Pennsylvania Climate Impacts Assessment 2021




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PennState

HAMEL ENVIRONMENTAL CONSULTING

Pennsylvania Climate Impacts Assessment 2021

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This update is a report that 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 regularly. The Pennsylvania Climate Change Advisory Committee provided input and feedback to the DEP and ICF for the preparation of this assessment. The Climate Change Advisory Committee has 18 members plus 3 ex officio members. The 2021 Impacts Assessment Update is the fifth iteration of the Pennsylvania Climate Impacts Assessment and builds on the previous impacts assessments. Unlike in years past, the 2021 update offers a risk-based approach to assessing risks and prioritizing adaptation needs.

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EXECUTIVE SUMMARY

Climate change is already affecting Pennsylvania. From severe heat waves to significant flooding, climate change influences weather events that have economic, health, and other impacts across the Commonwealth. These events can affect some Pennsylvanians more than others.

The Pennsylvania Climate Change Act (Act 70 of 2008) requires the Department of Environmental Protection to update the Impacts Assessment and Climate Action Plan regularly; this report, the 2021 Impacts Assessment, provides this update. It reviews current scientific findings and identifies relative risks to inform priority adaptation needs in the Climate Action Plan, but it is not a comprehensive or prescriptive assessment of all potential climate risks and impacts to Pennsylvania.

Projected Climate Changes

The 2021 Impacts Assessment presents updated climate projections based on the latest available downscaled climate model data. These projections align with projections from previous impacts assessments: Pennsylvania is expected to get warmer and wetter and undergo changes on its coastlines, including those of the Delaware Valley Estuary and Lake Erie.

By mid-century, key expected changes compared to a 1971-2000 baseline include:

- The average annual temperature statewide will continue to rise, and is expected to increase by 5.9°F (3.3°C) compared to the baseline.
- There will be more frequent and intense extreme heat events. For example, temperatures are expected to reach at least 90°F on 37 days per year on average across the state, up from the 5 days during the baseline period (see Figure 1). Days reaching temperatures above 95°F and 100°F will become more frequent as well.
- Increasing temperatures will continue to alter the growing season and increase the number of days that people need to cool their homes and workspaces, but will also decrease the number of days that people will need to use heating.
- Pennsylvania could experience more total average rainfall, occurring in less frequent but heavier rain events. Extreme rainfall events are projected to increase in magnitude, frequency, and intensity (see Figure 2) Drought conditions are also expected to occur more frequently due to more extreme, but less frequent precipitation patterns.
- Tidally influenced flooding is expected to increase in the Delaware Estuary coastal zone.
- Lake Erie is also expected to undergo significant changes in water level, coastal erosion, and water temperature. Notably, Lake Erie experienced record high water levels in 2019.

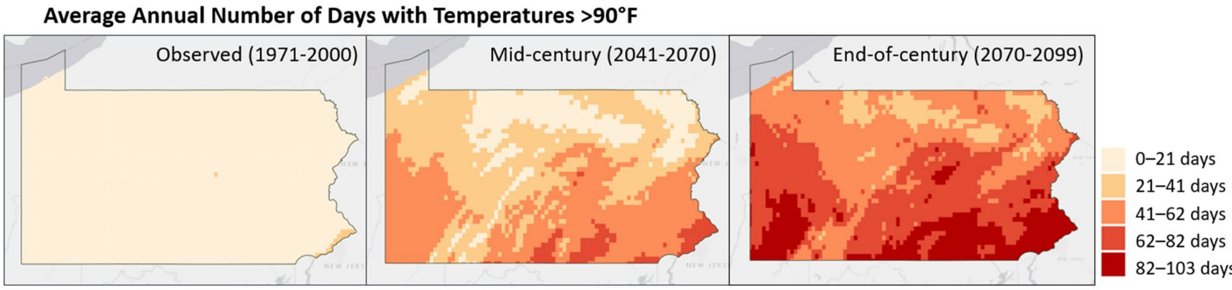


Figure 1. Observed and projected annual days with temperatures above 90°F

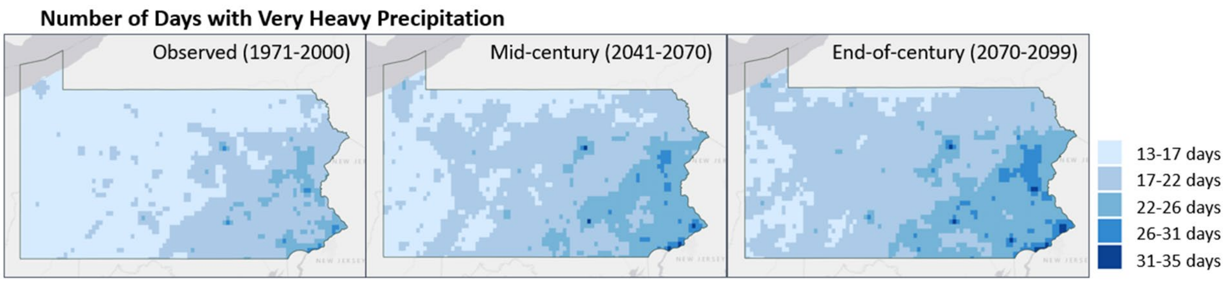


Figure 2. Observed and projected annual days with "very heavy" precipitation

Risk Assessment Approach

This impacts assessment evaluates the likelihood and consequences of six climate hazards:

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

The assessment focuses on risks at mid-century at the state level and also takes into consideration regional variations (e.g., urban or rural, proximity to waterways), as well as the populations, industries, and other areas disproportionately affected. The likelihood of a hazard occurring is evaluated on a scale of 1 to 4.

Key Terms

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

Impact – The effect of a climate hazard

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

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

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

EJ areas—PA Environmental Justice Areas. Includes any census block group where 20% or more of individuals live in poverty, and/or 30% or more is minority.

The severity of consequences is also evaluated on a scale of 1 to 4. The assessment examines the severity of consequences in the following categories:

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

The product of the scores for likelihood and for consequence severity creates the overall risk rating for each hazard.

The impacts assessment for 2021 also includes, for the first time, an analysis of environmental justice and equity. The assessment seeks to identify:

- Geographic areas most exposed to climate hazards
- Populations most vulnerable to impacts
- The subset of exposed communities with high proportions of already overburdened individuals.

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

Climate Risk Assessment Results

The risk assessment revealed several key findings:

- Flooding is currently the highest-risk hazard facing Pennsylvania, and flood risks are projected to increase. At the same time, by mid-century, risks from increasing average temperatures and heat waves could rise to be as high as flood risk is today (see Table 1).
    - Flooding from heavy rain events affects built infrastructure, human health, and agriculture, with ripple effects throughout the economy.
    - Increasing average temperatures could affect nearly every aspect of life in the Commonwealth; from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment.
- Heat waves will become increasingly common and will create particular health and economic risks for vulnerable populations, including low-income populations, the elderly, pregnant women, people with certain mental illnesses, outdoor workers, and those with cardiovascular conditions. These risks will be particularly acute in areas subject to the urban heat island effect.
- All hazards—especially heat waves, increasing temperatures, and flooding—could affect public health negatively. For example, higher temperatures mean more days with

hazardous heat conditions or reduced air quality, and increased risk of heat-related illness. Flooding increases the risks of direct injury from flood waters and of illness caused by contaminated water.

- Climate change will not affect all Pennsylvanians equally. Some may be more at risk because of their location, income, housing, health, or other factors. As Pennsylvania works to reduce its climate risks, care should also be taken to ensure that these inequitable impacts are addressed, and that adaptation efforts do not inadvertently exacerbate inequities.
- Landslides and sea level rise pose relatively low risks statewide but can cause severe impacts in the locations where they occur. For example, sea level rise in the Delaware estuary could drastically change the makeup of the estuary's ecology and threaten the built infrastructure near the tidal zone. Landslides can have severe consequences if they cut off critical transportation routes, particularly in rural areas.
- Severe tropical storms, flooding, and landslides already pose risks, and these could become more likely or severe in the future. Pennsylvania has an opportunity to build on its existing hazard mitigation practices for these risks.
- For changes that will come on gradually, such as rising temperature, Pennsylvania has an opportunity not only to reduce potential harm, but also to capitalize on potential opportunities and conditions not previously present in Pennsylvania. This is particularly true for rising average temperature, which could enable the cultivation of warmer-weather crops, expand warm-weather recreation and tourism, and lower wintertime heating energy demand.

Table 1. Overall Risk Assessment Results

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

Conclusions and Recommendations

Increasing average temperatures and heavy precipitation and inland flooding emerged as the two highest-risk hazards by mid-century. Both hazards could affect the entire state and all sectors (Figure 3). Increasing temperatures have the highest consequences for human health and environmental justice and equity, especially in urban areas. Heavy precipitation and flooding could also have severe consequences for human health, agriculture, and built infrastructure, with populations, farms, and infrastructure located in or near floodplains at particular risk.

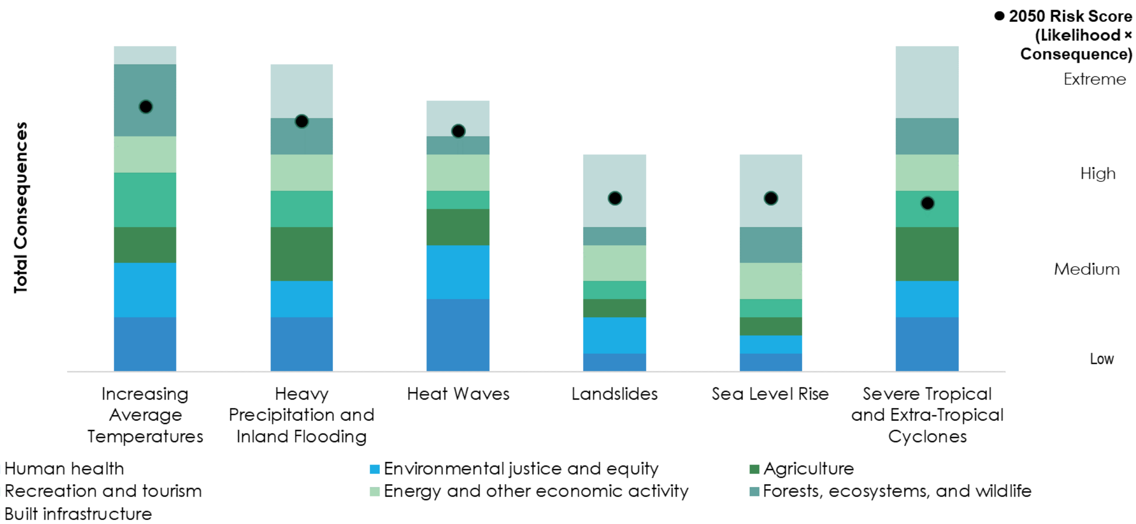


Figure 3. Total consequences by hazard (sorted highest to lowest overall risk)

Throughout this risk assessment the fact that climate change does not affect all Pennsylvanians equally was given particular focus. Some communities may be more vulnerable to impacts because of their location, and some populations may be more at risk because of housing, health, or other factors. Certain populations have greater physical exposure to risks (e.g., construction workers may be more exposed to heat waves) or have limitations on their ability to manage consequences if they occur (e.g., low income or wealth may hinder ability to pay for air conditioning). Consequences of historical discriminatory practices, such as redlining and disinvestment, may also manifest as inequities today. For example, individuals living in deteriorating housing may be more exposed to heat stress.

As Pennsylvania works to reduce its climate risks, it must address these inequitable impacts and ensure that adaptation efforts do not inadvertently exacerbate inequities. Instead, adaptation actions should reduce impacts on vulnerable populations. This assessment identified the following top priorities for adaptation action:

- Reduce extreme heat risks to human health, particularly for vulnerable populations
- Support the agriculture, recreation, and tourism sectors, as well as forests, ecosystems, and wildlife in the transition to a warmer climate
- Reduce flood risks to infrastructure and communities
- Help low-income households cope with an increased energy burden
- Enhance tropical storm and landslide risk mitigation.

Climate risks and related impacts in Pennsylvania could be severe, potentially causing increased infrastructure disruptions, higher risks to public health, economic impacts, and other changes, unless actions are taken by the Commonwealth to avoid and reduce the consequences of climate change.

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

1 INTRODUCTION

1.1 Purpose and objectives

The Pennsylvania Climate Change Act (Act 70 of 2008) requires Pennsylvania to improve its understanding of, and approach to, addressing and adapting to the causes and impacts of climate change. The act requires the Department of Environmental Protection (DEP) to update the Pennsylvania Impacts Assessment (IA) and Climate Action Plan (CAP) regularly. Impact assessments provide an understanding of the state of the science concerning the range of significant climate change hazards facing Pennsylvania, such as flood events and increasing temperatures. Figure 4 summarizes the impact assessments completed and in progress.

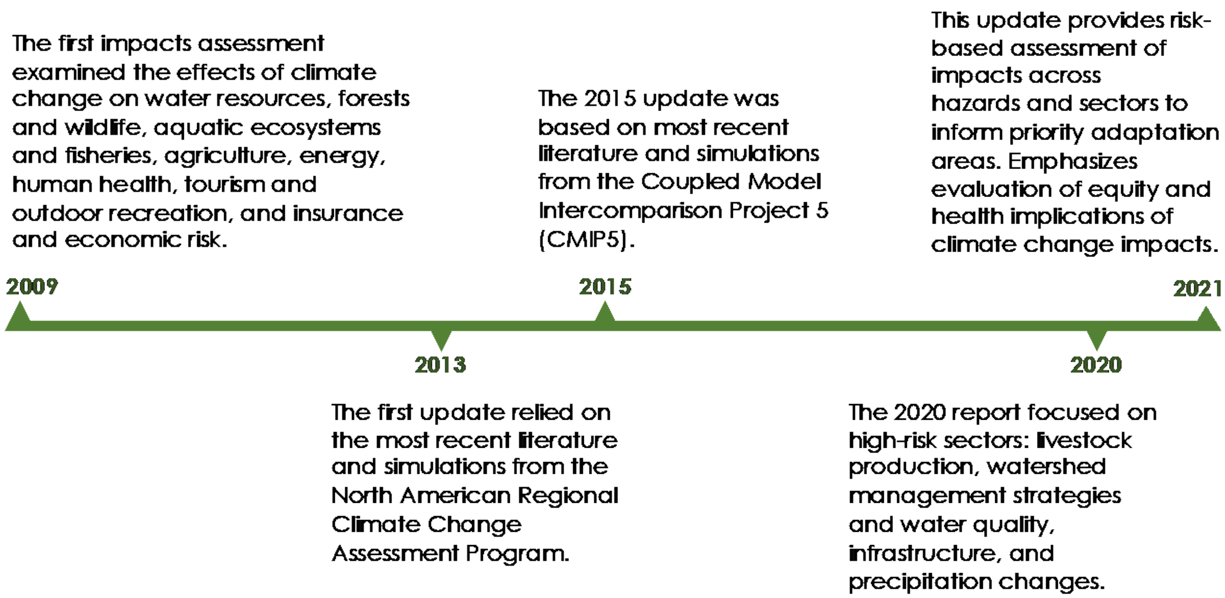


Figure 4. Timeline of Pennsylvania impact assessments

Climate change impacts create a variety of risks across sectors, resources, and populations. The 2021 Impacts Assessment is redesigned as a risk-based assessment to directly inform the CAP by helping decision-makers identify meaningful and prioritized adaptation actions.

This impacts assessment 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 impacts assessment are deliberate analysis and consideration of environmental justice and equity and health for each hazard included in the risk assessment. The assessment seeks to answer two key questions:

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

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.

1.2 Scope

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

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

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

> Appendix A defines the key terms used throughout the report. Appendix B provides more details on the risk assessment process and the approach to analyzing environmental justice and equity impacts. Appendix C provides additional information on the climate data analysis, including detailed methodology and additional data.

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

2 EXPECTED CLIMATE CHANGES IN PENNSYLVANIA

2.1 Overview of Key Updates

The 2021 Impacts Assessments presents updated climate projections based on the latest available downscaled climate model data. The projections are based on the Localized Constructed Analogs (LOCA) dataset, which includes daily temperature and precipitation projections for 32 model simulations. The 32-model ensemble was used to reduce uncertainty by aggregating the projections from all individual models into one projection.

The latest projections are in line overall with what has been presented in previous impacts assessments: 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).

Impacts Assessment Projections 2015 versus 2021

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

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 impacts assessment 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.

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

2.2 Temperature and Precipitation Changes

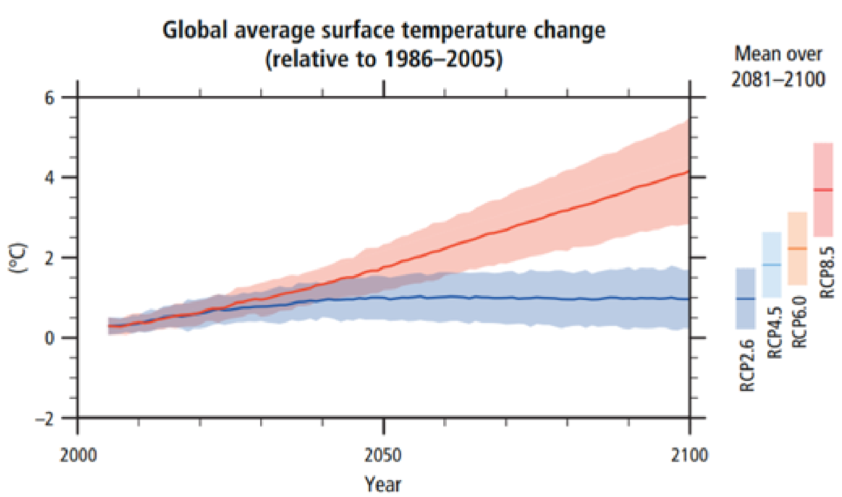
Projected values reported below for temperature and precipitation are presented for up to three future time periods, which represent the average values over 2011-2040 (present context), 2041-2070 (mid-century), and 2070-2099 (end-of-century). All are compared to a baseline period of 1971-2000. Projections are statewide averages of the 50th percentile of the 32 climate models.

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.

Key Term

Representative concentration pathways (RCP)—Scenarios of projected greenhouse gas emissions and atmospheric concentrations used in climate modeling.

Projected temperatures under RCP 4.5 are significantly lower than those under RCP 8.5 by the end of the century. 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—this is similar to the RCP 8.5 projections for mid-century. Projections for all variables under RCP 4.5 are provided in the appendix.



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

RCP 8.5 (baseline emissions scenario) and RCP 2.6 (lowest emissions scenario). RCP 4.5 is the next-lowest emissions scenario after RCP 2.6. Source: Adapted from IPCC Climate Change 2014 Synthesis Report.

2.2.1 Temperature

Temperatures are projected to increase substantially this century across the Commonwealth. 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.

Pennsylvania is projected to see higher average temperatures over the course of the next several decades. 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.[1]

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, or temperatures greater than 95 percent of all days in the baseline period of record. The temperature of very hot days is projected to increase as well as the number of annual occurrences of historical very hot days. Similarly, "extremely hot" days are days with temperatures greater than 99 percent of all days in the baseline period of record. Heat waves are approximated by the annual number of days above 90°F and 95°F as well as the number of consecutive days above 90°F and 95°F.

Although the average temperature trends upward, interannual temperature variability will continue; extremely cold temperatures are still possible. For example, though Pennsylvania has been warming the past decade, the 2017–2018 polar vortex created extremely cold conditions for weeks. Pennsylvania will continue to experience temperature fluctuations as the climate warms.

Key Temperature Findings

Temperatures are already rising and will continue to rise in Pennsylvania. Although temperatures will continue to be variable year-to-year, average annual temperature statewide is expected to increase by 5.9°F (3.3°C) by mid-century and 9.4°F (4.6°C) by end of century from a baseline time period of 1971–2000. Average annual temperature has already risen approximately 1.2°F from 2000 to 2020.

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 are expected to increase from 5 days at baseline to 37 days by mid-century and 61 days by end of century. Some parts of the state could experience more than 60 days over 90°F by mid-century. Days over 95°F are projected to increase from an average of 0.6 days during 1971-2000 to 11.5 days by mid-century and 30.5 by end of century.

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

Average Temperatures

Average temperatures are projected to increase from historical levels across the Commonwealth, as shown in Figure 6 and Figure 7. For all months, average daily temperatures are projected to increase by 4.0 to 8.0°F (2.2 to 4.5°C) mid-century and 6.4 to 12.4°F (3.6 to 3.9°C) by the end-of-century, with greatest warming in the summer season. Average monthly high

Temperatures Are Already Warming

Between 2000 and 2020, Pennsylvania's average temperature rose 1.2°**F**. The months of May, September, and October saw the greatest warming.

[1] The mid-century projection is 0.5°F higher than in the 2015 impacts assessment probably because of small methodological differences in statistical downscaling techniques, the set of global change models used, or in historical baseline datasets. Together, these factors can produce differences of 0.5°F.

temperatures will also increase. The southern corners of the state are projected to experience the highest temperatures in both the near and long terms, while the northwest could see the greatest change.

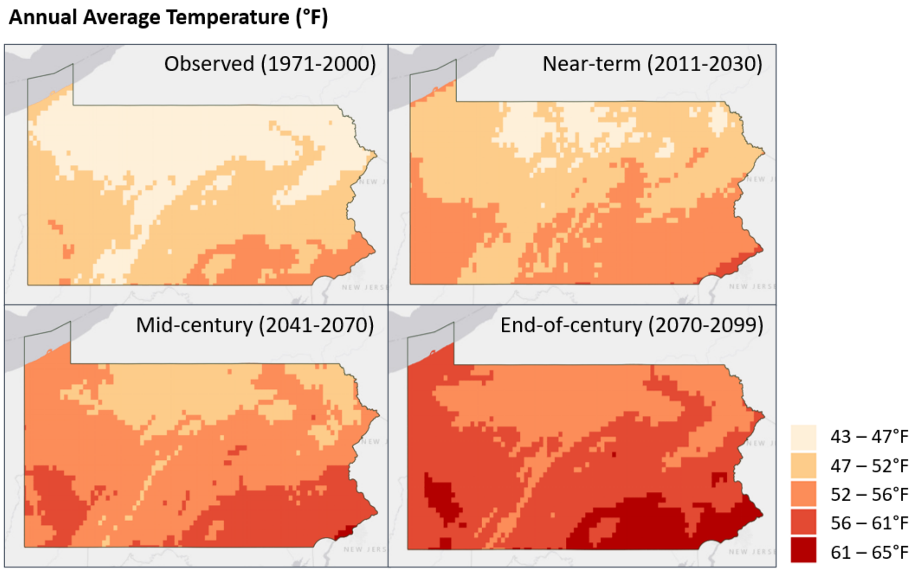


Figure 6. Observed and projected annual average temperatures in Pennsylvania

Based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5. The full range of observed and projected values is shown divided into equal increments.

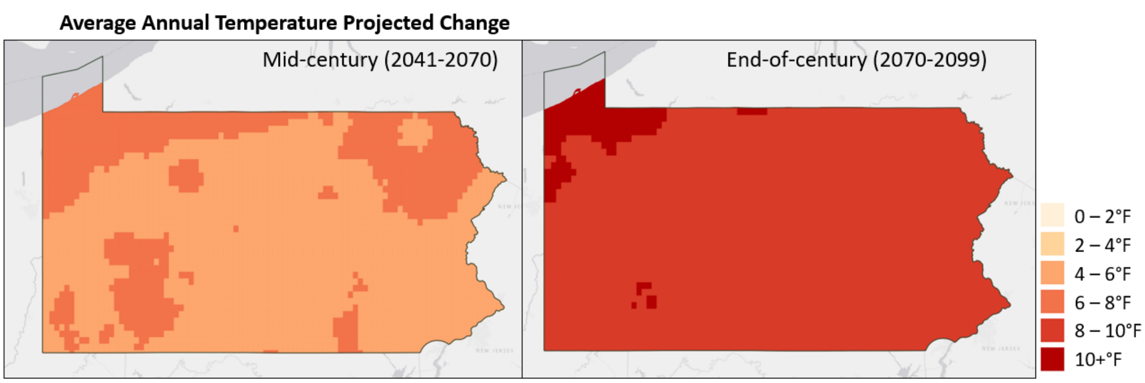


Figure 7. Projected change in average annual temperature from the historic period

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 37 days with temperatures over 90°F per year 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

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

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. The warmest parts of the state could experience up to 37 days above 95°F by 2050.

Warming Has Been Greater at Night than During the Day

Average nighttime temperatures have increased faster than average daytime temperatures. From 2000 to 2020, the warming trend was 0.4°F per decade during the day and 0.7°F per decade during the night.[3]

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.

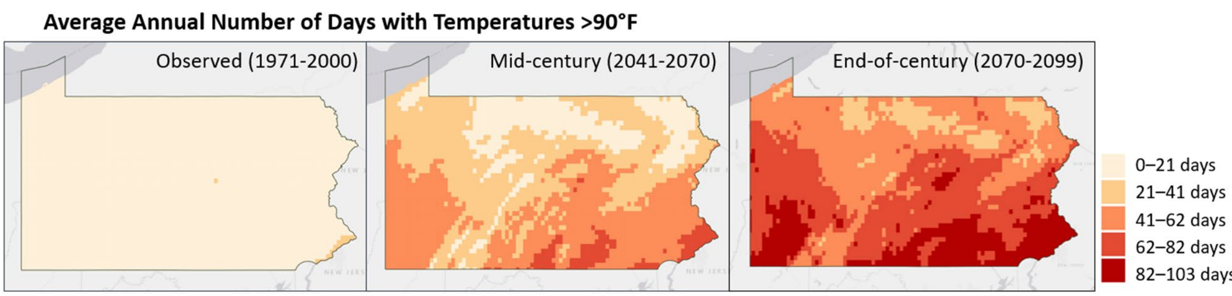


Figure 8. Observed and projected annual days with temperatures above 90°F

Based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5. The legend shows the 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 days shown in the temperature range that defines "very hot", "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% 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% 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.

[3] National Centers for Environmental Information. Climate at a Glance- Statewide Time Series. NOAA. https://www.ncdc.noaa.gov/cag/statewide/time-series

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.

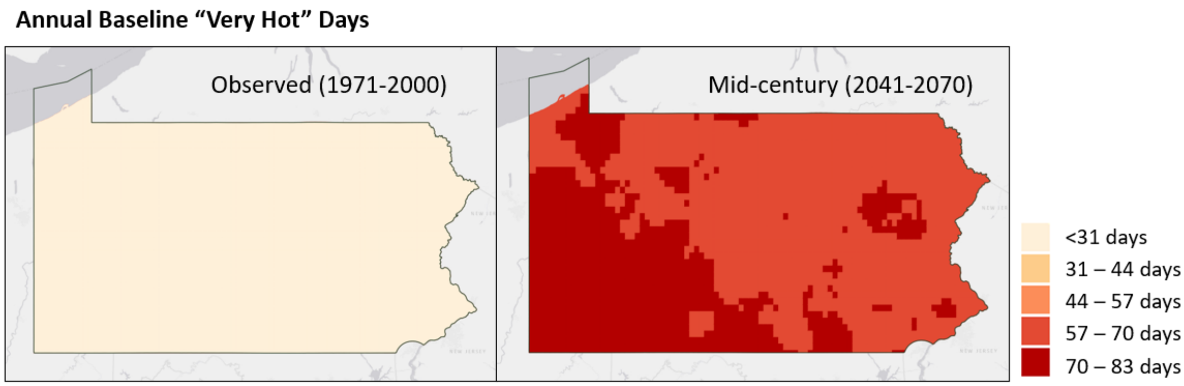


Figure 9. Observed and projected annual days with "very hot" temperatures

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. The legend shows the 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, cooling degree days, and growing degree days. Heating and cooling degree days are indicative of energy needed to heat and cool buildings, respectively.[4] As temperatures increase, heating degree days generally go down and 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. Annual total cooling degree days, however, are projected to increase by almost 150% by mid-century and by 260% by end-of-century. Figure 10 illustrates the shift in heating and cooling degree days in Pennsylvania.

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

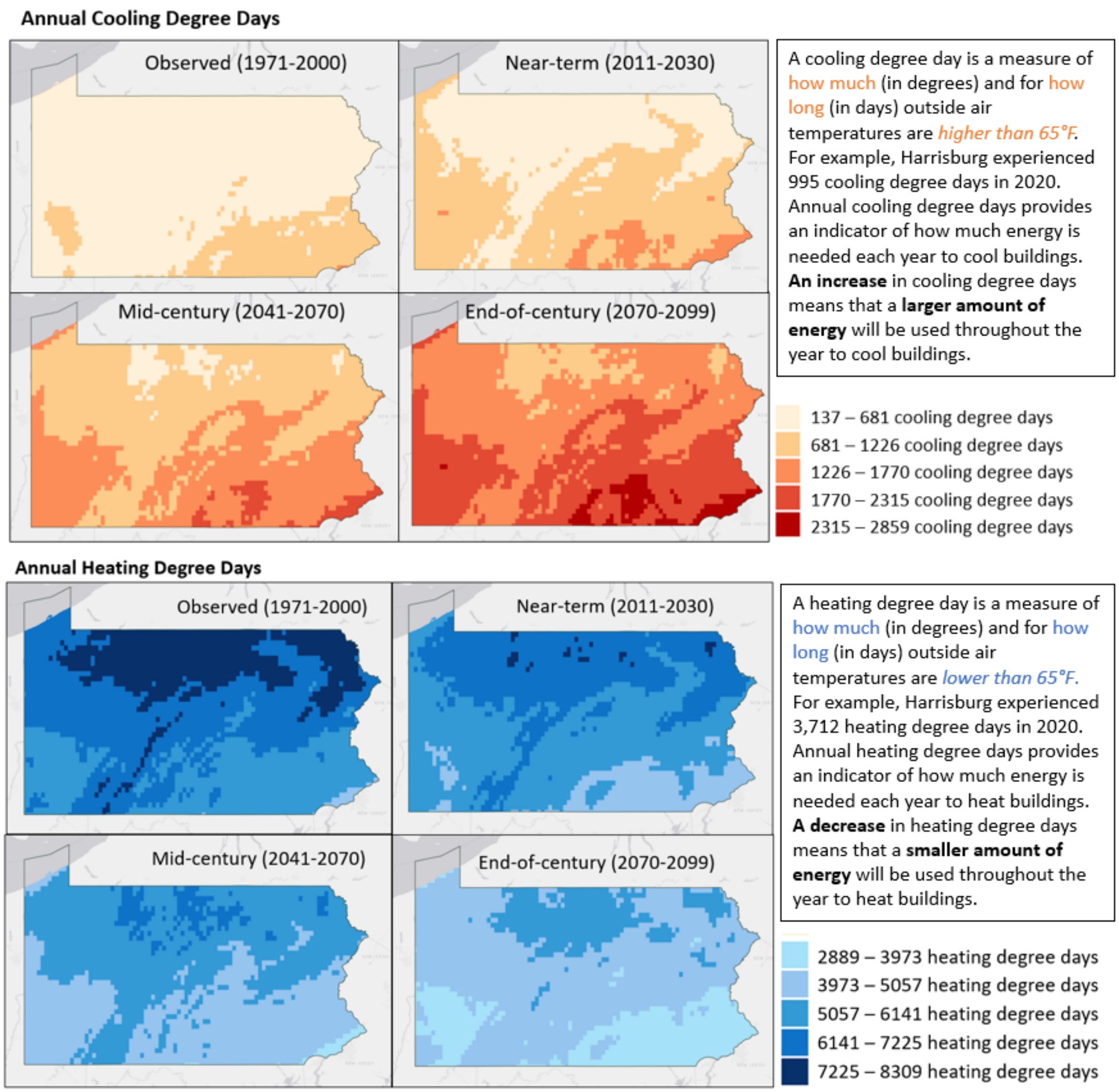


Figure 10. Observed and projected annual cooling and heating degree days

Based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5. The legend shows the 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.[5] 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

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

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 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. The full range of observed and projected values is shown divided into equal increments.

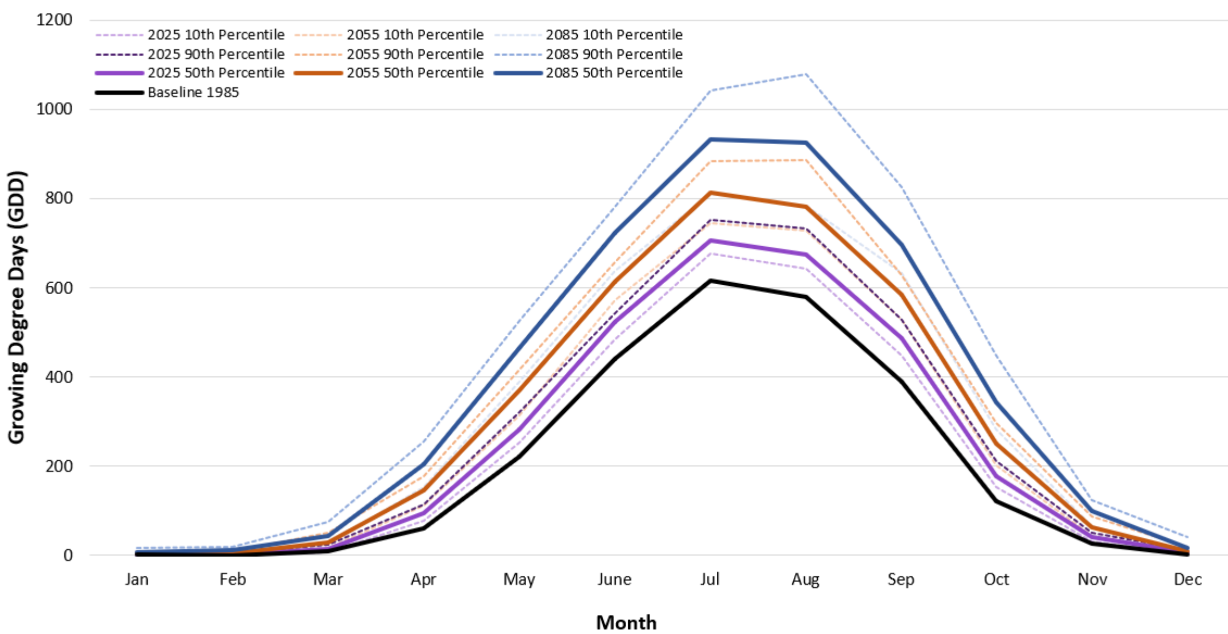

Figure 12. Observed and projected average monthly cumulative growing degree days

Based on 32-model ensemble of LOCA downscaled data, RCP 8.5. Values for 2025 represent all years 2011–2040, those for 2055 represent 2041–2070, and those for 2085 represent 2070–2099. Values are statewide averages.

Observed and Projected Temperature Data

Table 2 summarizes statewide average projections for temperature variables under RCP 8.5. Projections under the lower RCP 4.5 emission scenario are provided in Appendix C. The statewide average for the 10th to 90th percentile range is included to illustrate the spread in projections and highlight the range of possible outcomes.

Table 2. Statewide average observed and projected temperature variables for mid-century and end-of-century

		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
	Observed Baseline (1971–2000)	Projected Value (10th–90th Percentile)	50th Percentile Absolute Change	Projected Value (10th–90th Percentile)	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	5,165 (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)	1,239
"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 "very hot" baseline 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 temperature >100°F	0.0	2.4 (0.6 - 11.6)	2.4	9.3 (1.5 - 34.8)	9.3
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

Note: Projections are based a 32-model ensemble of LOCA downscaled data, RCP 8.5. Values reported are the median value of the 32-model ensemble and the 10th and 90th percentile values across models.

2.2.2 Precipitation

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.[6,7] 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.[8]

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.

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. Despite limitations, climate models help to provide insight into the potential changes in precipitation that Pennsylvania may experience in the coming decades.

Climate models project that the Commonwealth will see an increase in average annual precipitation, extreme precipitation events, and drought, as both "very heavy" precipitation events and consecutive dry days increase. Pennsylvania could experience more total average rainfall, occurring in less frequent but heavier rain events.

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[6] 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.

[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). 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] Lopez-Cantu, Prein, and Samaras. 2020. "Uncertainties in Future U.S. Extreme Precipitation from Downscaled Climate Projections."; Oyler and Nicholas. 2017. "Time of observation adjustments to daily station precipitation may introduce undesired statistical issues."

Finally, precipitation changes could include more precipitation falling as rain rather than snow, as well as increased snowmelt,[9] which could affect flooding and other hazards.[10]

Increased Average Precipitation

Pennsylvania has already been getting wetter. Between 2000 and 2020, Pennsylvania experienced an increase in annual precipitation of approximately 4.6 inches compared to the 1971–2000 period.[11] (see Figure 13).[12] May, June, and October saw the greatest increases in precipitation.

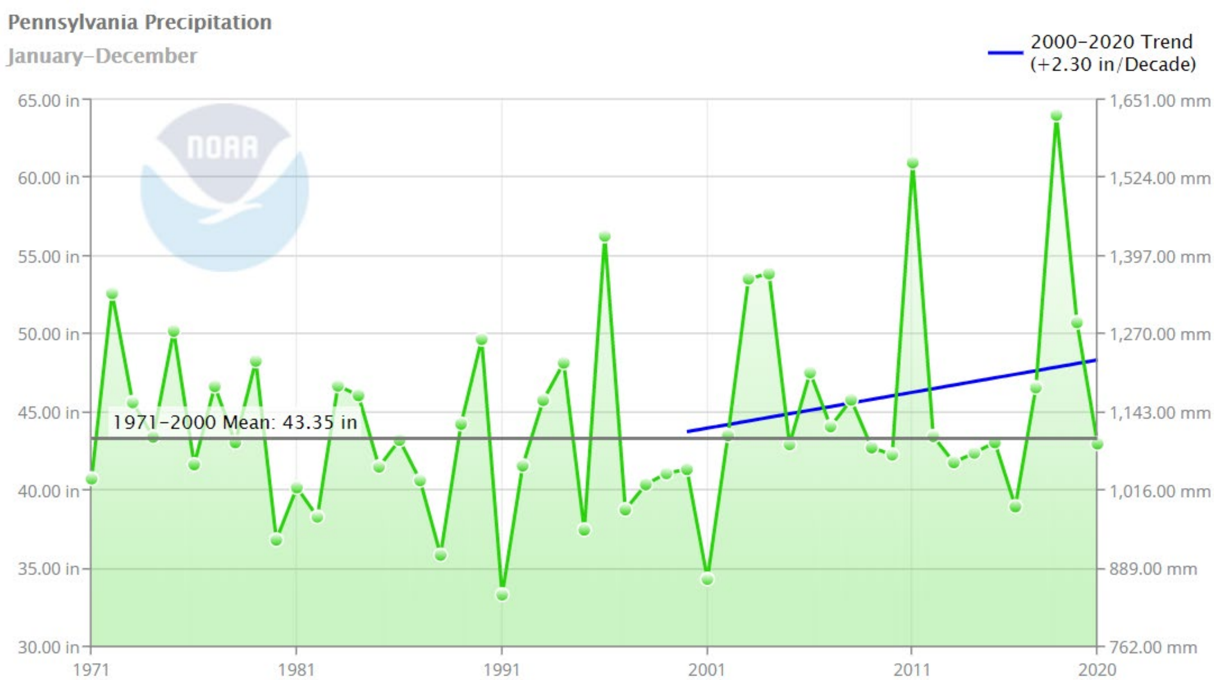

Figure 13. Annual precipitation in Pennsylvania 1971–2020

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

Annual average precipitation is projected to continue to increase. 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.[13] Historically, average annual precipitation was 44 inches (1,105 mm). Average annual precipitation is

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

[10] DEP. 2020 IA.

[11] National Centers for Environmental Information. Climate at a Glance- Statewide Time Series. NOAA. https://www.ncdc.noaa.gov/cag/statewide/time-series

[12] National Centers for Environmental Information. Climate at a Glance- Statewide Time Series.

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

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. Most increases in precipitation will occur in the winter and spring, with future precipitation conditions remaining similar to historic patterns during summer and fall (see Figure 15). This seasonal pattern of projected precipitation change is consistent with numerous past studies for the Commonwealth.[14] The range in monthly total precipitation values shown across models indicates the variability and uncertainty in precipitation projections (see Figure 15).

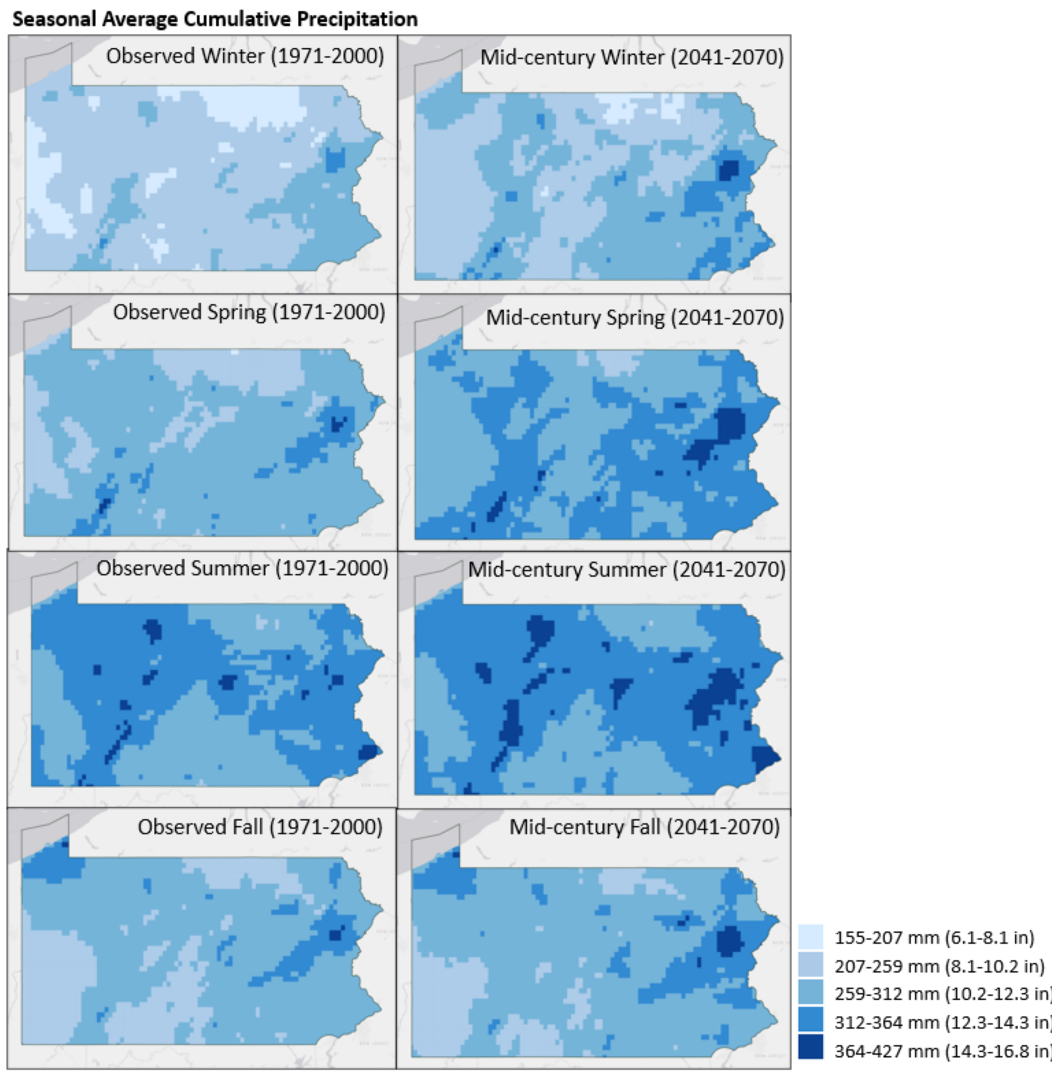

Figure 14. Observed and projected seasonal cumulative precipitation

Based on 50th percentile of 32-model ensemble of LOCA downscaled data, RCP 8.5. The legend shows the full range of observed and projected values divided into equal increments.

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

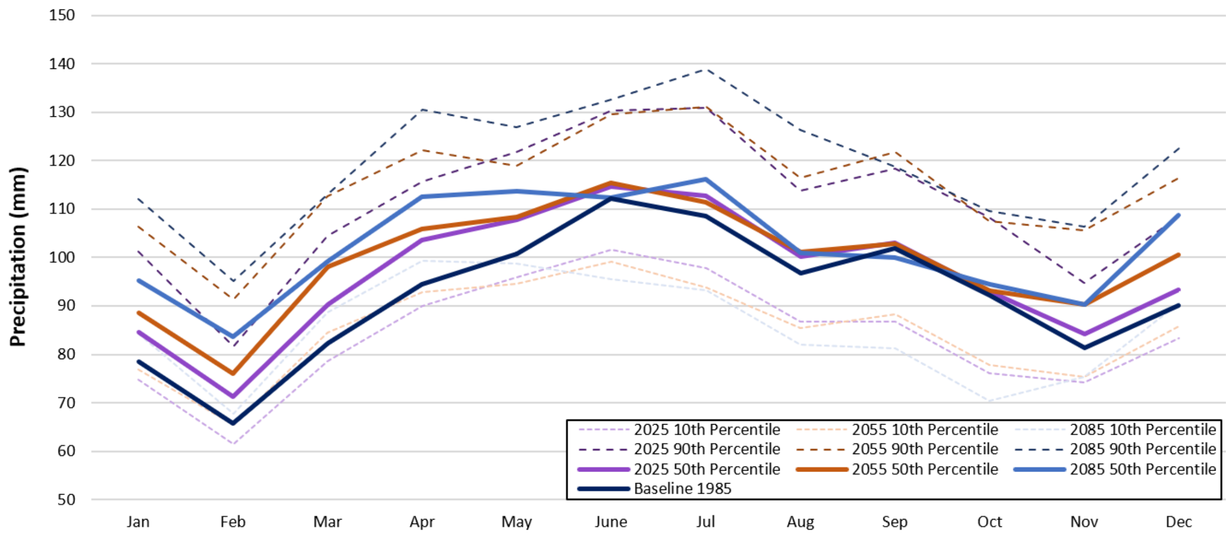

Figure 15. Statewide observed and projected average monthly precipitation

Based on 32-model ensemble of LOCA downscaled data, RCP 8.5. Values for 2025 represent all years 2011–2040, values for 2055 represent all years 2041-2070, and values for 2085 represent all years 2070–2099.

Increased Extreme Precipitation

Consistent with findings from prior assessments,[15],[16] extreme rainfall events are projected to increase in magnitude, frequency, and intensity as the century progresses. The statewide average amount of rainfall that falls during "very heavy" precipitation events (which occur less than 5% of the time) is projected to rise from 0.7 inch (17.2 mm) (historical baseline) to 0.8 inch (19.3 mm) by mid-century and to 0.8 inch (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 inch) (historical baseline) to 34.1 mm (1.3 inch) and 36.1 mm (1.4 inch) 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.

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[15] Shortle, J., Abler, D., Blumsack, S., et al. 2009. "Pennsylvania Climate Impact Assessment." Pennsylvania Department of Environmental Protection. http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/7000-BK-DEP4252%5B1%5D.pdf

[16] Ross, A., Benson, C., Abler, D., et al. 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

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 16). The Southeastern corner of Pennsylvania will continue to experience the highest number of days with very heavy precipitation throughout the century.

Number of Days with Very Heavy Precipitation

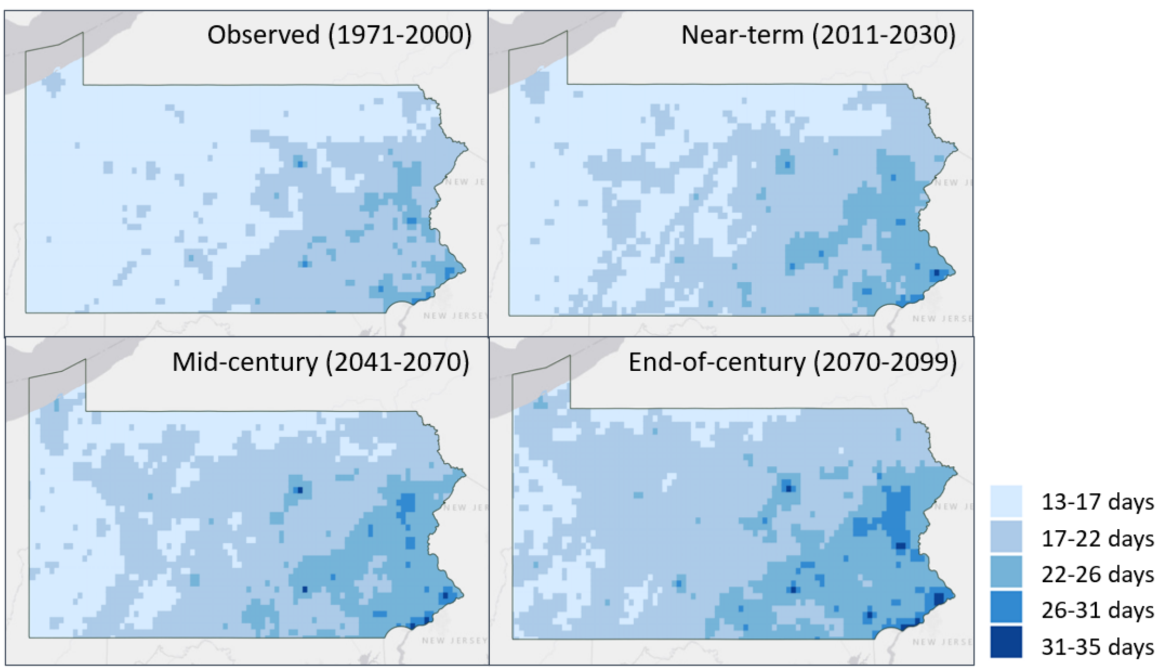

Figure 16. Observed and projected annual days with "very heavy" precipitation

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. The full range of observed and projected values is shown divided into equal increments.

This change is already occurring. Pennsylvania weather data shows that over 80% of Cooperative Observer Program sites surveyed by the state climatologist are seeing an increase in heavy rain events in the 2010s when compared to the 1980s.[17]

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[17] 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.

Additionally, the number of days with more than 3 inches (76.2 mm) 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 inches of rainfall and the number of days by mid- and end-of-century is projected to remain less than one day per year.

Finally, Pennsylvania will continue to experience an increase in more intense rain events. Sudden, short, and heavy rainfall events, known as cloudbursts, are often responsible for flash flooding. Pennsylvania experiences flash flooding, according to research by Pennsylvania Department of Transportation (PennDOT).[18] Climate change is expected to increase the intensity and frequency of cloudburst events.[19,20,21] These events result in significant impacts (i.e., flooding), but are not well captured in many climate models. The models used here attempt to capture precipitation events at daily resolution rather than hourly or sub-daily resolutions. Greater research on the change in frequency and intensity in cloudbursts over the coming century is needed.[22,23]

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.[24] 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.[25] As shown in Figure 17, 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

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[18] PennDOT and Michael Baker International. 2017. "Phase 1: PennDOT Extreme Weather Vulnerability Study," p. 16. http://s3.amazonaws.com/tmp-map/climate/doc/StudyReport-PaVulnerabilityStudy-ver040317.pdf.

[19] Westra, S., Fowler, H.J., Evans, J.P., et al. 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.

[20] Kendon, E.J., Roberts, N.M., Fowler, H.J., et al. 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.

[21] Prein, A.F., Rasmussen, R.M., Ikeda, et al. 2017. "The Future Intensification of Hourly Precipitation Extremes." *Nature Climate Change*, 7, p. 48–52. https://www.nature.com/articles/nclimate3168?cookies=accepted

[22] Rosenzweig, B., Ruddell, B., McPhillips, L., et al. 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.

[23] Westra et al., 2014. "Future Changes to the Intensity and Frequency of Short-Duration Extreme Rainfall."

[24] U.S. Global Change Research Program. 2018. Chapter 18: Northeast. Fourth National Climate Assessment. p. 270. https://nca2018.globalchange.gov/chapter/18/

[25] Shortle et al., 2009 IA; Ross et al., 2013 IA.

historical conditions in the winter and spring. Overall, changes in precipitation events will create wetter winters and springs and drier falls in the Commonwealth.

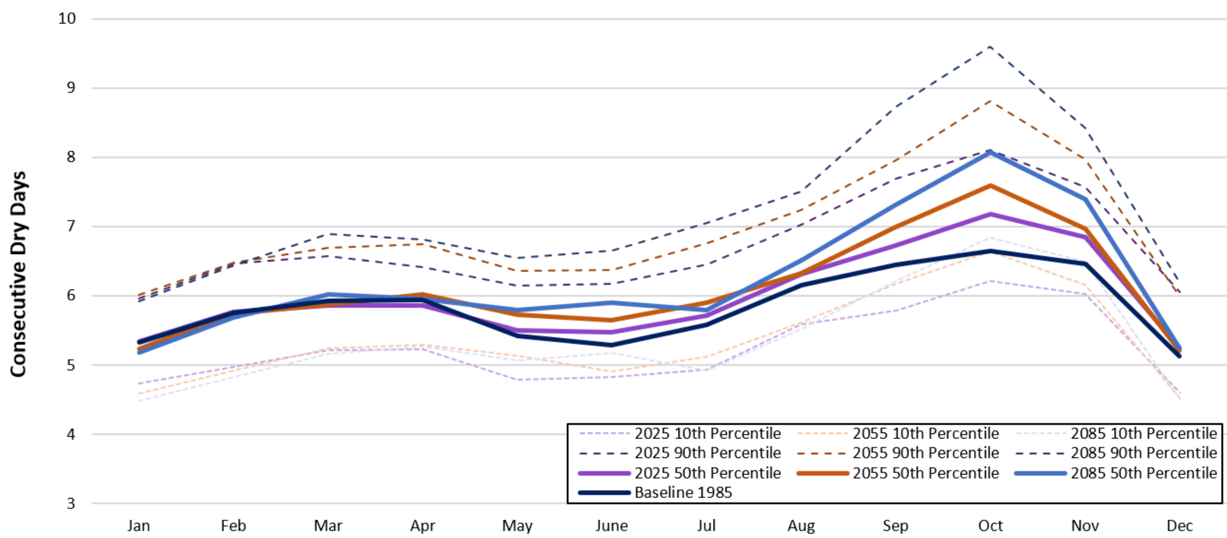

Figure 17. Statewide observed and projected average monthly consecutive dry days

Based on 32-model ensemble of LOCA downscaled data, RCP 8.5. Values for 2025 represent all years 2011–2040, values for 2055 represent all years 2041–2070, and values for 2085 represent all years 2070–2099.

Drought conditions have declined in recent decades but persist despite more overall precipitation, according to measurements using the Palmer Drought Severity Index (PDSI).[26] This is a standardized index used to understand the intensity and duration of long-term drought conditions.[27] A PDSI greater than zero represents wet conditions, while a PDSI less than zero indicates dry conditions. Figure 18 shows Pennsylvania's PDSI trends from January 1971 to December 2020 and highlights a trend toward increased precipitation and more wet months. It also highlights that drought conditions continue to occur even with a trend toward greater precipitation.

[26] National Centers for Environmental Information. Climate at a Glance- Statewide Time Series. NOAA.

[27] National Centers for Environmental Information. Climate at a Glance- Statewide Time Series. NOAA.

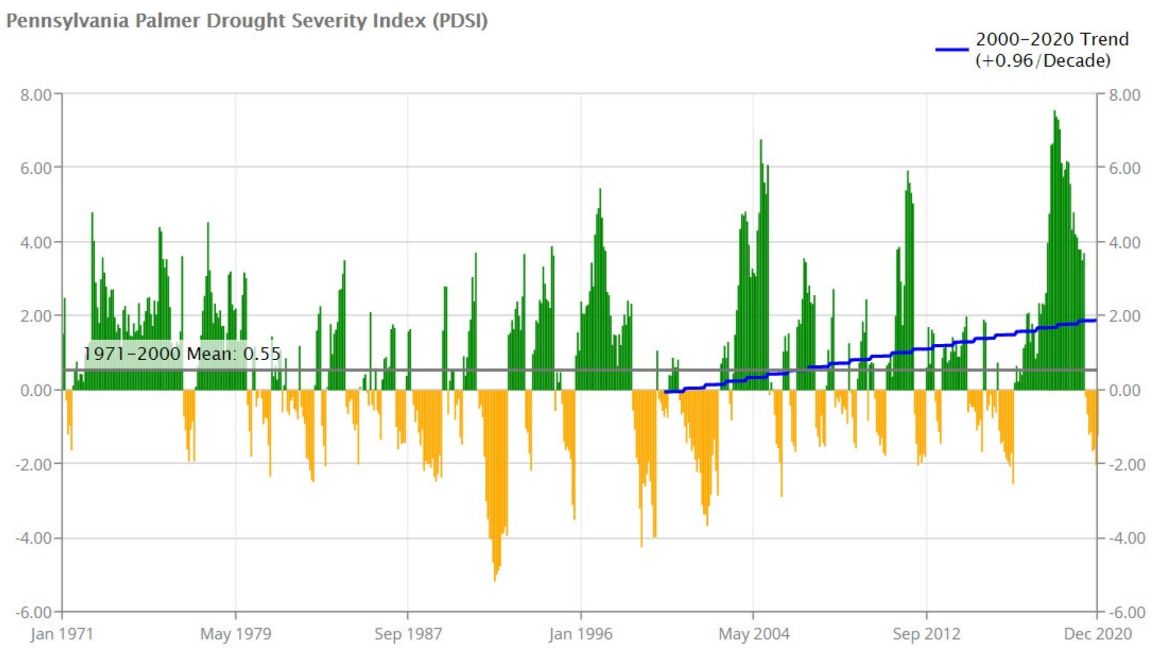

Figure 18. Pennsylvania Palmer Drought Severity Index for 1971–2020

The green bars represent wet months and the yellow bars represent dry months. Source: National Centers for Environmental Information. Climate at a Glance Statewide Time Series

Observed and Projected Precipitation Data

Table 3 summarizes statewide average projections for precipitation variables under RCP 8.5. Projections under the lower RCP 4.5 emission scenario are provided in Appendix C. The average for the 10th and 90th percentile range is included to illustrate the spread in projections and highlight the range of possible outcomes.

Table 3. Statewide average observed and projected precipitation variables

		Mid-Century (2041–2070)		End-of-Century (2070–2099)	
	Baseline (1971–2000)	Projected Value (10th–90th Percentile Range)	50th Percentile Percent Change	Projected Value (10th–90th Percentile Range)	50th Percentile Percent Change
Annual precipitation (inches)	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 (inches)	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%

	Baseline (1971–2000)	Mid-Century (2041–2070) Projected Value (10th–90th Percentile Range)	Mid-Century (2041–2070) 50th Percentile Percent Change	End-of-Century (2070–2099) Projected Value (10th–90th Percentile Range)	End-of-Century (2070–2099) 50th Percentile Percent Change
"Extremely heavy" (99th percentile) precipitation (inches)	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 (inches)	2.4	2.6 (2.3–3)	11.2%	2.8 (2.3–3.1)	16.3%

Note: Projections are based a 32-model ensemble of LOCA downscaled data, RCP 8.5. Values reported are the median for the 32-model ensemble, as well as the 10th and 90th percentile values across models.

2.3 Coastal Changes

2.3.1 Coastline along the Delaware Estuary

Pennsylvania has a small 56-mile coastline along the Delaware estuary, as seen in Figure 19. This coastline spans from Morrisville, PA to Marcus Hook, PA.[28] Because of land subsidence in the Mid-Atlantic region, local sea level rise is projected to be approximately 0.06 inch per year greater than the global average.[29] 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.[30] Figure 20 highlights sea level rise scenarios in the Delaware Estuary Coastal Zone over the course of the century, including the intermediate scenario.

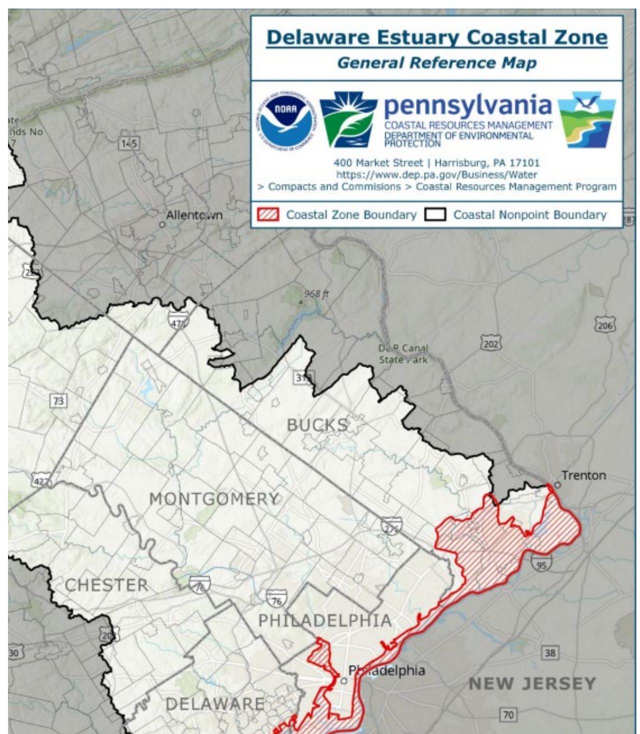

Figure 19. Delaware Estuary Coastal Zone

[28] PSU. 2015 IA.

[29] Delaware Valley Regional Planning Commission (DVRPC). 2004. Sea Level Rise Impacts in the Delaware Estuary of Pennsylvania. https://www.dvrpc.org/Products/04037

[30] U.S. Army Corps of Engineers (USACE). 2019. Sea Level Change Curve Calculator. http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

As the coastline experiences a rise in sea level, the abutting tidal wetlands may be inundated.[31] Already, Pennsylvania's coastline varies with the large tidal fluctuations in the Delaware River. 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 21 and Figure 22 highlight the change in areas that may be inundated under a 3-foot rise in sea level. Additionally, sea level rise is expected to result in salinity increases throughout the Delaware estuary, which will affect ecosystems and drinking water supplies. The consequences of sea level rise are further discussed in section 4.5.3.

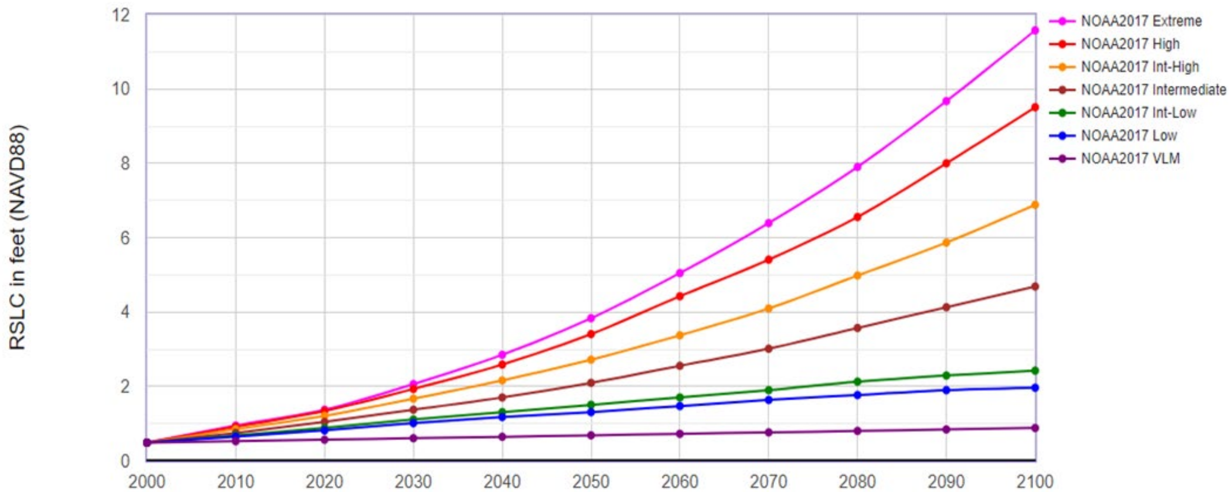

Figure 20. Sea level rise scenarios for Philadelphia tide gauge

[31] DVRPC. 2004.

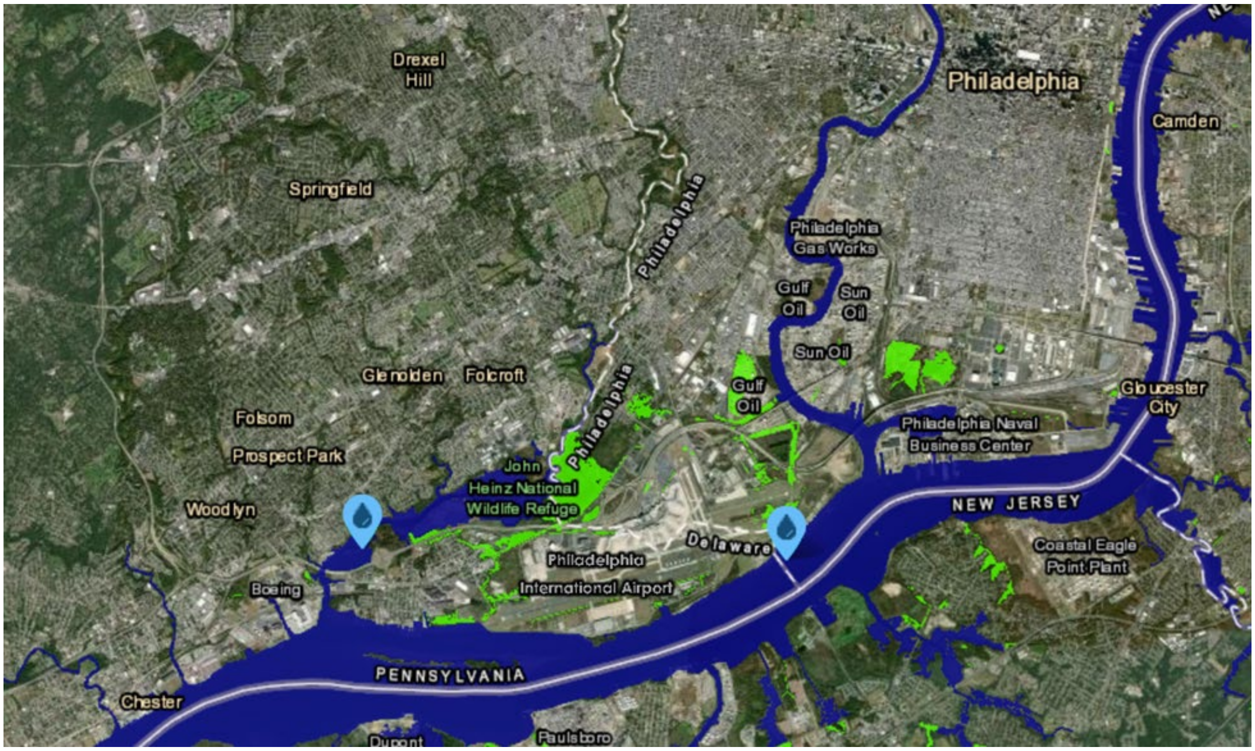

Figure 21. Current areas at risk from tidal flooding

Areas shaded in lime green represent low-lying areas, dark blue areas describe existing water bodies, and light blue areas highlight inundated areas. Source: NOAA Sea Level Rise Viewer. https://coast.noaa.gov/slr/

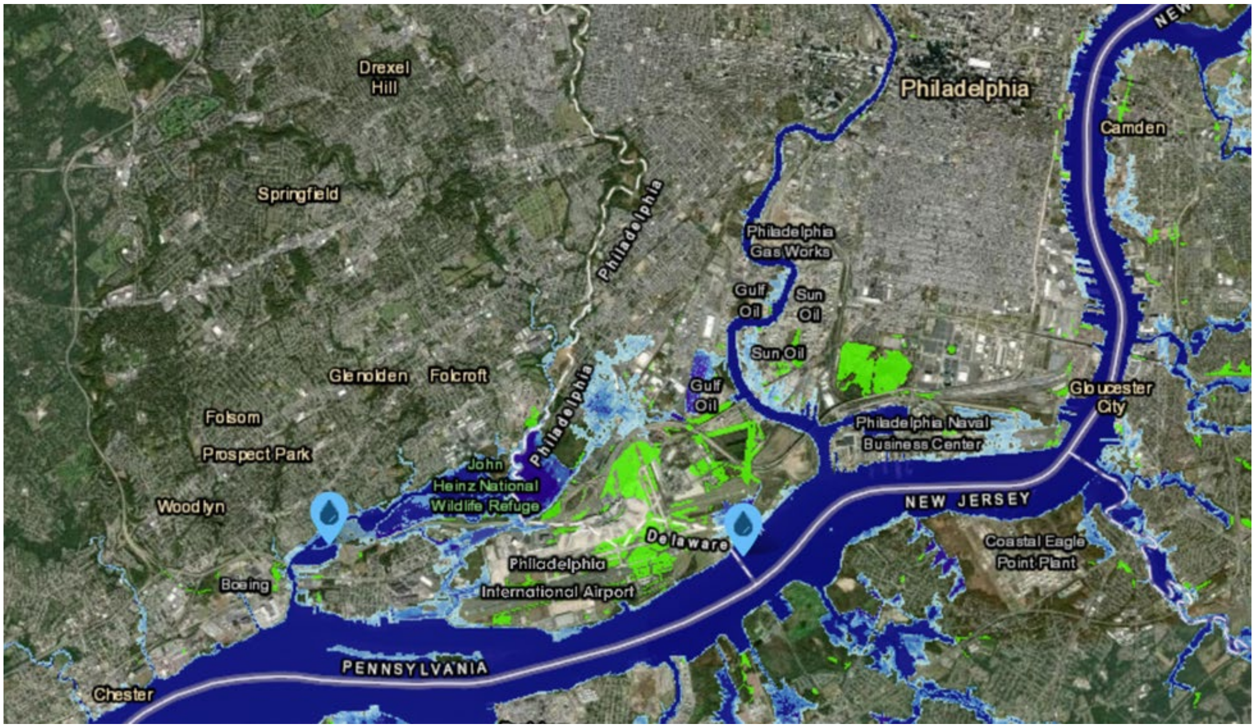

Figure 22. Areas at risk from tidal flooding from a 3-foot rise in sea levels

Areas shaded in lime green represent low-lying areas, dark blue areas describe existing water bodies, and light blue areas highlight inundated areas. Source: NOAA Sea Level Rise Viewer. https://coast.noaa.gov/slr/.

2.3.2 Coastline along Lake Erie

Pennsylvania also has a 64-mile coastline along Lake Erie (highlighted in Figure 23). With climate change, Lake Erie is projected to experience significantly higher variability in water levels.[32] Warmer temperatures and increased extreme precipitation events are anticipated to have substantial effect on Lake Erie. Warmer temperatures will increase evapotranspiration, which in turn is projected to lower levels in Lake Erie in some years or months.[33] However, at other points, increased average precipitation and greater extreme precipitation events are projected to raise water levels. [34] For example, as a result of increased rain, Lake Erie hit its highest ever water level in June 2019.[35] Lake Erie's water levels are expected to continue fluctuating in the decades to come.

Figure 23. Lake Erie watershed

Climate change is also projected to affect water quality and increase erosion. Climate change will result in higher lake water temperatures and greater runoff from the increased frequency of extreme precipitation events.[36] Combined warmer waters and increased runoff will boost the likelihood of e-coli and algal blooms.[37] In the summer of 2014, Lake Erie experienced a harmful algal bloom in its western basin. Algal blooms 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.[38] Additionally, 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.[39] Coastal

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[32] Gronewold, D., and Rood, R. 2019. "Climate Change Sends Great Lakes Water Levels Seesawing." Scientific American. https://www.scientificamerican.com/article/climate-change-sends-great-lakes-water-levels-seesawing/

[33] Foyle, A. 2018. The Lake Erie Bluff Coast of Pennsylvania.

[34] Gronewold and Rood. 2019. "Climate Change Sends Great Lakes Water Levels Seesawing." Scientific American.

[35] Johnston, L. 2020. Lake Erie broke May high water record—again. https://www.cleveland.com/news/2020/06/lake-erie-broke-may-high-water-record-again.html

[36] 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.

[37] Sea Grant Pennsylvania. Climate Impacts to Erie.

[38] Sea Grant Pennsylvania. Climate Impacts to Erie.

[39] Sea Grant Pennsylvania. Climate Impacts to Erie.

erosion rates are also expected to increase as the Lake's coastlines are impacted more frequently by severe storms.[40]

Warmer temperatures will also alter snow patterns. In the winter, warmer water and a lack of surface ice on the lake will likely result in an increase in lake effect snow events in the short term.[41,42] Lake Erie is anticipated to experience significant overall change from climate change.

2.4 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. Cumulative precipitation from storms is expected to increase.[43] The literature does not expect that climate change will impact the frequency of tropical cyclones or major winter cyclones.[44]

While severe non-tropical rain events are anticipated to become more likely,[45] snowstorms are projected to decrease in frequency.[46] Smaller storms rather than major storms are forecasted to comprise the majority of this reduction.[47] Figure 24 highlights the projected decrease in days in which snow events can occur. Increasing temperature may also decrease the severity of winter weather and reduce the amount of precipitation that falls as snow.[48] As mentioned in the previously in section 2.3.2 (Coastline along Lake Erie), lake-effect snow events are projected to

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[40] 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

[41] Liberto, T. 2017. The paradox of lake effect snow: global warming could bring the Great Lakes more of it, at least for a while. https://www.climate.gov/news-features/event-tracker/lake-effect-snow-paradox

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

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

[44] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

[45] PSU. 2015 IA.

[46] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

[47] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

[48] Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

increase in the short-term.[49] In the long-term, however, as winter temperatures warm significantly, lake effect snow events will decrease.[50]

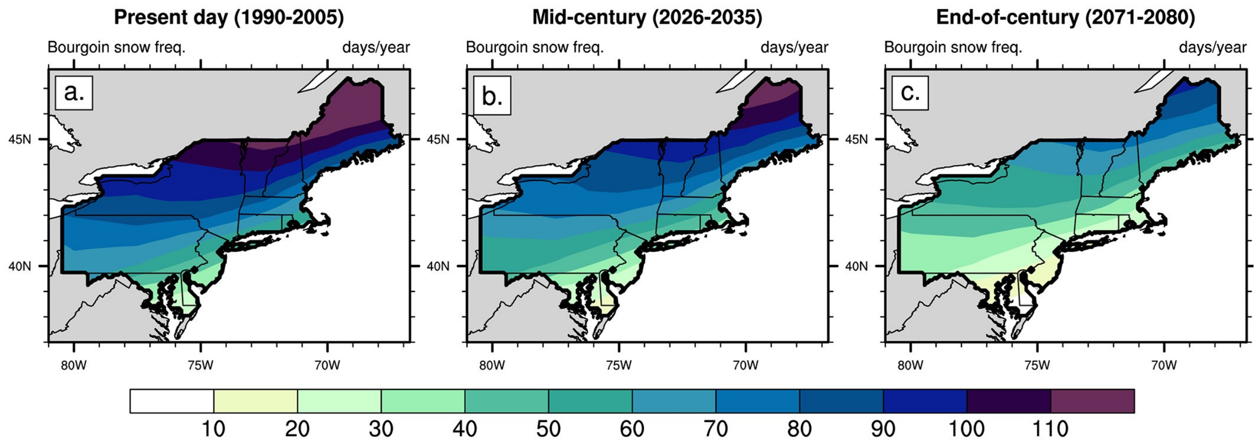

Figure 24. Average number of days per year where snowfall could occur, present-day, mid-century, and end-of-century.

Values for present day represent all years 1990–2005, values for mid-century represent all years 2026–2035, and values for end-of-century represent all years 2071–2080. Source: Zarzycki, C.M., 2018. Projecting changes in societally impactful Northeastern U.S. snowstorms.

From 2000 to 2020, 45 "billion-dollar" disaster events occurred in Pennsylvania as a result of tropical cyclones, severe storms, and winter storms.[51] Figure 25 highlights the change in the number of billion-dollar disaster events over the last 40 years. Heavy rains, flooding and damages from wind are significant driver of damage during these events. Overall, climate change is projected to alter the frequency and intensity of extreme weather events.

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[49] Liberto, T. 2017. The paradox of lake effect snow.

[50] Liberto, T. 2017. The paradox of lake effect snow.

[51] NOAA National

Centers for Environmental Information. 2020. Billion-Dollar Weather and Climate Disasters: Events. https://www.ncdc.noaa.gov/billions/events/PA/2000-2020

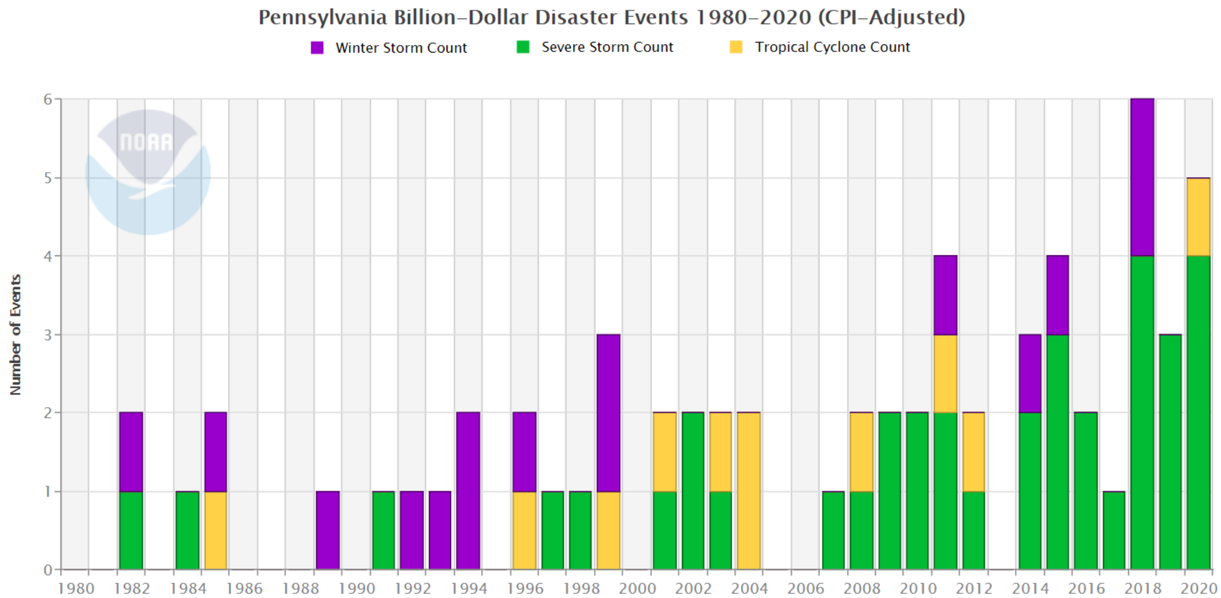

Figure 25. Billion-dollar extreme weather events in Pennsylvania 1980–2020

These events have been adjusted based on the Consumer Price Index (CPI) to 2020 to account for inflation (i.e., events that cost less than a billion dollars at the time of the event, but would cost a billion dollars in 2020 are included). Source: NOAA National Centers for Environmental Information. 2020. Billion-Dollar Weather and Climate Disasters: Time Series. https://www.ncdc.noaa.gov/billions/time-series

2.5 Landslides and Sinkholes

Currently, landslides and sinkholes are serious hazards in the Commonwealth that affect transportation networks and buildings and create serious health and safety concerns.[52] The effect of climate change on the location, quantity, frequency, and severity of landslides and sinkholes remains highly uncertain. The role that climate change will play in the highly complex and variate mechanisms that cause these hazards has not yet been established.

In research literature, there is confidence that climate change can affect the stability of slopes and therefore landslides,[53] but the nature of the effect is unclear. Projections indicate that an increase in the frequency and intensity of severe precipitation events could increase landslide risk, because heavy rainfall is a key cause of certain types of landslide events.[54] Significant uncertainty, however, is associated with these projections.

Little research has been conducted on how climate changes affects sinkhole development in the United States. Sinkhole development in the United States is caused by changes in the groundwater table (i.e., water input into or extraction from the ground), soil disturbance,

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[52] Pennsylvania Department of Conservation and Natural Resources Bureau of Geological Survey. "Landslides." 2020. https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/

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

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

concentrated water flow, erosion, and heavy surface loads.[55,56] Activities and conditions that may drive these mechanisms include the thawing of frozen ground, groundwater pumping, land use practices, construction, drought, declining water levels, mining, pipe leakage, water impoundments (i.e., basins, ponds, reservoirs), runoff, and drilling.[57,58] Drought and groundwater table decline have both been linked to climate change, and are significant drivers of sinkhole development.[59,60] With projected increases in the occurrence of drought and low summer groundwater levels in the coming century, sinkholes could potentially become more frequent as climate change intensifies. More research is needed to understand how climate change's impact on the mechanisms that cause sinkhole development might affect the occurrence of sinkholes in the Commonwealth.

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[55] Gutiérrez, F. 2016. Sinkhole Hazards. Oxford Research Encyclopedia of Natural Hazard Science. https://oxfordre.com/naturalhazardscience/view/10.1093/acrefore/9780199389407.001.0001/acrefore-9780199389407-e-40.

[56] Department of Environmental Protection. Sinkholes. https://www.dep.pa.gov/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx

[57] Gutiérrez, F. 2016. Sinkhole Hazards.

[58] Department of Environmental Protection. Sinkholes. https://www.dep.pa.gov/Citizens/My-Water/Sinkholes/Pages/What-causes-a-sinkhole.aspx

[59] Gutiérrez, F. 2016. Sinkhole Hazards.

[60] Rogelio, L et. al., 2017. The impact of droughts and climate change on sinkhole occurrence. A case study from the evaporite karst of the Fluvia Valley, NE Spain. Science of the Total Environment. Volume 579, p345-358. https://doi.org/10.1016/j.scitotenv.2016.11.091

3 RISK ASSESSMENT OVERVIEW

3.1 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
- Heavy precipitation and inland flooding
- Heat waves
- Landslides
- Sea level rise
- Severe tropical and extra-tropical cyclones

The process for analyzing and evaluating each hazard is shown in Figure 26. The likelihood of each hazard occurring is evaluated on a scale of 1 to 4 and the severity of each consequence category is also evaluated on a scale of 1 to 4 for the following categories:

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

Key Terms

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

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

Risk—The chance a climate hazard will cause harm. (Risk = Likelihood x Consequence.)

EJ areas—PA Environmental Justice Areas. Includes any census block group where 20% or more of individuals live in poverty, and/or 30% or more is minority.

Each hazard then receives an overall risk rating, based on the product of its likelihood and consequence scores, per the matrix in Table 4. Two hazards with similarly high consequence scores could therefore have significantly different overall risk ratings due to differences in the likelihood the hazard will occur. The likelihood and consequence rating scales, among other methodological details, can be found in Appendix B.

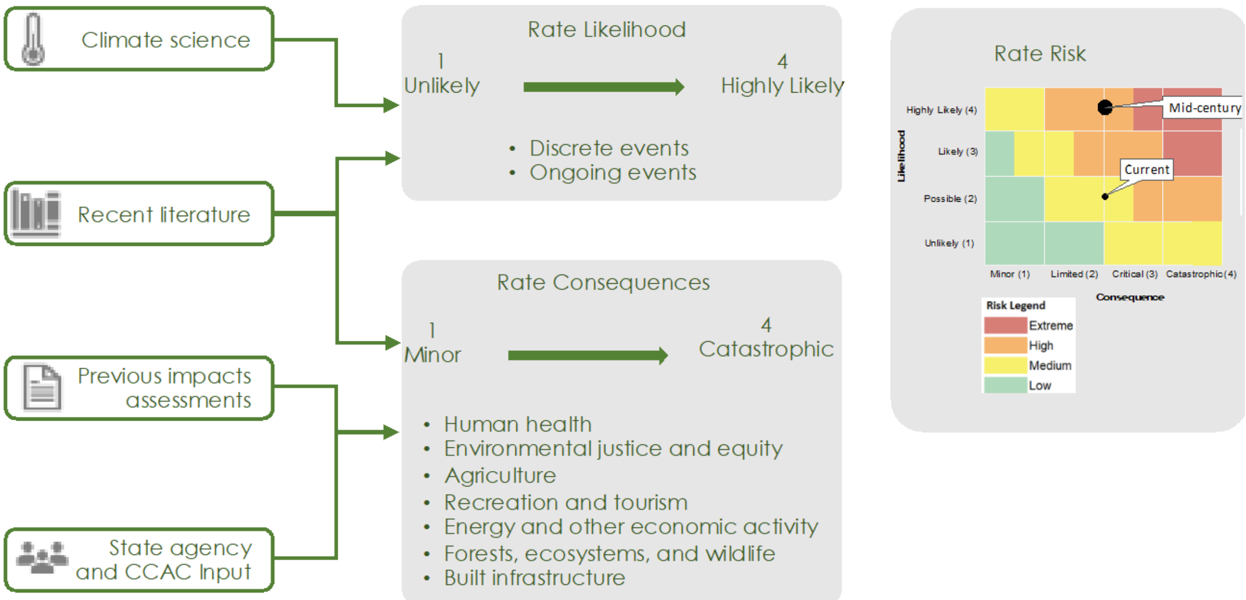

Figure 26. Risk assessment process overview

Table 4. Risk rating matrix and scoring rubric

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

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.

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

Figure 27 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.

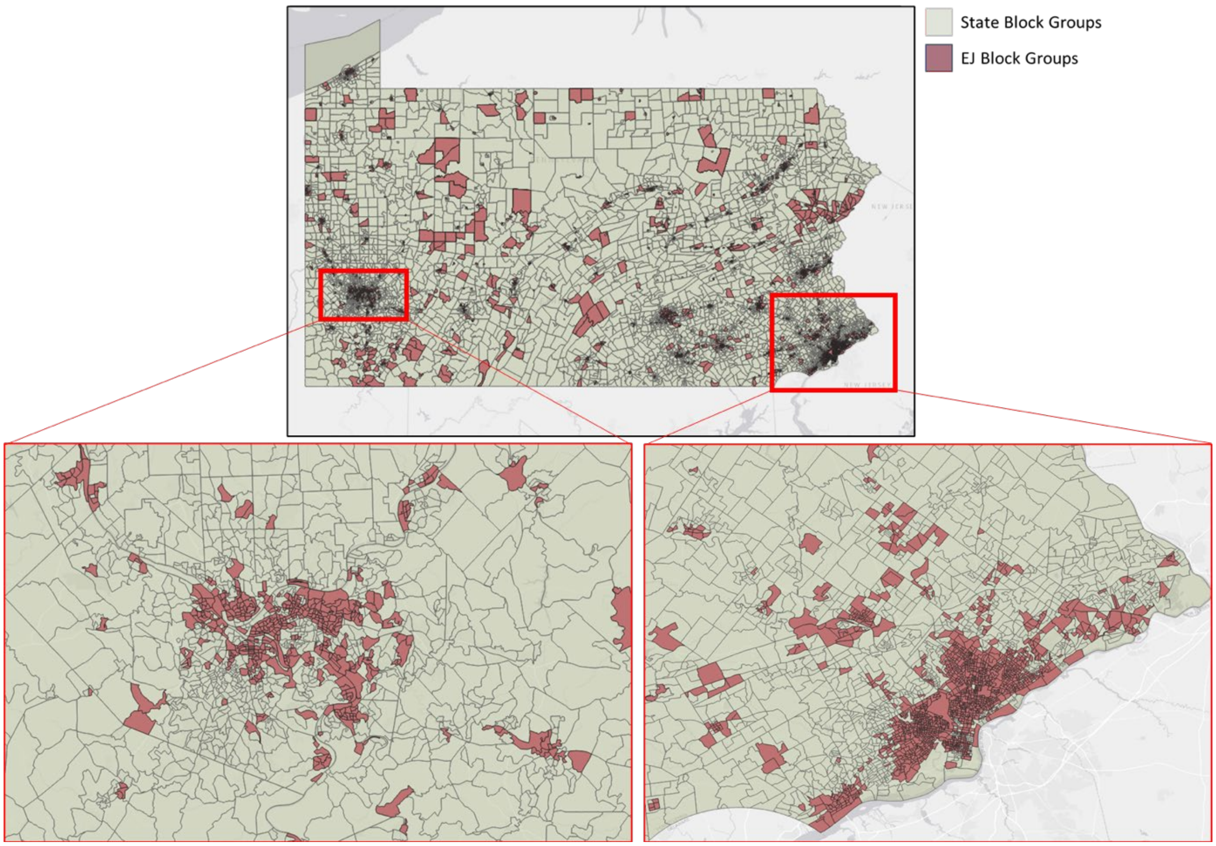

Figure 27. Environmental Justice census block groups in Pennsylvania

This analysis is not a comprehensive bottom-up assessment. While based solidly on evidence from past IAs, recent literature, and updated climate projections,[61] 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.

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

3.2 Key Findings and Overall Climate Risks

The risk assessment revealed several key findings:

- Flooding is currently the highest-risk hazard facing Pennsylvania, and flood risks are projected to increase. At the same time, risks from increasing average temperatures and heat waves could rise to be as high as flooding is today by mid-century (see Table 1).
  - Flooding from heavy rain events affects built infrastructure, human health, and agriculture, with ripple effects throughout the economy.
  - Increasing average temperatures could affect nearly every aspect of life in the Commonwealth, from infrastructure design to energy costs, recreational opportunities, agricultural practices, and the natural environment.
- Heat waves will become increasingly common and will create particular health and economic risks for vulnerable populations, including low-income populations; the elderly; pregnant women; people with certain mental illnesses, such as anxiety, depression, post-traumatic stress disorder, and substance abuse disorders; outdoor workers; and those with cardiovascular conditions. These risks will be particularly acute in areas subject to the urban heat island effect.
- All hazards—especially heat waves, increasing temperatures, and flooding—could affect public health negatively. For example, higher temperatures mean more days with hazardous heat conditions or reduced air quality, and increased risk of heat-related illness. Flooding increases the risks of direct injury from flood waters and of illness caused by contaminated water.
- Climate change will not affect all Pennsylvanians equally. Some may be more at risk because of their location, income, housing, health, or other factors. As Pennsylvania works to reduce its climate risks, it should also take care that these inequitable impacts are addressed, and that adaptation efforts do not inadvertently exacerbate inequities.
- Landslides and sea level rise pose relatively low risks statewide but can cause severe impacts in the locations where they occur. For example, sea level rise in the Delaware estuary could drastically change the makeup of the estuary's ecology and threaten the built infrastructure near the tidal zone. Landslides can have severe consequences if they cut off critical transportation routes, particularly in rural areas.
- Severe tropical storms, flooding, and landslides already pose risks, and these could become more likely or severe in the future. Pennsylvania has an opportunity to build on its existing hazard mitigation practices for these risks.
- For changes that will come on gradually, such as rising temperature, Pennsylvania has an opportunity not only to reduce potential harm, but also to capitalize on potential positive opportunities and conditions not previously present in Pennsylvania. This is particularly true for rising average temperature, which could enable the cultivation of warmer-weather crops, expand warm-weather recreation and tourism, and lower wintertime heating energy demand.

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

Key Potential Consequences from Increasing Average Temperatures

- Increase in health and safety risks such as more days with hazardous heat conditions for outdoor workers and reduced air quality from higher ground-level ozone and increased pollen
- Potential increased energy burden for low-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)

Key Potential Consequences from Heavy Precipitation and Flooding

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

Table 5 and Figure 28 summarize the overall risks at present and by 2050. **Increasing average temperatures** and **heavy precipitation and inland flooding** emerged as the two highest-risk hazards by mid-century. Both hazards could affect the entire state and all sectors. Increasing temperatures have the highest consequences for human health and environmental justice and equity, especially in urban areas. Heavy precipitation and flooding could also have severe consequences to human health, agriculture, and built infrastructure, with populations, farms, and infrastructure located in or near floodplains at particular risk.

Table 5. Overall risk assessment results

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

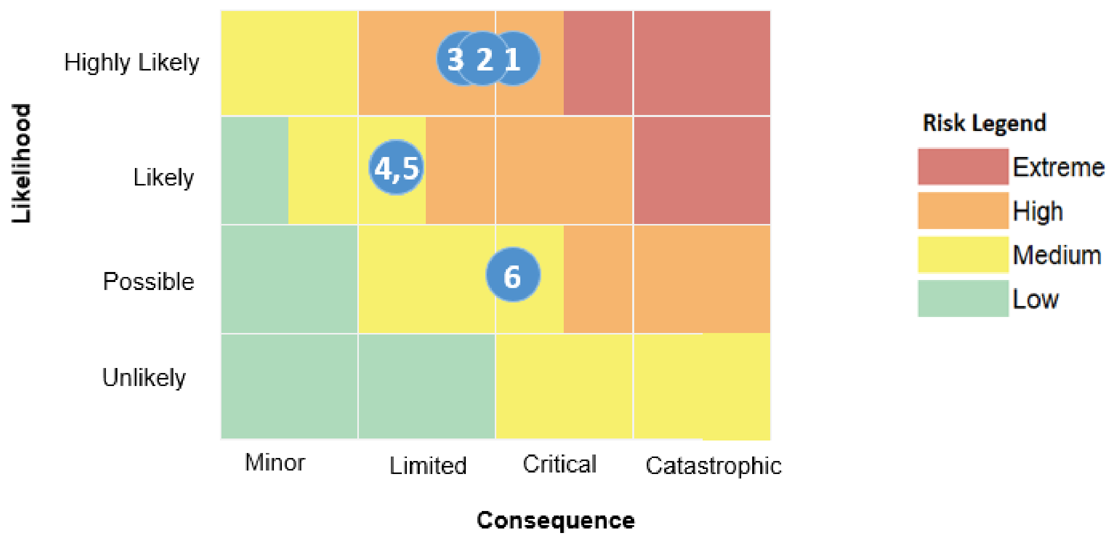

Figure 28. Overall summary risk matrix

1 = Increasing average temperatures, 2 = Heavy precipitation and inland flooding, 3 = Heat waves, 4 = Landslides, 5 = Sea level rise, 6 = Severe tropical and extra-tropical cyclones

Figure 29 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 severe tropical and extra-tropical cyclones had the most significant consequences overall. The black dot indicates the overall 2050 risk score, inclusive of both likelihood and consequence. For example, although severe tropical and extra-tropical cyclones had the most significant consequences, the event has a lower likelihood rating indicated by the overall score placement.

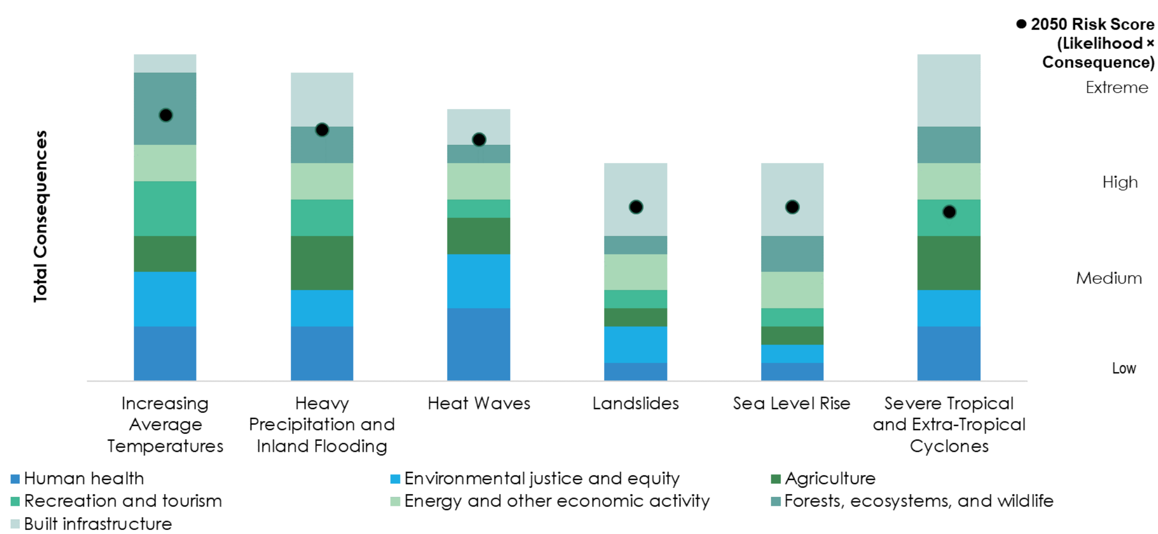

Figure 29. Total consequences and risks by hazard

Finally, Figure 30 illustrates the overall risk for each hazard and consequence category. Priority climate risks per consequence category can help identify adaptation priorities for the CAP per sector. The values represent the product of the 2050 likelihood rating and the individual consequence score, and reflect the key findings mentioned earlier.

	Human health	Environmental justice and equity	Agriculture	Recreation and tourism	Energy and other economic activity	Forests, ecosystems, and wildlife	Built infrastructure	Overall Risk Rating
Increasing average temperatures	12	12	8	12	8	16	4	10.7
Heavy precipitation and inland flooding	12	8	12	8	8	8	12	9.9
Heat waves	16	12	8	4	8	4	8	9.3
Landslides	3	6	3	3	6	3	12	5.6
Sea level rise	3	3	3	3	6	6	12	5.6
Severe tropical and extra-tropical cyclones	6	4	6	4	4	4	8	5.3

Figure 30. Overall summary risk matrix (2050 likelihood x individual consequences)

Impacts to human health are one of the greatest risks, especially related to extreme heat. Increasing average temperatures and heat waves are projected to increase heat-related illnesses or deaths, allergies, violence and crimes, and anxiety and mood disorders. Populations at greater risk from these heat-related hazards include the elderly, low-income communities, pregnant women, individuals with cardio-vascular disease, and outdoor workers. Flooding and severe cyclones can also have severe health impacts as critical services are disrupted and conditions are more hazardous. Figure 31 summarizes the health impacts of climate change.

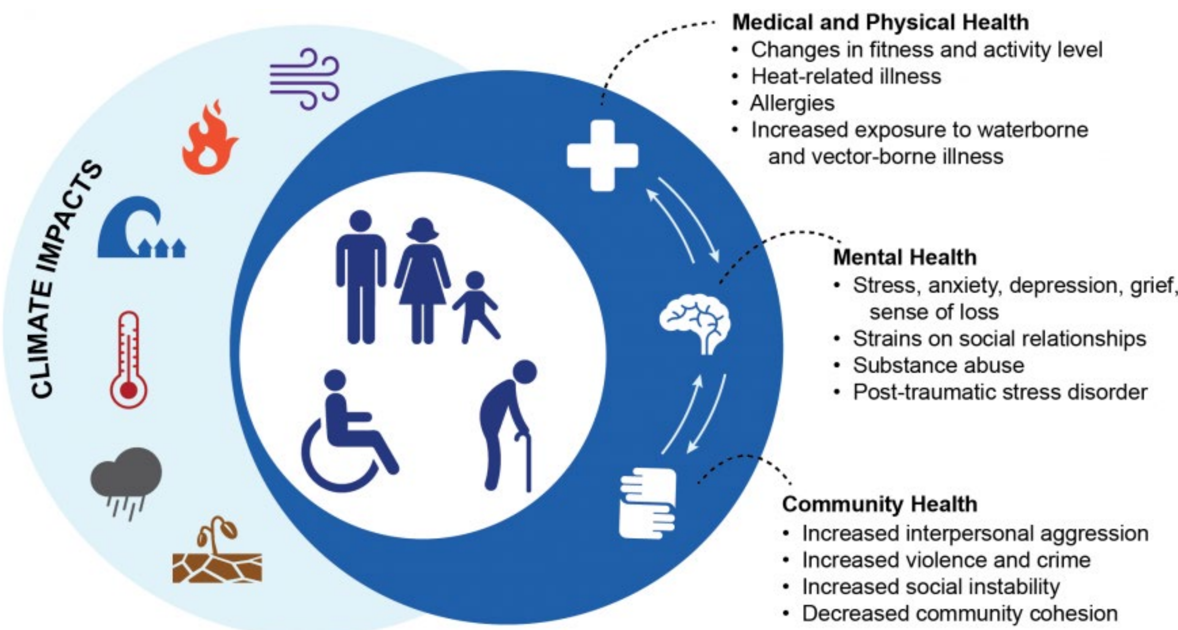

Figure 31. Impacts of climate change on physical, mental, and community health

Source: U.S. Global Change Research Program. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. https://health2016.globalchange.gov/

As reflected in Figure 30, consequence categories face significant and varying risks from different hazards. For example, forests, ecosystems, and wildlife face extreme risk from increasing temperatures but medium risk from heat waves. Ecosystems are generally more sensitive to long-term changes rather than short-term extreme events. On the other hand, the agricultural sector faces similar risks from increasing temperatures and heat waves. Livestock and crops are susceptible to heat stress from both increasing average temperatures, especially in the summer, and heat waves. For built infrastructure, landslides, sea level rise, and severe tropical and extra-tropical cyclones received catastrophic individual consequence ratings. However, the likelihood of these events differs. When factoring in likelihood, landslides, sea level rise, and heavy precipitation and flooding (which received a critical consequence rating) emerge as extreme risks to built infrastructure.

Risk summaries by hazard are presented in order from the highest to lowest overall risk:

- 4.1 Increasing Average Temperatures
- 4.2 Heavy Precipitation and Inland Flooding
- 4.3 Heat Waves
- 4.4 Landslides
- 4.5 Sea Level Rise
- 4.6 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. These summaries describe the risks to the Commonwealth from each climate hazard. While the likelihoods associated with climate hazards vary, the dangers posed by each are evident. To reduce these impacts on Pennsylvania, the Commonwealth must act to address priority adaptation needs.

4 RISK ASSESSMENT DETAILS

4.1 Increasing Average Temperatures

4.1.1 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 6 summarizes the likelihood and consequence ratings. Figure 32 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.

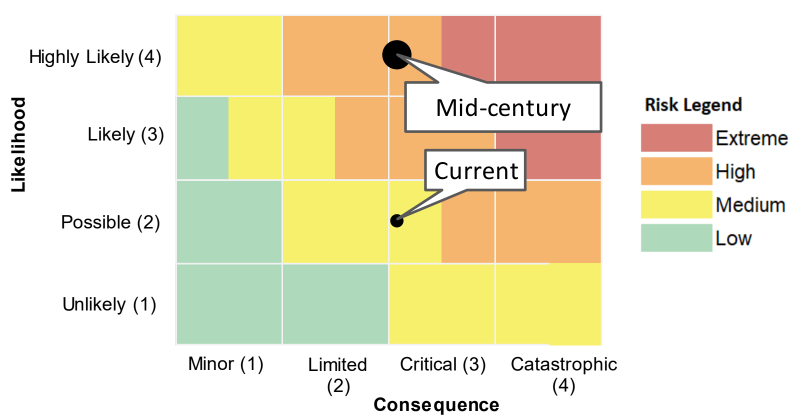

Figure 32. Increasing average temperatures risk matrix

Table 6. Increasing average temperature statewide risk summary

Timeframe or Sector	Rating	Justification Notes	Confidence	Differential Impacts
Likelihood (details in 4.1.2)				
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.
Mid-century	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.
Beyond 2050	N/A	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.	N/A	Same as above
Consequences (details in 4.1.3)				
Human health	3	Increased heat-related mortality Decreased cold-related mortality Increased prevalence of diseases (e.g., Lyme disease)	High	Vulnerable populations (e.g., the elderly, those with cardiovascular disease or respiratory conditions, outdoor workers, and populations with limited access to air conditioning) experience higher risk to heat-related illness and death.
Environmental justice and equity	3	EJ areas are approximately 1.8 times as exposed to high numbers of days >90°F than the state overall	High	See above.
Economy: Agriculture	2	Increased livestock heat stress Decreased dairy industry productivity Positive and negative impacts to crops	Medium	Animal husbandry is expected to face more severe impacts from increased temperatures than crops.
Economy: Recreation and tourism	3	Severe disruption to snow- and ice-based winter recreation and tourism	High	While winter recreation is expected to suffer, spring and fall recreation and summer water-based recreation may see increased demand.
Economy: Other	2	Increased energy demand Decreased timber supply due to forest die-back	Medium	

Timeframe or Sector	Rating	Justification Notes	Confidence	Differential Impacts
Forests, ecosystems, and wildlife	4	Local extirpation for certain species lacking suitable habitat Increase in pests and invasive species Decreased water quality	Medium	Species that require cooler climates are at greater risk than those suited to warmer climates. Specialist species with specific habitat requirements are also more vulnerable to habitat changes.
Built Infrastructure	1	Low infrastructure vulnerability Increased cooling demand More frequent mandatory capacity decreases Reduced efficiency of energy infrastructure	High	Managers should consider increased temperatures in planning and operations for built infrastructure that serves populations at greater risk to heat stress.
Overall Risk				
Current	5.3	Medium	High	
2050s	10.7	High	High	
Potential Opportunities				
▪ Use of biofuels to reduce reliance on fossil fuels poses an economic opportunity for the agricultural sector in Pennsylvania, with crops such as perennial shrub willow, perennial grasses, and annual sorghum and winter rye as potential biomass crop candidates ▪ Longer growing seasons and higher temperatures may provide opportunities to grow new, warmer-weather crops (e.g., soybeans, peaches) ▪ Increase in use of silvopasture for livestock operations, which reduces heat stress among other benefits ▪ Increase in participation in spring and fall recreation (e.g., biking, golfing) and summer water-based recreation ▪ Increase in suitable habitat for species at the northern extent of their range in Pennsylvania ▪ Decline in wintertime heating energy demand and costs				

4.1.2 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.[62] The National Climate Assessment gives very high confidence[63] to the statement that annual average temperature in the United States is

[62] 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.

[63] Very high confidence denotes "Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus."

projected to rise, and high confidence[64] to the statement that "recent record-setting years may be "common" in the next few decades."[65] 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 (highly likely).

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.

4.1.3 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 33 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 6.

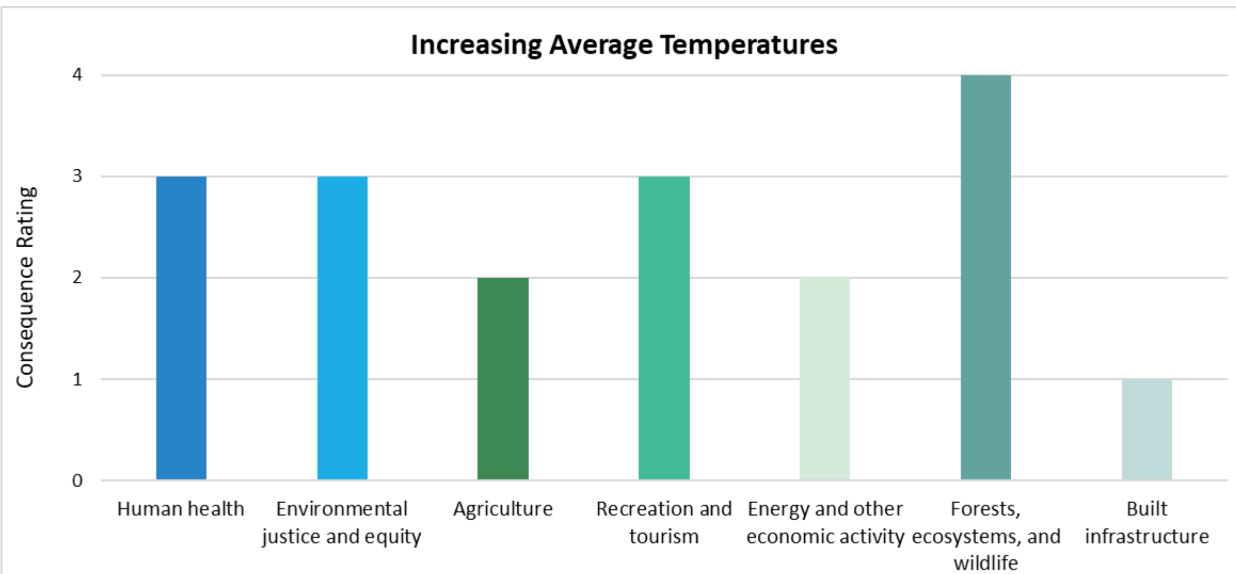

Figure 33. Increasing average temperatures consequences

Human Health

Rating: 3 out of 4 (Critical)

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

[64] High confidence denotes "Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus."

[65] 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.[66,67,68,69] Even small increases from seasonal average temperature can result in higher death rates.[70] Dramatic increases in the heat index in the Northeast[71] is also projected to make working, walking, and exercising outdoors more difficult certain times a year, and may create hazardous conditions for being outside.[72,73] However, the risk of mortality from extreme heat events has been decreasing, as more and more households install 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 also reduce air quality through increased ground-level ozone as well as increased allergen levels.[74] Higher temperatures can increase the rate at which ozone is formed and increase the prevalence of pollutants that act as precursors to ozone.[75] Warmer temperatures are also projected to raise pollen production, allergenicity, distribution, and seasonal timing. Combined, increased ground level ozone and allergens will decrease air quality. Poor air quality has been linked with medical emergencies, acute respiratory

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[66] 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

[67] 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/

[68] 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

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

[70] U.S. Global Change Research Program. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. https://health2016.globalchange.gov/

[71] The heat index is a measure of temperature and relative humidity. One study projected that days in which the heat index was especially dangerous are projected to quadruple in the Northeast. Dahl, K., et al., 2019. Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. In *Environmental Research Communications*. https://doi.org/10.1088/2515-7620/ab27cf

[72] Dahl, K., et al., 2019. Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. In *Environmental Research Communications*. https://doi.org/10.1088/2515-7620/ab27cf

[73] The National Weather Service issues heat advisories in Pennsylvania when the heat is 100–104°F. When the heat index reaches 100°F, the National Weather Service alerts individuals that prolonged exposure or strenuous activity is dangerous or extremely dangerous. National Weather Service. 2020. Heat. https://www.weather.gov/bgm/heat

[74] U. S. Global Change Research Program. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. Chapter 3: Air Quality Impacts. https://health2016.globalchange.gov/

[75] USGCRP. 2016. Impacts of Climate Change on Human Health in the United States.

symptoms, and premature deaths.[76] As shown in Figure 34, projected increases in ozone from climate-attributable temperature change are likely to contribute to an increase in premature deaths in Pennsylvania. Additionally, increased allergens will also lead to more individuals experiencing allergies.[77] Higher pollen production and longer pollen season could also increase asthma episodes.[78]

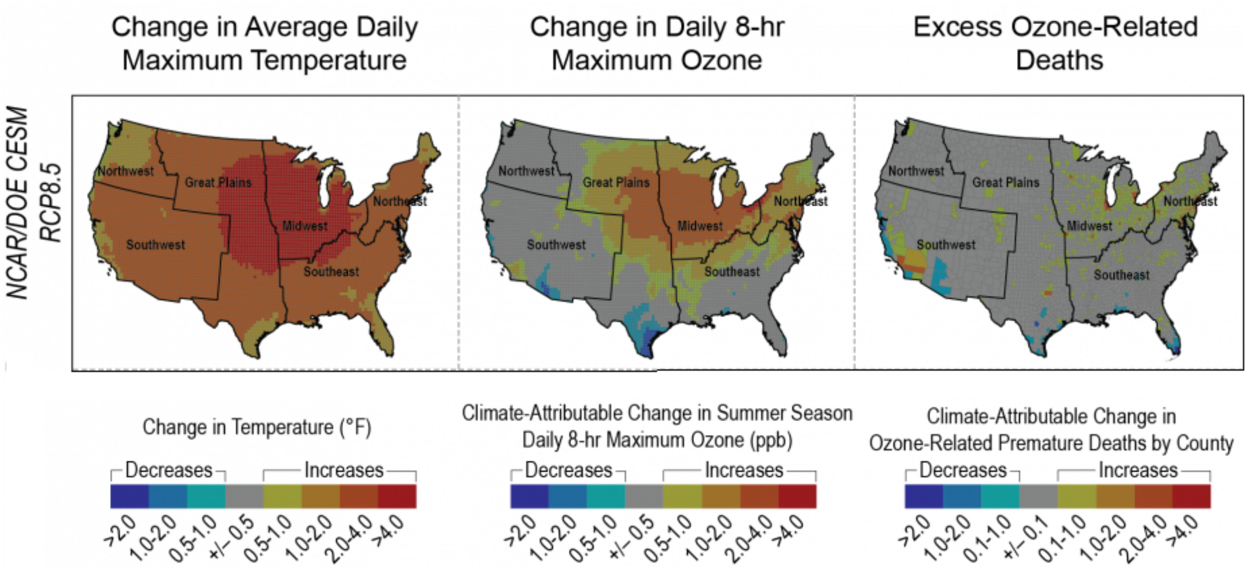

Figure 34. Projected premature deaths from changes in ozone

Projected change in average daily maximum temperature, daily 8-hour maximum ozone, and excess ozone-related premature deaths in the United states in 2030. RCP 8.5 and a downscaled global climate model projection was used. Blue circles highlight the Pennsylvania region.[79]

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.

Climate change also could affect the distribution and prevalence of vector-borne diseases (e.g., Lyme Disease and West Nile Virus) and air-borne infectious diseases. For example, warmer winters could increase the rates of Lyme disease. Already, Pennsylvania experiences the most Lyme diseases cases in the country as a result of increased winter temperatures and the westward expansion of tick populations that carry Lyme disease.[80] Higher temperatures could also lead to increases in the prevalence of mosquito-borne illnesses.[81] Warm summers and

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[76] USGCRP. 2016. Impacts of Climate Change on Human Health in the United States.
[77] USGCRP. 2016. Impacts of Climate Change on Human Health in the United States:
[78] USGCRP. 2016. Impacts of Climate Change on Human Health in the United States.
[79] USGCRP. 2016. Impacts of Climate Change on Human Health in the United States.
[80] Pennsylvania DEP. 2020. Climate Change in Pennsylvania.
http://www.depgis.state.pa.us/ClimateChange/index.html
[81] Pennsylvania DEP. 2020. Climate Change in Pennsylvania.

milder winters could lengthen the transmission seasons of these diseases. Finally, a more temperate Commonwealth may allow for greater movement of southern disease carrying species northward, like the lone star tick and the Asian tiger mosquito.[82]

Violence is also projected to increase as a result of climate change. Increased temperatures have a significant positive effect on criminal behavior.[83,84] Violent crimes are projected to increase as a result of warmer temperatures, including murder, rape, and aggravated assault.[85]

Human health impacts may be exacerbated in areas where populations experiencing heat-related impacts have less ability to adapt (e.g., low-income individuals that cannot afford air conditioning, or need to take public transportation or walk). Additionally, heat impacts may be more significant in certain urban areas. The urban heat island effect, which can raise local temperatures by 1-7°F and nighttime temperatures by 2-5°F, happens in areas with significant amounts of paved surfaces and buildings, which reflect heat, and low concentrations of greenery.[86] As a result, urban areas are projected to experience greater rates of mortality from heat events.[87]

Environmental Justice and Equity

Rating: 3 out of 4 (Critical)

Environmental Justice areas are more likely to experience highly frequent days > 90˚F compared to the state average. 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 areas are expected be nearly twice as exposed (1.8x) to those top-20% conditions compared to the Pennsylvania population as a whole. Although populations in EJ areas constitute less than a third of the statewide population, over half of all people in the state exposed to highly frequent heat days are members of EJ areas.

Figure 35 shows the number of days with temperatures >90˚F projected to occur across the state by mid-century, overlaid with state EJ areas. This indicator is useful for capturing the general areas where temperatures are projected to most frequently be very hot, and therefore where vulnerable populations may be most at risk. However, the indicator does not capture urban

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[82] Pennsylvania DEP. 2020. Climate Change in Pennsylvania.
[83] Ranson, M. 2014."Crime, weather, and climate change." In *Journal of Environmental Economics and Management, Volume 67, Issue 3.* p274-302. https://doi.org/10.1016/j.jeem.2013.11.008
[84] 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/
[85] Ranson, 2014; Heilmann, K., Kahn, M. 2019. "The Urban Crime and Heat Gradient in High and Low Poverty Areas." National Bureau of Economic Research. https://www1050.nber.org/papers/w25961.ack.
[86] U.S. Environmental Protection Agency (EPA). 2020. Heat Island Effect. Web. https://www.epa.gov/heatislands
[87] Wu, J. et al. 2014. Estimation and uncertainty analysis of impacts of future heat waves on mortality in the eastern United States. *Environmental Health Perspectives.*122:10–16. https://ehp.niehs.nih.gov/doi/full/10.1289/ehp.1306670

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[88] that can otherwise absorb heat and provide shade; as such, this map may underestimate the high-heat risks in certain vulnerable areas.

Projected Number of Days >90˚F in Mid-Century (2041-2070), with EJ Block Groups

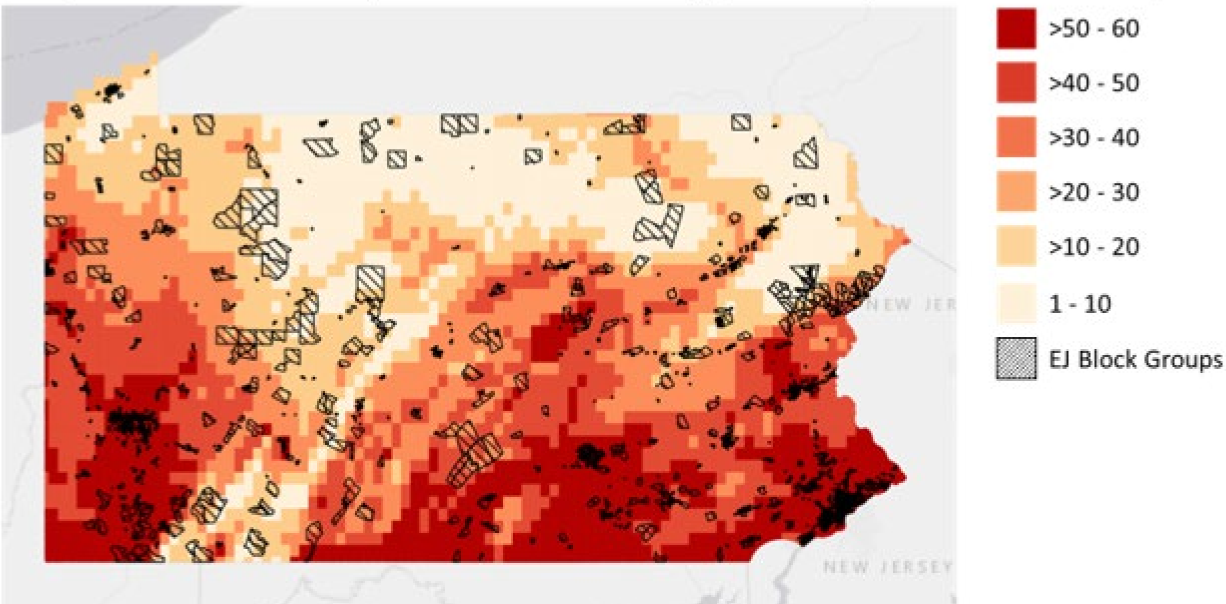

Figure 35. Projected annual number of days with temperatures over 90°F in 2050, with EJ block groups

Population data source: https://www.census.gov/data/developers/data-sets/acs-5year.html.

Risks of heat-related illness and mortality will increase with warmer average temperatures. Populations most at risk will likely be those that disproportionately lack access to the key methods of adapting to this risk – such as using air conditioning indoors (cost 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).[89]

A City of Philadelphia heat report found that average surface temperatures are up to 22°F hotter in some neighborhoods than others. Low income and minority residents are more likely to live in these neighborhoods.[90] The expected causes of hotter surface temperatures are limited

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[88] 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

[89] 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

[90] City of Philadelphia. 2019. Beat the Heat Hunting Park: A Community Heat Relief Plan.

green space and tree canopy, more exposed dark surfaces (e.g., asphalt), and aging housing stock due to a history of redlining and disinvestment. Residents interviewed for the study also indicated limited access and awareness of City cooling centers and a need for better air conditioning and fans at home to stay cool.

Economy

Agriculture

Rating: 2 out of 4 (Limited)

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). For example, soybean crops are expected to experience increased yields due to longer frost-free and growing seasons and higher concentrations of atmospheric carbon dioxide.[91] Other crops such as peaches, could also see an expansion in growing season and yield; Pennsylvania's current peach production has a value of approximately $20 million annually.[92] However, corn, which is Pennsylvania's crop with the highest agricultural sales, is projected to experience decreased yields due to hotter summers. Increased temperatures are also projected to harm corn crops by allowing pests such as corn earworm to increase their populations.[93]

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.

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 reduce heat stress, and lower-quality forage material.[94] However, poultry farms are expected to double in size by 2050 as Pennsylvania becomes a better alternative to the climate of southern states.[95]

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.[96]

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[91] 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

[92] Penn State Extension. 2017. Peach Production. https://www.fishandboat.com/Fish/Stocking/Pages/default.aspx

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

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

[95] DEP. 2020 IA.

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

Recreation and tourism

Rating: 3 out of 4 (Critical)

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%.

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.[97] 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. Cold-water fishing (e.g., trout) may no longer be supported. This impact could be particularly severe in southeastern and northwestern Pennsylvania. However, the Pennsylvania Fish and Boat Commission conducts an extensive annual trout stocking program that may help support trout populations under changing conditions.[98]

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

Energy and other economic activity

Rating: 2 out of 4 (Limited)

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.[99] Example economic impacts of increasing average temperatures are described in Exhibit 1.

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97 DEP. 2015 IA.

98 Pennsylvania Fish and Boat Commission. 2020. Fish Stocking. https://www.fishandboat.com/Fish/Stocking/Pages/default.aspx

99 Pennsylvania Department of Agriculture. 2020. State of the Forest Products Industry in Pennsylvania.

Exhibit 1. Example of 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.[100]

Agricultural Impacts

The agricultural industry in Pennsylvania generates approximately $135.7 billion in total economic impact each year and supports 579,000 jobs.[101]

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.[102]

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.[103]

About 58% of Pennsylvania is covered by forests, which face challenges from invasive species and disease.[104] As average temperature increases, the mix of tree species within forests may also change, opening 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.[105]

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.[106]

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),[107] however lake effect snowfall in north western PA is likely to increase.[108] 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.

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[100] NOAA National Center for Environmental Information, n.d. State Climate Summaries: Pennsylvania. Retrieved from: https://statesummaries.ncics.org/chapter/pa/

[101] 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

[104] PennState Extension, 2019. Forest Management and Timber Harvesting in Pennsylvania. Retrieved from: https://extension.psu.edu/forest-management-and-timber-harvesting-in-pennsylvania

[105] 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

[106] 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

[107] 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

Forest, ecosystems, and wildlife

Rating: 4 out of 4 (Catastrophic)

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).[109,110] Additionally, longer growing seasons and higher temperatures, among other climate-related factors, may increase overall forest growth rates; however, this may be offset by increased mortality in stressed forest species.

Some plant and animal species will experience increased stress due to changes such as decreases in suitable habitat area and habitat fragmentation, increases in the prevalence of pests and invasive species, and disruptions to the timing of natural cycles such as migration, emergence from dormancy or hibernation, and leaf development and blooming.[111] 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.[112]

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

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[106] 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

[107] 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

[108] 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

[109] PSU. 2015 IA.

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

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

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

of the ecosystem. To date, harmful algal blooms have been most prevalent and harmful in the western basin of Lake Erie but could become more common along the Pennsylvania coastline of Lake Erie and in other shallow lakes and reservoirs as temperatures warm.

Built infrastructure

Rating: 1 out of 4 (Minor)

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.[113]

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.[114] Extreme heat will also reduce efficiency of energy generation in solar PV panels, especially when temperatures exceed 77°F.[115],[116] However, rooftop solar can reduce the cooling energy needs of buildings and help reduce peak demand.[117]

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

4.2 Heavy Precipitation and Inland Flooding

4.2.1 Overview

Flood events are recognized as the costliest weather hazards in Pennsylvania.[118] From 1996 to 2018, flooding caused approximately $1.025 Billion in property damage, 31 fatalities, and 107 injuries. In addition, flash flooding specifically 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, and caused 12% and 7% respectively of all fatalities and injuries related to weather events.[119]

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

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

[115] 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/

[116] 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

[117] 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

[118] DEP. 2020 IA.

[119] DEP. 2020 IA.

In Pennsylvania's 2018 Hazard Mitigation Plan, the "flood, flash flood, and ice jam" hazard – which considers multiple types of flooding including 1%- and 0.2%-annual chance floodplain risks – received the highest risk factor ranking of all hazards assessed.[120]

Costs associated with infrastructure damage and increased risks to agricultural production and human health are particularly significant.[121] Figure 36 illustrates the overall risk rating from present-day to 2050 based on the likelihood and consequence ratings. Table 7 summarizes the statewide likelihood and consequences of heavy precipitation and inland flooding in Pennsylvania.

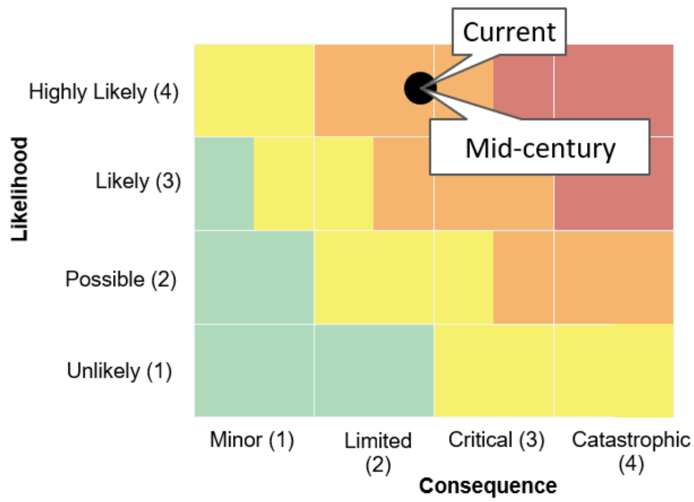

Figure 36. Heavy precipitation and inland flooding risk matrix

Table 7. Heavy precipitation and inland flooding statewide risk summary

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood				
Current	4	There are 24 counties that regularly experience one flood event per year.	High	Areas in FEMA 100- and 500-year floodplains or adjacent to water bodies or areas with high urban stormwater runoff may be most at risk.
Mid-century	4	Precipitation variability and flooding, including occurrence of heavy precipitation events and associated inland flooding impacts, are projected to increase by mid-century due to climate change. This may	Medium	Same as current differential impacts.

[120] PEMA. 2018. "Risk Assessment."
[121] DEP. 2020 IA.

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
		increase the frequency and severity of floods.		
Beyond 2050	N/A	Precipitation changes are expected to continue well beyond mid-century.	N/A	
Consequences				
Human health	3	Risk of direct injury from flood waters or health impacts from water quality contamination	High	Certain populations may be disproportionately exposed to and have greater barriers to managing flood impacts. For example, homeless and low-income individuals, people who work outside (e.g., agricultural or construction sector), and communities of color that have historically been disinvested in (e.g., older infrastructure) may be more at risk to impacts.
Environmental justice and equity	2	EJ areas slightly overrepresented in high-risk floodplains compared to the state overall	Medium	Vulnerable populations may face greater challenges in managing flood impacts. Also see above.
Economy: Agriculture	3	Increased runoff, erosion, and nutrient leaching Greater challenges in timing of crop planting	High	See above
Economy: Recreation and tourism	2	State parks and forests have experienced significant impacts from flooding and heavy precipitation events (e.g., closure, infrastructure damages, decreased water quality)	Medium	See above
Economy: Other	2	Significant damage to infrastructure, with broad downstream economic impacts Represents the most expensive weather hazard in the state	Medium	See above
Forests, ecosystems, and wildlife	2	Increased hydrological variability may impact wetland and stream ecosystems Increased pathogen loads and eutrophication and algal bloom risks	High	See above
Built Infrastructure	3	Increasing risk of flood damages to homes, small businesses, and major	High	See above

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
		energy and transportation assets Infrastructure in floodplains is particularly at risk		
Overall Risk				
Current	9.9	High risk	High	
2050s	9.9	High risk	Medium	
Potential Opportunities				
▪ Invest in more agricultural best management practices to reduce the shock of acute storm events.[122] ▪ Invest in healthy soils in agricultural land. One percent of organic matter in the top 6 inches of soil would hold approximately 27,000 gallons of water per acre.[123]				

4.2.2 Likelihood

Data on past events indicates that from 1950 to 2017, 24 counties experienced, on average, at least one flood event per year ("flood event" as defined by NOAA/NCEI), and disaster declarations in the state caused by flood events outnumbered those caused by other hazards.[124] And from 1955 to 2018, of the 60 Presidential Disaster and Emergency Declarations that affected the Commonwealth, 26 (43%) were flood events.[125] These flood events have occurred across the state, including in, though not limited to, areas defined as FEMA floodplains (see Figure 37).

Occurrence of heavy precipitation events and associated inland flooding impacts is projected to 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.[126]

Averages of statewide observed and projected precipitation data demonstrate this statewide trend of increased variability (more local information would be needed for local-level nuance).

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[122] DEP. 2020 IA.

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

[124] PEMA. 2018. "Risk Assessment."

[125] PEMA. 2018. "Risk Assessment."

[126] DEP. 2020 IA.

Mid-century (2041–2070) modeled conditions are compared to baseline observed data (1971–2000).

- By mid-century, the number of days with more rainfall than currently occurs on "very heavy" (95th percentile) rainfall days is projected to increase 24%, from 12 days to 15 days. The amount of precipitation falling on those days is also projected to increase 12%.
- 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.
- Notably, these numbers speak to events that all happen relatively infrequently but are projected to occur more often in the future.

This Assessment evaluates likelihood of damaging flood events, which are already occurring regularly and incurring significant damages, as detailed in the 2020 Impacts Assessment and 2018 Hazard Mitigation Plan. Notably, as more intense precipitation events become more common, the occurrence of extreme flood events – such as today's 1% annual chance floods (or 1-in-100-year floods) and 0.2% annual chance floods (or 1-in-500-year floods) – may as well. Due to uncertainty around localized projections of future intense precipitation conditions, the likelihood of specific types of future flood events (e.g., 1-in-500 year floods) occurring is difficult to quantify; nonetheless, projections of increased occurrence of intense precipitation events by end-of-century suggest associated intense flood events will likely increase as well. Decision makers will need to work with assumptions of deep uncertainty to manage potential increases in extreme flood events. Overall, the likelihood of Pennsylvania experiencing heavy precipitation and inland flooding is rated at 4 out of 4 (highly likely) both currently and in mid-century.

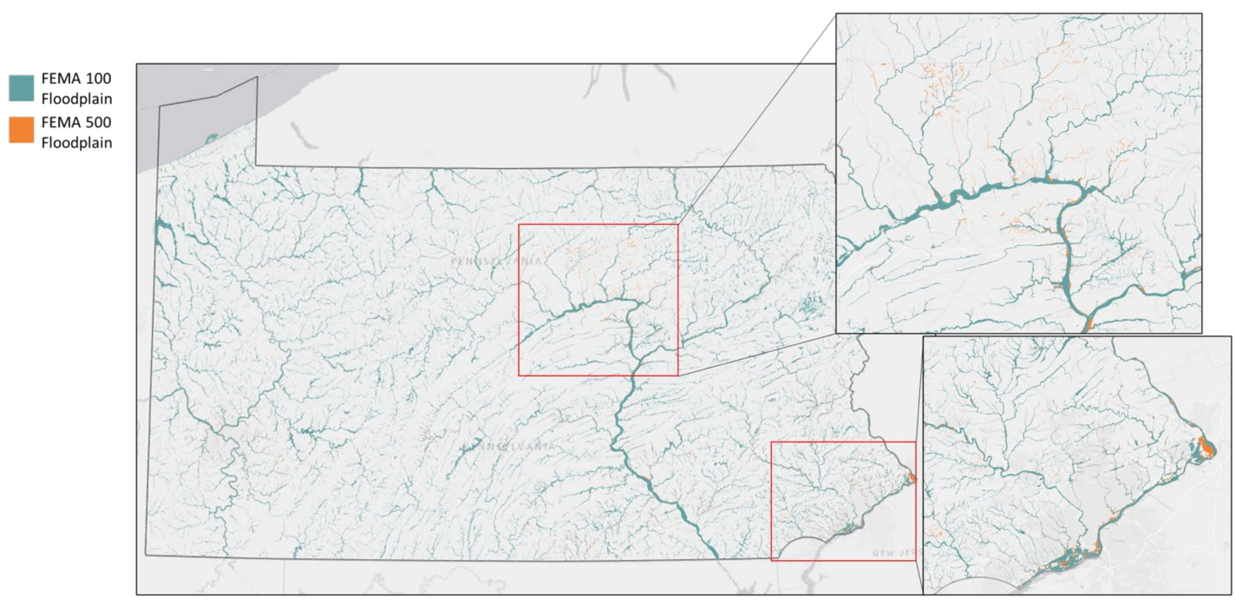

Figure 37. FEMA 100- and 500-year floodplains in Pennsylvania

Data source: FEMA

4.2.3 Consequences

Flood events are recognized as the costliest weather hazards in Pennsylvania. As shown in Figure 38, increased risks to human health and agricultural production and costs associated with infrastructure damage are particularly significant.[127]

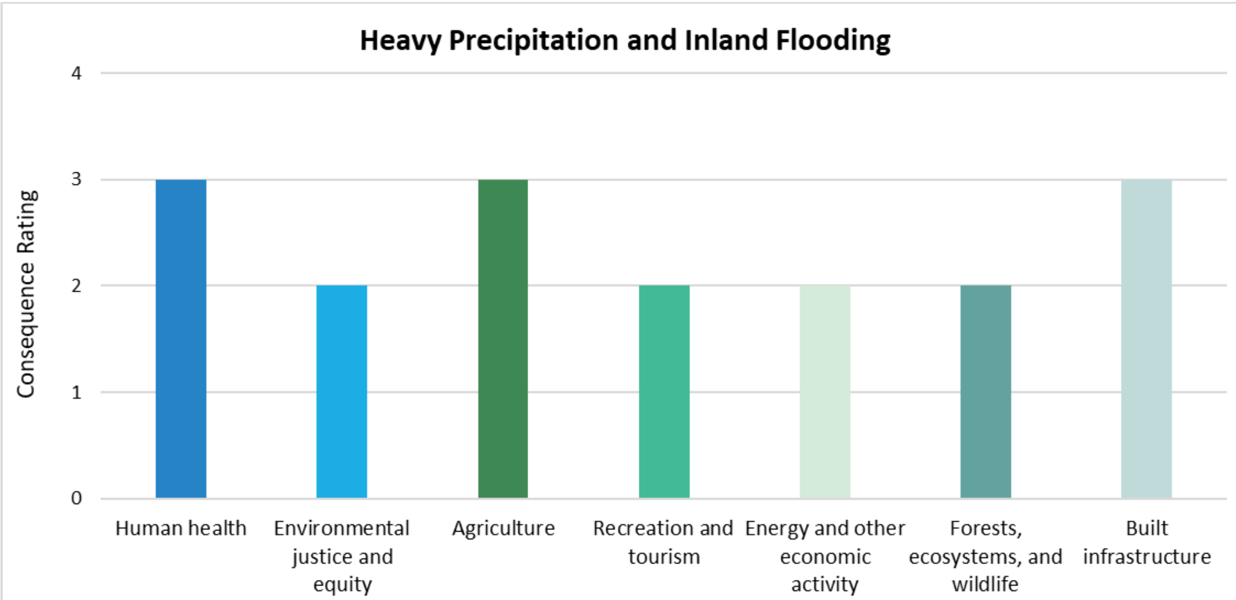

Figure 38. Consequences of heavy precipitation and inland flooding

Human Health

Rating: 3 out of 4 (Critical)

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

In the historical context, Pennsylvania has experienced extreme floods frequently, and the deadliest among those events have been caused by extreme precipitation.[128] Heavy precipitation can result in hazardous road conditions and reduced visibility, which can cause automobile accidents.[129] Data on births that occurred under flood conditions indicates flood exposure has been linked to hazardous birthing outcomes.[130] For events between 1959 and 2005, "Pennsylvania ranked 2nd, 10th, and 14th in the U.S. in the frequency of flash flood-related

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[127] PSU. 2020 IA.

[128] PSU. 2020 IA.

[129] Bell, J et al., 2016. Ch. 4: Impacts of Extreme Events on Human Health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program. 99–128. http://dx.doi.org/10.7930/J0BZ63ZV

[130] Tong, V. T., M. E. Zotti, and J. Hsia. 2011. Impact of the Red River catastrophic flood on women giving birth in North Dakota, 1994–2000. Maternal and Child Health Journal, 15, 281-288. doi:10.1007/s10995-010-0576-9; Xiong, X. et al., 2008. Exposure to Hurricane Katrina, post-traumatic stress disorder and birth outcomes. The American Journal of the Medical Sciences, 336, 111-115. doi:10.1097/MAJ.0b013e318180f21c.

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.[131] Tropical Storm Lee in 2011 led to 7 flooding-related deaths in the state and forced thousands of residents to evacuate, and the next year, Superstorm Sandy caused 14 fatalities in the state and left over 1.3 million residents without power across the Commonwealth.[132] More recently, two fatalities were attributed to heavy flooding events in 2018[133] and three were attributed to flash floods in 2019.[134]

Climate change can also potentially worsen water quality through a combination of weather changes and pollutant emissions; lower water quality may affect health through contact during outdoor recreation, or if drinking water is affected. Individuals who consume contaminated water may experience gastrointestinal illnesses.[135] Post flood-event health consequences may include physical safety risks related to standing flood water or limited access to critical services (e.g., due to transportation damages),[136] respiratory risks related to reduced indoor air quality (e.g., because of mold),[137] and mental health impacts.[138]

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.[139] Flooding of agricultural lands could spread contaminants from animal waste.

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[131] PSU. 2020 IA.

[132] Lee, Rick. March 20, 2018. "Death and destruction: These are the worst central Pa. weather-related disasters." *York Daily Record*. https://www.ydr.com/story/news/2018/03/20/death-and-destruction-these-worst-central-pa-weather-related-disasters/423430002/

[133] AP News. July 27, 2018. "Death toll in Pennsylvania floods hits 2 after body found." https://apnews.com/article/f5da832cafe14d99b16736713bdd5cd3

[134] Gambardello, Joseph A. July 12, 2019. "Drenching storms blamed for 3 deaths in Southeast Pa., tornado in South Jersey." *The Philadelphia Inquirer*. https://www.inquirer.com/news/pregnant-woman-8-year-old-son-killed-flooding-berks-county-pennsylvania-20190712.html

[135] Lane, K. et al., 2013. Health effects of coastal storms and flooding in urban areas: A review and vulnerability assessment. Journal of Environmental and Public Health. http://dx.doi.org/10.1155/2013/913064

[136] FEMA. N.d. "Critical Facilities and Higher Standards." https://www.fema.gov/media-library-data/1436818953164-4f8f6fc191d26a924f67911c5eaa6848/FPM_1_Page_CriticalFacilities.pdf; Ready.gov. 2020. "Floods." https://www.ready.gov/floods

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

[138] 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.

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

Environmental Justice and Equity

Rating: 2 out of 4 (Limited)

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

Nearly 5.5% of Pennsylvania land and 6.5% of Pennsylvania EJ areas are located in FEMA 100-year floodplains. Additionally, 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).

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

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

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

Riverine and coastal flooding challenges are likely to be exacerbated by existing underinvestment in stormwater management or flood protection infrastructure[140] – a cycle that

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[140] 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/

may leave poorest populations in most at-risk locations due to financial obstacles to leaving for higher ground.

Many factors can increase peoples' vulnerability to flood risk, such as:[141]

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

A range of flood consequences may be related to those indicators – such as impacts to employment (e.g., if someone's business is closed), food security (e.g., if crops are lost due to flooding), housing (e.g., if someone's home is damaged by flooding), emergency management (e.g., language and platform accessibility of communications), or access to services (e.g., education, healthcare, emergency management).[142]

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.[143] 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

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[141] 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
[142] NAACP. 2016. "Equity in Building Resilience in Adaptation Planning."
[143] 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

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".[144]

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.[145] Additionally, projects in three low-income neighborhoods—within 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.[146]

Economy

Agriculture

Rating: 3 out of 4 (Critical)

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 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.

Pennsylvania experienced prolific, statewide crop damage due to 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% 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.[147] The extended rainfall had a variety of

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[144] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning."
[145] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning."
[146] Chesapeake Bay Foundation. 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
[147] Pennsylvania Department of Agriculture. 2018. Letter to USDA Secretary Perdue, Dec. 3 2018, requesting a statewide disaster designation due to weather damages statewide.

other impacts as well; for example, severe flooding in July 2018 triggered a USDA disaster declaration for 33 Pennsylvania counties.[148]

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. Crops commonly used for biofuels such as miscanthus, shrub willow and switchgrass may benefit from warmer and wetter spring conditions, and can serve as natural riparian buffers for sensitive parts of the landscape.

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

Costs associated with crop impacts from flooding and heavy precipitation are significant. The agricultural sub-sector of crop and animal production generated about $9.2 Billion USD; this figure represents approximately 10% of the total economic output from the agricultural sector, and the crop and animal production sub-sector also provides about 29% of the total direct employment in the agricultural sector.[149]

Recreation and Tourism

Rating: 2 out of 4 (Limited)

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

- Heavy precipitation in December 2020, falling as rain due to high temperatures, caused flooding and fast river currents in the Delaware River corridor, leading the National Park

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[148] 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

[149] 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

Service to close travel on and access to the river in the Delaware Water Gap National Recreation Area.[150]

- An extended period of heavy precipitation in July 2018 forced multiple state parks as well as Hersheypark and Knoebels Amusement Park to close for several days due to flooding.[151]
- In August 2013, intense storms in Southwestern Pennsylvania led to flooding that forced a variety of recreation areas including boat launches, beaches, and campgrounds to close; many of the closures restricted recreation spaces over the Labor Day holiday.[152]
- "Torrential" rains and flooding in eastern and central Pennsylvania from Tropical Storm Lee (September 2011) forced closures of several recreation areas including Worlds End State Park, Bald Eagle State Park, and parts of the Canal Towpath, and eight other state parks reported damage from the storm (much of it due to flooding). Several of these areas had also been impacted by flooding in January 2010.[153]

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.[154]

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).[155]

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.[156] 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.[157]

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[150] Pierce, P. 2013. "Flooding closes recreation areas as holiday weekend under way." https://archive.triblive.com/local/westmoreland/flooding-closes-recreation-areas-as-holiday-weekend-under-way/

[151] Schneck, Marcus. January 30, 2019. "Flooding damage minor in Pennsylvania's state parks and forests." *PennLive.* https://www.pennlive.com/wildaboutpa/2018/07/flooding_damage_minor_in_penns.html; The Associated Press. July 28, 2018. "5 days of heavy rain bring flood waters, prompt evacuations." *Herald Mail Media.* https://www.heraldmailmedia.com/news/tri_state/pennsylvania/5-days-of-heavy-rain-bring-flood-waters-prompt-evacuations/article_59671c28-9003-11e8-b1c1-072ffaf1adfb.html

[152] Pierce, P. 2013. "Flooding closes recreation areas as holiday weekend under way." https://archive.triblive.com/local/westmoreland/flooding-closes-recreation-areas-as-holiday-weekend-under-way/

[153] Pennsylvania DCNR. 2014. "Tropical Storm Lee leaves state parks awash in central, eastern Pa. http://www.apps.dcnr.state.pa.us/news/resource/res2011/11-0914-spdamagelee.aspx

[154] PSU. 2015 IA.

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

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

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

Energy and Other Economic Activity

Rating: 2 out of 4 (Limited)

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.[158] Depending on the region and asset(s) impacted, consequences may vary significantly. Example economic impacts of flooding are described in **Error! Reference source not found.**.[159]

[158] DEP. 2020 IA.

[159] Post-Gazette.com. 2019. For farmers in Pa. and beyond, heavy rain has turned planting into erratic waiting game. June 1, 2019. https://www.post-gazette.com/business/pittsburgh-company-news/2019/06/01/As-rains-thrash-the-Midwest-AccuWeather-lowers-expectations-for-corn-and-soybeans/stories/201906010024

Exhibit 2. Example of economic impacts of flooding

Pennsylvania is one of the most flood-prone states, with an estimated 86,000 miles of streams and rivers, the most in the continental U.S. 2018 was Pennsylvania's wettest year on record with 63.97 inches of annual rainfall.[160,161]

Flooding along Rivers

From 1958 to 2012, Pennsylvania saw a 71% increase in the amount of precipitation falling during very heavy (defined as the heaviest 1%) rainfall events.[162]

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 which the governor requested for disaster relief in 16 counties.[163]

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.[164,165,166,167]

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.[168]

Rural Impacts

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

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.[169]

Heavy rain and flooding in 2019 negatively impacted PA farmers' corn and soybean crops as 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.[170,171, 172]

Forest, Ecosystems, and Wildlife

Rating: 2 out of 4 (Limited)

More intense rainfall projections are already beginning to manifest in Pennsylvania. More extreme streamflow associated with intense rainfall is already occurring across much of the state, except for the Southwest quadrant. In 2018, Pennsylvania experienced its wettest year on

[160] Fowler et al. 2018. Flood Mitigation for Pennsylvania's Rural Communities: Community-Scale Impact of Federal Policies. https://www.rural.palegislature.us/documents/reports/Flood-Mitigation-2017.pdf

[161] 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

[162] Melillo, Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

[163] 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

[164] PennDOT. 2018. PennDOT Estimates over $105M in Flood, Slide Damages. https://www.penndot.gov/PennDOTWay/Pages/Article.aspx?post=165

[168] Pennsylvania Department of Environmental Protection. N.d. Climate Change in PA. Retrieved from: https://www.depgis.state.pa.us/ClimateChange/index.html

[169] Fowler et al. 2018. Flood Mitigation for Pennsylvania's Rural Communities

record, and flash flooding across the state. This risk is projected to continue to increase under climate change, and bank erosion is therefore expected to become an increasingly large concern for the state. More broadly, greater hydrological variability, including more intense and less predictable floods and extreme streamflow, could have significant long-term impacts on wetland and stream communities.[173]

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).[174]

Hydraulic fracturing or "fracking" is currently underway in many parts of Pennsylvania, particularly in southwest and northeast Pennsylvania in the Marcellus Shale.[175] Laws such as Act 13[176] govern safe management of potentially toxic spills and runoff from fracking operations that can occur with heavy flooding.[177] Additionally, there are municipal waste landfills and

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167 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

168 Pennsylvania Department of Environmental Protection. N.d. Climate Change in PA. Retrieved from: https://www.depgis.state.pa.us/ClimateChange/index.html

169 Fowler et al. 2018. Flood Mitigation for Pennsylvania's Rural Communities

170 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

171 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

172 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

173 PSU. 2015 IA.

174 PSU. 2015 IA; DEP. 2020 IA.

175 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/*

176 DEP. 2020. "Act 13 Frequently Asked Questions." https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/Act13/Pages/Act-13-FAQ.aspx

177 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

other waste facilities located across Pennsylvania,[178] 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.[179]

Built Infrastructure

Rating: 3 out of 4 (Critical)

The greatest impacts that flooding is expected to have in Pennsylvania are on infrastructure systems. Flood-related damages are likely to be localized but intense (e.g., flooding alone may cause a local blackout but is unlikely to bring down a full regional power grid). However, if key infrastructure is damaged that may have broader downstream effects (e.g., damage to transportation infrastructure could lead to broader disruptions to the economy). Costs related to these damages are significant; for example, FEMA paid $953 million to National Flood Insurance Program (NFIP) policyholders in Pennsylvania between 1975 and 2019. NFIP insurance is available to businesses and property owners and renters; in high flood-risk areas, businesses and homes must have flood insurance if they have mortgages from government-backed lenders.[180]

Both rural and urban infrastructure face significant increasing flooding risk, though likely with differential risks and vulnerabilities across regions and demographics. For example, an evaluation of per capita property losses due to flooding found many of the higher losses were experienced in rural counties in Pennsylvania.[181]

Infrastructure at greatest risk of flooding are structures located in flood zones, though structures not in flood zones (e.g., underground pipelines) may be at significant risk as well. Significant portions of transportation and energy infrastructure in Pennsylvania may be susceptible to direct flooding damage, especially in the Southwestern region where heavy precipitation events may bring compounding flood and landslide risks. For example,

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[178] 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

[179] 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*

[180] FEMA. 2020. "Flood Insurance." https://www.fema.gov/flood-insurance

[181] DEP. 2020 IA.

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). For example, a pipeline ruptured from flooding in Lycoming County in 2016, spilling an estimated 55,000 gallons of gasoline.[182] 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.[183]

Greater frequency and intensity of intense rainfall events will also challenge urban stormwater and wastewater management systems, which could lead to combined outflows detrimental to water quality. Stormwater retrofits may be somewhat adapted to reduce or withstand impacts to some extent, and nature-based solutions may also increase adaptive capacity (this strategy is currently being implemented in Philadelphia, for example).[184]

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 prevent sewage release events and manage higher flow amounts.[185]

Additionally, a potential increase in area located in the 1% annual chance floodplain by end-of-century would put significantly more infrastructure at risk to flood impacts. A comparison of the number of state-owned or leased facilities located in the current 1% annual chance floodplain to the number located in the projected end-of-century floodplain in Delaware, Allegheny, and Lycoming counties highlights this risk. The comparison identified a nearly 500% increase in the number of vulnerable structures, with replacement value of structures in the future floodplain over $92 Billion.[186]

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.[187]

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[182] Phillips, Susan. 2016. "Sunoco gas pipeline ruptures in Lycoming County." https://stateimpact.npr.org/pennsylvania/2016/10/21/sunoco-gas-pipeline-ruptures-in-lycoming-county/#:~:text=Heavy%20rains%20brought%20flash%20floods%20to%20Lycoming%20County%2C,55%2C000%20gallons%20of%20gasoline%20into%20Wallis%20Run%20creek.

[183] DEP. 2020 IA.

[184] 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/

[185] DEP. 2020 IA.

[186] PEMA. 2018. "Risk Assessment."

[187] Pennsylvania Office of Water Programs. November 2020. Department staff expertise.

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.

4.3 Heat Waves

4.3.1 Overview

Heat waves will increase from a medium to a high risk by mid-century. Table 8 summarizes the likelihood and consequence ratings. Figure 39 illustrates the change in overall risk rating from present-day to 2050 based on the likelihood and consequence ratings.

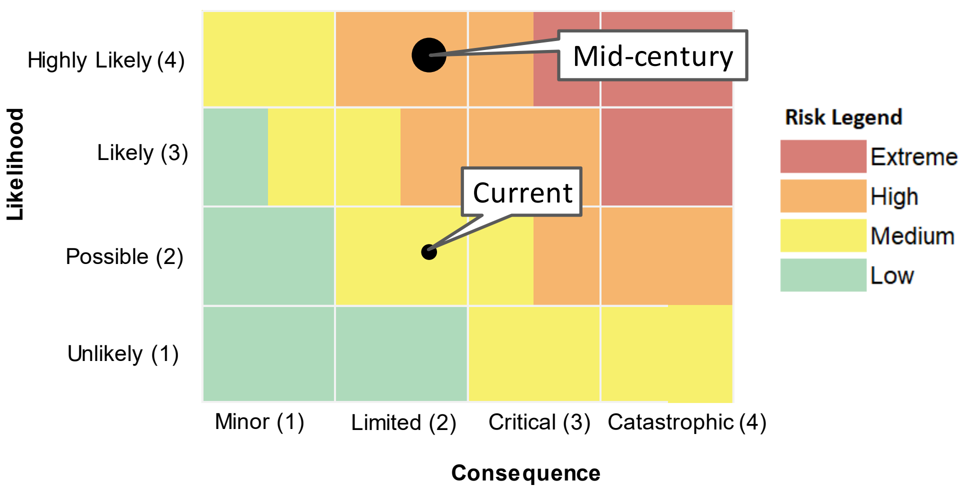

Figure 39. Heat waves risk matrix

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.

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

Table 8. Heat waves statewide risk summary

Timeframe or Category	Rating	Notes	Confidence	Differential Impacts
Likelihood (details in 4.3.2)				
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
Mid-century	4	By mid-century, Pennsylvania is expected to experience over 35 "extremely hot" days per year.	High	Southwestern PA will experience more days with high temperatures than other regions of the state
Beyond 2050	N/A	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	N/A	
Consequences (details in 4.3.3)				
Human health	4	Increased heat-related mortality and morbidity	High	The elderly, those with cardiovascular disease, those with certain mental health illnesses, outdoor workers, pregnant women, and populations with limited access to air conditioning experience higher risk to heat-related illness and death.
Environmental justice and equity	3	EJ areas are projected to experience a disproportionate increase in exposure to heat stress compared to the state overall	Medium	Lower-income populations have higher vulnerability to heat stress and less access to adaptive measures such as natural infrastructure (e.g., shade trees around a home), good insulation, and air conditioning. More broadly, vulnerable populations include those with: outdoor jobs, housing with less insulation/ access to natural infrastructure/ air conditioning, decreased access to quality healthcare, and populations living in densely populated urban areas experiencing urban heat island effects
Economy: Agriculture	2	Decreased production (e.g., of milk) Animal illness/death	Medium	

Timeframe or Category	Rating	Notes	Confidence	Differential Impacts
		Decreased crop yields		
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				
Current	4.7	Medium risk	High	
2050s	9.3	High risk	High	
Potential Opportunities				
Increase in utilization of silvopasture for livestock operations, which reduces heat stress among other benefits				

4.3.2 Likelihood

Additionally, there is high confidence[188] that "recent record-setting years [in terms of high temperatures] may be "common" in the next few decades."[189] 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 out of 4 (highly likely) for the mid-century timeframe. The current timeframe received a likelihood rating of 2 out of 4 (possible), since heat waves do occur currently, but only happen about 5-6 days per year.

[188] 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.
[189] Vose et al., 2017. "Temperature changes in the United States."

4.3.3 Consequences

Figure 40 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.

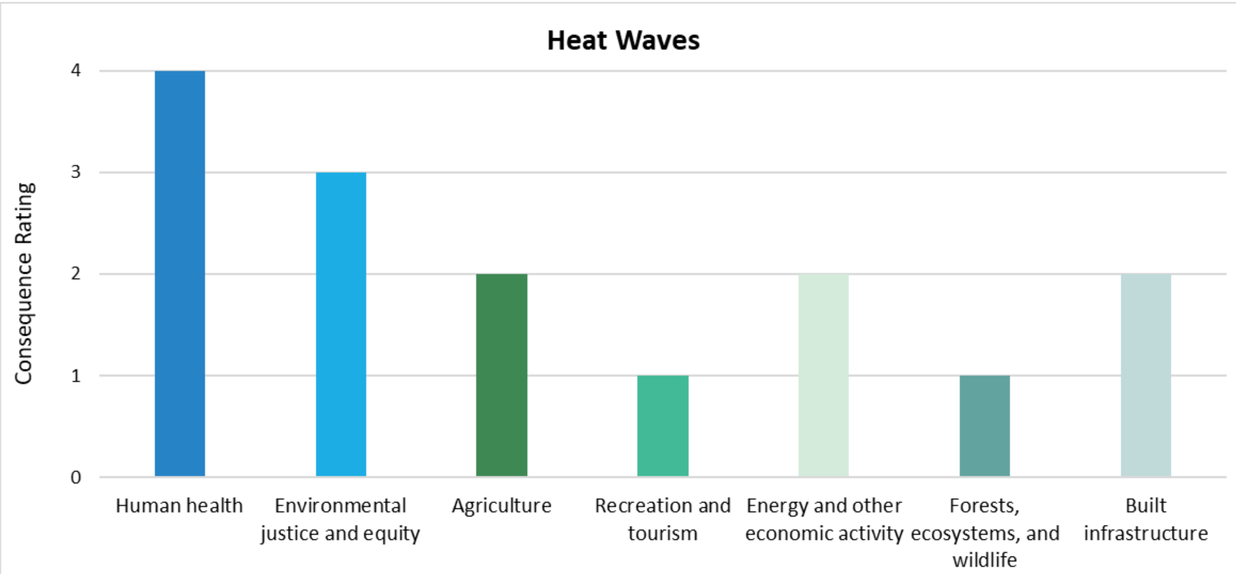

Figure 40. Heat wave consequences

Human Health

Rating: 4 out of 4 (Catastrophic)

Heat wave events will cause heat-related mortality and morbidity. Extreme heat is responsible for the most weather-related deaths in the United States.[190] By impeding the body's ability to thermoregulate, exposure to high temperatures can cause conditions like heat exhaustion, dehydration, heat rash, heat stroke, and heat cramps, which for more severe conditions can lead to death if left untreated.[191,192] 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.[193] However, the risk of mortality from extreme heat events has been decreasing, as more and more households are installing air conditioning.

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[190] 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

[191] Davis et al., 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives.*

[192] Kuehn, L., and McCormick, S. 2017. Heat Exposure and Maternal Health in the Face of Climate Change. *International journal of environmental research and public health*, *14*(8), 853. https://doi.org/10.3390/ijerph14080853

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

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.[194,195,196] Specifically, young children and the elderly are at heightened risk of morbidity or mortality.[197] Individuals with pre-existing psychiatric illnesses and those who are socially isolated are also at high risk during heat waves.[198,199] Heat can also contribute to death for individuals suffering from certain mental health conditions that change risk perception and understanding of exposure to extreme heat.[200] Pregnant people and their unborn children are at greater risk from extreme heat as their capacity to thermoregulate is compromised.[201] Exposure to extreme temperatures could affect multiple birth outcomes including length of gestation, birth weight, stillbirth, and neonatal stress.[202]

For outdoor workers, 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 near that threshold and people are working outside in direct sunlight and/or without wind to cool them down.[203] Beyond work, walking and exercising outdoors will also become more hazardous.[204]

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. [205] Heat stress can also affect the ability of children to learn and retain

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[194] Davis et al., 2003. Changing heat-related mortality in the United States. *Environmental Health Perspectives.*
[195] Pennsylvania Department of Agriculture. November 2020. Department staff expertise.
[196] 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
[197] U.S. Global Change Research Program. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. https://health2016.globalchange.gov/
[198] Bouchama, A et al., 2007. Prognostic Factors in Heat Wave-Related Deaths. Journal of the American Medical Association (JAMA) Internal Medicine 167(20):2170-2176. https://pubmed.ncbi.nlm.nih.gov/17698676/
[199] U.S. Global Change Research Program. 2016. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. https://health2016.globalchange.gov/
[200] Vaidyanathan et al., 2020. Heat-Related Deaths – United States, 2004–2018.
[201] Kuehn, L., and McCormick, S. 2017. Heat Exposure and Maternal Health in the Face of Climate Change. *International journal of environmental research and public health*, *14*(8), 853. https://doi.org/10.3390/ijerph14080853
[202] Kueh and McCormick. 2017. Heat Exposure and Maternal Health in the Face of Climate Change.
[203] U.S. Department of Labor, Occupational Safety and Health Administration. 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.
[204] Dahl, K., et al., 2019. Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. In *Environmental Research Communications*. https://doi.org/10.1088/2515-7620/ab27cf
[205] 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/

information and adults to be able to work productively.[206] Extreme heat is also associated with increased rates of suicide and contributes to heightened aggression, hostility, and violence.[207] Violent crimes are expected to increase as a result of extreme heat events.[208]

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

Environmental Justice and Equity

Rating: 3 out of 4 (Critical)

As shown in Figure 35, the number of hot days across the state is projected to increase, and populations in environmental justice areas are projected to disproportionately experience the most 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 areas are expected be nearly twice as exposed (1.8x) to those top-20% conditions compared to the Pennsylvania population as a whole.

Consequences of historical practices of redlining, building substandard housing in communities of color, and intentionally disinvesting in communities of color may also manifest today as inequities. For example, individuals living in deteriorating housing may be more exposed to heat stress.[209]

The elderly, those with cardiovascular disease, and populations with limited access to air conditioning experience higher risk to heat-related illness and death. Other at-risk populations include children playing outside, seniors living alone, construction workers, and athletes.[210]

Access to air conditioning is a key adaptation strategy for decreasing excess heat deaths and illness. Indeed, the rate of heat-related mortality has decreased over the 20th century and largely after 1960 due to air conditioning becoming more available and prevalent. It is therefore important that low-income residents who cannot afford air conditioning have access to publicly available cooling shelters or other assistance installing or accessing air conditioning. A survey of

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[206] Cianconi et al., 2020. The impact of climate change on mental health.

[207] Cianconi et al., 2020. The impact of climate change on mental health.

[208] Ranson, M. 2014."Crime, weather, and climate change." In *Journal of Environmental Economics and Management, Volume 67, Issue 3.* p274-302. https://doi.org/10.1016/j.jeem.2013.11.008

[209] 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, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11

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

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

Economy

Agriculture

Rating: 2 out of 4 (Limited)

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.[212]

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.[213],[214]

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.

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

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

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

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

Recreation and Tourism

Rating: 1 out of 4 (Minor)

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

Extreme heat could add additional pressure to natural and man-made water features (e.g., lakes, rivers, city pools) used for recreation and an escape from the heat. Additional water features may be necessary in urban areas to meet demand for cooling spaces.[215]

Energy and Other Economic Activity

Rating: 2 out of 4 (Limited)

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.

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

Exhibit 3. Example of economic impacts: heat waves

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

Vulnerable Populations

Nationally, heat is the leading cause of weather-related deaths over the last 30 years. In Pennsylvania, statistics show that between 2008 and 2018 PA has recorded at least 2 deaths per year except in 2014 and 2017. The high point occurred in 2011 with 36 heat-related deaths.[216]

More than 310,000 people in PA are especially vulnerable to extreme heat (over 65, under 5, or living below the poverty line).[217]

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.[218]

Apples, sweet corn, grapes, and dairy production could all see negative impacts, as extreme heat impacts growth and production.[219]

One study suggests that above a critical temperature threshold of 77 degrees Fahrenheit, dairy milk production may drop by up to 22%. This type of decline could inflict as much as $480 million in direct and indirect economic costs.[220]

Forest, Ecosystems, and Wildlife

Rating: 1 out of 4 (Minor)

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

Built Infrastructure

Rating: 2 out of 4 (Limited)

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,

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[216] PennLive, 2019. Heat stroke tops list of weather-related deaths. https://www.pennlive.com/news/2019/07/heat-stroke-tops-list-of-weather-related-deaths.html

[217] States at Risk, 2015. America's Preparedness Report Card 2015: Pennsylvania. https://reportcard.statesatrisk.org/report-card/pennsylvania/extreme_heat_grade

[218] CornProphet, 2019. Heat Waves and Corn Yield. Retrieved from: https://www.cropprophet.com/heat-waves-and-corn-yield-timing-matters/

[219] Pittsburg Post-Gazette, 2012. How climate change will affect Pennsylvania. https://www.post-gazette.com/news/environment/2012/04/22/How-climate-change-will-affect-Pennsylvania/stories/201204220205

[220] University of Maryland, 2008. Economic Impacts of Climate Change on Pennsylvania. http://cier.umd.edu/climateadaptation/Pennsylvania%20Economic%20Impacts%20of%20Climate%20Change%20Full%20Report.pdf

infrastructure failures. For example, roadways will become more pliable, experience greater wear and tear, and be more susceptible to buckling under extreme heat conditions.[221]

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.[222]

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.[223] 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.[224]

4.4 Landslides

4.4.1 Overview

Landslides can occur across Pennsylvania. As shown in Figure 41, they occur most often in the Southwestern region, though other regions may have significant landslide hazards as well—and this region may expand.[225]

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

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

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

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

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

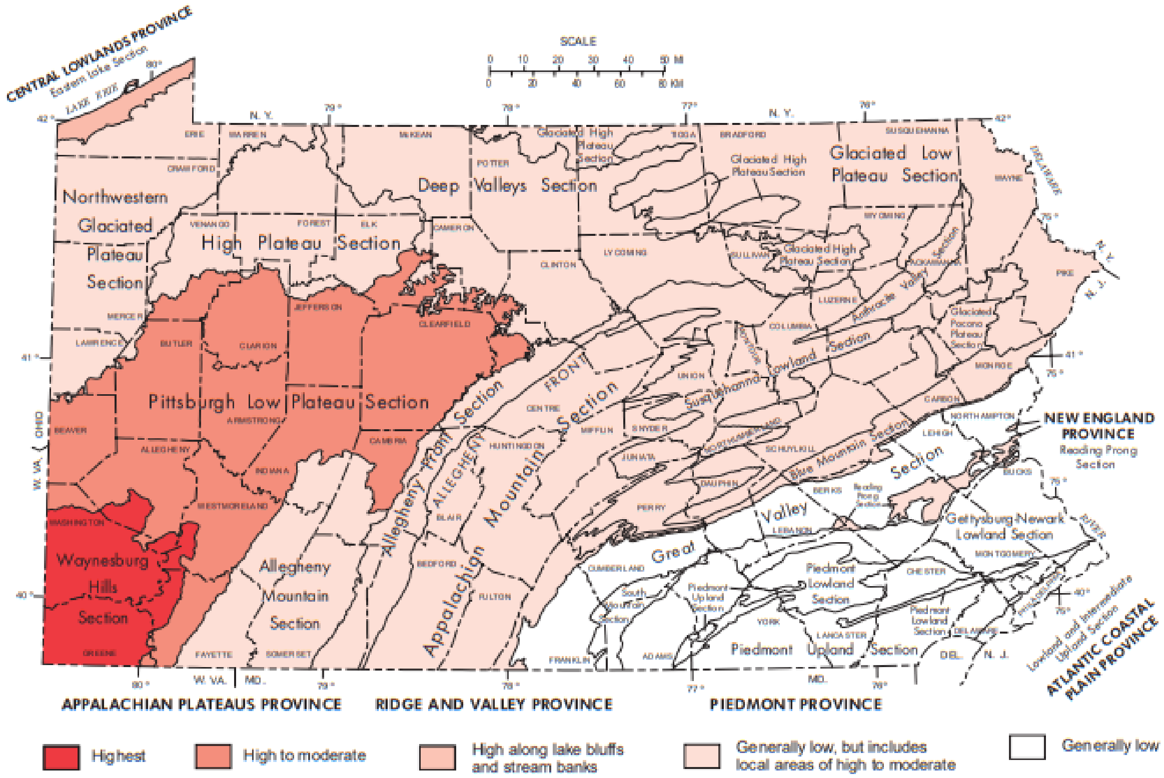

Figure 41. Physiographic information and landslide susceptibility in Pennsylvania

Source: Delano and Wilshusen, 2001.

Higher average and extreme precipitation may increase soil water saturation, which can destabilize soil and increase the risk of landslide occurrence.[226] 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.[227]

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

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 that falls as rain.

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[226] 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.

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

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 line could impact electricity end-users (e.g., homes, buildings like hospitals, farms with irrigation systems that run on electricity). Figure 42 plots the overall current and mid-century risk ratings for landslides. While landslide likelihood may increase with greater precipitation variability, not enough evidence exists to change the current likelihood (and therefore risk) rating.

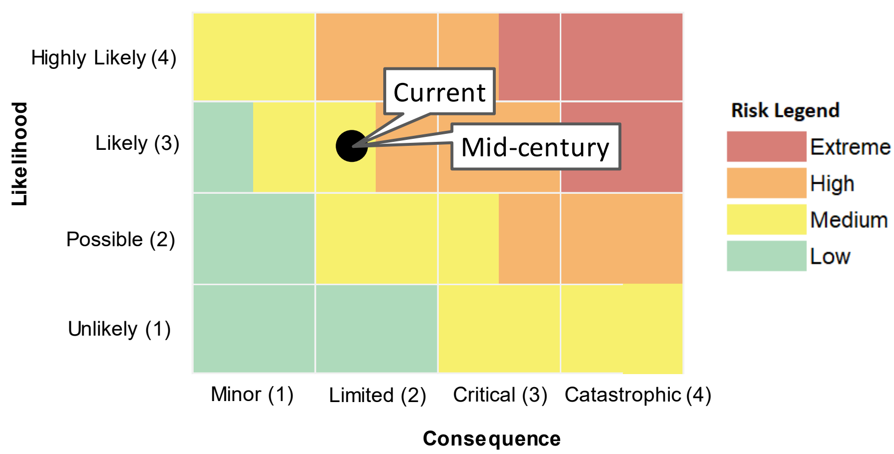

Figure 42. Landslides risk matrix

Table 9 summarizes the statewide likelihood and consequences of landslides in Pennsylvania.

Table 9. Landslides statewide risk summary

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood				
Current	3	The PA Hazard Mitigation Plan[228] identifies landslides of any magnitude as "highly likely" (over 90% probability) to occur any given year. More severe landslides like those analyzed in this scenario would be less likely.	High	In general, southwestern locations and populations are more exposed; there are also other localized areas with high vulnerability.
Mid-century	3	Landslide probability may increase with greater precipitation variability, though not enough evidence exists to change current likelihood rating.[229]	Medium	Same as current.
Beyond 2050	N/A	These trends are expected continue as precipitation variability increases beyond 2050.	N/A	Same as current.
Consequences				
Human health	1	Limited direct health impacts are expected, with some potential for indirect health impacts (e.g., due to infrastructure disruption)	Medium	Health risks may be particularly significant for low-income individuals with homes in high-risk areas or reliant on infrastructure (e.g., public transit) in high-risk areas to access jobs and income.
Environmental justice and equity	2	EJ areas 1.17x as exposed to high landslide risk compared to the state overall	Medium	Rural townships with low tax base and many miles of roads, which may be severely affected by landslides in some areas, and may not be captured in the EJ areas.
Economy: Agriculture	1	Localized impacts unless critical infrastructure is severely damaged	High	Severe economic disruptions may disproportionately impact low-income populations. Additionally, rural townships may be particularly impacted, and not captured by the EJ areas analysis.
Economy: Recreation and tourism	1	Few consequences expected	Medium	See Economy: Agriculture.

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

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

4.4.2 Likelihood

Landslides of any magnitude are currently highly likely (>90% annual probability) to occur in Pennsylvania, and with <6 hours warning time, but are anticipated to have minor impacts, negligible spatial extent, and short duration.[230] However, this assessment focuses on potential occurrence and impacts of more severe landslides, which are relatively less likely to occur. For example, while the Hazard Mitigation Plan analysis is based on any landslide occurring (e.g., even those with minimal impacts to built infrastructure and no human impacts), this assessment is focused on the subset of more extreme but lower probability events (e.g., a landslide causing significant damages to infrastructure, with potentially significant downstream economic or natural systems impacts, or human injuries or fatalities).

Literature on climate change and landslide risk[231] 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.

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

As shown in Figure 41, approximately 48% of land in Pennsylvania currently has high rates of landslide incidence or susceptibility, with risk primarily concentrated in the Southwestern region. Historical occurrences of landslides in Pennsylvania depict a similar risk region (Figure 43),[232] though slides have occurred in eastern PA.

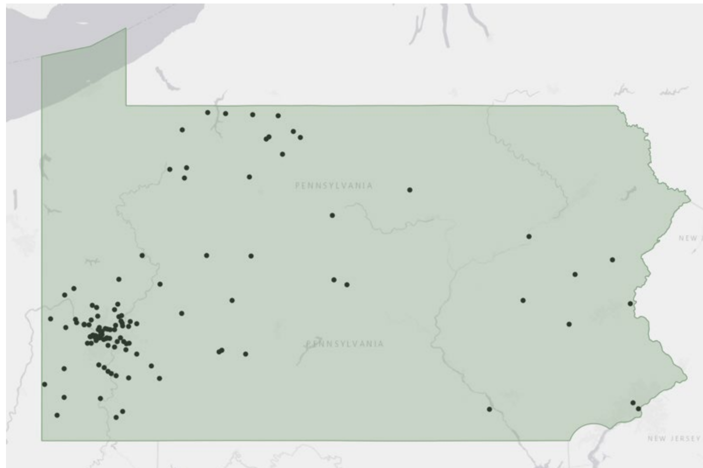

Figure 43. Historical incidence of landslides

Source: 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 (3 out of 4, likely) for 2050.

4.4.3 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.[233],[234] 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.[235]

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).

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

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

[234] 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#

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

Figure 44 summarizes the overall consequence ratings statewide for landslides– highest consequences are in built infrastructure, environmental justice and equity, and energy and other economic activity.

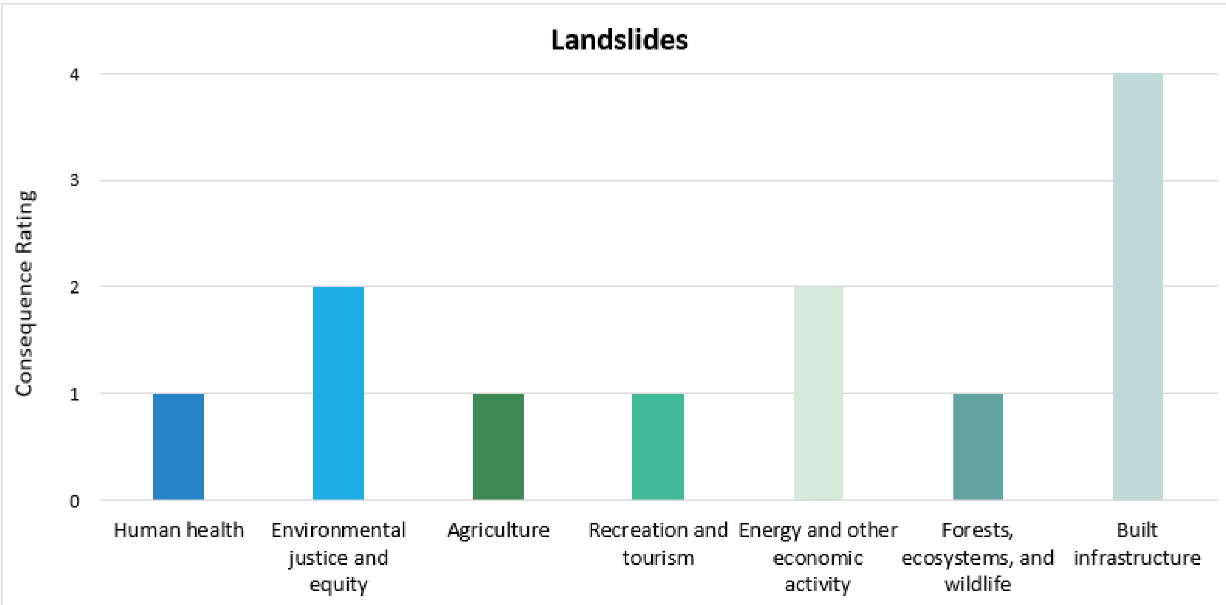

Figure 44. Landslide consequences

Human Health

Rating: 1 out of 4 (Minor)

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.[236]

Landslides can indirectly affect health if they disrupt infrastructure critical to supplying commodities and services that people rely on (e.g., energy infrastructure, electricity lines, transportation infrastructure needed to deliver medicine or roads critical to fast ambulance travel,[237] or water or wastewater systems and treatment facilities), accessing places of employment (e.g., road or rail infrastructure), or otherwise allowing economic function and revenue generation. [238],[239] 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

[236] Pennsylvania DCNR, N.d. "Landslides."
[237] Pennsylvania DCNR. November 2020. Department staff expertise.
[238] DEP. 2020 IA.
[239] Center for Disease Control. 2018. Landslides and Mudslides. https://www.cdc.gov/disasters/landslides.html

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.[240] Finally, landslides have the potential to negatively impact drinking water quality if sediment is introduced into water bodies.[241]

Environmental Justice and Equity

Rating: 2 out of 4 (Limited)

As shown in Figure 45, 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 state EJ areas are at risk. Therefore, EJ areas experience approximately 1.17 times the risk that the state experiences on average.

However, communities in EJ areas may nonetheless experience disproportionate impacts of landslides when they occur. For example:[242]

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

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

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240 Pennsylvania DCNR. November 2020. Department staff expertise.
241 Geertsema, M., Highland, L., and Vangeouis, L. 2009. Chapter 31: Environmental Impact of Landslides. In: Sassa K., Canuti P. (eds) Landslides – Disaster Risk Reduction. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-69970-5_9
242 Pennsylvania DCNR. November 2020. Department staff expertise.

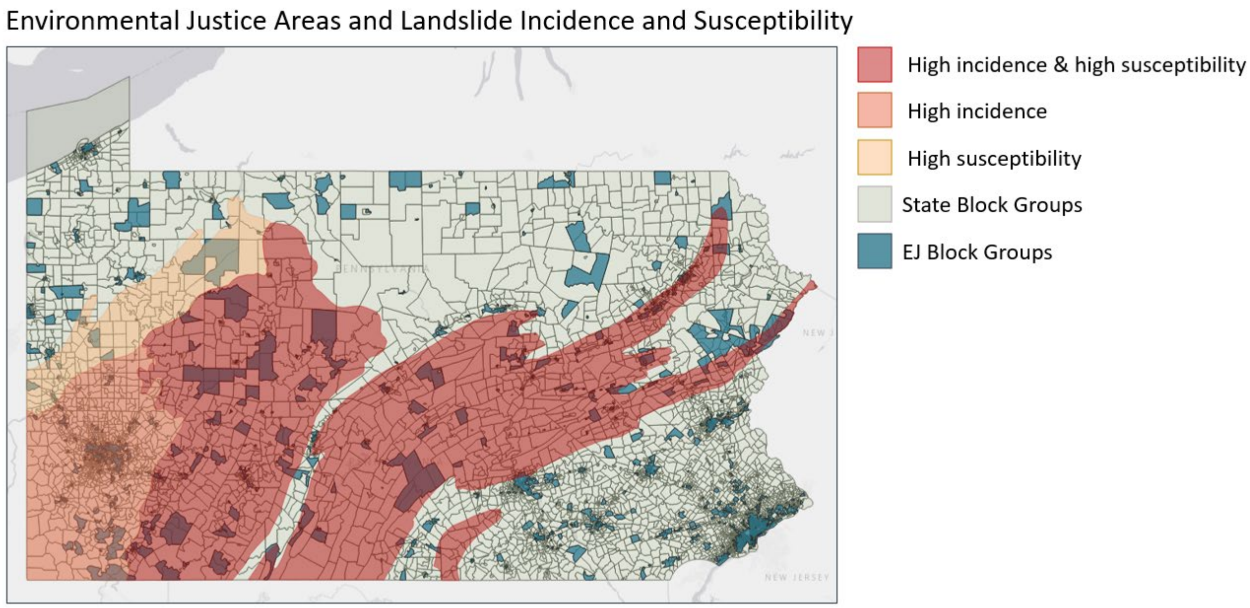

Figure 45. Historically high-risk landslide areas with EJ block groups

Landslide data source: USGS, National Landslide Information Center, Compilation of Landslide Overview Map of the Conterminous United States.

Economy

Agriculture

Rating: 1 out of 4 (Minor)

Disruptions to commerce and supply chains or physical damage to agricultural land due to landslides could impact the agricultural industry. A landslide occurring on agricultural land would have the most intense and direct impacts, including displacement of or damage to crops, livestock, or materials (e.g., stored feed, equipment).[243]

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. [244]

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

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

Recreation and Tourism

Rating: 1 out of 4 (Minor)

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

Rating: 2 out of 4 (Limited)

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.[245]

> **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.[246] Example economic impacts of landslides are described in the Exhibit 4.

[245] DEP. 2020 IA; Gariano and Guzzetti. 2016. "Landslides in a changing climate."
[246] Pennsylvania DCNR. November 2020. Department staff expertise.

Exhibit 4. Example of 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 Communities 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.[247]

"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.[248]

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.[249]

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.[250]

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.[251]

Forest, ecosystems, and wildlife

Rating: 1 out of 4 (Minor)

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).[252]

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

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[247] Pennsylvania Emergency Management Agency (PEMA), 2018. Landslide. 2018 Commonwealth of Pennsylvania State Hazard Mitigation Plan Update. Retrieved from: https://pahmp.com/landslide-2/

[248] Pennsylvania Department of Conservation and Natural Resources, n.d. Landslides. https://www.dcnr.pa.gov/Geology/GeologicHazards/Landslides/Pages/default.aspx

[249] TRIBLIVE, 2019. Landslide costs add to PennDOT's funding challenges. https://triblive.com/local/regional/landslide-costs-add-to-penndots-funding-challenges/

[250] The Times, 2018. PennDot faces uphill battle in fixing local landslides. https://www.timesonline.com/news/20181101/penndot-faces-uphill-battle-in-fixing-local-landslides

[251] E&E News, 2019. Landslides, explosions spark fear in pipeline country. https://www.eenews.net/stories/1060472727

[252] Geertsema, M., Highland, L. and L. Vaugeouis. 2009. "Environmental Impact of Landslides." In *Landslides – Disaster Risk Reduction [K. Sassa and P. Canuti, Eds.].*

of larger infrastructure failures (e.g., if a pipeline or storage tank were damaged, and contents spilled out).[253]

Built infrastructure

Rating: 4 out of 4 (Catastrophic)

Greater frequency and intensity of heavy precipitation events may increase landslide potential.[254]

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.[255]

If landslides impact major highways where federal or state funds become available, repairs can be fast, so that damages are relatively localized and temporary. However, impacts to other roads and homes may be long-lasting, if difficult to enumerate. For most state or local roads, repairs are often deferred for multiple years, or sometimes permanently, due to budget constraints. PennDOT district 11, for example, has a large backlog of landslide repairs. And there are hundreds of locations in Allegheny County where roadway repairs are waiting on funding or have been abandoned because they are not expected to ever be funded. If a municipality loses access to a road that is a link in emergency transportation routes or a significant commuter route, many peoples' daily lives and certain individuals' health may be impacted.[256]

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

[253] Pennsylvania DCNR. November 2020. Department staff expertise.
[254] Gariano and Guzzetti. 2016. "Landslides in a changing climate."
[255] PEMA. 2018. "Risk Assessment."
[256] Pennsylvania DCNR. November 2020. Department staff expertise.

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).[257]

Landslide risk maps developed for the 2020 Impact Assessment show natural gas (Figure 46), railway (

Figure 47) and electrical (Figure 48) 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.[258]

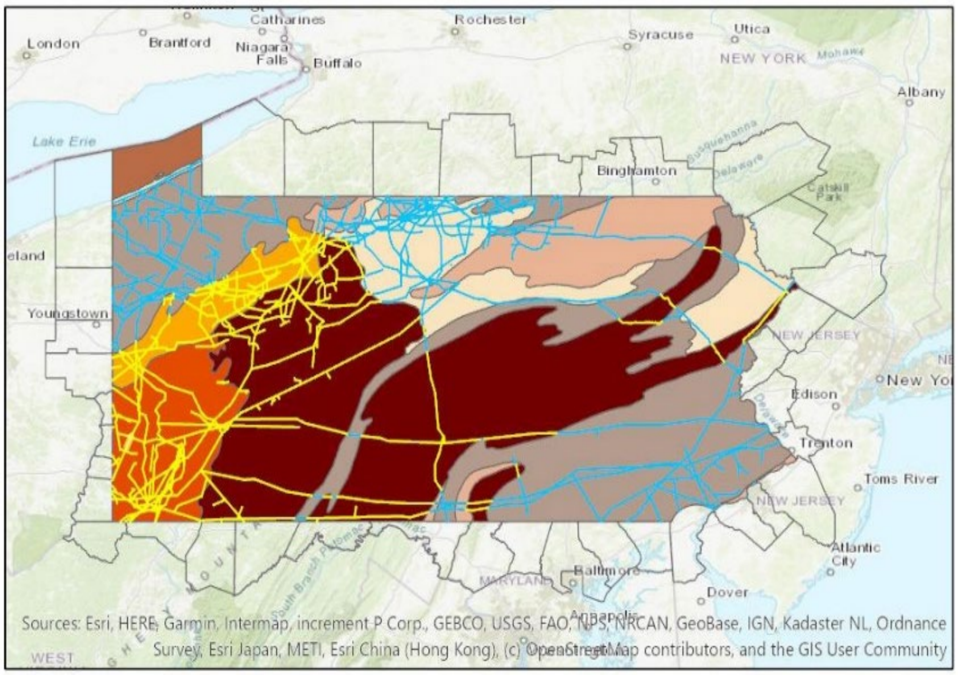

Figure 46. Natural gas pipelines in landslide hazard areas

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

[257] DEP. 2020 IA.
[258] DEP. 2020 IA.

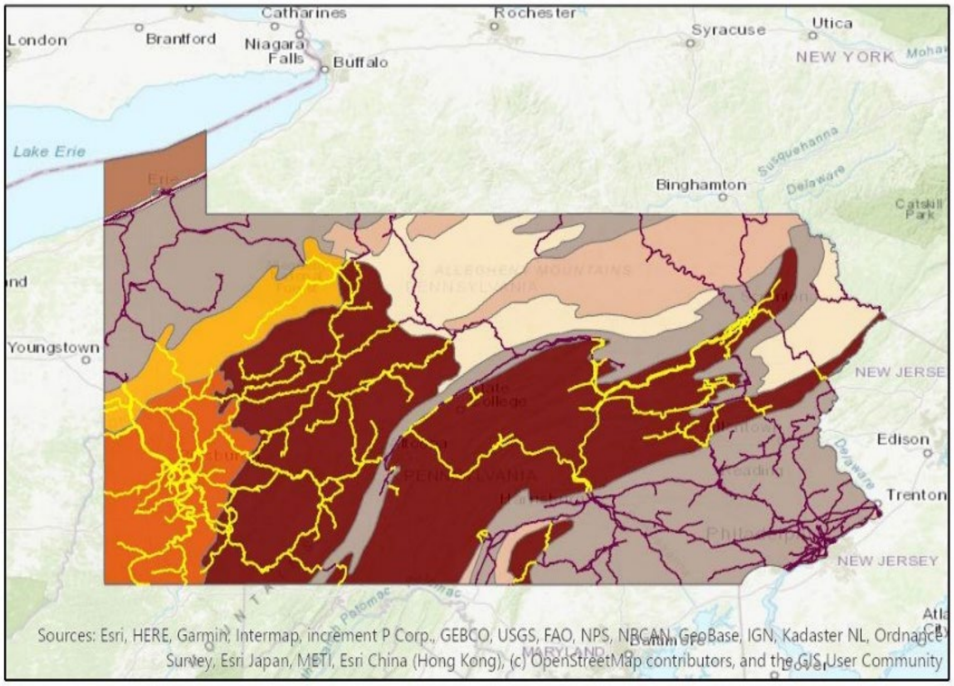

Figure 47. Railroads in landslide hazard areas

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

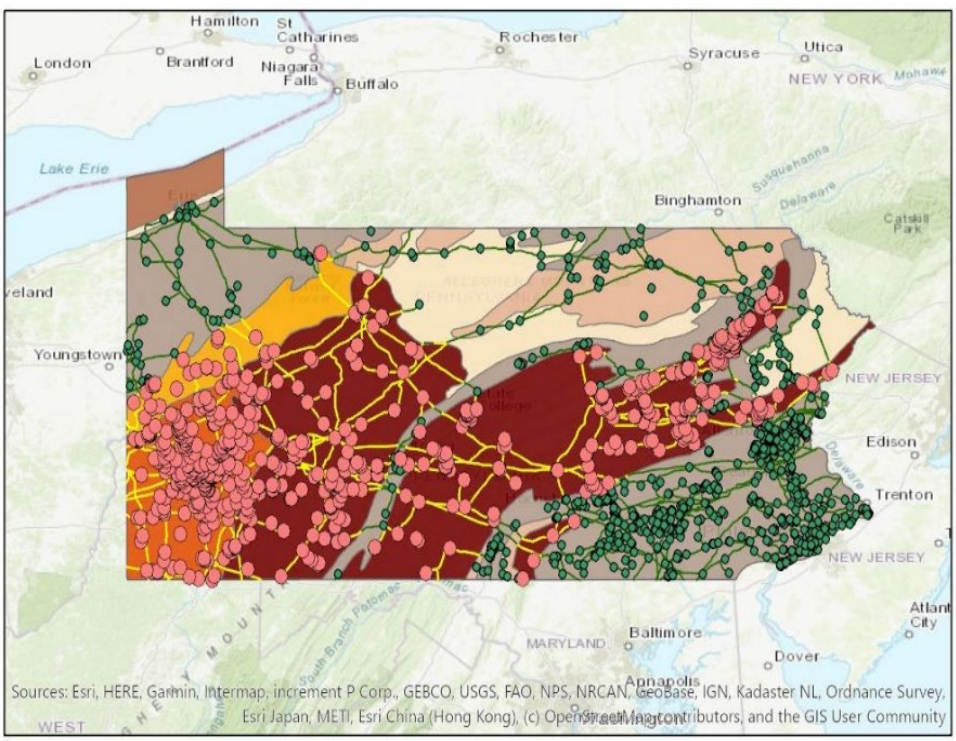

Figure 48. Electrical infrastructure in landslide areas

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

4.5 Sea Level Rise

4.5.1 Overview

Sea level rise is expected to increase risks 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.[259] As a result, storm surges will cause increased flooding in Philadelphia and the surrounding region, and could permanently inundate some low-lying areas.[260] 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.[261] 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 49 illustrates the overall risk rating in present-day and 2050 based on the likelihood and consequence ratings. Table 10 summarizes the statewide likelihood and consequences of sea level rise in Pennsylvania.

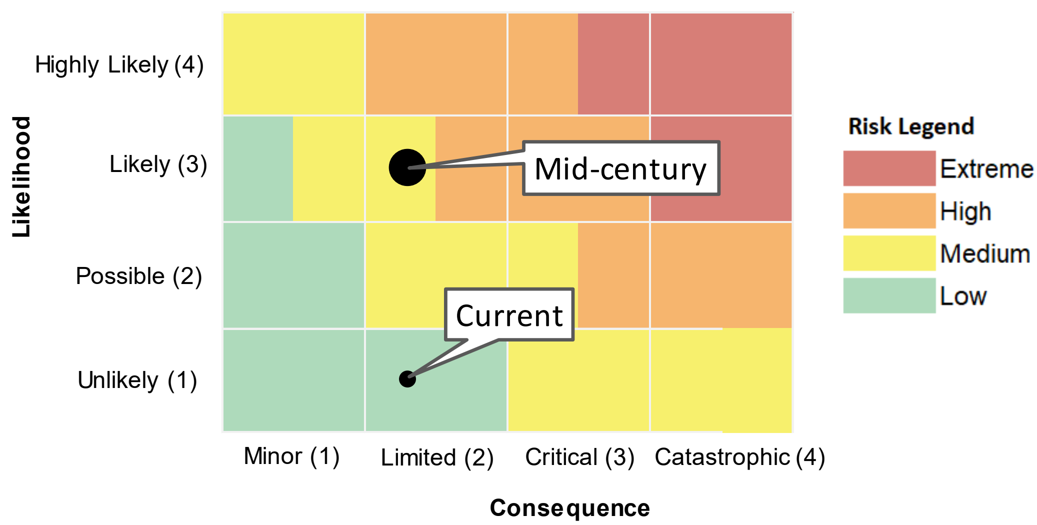

Figure 49. Sea level rise risk matrix

Source: Based on the consequence and likelihood ratings listed in Table 10

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[259] 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.

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

[261] DVRPC. 2004.

Table 10. Sea level rise statewide risk summary

Timeframe or Sector	Rating or Risk Score	Notes	Confidence	Differential Impacts
Likelihood				
Current	1	Sea level rise is increasing but has not neared the critical threshold of 2 feet of sea level rise.	High	The Delaware estuary is currently experiencing the most significant impacts of sea level rise.
Mid-century	3	Sea level rise will increase and is likely to approach 2 feet by mid-century.	High	The broader region of the Delaware River Valley is projected to be at risk. The Delaware estuary will also continue to face severe impacts.
Beyond 2050	N/A	NOAA projects sea level rise of 1.96 to 9.51 feet.[262] 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-ft. rise has a 17% chance of occurring.[263]	High	Same as mid-century.
Consequences				
Human health	1	Possible saltwater intrusion in water wells, though impacts on drinking water safety are not expected	High	Communities that receive water from rivers in the Delaware estuary may experience reduced water quality.
Environmental justice and equity	1	Not projected to experience disproportionate exposure to 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 severely affected	High	NA
Economy: Recreation and tourism	1	Not expected to be severely affected	High	Philadelphia International Airport could be flooded during storms.
Economy: Other	2	Millions of dollars in repairs and improvements costs from damage to water infrastructure	High	Industries receiving water from rivers in the Delaware estuary will

[262] U.S. Army Corps of Engineers (USACE). 2019. Sea Level Change Curve Calculator. http://corpsmapu.usace.army.mil/rccinfo/slc/slcc_calc.html

[263] NOAA Center for Operational Oceanographic Products and Services. 2017. Global and Regional Sea Level Rise Scenarios for the United States. P. 22. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf

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

4.5.2 Likelihood

According to the U.S. Global Change Research Program, global mean sea level is "very likely" (greater than 90% probability) to rise 0.5-1.2 feet by mid-century.[264] Sea level rise is expected to increase faster along the Mid-Atlantic coast than globally as described in the coastal change section.[265] The range of change varies. The US Army Corps of Engineers predicts that in Philadelphia,[266] water levels will likely rise by 1.5 to 2.7 feet by 2050, and 2.4 to 6.8 feet by 2100.[267],[268] 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. Overall, sea level rise is likely to approach the critical threshold of 2 feet by mid-century. As a result, the likelihood rating is a 3 (out of 4) in mid-century.

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

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

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

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

[268] 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.

4.5.3 Consequences

Figure 50 summarizes the overall consequence ratings statewide for sea level rise—highest consequences are in the built infrastructure, other economic activity, and the forests, ecosystems, and wildlife categories.

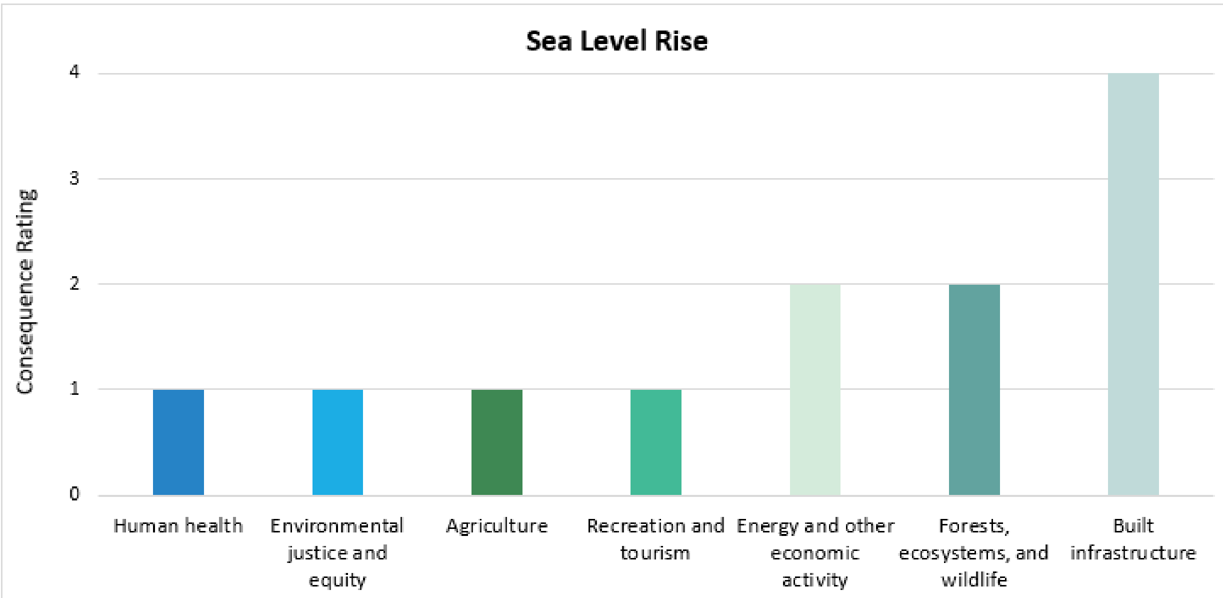

Figure 50. Sea level rise consequences

Human Health

Rating: 1 out of 4 (Minor)

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.[269] Philadelphia and other municipalities in the region would face impacts to their drinking water supply with only a 2.4-foot rise in sea level, which is possible by mid-century and likely by the end of the century.[270] Additionally, water wells may experience increase salinity if they are near areas where groundwater sources are facing salt water intrusion. Lower water-quality could increase health issues if greater investments in water treatment are not made. Additionally, with sea level rise, coastal storm surges might be greater during cyclone events. Subsequently, health risks outlined in section 4.6.3 could be exacerbated by sea level rise.

[269] DVRCP. 2004.
[270] DVRCP. 2004.

Environmental Justice and Equity

Rating: 1 out of 4 (Minor)

Spatial analysis (see Figure 51) indicates coastal Environmental Justice (EJ) areas are not projected to be disproportionately exposed to 2 feet of sea level rise-driven flooding (2 ft SLR). Figure 51 shows percent inundation from 2 ft SLR across coastal census block groups; black cross-hatching indicates EJ areas. About 20% of coastal "EJ areas" land is projected to experience flooding under 2 ft SLR. This flooding statistic does not differ significantly from the 21% of total area of *all* coastal communities that is projected to experience flooding under 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.

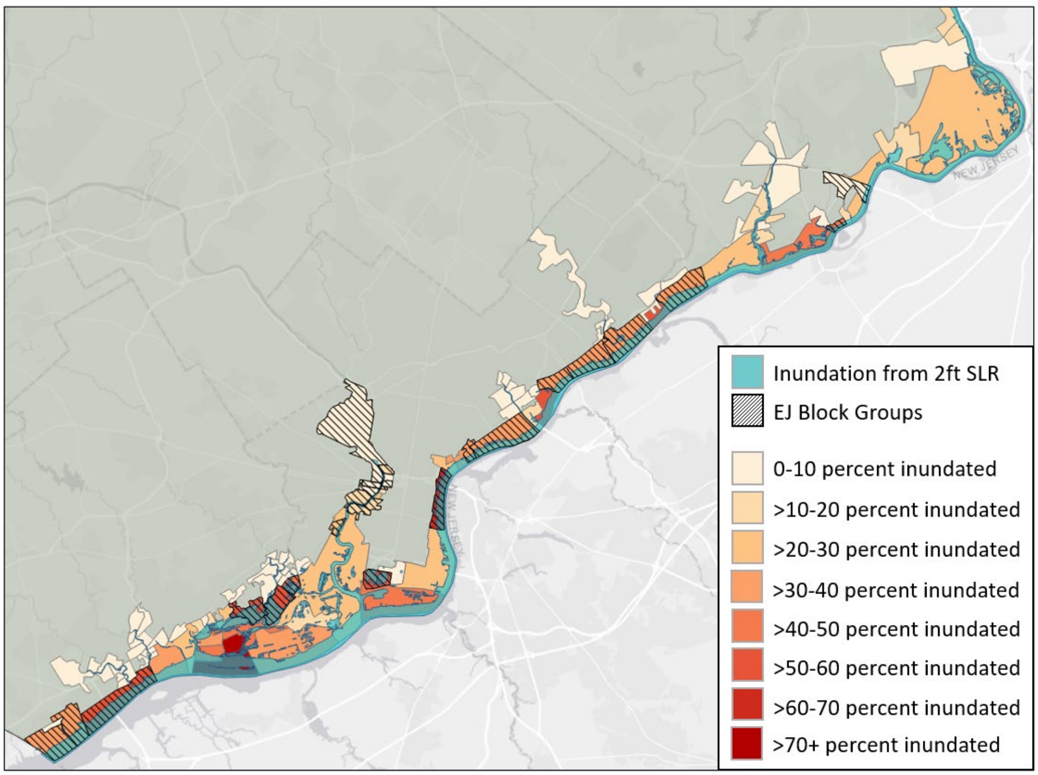

Figure 51. Projected areas inundated by 2 feet of sea level rise in 2050 with EJ block groups

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.

Indeed, certain populations may be disproportionately vulnerable to and/or impacted by this hazard. For example, as described in Section 4.5.3 (environmental justice and equity analysis for flooding), many flooding inequities prevalent in urban areas often place low-income people and communities of color at higher risk.[271] Those who live in economically distressed communities or in sub-standard housing may have a greater sensitivity to sea level rise driven from flooding events. They may experience greater impacts from sea level rise related flooding and be less able to recover as a result of limited access to resources.

Economy

Agriculture

Rating: 1 out of 4 (Minor)

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

Recreation and Tourism

Rating: 1 out of 4 (Minor)

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.[272] During a category one storm or a 100-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

Rating: 2 out of 4 (Limited)

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.[273] Brackish waters would be especially present during dry periods.[274] The use of brackish water threatens to damage equipment, raise water-treatment costs, and force a shift in water supplies.[275] 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. Sea level rise could have severe economic implications when combined with extra-tropical and tropical cyclones. Flooding associated with coastal storm surges amplified by

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[271] U.S. Water Alliance. 2020. "Water Rising: Equitable Approaches to Urban Planning."
[272] City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.
[273] DVRPC. 2004.
[274] DVRPC. 2004.
[275] DVRPC. 2004.

sea level rise is projected to threaten thousands of jobs and properties. Example economic impacts of sea level rise are described in

Exhibit 5.

Exhibit 5. Example of 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.[276] The airport's ongoing $6.2 billion expansion, to be completed in phases through 2025 lengthening two of the airport's four runways and building a fifth runway along the Delaware River, includes struggles against sea level rise such as filling 135 acres of floodplain and building 11 acres on storm-water basins.[277],[278]

In the Delaware River Basin, some 147,000 jobs and $20.4 billion in residential property values could be affected by the combined impact of sea level rise, storm surge and flooding.[279] The portion of that damage attributable to sea level rise alone is unknown.

Forest, Ecosystems, and Wildlife

Rating: 2 out of 4 (Limited)

Sea level rise threatens the ecology of Pennsylvania's portion of the Delaware Estuary. Specifically, the upper Delaware estuary is projected to experience a modest change in salinity as a result of climate change.[280,281] Increased salinity is projected to cause a change in habitat for the fauna that live in these waters. As the estuary's water levels rise and increase in salinity, marine species will likely advance up the estuary and freshwater species will retreat resulting in a significant shift in the makeup of the estuary's ecology.[282] Fish populations and other marine species that need lower salinity levels may be threatened. Specifically, oysters and mussels may be imperiled.[283,284] Tidal wetlands may also be damaged by sea level rise and changes in salinity

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276 Philadelphia Inquirer. 2019. As climate changes and seas rise, Philadelphia International Airport is in the crosshairs. Frank Kummer. September 17, 2019. https://www.inquirer.com/science/climate/philadelphia-international-airport-climate-change-sea-level-rise-flooding-delaware-river-20190917.html

277 Philadelphia Inquirer. 2019. Philadelphia Airport in the crosshairs.

278 Philadelphia Inquirer. 2011. Airport expansion estimate up $1.2B. Linda Loyd. October 7, 2011. https://www.inquirer.com/philly/insights/in_money/20111007_Airport_expansion_estimate_up__1_2B.html#:~:text=The%20long-range%20expansion%20of%20Philadelphia%20airport%20is%20now,Aviation%20Administration%20unveiled%20the%20proposal%20in%20May%202010

279 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

280 PSU. 2015 IA.

281 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.

282 DVRPC. 2004.

283 DVRPC. 2004.

284 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

levels as plant species are unable to adapt to higher water levels, saltier water, or frequent inundation.[285]

By mid-century, coastal wetlands are also projected to experience severe, localized damage. Sea level rise may result in the drowning of tidal and nontidal wetlands on Pennsylvania's southeastern coast.[286] Development in Southeastern Pennsylvania may hinder tidal flora and fauna from migrating horizontally to escape ecosystem changes.[287] Ultimately, sea level rise may stress or destroy freshwater tidal ecosystems.[288] Wetlands are a unique resource for Pennsylvania and face significant devastation. Though consequences for wetlands are serious, this category receives a rating of 2 to reflect the narrow subset of the Commonwealth's ecological resources exposed to sea level rise.

Built Infrastructure

Rating: 4 out of 4 (Catastrophic)

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.[289] 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.[290] 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.

4.6 Severe Tropical and Extra-Tropical Cyclones

4.6.1 Overview

Tropical cyclones include events such as tropical storms, tropical depressions, and hurricanes, while extra-tropical cyclones encompass events like nor'easters.[291] 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

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285 PSU. 2015 IA.
286 PSU. 2015 IA.
287 PSU. 2015 IA.
288 PSU. 2015 IA.
289 City of Philadelphia Mayor's Office of Sustainability and ICF International. 2015.
290 Climate Central. 2020. Surging Seas Risk Finder. https://riskfinder.climatecentral.org/state/pennsylvania.us?comparisonType=county&forecastType=NOAA2017_int_p50&level=2&unit=ft
291 DEP. 2020 IA.

precipitation in the Northeastern United States.[292] As a result, the consequences of flooding and extreme rainfall outlined in the "Precipitation and Inland Flooding" hazard section also apply to cyclones.

Tropical and extra-tropical cyclones are projected to have significant consequences for human health, the energy sector, and, built infrastructure. Stronger cyclones are expected to endanger individuals as high winds damage buildings and flooding causes accidents. Significant destruction and harm follow cyclone events as seen with 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.[293]

Figure 52 illustrates the current and 2050 overall risk rating based on the likelihood and consequence ratings.

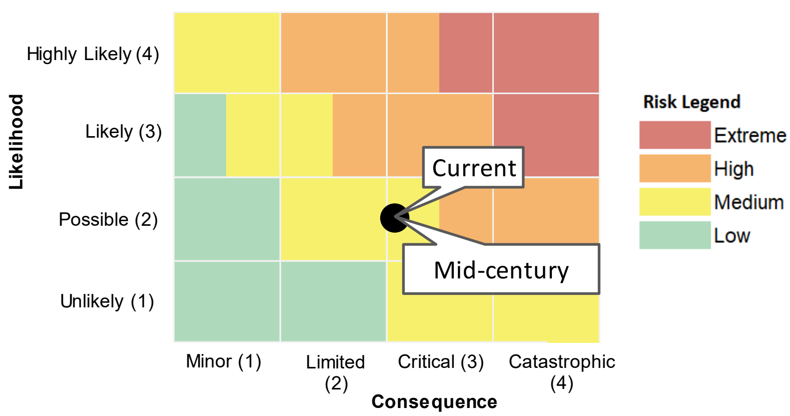

Figure 52. Tropical and extra-tropical cyclones risk matrix

Table 11 summarizes the statewide likelihood and consequences of tropical and extra-tropical cyclones in Pennsylvania.

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[292] DEP. 2020 IA.

[293] National Weather Service. 2015. Fourth 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.

Table 11. Tropical and extra-tropical cyclones statewide risk summary

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

Timeframe or Category	Rating or Risk Score	Notes	Confidence	Differential Impacts
Built Infrastructure	4	Transportation and local electricity infrastructure could be severely hit	High	Southeastern Pennsylvania may be hit severely where flooding is exacerbated because of the region's proximity to the coast.
Overall Risk				
Current	4.8	Medium risk	Medium	
2050s	4.8	Medium risk	Medium	
Potential Opportunities				
▪ Investments in healthy soils in agricultural land and best management practices reduce the shock of an acute storm event. ▪ After tropical and extra-tropical cyclones, communities often experience a boom in construction and car sales as individuals seek to replace lost property.				

4.6.2 Likelihood

Tropical and extra-tropical cyclones are possible each year, and have a likelihood rating of 2 out of 4, both currently and in mid-century. For example, eight tropical and extra-tropical cyclones passed through Pennsylvania since 2000.[294] 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.[295] 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.[296] No consensus has been reached on whether there has been a demonstrated trend in a change in tropical cyclones' likelihood.[297] 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.

4.6.3 Consequences

Figure 53 summarizes the overall consequence ratings statewide for tropical and extra-tropical cyclones—highest consequences are in built infrastructure, human health, and agriculture. These consequence ratings are also in Table 11.

[294] NOAA National Hurricane Center. 2020. Historical Hurricanes Tracks. https://oceanservice.noaa.gov/news/historical-hurricanes/
[295] PSU. 2015 IA.
[296] U.S. Global Change Research Program. 2018. "Chapter 18: Northeast."
[297] U.S. Global Change Research Program. 2018. "Chapter 18: Northeast."

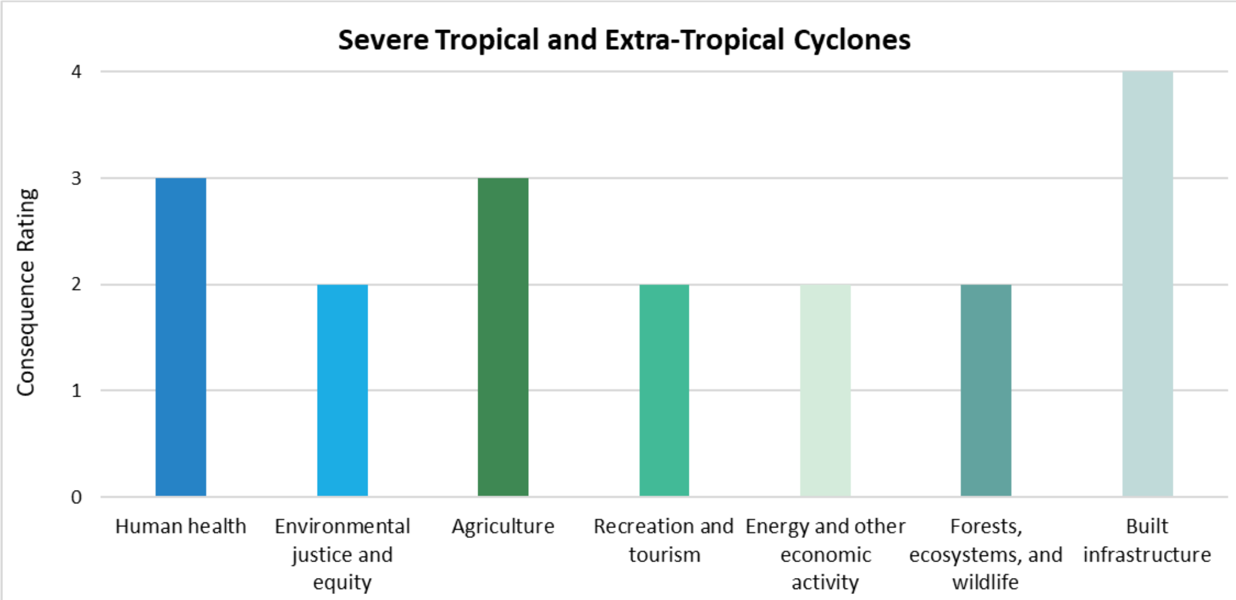

Figure 53. Tropical and extra-tropical cyclones consequences

Human Health

Rating: 3 out of 4 (Critical)

The health impacts of severe cyclones are limited but can be severe. 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. Cyclones can directly cause injuries and death from drowning and trauma sustained during the event. Additionally, severe cyclone events can have significant mental health impacts. Trauma of the event, loss of resources, and economic and social consequences can lead to stress and anxiety, post-traumatic stress disorder, and depression.[298]

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

In addition, cyclones threaten to disrupt critical services to human health such as telecommunications, water, wastewater, emergency services, and transportation infrastructure. Loss or interruption of these services can result in serious harm and mortality.[299] Numerous

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[298] Dodgen, D., D. Donato, N. Kelly, et al., 2016: Ch. 8: Mental Health and Well-Being. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program, Washington, DC, 217–246. http://dx.doi.org/10.7930/J0TX3C9H

[299] Bell, J et al., 2016. Ch. 4: Impacts of Extreme Events on Human Health. The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment. U.S. Global Change Research Program. 99–128. http://dx.doi.org/10.7930/J0BZ63ZV

individuals could face serious risk of harm during or after a cyclone event because of hazardous conditions created by the event. For example, disruption of electricity and inability to refrigerate food can result in foodborne diarrheal illnesses if individuals consume spoiled foods.[300] Death from electrocution from fallen power lines, carbon monoxide poisoning, candle started fires, and car accidents can all also be indirectly caused by severe cyclones.[301] Heavy rain and winds can reduce visibility while driving and cause other hazardous road conditions which can also result in greater car accidents.

Finally, winter extra-tropical cyclones can be dangerous because of snow accumulation, winds, and freezing temperatures.[302] Resulting health risks include frostbite and hypothermia. [303]

Environmental Justice and Equity

Rating: 2 out of 4 (Limited)

Many of the same environmental justice and equity concerns raised in the "Precipitation and Inland Flooding" hazard section apply to cyclone events. Cyclones will threaten those in low-lying areas, as these extreme storm events exacerbate flooding. EJ areas are slightly over-represented in FEMA 500-year floodplains compared to the state average (1.2x as exposed).

Beyond being slightly over-represented in terms of exposure, communities with a high percentage of low-income individuals are more at-risk of facing serious consequences after an extreme storm. Low-income households are more likely to lack the resources to recover quickly from an extreme cyclone, and to reside in substandard housing, which increases the risk of mold, mildew, poor indoor air quality, and damage after intense rain and wind during storms.[304],[305] Similarly, areas with a high percentage of low-income individuals are more likely to have less climate-resilient infrastructure.[306]

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[300] Lin, S., B. A. Fletcher, M. Luo, R. Chinery, and S. -. A. Hwang, 2011: Health impact in New York City during the Northeastern blackout of 2003. Public Health Reports, 126, 384-93.

[301] McKinney, N., Houser, C., Meyer-Arendt, K. 2011. Direct and indirect mortality in Florida during the 2004 hurricane season. *Int J Biometeorol* 55**,** 533–546. https://doi.org/10.1007/s00484-010-0370-9

[302] Bell, J et al., 2016. Impacts of Extreme Events on Human Health

[303] Bell, J et al., 2016. Impacts of Extreme Events on Human Health

[304] 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

[305] Clifton, 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/

[306] Clifton, Majumder and Kelly. 2020. Preparedness.

Economy

Agriculture

Rating: 3 out of 4 (Critical)

Rainfall during tropical cyclones and extra-tropical cyclones will parallel many of the consequences of extreme precipitation on agriculture discussed in the "Heavy Precipitation and Inland Flooding" hazard section (Section 4.2). 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

Rating: 2 out of 4 (Limited)

Cyclones and extra-cyclones will have limited consequences for recreation and tourism. Though the consequences appear mild, extreme storms could damage the Philadelphia International Airport when combined with other climate stressors like 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 in the state. For example, in the aftermath of Hurricane Irene, which occurred in 2011, the National Park Service had to remove fallen trees and debris, repair minor road damage, and clear culverts.[307] State parks and forests have also experienced significant disruptions from cyclones that have reduced tourism opportunities and resulted in lost revenue for the state. Overall, cyclone impacts to this sector are limited.

Energy and Other Economic Activity

Rating: 2 out of 4 (Limited)

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.[308] 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 (2011) and Superstorm Sandy (2012), electric service was down for 4 to 8 days.[309] Blackouts during Hurricane Irene affected 700,000 people, while outages during Hurricane Sandy affected 1.2 million Pennsylvanians. Extreme storms temporarily disrupt energy delivery services and

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

[308] DEP. 2020 IA.

[309] PSU. 2015 IA.

hurt business revenue. Examples of the economic impacts of severe tropical storms are described in Exhibit 6.

Exhibit 6. Example of economic impacts: severe tropical storms

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

2018 Hurricane Season: Hurricane Florence and Tropical Storm Gordon

Tropical Storm 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.[310] Allegheny County declared a State of Emergency due to this event. Numerous roads were closed due to high water and localized flooding.[311] September 16-17, 2018, Hurricane Florence dumped 3 to 4 inches of rain along and just east of the Appalachians. Florence made 2018 the wettest year ever for Pennsylvania.[312]

2020 Hurricane Season: Tropical Storm Isaias

In August 2020, Tropical Storm Isaias caused considerable inland flooding in PA. Estimated damage costs associated with the storm total more than $27.6 million and 2 dead.[313, 314]

2011 Hurricane Season: Irene and Tropical Storm Lee

Tropical storm Lee caused considerable damage from record flooding across the northeast. Tropical Storm Lee cost Pennsylvania $67.9 million in flooding and landslide costs and 7 deaths. [315,316] 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.[317]

[310] 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;

[311] 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

[312] 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

[313] 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/

[314] 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

[315] 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

[316] Weather.gov. 2015. 4th Anniversary of the Flooding from Tropical Storm Lee. NWS. Retrieved from: https://www.weather.gov/ctp/TSLeeFlooding

[317] 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

Forest, Ecosystems, and Wildlife

Rating: 2 out of 4 (Limited)

The evidence exploring severe storms' effect on forests, ecosystems, and wildlife is limited. Pennsylvania's Department of Conservation and Natural Resources (DCNR) reports significant increases in wind damage in the state's forests and other ecosystems in recent years. Both heavy precipitation and high winds can stress trees.[318] These stressors can make trees more susceptible to pests and disease, and ultimately cause a decline in the tree's health and lead to mortality.[319] If this trend continues, it could lead to increasingly significant damage to natural assets that increase the time needed for habitats to recover.

Built Infrastructure

Rating: 4 out of 4 (Catastrophic)

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

Extreme storms are likely to cause significant damage to transportation systems in the Commonwealth. Pennsylvania's existing infrastructure is not built to withstand high winds and extreme precipitation. For example, Pennsylvania's bridges are particularly susceptible to damage because of the high rate of structurally deficient bridges in the state.[320,321] Additionally, significant levels of infrastructure assets (e.g., roads, bridges, culverts) are aging and in need of repair. These existing vulnerabilities could exacerbate the potential for further damage to assets and/or system failures during an extreme weather event.[322]

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

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[318] DCNR. 2020. Forests Insects and Diseases. https://www.dcnr.pa.gov/Conservation/ForestsAndTrees/InsectsAndDiseases/pages/default.aspx

[319] DCNR. 2020. Forests Insects and Diseases.

[320]ASCE, 2014: 2014 Pennsylvania Infrastructure Report Card. American Society of Civil Engineers (ASCE), Washington, DC. https://infrastructurereportcard.org/state-item/pennsylvania/

[321] U.S. Global Change Research Program. 2018. Chapter 18: Northeast. Fourth National Climate Assessment. p. 270. https://nca2018.globalchange.gov/chapter/18/

[322] U.S. Global Change Research Program. 2018. Chapter 11: Built Environment, Urban Systems, and Cities. Fourth National Climate Assessment. p. 270. https://nca2018.globalchange.gov/chapter/11/

result. Additionally, high winds can damage building materials and lower these materials' expected lifetimes.

The consequences of extreme storms will vary as counties' preparedness ranges. In Philadelphia alone, a single more intense hurricane could cost between $20 million and $900 million, depending on the severity of flooding and strength of wind gusts.[323] Cyclones have the potential to result in significant damage and a complete shutdown of critical infrastructure. Overall, cyclones pose a substantial risk to the Commonwealth's built infrastructure.

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

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Adaptation Priorities

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

- Reduce extreme heat risks to human health, particularly for vulnerable populations
- Support key sectors in the transition to a warmer climate, including agriculture, recreation and tourism, and forests, ecosystems, and wildlife
- Reduce flood risks to infrastructure and communities
- Help low-income households cope with potential increased energy burden
- Enhance tropical storm and landslide risk mitigation

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

5.2 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. For example, certain populations may have greater physical exposure to risks (e.g., construction workers may be more exposed to heat waves), or and limitations to their ability to manage consequences if they occur (e.g., income or wealth may impact ability to pay for air conditioning).

Disproportionate impacts are often not random. Consequences of historical discriminatory practices, such as redlining and disinvestment, may also manifest as inequities today. For example, individuals living in deteriorating housing may be more exposed to heat stress.[324]

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[324] 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.

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.

5.3 Continued Research Needs

This IA Update is the first time Pennsylvania has evaluated its climate change impacts in terms of relative risk ratings to inform adaptation priorities. The risk assessment focused at a high level, and additional detail and quantification of risks could be incorporated over time.

In addition, there remain open research questions around several important risk factors in the state, particularly related to heavy precipitation and flood risk. Remaining open research questions include: what is the main driver of flooding in 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.

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

Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 438–478. doi: 10.7930/NCA4.2018.CH11

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 (e.g., Risk = Likelihood x Consequence).
Impact	The effect of a climate hazard.
Critical threshold	A defined tipping point for an ongoing hazard at which significant impacts occur.
Climate hazard	Changes or events related to global climate change. Climate hazards can be discrete (e.g., severe storms) or ongoing (e.g., increasing average temperatures).
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	Used 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)
Exposed areas	Geographic areas projected to be affected by climate change based on climate change projections.
Vulnerable populations	Populations more likely to experience adverse impacts from exposure to climate hazards because of demographics factors (e.g., race, gender), socio-economic status, and life- or livelihood-sustaining needs (e.g., dependence on electricity for critical medical care).
EJ areas	Environmental Justice census tracts, where 20% or more individuals live in poverty, and/or 30% or more of the population is minority.[325]
Overburdened populations	"Minority, low-income, tribal, or indigenous populations or geographic locations … that potentially experience disproportionate environmental harms and risks."[326] EJ areas are used in this assessment as a proxy for locations where populations are already overburdened by hazards and other structural disadvantages.

[325] Pennsylvania Office of Environmental Justice (OEJ). N.d. "PA Environmental Justice Areas."

[326] EPA. 2020. "EJ 2020 Glossary." https://www.epa.gov/environmentaljustice/ej-2020-glossary

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 54.

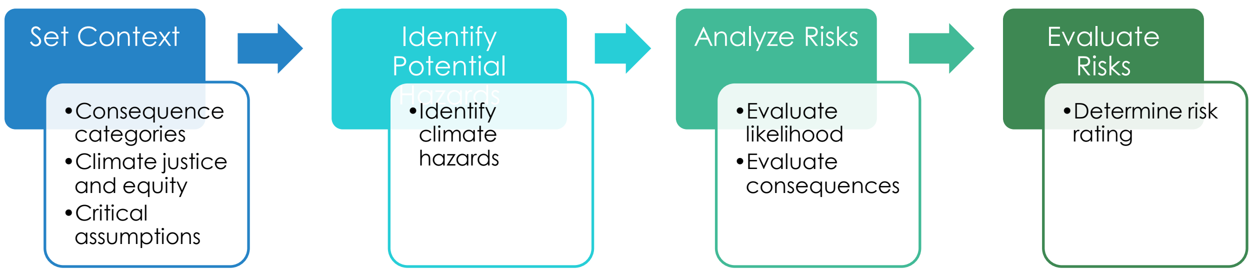

Figure 54. Risk assessment process

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 focuses 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:

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

Key Terms

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

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

EJ areas—Shorthand for "Environmental Justice census tracts," where 20% or more individuals live in poverty, and/or 30% or more of the population is minority.[327]

Overburdened populations—"Minority, low-income, tribal, or indigenous populations or geographic locations … that potentially experience disproportionate environmental harms and risks."[328] EJ areas are used in this assessment as a proxy for locations where populations are already overburdened by hazards and other structural disadvantages.

Overburdened Populations

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

EJ areas are used as a proxy for locations where populations are already overburdened by hazards and other structural disadvantages. These areas are commonly used by DEP and other state agencies for similar purposes. 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.[329]

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

Vulnerable Populations

The environmental justice and equity consequence sections in this assessment also dive deeper into the nuances of what drives risks of each hazard, identifying specific populations that may

[327] Pennsylvania Office of Environmental Justice (OEJ). N.d. "PA Environmental Justice Areas."

[328] EPA. 2020. "EJ 2020 Glossary." https://www.epa.gov/environmentaljustice/ej-2020-glossary

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

be more vulnerable to certain climate changes, and noting where additional factors critical to equity analysis come into play. For example:

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

Other Critical Assumptions

Risks were assessed under the assumption that Pennsylvania's 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 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.[330] 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.[331] 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 12 summarizes expected impacts of climate change by sector in Pennsylvania, as described in previous iterations of the impacts assessment. The six focus hazards identified (increasing average temperatures, heat waves, heavy precipitation and inland flooding, landslides, sea level rise, and severe tropical and extra-tropical cyclones) represent the primary hazards expected to affect the Commonwealth drawn from previous impacts assessments—see Table 12. These hazards cover nearly all impacts in the table. The 2021 Impacts Assessment focuses on updates

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

to the expected impacts from the selected hazards based on the latest science, with priority given to providing additional information about impacts on equity and human health.

Table 12. Climate impacts and associated hazards identified in previous impact assessments

Sector	Impact	Hazard
Human health	Decreased mortality from cold-related stress	Higher average temperatures or 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
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

Sector	Impact	Hazard
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 precipitation ▪ More intense precipitation events (e.g., 95th, 99th percentile) ▪ Higher CO2 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
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 participation 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 work may help mitigate 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/cooling degree days) ▪ Higher peak temperatures during the summer (95th or 99th 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	▪ Extreme weather events ▪ Higher average temperatures

Sector	Impact	Hazard
	mediated by a more distributed generation system.	
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
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 CO2, 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 CO2 ▪ 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	Short-term drought

Sector	Impact	Hazard
	resources in low-flow, high-temperature periods between different sectors, and water availability issues for vulnerable populations may exist due to multidimensional inequalities.	
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)
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

Sector	Impact	Hazard
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
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 13 builds on this guide and describes climate hazards' likelihood in terms of their probability of occurring in a given year. Discrete hazards are those related to individual extreme events (e.g., a heat wave) that occur over a relatively short period of time (e.g., days or weeks). Ongoing risks are those related to gradual changes in climate occurring over many years (e.g., higher average temperatures or sea level rise); they may include critical thresholds which, if reached or surpassed, engender particular risks (e.g., X feet of sea level rise). Critical thresholds are defined tipping points at which significant impacts occur.

Table 13. Likelihood rating scale

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

The rating scale for discrete hazards (i.e., individual events like heat waves or storms) is consistent with the Pennsylvania All-Hazard Mitigation Planning Standard Operating Guide[332] and the PEMA Hazard Mitigation Plan.[333] 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.[334],[335] A comparison of the different likelihood scales and terminology are shown in Table 14. The critical thresholds for ongoing hazards (e.g., increasing average temperatures) are based on likely projections for mid-century.

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

PEMA Hazard Mitigation Plan		NCA4		IPCC	
Term	**Likelihood**	**Term**	**Likelihood**	**Term**	**Likelihood**
Highly likely	90–100% annual probability	Very likely	≥9 in 10 (90%)	Virtually certain	99–100%
				Very likely	90–100% probability
Likely	50–90% annual probability	Likely	≥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

332 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

333 PEMA. 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

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

335 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/

Consequences

DEP and ICF applied a consequence rating scale to assess the severity of impacts for key consequence categories and indicated the rationale behind the ratings. After updating climate science projections, DEP and ICF sought input from PSU experts and key stakeholders 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 on 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 for all consequence categories, because the types of priority impacts in each category are different (e.g., impacts to human health vs. infrastructure). The scale was applied to expected consequences from the climate hazards at the state scale by mid-century. It evaluates consequences from individual discrete hazard events, and the cumulative impacts of ongoing hazards.

Using the scale, the overall consequence score is compiled as an average of the five consequence category ratings. The overall risk assessment results also emphasize the disaggregated nine consequence ratings. Finally, while the climate change risk assessment is focused on evaluating negative consequences of the hazards (in order to inform adaptation priorities), the assessment includes information on positive impacts or opportunities that may arise (see Table 6).

Table 15. Consequence rating scale

Scale	Human Health	Environmental Justice & Equity	Economy: Agriculture	Economy: Recreation and Tourism	Economy: Energy and Other Economic Activity	Forests, Ecosystems, and Wildlife	Built Infrastructure
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 the area damaged, destroyed or shut down; long-duration impact for critical facilities (30+ days) or potential for at least impact across >50% of the state
3 Critical	100-1000 people affected; multiple deaths, sicknesses, or injuries possible; moderate to long duration of impact	Percent of population in EJ areas that is exposed is 1.5-2x the average percent of population exposed statewide	▪ 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 exposed population in EJ areas 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:

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

Step 4—Evaluate Risks

To compute a total risk score and corresponding risk rating for each climate hazard, the likelihood score and overall consequence score are multiplied together. A risk matrix and scoring rubric are then used to determine total risk as shown in Table 16.

Table 16. Risk rating matrix and rating rubric

	Consequence			
Likelihood	**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 – 11.9	High
3 – 5.9	Medium
1 – 2.9	Low

APPENDIX C. CLIMATE ANALYSIS

Data and Projection Methods

The updated projections presented in this report 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.[336] This represents the same underlying dataset used in the most recent National Climate Assessment.[337]

The 32 models included in the ensemble are:

- 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

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[338]. Projected values

[336] 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.
[337] Avery, C.W., D.R. Reidmiller, M. Kolian, et al., 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
[338] To capture the variation and uncertainty across the 32 climate models in the LOCA dataset, the 10th, 50th, and 90th percentiles in the models' projected values are reported. Each model projects different values for daily

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 reanalysis339 dataset, which uses meteorological station data across Continental United States.[340] 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. Late-century projections are provided for both a low-emissions pathway (RCP 4.5) and high-emissions pathway (RCP 8.5) to capture the potential range of outcomes depending on global greenhouse gas emissions over this century.

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

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

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minimum and maximum temperature and daily precipitation, making percentiles necessary to capture the range of possible future climate outcomes.

[339] "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.

[340] Livneh, B., Bohn, T., Pierce, D., et al. 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.

Monthly Average and Maximum Temperature Charts

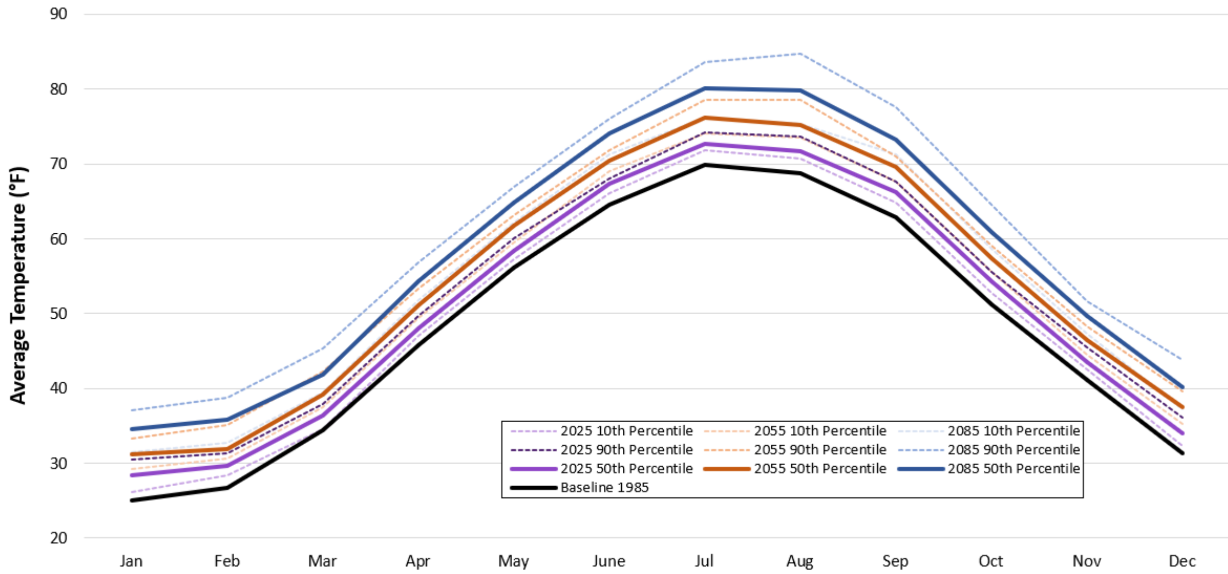

Figure 55. Statewide average observed and projected monthly average temperatures

Based on 32-model ensemble of LOCA downscaled data, RCP 8.5. Values for 2025 represent all years 2011–2040, those for 2055 represent 2041–2070, and those for 2085 represent 2070–2099.

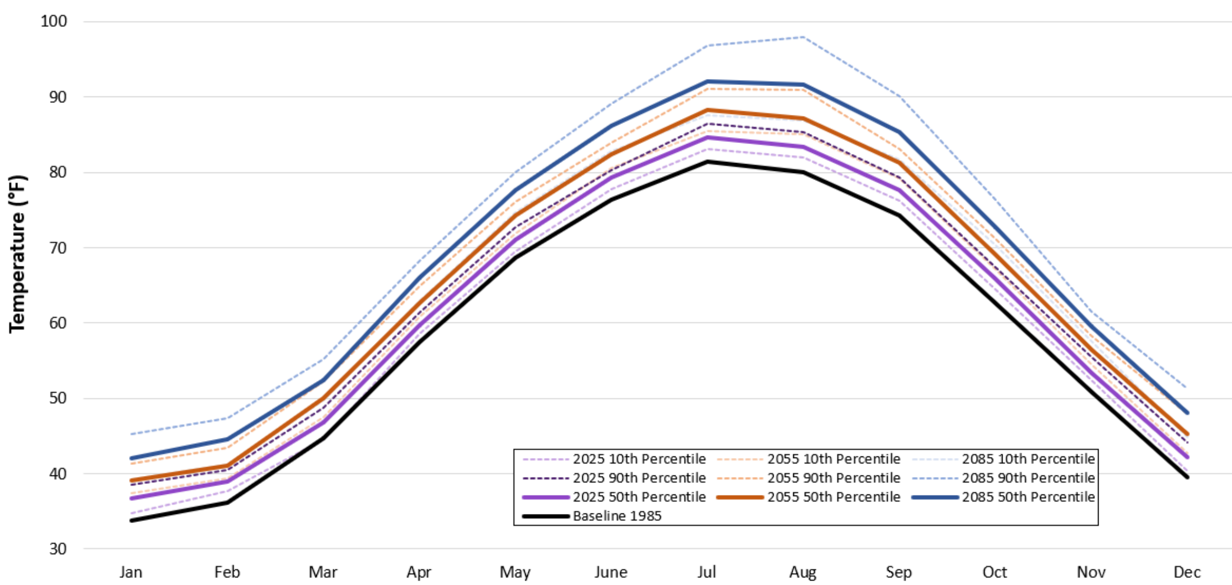

Figure 56. Statewide average observed and projected monthly maximum temperatures

Based on 32-model ensemble of LOCA downscaled data, RCP 8.5. Values for 2025 represent all years 2011–2040, those for 2055 represent 2041–2070, and those for 2085 represent 2070–2099. Values are statewide averages.

End-of-Century Projections under RCP 4.5

Table 17. Statewide average observed and projected temperature variables

	Observed Baseline (1971–2000)	End-of-Century RCP 4.5 (2070–2099)	
		Projected Value (10th–90th Percentile Range)	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
Cooling degree days (degree days)	483	1,089 (815–1,484)	606
"Very hot" (95th 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" (99th 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 temperature >100°F	0.0	1.3 (0.6 - 10.4)	1.3
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

Note: Projections are based a 32-model ensemble of LOCA downscaled data, RCP 4.5. Values reported are the median value of the 32-model ensemble and the 10th and 90th percentile values across models.

Table 18. Statewide average observed and projected precipitation variables

Variable	Observed Baseline (1971–2000)	End-of-Century RCP 4.5 (2070–2099)	
		Projected Value (10th–90th Percentile Range)	50th Percentile Percent 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%

Note: Projections are based a 32-model ensemble of LOCA downscaled data, RCP 4.5. Values reported are the median value for the 32-model ensemble and the 10th and 90th percentile values across models.

Projections by County

Table 19. County-wide average observed and projected annual average temperature (°F)

County	Observed (1971–2000)	Mid-Century (2041–2070)	End of Century (2070–2099)	County	Observed (1971–2000)	Mid-Century (2041–2070)	End of Century (2070–2099)
Adams	51.8	57.4	60.7	Lackawanna	46.1	52.3	55.8
Allegheny	51.2	57.0	60.7	Lancaster	52.0	57.9	61.2
Armstrong	48.4	54.4	57.9	Lawrence	48.8	54.7	58.4
Beaver	50.4	56.1	59.8	Lebanon	50.9	56.7	60.1
Bedford	49.4	55.0	58.6	Lehigh	50.7	56.6	60.0
Berks	50.6	56.2	59.5	Luzerne	47.2	53.3	56.8
Blair	48.3	54.0	57.4	Lycoming	46.5	52.4	55.7
Bradford	46.2	52.3	55.7	McKean	44.0	50.1	53.8
Bucks	51.9	57.5	60.7	Mercer	47.9	54.1	57.9
Butler	48.2	54.1	57.6	Mifflin	49.0	54.4	57.8
Cambria	47.1	53.0	56.6	Monroe	47.5	53.4	56.9
Cameron	45.2	50.9	54.2	Montgomery	51.8	57.5	60.8
Carbon	46.9	52.9	56.3	Montour	48.9	54.7	58.2
Centre	47.5	53.2	56.6	Northampton	50.1	55.7	59.0
Chester	52.1	57.8	61.2	Northumberland	49.0	54.8	58.2
Clarion	46.9	52.8	56.3	Perry	50.4	55.8	59.2
Clearfield	46.3	52.2	55.7	Philadelphia	53.9	59.7	63.0
Clinton	46.2	51.9	55.0	Pike	46.5	52.3	55.9
Columbia	48.1	54.0	57.4	Potter	44.2	50.1	53.6
Crawford	46.5	52.8	56.6	Schuylkill	48.2	53.9	57.2
Cumberland	51.5	57.2	60.7	Snyder	49.8	55.4	58.8
Dauphin	50.7	56.5	59.9	Somerset	46.9	53.0	56.5
Delaware	54.1	59.7	63.1	Sullivan	45.1	51.0	54.3
Elk	44.4	50.3	53.9	Susquehanna	44.9	50.9	54.3
Erie	48.0	54.3	58.2	Tioga	44.5	50.4	53.9
Fayette	49.4	55.3	58.9	Union	49.4	55.3	58.8
Forest	45.3	51.3	54.8	Venango	46.5	52.5	55.9
Franklin	51.2	57.0	60.4	Warren	45.5	51.8	55.6
Fulton	50.0	55.5	59.0	Washington	50.6	56.5	60.2
Greene	50.2	56.1	59.6	Wayne	45.2	51.3	54.8
Huntingdon	49.6	55.0	58.3	Westmoreland	49.6	55.7	59.4
Indiana	48.5	54.5	58.1	Wyoming	47.1	53.2	56.5
Jefferson	46.8	52.7	56.3	York	52.4	58.4	61.9
Juniata	49.9	55.3	58.6				

Note: 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.