 8 summarizes the likelihood and consequence ratings. Figure 30 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 events. Across the state, on average the annual number of days experiencing temperatures above 95°F is expected to increase by 5-26 days by the mid-century and 10-61 days by the end-of-century. Similarly, the number of consecutive days experiencing temperatures above 95°F is expected to increase by 0-5 days by the mid-century and 1-14 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 20-50 days by the mid-century and 34-88 days by the end-of-century.

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.

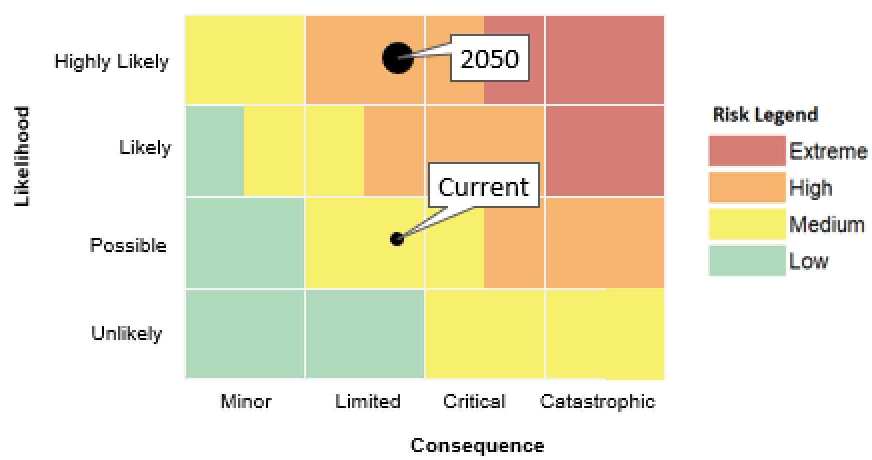

Figure 30. Heat Waves Risk Matrix

Table 8 summarizes the statewide likelihood and consequences of heat waves in Pennsylvania.

Table 8. Heat Waves Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.2.2)**	**Confidence**	**Differential Impacts**
Current	2	Currently, Pennsylvania experiences, on average, about 4 days per year that are "extremely hot."	High	No significant geographic differences in observed high temperature days
2020-2050	4	By mid-century, Pennsylvania is expected to experience over 35	High	Southwestern PA will experience more days with

		"extremely hot" days per year.		high temperatures than other regions of the state
Beyond 2050	Temperature are expected to continue increasing beyond 2050 without significant greenhouse gas reductions. On a business-as-usual emission trajectory (RCP 8.5), Pennsylvania could experience over 65 "extremely hot" days annually.			
Consequences				
Category	**Rating**	**Justification Notes (details in 5.2.3)**	**Confidence**	**Differential Impacts**
Human health	4	• Increased heat-related mortality and morbidity	High	The elderly, those with cardiovascular disease, and populations with limited access to air conditioning experience higher risk to heat-related illness and death.
Environmental justice and equity	3	• EJ communities face increased exposure to heat stress: outdoor jobs, housing with less insulation/ access to natural infrastructure/ air conditioning, decreased access to quality healthcare, and living with cities	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.
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 urban heat island effect	Medium	
Overall Risk		**Risk Score**	**Confidence**	
	Current	**4.7 (Medium)**	High	
	2050s	**9.3 (High)**	High	
Potential Opportunities				
• **Increase in utilization of silvopasture for livestock operations, which reduces heat stress among other benefits**				

5.2.2 Likelihood

Additionally, there is high confidence[66] that "recent record-setting years [in terms of high temperatures] may be "common" in the next few decades."[67] While currently, the state experiences about 4 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 35 days by mid-century, with a potential range of about 20 to 50 days.

Risks of heat waves are higher in urban areas due to the urban heat island 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 4 for the mid-century timeframe. The current timeframe received a likelihood rating of 2, since heat waves do occur currently, but only happen about 5-6 days per year.

5.2.3 Consequences

Figure 31 summarizes the overall consequence ratings statewide for heat waves – highest consequences are in human health and in environmental justice and equity. These consequence ratings are also in Table 8.

[66] 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.

[67] Vose et al., 2017. "Temperature changes in the United States."

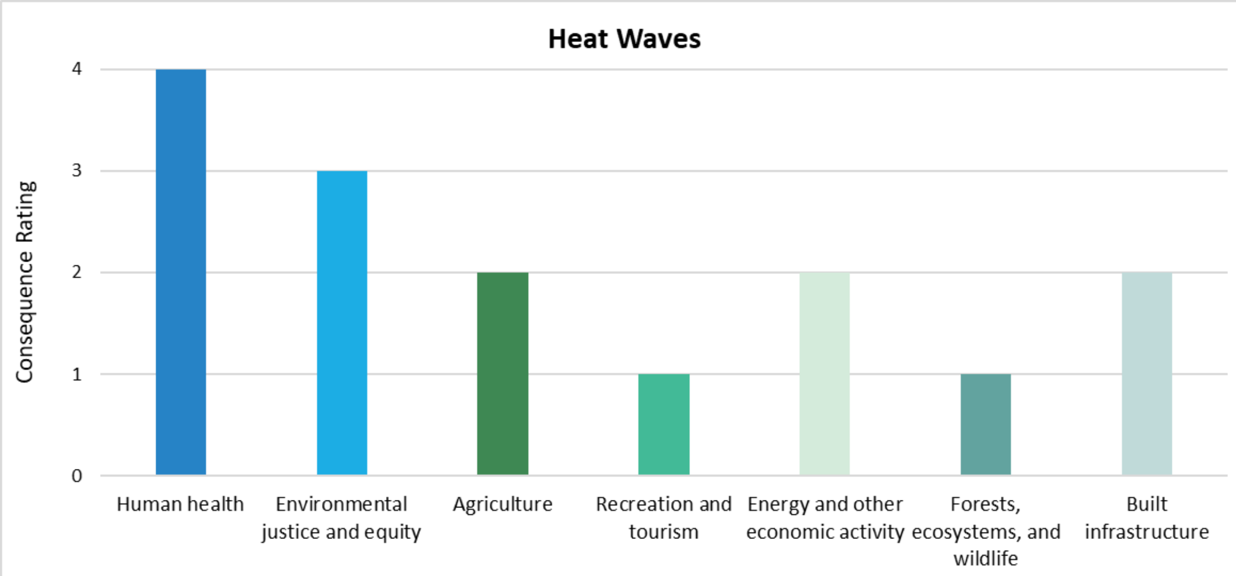

Figure 31. Heat Wave Consequences

Human health: 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.[68] Exposure to high temperatures can cause conditions like heat exhaustion, dehydration, heat rash, heat stroke, and heat cramps, which for the more severe conditions can lead to death if left untreated.[69] 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.[70]

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.[71,72,73] However, the risk of mortality from extreme heat events has been decreasing, as more and more households are installing air conditioning.

Notably, the Occupational Safety and Health Administration (OSHA) cautions that worker heat protection measures should be taken if temperatures exceed 91˚F, or if temperatures come

[68] Davis et al., 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives.*111:1712-1718. https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336

[69] Davis et al., 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives.*111:1712-1718. https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336

[70] Vaidyanathan et al., 2020. Heat-Related Deaths – United States, 2004–2018. Centers for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Report (MMWR) 69:729–734. https://www.cdc.gov/mmwr/volumes/69/wr/mm6924a1.htm

[71] Davis et al., 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives.*111:1712-1718. https://ehp.niehs.nih.gov/doi/pdf/10.1289/ehp.6336

[72] Pennsylvania Department of Agriculture. November 2020. Department staff expertise.

[73] Vaidyanathan et al., 2020. Heat-Related Deaths – United States, 2004–2018. Centers for Disease Control and Prevention (CDC) Morbidity and Mortality Weekly Report (MMWR) 69:729–734. https://www.cdc.gov/mmwr/volumes/69/wr/mm6924a1.htm

near that threshold and people are working outside in direct sunlight and/or without wind to cool them down.[74]

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. [75] Heat stress can also affect the ability of children to learn and retain information and adults to be able to work productively.[76] Extreme heat is also associated with increased rates of suicide and contributes to heightened aggression, hostility, and violence.[77]

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 to purchase A/C or take time off work on high heat days).

Environmental justice and equity: 3

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 and seniors living alone, construction workers, and athletes.[78]

Access to air conditioning is a key adaptation strategy for decreasing excess heat deaths and illness. Indeed, rate of heat-related mortality has decreased over the 20th century and largely after 1960 due to air conditioning becoming 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.

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 "residents of color" 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."[79] The expected causes of hotter temperatures in

[74] U.S. Department of Labor, Occupational Safety and Health Administration (OSHA). N.d. "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.

[75] Cianconi et al., 2020. The impact of climate change on mental health: A systematic descriptive review. *Front Psychiatry.* 11(74). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/

[76] Cianconi et al., 2020. The impact of climate change on mental health: A systematic descriptive review. *Front Psychiatry.* 11(74). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/

[77] Cianconi et al., 2020. The impact of climate change on mental health: A systematic descriptive review. *Front Psychiatry.* 11(74). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7068211/

[78] Maxwell et al., 2018. "Built Environment, Urban Systems, and Cities."

[79] City of Philadelphia. 2019. Beat the Heat Hunting Park: A Community Heat Relief Plan. https://www.phila.gov/media/20190719092954/HP_R8print-1.pdf

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.

As shown in Figure 29, the number of hot days across the state is projected to increase, and populations in environmental justice areas are projected to disproportionately experience highly frequent days with hot temperatures. Isolation of the census blocks projected to see the top 20% of numbers of days with temperatures >90°F in the state indicates that, proportionately, EJ populations are expected be almost twice as exposed to those top-20% conditions compared to the Pennsylvania population as a whole. This impact is not random; consequences of historical practices of redlining, building substandard housing in communities of color, and intentionally disinvesting in communities of color manifest today as inequities where communities of color are disproportionately in older or substandard housing that is particularly susceptible to deterioration by heat waves.

Economy

Agriculture: 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.[80]

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.[81,82]

Extreme heat also threatens worker safety and health as described under the human health section. Time spent working outdoors generally declines above 85°F for agriculture workers.

Recreation and tourism: 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.

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80 Pennsylvania Department of Agriculture. November 2020. Department staff expertise.

81 Pennsylvania Emergency Management Agency. November 2020. Department staff expertise.

82 Pennsylvania Department of Environmental Protection, Office of Water Programs. November 2020. Department staff expertise.

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.[83]

Energy and other economic activity: 2

Heat wave events increase demand for cooling, requiring power grid operators to reduce operable capacity on electric generation facilities and electric transmission lines to avoid heat-related damage. Example economic impacts of heat waves are described below.[84]

Example 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 2 deaths per year except in 2014 and 2017. The high point occurred in 2011 with 36 heat-related deaths.[1]

More than 310,000 people in PA are especially vulnerable to extreme heat (over 65, under 5, or living below the poverty line).[2]

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.[3]

Apples, sweet corn, grapes, and dairy production could all see negative impacts, as extreme heat impacts growth and production.[4]

One study suggests that above a critical temperature threshold of 77 degrees Fahrenheit, dairy milk production may drop by up to 22 percent. This type of decline could inflict as much as $480 million in direct and indirect economic costs.[5]

Sources: Sources: [1] PennLive, 2019; [2] States at Risk, 2015; [3] CornProphet, 2019; [4] Pittsburgh Post-Gazette, 2012; [5] University of Maryland, 2008

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[83] Pennsylvania Department of Conservation and Natural Resources. November 2020. Department staff expertise.

[84] PennLive, 2019. Heat stroke tops list of weather-related deaths. Retrieved from: https://www.pennlive.com/news/2019/07/heat-stroke-tops-list-of-weather-related-deaths.html; States at Risk, 2015. America's Preparedness Report Card 2015: Pennsylvania. Retrieved from: https://reportcard.statesatrisk.org/report-card/pennsylvania/extreme_heat_grade; CornProphet, 2019. Heat Waves and Corn Yield. Retrieved from: https://www.cropprophet.com/heat-waves-and-corn-yield-timing-matters/; Pittsburg Post-Gazette, 2012. How climate change will affect Pennsylvania. Retrieved from: https://www.post-gazette.com/news/environment/2012/04/22/How-climate-change-will-affect-Pennsylvania/stories/201204220205; University of Maryland, 2008. Economic Impacts of Climate Change on Pennsylvania. Retrieved from: http://cier.umd.edu/climateadaptation/Pennsylvania%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf

Forest, ecosystems, and wildlife: 1

Increasing average temperatures represent a greater threat 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: 2

Extreme heat can stress infrastructure, including pavements, 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. For example, roadways will become more pliable, experience greater wear and tear, and be more susceptible to buckling under extreme heat conditions.[85]

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 urban heat island. 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.[86]

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.[87] Power outages are possible is the system is overloaded.

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.[88]

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[85] Pennsylvania Emergency Management Agency. November 2020. Department staff expertise.

[86] Pennsylvania Department of General Services. November 2020. Department staff expertise.

[87] Pennsylvania Department of General Services. November 2020. Department staff expertise.

[88] Pennsylvania Department of Environmental Protection, Office of Water Programs. November 2020. Department staff expertise.

5.3 Heavy Precipitation and Inland Flooding

5.3.1 Overview

Flood events are recognized as the costliest weather hazards in Pennsylvania. From 1996 to 2018, flooding (general) caused approximately $1.025 Billion in property damage, 31 fatalities, and 107 injuries. Flash flooding caused approximately $2.156 Billion in property damage, 58 fatalities, and 52 injuries. These two types of flooding together generated 79% of the property damage of all weather-related impacts in the state, though only 12% and 7% respectively of fatalities and injuries are related to weather events.

As shown in Figure 34, not only are the costs associated with infrastructure damage high, but increased risks to agricultural production, human health and equity challenges, and natural resources are significant.[89] Figure 32 illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

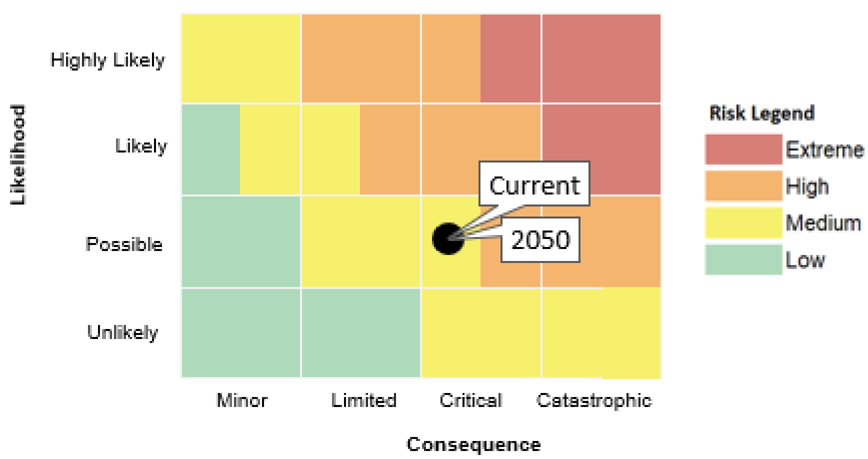

Figure 32. Heavy Precipitation and Inland Flooding Risk Matrix

Table 9 summarizes the statewide likelihood and consequences of heavy precipitation and inland flooding in Pennsylvania.

Table 9. Heavy Precipitation and Inland Flooding Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.3.2)**	**Confidence**	**Differential Impacts**
Current	2	Precipitation variability is increasing Critical inland floodplains (e.g., FEMA 100-Year Floodplain) are rarely inundated	High	Areas in FEMA 100- and 500-year floodplains may be most at risk
2020-2050	2	Precipitation variability and flooding are projected to	Medium	Same as current differential impacts

[89] DEP. 2020 IA.

		significantly increase by mid-century, though not to the degree projected for late-century		
Beyond 2050	As described in section 3.2.2, precipitation changes are expected to continue well beyond mid-century.			
Consequences				
Category	**Rating**	**Justification Notes (details in 5.3.3)**	**Confidence**	**Differential Impacts**
Human health	3	• Main risks: flooding, decreased water quality • Flooding may impact large swaths of the population and can prove fatal in extreme events	High	Certain communities 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 communities of color that have historically been disinvested in (e.g., older infrastructure) may be more vulnerable to impacts.
Environmental justice and equity	3	• Spatial analysis finds similar exposure of EJ and non-EJ areas • Frontline communities are known to face greater vulnerabilities to and obstacles in managing flood impacts	Medium	See above
Economy: Agriculture	3	• Increased flooding risks include augmented runoff, erosion, and nutrient leaching, and challenges in timing of crop planting	High	See above
Economy: Recreation and tourism	1	• Flooding and heavy rainfall may cause minimal to moderate disruption to outdoor	Medium	See above

		recreation and the tourism industry		
Economy: Other	2	• Flooding could significantly damage infrastructure, with broader downstream economic impacts	Medium	See above
Forests, ecosystems, and wildlife	2	• Increased hydrological variability may impact wetland and stream ecosystems • Increased flooding and runoff may increase pathogen loads and eutrophication and algal bloom risks	High	See above
Built Infrastructure	4	• Built infrastructure may be at increasing risk of flood damages (e.g., homes, small businesses, major energy and transportation assets) • Infrastructure in floodplains is particularly at risk	High	See above
Overall Risk		**Risk Score**		**Confidence**
	Current	**5.6 (Medium)**		High
	2050s	**5.6 (Medium)**		Medium
Potential Opportunities				
• **Invest in healthy soils in agricultural land – 1% of organic matter in the top 6 inches of soil would hold approximately 27,000 gallons of water per acre**[90] • **Invest in more agricultural best management practices (BMPs) to reduce the shock of acute storm events**				

5.3.2 Likelihood

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.[91]

[90] USDA Natural Resources Conservation Service (NRCS). 2013. "Soil Health: Key Points." https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082147.pdf

[91] PSU. 2020 IA.

Together, several precipitation metrics can guide better understanding of future conditions. Local information can indicate local-level changes; state averages are described here, with mid-century (2041-2070) modeled conditions 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 24%, from 17 days to 19 days. The amount of precipitation falling on those days is also projected to increase 12%. Additionally, the annual number of days with more than 3 inches of precipitation is projected to increase 52%, from 0.07 days to 0.11 days. Though these numbers speak to events that happen relatively infrequently, all are projected to occur more often in the future, demonstrating the trend of increased variability.

As more intense precipitation events become more common, the chance of associated flooding events, including the 1% annual chance floods (or 1-in-100 year floods) and 0.2% annual chance (or 1-in-500 year floods) may also increase. As shown in Figure 33, a significant portion of land in Pennsylvania may be susceptible to inundation in these events. Notably, land projected to be inundated in the 100-year and 500-year floodplains is very similar; the 500-year floodplain covers only 0.3% more of the state (total 5.8%) compared to the 100-year floodplain (total 5.5%).

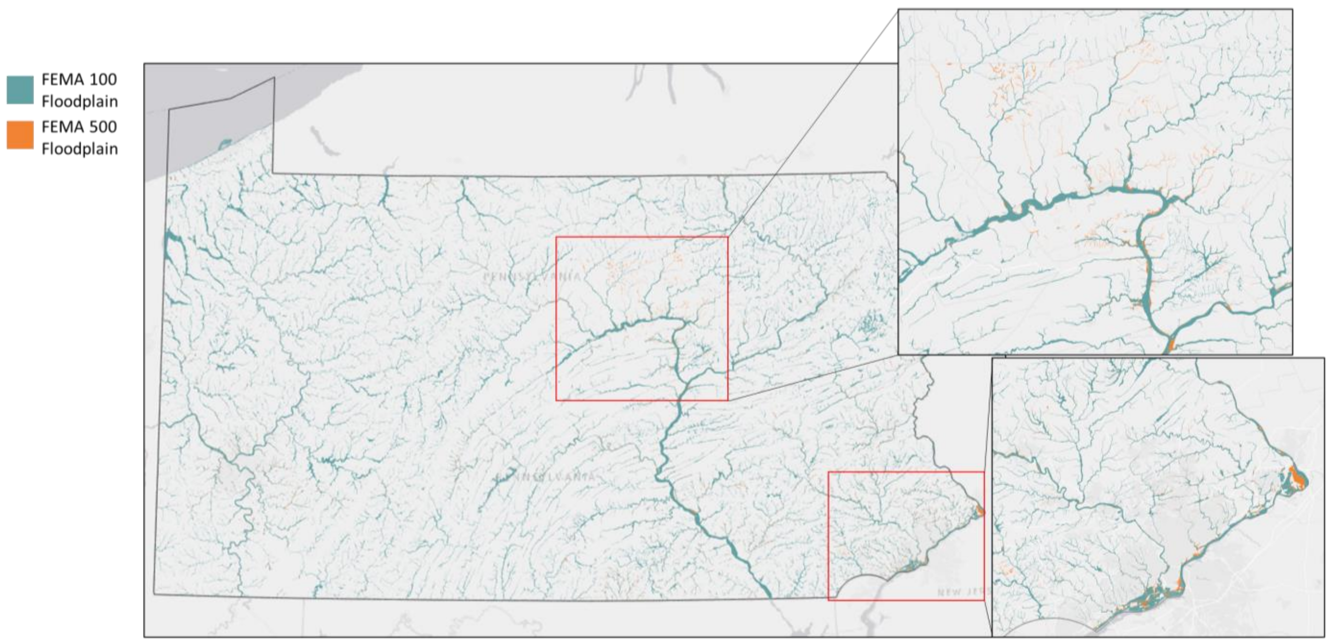

Figure 33. FEMA 100- and 500-Year Flood Zones in Pennsylvania. Data source: FEMA

5.3.3 Consequences

Flood events are recognized as the costliest weather hazards in Pennsylvania. As shown in Figure 34, not only are the costs associated with infrastructure damage high, but increased risks to agricultural production, human health and equity challenges, and natural resources are significant.[92]

[92] PSU. 2020 IA.

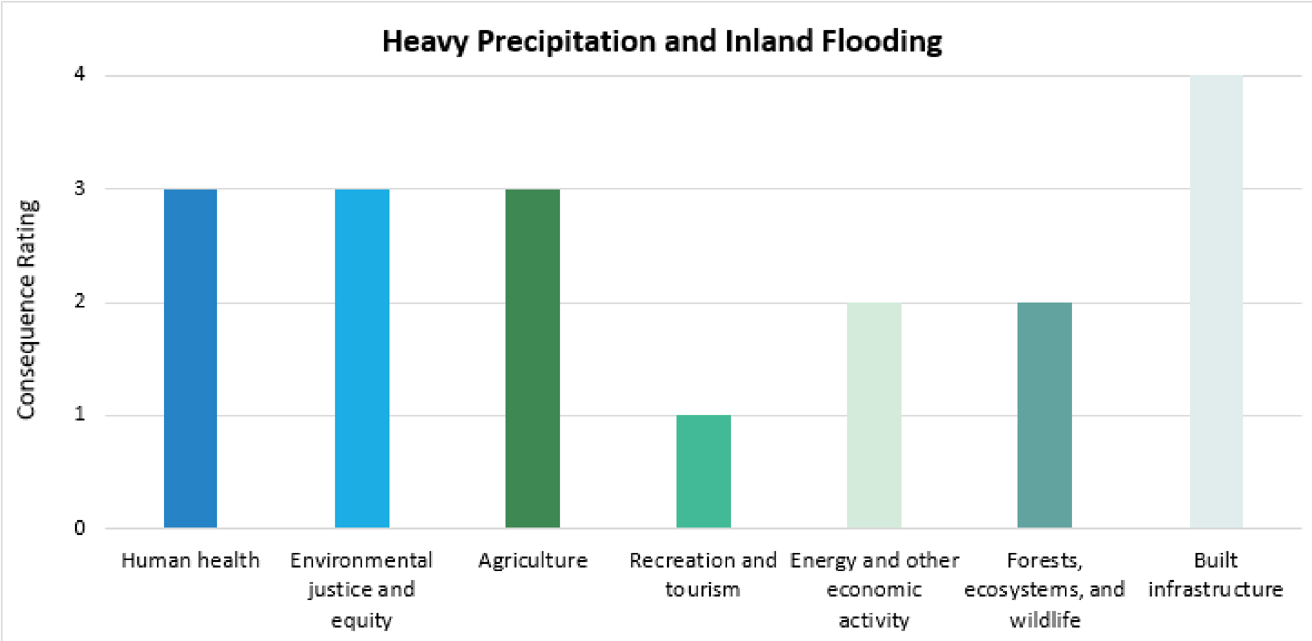

Figure 34. Heavy Precipitation and Inland Flooding Consequences

Human health: 3

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

Historically, Pennsylvania has frequently experienced extreme floods, and the deadliest among those events have been caused by extreme precipitation.[93] 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.[94] Additionally, 2 of the 72 deaths directly caused by extreme storm Hurricane Sandy in 2012 occurred in Pennsylvania.[95]

Climate change can potentially also 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. Post flood-event health consequences may include physical safety risks related to standing flood water or limited access to critical services

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[93] PSU. 2020 IA.
[94] PSU. 2020 IA.
[95] PSU. 2020 IA.

(e.g., due to transportation damages)[96,97], respiratory risks related to reduced indoor air quality (e.g., because of mold)[98,99], and mental health impacts.[100]

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.[101]

Environmental justice and equity: 3

Spatial analysis of area at risk in FEMA 100-year and 500-year floodplains indicates that in percentage of land cover, EJ areas have a slightly higher level of exposure compared to the state overall. (For more information on the EJ areas approach used in this Assessment, see Appendix B – Risk Assessment Methodology.)

Nearly 5.5% of Pennsylvania land and 6.5% of Pennsylvania EJ areas are located in FEMA 100-year floodplains. And 5.8% of Pennsylvania land and 7.1% 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 (1.18x as exposed and 1.22x as exposed, respectively).

Notably, these land cover spatial analyses do not capture how many people live in each floodplain, how vulnerable they are to flood risks, or their base level of adaptive capacity.

Rural communities in Pennsylvania have seen some of the highest per capita property losses related to flooding, on average, within the state.

In addition, riverine and coastal flooding challenges are likely to be exacerbated by existing underinvestment in stormwater management or flood protection infrastructure[102] – a cycle that may leave poorest communities in most at-risk locations due to financial obstacles to leaving for higher ground. Pre-existing indicators that can be assets or vulnerabilities for flood risk include demographics (e.g., age, race, English fluency) and housing security (e.g., if your home is in a flood plain, having floodproofing and/or a flood clause in homeowners insurance) and business security (e.g., if your business has flood-proofing measures). Related outcomes in the event of flooding impact everything from jobs (e.g., if your business is closed) to food security (e.g., if crops are lost due to flooding) to housing (e.g., if your home is damaged by flooding) to

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[96] FEMA. N.d. "Critical Facilities and Higher Standards." https://www.fema.gov/media-library-data/1436818953164-4f8f6fc191d26a924f67911c5eaa6848/FPM_1_Page_CriticalFacilities.pdf

[97] Ready.gov. 2020. "Floods." https://www.ready.gov/floods

[98] Berkeley Lab. 2020. "Dampness and Mold from Severe Storms and Flooding." https://iaqscience.lbl.gov/cc-dampness

[99] U.S. Environmental Protection Agency (EPA). 2015. "Flood Cleanup: Protecting Indoor Air Quality." https://www.epa.gov/sites/production/files/2015-09/documents/floods.pdf

[100] Stanke, C., Murray, V., Amlôt, R., Nurse, J., and R. Williams. 2012. "The effects of flooding on mental health: Outcomes and recommendations from a review of the literature." *PLOS Currents*, 4, May 30. DOI: 10.1371/4f9f1fa9c3cae.

[101] Pennsylvania DCNR. November 2020. Department staff expertise.

[102] Russek, Karl. The Water Center at Penn. 2020. "Building Community Capacity at the Intersection of Water, Equity, and Climate Change." https://watercenter.sas.upenn.edu/building-community-capacity-at-the-intersection-of-water-equity-and-climate-change/

emergency management (e.g., language and platform accessibility of communications) and access to services (e.g., education, healthcare, emergency management.[103]

Analysis of equity and urban flood risks by the US 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.[104] The analysis identifies five key types of flooding inequities often experienced in urban environments: "1) Historical development practices placed low-income people and communities of color 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".[105]

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 community stakeholders and leaders' voices central in the planning, decision-making, and communications processes.[106] 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 (CBF) to design and implement mitigation measures in their neighborhoods, from planting street trees to putting together rain gardens.[107]

Economy

Agriculture: 3

Pennsylvania's hydrological climate may become more extreme in the future. 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. Crop, equipment, and livestock losses or damage may also occur. 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 will continue to be as heavy precipitation events become more frequent and intense.

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[103] National Association for the Advancement of Colored People (NAACP). 2016. "Equity in Building Resilience in Adaptation Planning." https://www.naacp.org/wp-content/uploads/2016/04/Equity_in_Resilience_Building_Climate_Adaptation_Indicators_FINAL.pdf
[104] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning." www.uswateralliance.org/sites/uswateralliance.org/files/publications/Final_USWA_Water%20Rising_0.pdf
[105] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning."
[106] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning."
[107] Chesapeake Bay Foundation (CBF). N.d. "Environmental Justice Projects Take Hold." https://www.cbf.org/about-cbf/locations/pennsylvania/whats-up-in-pennsylvania/environmental-justice-projects-take-hold.html

Pennsylvania experienced prolific, statewide crop damage resulting from extended rainfall throughout 2018. Planting delays, repeated damage to planted fields, and an inability to harvest impacted crop and commodity producers, as well as livestock producers who grow their own feed and forage. The Pennsylvania Department of Agriculture estimated that 30 percent of corn and soybean acres were still unharvested at the beginning of December 2018, and these acres were at risk of rot or severely reduced yield due to disease and mold.[108]

After the state requested a statewide disaster designation, the United States Department of Agriculture designated 33 Pennsylvania counties as primary natural disaster areas for losses caused by excessive rain, flash flooding, and flooding that occurred on or after July 21, 2018. Adams, Blair, Cambria, Cameron, Centre, Clearfield, Clinton, Columbia, Crawford, Elk, Erie, Fayette, Franklin, Fulton, Greene, Huntingdon, Indiana, Jefferson, Lancaster, Lebanon, Luzerne, Lycoming, McKean, Northampton, Potter Schuylkill, Snyder, Somerset, Susquehanna, Washington, Westmoreland, Wyoming, and York counties made up the primary damaged area. Producers in the contiguous counties were also eligible to apply for emergency loans available through the Farm Service Agency.[109]

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. 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. Notably, 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.

A 2015 Pennsylvania analysis found the agricultural sub-sector of crop and animal production generated about $9.2 Billion USD, approximately 10% of the total economic output from the agricultural sector, though this sub-sector provides about 29% of the total direct employment in the agricultural sector.[110]

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[108] Pennsylvania Department of Agriculture. 2018. Letter to USDA Secretary Perdue, Dec. 3 2018, requesting a statewide disaster designation due to weather damages statewide.

[109] USDA. 2019. News Release No. 0018.19: "USDA Designates 33 Pennsylvania Counties as Primary Natural Disaster Areas." https://www.fsa.usda.gov/news-room/emergency-designations/2019/ed_2019_0326_rel_0018

[110] Pennsylvania Department of Agriculture. 2018. "Pennsylvania Agriculture: A Look at the Economic Impact and Future Trends." https://www.agriculture.pa.gov/Documents/PennsylvaniaAgriculture_EconomicImpactFutureTrends.pdf

Recreation and tourism: 1

Potential effects of climate change and pollution on water quality may increase risks of outdoor recreation where people could come in contact with dirtier or more polluted water.[111]

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).[112]

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.[113] 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.[114]

Energy and other economic activity: 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, or local power blackouts caused by flood damage to energy infrastructure could impact those reliant on that power supply.[115] Depending on the region and asset(s) impacted, consequences may vary significantly. Example economic impacts of flooding are described below.[116]

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[111] PSU. 2015 IA.

[112] Pennsylvania DCNR. 2018. Climate Change Adaptation and Mitigation Plan.

[113] Pennsylvania DCNR. 2018. Climate Change Adaptation and Mitigation Plan.

[114] Pennsylvania DCNR. November 2020. Department staff expertise.

[115] DEP. 2020 IA.

[116] Federal Reserve Bank of St. Louis. 2019. Crop Prices and Flooding: Will 2019 Be a Repeat of 1993? June 6, 2019. Retrieved from: https://www.stlouisfed.org/on-the-economy/2019/june/crop-prices-flooding-2019-repeat-1993; Fowler et al. 2018. Flood Mitigation for Pennsylvania's Rural Communities: Community-Scale Impact of Federal Policies. Retrieved from: https://www.rural.palegislature.us/documents/reports/Flood-Mitigation-2017.pdf; National Weather Service (NWS). N.d. 2018 in Context: Record Precipitation across Pennsylvania. National Oceanic and Atmospheric Administration. Retrieved from: https://www.weather.gov/ctp/RecordPrecip2018; Pennsylvania Department of Environmental Protection (PA-DEP). N.d. Climate Change in PA. Retrieved from: https://www.depgis.state.pa.us/ClimateChange/index.html; Pennsylvania Department of Transportation (PENNDOT). 2018. PENNDOT Estimates over $105M in Flood, Slide Damages. Retrieved from: https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165; Pennsylvania Media (PA Media). 2018. Governor Wolf Requests Federal Aid for Severe Storms In August. Retrieved from: https://www.media.pa.gov/Pages/PEMA-Details.aspx?newsid=85; PennLive, 2019. For Pa. farmers, year of record rain a 'big nuisance.' Pennsylvania Real-Time News. Retrieved from: https://www.pennlive.com/news/2019/06/for-pa-farmers-year-of-record-rain-often-a-big-nuisance.html; Post-Gazette.com. 2018a. Flooding shuts down many local roads; some school districts close. January 12, 2018. Retrieved from: https://www.post-gazette.com/local/region/2018/01/12/TRAFFIC-Flooding-closes-pittsburgh-roads-Mon-Wharf-roadwork/stories/201801120139; Post-Gazette.com. 2018b. Precipitation rates raising the potential for flooding. April 15, 2018. David Templeton. Retrieved from: https://www.post-gazette.com/local/city/2018/04/15/Rain-raising-concern-National-Weather-Service-landslide-

Example Economic Impacts: 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.[1,2]

Flooding along Rivers

From 1991 to 2012, Pennsylvania saw a 71 percent increase in heavy rainfall events of 2 or more inches.[1]

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.[3]

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.[4,5,6,7]

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.[8]

Rural Impacts

Roughly 6.5 percent 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.[1]

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.[9,10,11]

Sources: [1]Fowler et al., 2018; [2]NWS, n.d.; [3]PA Media, 2018; [4]PENNDOT, 2018; [5]Post-Gazette.com, 2018a; [6]Post-Gazette.com 2018b; [7]Post-Gazette.com, 2018c; [8]PA-DEP, n.d; [9]PennLive, 2019; [10]Post-Gazette.com, 2019; [11]Federal Reserve Bank of St. Louis, 2019

Forest, ecosystems, and wildlife: 2

More intense rainfall projections are already beginning to manifest in Pennsylvania. As described in the 2015 Impacts Assessment, more extreme streamflow associated with intense rainfall is already occurring across much of the state, except for the Southwest quadrant. In 2018, Pennsylvania experienced its wettest year on record and caused flash flooding across the state. This risk is projected to continue to increase under climate change, and bank erosion is

flooding/stories/201804150192; Post-Gazette.com. 2018c. Rainstorms cause damage, flooding throughout region. February 15, 2018. Retrieved from: https://www.post-gazette.com/local/region/2018/02/15/Rainstorms-cause-damage-flooding-throughout-region-Allegheny-Beaver-Washington-Westmoreland/stories/201802150227; Post-Gazette.com. 2019. For farmers in Pa. and beyond, heavy rain has turned planting into erratic waiting game. June 1, 2019. Retrieved from: 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 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.[117]

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 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).[118]

Hydraulic fracturing or "fracking" is currently underway in many parts of Pennsylvania, particularly in southwest and northeast Pennsylvania in the Marcellus Shale.[119] Laws such as Act 13[120] govern safe management of potentially toxic spills and runoff from fracking operations that can occur with heavy flooding.[121] Additionally, there are municipal waste landfills and other waste facilities located across Pennsylvania,[122] 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.[123]

Built infrastructure: 4

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), though if key infrastructure is damaged that may have broader downstream affects (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 $953 million to National Flood Insurance Program (NFIP) policyholders in Pennsylvania between 1975 and 2019. NFIP insurance is

[117] PSU. 2015 IA.
[118] PSU. 2015 IA; DEP. 2020 IA.
[119] Amico, C., DeBelius, D., Detrow, S. and M. Stiles. 2011. "Shale Play: Natural Gas Drilling in Pennsylvania." *StateImpact Pennsylvania. http://stateimpact.npr.org/pennsylvania/drilling/*
[120] DEP. 2020. "Act 13 Frequently Asked Questions." https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/Act13/Pages/Act-13-FAQ.aspx
[121] Mall, A. 2012. "Big storms and fracking: what's at stake?" *Natural Resources Defense Council (NRDC)*. https://www.nrdc.org/experts/amy-mall/big-storms-and-fracking-whats-stake
[122] DEP. 2020. "Municipal Waste Landfills and Resource Recovery Facilities." https://www.dep.pa.gov/Business/Land/Waste/SolidWaste/MunicipalWaste/MunicipalWastePermitting/Pages/MW-Landfills-and-Resource-Recovery-Facilities.aspx
[123] Cosier, Susan. 2019. "Great Lakes Levels Are Rising – a Sign of Things to Come?" *Natural Resources Defense Council (NRDC)*. https://www.nrdc.org/stories/great-lakes-levels-are-rising-sign-things-come

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.[124]

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 capital property losses due to flooding found many of the higher losses were experienced in rural counties in Pennsylvania.

Infrastructure at greatest risk of flooding are those 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 Irene and Superstorm Sandy) and flooding events indicate that local electricity infrastructure may be more susceptible to heavy rainfall hazards than the regional bulk power grid.[125]

Additionally, greater frequency and intensity of intense rainfall events will 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).[126]

Issues such as storm sewer backup may lead to ground-water 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 mitigate sewage release events and manage higher flow amounts.[127]

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.[128]

Various flood protection efforts, ranging from monitoring to education to real-time warning plans to policy and strategy revision, are underway, described in detail in the 2019 Update to the Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan.

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124 FEMA. 2020. "Flood Insurance." https://www.fema.gov/flood-insurance
125 DEP. 2020 IA.
126 The Nature Conservancy. N.d. "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/
127 DEP. 2020 IA.
128 Pennsylvania Office of Water Programs. November 2020. Department staff expertise.

5.4 Landslides

5.4.1 Overview

Landslides can occur across Pennsylvania. As shown in Figure 35, they occur most often in the Southwestern region, though other regions may have significant landslide hazards as well – and this region may expand.[129]

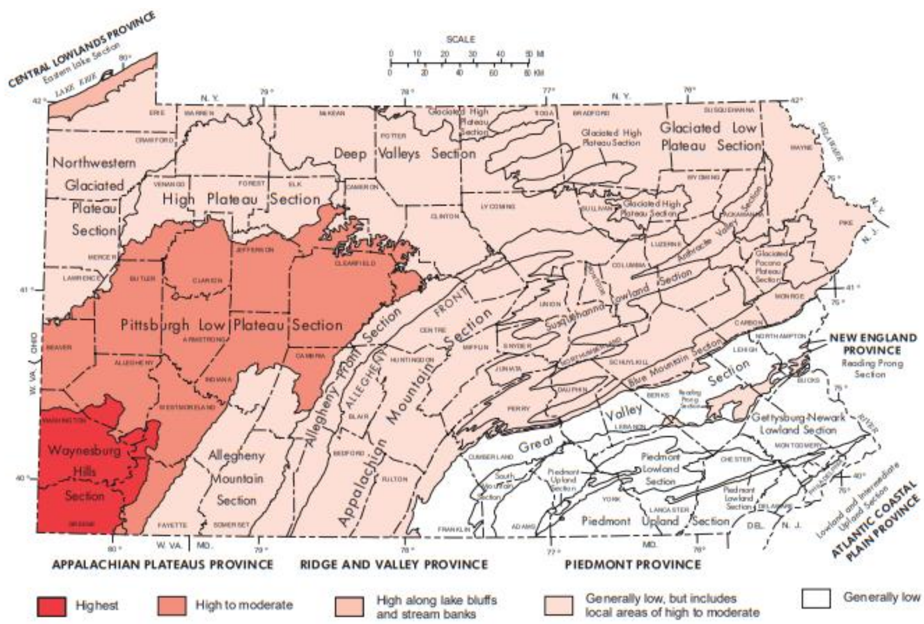

Figure 35. Physiographic information and landslide susceptibility in Pennsylvania. Taken from Delano and Wilshusen, 2001.

Higher average and extreme precipitation may increase soil water saturation, which can destabilize soil and increase the risk of landslide occurrence.[130] 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.[131]

Temperature is also relevant to landslide risk. For example, one component of the extreme landslide occurrences in 2018 was warm weather. In 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.

Under 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

[129] Pennsylvania DCNR. November 2020. Department staff expertise.

[130] Gariano, S. L. and F. Guzzetti. 2016. "Landslides in a changing climate." *Earth-Science Reviews,* 162, p. 227-252. https://www.sciencedirect.com/science/article/pii/S0012825216302458.

[131] Pennsylvania DCNR. November 2020. Department staff expertise.

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 the slide, and the amount of time and spread of consequences vary.

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 could impact electricity end-users (e.g., homes, buildings like hospitals, farms with irrigation systems that run on electricity). Figure 36 illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

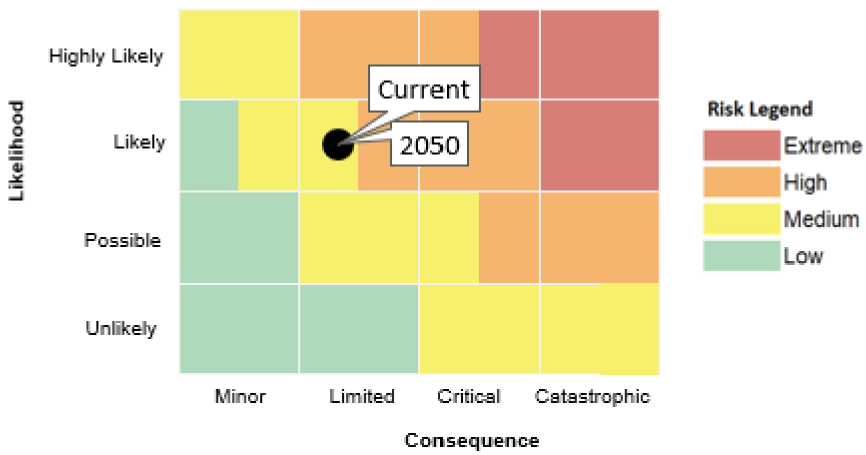

Figure 36. Landslides Risk Matrix

Table 10 summarizes the statewide likelihood and consequences of landslides in Pennsylvania.

Table 10. Landslides Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.4.2)**	**Confidence**	**Differential Impacts**
Current	3	The PA HMP[132] identifies landslides of any magnitude as "highly likely" (over 90% probability) to occur any given year. More severe landslides	High	In general, southwestern locations and populations are more vulnerable; there are also other localized areas with high vulnerability.

[132] Pennsylvania Emergency Management Agency (PEMA). 2018. "Risk Assessment." https://pahmp.com/risk-assessment/.

		like those analyzed int his scenario would be less likely.		
2020-2050	3	Landslide probability may increase with greater precipitation variability, though not enough evidence exists to change current likelihood rating.[133]	Medium	Same as current.
Beyond 2050	These trends are expected continue as precipitation variability increases beyond 2050.			Same as current.
Consequences				
Category	**Rating**	**Justification Notes (details in 5.4.3)**	**Confidence**	**Differential Impacts**
Human health	1	• Few health consequences expected	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	• Impacts likely to be localized 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 economic consequences expected	Medium	See Economy: Agriculture.
Economy: Other	2	• Unless critical infrastructure is severely damaged, impacts are likely to be localized.	High	See Economy: Agriculture.

[133] Gariano and Guzzetti. 2016. "Landslides in a changing climate."

Forests, ecosystems, and wildlife	1	• Few consequences expected	Medium	N/A
Built Infrastructure	4	• Direct damages to energy or transportation infrastructure, and downstream impacts, may be relatively localized, but significant	High	See Economy: Agriculture.
Overall Risk		**Risk Score**	**Confidence**	
	Current	**5.6 (Medium)**	High	
	2050s	**5.6 (Medium)**	High	
Potential Opportunities				
None identified				

5.4.2 Likelihood

The 2018 update to the Pennsylvania State Hazard Mitigation Plan,[134] which identified annual probability of risk events occurring as well as the estimated impact, spatial extent, length of warning time, and duration if the event does occur, found that landslides currently present a moderate risk. The assessment found landslides of any magnitude are highly likely (>90% annual probability) to occur, and with <6 hours warning time, but are anticipated to have minor impacts, negligible spatial extent, and short duration. Minor impacts are defined as "very few injuries, if any" as well as "minimal disruption on quality of life," "only minor property damage," and potential "temporary shutdown of critical facilities." Though landslides have caused injuries and fatalities, these occurrences have been infrequent.

Literature on climate change and landslide risk[135] 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.

[134] PEMA. 2018. "Risk Assessment."
[135] Gariano and Guzzetti. 2016. "Landslides in a changing climate."

As shown in Figure 35, approximately 48% of land in Pennsylvania currently have 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 37),[136] though slides have occurred in eastern PA.

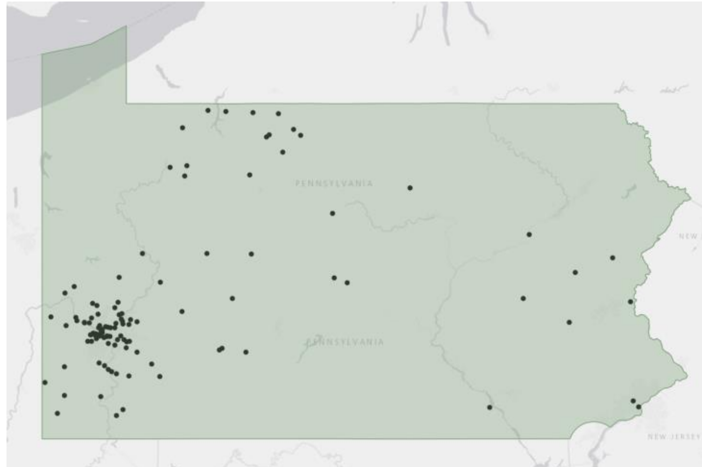

Figure 37. Historical incidence of landslides. Taken from the U.S. Landslide Inventory (USGS, N.d.).

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 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.

5.4.3 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.[137,138] 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) if unknown thresholds are reached.[139]

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 impacts are damages to infrastructure (e.g., highways, buildings, utility facilities).

Figure 38 summarizes the overall consequence ratings statewide for landslides– highest consequences are in environmental justice and equity and built infrastructure.

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[136] U.S. Geological Survey (USGS). N.d. "U.S. Landslide Inventory." https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=ae120962f459434b8c904b456c82669d

[137] Pennsylvania Department of Conservation and Natural Resources (DCNR). N.d. "Landslides." https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx

[138] Delano, H. L., and J.P. Wilshusen. 2001. "Landslides in Pennsylvania: Pennsylvania Geological Survey." 4th ser., Educational Series 9. http://elibrary.dcnr.pa.gov/GetDocument?docId=1752504&DocName=ES9_Landslides_Pa.pdf#

[139] Pennsylvania DCNR. November 2020. Department staff expertise.

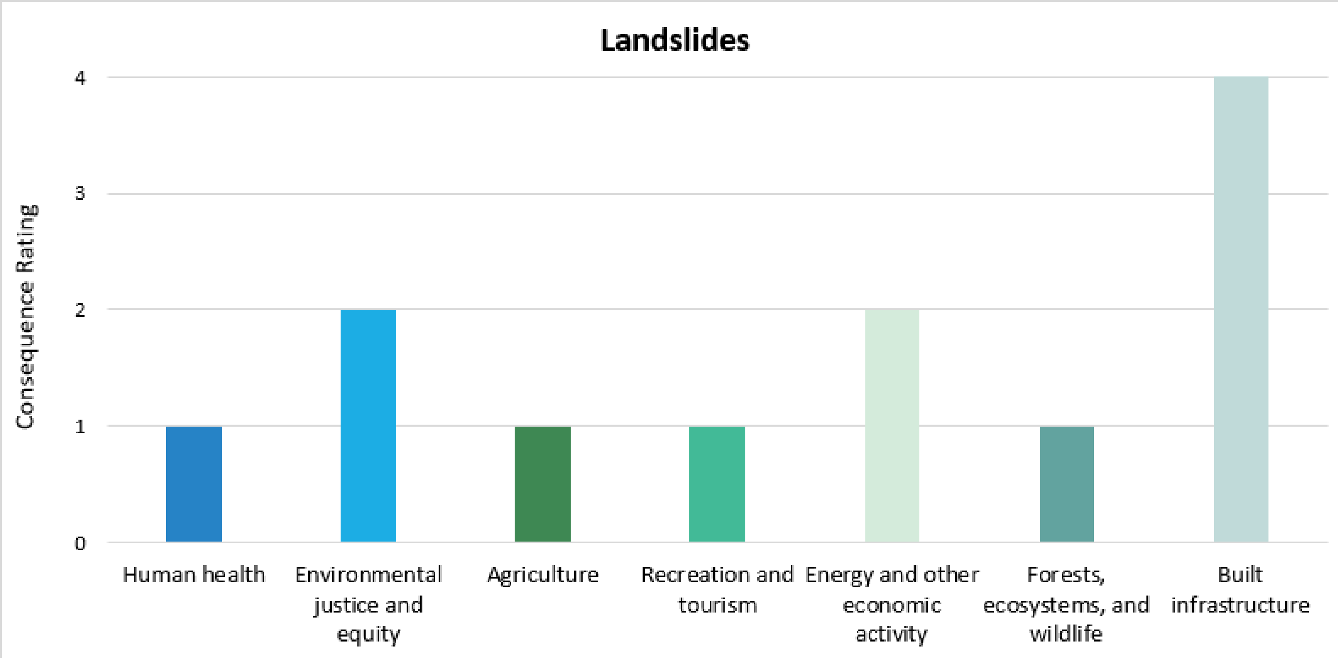

Figure 38. Landslide Consequences

Human health: 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.[140]

Landslides can indirectly affect health if they disrupt infrastructure critical to supplying commodities and services that people rely on (e.g., energy infrastructure, transportation infrastructure needed to deliver medicine or roads critical to fast ambulance travel,[141] or water or wastewater treatment facilities), accessing places of employment (e.g., road or rail infrastructure), or otherwise allowing economic function and revenue generation.[142] 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.[143]

Environmental justice and equity: 2

As shown in Figure 39, spatial analysis of regions with high landslide incidence rates and susceptibility finds 48% of total sq. miles in the state are at risk, while 56% of total sq. miles of all

[140] Pennsylvania DCNR, N.d. "Landslides."
[141] Pennsylvania DCNR. November 2020. Department staff expertise.
[142] DEP. 2020 IA.
[143] Pennsylvania DCNR. November 2020. Department staff expertise.

state EJ areas are at risk. Therefore, EJ areas experience approximately 1.17 times the risk that the state experiences on average.

However, EJ communities may nonetheless experience disproportionate impacts of landslides when they occur. For example[144]:

- 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.

Notably, impacts may be different in different regions. 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.

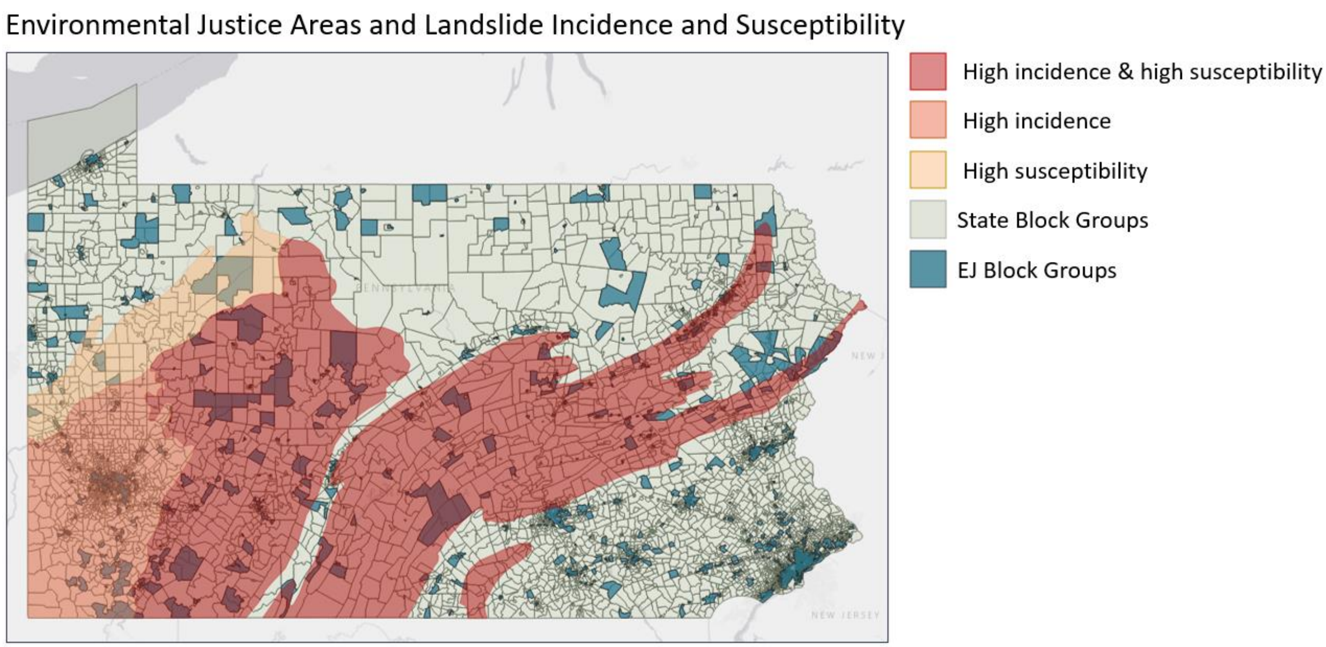

Figure 39. High landslide risk areas (historical) and environmental justice census block groups (EJ areas). Landslide data source: USGS, National Landslide Information Center: *Compilation of Landslide Overview Map of the Conterminous United States.*

Economy

Agriculture: 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

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144 Pennsylvania DCNR. November 2020. Department staff expertise.

would have the most intense and direct impacts, including displacement of or damage to crops, livestock, or materials (e.g., stored feed, equipment).[145]

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. [146]

Recreation and tourism: 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.

Energy and other economic activity: 2

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 increase in the future, as heavy precipitation events, which are projected to become more frequent and intense, are associated with increased landslide potential.[147]

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.

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 busses, commuters, 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.[148] Example economic impacts of landslides are described below.[149]

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[145] Food and Agriculture Organization of the United Nations (FAO). 2020. "Landslides." http://www.fao.org/emergencies/emergency-types/landslides/en/?page=3&ipp=10&no_cache=1&tx_dynalist_pi1[par]=YToxOntzOjE6IkwiO3M6MToiMCI7fQ==

[146] Pennsylvania Department of Agriculture. November 2020. Department staff expertise.

[147] DEP. 2020 IA; Gariano and Guzzetti. 2016. "Landslides in a changing climate."

[148] Pennsylvania DCNR. November 2020. Department staff expertise.

[149] Pennsylvania Emergency Management Agency (PEMA), 2018. Landslide. 2018 Commonwealth of Pennsylvania State Hazard Mitigation Plan Update. Retrieved from: https://pahmp.com/landslide-2/; Pennsylvania Department of Conservation & Natural Resources, n.d. Landslides. Retrieved from: https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx; E&E News, 2019. Landslides, explosions spark fear in pipeline country. Retrieved from: https://www.eenews.net/stories/1060472727; The Times, 2018. PennDot faces uphill battle in fixing local landslides. Retrieved from: https://www.timesonline.com/news/20181101/penndot-faces-uphill-battle-in-fixing-local-landslides; TRIBLIVE, 2019. Landslide costs add to PennDOT's funding challenges. Retrieved from: https://triblive.com/local/regional/landslide-costs-add-to-penndots-funding-challenges/

Example Economic Impacts: 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.

Vulnerable Populations and Infrastructure

Much of Pennsylvania is susceptible to landslides, with 4.48 million people, 6,318 critical facilities, and more than $510 billion in exposed building infrastructure.[1]

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.[2]

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.[3]

Transportation and Natural Gas Infrastructure

Great portions of the Pennsylvania roadway network runs through mountainous terrain, and are continually at risk. In three counties alone (Beaver, Allegheny, and Lawrence), 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.[4]

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.[5]

Sources: [1] Pennsylvania Emergency Management Agency (PEMA), 2018; [2] PA Department of Conservation and Natural Resources, n.d.; [3] TRIBLIVE, 2019; [4] The Times, 2018; [5] E&E News, 2019.

Forest, ecosystems, and wildlife: 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).[150]

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).[151]

Built infrastructure: 4

Greater frequency and intensity of heavy precipitation events may increase landslide potential.[152]

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[150] Geertsema, M., Highland, L. and L. Vaugeouis. 2009. "Environmental Impact of Landslides." In *Landslides – Disaster Risk Reduction [K. Sassa and P. Canuti, Eds.].*
[151] Pennsylvania DCNR. November 2020. Department staff expertise.

[152] Gariano and Guzzetti. 2016. "Landslides in a changing climate."

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. Pennsylvania DOT 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. 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.[153]

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 as 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 particular individuals' health may be impacted.[154]

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. And due to infrastructure interdependencies, if landslides cause service disruptions or transportation and shipping impacts, they 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).[155]

Landslide risk maps developed for the 2020 Impact Assessment show natural gas (Figure 40), railway (Figure 41) and electrical (Figure 42) 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.[156]

153 PEMA. 2018. "Risk Assessment."
154 Pennsylvania DCNR. November 2020. Department staff expertise.
155 DEP. 2020 IA.
156 DEP. 2020 IA.

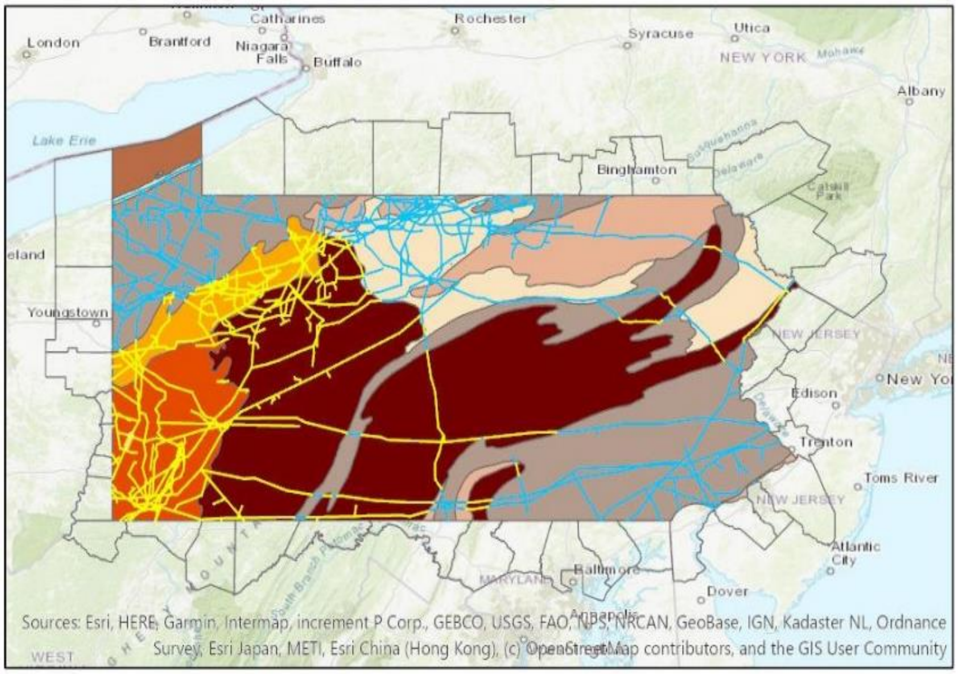

Figure 40. Electric power substations in identified landslide hazard areas (red dots) and electric transmission lines whose support towers are in identified landslide hazard areas (yellow lines). Green dots and green lines indicates substations and transmission lines that lie outside of identified landslide hazard areas. Taken from DEP, 2020 IA.

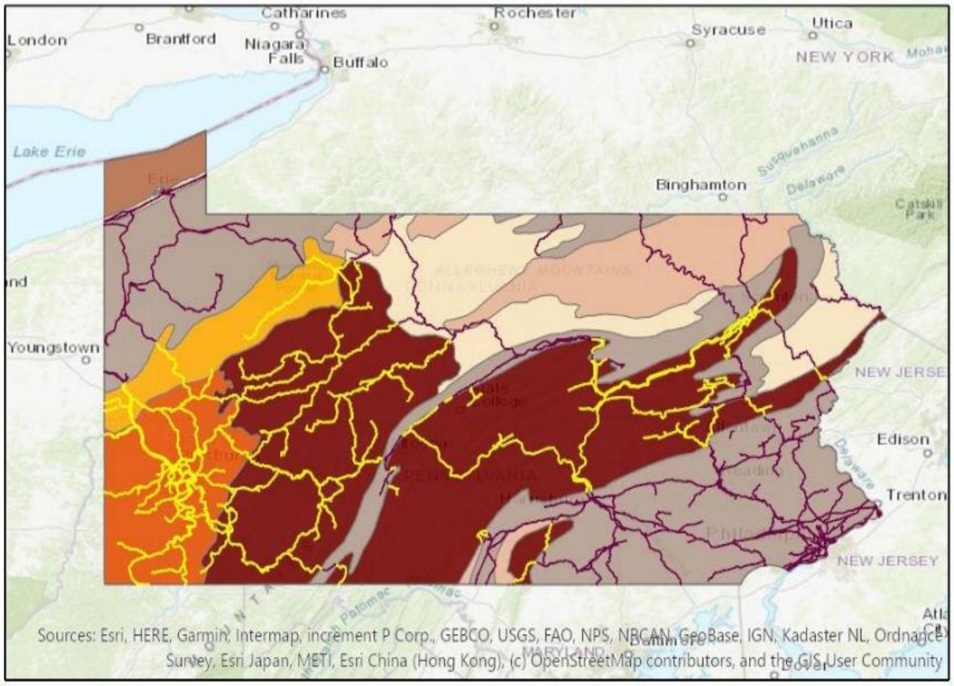

Figure 41. Railroads in identified landslide hazard areas (yellow lines). Purple lines indicate railroads that lie outside of identified landslide hazard areas. Taken from DEP, 2020 IA.

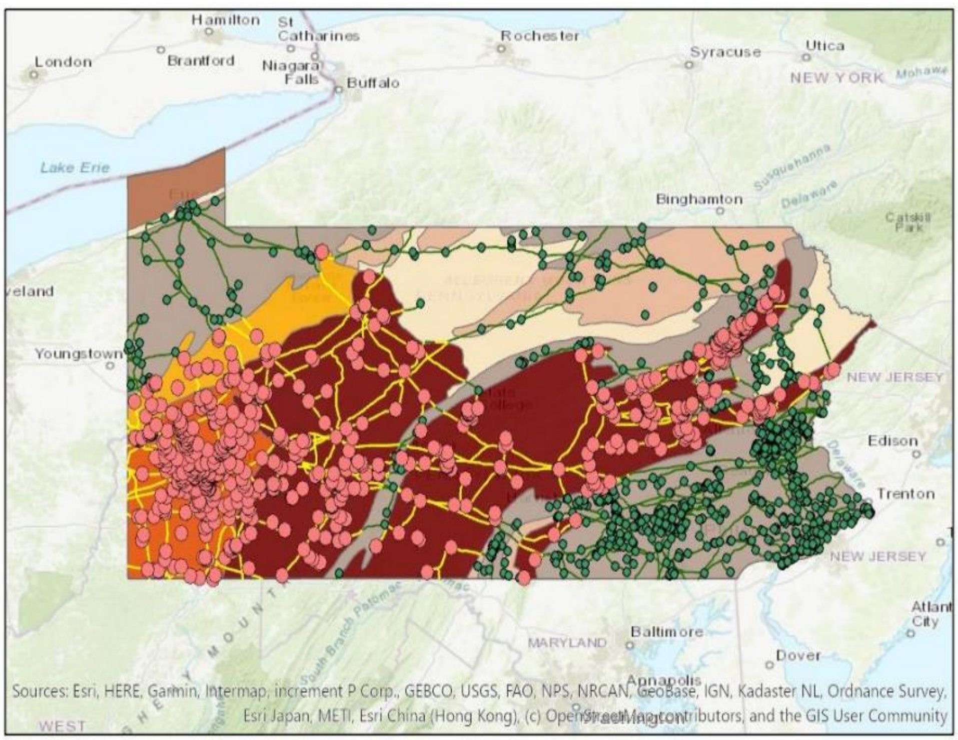

Figure 42. Electric power substations in identified landslide hazard areas (red dots) and electric transmission lines whose support towers are in identified landslide hazard areas (yellow lines). Green dots and green lines indicate substations and transmission lines that lie outside of identified landslide hazard areas. Taken from DEP, 2020 IA.

5.5 Sea Level Rise

5.5.1 Overview

Sea level rise is expected to increase threats to freshwater tidal wetlands and fauna, and exacerbate flooding. Sea level rise has the potential to add to the existing stresses on Southeastern Pennsylvania's freshwater tidal ecosystems. Additionally, sea level rise is projected to increase water levels and the salinity of inland rivers, including the Delaware and Schuylkill rivers that run through Philadelphia.[157] As a result, storms surges will cause increased flooding in Philadelphia and the surrounding region, and could permanently inundate some low-lying areas.[158] 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.[159] In Pennsylvania more broadly, sea level rise mainly threatens built infrastructure as well as forest, ecosystems, and wildlife along the state's coastline and tidally-influenced rivers. However, sea level rise will have relatively minor consequences in Pennsylvania overall and will be a low risk for the state. Figure 43 illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

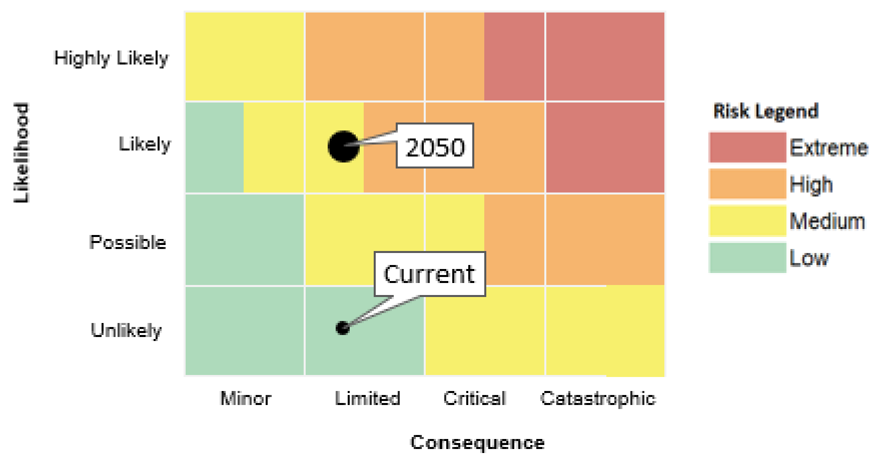

Figure 43. Sea Level Rise Risk Matrix[160]

Table 11 summarizes the statewide likelihood and consequences of sea level rise in Pennsylvania.

Table 11. Sea Level Rise Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.5.2)**	**Confidence**	**Differential Impacts**
Current	1	Sea level rise is increasing, but has not neared the critical threshold of 2 feet of sea level rise. 2 feet is the	High	

[157] City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015. "Toward a Climate-Ready Philadelphia." https://www.phila.gov/media/20160504162056/Growing-Stronger-Toward-a-Climate-Ready-Philadelphia.pdf.
[158] City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.
[159] DVRPC. 2004.
[160] The sea level rise matrix is based on the consequence and likelihood ratings listed in Table 11.

		critical threshold given this is a likely and significant increase.		
2020-2050	3	Sea level rise will increase, and is likely to approach 2 feet by mid-century.	High	
Beyond 2050	NOAA projects sea level rise of 1.96 to 9.51 feet.[161] By end-of-century, a rise of 1.96 feet has a 96% chance of occurring under RCP 8.5 scenario, whereas at least a 2.42 feet rise has a 17% chance of occurring.[162]		High	
Consequences				
Category	**Rating**	**Justification Notes (details in 5.5.3)**	**Confidence**	**Differential Impacts**
Human health	1	• Water wells could be affected by saltwater intrusion	High	Communities receiving water from rivers in the Delaware estuary.
Environmental justice and equity	1	• Not projected to experience disproportionate exposure to sea level rise-driven flooding	Medium	People living in lower-elevation areas are more likely to experience impacts from sea level rise.
Economy: Agriculture	1	• Not expected to be significantly impacted	High	NA
Economy: Recreation and tourism	1	• Not expected to be severely affected	High	Philadelphia International Airport could be threated during storms with sea level rise.
Economy: Other	2	• Damage to water infrastructure could cost millions of dollars in repairs and improvements	High	Industries receiving water from rivers in the Delaware estuary will have to cope with saltier water.
Forests, ecosystems, and wildlife	2	• Wetlands may face inundation • Tidal freshwater flora and fauna may be threatened with 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 sea level rise.

[161] U.S. Army Corps of Engineers (USACE). 2019. Sea Level Change Curve Calculator. http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html
[162] NOAA Center for Operational Oceanographic Products and Services. 2017. Global and Regional Sea Level Rise Scenarios for the United States. 22. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

Built Infrastructure	4	• Infrastructure and river-adjacent areas could be inundated or experience increased flooding, particularly wastewater treatment plants	High	Southeastern Pennsylvania, particularly Philadelphia, will see greater flooding, as river levels rise.
Overall Risk		**Risk Score**	**Confidence**	
	Current	**1.9 (Low)**	High	
	2050s	**5.6 (Medium)**	High	
Potential Opportunities				
Opportunities for the development of improved water treatment. Higher water levels might also open greater shipping opportunities.				

5.5.2 Likelihood

Global mean sea level is very likely (greater than 90% probability) to rise 0.5-1.2 feet by mid-century.[163] Sea level rise is expected to increase faster along the Mid-Atlantic coast than globally as described in the coastal change section.[164] The range of change varies. The US Army Corps of Engineers predicts that in Philadelphia,[165] water levels will likely rise by 1.5 to 2.7 feet by 2050, and 2.4 to 6.8 feet by 2100.[166,167] This range represents intermediate low to intermediate high sea level rise scenarios. Even in the low sea level rise scenario, water levels will increase by 1.3 feet by 2050 and 2 feet by the end of the century. In an extreme scenario, sea levels could rise by 3.83 feet by 2050 in the Philadelphia area.

5.5.3 Consequences

Figure 44 summarizes the overall consequence ratings statewide for sea level rise – highest consequences are in the other economic activity category and the forests, ecosystems, and wildlife category.

[163] U.S. Global Change Research Program. 2018. Fourth National Climate Assessment, Volume 1 "Chapter 12: Sea Level Rise."

[164] U.S. Global Change Research Program. 2018. Fourth National Climate Assessment, Volume 2 "Chapter 18: Northeast."

[165] Projections were created for the NOAA water level gauge in Philadelphia.

[166] USACE. 2019. Sea Level Change Curve Calculator.

[167] This projection is pulled from the USACE Sea Level Change Curve Calculator. The data is projected for the gauge in Philadelphia using the NOAA et al. 2017 scenarios. The output datum is NAVD88.

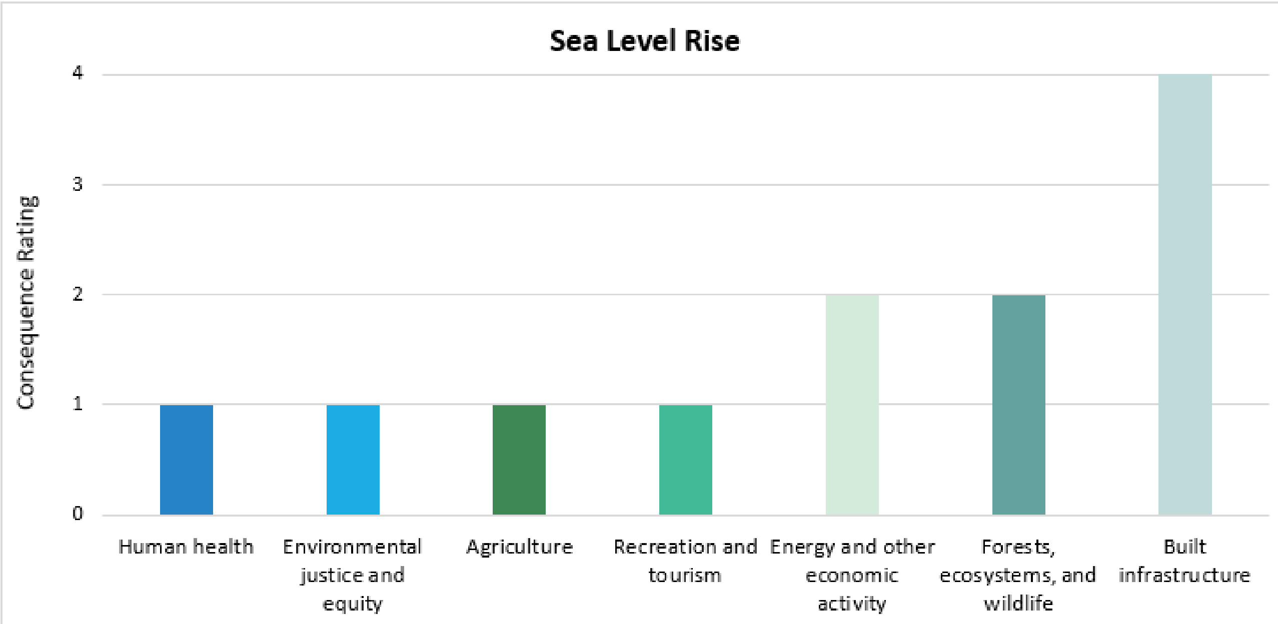

Figure 44. Sea Level Rise Consequences

Human health: 1

Sea level rise will have a minimal impact on human health. However, sea level rise has the potential to reduce water quality which could be a threat to long-term public health if not addressed. Given a 2 to 8-foot rise in sea level, the salt level would increase 10 to 25 miles farther upriver in years with high drought.[168] Philadelphia and other municipalities in the region would face threats to their drinking water supply with only a 2.4-foot rise in sea level, which is possible by mid-century and likely by the end of the century.[169] 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.

Environmental justice and equity: 1

Overall, sea level rise will not pose a disproportionate risk to environmental justice areas. Analysis of demographic and geospatial data for Pennsylvania's coastal communities does not indicate significant disparities in exposure to 2 feet of sea level rise-driven flooding (2 ft SLR). Additionally, the total number of people projected to experience inundation under the 2 ft SLR scenario is relatively lower than that exposed to other climate hazards, given the smaller size of coastal populations.

Figure 45 shows percent inundation from 2 ft. of sea level rise across coastal census block groups. Black cross-hatching indicates Environmental Justice communities. This geospatial analysis of percent area inundation by block group does not highlight disparities in flooding extents. Specifically, about 20% of land designated as "EJ areas" along the coastline is projected to experience flooding under 2 ft. of sea level rise. This flooding statistic does not differ

[168] DVRCP. 2004.
[169] DVRCP. 2004.

significantly from the 21% of total area of *all* coastal communities that is projected to experience flooding under the same sea level rise scenario.

Area-based findings on coastal flood exposure offer limited nuance in regard to 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). As such, findings from this analysis may not fully capture on-the-ground disparities in flood risk.

Given the available data, findings on sea level rise-driven flooding do not indicate this hazard poses a disproportionate risk to vulnerable populations along coastal Pennsylvania.

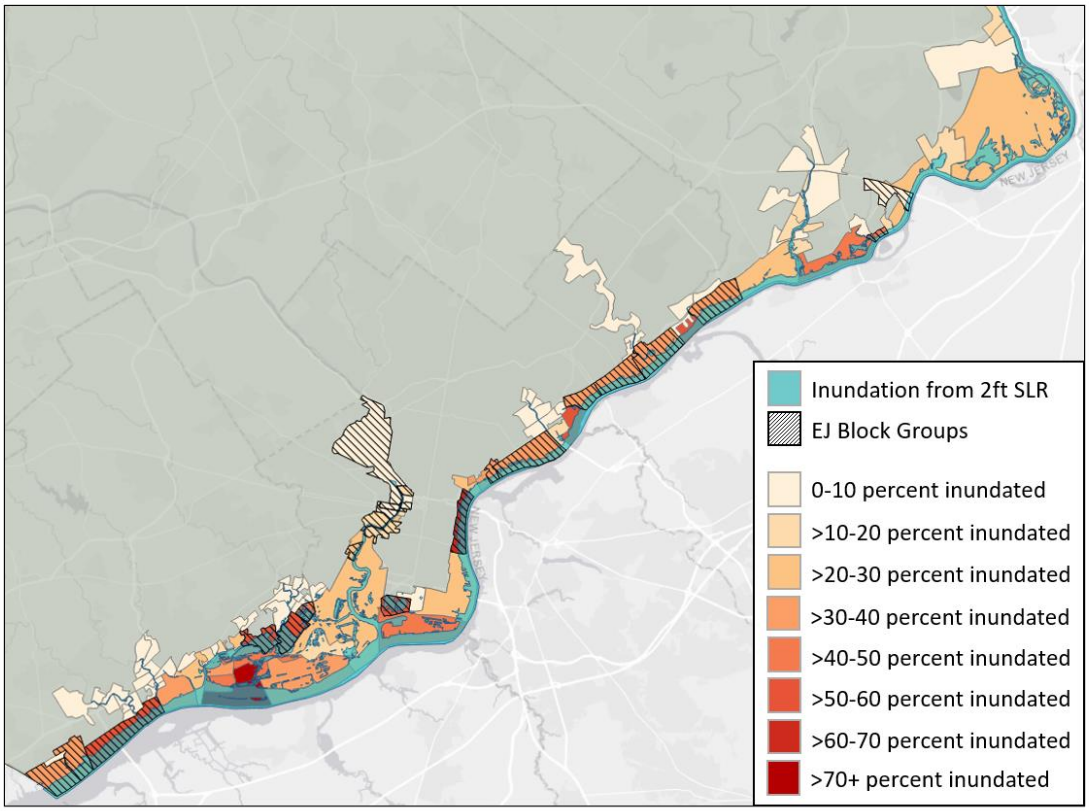

Figure 45. Areas projected to be inundated by 2 feet of sea level rise in 2050, overlaid with EJ census block groups.

Economy

Agriculture: 1

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

Recreation and tourism: 1

This hazard will have minor impacts on the sector. The overall impact of sea level rise will be minimal on recreation and tourism. However, sea level rise will increase key tourism infrastructure's vulnerability to flooding: with only two feet of sea level rise, the Philadelphia International Airport would be exposed to flooding.[170] During a category one storm or a 100-

[170] City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.

year flood, 10 to 11 terminals and hangers (out of 12) and 5 to 18 terminals (out of 20) would be inundated with 2 feet of sea level rise. Repairs from storm damage with 2 feet of sea level rise could be significant. However, overall sea level rise is not expected to have significant consequences for recreation and tourism in Pennsylvania.

***Energy and other economic activity:* 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.[171] Brackish waters would be especially present during dry periods.[172] The use of brackish water threatens to damage equipment, raise water-treatment costs, and force a shift in water supplies.[173] 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. Example economic impacts of sea level rise are described below.[174]

Example Economic Impacts: Sea Level Rise

Sea level rise 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 sea-level rise.[1] The airport's ongoing $6.2 billion expansion, to be completed in phases through 2025 lengthening two of the airport's four existing runways and building a fifth runway along the Delaware River, includes struggles against sea level rise such as filling 135 acres of floodplain and building 11 acres on storm-water basins.[1,2]

In the Delaware River Basin, some 147,000 jobs and $20.4 billion in residential property values could be affected by the combined threat of sea level rise, storm surge and flooding.[3]

Sources: [1] Philadelphia Inquirer, 2019; [2] Philadelphia Inquirer, 2011; [3] University of Pennsylvania, 2008.

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171 DVRPC. 2004.
172 DVRPC. 2004.
173 DVRPC. 2004.
174 Philadelphia Inquirer. 2011. Airport expansion estimate up $1.2B. Linda Loyd. October 7, 2011. Retrieved from: 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; Philadelphia Inquirer. 2019. As climate changes and seas rise, Philadelphia International Airport is in the crosshairs. Frank Kummer. September 17, 2019. Retrieved from: https://www.inquirer.com/science/climate/philadelphia-international-airport-climate-change-sea-level-rise-flooding-delaware-river-20190917.html; University of Pennsylvania, 2008. Climate Change: Impacts and Responses in the Delaware River Basin. Retrieved from: https://planning-org-uploaded-media.s3.amazonaws.com/legacy_resources/awards/studentprojects/2009/pdf/climatechangedelaware.pdf

Forest, ecosystems, and wildlife: 2

By mid-century, coastal wetlands will experience severe, localized damage. Sea level rise threatens the ecology of Pennsylvania's portion of the Delaware Estuary. The upper Delaware estuary may see a modest change in salinity as a result of climate change.[175,176] Increased salinity will 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 advance up the estuary and freshwater species will retreat resulting in a significant shift in the makeup of the estuary's ecology.[177] Fish populations and other marine species that need lower salinity levels may be threatened. Specifically, oysters and mussels may be imperiled.[178,179] Similarly, tidal wetlands may be damaged by sea level rise and changes in salinity levels as plant species are unable to adapt to higher water levels, saltier water, or frequent inundation.[180] Sea level rise may also result in the drowning of tidal and nontidal wetlands on Pennsylvania's southeastern coast.[181] Development in Southeastern Pennsylvania may hinder tidal flora and fauna from migrating horizontally to escape ecosystem changes.[182] Ultimately, sea level rise may stress or destroy freshwater tidal ecosystems.[183] Wetlands are a unique resource for Pennsylvania and face significant devastation.

Built infrastructure: 4

Though Pennsylvania has a small coastline, sea level rise will increase river levels. As a result, the frequency, exposure, and severity of flooding in Southeastern Pennsylvania is expected to grow. Sea level rise 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.[184] With a 4-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.[185] These damages will be concentrated in the Philadelphia region. Overall, sea level rise will have a localized impact in Southeastern Pennsylvania, but will result in significant damage when combined with storms.

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175 PSU. 2015 IA.

176 Ross, A.C., Najjar, R.G., Li, M., Mann, M.E., Ford, S.E., Katz, B., 2015. Sea-level rise and other influences on decadal-scale variations of salinity in a coastal plain estuary. Estuarine Coastal and Shelf Science 157, 79-92.

177 DVRPC. 2004.

178 DVRPC. 2004.

179 Partnership for the Delaware Estuary. 2017. Technical Report for the Delaware Estuary and Basin. Chapter 6 Living Resources. https://www.delawareestuary.org/wp-content/uploads/2018/01/TREB-2017-complete.pdf

180 PSU. 2015 IA.

181 PSU. 2015 IA.

182 PSU. 2015 IA.

183 PSU. 2015 IA.

184 City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.

185 Climate Central. 2020. Surging Seas Risk Finder. https://riskfinder.climatecentral.org/state/pennsylvania.us?comparisonType=county&forecastType=NOAA2017_int_p50&level=2&unit=ft

5.6 Severe Tropical and Extra-Tropical Cyclones

5.6.1 Overview

Tropical cyclones include events such as tropical storms, tropical depressions, and hurricanes, while extra-tropical cyclones encompass events like nor'easters.[186] 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.[187] 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 will also 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 Tropical Storm 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.[188]

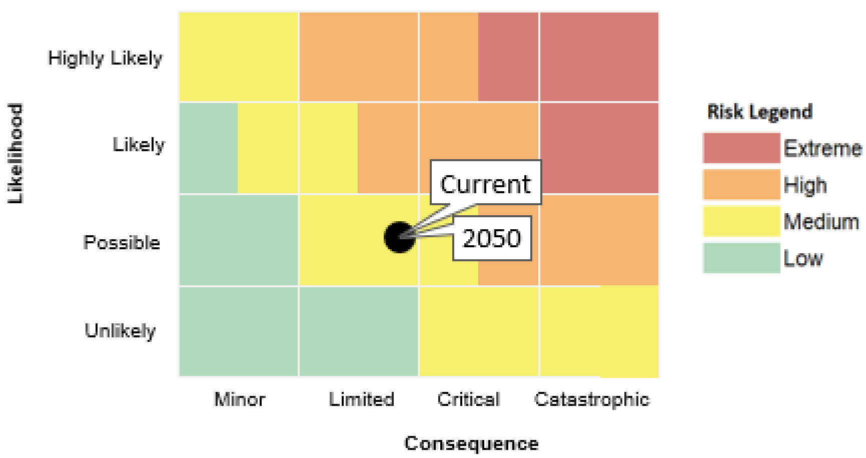

Figure 46Figure 46 illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

[186] DEP. 2020 IA.
[187] DEP. 2020 IA.
[188] National Weather Service. 2015. 4th Anniversary of the Flooding from Tropical Storm Lee. https://www.weather.gov/ctp/TSLeeFlooding#:~:text=In%20Pennsylvania%2C%20over%2016%2C000%20homes,Lee%20are%20over%20%242%20billion.

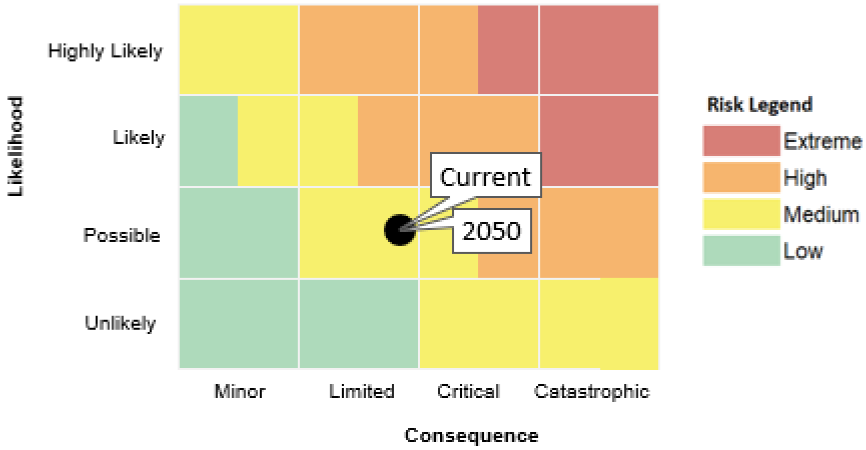

Figure 46. Tropical and Extra-Tropical Cyclones Risk Matrix

Table 12 summarizes the statewide likelihood and consequences of tropical and extra-tropical cyclones in Pennsylvania.

Table 12: Tropical and Extra-Tropical Cyclones Statewide Risk Summary

Likelihood				
Timeframe	**Rating**	**Justification Notes (details in 5.6.2)**	**Confidence**	**Differential Impacts**
Current	2	Extra-tropical cyclones have become more frequent. Tropical cyclones have not increased in frequency.	High	
2020-2050	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				
Category	**Rating**	**Justification Notes (details in 5.6.3)**	**Confidence**	**Differential Impacts**
Human health	3	• Dozens of people could be severely injured	High	Individuals who live in low-lying areas or who face serious dangers to their health during power outages.

Likelihood				
Environmental justice and equity	2	• Environmental justice areas are slightly over-represented in the FEMA 500-year floodplain	High	See justification
Economy: Agriculture	3	• Flooding could severely damage crops	Medium	NA
Economy: Recreation and tourism	1	• Damage to the Philadelphia International Airport and recreation sites in the state	Medium	Southeastern Pennsylvania may be hit more severely as flooding is exacerbated by sea level rise.
Economy: Other (e.g., energy)	2	• Shot-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 sea level rise.
Forests, ecosystems, and wildlife	1	• Downed trees due to 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		**Risk Score**	**Confidence**	
	Current	**4.8 (Medium)**	Medium	
	2050s	**4.8 (Medium)**	Medium	

Potential Opportunities

- **Investments in healthy soils in agricultural land and best management practices reduce the shock of an acute storm event.**[189]
- **After tropical and extra-tropical cyclones, communities often experience a boom in construction and car sales as individuals seek to replace lost property.**[190]

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[189] U.S. Department of Agriculture Natural Resource Conservation Service. "Soil Health Key Points." https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1082147.pdf

[190] Torry, H. and S. Chaney. 2018. "Big Storms Leave Small Marks on the U.S. Economy." *Wall Street Journal.* September 15. https://www.wsj.com/articles/big-storms-leave-small-marks-on-the-u-s-economy-1537027200.

5.6.2 Likelihood

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.[191] 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.[192] No consensus has been reached on whether there has been a demonstrated observed trend in a change in tropical cyclones' likelihood.[193] 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.

5.6.3 Consequences

Figure 47 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. These consequence ratings are also in Table 12 summarizes the statewide likelihood and consequences of tropical and extra-tropical cyclones in Pennsylvania.

Table 12.

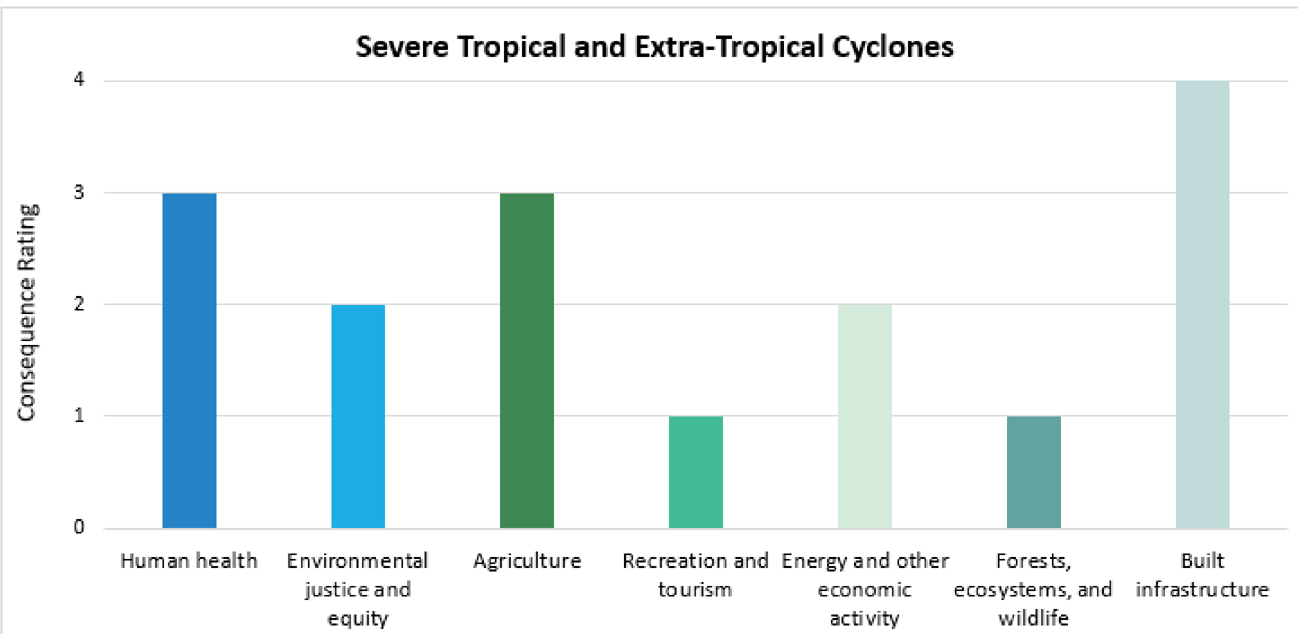

Figure 47. Tropical and Extra-Tropical Cyclones Consequences

Human health: 3

The health impacts of severe cyclones are limited. Flooding during tropical and extra-tropical cyclones poses significant dangers to human health. These extreme storms can result in significant mortality, especially as storms' strength intensifies. However, risks to human health depend mainly on exposure and vulnerability rather than on changes in storms' intensity.

[191] PSU. 2015 IA.
[192] U.S. Global Change Research Program. 2018. "Chapter 18: Northeast."
[193] U.S. Global Change Research Program. 2018. "Chapter 18: Northeast."

Vulnerability 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 vulnerable if they face a serious health threat 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. The interruption of these services can result in significant health consequences. Dozens of people could face serious risk of harm during a cyclone event.

Environmental justice and equity: 2

Environmental justice and equity consequences of cyclones are limited. Many of the same environmental justices 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. Environmental justice areas are slightly over-represented in FEMA 500-year floodplains than the overall state population as mentioned in the "Precipitation and Inland Flooding" section with an exposure 1.2 times higher than the state average. However, low-income communities are more vulnerable to serious consequences after an extreme storm. Low-income households are more likely to lack the resources to recover quickly from an extreme cyclone and live in substandard housing which increases the threat of mold, mildew, poor indoor air quality, and damage after intense rain and wind during storms.[194,195] Similarly, low-income communities are more likely to have less climate-resilient infrastructure.[196] Overall, Pennsylvania's low-income and minority communities face a serious threat from cyclones, but do not necessarily have high exposure to this hazard.

Economy

Agriculture: 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. As described in that hazard section, heavy precipitation during extreme weather events will increase risks associated with flooding such as augmented runoff, erosion, and nutrient leaching.

Recreation and tourism: 1

Cyclones and extra-cyclones are not a significant threat to recreation and tourism. Though the consequences appear mild, extreme storms could damage the Philadelphia International Airport when combined with other climate stressors like sea level rise, as discussed in the "Sea Level Rise" hazard section. For example, a 2-foot rise in sea level, a Category 1 storm would inundate 25% of the airport's supporting infrastructure and 42% of the airport's terminals and hangars. Like with other infrastructure, cyclones could damage recreation and tourism facilities

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194 Urban Sustainability Directors Network (USDN) and Raimi Associates. 2017. "Equitable Community-driven Climate Preparedness Planning." 46. https://www.usdn.org/uploads/cms/documents/usdn_guide_to_equitable_community-driven_climate_preparedness-_high_res.pdf

195 Cliffton, R., Majumder, B., and Kelly, C. 2020. "Equitable and Just Hurricane and Disaster Preparedness Amid COVID-19." *Center for American Progress.* https://www.americanprogress.org/issues/green/reports/2020/09/30/490964/equitable-just-hurricane-disaster-preparedness-amid-covid-19/

196 Clifton, Majumder and Kelly. 2020..

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.[197] Overall, cyclone impacts are relatively minor.

Energy and other economic activity: 2

Cyclones will likely temporarily disrupt economic activity. Consequences are significant for the energy sector and for small businesses dependent on electricity. 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.[198] Additionally, high winds and precipitation associated with severe storms disrupts electricity delivery which impacts communities and small businesses. Storms force stores, restaurants, and other business to close. During Hurricane Irene and Superstorm Sandy, electric service was down for 4 to 8 days.[199] Blackouts during Hurricane Irene affected 700,000 people, while outages during Hurricane Sandy impacted 1.2 million Pennsylvanians. Overall, extreme storms will temporarily disrupt energy delivery services and hurt businesses' revenues. Example economic impacts of severe tropical storms are described below.[200]

Example Economic Impacts: Severe Tropical Storms

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

2018 Hurricane Season: Hurricane Florence & Tropical Storm (TS) Gordon

TS Gordon dumped rain throughout PA and, on September 9, set the record as the second wettest day ever recorded at the Pittsburgh airport, yielding 3.73 inches of rain.[1] Allegheny County declared a State of Emergency due to this event. Numerous roads were closed due to high water and localized

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[197] Nordeen, D. 2011. Delaware Water Gap News. https://www.nps.gov/dewa/learn/news/storm-damage-assessment-and-cleanup-continue.htm

[198] DEP. 2020 IA.

[199] PSU. 2015 IA.

[200] CBS Pittsburgh. 2018. Historic Rainfall Sets Record For 2nd Wettest Day Ever Recorded in Pittsburgh. Ron Smiley. Sept. 10, 2018. Retrieved from: https://pittsburgh.cbslocal.com/2018/09/10/second-wettest-day-ever-recorded-pittsburgh/; Esri. N.d. A Recap of the Wettest Year on Record in Allegheny County. Retrieved from: https://www.arcgis.com/apps/Cascade/index.html?appid=8834fd8de2954613941caa0553c6adfa; National Weather Service (NWS). N.d. 2018 in Context: Record Precipitation across Pennsylvania. National Oceanic and Atmospheric Administration. Retrieved from: https://www.weather.gov/ctp/RecordPrecip2018; Pennsylvania Department of Transportation (PENNDOT). 2018. PENNDOT Estimates over $105M in Flood, Slide Damages. Retrieved from: https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165; Pocono Record. 2020. Wolf seeks federal relief funds for Isaias damage in nine PA counties. Brian Myszkowski and Christopher Dornblaser. October 6, 2020. Retrieved from: https://www.poconorecord.com/story/news/2020/10/05/gov-wolf-seeks-out-isaias-relief-funds-nine-pa-counties/3631225001/; Weather.com. 2020. Tropical Storm Isaias' Aftermath: At Least 12 Dead in Eastern U.S., Millions Left Without Power. Jan Wesner Childs. August 06, 2020. Retrieved from: https://weather.com/storms/hurricane/news/2020-08-05-isias-damage-impacts-power-outages-flooding-carolina-northeast; Weather.gov. 2015. 4th Anniversary of the Flooding from Tropical Storm Lee. NWS. Retrieved from: https://www.weather.gov/ctp/TSLeeFlooding

flooding.[2] On September 16-17, 2018, Hurricane Florence dumped 3-4" of rain along and just east of the Appalachians. Florence reinforced 2018 as the wettest year ever for PA.[3]

2020 Hurricane Season: TS Isaias

In August 2020, TS Isaias caused considerable inland flooding in PA. Estimated damage costs associated with TS Isaias total more than $27.6 million and 2 dead.[4, 5]

2011 Hurricane Season: Irene & TS Lee

TS Lee caused considerable damage from record flooding across the northeast. TS Lee cost Pennsylvania $67.9 million in flooding and landslide costs and 7 deaths.[6,7] 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.[6]

Sources: [1] CBS Pittsburgh, 2018; [2] Esri, n.d.; [3] NWS, n.d.; [4] Pocono Record, 2020; [5] weather.com, 2020; [6] PENNDOT, 2018; [7] weather.gov, 2015

Forest, ecosystems, and wildlife: 1

Severe storms are not expected to have a significant effect on forests, ecosystems, and wildlife.

Built infrastructure: 4

Cyclones' consequences to 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 hurricane 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. 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 dollars depending on the severity of flooding and strength of wind gusts.[201] Cyclones have the potential to result in significant damage and a complete shutdown of critical infrastructure. Overall, cyclones pose a substantial threat to the Commonwealth's built infrastructure.

[201] City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Adaptation Priorities

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 agriculture sector, forestry, ecosystems, other natural resources, and recreation sector in transition to warmer climate
- Reduce flood risks to infrastructure and communities
- Help low-income households cope with potential increased energy burden
- Enhance tropical storm and landslide risk mitigation
- Heat-related health impacts, particularly for vulnerable populations

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 adaptation and mitigation work needs to begin soon.

6.2 Environmental Justice and 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. Disproportionate impacts are not random. For example, disadvantaged populations may have greater physical exposure to risks (e.g., construction workers more exposed to heat waves, low-elevation houses more exposed to flood risk) and limitations to their ability to manage consequences if they occur (e.g., being able to purchase or run an air conditioner, or being able to read heat safety emergency communications). And consequences of historical discriminatory practices in communities of color (e.g., redlining, systemic disinvestment) manifest today with communities of color 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.

6.3 Continued Research Needs

This IA Update provided a first pass at rating relative risks 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 PA; 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 here.

APPENDIX A – KEY TERMS

Term	Definition
Risk	The chance a climate hazard with cause harm. Risk is a function of the likelihood of an adverse climate impact occurring and the severity of its consequences.
Impact	The effect of a climate hazard.
Critical Threshold	A defined tipping point for an ongoing hazard at which significant impacts occur.
Climate Hazard	Climate related events or indicators, such as temperature and precipitation. Climate hazards can be discrete (e.g., heat wave) or ongoing (e.g., increasing average temperature).
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
Emission Scenario	A general term for Representative Concentration Pathway to describe scenarios of projected GHG emissions and atmospheric concentrations used in climate modeling.
Representative Concentration Pathways (RCP)	Scenarios of projected GHG emissions and atmospheric concentrations used in climate modeling. RCP 8.5 represents a global "baseline" scenario and RCP 4.5 represents a lower emission scenario.
Growing Degree Days (GDD)	Cumulative degree difference between average daily temperature (Tavg) and 50°F when Tavg > 50°F
Cooling Degree Days	Cumulative degree difference between average daily temperature (Tavg) and 65°F when Tavg > 65°F
Heating Degree Days	Cumulative degree difference between average daily temperature (Tavg) and 65°F when Tavg < 65°F
"Very Hot" Temperature	95th percentile maximum daily temperature reported in degrees
"Extremely Hot" Temperature	99th percentile maximum daily temperature reported in degrees
Consecutive Dry Days	Number of days in a row when precipitation is equal to 0 mm
3-Day Precipitation	Largest 3-day precipitation event in a given time period (e.g. season or year)

APPENDIX B – RISK ASSESSMENT METHODOLOGY

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 48.

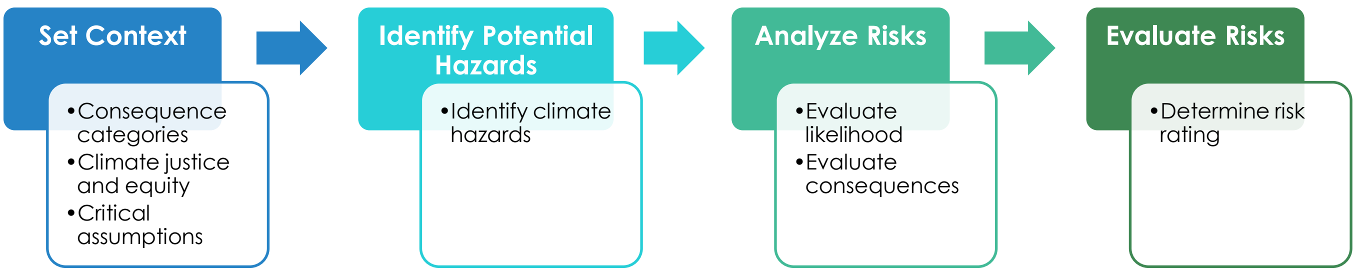

Figure 48. Risk Assessment Process

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 (e.g., energy sector)
- Forests, ecosystems, and wildlife
- Built infrastructure

Approach to Climate Justice and Equity

The 2021 Impacts Assessment focuses on improving understanding of the equity impacts of climate change in the Commonwealth. The assessment seeks to answer two key questions:

- Identifying vulnerable communities – Which communities will be disproportionately bear the impacts of climate changes?

- Identifying overburdened communities – To what extent are climate changes affecting overburdened communities that are already disproportionately burned with environmental, economic, health, or other concerns?

Identifying Vulnerable Communities

The Impacts Assessment describes and highlights (using call-out boxes, summary tables, or other visual cues as appropriate) the factors that would exacerbate vulnerability to each type of consequence for each hazard. For example, factors such as demographics (e.g., race, gender), socio-economic status, and life- or livelihood-sustaining needs (e.g., dependence on electricity for critical medical care) may affect populations' risk factors. For instance, people who do not speak English may face barriers related to accessing social or health services, making those groups more vulnerable to climate hazards such as increased frequency of extreme heat conditions. As another example, 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.

Identifying Overburdened Communities

In addition, the impacts assessment applied a rating for each hazard to describe the degree to which impacts are projected to fall to already disadvantaged communities. The impacts assessment uses Pennsylvania's defined "Environmental Justice (EJ) areas" to represent these communities. An EJ area is any census tract where 20 percent or more individuals live in poverty, and/or 30 percent or more of the population is minority.[202] These areas are commonly used by DEP and other state agencies for similar purposes. This approach is also consistent with the approach used in the North Carolina 2020 Climate Risk Assessment and Resilience Plan and is commonly used in similar analysis to capture potentially underserved populations.[203]

EJ areas serve as an indicator of locations that are overburdened by environmental hazards and other structural disadvantages. While they cannot capture all characteristics of disadvantaged, vulnerable, or historically overburdened or underserved communities (e.g., these areas draw defined lines of EJ locations, are based on percentiles, and are based on thresholds from two indicator variables), they provide an approach to identify which climate change impacts could be falling disproportionately to overburdened communities. The environmental justice and equity consequence analyses in this assessment will dive deeper into the nuances of what drives vulnerabilities to each hazard, identifying specific communities or groups that may be vulnerable to particular climate changes, and noting where additional factors critical to equity analysis come into play. Table 7 provides an example of how the risk assessment information (likelihood, consequences, equity considerations, etc.) could be summarized for a given hazard to present the overall impacts, relative risks, key target areas, and overall equity implications of the impacts.

Other Critical Assumptions

Risks were assessed under the assumption that Pennsylvania's makeup would remain similar to its current composition. The assessment assumed today's population, demographics, and economy would continue into 2050 and beyond. Though this assumption does not provide a

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[202] Pennsylvania Office of Environmental Justice (OEJ). N.d. "PA Environmental Justice Areas." https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx

[203] North Carolina Department of Environmental Quality (DEQ). 2020. "Climate Risk Assessment and Resilience Plan." https://files.nc.gov/ncdeq/climate-change/resilience-plan/2020-Climate-Risk-Assessment-and-Resilience-Plan.pdf

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.[204] 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.[205] However, the extent to which Pennsylvania's makeup will change is dynamic. The COVID-19 pandemic exemplifies how an exogenous variable could drastically shift population and demographic trends. The post-pandemic era could represent a change social habits, work environments, population distributions, and transportation and travel patterns from pre-pandemic norms. 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. Table 13 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 Impact Assessments—see Table 13. These hazards cover nearly all of the impacts represented in Table 13 below. The 2021 Impacts Assessment focuses on updates to the expected impacts from the selected hazards based on the latest science, with priority placed on providing additional information with respect to impacts on equity and human health.

Table 13. Summary of Climate Impacts and Associated Hazards from Previous Pennsylvania Climate Impact Assessments

Sector	Impact	Hazard
Human Health	Decreased mortality from cold-related stress	Higher average temperatures / decreased frequency of extreme low temps
Human Health	Negative health impacts to agricultural workers; in most agricultural fields, workers will be exposed to more extreme heat.	Higher average temperatures / increased frequency and temperature of extreme high temps
Human Health	Increased mortality from heat-related stress (e.g., excessive heat event days). Greatest risk for elderly and those with cardiovascular disease. Air conditioning is key adaptation option. Equity may be an issue here due to costs of air conditioning and impacts felt most by those required to be outside for long periods of time.	Greater frequency of extreme heat/heat waves

[204] The Center for Rural Pennsylvania. 2014. Pennsylvania Population Projections 2010-2040. https://www.rural.palegislature.us/documents/reports/Population_Projections_Report.pdf

[205] The Center for Rural Pennsylvania. 2014. Pennsylvania Population Projections 2010-2040. https://www.rural.palegislature.us/documents/reports/Population_Projections_Report.pdf

Sector	Impact	Hazard
Human Health	Increased air pollutants and associated increased respiratory and cardiac illness (e.g., increased emergency room visits for childhood asthma) if increased ozone, etc. creation not balanced by emissions reduction	Higher temperatures and increased ground-level ozone Potential change in concentration of small airborne particulates Increase in pollen and mold concentrations (e.g., more pollen with faster plant growth; more thunderstorms = trigger for pollen-induced asthma)
Human Health	Reduced water quality and associated impacts on health through drinking water and contact during outdoor recreation	Higher average temperatures, increase in heavy rain events, surface runoff and more growth and potential greater concentration of water-borne pathogens in wastewater and surface water
Human Health	Increased pathogen loads from increased surface runoff from livestock farms, sewer overflows (esp. in older cities, which may also have more equity and EJ concerns)	Increase in heavy rain events, surface runoff
Human Health	Increased risk of harmful algal blooms in eutrophied lakes and reservoirs (e.g., impacts already experienced on Lake Erie)	Increase in heavy rain events, surface runoff
Human Health	Possible injury and death, especially associated with flooding from severe storms (e.g., from driving through floodwaters or structural damage to buildings from high winds).	Increase in extreme weather events
Human Health	Change in distribution and prevalence of vector-borne diseases (e.g., Lyme disease, West Nile Virus). Greatest effects may be to those with limited healthcare coverage (e.g., low income and rural populations).	Higher average temperatures
Agriculture	Change in heating/cooling costs for mushroom production	Higher average temperatures
Agriculture	Change in price of agricultural commodities	Indirect
Agriculture	Mixed effects on field crop and livestock production, including: - movement of livestock industries northward -indoor livestock production (e.g., poultry) - invasive species (e.g., spotted lanternfly) may be able to survive in more northerly climates	Higher average temperatures Higher average precip More intense precip events (e.g., 95^{th}, 99^{th} percentile) Higher CO_2 concentrations
Agriculture	Negative impacts to dairy production, including loss in milk yield, lower levels of forage quality	Higher average temperatures Increased periods of sustained high temperatures

Sector	Impact	Hazard
Outdoor Recreation	Longer warm season, increase in outdoor recreation (opportunity)	Higher average temperatures (warmer spring and fall temperatures)
Outdoor Recreation	Severe, negative impact on snow based recreation (e.g., skiing)	Higher average temperatures (loss of snow cover)
Outdoor Recreation	Change in types of recreational fishing. Certain species such as trout may experience a decline in suitable habitat. However, total precipitation in recreational fishing may increase due to the longer season	Higher average temperatures (air and stream temperatures)
Outdoor Recreation	Negative impact to sport fish populations	Reduced summer stream flows
Outdoor Recreation	Increased demand for water-based recreation (likely small)	Higher average temperatures
Outdoor Recreation	Shift in types of general outdoor leisure activity and a generally lengthened outdoor recreation season	Higher average temperatures and high-threshold temperatures (days with Tmax between 75 and 100)
Outdoor Recreation	Increase need for shaded parks and cooling centers	Higher average temperatures (and urban island effect)
Energy	Increased demand for energy (esp. electricity sector) in summer and fall, and at peak times. Pennsylvania's Alternative Energy Portfolio Standard (AEPS) work may help mediate impacts, and additionally energy efficiency, demand side management, and more backup power sources could help adapt.	- Higher average temperatures (monthly avg temps; heating degree days [HDD]/cooling degree days [CDD]) - Higher peak temperatures during the summer (95^{th} or 99^{th} percentile temperatures by month or season)
Energy	Impacts on energy transportation (e.g., decreased air travel in polar vortex; warmer climate could lower infrastructure maintenance costs)	Extreme weather events Higher average temperatures Occurrence of freeze-thaw cycles
Energy	Impacts to energy delivery reliability: extreme weather events can damage infrastructure, and increased cooling demand places higher demand on infrastructure at times when it's likely to be stressed already; large impacts may be mediated by a more distributed generation system.	Extreme weather events Higher average temperatures
Energy	Potential improved reliability of energy availability in winter months	Decreased occurrence of extreme cold-weather events
Energy	Declines in energy commodity prices, particularly for electricity and natural gas, may present challenges to some technology options that could contribute to mitigation, as well as "stranded gas" issues.	Policy/regulatory transition
Forests	Shift in suitable habitat for tree species and wildlife species to higher latitudes and elevations	Higher average temperatures

Sector	Impact	Hazard
Forests	Increased stress for some species inhabiting decreasingly suitable habitat	Higher average temperatures
Forests	Increased overall forest growth due to longer growing seasons, warmer temperatures, higher rainfall, nitrogen deposition, and increased atmospheric CO_2, but the increased growth rates for some species may be offset by increased mortality for others	Higher temperatures (longer growing seasons) Higher rainfall Increased atmospheric CO_2 Nitrogen deposition
Forests	Associated shift in forest products industry	Higher average temperatures
Forests	Exacerbated impacts/stress from non-climate threats to forest health and diversity (e.g., insect pests, diseases, invasive plants and animals, overabundant deer populations, unsustainable harvest practices, and atmospheric deposition)	Higher average temperatures
Forests	Increase insect metabolic and reproductive rates. Increase in insect range northward and to higher elevations	Higher average temperatures
Forests	Shift in timing of key biological events (e.g., broods hatcher later or earlier than timing of peak food supply)	Higher average temperatures, change in seasonal temperature and precipitation patterns
Forests	Increased mortality from heat-related stress and increased evapotranspiration rates (e.g., drier soil moisture conditions, high temperatures).	Higher average temperatures / increased frequency of extreme high temps
Water	Increased flood risks (and associated impacts across sectors) in both urban and rural areas River/stream bank erosion Higher sediment output	Higher precipitation, increased extreme precipitation, storm surge
Water	Low summer flows (magnitude and severity will vary by location/ watershed). The impacts of droughts are likely to be short-term, but risks include wetlands degradation and competition for water resources in low-flow, high-temperature periods between different sectors, and water availability issues for vulnerable communities may exist due to multidimensional inequalities.	Short-term drought
Water	Decreased water supplied for urban areas and irrigation	Short-term drought
Water	Reduced quality of raw water and increased drinking water risks	Higher average temperatures Extreme precipitation and flooding (increased sediment, nutrient, and pollutant loadings; disruption of treatment facilities) Drought (increased concentration of pollutants)

Sector	Impact	Hazard
Water	Water pollution from increased stormwater runoff and pollution	Extreme precipitation and flooding
Water	Fish impacts	Higher average temperatures (stream temperatures), including hottest-day temperatures, esp. in summer, and sediment from runoff
Water	Increased potential for eutrophication causing lower dissolved oxygen levels and an increase in the prevalence of harmful algal blooms in Lake Erie or other water bodies	Higher average temperatures (summer) Drought (reduced stream flows)
Wetlands and Aquatic Ecosystems	Drying of wetland acreage in Ridge and Valley ecoregion and loss of associated ecosystem services (e.g., water quality)	Higher average temperatures
Wetlands and Aquatic Ecosystems	Changes in stream flow quantity and quality lead to loss of biodiversity and habitat fragmentation from hydrologic modification and stream-bank erosion	Higher average temperatures Heavy precipitation and flooding Drought
Wetlands and Aquatic Ecosystems	Negative physiological and behavioral changes to macroinvertebrate and fish species	Higher average temperatures (Increase in stream temperatures)
Wetlands and Aquatic Ecosystems	Decreased survival and reproductive success for fish and macroinvertebrates due to higher rates of sedimentation and increased scouring of stream banks and floodplains	Heavy precipitation and flooding (increased stream flows)
Wetlands and Aquatic Ecosystems	Impacts to species that have adapted their life cycles to coincide with times of high water (e.g., mismatched timing of life cycle stages, insufficient duration of inundation, lack of sufficient habitat refugia)	Heavy precipitation and flooding (change to seasonal flood patterns and reeducated groundwater recharge)
Coastal resources	Reduced water quality (and associated threats to fauna) in tidal freshwater portion of Delaware estuary and along Lake Erie	Increased water temperature (decreased dissolved oxygen concentration) Saltwater intrusion / sea level rise
Coastal resources	Potential drowning of wetlands	Sea level rise
Built Infrastructure	"Large portions of multiple energy and transport infrastructures in Pennsylvania are potentially susceptible to direct damage from flooding. Particularly in the Southwestern portion of Pennsylvania, infrastructures face additional risk exposure from landslide potential associated with heavy precipitation events"	Heavy precipitation and flooding Landslides
Built Infrastructure	Flooding and associated infrastructure damage	Coastal storm surge

Sector	Impact	Hazard
Built Infrastructure	Extreme heat in particular has been associated with public health challenges, and represents an adaptation need for Pennsylvania's infrastructure	Higher average temperatures / increased frequency of extreme high temps

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 IAs 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 below. 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 14 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 14. Likelihood Rating Scale

Likelihood	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.
Unlikely	1	Less than 1% annual probability	Risk is unlikely (less than 33%) to cross critical threshold by 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 Guide[206]

[206] PEMA. 2020. "Pennsylvania Hazard Mitigation Plan: Standard Operating Guide." https://www.pema.pa.gov/Mitigation/Planning/Documents/All-Hazard-Mitigation-Planning-Standard-Operating-Guide.pdf

and the PEMA Hazard Mitigation Plan.[207] 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 Fourth National Climate Assessment and Intergovernmental Panel on Climate Change defines likelihood of climate changes.[208,209] A comparison of the different likelihood scales and terminology are shown in Figure 49. The 'critical thresholds' for ongoing hazards (e.g., increasing average temperatures) are based on likely projections for mid-century.

PEMA Hazard Mitigation Plan		NCA4		IPCC	
Term	Likelihood	Term	Likelihood	Term	Likelihood
Highly likely	90-100% annual probability	Very likely	≥ 9 in 10 (90%)	Virtually certain	99-100% probability
				Very likely	90-100% probability
Likely	50-90% annual probability	Likely	≥ 9 in 10 (66%)	Likely	66-100% probability
Possible	1-49.9% annual probability	As likely as not	= 1 in 2 (50%)	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

Figure 49 Likelihood scale comparison.

Consequences

DEP and ICF applied a consequence rating scale to assess the severity of impacts for key consequence categories, and indicated the rationale behind different ratings. After updating relevant climate science projections, DEP and ICF sought input from PSU experts and key stakeholders as needed 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 15.

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 upon this guidance as needed to fit additional consequence categories for the climate impact 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 across 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

[207] Pennsylvania Emergency Management Agency. 2018. Commonwealth of Pennsylvania 2018 State Hazard Mitigation Plan. https://pahmp.com/wp-content/uploads/2018/07/PA-2018-HMP-FEMA-Review-Full-Plan.pdf

[208] U.S. Global Change Research Program. 2018. Fourth National Climate Assessment: Guide to this Report. https://nca2018.globalchange.gov/chapter/front-matter-guide/

[209] Intergovernmental Panel on Climate Change. 2017. Fifth Assessment Report – Climate Change 2013: The Physical Science Basis, Chapter 1. https://www.ipcc.ch/report/ar5/wg1/

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. Additionally, 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 Table 7.

Table 15. Consequence Rating Scale

	Human Health	Environmental Justice & Equity	Economy			Forests, Ecosystems, and Wildlife	Built Infrastructure
			Agriculture	Recreation and Tourism	Other (e.g., Energy)		
4 – Catastrophic	1000+ people potentially affected; high number 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	Severe, disruption to multiple industries and employment lasting months to years Over $1 billion in potential annual losses	Severe disruption to multiple seasons or employment Over $1 billion in potential annual losses	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 affected area damaged, destroyed or completely 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	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	Severe disruption to one season or employment $100 million to $1 billion in potential annual losses	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	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	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	Moderate disruption to multiple seasons or employment; or severe weeks-long disruption to one season $10 million to $100 million in potential annual losses	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	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 population in EJ areas that is exposed is equal to or less than the average percent of population exposed statewide	Moderate-to-minor disruption to industries and employment Or < $10 million in potential annual losses	Moderate disruption to one season or employment Less than $10 million in potential annual losses	Moderate-to-minor disruption to industries and employment Or < $10 million in potential annual losses	Localized, moderate damage to a natural asset Recovery would take months to years	Only minor property damage. Temporary shutdown of critical facilities.

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.

Table 16. Confidence rating scale

High confidence	Medium confidence	Low confidence
Multiple sources of independent evidence based on reliable analysis and methods, with widespread agreement	Several sources of high quality independent evidence, with some degree of agreement	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 17.

Table 17. Risk Rating Matrix and Rating Rubric

Likelihood	**Consequence**			
	Minor	**Limited**	**Critical**	**Catastrophic**
Highly Likely	4	8	12	16
Likely	3	6	9	12
Possible	2	4	6	8
Unlikely	1	2	3	4

Risk Score	**Rating**
(low end inclusive)	
12+	Extreme
6 - 9	High
3 - 6	Medium
1 - 2	Low

APPENDIX C – CLIMATE ANALYSIS

Data and Projection Methods

The updated projections presented in this section are based on temperature and precipitation projections from an ensemble of 32 climate models, downscaled to a 1/16th degree grid (or approximately 6 km square grid) using the Localized Constructed Analogs (LOCA) method.[210] Table 18 lists all 32 models downscaled using the LOCA downscaling method included in the climate data and projection analysis of this report. This represents the same underlying data that was used in the most recent National Climate Assessment.[211]

Projected values represent the averages over three time periods: 2011–2040 (present context), 2041-2070 (mid-century), and 2070-2099 (end-of-century).

Projected values reported represent the 50th percentile of the 32 climate models. The report and figures below also provide the 10th and 90th percentile range across models[212]. 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[213] dataset, which uses meteorological station data across Continental United States.[214] Historical conditions represent the average over the 1971-2000 baseline.

Present context and mid-century projections assume a global baseline (i.e., no new emission reduction actions) GHG representative concentration pathway (RCP 8.5). This baseline emissions pathway is relatively similar to the low-emissions pathway (RCP 4.5) through 2050, at which point the difference between the two scenarios becomes greater. Therefore, late-century projections were developed for both a low-emissions pathway (RCP 4.5) and high-emissions pathway (RCP 8.5).

Because each value provided in this report is generated by averaging the 10th, 50th or 90th percentile outputs from 32 models across the geography of Pennsylvania, these values are estimates of future conditions, but are not intended to be used as precise projections.

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[210] Pierce, D., Cayan, D., and B. Thrasher. 2014. "Statistical Downscaling Using Localized Constructed Analogs (LOCA)." *Journal of Hydrometeorology*, 15, no. 6, p. 2558–2585. https://doi.org/10.1175/JHM-D-14-0082.1.

[211] Avery, C.W., D.R. Reidmiller, M. Kolian, K.E. Kunkel, D. Herring, R. Sherman, W.V. Sweet, K. Tipton, and C. Weaver, 2018: Data Tools and Scenario Products. 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, Washington, DC, USA, pp. 1413–1430. doi: 10.7930/NCA4.2018.AP3

[212] In order to capture the variation and uncertainty across the 32 climate models within the LOCA dataset, the 10th, 50th, and 90th percentiles across the models' projected values are reported. Each model projects different values for daily minimum and maximum temperature and daily precipitation, making percentiles necessary to capture the range of possible future climate outcomes.

[213] "Reanalysis" is a term-of-art referring to the use of a model to interpolate observations in order to create spatially and temporally continuous information about past weather and climate conditions.

[214] Livneh, B., Bohn, T., Pierce, D., Munoz-Arriola, F., Nijssen, B., Vose, R., Cayan, D., and L. Brekke. 2015. "A Spatially Comprehensive, Hydrometeorological Data Set for Mexico, the U.S., and Southern Canada 1950–2013." *Scientific Data*, 2, p. 1–12. https://doi.org/10.1038/sdata.2015.42.

Additionally, the projections may not reflect extreme scenarios that are plausible but projected by a minority of models.

Table 18 List of global climate models included in climate projection analysis

ACCESS1-0	ACCESS1-3	bcc-csm1-1	bcc-csm1-1-m
CCSM4	CESM1-BGC	CESM1-CAM5	CMCC-CM
CMCC-CMS	CNRM-CM5	CSIRO-Mk3-6-0	CanESM2
EC-EARTH	FGOALS-g2	GFDL-CM3	GFDL-ESM2G
GFDL-ESM2M	GISS-E2-H	GISS-E2-R	HadGEM2-AO
HadGEM2-CC	HadGEM2-ES	inmcm4	IPSL-CM5A-LR
IPSL-CM5A-MR	MIROC-ESM	MIROC-ESM-CHEM	MIROC5
MPI-ESM-LR	MPI-ESM-MR	MRI-CGCM3	NorESM1-M

Additional Data and Results

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

Monthly Average and Maximum Temperature Charts

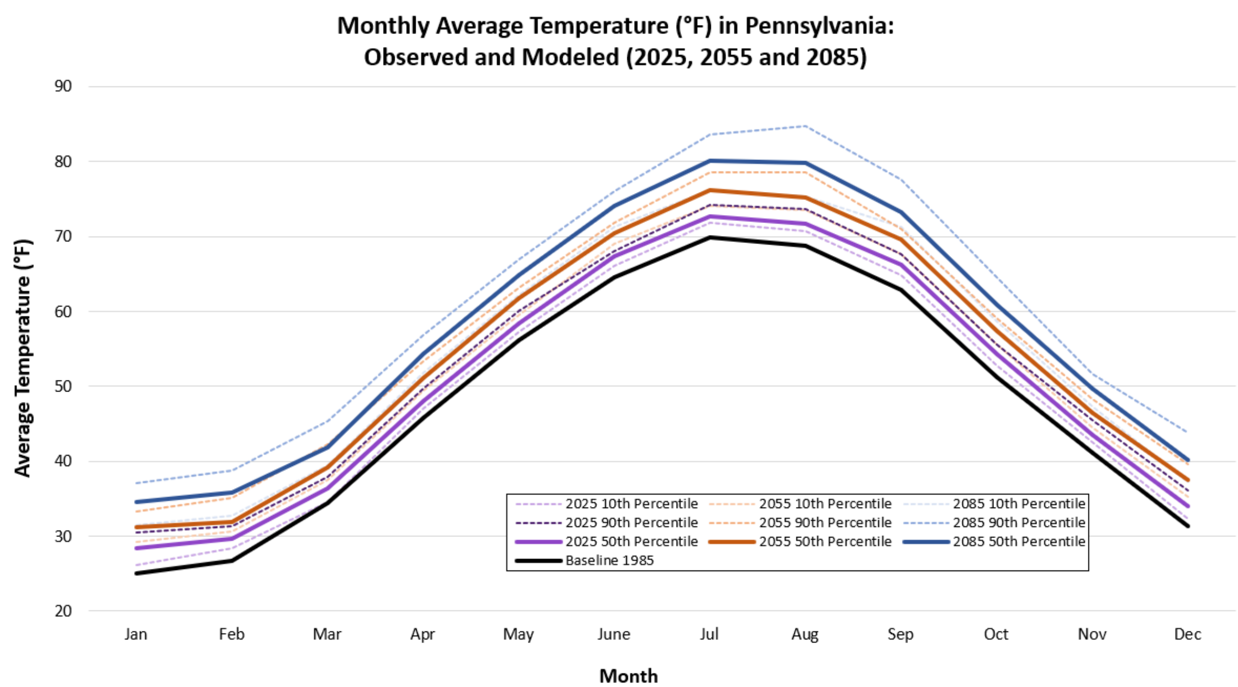

Figure 50. Statewide average observed and projected monthly average temperatures (based on 32-model ensemble of LOCA downscaled data, RCP 8.5) Solid lines represent 50th percentile model outputs, and narrower dotted lines represent 10th percentile and 90th percentile model

outputs. 2025 values represent all years 2011-2040, 2055 represents 2041-2070, and 2085 represents 2070-2099.

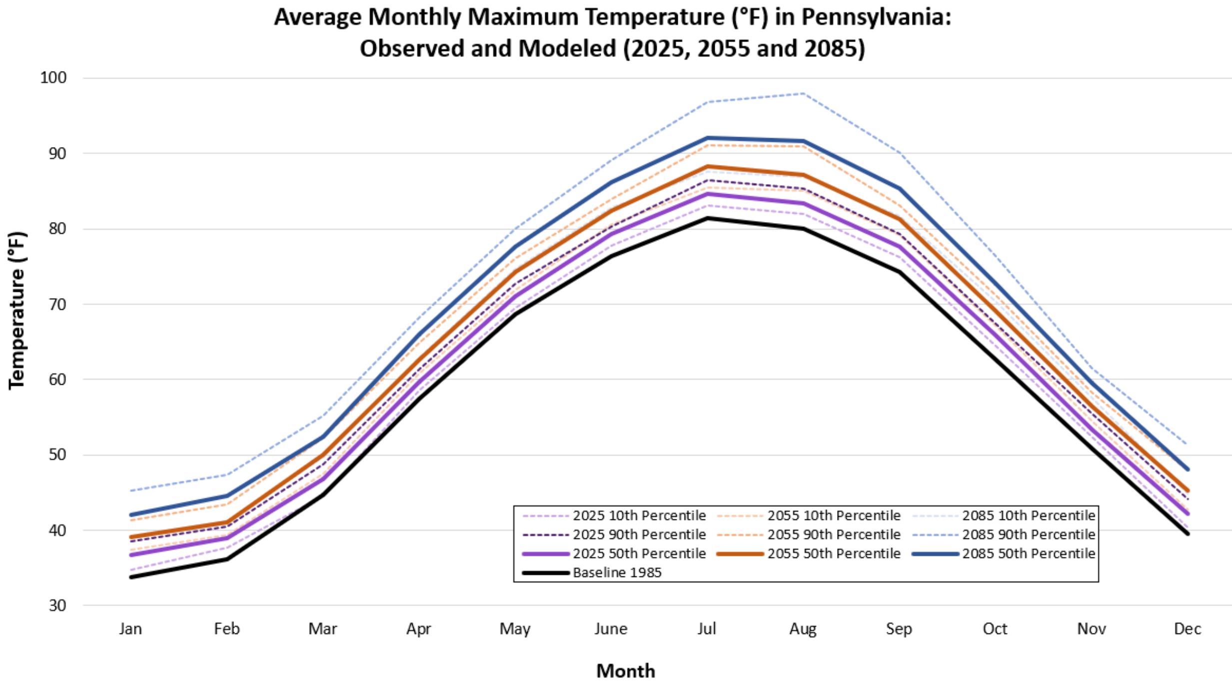

Figure 51. Statewide average observed and projected monthly maximum temperatures (based on 32-model ensemble of LOCA downscaled data, RCP 8.5) Solid lines represent 50th percentile model outputs, and narrower dotted lines represent 10th percentile and 90th percentile model outputs. 2025 values represent all years 2011-2040, 2055 represents 2041-2070, and 2085 represents 2070-2099.

End-of-Century Projections under RCP 4.5

Table 19. Statewide average observed and projected temperature variables. Projections are based a 32-model ensemble of LOCA downscaled data, RCP 4.5. Values reported are the median value (bold) across the 32-model ensemble, as well as the 10th and 90th percentile values across models.

	Observed Baseline (1971–2000)	**End-of-Century RCP 4.5 (2070–2099)**	
		Projected Value	50th Percentile Absolute Change
Average annual temperature (°F)	48.3	**53.8** (51.7 - 55.9)	5.5
Average annual minimum temperature(°F)	37.6	**43** (41.2 - 45)	5.4
Average annual maximum temperature(°F)	58.9	**64.4** (62.4 - 66.6)	5.5
Heating Degree Days (degree days)	6,600	**5,178** (4,772 – 5,706)	-1,422

	Observed Baseline (1971–2000)	**End-of-Century RCP 4.5 (2070–2099)**	
		Projected Value	50^{th} Percentile Absolute Change
Cooling degree days (degree days)	483	**1,089** (815 – 1,484)	606
"Very hot" (95^{th} percentile) temperature (°F)	85.4	**91.5** (89 - 96.4)	6.1
Days with temperature above baseline "very hot" temperature(°F)	18.3	**62.8** (41.1 - 79)	44.5
"Extremely hot" (99^{th} percentile) temperature(°F)	90.1	**96.2** (94.5 - 102.5)	6.1
Days above baseline "extremely hot" temperature	3.7	**28.8** (15.3 - 48.6)	25.1
Days with temperature >90°F	5.1	**31.0** (17.4 - 50.4)	25.9
Days with temperature >95°F	0.6	**8.7** (4.4 - 26.2)	8.1
Days with low temperature > 68°F	3.6	**20.4** (13.7 - 39.2)	16.8
Consecutive days above 90°F	1.4	**7.4** (2.3 - 14.1)	6.0
Consecutive days above 95°F	0.1	**2.7** (0.3 - 6.9)	2.6
Growing Degree Days (degree days)	2,472	**3,588** (3,116 – 4,126)	1,116

Table 20. Statewide average observed and projected precipitation variables. Projections are based a 32-model ensemble of LOCA downscaled data, RCP 4.5. Values reported are the median value (bold) across the 32-model ensemble, as well as the 10th and 90th percentile values across models.

	Observed Baseline (1971–2000)	End-of-Century RCP 4.5 (2070–2099)	
		Projected Value	% Change
Annual Precipitation (inches)	43.5	**46.5** (44.6 - 49.5)	6.8%
Days with rainfall > 3 inches (days)	0.1	**0.1** (0 - 0.2)	56.5%
Annual Maximum Consecutive Dry Days(days)	12.5	**13.2** (12 - 14.6)	5.5%
"Very heavy" (95th percentile) precipitation (inches)	0.7	**0.7** (0.7 - 0.8)	10.2%
Days with precipitation above baseline "very heavy" precipitation (days)	12.4	**15.0** (13.4 - 16.9)	21.2%
"Extremely heavy" (99th percentile) precipitation (inches)	1.2	**1.3** (1.2 - 1.4)	11.5%
Days with precipitation above baseline "extremely heavy" precipitation (days)	2.5	**3.4** (2.8 - 4.2)	37.5%
Annual Maximum 3 -Day Precipitation Event (inches)	2.5	**2.6** (2.3 - 2.9)	9.9%

Projections by County

Table 21. County-wide average observed and projected annual average temperature. Projections are based a 32-model ensemble of LOCA downscaled data, RCP 8.5. Values reported are the median value (bold) across the 32-model ensemble.

Annual Average Temperature (°F)			
County	Observed (1971-2000)	Mid-Century (2041-2070)	End of Century (2070-2099)
Adams	51.8	57.4	60.7
Allegheny	51.2	57.0	60.7
Armstrong	48.4	54.4	57.9
Beaver	50.4	56.1	59.8
Bedford	49.4	55.0	58.6
Berks	50.6	56.2	59.5

Blair	48.3	54.0	57.4
Bradford	46.2	52.3	55.7
Bucks	51.9	57.5	60.7
Butler	48.2	54.1	57.6
Cambria	47.1	53.0	56.6
Cameron	45.2	50.9	54.2
Carbon	46.9	52.9	56.3
Centre	47.5	53.2	56.6
Chester	52.1	57.8	61.2
Clarion	46.9	52.8	56.3
Clearfield	46.3	52.2	55.7
Clinton	46.2	51.9	55.0
Columbia	48.1	54.0	57.4
Crawford	46.5	52.8	56.6
Cumberland	51.5	57.2	60.7
Dauphin	50.7	56.5	59.9
Delaware	54.1	59.7	63.1
Elk	44.4	50.3	53.9
Erie	48.0	54.3	58.2
Fayette	49.4	55.3	58.9
Forest	45.3	51.3	54.8
Franklin	51.2	57.0	60.4
Fulton	50.0	55.5	59.0
Greene	50.2	56.1	59.6
Huntingdon	49.6	55.0	58.3
Indiana	48.5	54.5	58.1
Jefferson	46.8	52.7	56.3
Juniata	49.9	55.3	58.6
Lackawanna	46.1	52.3	55.8
Lancaster	52.0	57.9	61.2
Lawrence	48.8	54.7	58.4
Lebanon	50.9	56.7	60.1
Lehigh	50.7	56.6	60.0
Luzerne	47.2	53.3	56.8
Lycoming	46.5	52.4	55.7
McKean	44.0	50.1	53.8
Mercer	47.9	54.1	57.9
Mifflin	49.0	54.4	57.8
Monroe	47.5	53.4	56.9
Montgomery	51.8	57.5	60.8
Montour	48.9	54.7	58.2
Northampton	50.1	55.7	59.0
Northumberland	49.0	54.8	58.2
Perry	50.4	55.8	59.2
Philadelphia	53.9	59.7	63.0

Pike	46.5	52.3	55.9
Potter	44.2	50.1	53.6
Schuylkill	48.2	53.9	57.2
Snyder	49.8	55.4	58.8
Somerset	46.9	53.0	56.5
Sullivan	45.1	51.0	54.3
Susquehanna	44.9	50.9	54.3
Tioga	44.5	50.4	53.9
Union	49.4	55.3	58.8
Venango	46.5	52.5	55.9
Warren	45.5	51.8	55.6
Washington	50.6	56.5	60.2
Wayne	45.2	51.3	54.8
Westmoreland	49.6	55.7	59.4
Wyoming	47.1	53.2	56.5
York	52.4	58.4	61.9