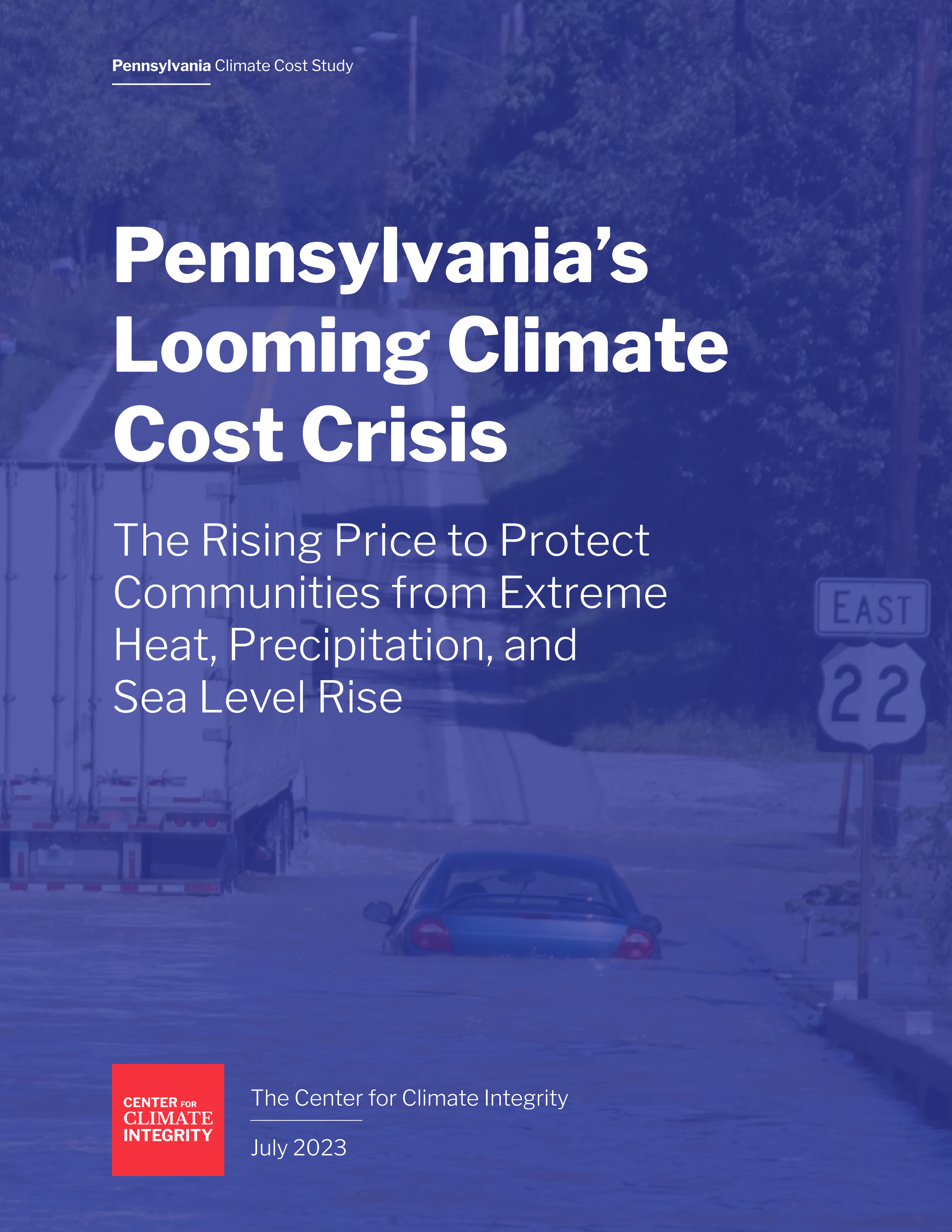




# Pennsylvania's Looming Climate Cost Crisis

## The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise

The Center for Climate Integrity

July 2023

# Pennsylvania's Looming Climate Cost Crisis

## The Rising Price to Protect Communities from Extreme Heat, Precipitation, and Sea Level Rise

This study and the data it produced are available at climateintegrity.org/pa-costs.



The **Center for Climate Integrity** empowers communities and elected officials with the knowledge and tools they need to hold oil and gas corporations accountable for the massive costs of climate change.
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# 1 Executive Summary

In just the past two months, Pennsylvania has witnessed multiple extreme weather events that once would have been considered freak, isolated acts of nature. Torrential rain turned quiet creeks into roaring rivers and killed at least six people in flash floods in Bucks County.[1] Extreme heat forced nearly 100 Philadelphia schools to close early rather than keep students in unsafe classrooms that lacked air conditioning.[2] Pollution from wildfire smoke led state officials to declare a Code Red Air Quality Action Day for all of Pennsylvania,[3] and on June 8, Philadelphia had the worst air quality of any major city in the world.[4]

This relentless onslaught has delivered a clear message across Pennsylvania: the climate crisis is here, it's taking a toll on Pennsylvania's public health and infrastructure, and local governments will need to make significant investments to ensure their communities are resilient to our new unforgiving reality.

**This study is the first-ever attempt to calculate the true costs of the climate crisis on municipal governments across Pennsylvania.**

We estimate:

**Pennsylvania's municipal governments will need to spend at least $15.47 billion by 2040, or nearly $1 billion a year, to protect residents from extreme heat, heavy precipitation events, and rising sea levels.**

This finding is based on a moderate climate scenario (RCP 4.5) and does not account for the costs of recovering from any climate-driven disasters that will almost certainly occur, creating additional damages. This study does not include any costs the state or federal government will pay for and is confined to the municipal costs created by only eight out of many climate impacts that communities will ultimately face. The costs are calculated in 2023 dollars and assume that governments will make less expensive proactive adaptation repairs as opposed to potentially more expensive reactive repairs. Finally, these calculations are limited to the cost of adapting to these climate impacts, not reversing them.

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1 CBS News Philadelphia Staff, "Search continues for missing 9-month-old-baby swept away in Bucks County flash flooding," *CBS News Philadelphia*, July 23, 2023, https://www.cbsnews.com/philadelphia/news/buck-county-flash-flooding-conrad-sheils-search/.

2 Kristen A. Graham, "91 Philly schools will close early Friday because of expected heat," *The Philadelphia Inquirer*, June 1, 2023, https://www.inquirer.com/news/philadelphia-school-district-heat-early-dismissal-closure-air-conditioning-20230601.html.

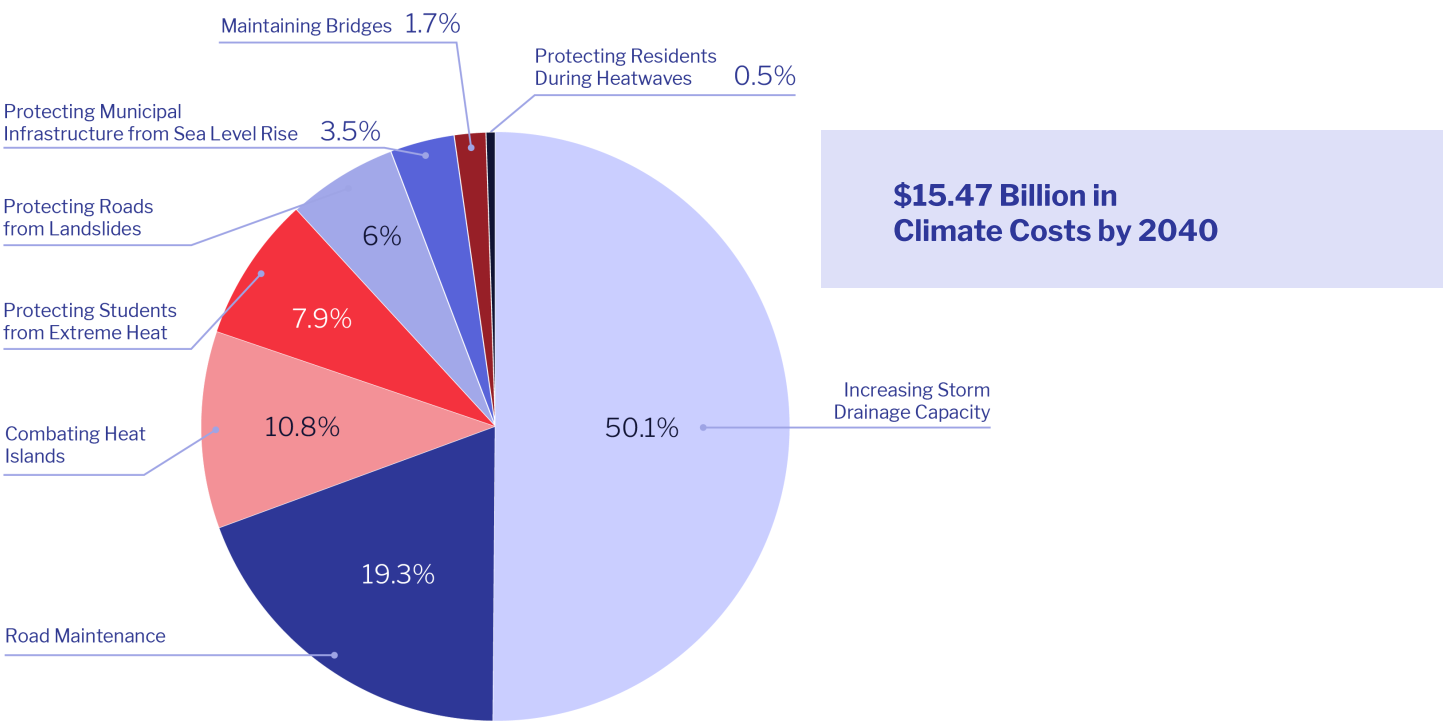
3 Pennsylvania Department of Environmental Protection, "Poor Air Quality Conditions Persist Across Pennsylvania," June 30, 2023, https://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=22314&typeid=1.

4 CBS News Philadelphia Staff, "Philadelphia now has worst air quality compared to all major cities," *CBS News Philadelphia*, June 7, 2023, https://www.cbsnews.com/philadelphia/news/philadelphia-air-quality-smoke-fire-canada-wildfire/.

**We calculated the climate adaptation costs that municipalities will face by 2040 in the following areas:**

- Installing and upgrading air conditioning in schools ($1.23 billion);
- Expanding and operating cooling centers ($78.8 million);
- Planting trees to combat urban heat islands ($1.7 billion);
- Increasing storm drainage capacity to avoid additional sewage overflows and flooding ($7.8 billion);
- Increased road maintenance due to increased heavy rain and heat stress ($2.98 billion);
- Reinforcing bridges against anticipated climate wear and tear ($268 million);
- Protecting against more frequent landslides ($935 million);
- Building coastal defenses to protect infrastructure from rising seas ($547 million).

**Figure 1**: Increasing stormwater drainage capacity makes up half of total climate adaptation costs in Pennsylvania.




**Even with this narrow scope, the impact of climate change on local budgets and taxpayers is potentially calamitous.**

In one quarter of all Pennsylvania counties, municipalities will need to increase their municipal budgets by 5% or more per year to address these eight identified climate change impacts; that's roughly three times the average 1.8% annual municipal tax increase statewide from 1993 to 2021.

- **Philadelphia will need to spend $3.3 billion** to adapt to increasing heat, precipitation, and rising seas by 2040, or approximately $190 million per year. With an annual budget of $5.8 billion in 2023, Philadelphia's annual climate adaptation costs would exceed annual budgets for 40 of the city's 48 departments by 2040. The annual cost of increasing storm drainage capacity, $110 million, is comparable to 96% of the city's 2023 Department of Streets budget.

- **Pittsburgh, Pennsylvania's second-largest city, will face $520 million** in adaptation costs by 2040. This $31 million in annual climate adaptation costs is more than the budgets of 23 of the city's 27 departments, including operations and facilities. Nearly two-thirds of these expenses, $22 million per year, are for storm drainage, with another $5 million to control landslides.

- **Falls Township, a Philadelphia suburb of 34,000 people, would need to increase its annual budget by 43%** to pay for the $290 million in climate adaptation costs, mostly to increase storm drainage capacity and protect against sea level rise, by 2040. This $290 million by 2040 is equal to more than seven years of the township's current $40 million budget.

- **Hempfield, a Pittsburgh suburb of 41,000 people, would have to spend 59% of its $16.3 million annual budget, or about $9.6 million,** on climate adaptations every year until 2040 to stave off climate impacts. Nearly all of these expenses, a whopping $9.4 million, would go toward increased storm drainage capacity and road maintenance costs.

These case studies are based on publicly available municipal budget data, which is limited or simply not available for the majority of Pennsylvania municipalities; it's likely that many more municipalities could have a majority of their budgets consumed by annual climate adaptation costs.

**Table 1.** Local governments facing highest costs from eight climate impacts by 2040.

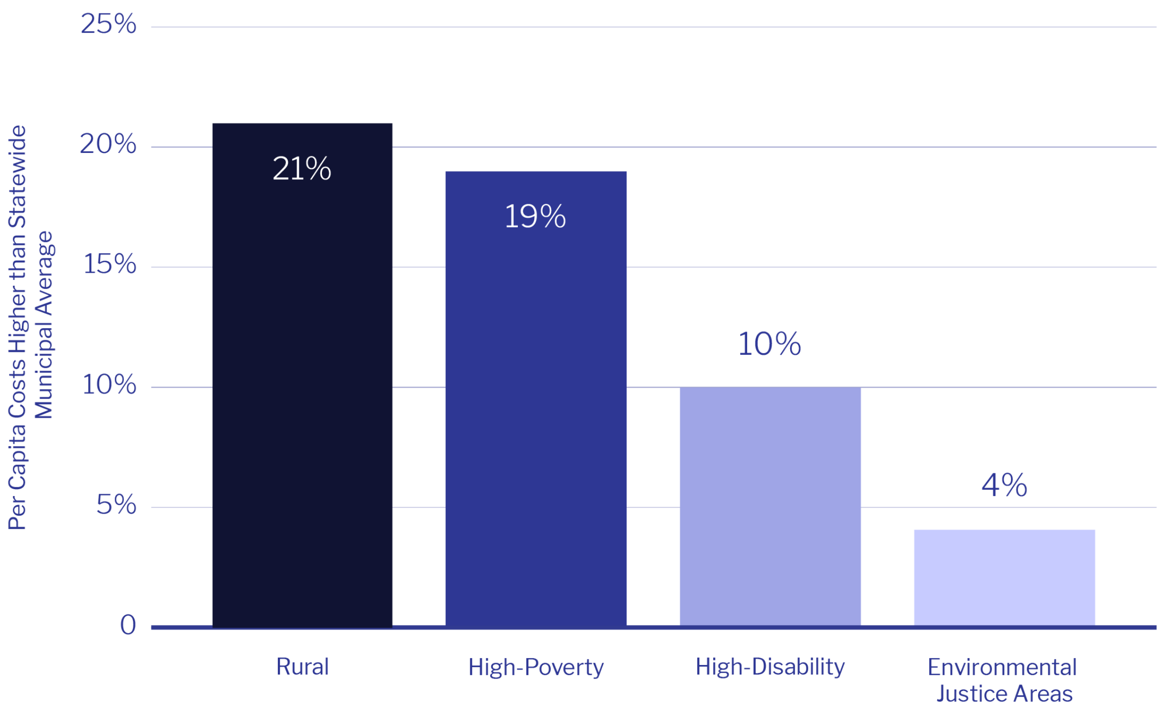
| Rank | Municipality | County | Cost by 2040 |
|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | $ 3,269,396,000 |
| 2 | Pittsburgh | Allegheny County | $ 522,693,000 |
| 3 | Falls | Bucks County | $ 286,507,000 |
| 4 | Hempfield | Westmoreland County | $ 163,914,000 |
| 5 | Unity | Westmoreland County | $ 137,321,000 |
| 6 | Bensalem | Bucks County | $ 119,936,000 |
| 7 | Upper Darby | Delaware County | $ 115,056,000 |
| 8 | Tinicum | Delaware County | $ 99,832,000 |
| 9 | Rostraver | Westmoreland County | $ 87,711,000 |
| 10 | Mount Pleasant | Westmoreland County | $ 86,977,000 |

**The burden of climate adaptation will not fall equally on Pennsylvania residents.**

By 2040, the average Pennsylvania municipality will face $4,930 per capita in climate adaptation costs to protect residents from the eight climate harms analyzed in this report. Pennsylvanians who live in rural, high-poverty, and high-disability areas of the state will face substantially higher costs. Rural communities will face an estimated $5,990 in costs per capita by 2040 because of needed investment in roads, bridges, landslide prevention, and cooling centers. Protecting residents in areas with higher rates of poverty and residents with disabilities will require an estimated $5,870 and $5,420, respectively, because of greater needs for investments in tree planting, stormwater drainage, landslide prevention, and cooling centers.

Communities that Pennsylvania defines as Environmental Justice Areas,[5] areas where at least 20% of the population live at or below the federal poverty line, and/or at least 30% of residents identify as a non-white minority, will also face higher climate adaptation costs than the statewide municipal average. Environmental Justice municipalities will face adaptation costs of an estimated $5,150 per capita by 2040.

**Figure 2**: Rural and high-poverty municipalities face the highest per capita climate adaptation costs.

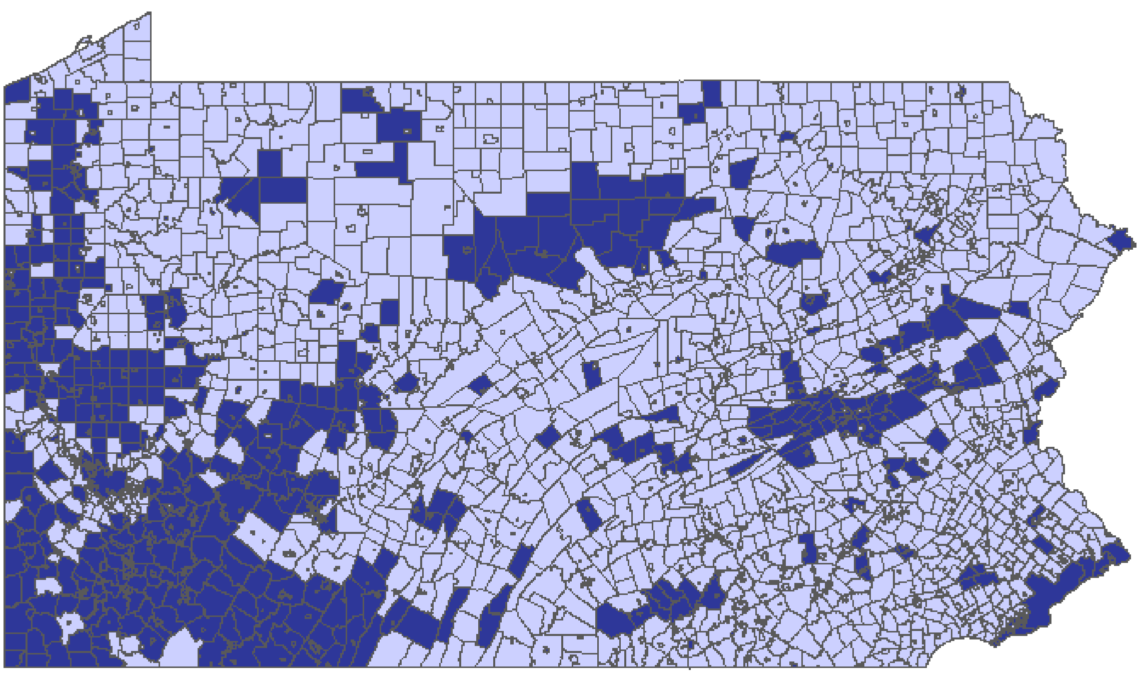



5 Pennsylvania Department of Environmental Protection, "PA Environmental Justice Areas," (accessed on June 27, 2023), https://www.dep.pa.gov/PublicParticipation/OfficeofEnvironmentalJustice/Pages/PA-Environmental-Justice-Areas.aspx.

**Without a viable alternative, Pennsylvania taxpayers are currently on the hook for local municipalities' climate adaptation costs.** Pennsylvania leaders could turn to the federal government for financial assistance, but there is no current source of federal funds for adaptation at this scale, and every other state faces its own significant climate costs. National funds will likely be limited and competitive — and that funding is still coming from taxpayers.

A more just alternative is to make the polluters most responsible for the climate crisis pay their fair share of the costs facing Pennsylvania communities. Major oil and gas companies knew for decades that their products could lead to catastrophic environmental conditions,[6] yet they intentionally obscured climate science and misled the public, while communities in Pennsylvania and across the U.S. paid the price for their pollution. We're in a climate crisis because Big Oil companies lied about their products for decades; it's only right that they pay their fair share of the costs they have imposed on communities.

Dozens of states and communities, including the neighboring states of New Jersey, Delaware, and three Maryland municipalities, have filed lawsuits to recover the costs of climate damages from major oil companies, following the same legal framework as landmark tobacco and opioid lawsuits. Pennsylvania and its local governments should consider similar legal action to make polluters pay their fair share of climate costs and ensure that taxpayers aren't left to pay the bill alone.



**Map 1**: Rural and high-poverty municipalities face the highest per capita climate adaptation costs.

Map developed by Scioto Analysis.



6 Center for Climate Integrity, "The Lie-brary," (accessed on June 27, 2023), https://climateintegrity.org/lie-brary.

# 2 Climate Impacts

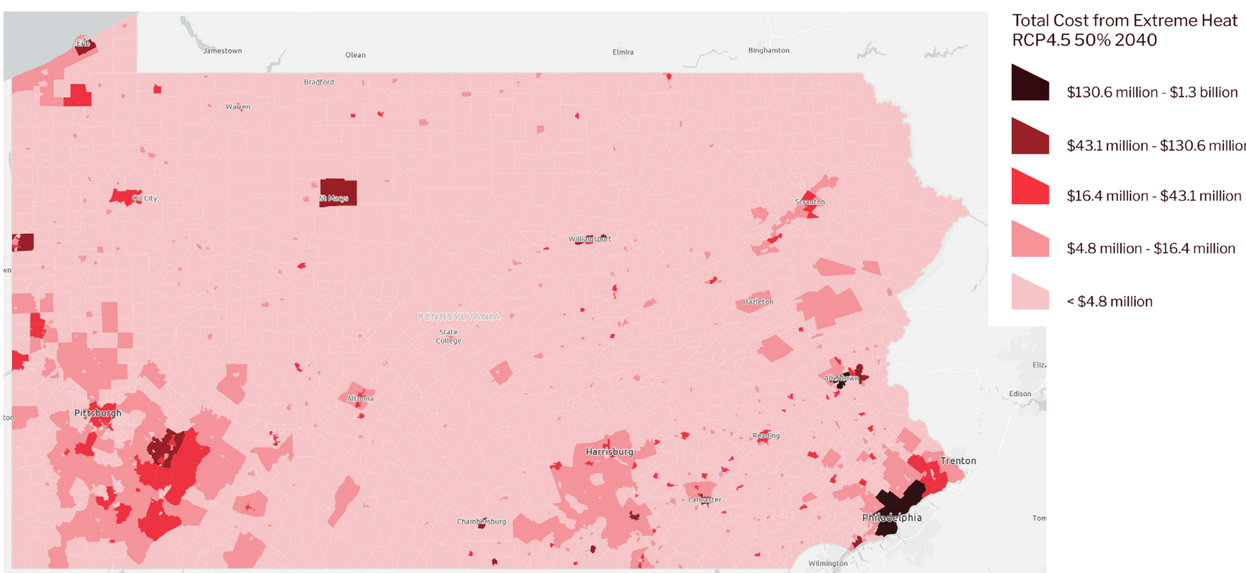
Stormwater runoff in Pittsburgh: July 11, 2019.

# Temperature-Related Impacts

Two decades ago, Pennsylvania experienced an average of five extreme heat days annually, defined as days with a high temperature above 90°F.[7] By 2050, Pennsylvanians will be burdened with 37 extreme heat days annually. As the average annual temperature increases by approximately 6°F by mid-century compared to 1971 to 2000,[8] Pennsylvanians can anticipate more frequent and intense heat waves and hot weather events.

While all Pennsylvanians will feel the rising temperatures, some communities and demographics will likely be disproportionately burdened by the effects of the heat. Philadelphia County residents will experience anywhere from a 23% to 55% higher risk of having a heat-related illness compared to the average county in Pennsylvania. Communities with high rates of languages other than English spoken at home, high percentages of foreign-born populations, and Environmental Justice Areas, defined by the state, are all projected to have heat-illness risk increases higher than the statewide average as well, ranging from 13% to 46% higher than the statewide county average. Counties with high populations of racial minorities are also expected to experience increases in rates of heat-related illness hospitalization that are higher than the statewide county average, with increases ranging from 2% to 20% higher depending on the scenario.

For more information on climate projections see full methodology on page 42.




**Map 2**: The costs of adapting to extreme heat is most significant in high population areas of the state.

Map developed by Resilient Analytics.

7 Pennsylvania Department of Environmental Protection, "Pennsylvania Climate Impacts Assessment 2021," (2021), https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/2021/2-23-21/2021_Impacts_Assessment_Final_2-09-21_clean.pdf.

8 ibid

## Protecting Students from Extreme Heat: $1.23 Billion

A growing body of evidence shows hotter classrooms lead to learning loss and lower test scores.[9] Most schools in Pennsylvania were built well before climate change began driving temperatures up to levels that impact learning. But as Pennsylvania faces many more days over 80°F during the school year — well within the threshold at which students in schools with no AC begin to experience learning loss — tens of thousands of students across the state will be robbed of a fair chance to learn.

At the beginning of the 2022 school year, unusually hot weather led to some Philadelphia classroom temperatures exceeding 90°F. With no infrastructure to cool down the classrooms, 118 Philadelphia schools canceled afternoon classes, limiting instruction time for thousands of students.[10] In June of this year, nearly 100 Philadelphia schools were forced to close early because of extreme heat.[11]

Local municipalities across the state will need to invest $1,230,060,000 in HVAC by 2040 in order to maintain safe classroom temperatures. The highest HVAC costs will be in Philadelphia, which will need to dedicate $152.4 million to keep school classrooms at safe temperatures.

### Classroom Closures

In August 2022, 118 Pennsylvania schools closed early after the first day of the school year[12] as temperatures soared, pushing classroom temperatures into the 90s. Hot weather also triggered similar school closures in June 2023,[13] sending thousands of students home early. While news reports frame the weather as unusually "summerlike,"[14] climate modeling shows that Pennsylvania should expect an additional 37 extreme heat days – days over 90°F – per year by 2040. In addition to learning loss, classroom closures create cascading challenges for parents who rely on in-person school for child care, students who receive their daily meals from school, and all school attendees whose home environments may be even hotter than the school buildings.

9 Joshua Goodman et al., "Heat and Learning," *National Bureau of Economic Research*, Working Paper 24639 (2018), https://www.nber.org/papers/w24639.

10 Aubri Juhasz, "118 Philly schools will close early Tuesday and Wednesday due to high heat," *WHYY*, August 30, 2022, https://whyy.org/articles/100-philadelphia-schools-early-dismissal-high-heat/.

11 Kristen A. Graham, "91 Philly schools will close early Friday because of expected heat," *The Philadelphia Inquirer*, June 1, 2023, https://www.inquirer.com/news/philadelphia-school-district-heat-early-dismissal-closure-air-conditioning-20230601.html.

12 Aubri Juhasz, "118 Philly schools will close early."

13 Kristen A. Graham, "91 Philly schools will close early."

14 Associated Press, "Summerlike Heat Across Great Lakes Region Forces School Closings," *U.S. News & World Report*, June 1, 2023, https://www.usnews.com/news/us/articles/2023-06-01/summerlike-heat-across-great-lakes-region-forces-school-closings.

According to researchers, a 1°F increase in school-year temperature leads to a 1% learning loss on average.[15] Like most climate change impacts, the burden is not felt equally: learning loss from extreme heat days was found to be three times as damaging for students who are Black, Hispanic, or living in the lowest-income ZIP codes.[16] Without mitigation, the authors note, these findings suggest that long-term effects of prolonged heat exposure could threaten the nation's rate of economic growth.[17]

Not surprisingly, school air conditioning "almost entirely offset"[18] the learning impacts caused by hot classroom environments, making the case for cooling infrastructure in schools.

**Table 2**: Pennsylvania municipalities facing the highest costs to install AC in public schools by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 152,397,000 |
| 2 | Pittsburgh | Allegheny County | 302,900 | $ 20,835,000 |
| 3 | Allentown | Lehigh County | 126,000 | $ 16,573,000 |
| 4 | Reading | Berks County | 95,100 | $ 11,363,000 |
| 5 | Upper Darby | Delaware County | 85,700 | $ 7,976,000 |
| 6 | Lancaster | Lancaster County | 58,000 | $ 7,679,000 |
| 7 | Abington | Montgomery County | 58,500 | $ 7,615,000 |
| 8 | Scranton | Lackawanna County | 76,300 | $ 6,830,000 |
| 9 | Bensalem | Bucks County | 62,800 | $ 6,188,000 |
| 10 | Lower Paxton | Dauphin County | 53,500 | $ 6,048,000 |

Municipalities with higher populations of racial minority residents, people born outside of the U.S., and communities facing higher rates of poverty, as well as state-defined Environmental Justice Areas, will face higher per capita school building cooling system installation and upgrade costs by 2040 than the statewide municipal average. Municipalities with greater racial minority populations will face the highest costs of any of the equity categories analyzed, exceeding the statewide municipal per capita average by more than $20, or an increase of 30%.

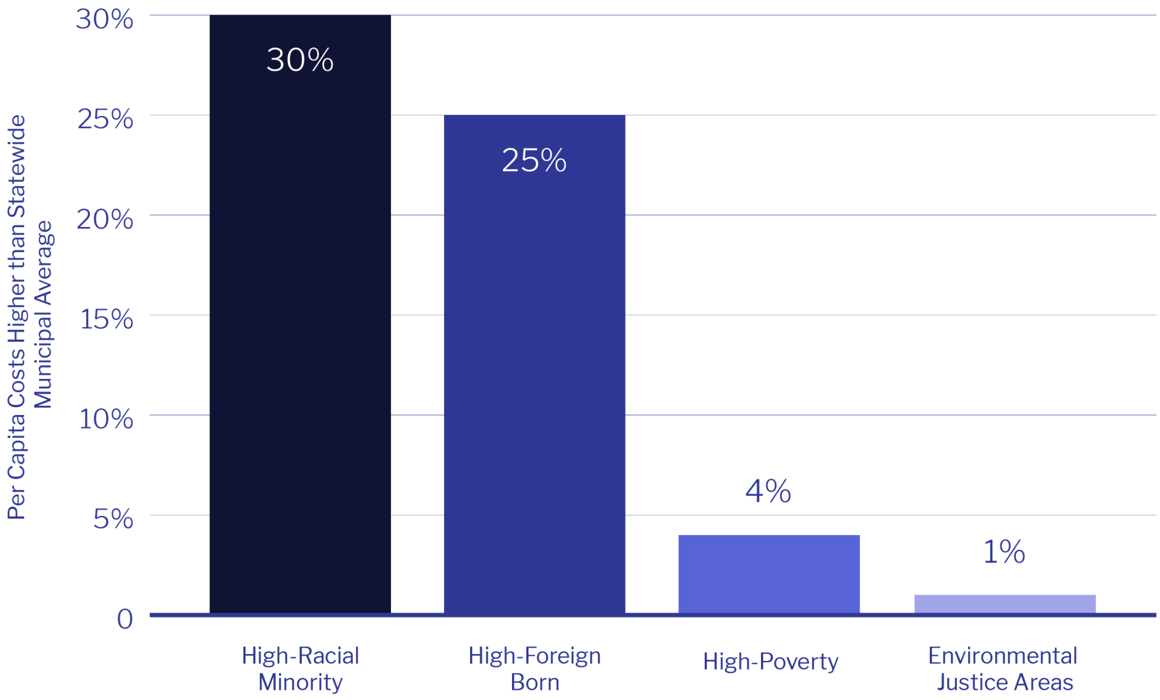
15 Goodman, "Heat and Learning."

16 R. Jisung Park et al., "Heat and Learning," *American Economic Journal: Economic Policy 12*, no. 2 (2020): 306-39, https://www.aeaweb.org/articles/pdf/doi/10.1257/pol.20180612.

17 Goodman, "Heat and Learning."

18 ibid

**Figure 3**: Communities of color face the highest per capita costs for school air conditioning.




## Protecting Residents During Heatwaves: $78.8 Million

Climate change has led to an increase in extreme heat and, by extension, extreme heat-related health impacts like heat stroke and death. As the frequency of hot days and heatwaves ramps up, Pennsylvania municipalities will need to operate additional emergency weather shelters, such as cooling centers. Cooling centers are staffed, air-conditioned spaces stocked with food and hot weather supplies where members of the public can escape the heat. Municipalities that contain "vulnerable areas," like dense populations of older adults, children, people who work outside, unhoused people, communities of color, and low-income communities, are predicted to experience the highest demand for additional cooling centers.[19]

In order to adequately scale-up cooling center operations in heat-vulnerable communities, Pennsylvania municipalities will have to spend approximately $78,777,000 by 2040 to expand and operate cooling centers.

In Philadelphia alone, officials will need to find $2,896,000 in the budget to protect their 1.6 million residents from extreme heat.

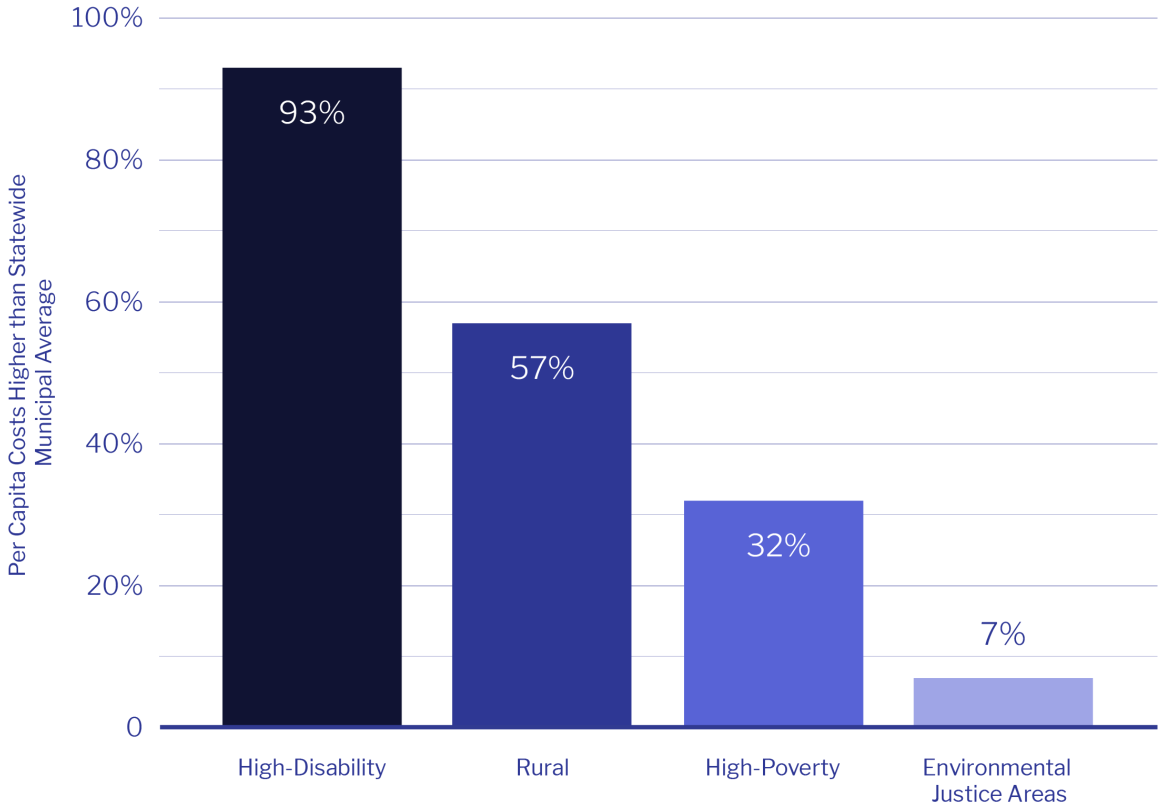
**Table 3**: Pennsylvania municipalities facing the highest costs to maintain and expand cooling centers by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 2,896,000 |
| 2 | St Mary's | Elk County | 12,700 | $ 2,075,000 |
| 3 | Pittsburgh | Allegheny County | 302,900 | $ 1,580,000 |
| 4 | Nesquehoning | Carbon County | 3,300 | $ 776,000 |
| 5 | New Beaver | Lawrence County | 1,400 | $ 646,000 |
| 6 | Hermitage | Mercer County | 16,200 | $ 639,000 |
| 7 | California | Washington County | 5,400 | $ 502,000 |
| 8 | Sugarcreek | Venango County | 4,800 | $ 502,000 |
| 9 | Scranton | Lackawanna County | 76,300 | $ 449,000 |
| 10 | Allentown | Lehigh County | 126,000 | $ 384,000 |

Municipalities with residents who experience higher rates of disability and poverty, as well as rural and Environmental Justice Areas of the commonwealth, are projected to experience higher per capita costs to expand and operate cooling centers than the statewide municipal average. Municipalities with higher numbers of people with disabilities will face per capita cooling center costs at nearly twice the statewide average, while rural areas will face nearly 60% higher costs. Municipalities with higher rates of poverty are projected to experience 30% higher per capita cooling center costs compared to the statewide municipal average.

19 Stasia Widerynski et al., "The Use of Cooling Centers to Prevent Heat-Related Illness: Summary of Evidence and Strategies for Implementation," (2017), *National Center for Environmental Health (U.S.) Division of Environmental Hazards and Health Effects*, https://www.cdc.gov/climateandhealth/docs/UseOfCoolingCenters.pdf.

**Figure 4**: Communities with higher rates of residents with disabilities face nearly twice the statewide average costs for scaling up cooling centers.




## The Threat of Heat

Extreme heat is a stealthy and deadly threat that is only growing as climate change impacts become more severe. Recent research found that 13,000 to 20,000 adult deaths between 2008 and 2017 were linked to extreme heat from a combination of outright hyperthermia and other diseases that were exacerbated by the heat, like heart disease.[20] Seniors, young children, and people with preexisting health concerns are also more susceptible to heat-related illnesses. Cooling centers act as a life-saving resource for residents, especially those who can't afford to install or run air conditioning units during extreme heat events.

20 Sameed Khatana, "The Increasing Death Toll in the U.S. From Extreme Heat," *Time*, July 20, 2022, https://time.com/6198720/heatwave-health-death-toll/.

## Combating Heat Islands: $1.7 Billion

Heat has been the single largest contributor to weather-related deaths in the U.S. over the past 30 years, with heat islands undoubtedly playing a role in that grim statistic.[21] Heat islands are areas where extreme heat is intensified because buildings and roads absorb and radiate the sun's heat, making the area warmer during the day compared to natural spaces like forests and parks,[22] increasing the chances that nearby residents will succumb to heat related illnesses and death.

Planting trees within heat islands is an effective, and common, strategy to reduce the severity of a heat island's impact on the surrounding area.[23]

In order to maintain the impact of heat islands at their current level, which has already been aggravated by climate change, and prevent the creation of more heat islands in Pennsylvania, cities and boroughs will need to spend $1,674,265,000 on planting and maintaining trees in urban areas by 2040.

**Table 4**: Pennsylvania municipalities facing the highest tree planting costs by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 721,511,000 |
| 2 | Allentown | Lehigh County | 126,000 | $ 49,068,000 |
| 3 | Williamsport | Lycoming County | 27,700 | $ 30,514,000 |
| 4 | York | York County | 44,700 | $ 30,287,000 |
| 5 | Chester | Delaware County | 32,600 | $ 29,351,000 |
| 6 | Bethlehem | Northampton County | 56,000 | $ 27,225,000 |
| 7 | Chambersburg | Franklin County | 21,900 | $ 24,311,000 |
| 8 | Pittsburgh | Allegheny County | 302,900 | $ 20,582,000 |
| 9 | Lancaster | Lancaster County | 58,000 | $ 20,563,000 |
| 10 | Reading | Berks County | 95,100 | $ 18,322,000 |

21 National Oceanic and Atmospheric Administration, "Weather Related Fatalities 2022," Weather Related Fatality and Injury Statistics, (accessed June 27, 2023), http://www.weather.gov/hazstat/.

22 Kathleen Hibbard et al., "Changes in land cover and terrestrial biogeochemistry," *Climate Science Special Report: A Sustained Assessment Activity of the U.S. Global Change Research Program*, U.S. Global Change Research Program, (2017): 405-442, https://www.researchgate.net/publication/320820444_Changes_in_land_cover_and_terrestrial_biogeochemistry.

23 X.H. Wang et al., "Urban planning design and sustainable development of forest based on heat island effect," *Applied Ecology and Environmental Research 17*, no. 4 (2019): 9121-9129, https://aloki.hu/pdf/1704_91219129.pdf.

Municipalities with residents experiencing higher rates of poverty, Environmental Justice Areas, and populations with more people with disabilities and racial minorities will face higher per capita costs for planting and maintaining trees to combat heat islands than the statewide municipal average.

Municipalities with high rates of poverty will face the highest costs of any of the equity categories, with the average per capita cost for a high-poverty municipality during the first year of tree planting projected to be $42 — nearly twice the statewide municipal average. Over 20 years, the average high-poverty municipality will pay $132 more per capita than the average municipality statewide.

**Table 5**: High-poverty and environmental justice communities that endure the most dangerous heat face nearly double the statewide average costs for tree canopy installation and maintenance.

| Municipality Type | Year 1 per capita cost | Post year 6 per capita cost | 10-year per capita cost | 20-year per capita cost |
|---|---|---|---|---|
| High-Poverty | $42 | $12 | $154 | $273 |
| Environmental Justice Areas | $37 | $11 | $138 | $245 |
| High-Disability | $30 | $9 | $112 | $199 |
| High-Racial Minority | $26 | $7 | $95 | $169 |
| **Statewide** | **$21** | **$6** | **$79** | **$141** |

### Inequitably Hot

Hunting Park, a north Philadelphia neighborhood surrounded by industrial areas, highways, and minimal tree canopy, reaches temperatures 22°F higher than shadier parts of the city on a hot day, according to Philadelphia city data.[24] Not only do residents lack green spaces to cool off in, but many of the hottest neighborhoods in Philadelphia overlap with the poorest, and historically redlined, areas of the city, limiting residents' access to air conditioning and ability to foot the higher electrical bills that come with it.[25] During a 2018 heat wave, Hunting Park residents Milagros Soto and Pablo Cuevas told WHYY that they couldn't afford an air conditioner, so they watered themselves with a hose and sat in front of a box fan to avoid overheating.[26]

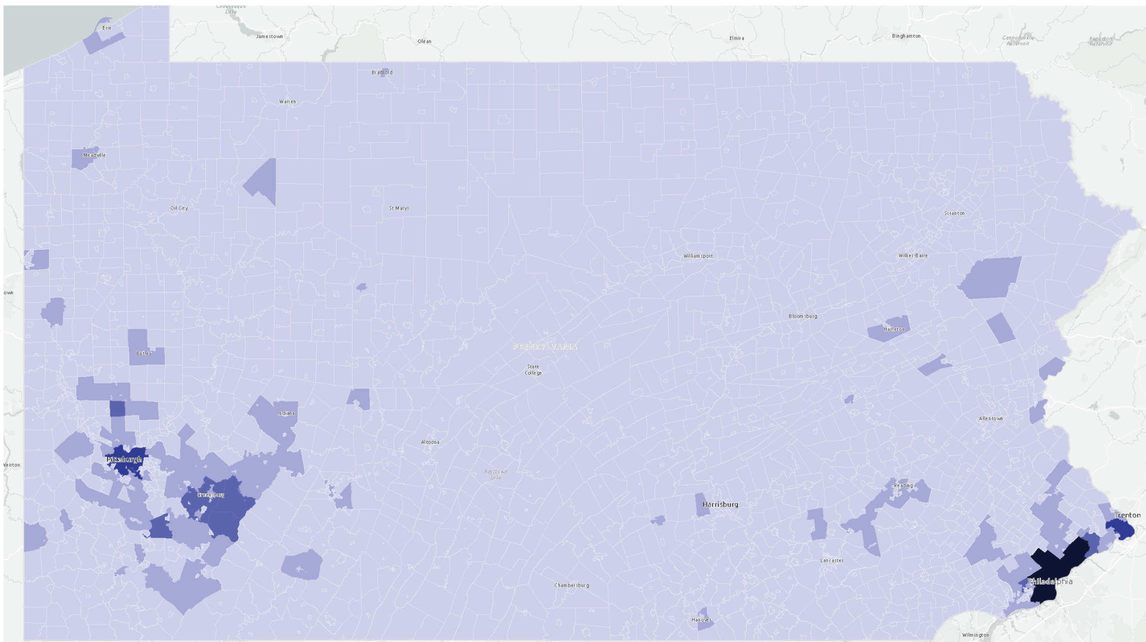
24 City of Philadelphia, *Philadelphia Heat Vulnerability Index*, (n.d.), distributed by ArcGIS, https://phl.maps.arcgis.com/apps/webappviewer/index.html?id=9ef74cdc0c83455c9df031c868083efd.

25 Catalina Jaramillo, "Racism left Hunting Park overheated. Neighbors are making a cooler future," *WHYY*, September 14, 2020, https://whyy.org/articles/racism-left-hunting-park-overheated-neighbors-are-making-a-cooler-future/.

26 Catalina Jaramillo, "Inside Philadelphia's inequitable deadly heat," *WHYY*, July 25, 2018, https://whyy.org/articles/exploring-ways-to-cool-down-neighborhoods-vulnerable-to-the-heat/.

# Precipitation-Related Impacts

From billions of gallons of untreated sewage overflowing into waterways annually,[27] to excessive cracks and potholes rupturing local roads, Pennsylvania's infrastructure is already overwhelmed by the level of precipitation it experiences — and it's going to get worse. Pennsylvania's average annual precipitation has already increased 5% to 10% because of climate change.[28] In addition to continued increases in precipitation, Pennsylvania will also see a shift in the seasonal patterns of precipitation. Scientists predict that Pennsylvania, like neighboring states, will experience less frequent rain, but heavier deluges of rain when precipitation occurs.[29]




**Map 3:** High adaptation costs for more intense storms are concentrated in the Pittsburgh and Philadelphia metro areas.

Map developed by Resilient Analytics.

Total Cost from Extreme Precipitation
RCP4.5 50% 2040

- $475.8 million - $1.9 billion
- $170 million - $475.8 million
- $49.3 million - $170 million
- $11.6 million - $49.3 million
- < $11.6 million

27 Jillian Forstadt, "Report finds ALCOSAN's $2 billion sewage clean-up plan isn't enough to eliminate overflows," WESA, October 13, 2022, https://www.wesa.fm/environment-energy/2022-10-13/report-finds-alcosans-2-billion-sewage-clean-up-plan-isnt-enough-to-eliminate-overflows.

28 United States Environmental Protection Agency, "What Climate Change Means for Pennsylvania," *EPA 430-F-16-040*, August, 2016, https://19january2017snapshot.epa.gov/sites/production/files/2016-09/documents/climate-change-pa.pdf.

29 Pennsylvania Department of Environmental Protection, "Pennsylvania Climate Impacts Assessment 2021."

Previous research has shown that rising flood risk is not distributed equally across communities, with low income residents in urban areas feeling the brunt of the impacts.[30] For example, West Ambler, a Pennsylvania town where residents experience higher rates of poverty and are severely impacted by the mining industry, requires a more complex approach to mitigate urban flooding and associated water contamination.[31] This has led to increased awareness that stormwater management plans should include an environmental justice component.[32]

## Increasing Storm Drainage Capacity: $7.8 Billion

In Pennsylvania's sewer system, it's common for rainwater, wastewater, and sewage to all flow through the same combined system, meaning an increase in any single water source can lead to an overflow of the entire system. Larger rainfall events in Pennsylvania will lead to more sewage system overflows, blockages, and breakages, challenging and finding the failure points in the current infrastructure's capacity.

During extreme weather events, wastewater system operators are often forced to activate a system bypass to allow wastewater to flow past part or all of the treatment process to prevent an overflow. In a typical year, approximately 9 billion gallons of untreated sewage and wastewater overflows into waterways in Allegheny County alone.[33] Throughout 2018, raw sewage flowed into the Susquehanna River near Harrisburg 150 days out of the year.[34] If Pennsylvania does not increase wastewater infrastructure capacity in response to more precipitation, system bypasses will be triggered more often, increasing the amount of raw sewage flowing directly into the surrounding waters and bubbling up through manhole covers on city streets.

In order to keep sewage overflows at current levels and adapt wastewater systems to withstand projected increases in wet weather events, Pennsylvania's municipalities will have to pay $7,755,666,000 by 2040.

30 Simon Moulds et al., "Modeling the Impacts of Urban Flood Risk Management on Social Inequality," *Water Resources Research 57*, no. 6, https://doi.org/10.1029/2020WR029024.

31 Mahbubur Meenar, Richard Fromuth, and Manahel Soro, "Planning for watershed-wide flood-mitigation and stormwater management using environmental justice framework," *Environmental Practice 20*, no. 2-3 (2018): 55-67, https://www.tandfonline.com/doi/abs/10.1080/14660466.2018.1507366.

32 Amy Vanderwarker, "Water, Environmental Justice and Land Use Planning: Richmond, California," *Progressive Planning*, no. 169 (2006): 26-29, http://www.plannersnetwork.org/wp-content/uploads/2012/07/2006_169_fall_p.pdf.

33 PennEnvironment, "Clean Water for the Three Rivers," (October 12, 2022), https://environmentamerica.org/pennsylvania/resources/clean-water-for-the-three-rivers/.

34 Sean Sauro, "Raw sewage was discharged into Harrisburg waterways on 150 days last year," *PennLive*, (July 22, 2019), https://www.pennlive.com/news/2019/07/raw-sewage-was-discharged-into-harrisburg-waterways-on-150-days-last-year.html.

**Table 6**: Pennsylvania municipalities facing the highest costs to expand storm drain capacity by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 1,876,365,000 |
| 2 | Pittsburgh | Allegheny County | 302,900 | $ 382,193,000 |
| 3 | Falls | Bucks County | 34,700 | $ 169,409,000 |
| 4 | Upper Darby | Delaware County | 85,700 | $ 105,525,000 |
| 5 | Hempfield | Westmoreland County | 41,400 | $ 102,300,000 |
| 6 | Bensalem | Bucks County | 62,800 | $ 66,683,000 |
| 7 | Pine | Allegheny County | 14,700 | $ 54,287,000 |
| 8 | Unity | Westmoreland County | 21,600 | $ 50,576,000 |
| 9 | Johnstown | Cambria County | 18,400 | $ 46,163,000 |
| 10 | New Castle | Lawrence County | 22,000 | $ 45,938,000 |

Environmental Justice Areas, municipalities with higher racial minority populations, and municipalities with residents experiencing higher rates of disabilities and poverty, will face higher per capita stormwater drainage costs than the statewide municipal average. Municipalities in Pennsylvania's Environmental Justice Areas will face an average $920 per capita by 2040 to address storm drain capacity — nearly 46% more than the statewide municipal average.

### Deadly Flooding

Flash flooding killed at least six people in Bucks County, Pennsylvania, in mid-July 2023.[35] The sudden deluge turned quiet creeks into roaring rivers, overwhelmed local drainage systems, and created eight-foot floodwaters, trapping residents in their homes and sweeping away at least three cars in a spontaneous torrent.[36] A family driving to a barbeque was caught in the flash flood, forcing them to try to escape their car. The father was able to escape the floodwaters with his 4-year-old son, but the mother and two other children — 9 months old and 2 years old — were swept away in the raging waters. Authorities confirmed the mother and 2-year-old were later found deceased, but they were still looking for the 9-month-old at the time this study was published.

35 CBS News Philadelphia Staff, "Search continues."

36 Anna Betts and Elise Young, "Five Dead in Flash Flooding in Philadelphia Suburbs," *The New York Times*, July 16, 2023, https://www.nytimes.com/2023/07/16/us/pennsylvania-flooding-family.html.

## Maintaining Roads: $2.98 Billion

Wetter weather and greater temperature variations in Pennsylvania will rapidly increase the amount of cracks, potholes, and breakage in roads throughout the state. With higher precipitation comes increased erosion, which will weaken the road base and create more maintenance demands in order to keep the infrastructure functioning as designed.

In order for county and municipal roads to stay at their current service level, Pennsylvania's municipalities will have to pay $2,982,992,000 by 2040 in road maintenance costs. This figure does not include the costs of improving any state roads or highways to combat climate impacts.

Road and bridge damaged by heavy flooding in Lancaster County: 2013

### Notoriously Bumpy Roads

Pennsylvania has gained a reputation for its frequent potholes and poor road conditions that deteriorate both street conditions and local cars. According to reporting by Stacker, Pennsylvania is ranked eighth in the nation for the most pothole complaints and reports from residents, with 15.4 complaints for every 1,000 km of road.[37] Another report found that the state ranks in the bottom 10 in the nation for road conditions.[38] Driving on poor roads can cost the average driver more than $600 in annual car maintenance costs[39] — a burden that will worsen if road conditions are not maintained as climate change ramps up potholes and cracks.

37 Stacker, "Pennsylvania among states with the most pothole complaints," *ABC27 WHTM*, February 21, 2022, https://www.abc27.com/news/top-stories/pennsylvania-among-states-with-the-most-pothole-complaints/.

38 Baruch Feigenbaum, Truong Bui, and Thuy Nguyen, "27th Annual Highway Report: State Summaries," Reason Foundation, (2023): 115-118, https://reason.org/wp-content/uploads/27th-annual-highway-report-state-by-state-summaries.pdf.

39 Stacker, "Pennsylvania among states with the most pothole complaints."

**Table 7**: Pennsylvania municipalities facing the highest road maintenance costs by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 172,980,000 |
| 2 | Hempfield | Westmoreland County | 41,400 | $ 57,377,000 |
| 3 | Bensalem | Bucks County | 62,800 | $ 26,506,000 |
| 4 | Middletown | Bucks County | 46,000 | $ 24,934,000 |
| 5 | Unity | Westmoreland County | 21,600 | $ 24,843,000 |
| 6 | Scranton | Lackawanna County | 76,300 | $ 24,451,000 |
| 7 | Bristol | Bucks County | 54,400 | $ 23,166,000 |
| 8 | North Union | Fayette County | 11,800 | $ 22,981,000 |
| 9 | East Huntingdon | Westmoreland County | 7,700 | $ 20,999,000 |
| 10 | Bullskin | Fayette County | 6,700 | $ 19,519,000 |

Municipalities in rural parts of the state and populations experiencing higher rates of disabilities will face higher per capita road costs than the statewide municipal average. Rural municipalities will face an average per capita cost of approximately $460 to maintain roads by 2040, approximately 27.4% higher than the municipal average across the state.

## Maintaining Bridges: $268 Million

An increase in precipitation will lead to greater flow rates in Pennsylvania's waterways. More vigorous flow rates will put more wear and tear on the bases and pillars of bridges. While there are multiple climate-related costs associated with bridge maintenance, this study quantifies the cost of proactively protecting the base of bridges to prevent wear and tear that could threaten the structural integrity of the bridge. Pennsylvania municipalities will have to pay $268,511,000 by 2040 to maintain their bridges in the face of climate-fueled weather.

**Table 8**: Pennsylvania municipalities facing the highest bridge maintenance costs by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 12,039,000 |
| 2 | Pittsburgh | Allegheny County | 302,900 | $ 8,577,000 |
| 3 | Allentown | Lehigh County | 126,000 | $ 5,353,000 |
| 4 | York | York County | 44,700 | $ 2,950,000 |
| 5 | Scranton | Lackawanna County | 76,300 | $ 2,740,000 |
| 6 | Whitehall | Lehigh County | 29,200 | $ 1,891,000 |
| 7 | Glassport | Allegheny County | 4,500 | $ 1,816,000 |
| 8 | Stowe | Allegheny County | 6,400 | $ 1,585,000 |
| 9 | Turtle Creek | Allegheny County | 5,100 | $ 1,513,000 |
| 10 | Bethlehem | Lehigh County | 19,800 | $ 1,413,000 |

Rural municipalities and municipalities with high rates of residents who speak languages other than English at home are projected to experience higher per capita bridge maintenance costs than the statewide municipal average. Rural municipalities will face 33% higher per capita costs to repair and maintain bridges by 2040 than the average municipality.

### Overwhelmingly Poor Bridges

Pennsylvania has some of the worst bridge conditions in the country, ranking second in the nation for the largest number of bridges designated to be in "poor" condition by the Federal Highway Administration.[40] Philadelphia captured national attention in June when an Interstate 95 overpass collapsed, shutting down a major trucking route, disrupting more than 150,000 daily commuters, and demanding a massive mobilization of emergency workers to clear the rubble and rebuild the overpass.[41] While the bridge collapse was triggered by a fire, not climate change, the catastrophic event provided insight into the massive traffic burdens, emergency response, and potential loss of life if Pennsylvania municipalities don't respond proactively to worsening bridge conditions caused by climate change.

40 Alison Premo Black, "2022 Bridge Report," *American Road & Transportation Builders Association*, (2022), https://artbabridgereport.org/reports/2022-ARTBA-Bridge-Report.pdf.

41 Colbi Edmonds, "After Dramatic I-95 Collapse in Philadelphia, State Accelerates Repairs," *The New York Times*, (June 22, 2023), https://www.nytimes.com/2023/06/22/us/i-95-collapse-philadelphia-repairs.html.

## Protecting Roads from Landslides: $935 Million

More precipitation leads to oversaturated and unstable ground, increasing Pennsylvania's chances for landslides. Parts of the state, such as the Pittsburgh area, are uniquely susceptible to landslides because of their geology and will face greater prevention costs, such as building retaining walls. As a result of climate-caused precipitation increases throughout the state, Pennsylvania municipalities will need to spend $935,786,000 by 2040 to protect public roads against landslides.

**Table 9**: Pennsylvania municipalities facing the highest landslide prevention costs by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 107,840,000 |
| 2 | Pittsburgh | Allegheny County | 302,900 | $ 85,049,000 |
| 3 | Unity | Westmoreland County | 21,600 | $ 59,068,000 |
| 4 | Mount Pleasant | Westmoreland County | 10,200 | $ 49,535,000 |
| 5 | Rostraver | Westmoreland County | 11,400 | $ 40,401,000 |
| 6 | Monroeville | Allegheny County | 28,600 | $ 35,096,000 |
| 7 | Penn Hills | Allegheny County | 41,000 | $ 26,693,000 |
| 8 | Murrysville | Westmoreland County | 21,000 | $ 26,216,000 |
| 9 | Penn | Westmoreland County | 20,000 | $ 25,849,000 |
| 10 | Moon | Allegheny County | 27,200 | $ 25,403,000 |

Rural municipalities, as well as municipalities with residents experiencing higher rates of poverty and disabilities, are projected to experience higher per capita landslide costs than the statewide municipal average. Rural municipalities will face the highest costs per capita at $110 by 2040, compared to the statewide municipal average of roughly $70.

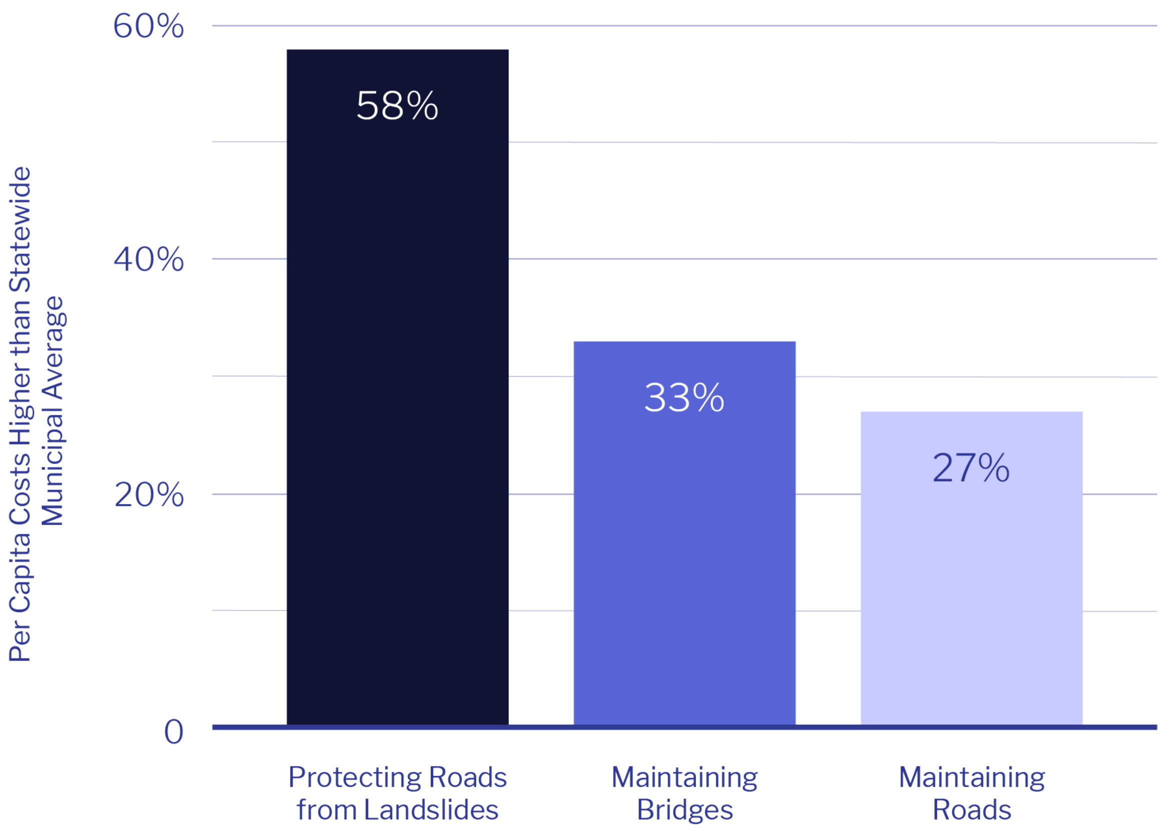
### Slippery Slopes

Sloping banks along Pennsylvania's rivers and hilly landscapes combined with the state's wet weather have made landslides commonplace in the commonwealth. While Pennsylvania is well-practiced in responding to and cleaning up landslides,[42] the already increasing rate of landslides is outpacing the state's annual budget to provide emergency clean up and diverting money that could have been spent on other public infrastructure projects. Additionally, landslides that occur on homeowners' land are often not covered by insurance, leaving some residents with repair bills as high as $1 million.[43] As climate change increases the likelihood of landslides, the geological shifts could become a source of housing instability without mitigating infrastructure or a dedicated financial aid source for landslide victims.

42 John Hayes, "Pa. emergency workers deployed to California disaster for flood and lanslide assistance," *Pittsburgh Post-Gazette*, (January 23, 2023), https://www.post-gazette.com/news/state/2023/01/23/california-disaster-flooding-storm-pennsylvania-emergency-management/stories/202301220167.

43 Quinn Glabicki and Charlie Wolfson, "Slippy slopes: Pittsburgh, built on slide-prone riverbanks, could face a deluge of impacts from climate change," *PublicSource*, (January 5, 2023), https://www.publicsource.org/pittsburgh-landslides-2022-pennsylvania-allegheny-county-climate-change/.

**Figure 5**: Rural municipalities will face the highest per capita costs for maintaining roads and bridges and protecting roads from landslides.



# Sea Level Rise

With 56 miles of coastline along the Delaware Estuary and extensive tidal rivers, Pennsylvania faces a serious threat from sea level rise. Under even moderate climate change scenarios, the sea level is expected to rise 2.1 feet by mid-century and 4.7 feet by the end of the century.[44]

## Protecting Public Infrastructure: $547 Million

Roads, rails, and other public infrastructure will be hit with unavoidable rising tides, unless state officials invest in mitigating infrastructure, such as seawalls. This study provides a planning-level assessment of the cost to build coastal and inland seawalls in every location in Pennsylvania that will need some form of protection against rising seas. In reality, most communities will be grappling with complicated, multi-faceted engineering solutions, higher costs, and painful decisions about "managed retreat", displacing residents prior to the water's arrival at their doorstep.

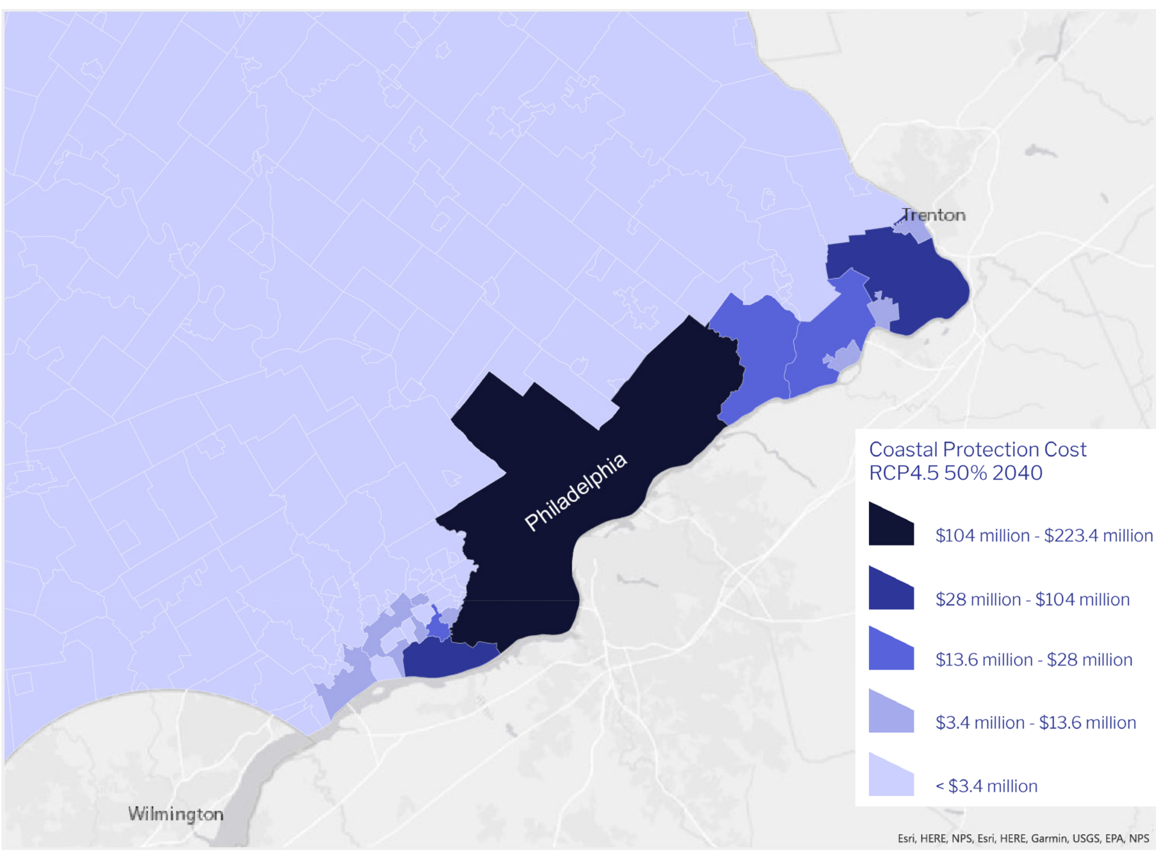
By 2040, Pennsylvania will need to invest $547,640,000 to protect public infrastructure from rising sea levels.


Storm surge flooding during Hurricane Ida: September 2, 2021.

44 U.S. Army Corps of Engineers, "Sea Level Change Curve Calculator," https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html.

**Table 10**: Pennsylvania municipalities facing the highest seawall construction costs by 2040.

| Rank | Municipality | County | Population | Cost by 2040 |
|---|---|---|---|---|
| 1 | Philadelphia | Philadelphia County | 1,603,800 | $ 223,368,000 |
| 2 | Falls | Bucks County | 34,700 | $ 103,949,000 |
| 3 | Tinicum | Delaware County | 4,000 | $ 68,805,000 |
| 4 | Folcroft | Delaware County | 6,800 | $ 27,991,000 |
| 5 | Bristol | Bucks County | 54,400 | $ 27,394,000 |
| 6 | Bensalem | Bucks County | 62,800 | $ 20,412,000 |
| 7 | Tullytown | Bucks County | 2,300 | $ 13,641,000 |
| 8 | Bristol | Bucks County | 9,800 | $ 8,846,000 |
| 9 | Ridley | Delaware County | 31,000 | $ 7,945,000 |
| 10 | Chester | Delaware County | 32,600 | $ 7,931,000 |




**Map 3:** Philadelphia will need to spend hundreds of millions to protect itself from storm surge and rising seas.

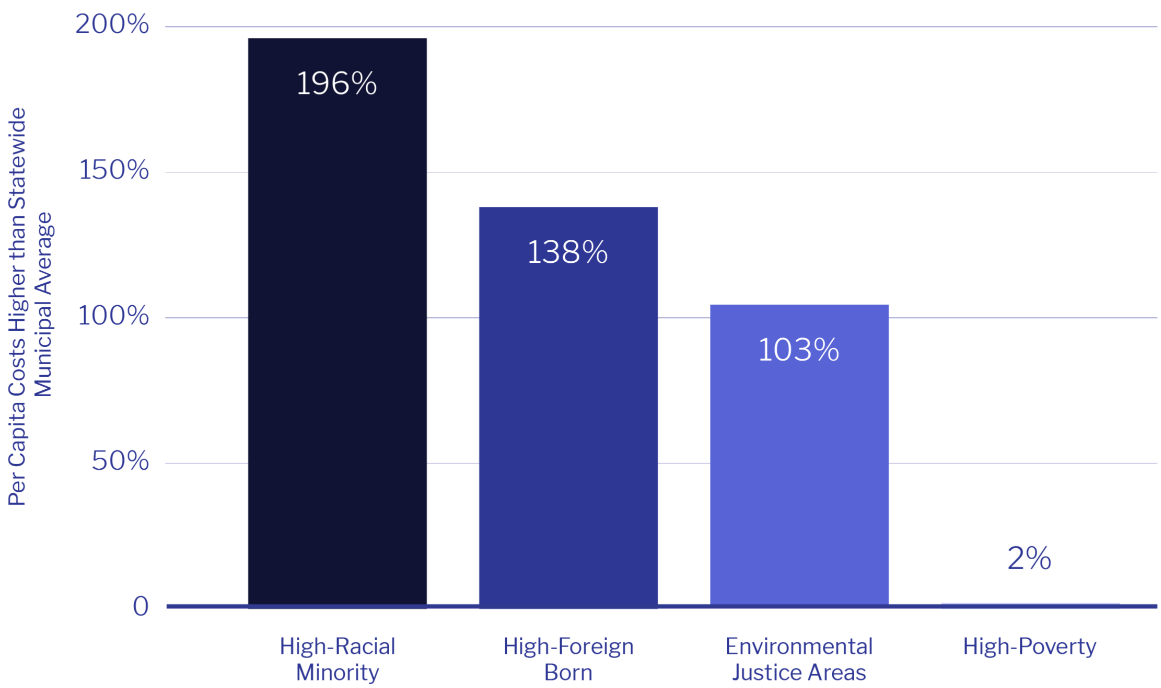
Map developed by Resilient Analytics.

Communities bearing costs for floodproofing tend to be high-racial minority, high-poverty, high-foreign born, and high-non-English-speaking compared to the rest of the state. While only 11% of municipalities statewide are high-racial minority, 75% of communities incurring sea level rise costs are. Only 10% of municipalities statewide have high concentrations of residents experiencing poverty, but 39% of communities incurring sea level rise costs are impoverished.

Immigrant communities are also concentrated on the coast, with 25% of coastal or tidal river-adjacent communities having high-foreign born communities compared to 6% statewide and 11% of river-adjacent communities having high levels of non-English speaking households compared to 5% statewide.

Municipalities with high racial minority populations will face per capita sea level rise adaptation costs more than three times the statewide municipal average. Municipalities with higher rates of residents born outside the U.S. and municipalities that fall under Environmental Justice Areas will also face higher adaptation costs than the statewide municipal average.

**Figure 6**: Municipalities with high racial minority populations, higher rates of residents born outside the U.S., and Environmental Justice Areas will face higher per capita costs to adapt to sea level rise than the average Pennsylvania municipality.



# 2 Pennsylvania Local Government Budget Analysis

## Budget Analysis

The budget analysis presented in this report is based on data from the Annual Survey of State and Local Government Finances,[45] which aggregates municipal spending to the county level, in order to create a baseline for local costs. Therefore, the results presented in this section are an aggregation of municipal spending by county. Costs for communities with populations fewer than 100 were excluded from per capita budget analysis because, while some of these smaller communities will experience devastating climate impacts, applying cost models to such small populations can create outlying cost estimates and uncertainty in the overall data. School budget spending is not included in this analysis.

**In one quarter of all Pennsylvania counties, municipalities will need to increase their budgets by 5% or more to address these eight identified climate change impacts.**

Comparatively, average annual tax increases hover around 1.8% from 1993-2021, meaning that municipalities facing budget increases of 5% or more would need to nearly triple their annual tax increases to cover climate adaptation costs in their annual budgets, according to data from the Annual Survey of State and Local Government Finances.

**Table 13**: Five largest and smallest Pennsylvania counties by local government expenditures (according to the Annual Survey of State and Local Government Finances).

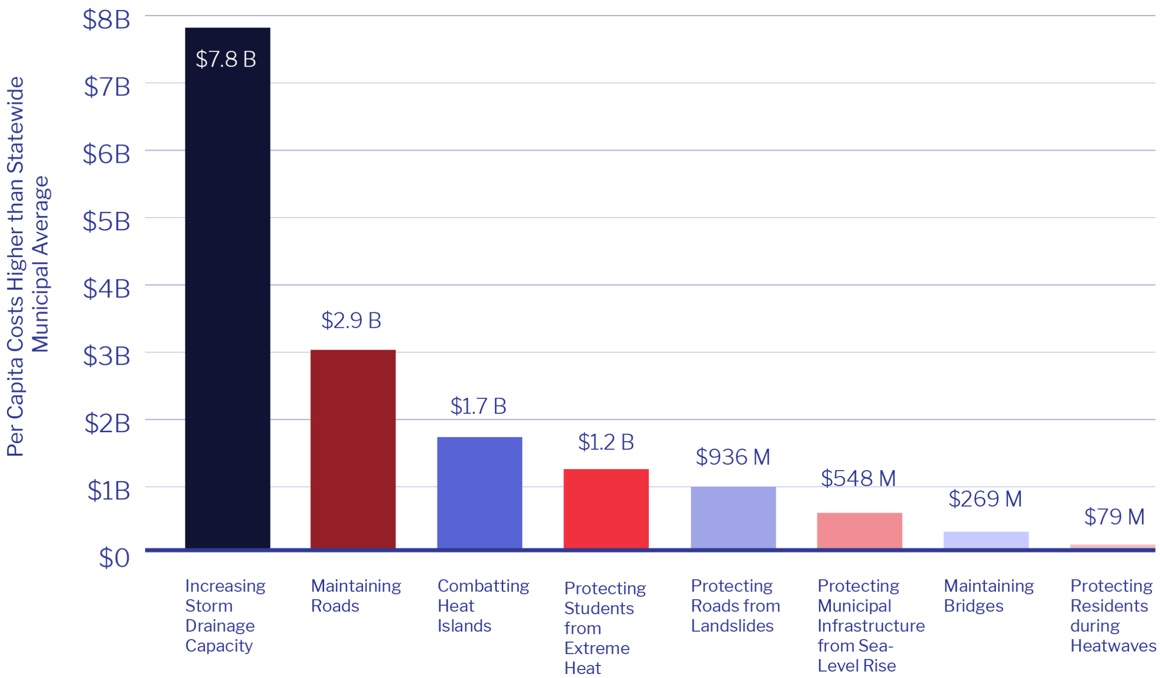
| County | Total Local Government Expenditures |
|---|---|
| Philadelphia County | $ 9,511,198,000 |
| Allegheny County | $ 4,294,035,000 |
| Montgomery County | $ 1,831,243,000 |
| Delaware County | $ 1,607,946,000 |
| Bucks County | $ 1,316,228,000 |
| Juniata County | $ 21,517,000 |
| Fulton County | $ 18,526,000 |
| Sullivan County | $ 16,289,000 |
| Forest County | $ 12,744,000 |
| Cameron County | $ 9,536,000 |

45 United States Census Bureau, "Annual Survey of State and Local Government Finances," (accessed February, 2023), https://www.census.gov/programs-surveys/gov-finances.html.

Municipalities in four counties, Fayette, Westmoreland, Forest, and Indiana counties, will need to increase their spending by 10% or more, increasing three of the county budgets to more than $100 million.

Of the eight climate costs categories, addressing storm drainage capacity makes up 50% of the total costs by 2040, followed by road maintenance at 19%. About 11% of the total costs are from necessary tree planting, installing cooling systems in schools accounts for 8%, and 6% of the total costs are from protecting against landslides. Building seawalls accounts for 4% of total costs, 2% is from bridge maintenance costs, and expanding cooling centers is 1% of the total climate adaptation costs.

**Figure 7**: Upgrading stormwater drainage capacity to manage more severe precipitation is the largest municipal climate cost by far.



# Municipal Fiscal Stress

The rising costs of climate adaptation for Pennsylvania's municipal governments will place enormous stress on local revenue sources. One way to analyze fiscal stress at the municipal level is to compare per capita costs of adaptation to historical growth in local government revenues.

The Annual Survey of State and Local Government Finances shows that local general revenue in Pennsylvania increased from $21 billion to $43 billion from 2000 to 2020.[46] Adjusted for inflation, this represents an annual tax increase of $1,000 per capita.[47]

Therefore, if municipal governments are facing annual spending increases of $1,000 per capita from costs related to climate change, that means climate costs would consume the entirety of the historical average annual municipal revenue growth. This would constitute a severe fiscal stress for local governments.

After accounting for the eight climate-driven costs estimated in this report — protecting students and residents from extreme heat, mitigating heat island effect, increasing storm drainage capacity, maintaining roads and bridges, protecting roads from landslides, and adapting to sea level rise — four Pennsylvania municipalities with populations of 100 or greater will incur annual per capita climate costs of $1,000 or more: Kingsley Township (Forest County), Franklin Borough (Cambria County), Tinicum Township (Delaware County), and Glenfield Borough (Allegheny County).

- **Kingsley Township (Forest County)** is projected to have the highest total annual per capita climate costs, at a total additional cost of $3,700 per capita. This is because the township's small population, just 300 people, is expected to endure a total projected cost of $16 million to protect their roads from landslides.
- **Franklin Borough (Cambria County)** will have to spend over $1,600 per capita per year before 2040, mostly from costs to increase stormwater drainage capacity.
- **Tinicum Township (Delaware County)** is projected to spend $1,474 per capita per year on climate adaptation costs by 2040.
- **Glenfield Borough (Allegheny County)** will face climate adaptation costs of $1,103 per capita per year before 2040.

46 United States Census Bureau, "2000 Annual Surveys of State and Local Government Finances", (accessed February 23, 2023), https://www2.census.gov/programs-surveys/gov-finances/tables/2000/summary-tables/00slss2.xls.

47 United States Bureau of Labor Statistics, "CPI Inflation Calculator," (accessed February 23, 2023), https://www.bls.gov/data/inflation_calculator.htm; United States Census Bureau, "2020 Census Data," (accessed February 23, 2023), https://data.census.gov/all?q=population+of+pennsylvania+in+2020.

# 3 Case Studies

## Philadelphia

**$3.3 billion needed for climate resilience and adaptation by 2040**
Philadelphia is Pennsylvania's largest city and the sixth-largest city in the United States.[48] Philadelphia's 2023 budget is $5.8 billion.[49] The $3.3 billion estimated to address climate resilience and adaptation in Philadelphia by 2040 is equal to over half the annual revenue of the city.

If Philadelphia's $3.3 billion in climate change costs were annualized at $190 million, the annual climate costs would exceed spending for 40 of the city's 48 departments, including the entire city Department of Human Services or Department of Public Health. Philadelphia's largest category of climate spending, increasing storm drainage capacity, will come out to an average of $110 million a year; this is equivalent to 96% of the city's entire 2022 Department of Streets budget.

## Pittsburgh

**$520 million needed for climate resilience and adaptation by 2040**
Pittsburgh is Pennsylvania's second-largest city and has a total budget of $660 million for 2023.[50] The city's forecasted total climate change adaptation spending by 2040 is $520 million: 80% of Pittsburgh's entire 2023 budget.

If Pittsburgh's $520 million in climate adaptation costs are annualized at $31 million, it will amount to more than the total spending for 23 of its 27 city departments, including operations, facilities, and office of management and budget spending. Only the finance, police, fire, and human resources and civil services budgets would exceed annual climate adaptation spending.

The largest category of climate adaptation spending in Pittsburgh is stormwater drainage, at projected costs of $380 million by 2040. This comes out to an annual cost of $22 million, which would consume 35% of the city's 2022 Public Works budget.

48 United States Census Bureau, "City and Town Population Totals: 2020-2022," (accessed April 17, 2023), https://www.census.gov/data/tables/time-series/demo/popest/2020s-total-cities-and-towns.html.

49 Office of the Controller, City of Philadelphia, "Interactive: The Proposed FY23 Budget," April 4th, 2022, https://controller.phila.gov/philadelphia-audits/the-proposed-fy23-budget/.

50 Pittsburgh City Council, "2023 Operating Budget & Five Year Plan," (accessed April 17, 2023), https://apps.pittsburghpa.gov/redtail/images/20124_2023_Operating_Budget.pdf.

## Falls Township

**$290 million needed for climate resilience and adaptation by 2040**

Falls Township is a suburban Philadelphia township of 34,000 people located across the Delaware River from Trenton, New Jersey. Falls Township has budgeted $40 million of municipal spending for fiscal year 2023.[51] Its $290 million in projected climate adaptation costs by 2040 is equal to over seven years of Falls Township's total municipal spending. If these costs were spread out over the 17 years before 2040, Falls Township would need to increase its municipal budget by 43% in order to finance its climate adaptation demands.

The largest categories of costs for Falls Township are stormwater drainage at $170 million total or $10 million per year, and sea level rise at $104 million total or $6.1 million per year. These two costs each are higher than 18 of 20 spending categories in Falls Township's budget, coming only behind police and a general "other financing uses" category. This means Falls Township will have to spend more per year on stormwater drainage than on employee benefits, its public works department, code enforcement, debt service, and its finance department combined.

## Hempfield Township

**$9.6 million needed for climate resilience and adaptation by 2040**

Hempfield is a township in Westmoreland County, about 20 miles southeast of Pittsburgh. It's the largest suburb of Pittsburgh with more than 41,000 residents. Hempfield's 2023 budget projects municipal spending to be $16.3 million.[52] By 2040, Hempfield is projected to face $9.6 million annually in climate adaptation costs, almost 59% of its total budget today.

The largest of these costs is spending to improve stormwater drainage, with Hempfield expected to incur an average annual stormwater drainage cost of $6 million, roughly the same amount as the municipality's entire general budget. The other major cost for Hempfield is additional road maintenance. Hempfield is projected to face $3.4 million annually in additional road repairs as a result of climate change, which is triple its current spending on all parks and recreation.

51 Township of Falls, "2023 Adopted Budget," (accessed April 18, 2023), https://www.fallstwp.com/media/3722/2023-adopted-budget.pdf.

52 Hempfield Township, "Budget Information," (accessed April 18. 2023), https://www.hempfieldtwp.com/228/Budget-Information.

## Unity Township

**$8.1 million needed for climate resilience and adaptation by 2040**
Unity is a township of almost 22,000 people in Westmoreland County with $7.6 million in municipal expenses in its 2023 budget.[53] By 2040, Unity is expected to face $8.1 million in additional annual costs as a result of climate change. This means that in order to pay for these expenses, Unity would need to increase its total municipal expenditures by 107%.

The largest individual climate adaptation cost is the increased incidence of landslides, which are expected to cost Unity $3.5 million annually.

## Tinicum Township

**$99.8 million needed for climate resilience and adaptation by 2040**
Tinicum is a township in Delaware County on the southern edge of Philadelphia and is home of the Philadelphia International Airport. It has a population of more than 4,000, and in 2023 it expects to spend $2.1 million for its total budget.[54]

Situated along the Delaware River, Tinicum is vulnerable to rising sea levels. In order to protect infrastructure from this single climate impact, Tinicum will need to spend an average of $4 million annually, an almost 200% increase over their entire municipal budget. Additionally, Tinicum will need to improve its stormwater drainage infrastructure to counter the effects of climate change — an additional $1.8 million in annual climate adaptation costs. In total, all of the climate adaptations outlined in this report will require Tinicum to increase its total municipal budget by 277% annually by 2040.

53 Amy Fauth, “Unity Township Adopts 2023 Budget,” *Latrobe Bulletin*, December 9, 2022, https://www.latrobebulletinnews.com/news/local/unity-township-adopts-2023-budget/article_9ce36a90-551e-57a9-a38d-d07ae15cd132.html.

54 Tinicum Township, “2023 Proposed Budget Draft,” October 24, 2022, http://www.tinicumbucks.org/township_docs/web%20Advertised%202023%20Proposed%20Budget.pdf.

# 4 Conclusion

This report identifies more than $15 billion in climate adaptation costs Pennsylvania's local governments face by 2040, but these figures capture only a portion of the total bill that climate polluters have wracked up for Pennsylvania taxpayers.

Without further action, the burden of paying for these necessary measures will fall on the same residents who are suffering from heatwaves, intense flooding, and crumbling infrastructure. Many municipalities will simply not be able to afford these costs to protect communities and infrastructure, and their residents will pay an even greater price as the climate crisis worsens. Our findings show that Pennsylvania communities with rural populations, higher rates of poverty, higher rates of disability, and Environmental Justice Areas will often be the hardest hit by projected future impacts.


Landslide affects Route 30 in East Pittsburgh: April 10, 2018.

Pennsylvania communities did not create the climate crisis; major oil and gas companies did. Just 100 companies are responsible for more than 70% of global emissions since 1988, with ExxonMobil, Shell, Chevron, and BP ranking among the most egregious polluters.[55] It's only fair for major polluters that knowingly caused and profited from the climate crisis to pay their share of the resulting costs.

When state and local governments have sought to hold corporations accountable and recover costs incurred by harmful products, they have traditionally turned to the courts. Successful legal actions to make tobacco companies, opioid manufacturers, and other deceitful actors pay for the damages they've caused provide a familiar model.

Across the country, there is now also a viable path for cost recovery litigation against major oil and gas companies that lied to the public about their products and continue to profit from climate destruction.

A growing number of state and local governments are taking legal action to hold oil majors accountable for the cost to protect communities from climate damages.[56] These cases received a major boost this spring when the U.S. Supreme Court denied fossil fuel industry requests to stop them from advancing in state courts.[57] Notably, one of the rulings the high court let stand was a decision from the U.S. Court of Appeals for the Third Circuit affirming that climate accountability lawsuits from the State of Delaware and Hoboken, New Jersey, could proceed toward trial in state courts. That same appeals court has jurisdiction over Pennsylvania.

Rising sea levels, more frequent hotter days, and larger rainfall events are an unavoidable part of Pennsylvania's future, but passing the burden of paying for climate adaptation to taxpayers doesn't have to be. Pennsylvania leaders have an opportunity to take bold action to protect their residents by holding fossil fuel companies accountable and demanding these polluters pay their fair share of the crisis they imposed on Pennsylvanians.

55 Tess Riley, "Just 100 companies responsible for 71% of global emissions, study says," *The Guardian*, July 10, 2017, https://www.theguardian.com/sustainable-business/2017/jul/10/100-fossil-fuel-companies-investors-responsible-71-global-emissions-cdp-study-climate-change.

56 Center for Climate Integrity, "Climate Liability Litigation," (accessed June 27, 2023), https://climateintegrity.org/cases.

57 Dharna Noor, " 'Game Changing:' spate of US lawsuits calls big oil to account for climate crisis," *The Guardian*, June 7, 2023, https://www.theguardian.com/us-news/2023/jun/07/climate-crisis-big-oil-lawsuits-constitution.

# Appendix

## Appendix A: Climate baselines

The climate projections in this report are derived from the Localized Constructed Analogs (LOCA)[58] statistically downscaled CMIP5 (Coupled Model Intercomparison Project Phase 5" before "CMIP5" and put "CMIP5 )[59] climate projections for North America. We selected different climate variables at 1/16th of a degree (approximately 3.7 mile$^2$) resolution from 32 global climate models under a moderate greenhouse gas and aerosol emission scenario (Representative Concentration Pathway [RCP] 4.5).[60] The 50th percentile of the 32 model outputs is presented for each of the analyses. The projection time periods used are 30-year averages centered on 2040. The climate baseline in this study is derived from Livneh et al. (2015), which provides a historical gridded dataset from 1950 to 2013.[61]

## Appendix B: Methodologies for estimating the cost to address temperature-related impacts

### Appendix B.1: Protecting Students from Extreme Heat

*School and School District Data*

The school data are from the U.S. Department of Education's National Center for Education Statistics (NCES) Common Core of Data (CCD), which provides publicly available, comprehensive annual data on all public elementary and secondary schools in the U.S.[62] The school dataset used in this report is composed of all public primary and secondary education facilities in Pennsylvania for the school year 2018–2019. We removed facilities that the NCES designated as either virtual, home, or charter schools. The school district and county boundaries are from the NCES and the U.S. Census.[63]

*Additional Information on Climate Baseline and Projections*

Using the LOCA model output, we selected daily maximum and minimum temperatures ($T_{max}$ and $T_{min}$) at 1/16th of a degree (approximately 3.7 mile$^2$) resolution.[64] The climate baseline in this study is derived from Livneh et al. (2015), a modeled historic dataset of gridded climate data.[65] We define the climate baseline in this study as the 20-year period from 1991-2010.

58 David Pierce, Daniel Cayan, and Bridget Thrasher, "Statistical Downscaling Using Localized Constructed Analogs (LOCA)," *Journal of Hydrometeorology 15*, no. 6 (2014): 2258-2585, https://doi.org/10.1175/JHM-D-14-0082.1; David Pierce et al., "Improved Bias Correction Techniques for Hydrological Simulations of Climate Change," *Journal of Hydrometeorology 16*, no. 6 (2015): 2421-2442, https://doi.org/10.1175/JHM-D-14-0236.1.

59 World Climate Research Programme's Working Group on Coupled Modelling, *Coupled Model Intercomparison Project Phase 5*, (2008), distributed by United States Department of Energy, https://pcmdi.llnl.gov/mips/cmip5/.

60 Detlef P. Van Vuuren et al., "The representative concentration pathways: an overview," *Climatic Change 109*, no.1-2: 5-31, https://doi.org/10.1007/s10584-011-0148-z.

61 Ben Livneh et al., "A spatially comprehensive, hydrometeorological data set for Mexico, the U.S., and Southern Canada 1950-2013," *Scientific Data 2*, 150042 (2015), https://doi.org/10.1038/sdata.2015.42.

62 National Center for Education Statistics, *Public Elementary/Secondary School Universe Survey*, 2018–2019, distributed by United States Department of Education, https://nces.ed.gov/ccd/pubschuniv.asp.

63 ibid; United States Census Bureau, *Cartographic Boundary Files - Shapefile*, (2018), distributed by United States Census Bureau, https://www.census.gov/geographies/mapping-files/time-series/geo/carto-boundary-file.html.

64 Detlef P. Van Vuuren et al., "Representative concentration pathways," 5-31.

65 Ben Livneh et al., "A spatially comprehensive, hydrometeorological data set."

*Climate Metrics*

We calculated the cooling degree days (CDD)[66] for the baseline and projection time periods for each individual school. The CDD metric represents the 20-year average CDD for both base 50°F (CDD50) and base 65°F (CDD65), though we ultimately settled on CDD50 for reasons that will be explained in the next section. We used the median RCP $T_{max}$ value of the 32 global climate models for 2040 (2030–2049).[67]

*Estimating Costs*

Step 1: Establish relationship between CDD and cooling system capacity

The U.S. Department of Energy's (DOE) commercial reference building models[68] define the characteristics of a representative primary and secondary school for every climate zone defined by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE)[69] based on nationwide survey data. DOE reference models were available for buildings constructed pre-1980, post-1980, and new (2010). We used only the post-1980 models for the purposes of this study. Cooling system type, cooling system capacity, and building square footage as defined by the DOE Reference Building Models were used to calculate cooling capacity intensity (square foot per ton) for a representative primary and secondary school in each ASHRAE climate zone.

A linear regression using the annual CDD50 reported in ASHRAE 90.1 2004 (ASHRAE Standard 90.1, 2004) and the cooling capacity intensity for each representative building established a relationship that was used to calculate cooling system capacity for all Pennsylvania buildings using inputs of baseline and projected CDD50, building area and building type. CDD with a base of 50°F was used because it showed a closer correlation to cooling capacity intensity than it did for CDD with a base of 65°F.

Step 2: Calculate cooling system capacity for each building

To identify the relationship between CDD50/CDD65 (reported in ASHRAE Standard 90.1- 2004)[70] and the cooling capacity intensity for each representative school, we fit a linear regression model to the data. CDD50 showed a closer correlation to cooling capacity intensity than did CDD65.

We applied the cooling system capacity relationship to each school in the national database. Baseline and projected annual CDD50 was calculated from the climate datasets and used, along with school area and type (primary or secondary), to calculate cooling system capacities for each building in the analysis. Since there is no open-source data available for school area, we assume that the area of a school is a function of the school enrollment, and we adopted the area-per-student assumptions presented in the Annual Official Education Construction Reports from 2003 to 2009: 123, 145, and 150 square feet per student for elementary, middle, and high schools, respectively.[71]

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66 Cooling degree days (CDD) is a measure of how much (in degrees), and for how long (in days), the outside air temperature is above a specified temperature threshold.

67 Pierce, Cayan, and Thrasher, "Localized Constructed Analogs (LOCA)," 2258-2585.

68 Office of Energy Efficiency & Renewable Energy, *Existing Commercials Reference Buildings Constructed In or After 1980*, (2010), distributed by United States Department of Energy, https://www.energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-or-after-1980.

69 American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), *ANSI/ASHRAE Standard 169-2013: Climatic Data for Building Design Standards*, (2013), distributed by ASHRAE.

70 *ASHRAE, ANSI/ASHRAE/IESNA Standard 90.1-2004: Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings*, (2004), distributed by ASHRAE.

71 Joe Argon, "Annual Official Education Construction Reports", *American School and University*, (2003–2009), https://www.asumag.com/research/education-construction-report.

Step 3: Estimate per-unit cooling system install and operating costs

We calculated cooling system upgrade costs on a dollar per ton basis using the system types in the DOE Commercial Reference Building documentation and RSMeans construction cost estimating data.[72] System installation and upgrade use the same dollar per ton costs based on RSMeans Assembly costs in the 2021 edition of the RSMeans Square Foot Cost Book:[73] $4,696/ton for primary school (primary and secondary system), $6,201/ton for secondary school primary system, and $4,696/ton for secondary school secondary system. Costs are in Q3-2022 dollars and include material, labor, sales tax (6%), general requirements (10%), general contractor overhead (5%) and profit (5%), and a Pennsylvania average location factor from the national average (97.6). No architect fee or contingency was added. Percentages all follow RSMeans methodology. Other costs will vary on a case-by-case basis that are outside of the scope of this study.

Step 4: Calculate install and upgrade costs for each building

Cooling system install costs were calculated for each building in the database based on the total projected amount of cooling the system can provide.

A cooling system upgrade was assumed to be necessary in a projection scenario if the change in cooling system capacity in that projection was more than 10% higher than the cooling system capacity for the baseline. Cooling system upgrade costs were calculated for each building in the database based on the projected capacity increase from baseline. To limit the upgrade costs to those related to anthropogenic climate change, we project costs for only the cooling system components that require upgrading to meet the increased system capacity. We note that energy costs are not included since we are focused on construction and installation of HVAC systems. Additional costs that are outside the scope of this study will be incurred on a case-by-case basis. *See Assumptions section below for additional information.*

Costs are presented on a municipality scale by summing upgrade and install costs for all school buildings within a municipality. Since the prevalence of air conditioning within schools is unknown, the upgrade and install costs are presented in a series of bins according to the prevalence of air conditioning across the municipality's building stock. As an example, the 25% bin implies that 25% of a municipality's buildings have existing cooling, and so 25% of the upgrade costs are reported while 75% of the install costs are reported.

*Note: We did not assess changes to operating costs because while cooling costs will increase in Pennsylvania schools, winter-time heating costs will decrease.*

Assumptions

For both installation and upgrade costs, we used the cooling system type assigned to post-1980 primary and secondary schools in the DOE's reference building documentation:

- Primary Schools: Multi-zone packaged rooftop air conditioning units for core spaces, and single-zone packaged rooftop air-conditioning units for gymnasiums, kitchens, and cafeterias.
- Secondary Schools: Air-cooled chiller and air handling unit for core spaces, and single-zone packaged rooftop air-conditioning units for gymnasiums, auxiliary gymnasiums, auditoriums, kitchens, and cafeterias.

72 RSMeans, Building Construction Cost Data, (2021), distributed by Gordian, https://www.rsmeans.com/.

73 ibid

We used the following RSMeans assembly types, which were deemed most similar to those system types assigned in the DOE's reference building documentation:

- Primary schools: Rooftop Single Zone Unit System for all spaces.
- Secondary schools: Chilled Water, Air Cooled Condenser System for core spaces, and Rooftop Single Zone Unit System for secondary spaces.

Only components that are included in the RSMeans assemblies were costed. Other items that may incur costs not included in analysis: required code improvements, structural improvements, asbestos abatement, redundant equipment, electrical upgrades, inflation, design fees, permitting, inspections, crane, constructability, demolition, waste disposal. Costs are based on the average dollar per ton across all system capacities reported in RSMeans. The cooling capacity intensity relationship with CDD50 was calculated without the equipment sizing factor of 1.2 used by the DOE reference building models.

Appendix B.2: Protecting Residents During Heatwaves

We quantified how much it will cost Pennsylvania municipalities to expand and operate cooling centers in order to protect residents from extreme heat in "vulnerable areas." For municipalities designated as cities or boroughs, we used 2019 U.S. Census block data and the Pennsylvania Municipal Bounds to identify the "vulnerable areas" within each municipality, defined as an area that has a median income at or below twice the poverty line for a family of four ($55,500). We used ArcGIS to assess the vulnerable area (mile$^2$) within each municipality.

Using U.S. Census block groups[74] to identify vulnerable areas in rural communities results in large regions of undeveloped areas being considered vulnerable, and therefore overestimates the amount of cooling centers required. To remedy this, we used National Land Cover Database (NLCD) developed areas, rather than block groups, to identify vulnerable areas in townships. We used the NLCD land form classifications to create a layer of only developed areas. In ArcGIS, we layered the NLCD classifications over the previously created vulnerable block groups. We saved only the overlapping NLCD developed areas, which leaves developed areas that are within vulnerable areas.

We assume that a cooling center within a vulnerable area must be within 0.5 miles radius walking distance, thus every cooling center covers 0.785 sq. mi. Using this calculated area served by a cooling center, we divided the vulnerable area of each municipality by 0.785 to determine the number of required cooling centers. We further refined the number of cooling centers needed using the following percentages from a CDC study: 62% operate at no additional cost, 15% have additional HVAC costs, and 23% have both additional HVAC and staff costs.[75] Importantly this is only applicable for centers operating within an 8-hour schedule. However, 54% of cooling centers operate on a 12-hour schedule. To calculate costs, we separated costs into 8-hour and 12-hour costs (see Costing Example below).

Because some rural areas are vulnerable by our definition but will not require cooling centers, there is an additional filter that if a municipality has a vulnerable area less than half of the area covered by a cooling center (0.785 sq. mi), then it is determined that area does not require a cooling center. Areas with this occurrence are most likely very rural areas that have extremely low populations relative to other urban environments.

74 United States Census Bureau, "Glossary," under "Block Groups," (accessed June 26, 2023), https://www.census.gov/programs-surveys/geography/about/glossary.html#par_textimage_4.

75 Stasia Widerynski et al., "The Use of Cooling Centers."

We estimated the operational costs by using a report from the City of Los Angeles that details their cooling center costs. They report that HVAC costs were $26.86 per hour, and HVAC and staffing costs were $292.72 per hour.[76] We approximated HVAC costs for the PA area using a conversion ratio of 0.64, determined by dividing the average electricity cost in Pennsylvania (16 ¢/kWh) by Los Angeles County (25 ¢/kWh). We found that hourly HVAC costs in Pennsylvania would be $17.19 per hour. We chose to leave labor costs unchanged due to estimated union labor costs. Accounting for the change in the cost of electricity, we estimate the HVAC and staffing costs to be $283.12 per hour.

| Municipality | Vulnerable Sq. Mi | # of Cooling Centers | Additional HVAC Costs | Additional HVAC and Staffing Costs | 8 Hours Costs | 4 Additional Hours Costs | Total Daily Costs |
|---|---|---|---|---|---|---|---|
| Fake Town, USA | 25.9 | 33 | $680.72 | $17,191.04 | $17,871.76 | $12,512.09 | $30,383.85 |
| | | Vulnerable area / 0.785 sq. mi, round up to nearest whole number | (Total CC# * 0.15 ) * $17.19 * 8 | ( Total CC# * 0.23 ) * $283.12 * 8 | Sum (Additional HVAC + HVAC & Staffing costs) | ((Total CC# * 0.62) * 0.54) * $283.12 * 4 | Sum ( 8 Hours Costs + 4 Additional Hours Costs) |

This costing method calculates the daily operation cost for cooling centers for each municipality in Pennsylvania. The next step is to multiply the daily costs by the number of days that the municipality experiences over 85°F. The resulting amount will be the rough estimation for each municipality's cooling center costs on a yearly basis.

## Appendix B.3: Combating Heat Islands

We quantified how much it will cost Pennsylvania's cities and boroughs to increase urban tree canopy in order to adapt to an urban heat island exacerbated by higher temperatures. An urban tree constitutes any tree located in a developed area of medium or high intensity according to the National Land Cover Database (NLCD).[77]

### *Quantifying canopy coverage in Pennsylvania urban environments*

We used NLCD 2019 Land Use data[78] and NLCD 2016 Canopy Coverage[79] to quantify the current canopy coverage in cities and boroughs across Pennsylvania.

### *Cost data*

We used RSMeans to collect cost data. We broke the initial planting data into labor costs, stake out costs, and material costs. Labor and material costs were estimated using an average across multiple planting sizes as well as a variety of representative sapling species. We calculated tree maintenance costs by combining water, fertilizer, pruning, and pest spraying. We adjusted

76 Carol Parks, "Cooling Center Operations in Los Angeles City," City of Los Angeles Emergency Management Department (2002), https://clkrep.lacity.org/onlinedocs/2021/21-1277_rpt_07-29-22.pdf.

77 National Land Cover Database, "National Land Cover Database Class Legend and Description," *Multi-Resolution Land Characteristics (MRLC) Consortium*, (accessed June 21, 2023), https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description.

78 National Land Cover Database, Land Cover/CONUS/2019, (2019), distributed by Multi-Resolution Land Characteristics Consortium, https://www.mrlc.gov/data.

79 National Land Cover Database, "NLCD 2016 Tree Canopy Cover (CONUS)," distributed by Multi-Resolution Land Characteristics Consortium, https://www.mrlc.gov/data/nlcd-2016-tree-canopy-cover-conus.

the costs to 2022 values using an inflation rate of 2.2%, per the Turner Building Cost Index.[80] Additionally, we adjusted the national average to Pennsylvania specific city cost index data.

*Determining Ideal Canopy Numbers*

We compiled canopy cover data from 16 metropolitan areas across the country to serve as representative models for different size municipalities in Pennsylvania including each city's canopy coverage goal percent, canopy goal year, current canopy coverage, the year the current canopy coverage was calculated, and the current population density. Regressing on these variables with goal canopy percent as the dependent value resulted in an adjusted R squared value of 0.73. The output regression formula is below.

$$\begin{aligned}\text{Canopy Cover Goal \%} = \; & -5.4913424 + (-3.74075E\text{-}06 * (\text{Pop Density})) \\ & + (1.073584308 * (\text{Initial Canopy Cover})) \\ & + (0.003353585 * (\text{year assessed})) \\ & + (-0.000552275 * (\text{Target Year}))\end{aligned}$$

We used the formula to calculate goals for both cities and boroughs separately for each development level as shown below. We used a target year of 2032 based on a 10-year period for trees to reach their average canopy cover (Table A).

Table A. Current and ideal future canopy numbers for Pennsylvania's cities and boroughs, broken down into the four NLCD Developed Area designations.

| | Cities | Boroughs |
|---|---|---|
| Population Density | 5050 | 1680 |
| Year Assessed | 2022 | 2022 |
| Target Year | 2032 | 2032 |
| Cities | | |
| Developed Area | Current Canopy Cover (%) | Predicted Canopy Cover (%) |
| High Intensity | 0.71 | 0.91 |
| Medium Intensity | 5.37 | 5.92 |
| Low Intensity | 16.65 | 18.02 |
| Open Space | 32.24 | 34.76 |
| Boroughs | | |
| Developed Area | Current Canopy Cover (%) | Predicted Canopy Cover (%) |
| High Intensity | 1.59 | 1.87 |
| Medium Intensity | 6.77 | 7.43 |
| Low Intensity | 16.07 | 17.41 |
| Open Space | 31.68 | 34.18 |

80 Turner Construction Company, *Turner Building Cost Index*, (2022), distributed by Turner Construction Company, http://turnerconstruction.com/cost-index.

*Cost Model*

The cost model uses a variety of inputs to calculate a final cost value. Important inputs include:

- Average Canopy Cover per tree (sq. ft.)
  - Calculated using a representative sample of 15 tree urban trees in Philadelphia,[81] and averaging their canopy size at year 10 determined from a Virginia Tech Urban Forestry database.[82]
- Average Annual Cost to maintain an urban tree ($)
  - Explained above
- Initial cost to plant a tree ($)
  - Explained above
- Cost per Canopy ($/sq. ft.)
  - Calculated by dividing cost to maintain an urban tree by the average canopy cover per tree.
- Tree mortality rate year 1-5 and Year 6+[83]

Next we priced out these costs into the future. Year one costs include both the initial maintenance cost as well as the initial cost to plant trees. After year one, the maintenance cost stays the same. However, there is a tree mortality cost: for years 1-5 there is an assumed 6.8% loss of trees per year, and there is an assumed 3.3% loss for year 6+. Each year, this loss is translated into the cost to replace that amount of trees. The cost model can be extended for as many years as desired, as well as incorporating inflation costs based on whatever rate deemed appropriate. Note that the model does not specify where trees are planted within the municipalities.

## Appendix C: Methodologies for estimating the cost to address precipitation-related impacts

### Appendix C.1: Increasing Storm Drainage Capacity

We assessed the cost to adapt both the wastewater conveyance systems and the treatment plants and processes to projected increases in extreme wet weather events.

The most significant impact of increased rainfall on wastewater conveyance systems are increased overflows, blockages, and breakages. Increased rainfall intensity and extreme weather events are likely to lead to increased occurrence of inflow and infiltration (I&I) into wastewater networks. This occurs when stormwater directly enters combined networks or infiltrates the sewer network through cracks, direct connections, and poorly constructed or corroded manholes.[84]

The most significant impacts likely to affect treatment plants and processes are increased inflows and power outages. Increased rainfall will result in larger volumes and peak inflows into waste water treatment plants as a result of flow from combined systems and I&I. While the volume or 'flow' of the wastewater increases during increased stormwater infiltration, the total suspended solids of the wastewater remains the same, resulting in a dilution of the influent to the wastewater treatment plant, which can affect biological treatment processes.[85] During

81 United States Department of Agriculture, "The Urban Forest of Philadelphia," *Resource Bulletin NRS-106* (2016), https://www.fs.usda.gov/nrs/pubs/rb/rb_nrs106.pdf.

82 Virginia Tech Urban Forestry, *Tree Canopy Spread & Coverage in Urban Landscapes*, (November 3, 2010), distributed by Virginia Nursery and Landscape Association, http://dendro.cnre.vt.edu/predictions/canopy.cfm.

83 Deborah Hilbert, "Urban Tree Mortality: What the Literature Shows Us," *Arborist News*, (October 2019): 22–26, https://www.fs.usda.gov/nrs/pubs/jrnl/2019/nrs_2019_hilbert_003.pdf.

84 James Hughes et al., "Impacts and implications of climate change on wastewater systems: A New Zealand perspective," *Climate Risk Management 31*, (2021): 100262, https://doi.org/10.1016/j.crm.2020.100262.

85 Richard Mines Jr, Laura Lackey, and Glen Behrend, "The Impact of Rainfall on Flows and Loadings at Georgia's Wastewater Treatment Plants," *Water, Air, and Soil Pollution 179*, (2007): 135-157, https://doi.org/10.1007/s11270-006-9220-0.

extreme weather events, system bypasses can be activated, diverting flows past part or all of the treatment process. This causes partially treated or untreated wastewater to directly enter the receiving environment.[86]

*Change in wet weather events*

We look at the change in magnitude of the 98% precipitation event and the 99.6% precipitation event. The 98% precipitation event represents the threshold for a "high-precipitation event," which occurs approximately 7 times a year and could cause moderate increases of inflow into the wastewater treatment plants. The 99.6% precipitation event represents the extreme wet weather event that could cause large increases of inflow into the wastewater treatment plants and occurs approximately once per year.

We calculate the percent change in these events from the change in depth of these events. For example, if the 99.6% baseline wet weather event is 3 inches and the projected 99.6% wet weather event is 3.3 inches, then we would say the extreme wet weather event increased by 10%. We use the maximum of the high (98%) and extreme (99.6%) change for the next step.

Given a change in wet weather events, we assume that the municipality must invest to offset the additional runoff (thus infiltration and inflow) into the wastewater treatment plant. We assume the offset is proportional to the percent change in wet weather events. If the wet weather events are increasing by 10%, then 10% of the developed impervious area needs to be offset by green infrastructure.

We calculate the developed impervious area using the National Land Cover Database.[87]

We derived the unit costing for green stormwater infrastructure from the Allegheny County Sanitary Authority (ALCOSAN).[88]

Final equation for cost calculation is below:

- $Cost = A * \Delta WWE * GSI$
- Where:
  - A is Area of developed impervious surfaces (acres)
  - ΔWWE is the change in wet weather events (%)
  - GSI is the unit cost of green stormwater infrastructure ($ per impervious acre controlled)

<u>Appendix C.2: Maintaining Roads</u>

To determine the level of potential future damage to municipal and county roads in Pennsylvania, we analyzed both the historic environment and projected future conditions to determine how climate change will affect the as-designed condition of the infrastructure. Increasing temperatures cause more surface degradation[89] and decreases road lifespan.[90] Increasing precipitation levels

86 Jeroen Langeveld, Remy Schilperoort, and Stefan Weijers, "Climate change and urban wastewater infrastructure: There is more to explore," *Journal of Hydrology 476*, no. 2 (2013): 112-119, http://dx.doi.org/10.1016/j.jhydrol.2012.10.021.

87 Earth Resources Observation and Science Center, *National Land Cover Database*, (September 11, 2018), distributed by United States Geological Survey, https://www.usgs.gov/centers/eros/science/national-land-cover-database.

88 Allegheny County Sanitary Authority, "Appendix E-3 — GSI Cost Literature Review" in ALCOSAN Clean Water Plan, (2015), https://www.alcosan.org/docs/default-source/clean-water-plan-documents/cwp-appendixe/cwp-appendix-e-3_gsi-cost-literature-review.pdf?sfvrsn=6d863977_2.

89 Degradation is the projected increase in raveling and cracking that will occur due to pavement weakening.

90 Transportation Research Board SUPERPAVE Committee, "SUPERPAVE Performance by Design," *Transportation National Academy of Sciences*, (2005), https://www.trb.org/publications/sp/superpave.pdf.

cause erosion, which weakens the roadbase, causing increases in cracking, potholes, and breakage.[91] We designated distinct stressor-response functions for paved, gravel, and unpaved roads. Furthermore, within each category we made refinements for primary, secondary, and tertiary roads.[92] We identified local roads using a database containing Pennsylvania roads that are owned and operated by municipalities and counties, so we can not differentiate between the two.[93] However, it should not contain any state-owned roadways.

*Temperature*

We used historic and projected 7-day maximum ambient temperatures to determine if the design mix for the pavement is adequate to prevent heat-related cracking or softening on the surface. It is used as the basis for a relationship between pavement temperature and ambient temperature. Pavement temperature is what is ultimately needed for determining required pavement design. This approach allows for determining when a projected change in temperature will be significant enough to cause climate-based damage to infrastructure.[94]

When pavement temperature rose above the mixture threshold, we calculated the increased degradation based on published material studies. This increased cracking requires more maintenance, or would result in a decrease in the projected lifespan of the road.[95]

*Precipitation*

We used maximum monthly precipitation amounts to determine if excessive erosion will increase damage to the roadbase. Increased erosion rates are related to increases in precipitation levels. The erosion weakens the roadbase, causing increases in cracking, potholes, and breakage. We compared the historic maximum monthly precipitation to the projected increases in maximum monthly rates at the time-slice of interest. We used a threshold based on the type of road surface to determine if increased damage will occur to the road. If a threshold is exceeded, then a percentage decrease in lifespan is calculated based on the level of projected damage. Adaptation for this scenario requires a strengthening of the roadbase to resist the increased potential for erosion.

*Cost Estimates*

We conducted this analysis with the goal of retaining the original design life and service level of the roadways. Our costing method assumes a proactive adaptation approach, rather than reactive. Our method includes the additional costs required to adapt design and construction to defend against projected changes in climate expected to occur over the asset's lifespan. We estimated total costs based on the cost associated with enhancing the materials selected or alternate design requirements. We designed infrastructure to a level that protects against future changes in climate conditions and the accompanying changes in material or design requirements. The method accounts for whether any new or rehabilitated structures will be subject to material changes when it is anticipated that a significant climate change stressor will occur during the lifespan.

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91 James Neumann et al., "Climate change risks to US infrastructure: impacts on roads, bridges, coastal development, and urban drainage," *Climatic Change 131*, (2015): 97-109, https://doi.org/10.1007/s10584-013-1037-4.

92 Paul Chinowsky and Channing Arndt, "Climate Change and Roads: A Dynamic Stressor–Response Model," *Review of Development Economics 16*, no. 3 (2012): 448-462, https://doi.org/10.1111/j.1467-9361.2012.00673.x.

93 Pennshare, *Pennsylvania Local Roads*, (January 14, 2020), distributed by ArcGIS, https://data-pennshare.opendata.arcgis.com/datasets/PennShare::pennsylvania-local-roads/about.

94 Patrick Lavin, *Asphalt Pavements A Practical Guide to Design, Production and Maintenance for Engineers and Architects*, 1st ed. (London: CRC Press: 2014), https://www.taylorfrancis.com/books/mono/10.1201/9781482267716/asphalt-pavements-patrick-lavin.

95 M. Miradi, "Artificial neural network (ANN) models for prediction and analysis of ravelling severity and material composition properties," in M. Mohammadian (Ed.), *CIMCA 2004*, (2004): 892-903, https://research.tudelft.nl/en/publications/artificial-neural-network-ann-models-for-prediction-and-analysis-.

## Appendix C.3: Maintaining Bridges

Climate-driven changes in precipitation will increase the flow rates of waterways, thereby increasing the rate of wear and tear on bridges that span them. In order to approximate bridge-related costs associated with the projected increase in precipitation, we developed a method that translates increases in 24-hour precipitation rates to changes in flow rates in waterways where bridges are present. From there, we calculated the potential increase in damage to bridges resulting from increases in scour around the base of the piers. While there are multiple climate-related costs associated with bridges, we chose to quantify the cost to proactively rehabilitate bridges in order to prevent disruption.

The method we employed to translate increases in 24-hour precipitation rates to changes in flow rates is based on the U.S. Department of Agriculture's Natural Resources Conservation Service TR-55 model.[96] The bridge data is from the National Bridge Inventory, from which we selected only inland bridges that spanned bodies of water.[97] The location and details of the rivers was derived from the United States Geological Survey Hydrologic Unit Code 8 (HUC 8) database.[98]

We established the observed rates of daily runoff in Pennsylvania using simulations with the Variable Infiltration Capacity (VIC) model[99] using the Livneh et al. (2015) observational dataset as inputs for the 1950-2005 period.[100] We established the projected climate variables using daily runoff outputs from simulations with the VIC model using GCM projections from the Coupled Model Intercomparison Project Phase 5 (CMIP5) as inputs.

Using the 52 HUC8 shapefiles, we calculated the maximum 7-day totals of runoff for each year and for each HUC8 basin in PA. The projected changes from the historical baseline were calculated including absolute, percent, and ratio percent changes of 100- and return values from the historical and future period return values for both RCPs, all 32 models, and all 52 HUC8 basins.

We quantified the cost to proactively rehabilitate bridges to prevent disruptions by applying riprap to stabilize bridges, and additional concrete to strengthen piers and abutments.
We rehabilitate bridges only if they are known to be threatened by a near-term river flow level that crosses one of the thresholds. This method may underestimate potential damages because proactive costs are likely far lower than repairing or rebuilding a failed bridge.[101] Notably, our analysis does not estimate damages associated with delays/disruptions from the bridge being closed.

## Appendix C.4: Protecting Roads from Landslides

We performed the landslide risk analysis largely in ESRI ArcGIS Pro software, split into five steps outlined below.

96 Len Wright et al., "Estimated effects of climate change on flood vulnerability of U.S. bridges," *Mitigation and Adaptation Strategies for Global Change 17*, (2012): 939–955, https://doi.org/10.1007/s11027-011-9354-2.

97 Federal Highway Administration, *National Bridge Inspection ASCII files*, (2022), distributed by United States Department of Transportation, https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm.

98 United States Geological Survey, *Hydrologic Unit Maps*, (n.d.), distributed by United States Department of the Interior, https://water.usgs.gov/GIS/huc.html.

99 Joseph Hamman, "The Variable Infiltration Capacity model version 5 (VIC-5): infrastructure improvements for new applications and predictability," *Geoscientific Model Development 11, no. 8* (2018): 3481-3496, https://doi.org/10.5194/gmd-11-3481-2018.

100 Ben Livneh et al., "A spatially comprehensive, hydrometeorological data set."

101 James Neumann et al., "Climate change risks to US infrastructure."

*Step 1: Analyze Landslide Risk*

In order to create a baseline landslide hazard map, we established landslide risk with the Landslide Risk Assessment Model (LRAM), which accounts for: slope, soil component (texture, drainage, stability, and depth), and normalized difference vegetation index (NDVI). The data was scored and combined using a conditional statement (described below) to create a statewide baseline landslide hazard map. We made two modifications to the original LRAM: geology structure was not included because of a lack of data availability, and slope score was altered to give greater weight to steep slope areas.

| Slope Degrees | Original Score | Updated Score |
|---|---|---|
| 0 - 8 | 1 | 0 |
| 8 - 15 | 2 | 1 |
| 15 - 25 | 3 | 3 |
| 25- 45 | 4 | 4 |
| > 45 | 5 | 5 |

The baseline hazard score was calculated with a conditional IF statement to prevent flat areas from having high risk scores. This is especially useful for areas with high-risk scores but low slope, such as downtown areas, where logically we know landslide risk is extremely low. The resulting baseline hazard map was a 150-meter pixel resolution for the entirety of Pennsylvania.

*Step 2: Identify Road Vulnerability*

The next step was to identify road infrastructure that is exposed to hazard risk. We did not consider small local roads and expressway/interstates, and focused on primary and secondary state roads. We accomplished this using PennDOT Administrative Classification of Roadway GIS data.[102] We defined “Other Principal Arterial” and “Minor Arterial” as the Primary subset, and “Major Collector” and “Minor Collector” as the secondary subset.

We intersected road selection with the baseline hazard map, so every road segment had an associated hazard score. The score was broken into 5 quantiles, allowing for the selection of the top 40% hazard score of primary and secondary roads respectively.

*Step 3: Assess Climate Projection Data*

Landslides are more likely to occur during high intensity precipitation events, so we determined if the average number of annual high-precipitation events would be increasing or decreasing in 2040 compared to baseline. We established a baseline by calculating the daily 3-day rolling precipitation sum between 1990 and 2010 (the climate baseline). We used the 3-day rolling sum because it is a variable utilized in multiple landslide analyses as an indicator of risk.[103]

The 98th percentile of each year was selected, and then averaged across all 20 years. The output represents the threshold for what a “high-precipitation event” is for each municipality.

If a municipality exhibited an increased number of high-precipitation days, then we classified it as a municipality of concern.

102 PennDOT GIS Data Dictionary Hub, *Administrative Classification of Roadway (RMSADMIN)*, (n.d.), distributed by Pennsylvania Department of Transportation, https://docs-pennshare.hub.arcgis.com/pages/administrative-classification-of-roadway-rmsadmin.

103 Alan Chleborad, “Preliminary Method for Anticipating the Occurrence of Precipitation-Induced Landslides in Seattle, Washington,” *United State Geological Survey*, Open-File Report 00-469, (2000), https://pubs.usgs.gov/of/2000/ofr-00-0469/ofr-00-0469.html.

*Step 4: Establish Unit Costs*

To establish the cost to protect high-risk areas from increasing landslide risk, we employed a middle-of-the-road cost using a single mitigation strategy. We found the average construction costs for a 6-foot, 8-foot, and 10-foot reinforced concrete cantilever retaining wall on a 33-degree slope embankment using RSMeans, adjusted for Pennsylvania city cost averages, and for inflation to 2023 dollars, and adjusted from a per foot to per mile value.

*Step 5: Calculate Costs*

We calculated the cost for a given municipality by multiplying the municipality's high risk road mileage with the established cost of mitigation per mile.

### Appendix D: Protecting Infrastructure from Sea Level Rise

We estimated the costs of constructing seawalls needed to protect Pennsylvania's public infrastructure from sea level rise. By pairing a sophisticated sea level rise model[104] with 1-year storm surge estimates,[105] as well as the NOAA Medium Resolution Shoreline dataset, we produced planning-level cost estimates for 2040 under the moderate emissions scenario RCP 4.5, with and without a 1-year storm surge for Pennsylvania's municipalities.

We chose one of the more conservative future scenarios in order to avoid worst-case assessments and focus the discussion on the baseline costs that will be required to protect coastal communities against unavoidable, short-term sea level rise.

A 1-year storm surge is the level to which coastal water rises in any given year during a typical storm according to historical sea level data. It is a common storm event, as opposed to a 100-year storm surge, which represents a severe event that statistically occurs once every 100 years. This study relied on geographically specific storm surge predictions based on work by Tebaldi et al. (2012) and Buchanan et al. (2016).

The methods employed by Resilient Analytics to assess the cost of protecting the coastline from the impacts of sea level rise and 1-year storm surge entailed a multi-step process incorporating climate projections, processing detailed coastline flooding maps, a computational assessment of where tidal shorelines needed protection, and a calculation of the costs associated with this protection. The process developed for this estimation is based on previous work developed by Resilient Analytics and other scholars for calculating climate impacts on infrastructure locally, regionally, and globally.[106]

Defining Infrastructure

In order to understand the impact that the projected flooding would have on public infrastructure, it was necessary to determine the location of infrastructure in the impacted areas. Analysts at

104 Robert Kopp et al., "Evolving understanding of Antarctic ice-sheet physics and ambiguity in probabilistic sea level projections," *Earth's Future 5*, no. 12 (2017): 1217-1233, https://doi.org/10.1002/2017EF000663.

105 Claudia Tebaldi, Benjamin Strauss, and Chris Zervas, "Modeling sea level rise impacts on storm surges along US coasts," *Environmental Research Letters 7*, no. 1 (2012): 014032, http://dx.doi.org/10.1088/1748-9326/7/1/014032; Maya Buchanan et al., "Allowances for evolving coastal flood risk under uncertain local sea level rise," *Climatic Change 137*, no. 3-4 (2016): 347-362, https://doi.org/10.1007/s10584-016-1664-7.

106 Raffaello Cervigni et al., "The Roads and Bridges Sector," in *Enhancing the Climate Resilience of Africa's Infrastructure Conference Edition*, Publication 110137 (2016), https://www.worldbank.org/content/dam/Worldbank/Feature%20Story/Africa/Conference%20Edition%20Enhancing%20Africas%20Infrastructure.pdf; Paul Chinowsky et al., "Impacts of climate change on operation of the US rail network," *Transport Policy 75*, (2017): 183-191, https://doi.org/10.1016/j.tranpol.2017.05.007; Amy Schweikert, Xavier Espinet, and Paul Chinowsky, "The triple bottom line: bringing a sustainability framework to prioritize climate change investments for infrastructure planning," *Sustainability Science 13*, no. 2 (2018): 377-391, https://doi.org/10.1007/s11625-017-0431-7.

Climate Central provided this study with GIS files of public infrastructure locations, based on previous work and public databases.[107] The infrastructure identification process emphasized public infrastructure including schools, hospitals, medical facilities, government buildings, airports, and all public horizontal infrastructure (roads, railways, and runways). Although the study does not consider private residences directly, the location of most residential areas can be determined through the location of public roads that are used to access residential areas. By considering all areas that contain a road (both paved and unpaved), the majority of residential areas were also considered. Areas that do not have any public infrastructure, such as national parks or protected wildlife areas, were not included in the study as pieces of infrastructure and were therefore not considered for protection.

The sea level rise impacts and infrastructure locations were merged into one data set, and the results were placed onto a gridded map (each grid square was 150 mile$^2$).

Determining Where to Place Seawalls

The next step of the process was determining what areas of coastline needed protection from flooding. This determination requires a series of logic tests performed by a computer model to understand if a flooded grid is directly impacted by flooding from adjacent waterways, or if it is indirectly affected by other grids that are adjacent to waterways.

The first logic question determined whether any given gridded square is located within an area that is expected to flood, according to a specific climate scenario. This question is nuanced in that there must be a determination as to how much of a grid cell needs to be flooded for it to be considered a flooded grid. For the purposes of this study, grid squares are considered flooded if 15% or more of the land area within that grid is inundated. This 15% limit assisted in eliminating overprotection scenarios and was chosen based on engineering judgment upon inspection of protection patterns using 5%, 10%, 15%, and 20%.

Next, the model determines whether a grid is flooded as a result of direct flooding or indirect flooding. Direct flooding occurs when a grid is adjacent to a waterway and the scenario indicates that the grid is flooded due to an overtopping of that adjacent waterway. In these cases, the adjacent shoreline needs to be protected to prevent the grids from incurring flooding. The indirect case occurs when an inland grid is flooded because it is connected to a water-facing grid. In this case, the model must trace the path of the flood back to its origin, which is the grid adjacent to the coastline. The model then protects the coastline adjacent grid to eliminate the threat to the overall flood area.

In the next logic test, the model determined what portion of the identified flood area needs to be protected based on the presence of infrastructure. This eliminates the need for protection in areas such as nature preserves or remote areas that are uninhabited.

Finally, the model calculates the length of coastline to be protected. This study utilizes the NOAA Medium Resolution Shoreline Data in order to determine what is considered shoreline. The model analyzed the coastline for every grid that was determined to require protection from flooding. For each of the identified grids, the length of coastline in that grid was calculated to the linear foot.

107 Benjamin Strauss et al., "Tidally adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States," *Environmental Research Letters 7*, no. 1 (2012) :021001, http://dx.doi.org/10.1088/1748-9326/7/1/014033.

Seawall Cost Estimates

The estimated costs of seawall construction were created using a combination of nationally recognized construction cost estimates from the engineering community and local estimates from seawall design and construction companies to establish realistic localized per-foot costs. The location factor was important to ensure that costs reflected the rates at a local level since these rates can vary by more than 10% depending on location.

The cost estimates are divided into two categories: coastal seawalls and inland seawalls. Coastal seawalls have been used to protect wave-impacted coastlines to stop or reduce the impacts of flooding. In this study, coastal seawalls are defined as retaining walls that are either adjacent to shore structures or serve as standalone offshore structures. This design is used wherever the coast is directly exposed to open water. Inland seawalls, often referred to as bulkheads, are used to protect property against rising inland water levels and indirect wave action.

Once the model determines whether a coastal or inland design is appropriate for the given grid location, the cost of that solution is multiplied by the linear feet of protection required to obtain a total cost. The results are presented as total cost and per capita cost, calculated using population estimates from the U.S. Census Bureau's American Community Survey 5-year estimates.

## Appendix E: Technical Documentation for Budget Analysis

Survey of State and Local Government Finance

The budget analysis for Pennsylvania is conducted using the most recent data available of state and local government finances, a 2017 survey reported by the U.S. Census Bureau.[108] In Pennsylvania, 83.3% of all local governments responded to the survey, with the other 16.7% of results supplied by the U.S. Census Bureau. The survey aggregates municipal spending to the county level, in order to create a baseline for local costs. Therefore, the results presented by this budget analysis are an aggregation of spending by all the municipalities in a given county, not spending by the county government itself.

Each response in the survey data represents an individual spending category for a local government (e.g. fire protection, parks and recreation, housing and community development, etc). The total local government spending within each county in Pennsylvania is calculated by adding up all of the spending within the categories labeled as direct expenditures for city and township governments. It's assumed that large capital expenditures (e.g., seawalls, bridges, etc.) are debt financed with a conservative 0% interest rate to be paid over the course of the 17 years between 2023 and 2040, so they are completely paid off by the year 2040. For tree planting, an average annual cost of 20-year estimates is used to estimate annual costs.

All cost estimates have been adjusted to present day dollars using the Bureau of Labor Statistics producer price index adjustment for total government purchases.[109] Communities with populations fewer than 100 were excluded from all per capita cost analysis because, while some of these smaller communities will experience devastating climate impacts, applying cost models to such small populations can create outlying cost estimates and uncertainty in the overall data. In order to determine a conservative and reliable estimate of climate adaptation costs throughout Pennsylvania, communities with fewer than 100 people were excluded.

108 United States Census Bureau, "2017 State & Local Government Finance Tables," (2017), https://www.census.gov/data/tables/2017/econ/gov-finances/summary-tables.html.

109 United States Bureau of Labor Statistics, "Producer Price Indexes," (accessed June 27, 2023), https://www.bls.gov/ppi/.

## Appendix F: Technical Documentation for Equity Analysis

Categorizing Municipalities

In order to conduct equity analysis of climate adaptation costs, municipalities in the state are defined as “high-poverty,” “high-racial minority,” “high-disability,” “high-non-English speaking,” “high-foreign-born,” “rural,” and “Environmental Justice Area.”

For the categories of high-poverty, high-racial minority, and high-disability, at least 20% of a given municipality’s population must meet the description to fall under the “high” risk equity category. This roughly equates to the 90th percentile of Pennsylvania municipalities for the high-poverty and high-racial minority categories.

For the high-non-English speaking and high-foreign-born equity categories, the upper bounds are determined by the 95th and 94th percentiles, respectively. These boundaries keep similar numbers of municipalities in each equity category.

Defining Equity Categories

Table B: Equity Criteria for Pennsylvania Municipalities

| Equity Category | Threshold | Percentiles (% Above) |
|---|---|---|
| High-Poverty | >20% in poverty | 90th Percentile (9.7%) |
| High-Racial Minority | >20% racial minority | 89th Percentile (10.6%) |
| High-Disability | >20% disability | 82nd Percentile (17.8%) |
| High-Non-English Speaking | >20% speaking language other than English at home | 95th Percentile (5.1%) |
| High-Foreign-Born | >10% foreign-born | 94th Percentile (5.5%) |

For rural municipalities and Environmental Justice Areas, we rely on definitions from the U.S. Census Bureau and the Pennsylvania Department of Environmental Protection, respectively. Full definitions for these categories are listed below.

Listed below are explanations of how other researchers have defined these equity categories, which informed this report’s thresholds.

- **High-Poverty**: The U.S. Census Bureau defines a “poverty area” as a census tract with a poverty rate greater than or equal to 20%.[110]
- **High-Racial Minority**: The Pennsylvania Department of Environmental Protection sets 30% “non-white minority” as its threshold for its definition of an “Environmental Justice Area.”[111] A Washington Post analysis of the prevalence of “mixed-race neighborhoods” in the United States defined a “mixed-race neighborhood” as one where at least 20% of the population is “non-white.”[112] The Washington Post analysts set this threshold based on their finding of “that threshold to be a tipping point that’s often followed by steady diversification.” Neither study is explicit about whether Hispanic whites are or are not included in their definition of “non-white,” though the definitions both imply they would be excluded from the definition.

110 Bureau of the Census, “Poverty Areas,” *Economic and Statistics Administration, U.S. Department of Commerce*, Statistical Brief (1995), 95-13, (accessed January 23, 2023), https://www2.census.gov/library/publications/1995/demographics/sb95-13.pdf.

111 ibid

112 Ted Mellnik and Andrew Van Dam, “How mixed-race neighborhoods quietly became the norm in the U.S.,” *The Washington Post*, November 4, 2022, https://www.washingtonpost.com/business/2022/11/04/mixed-race-neighborhoods/.

- **High-Disability:** A March 2022 study on the geography of disability and food insecurity by Urban Institute researchers define a high-disability county as those with a "share of people with disabilities at or above the 75th percentile of the nation."[113] A 2020 study in the journal Preventing Chronic Disease on disability prevalence among veterans analyzed geographic areas based on quintiles of disability prevalence.[114] Quintiles are often a cutoff used for "high disability" as well and have been since the 1990s.[115]
- **High-Non-English Speaking:** Linguistic diversity has been analyzed by researchers less than poverty prevalence, racial diversity, and disability prevalence. An August 2022 Census Bureau report includes a map of the U.S. organized by prevalence of languages other than English spoken at home, but does not have any defined methodology for categorization.[116] In Pennsylvania, 5% of municipalities have more than 20% of residents speaking a language other than English at home.
- **High-Foreign-Born**: Geographic differences in citizenship status within states have also not received as much attention from researchers as differences in poverty rates or racial diversity. While descriptions of "highest" noncitizen or foreign-born population abound, few researchers have applied definitions of "high" with accompanying thresholds for equity analysis. An exception is a definition applied by a 1997 study by the Hoover Institute, a conservative think tank, which sets a threshold of 20% for high-foreign born populations.[117] Only 117 cities in the U.S. meet this definition, none of which are in Pennsylvania. Therefore, this study uses a 10% threshold to define municipalities with high foreign-born populations.
- **Environmental Justice Area:** "Environmental Justice Areas" are defined by the Pennsylvania Department of Environmental Protection as census tracts where at least 20% of individuals live at or below the federal poverty line, and/or 30% or more of the population identifies as non-white.
- **Rural:** The 2020 U.S. Census designates rural geographies as encompassing all population, housing, and territory not included within a designated urban area (urban areas are defined by minimum housing unit density and/or population density requirements).

113 Barbara Butrica, Stipica Mudrazija, and Jonathan Schwabish, "The Geography of Disability and Food Insecurity," *Urban Institute*, (March 2022), https://www.urban.org/sites/default/files/2022-03/The%20Geography%20of%20Disability%20and%20Food%20Insecurity.pdf.

114 Justin McDaniel, "Geographic Distribution of Disability Among Older Veterans, United States, 2013–2017," *Preventing Chronic Disease 17*, (2020): 190340, http://dx.doi.org/10.5888/pcd17.190340.

115 John McCoy, Miles Davis, and Russell Hudson, "Geographic Patterns of Disability in the United States," *Social Security Bulletin 57*, no. 1 (1994): 25-26, https://www.ssa.gov/policy/docs/ssb/v57n1/v57n1p25.pdf.

116 Sandy Dietrich and Erik Hernandez, "Language use in the United States: 2019," *American Community Survey Reports* (2022), https://www.census.gov/library/publications/2022/acs/acs-50.html.

117 Moore, Stephen, "Immigration and the rise and decline of American cities," *Hoover Institution*, 1997, https://www.hoover.org/research/immigration-and-rise-and-decline-american-cities.

## Methodology

*Temperature-Related Impacts*

- Heat-Related Illness: Using incidence estimates made by Scioto Analysis, we calculate the increase in heat-related hospitalizations per 100,000 people for each equity category. We then compare those to the statewide increase in hospitalization per 100,000 people to see if the increase in hospitalizations in the equity category are higher or lower.
- Protecting students from extreme heat: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of school building installation and upgrade in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.
- Protecting residents during heatwaves: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of cooling costs in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.
- Combating Heat Islands: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of tree planting in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.

*Precipitation-Related Impacts*

- Increase stormwater capacity: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of increasing stormwater capacity in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.
- Maintaining roads: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of maintaining roads in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.
- Maintaining bridges: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of bridges in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.
- Protecting roads from landslides: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of landslides in communities defined by the above criteria. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower.

*Sea Level Rise*

- Protecting municipal infrastructure: Using cost estimates provided by Resilient Analytics, we calculate the per capita costs of sea level rise in communities defined by the above criteria, limited to communities that incurred any costs at all. We then compare those to the statewide per capita cost to see if per capita costs in a given equity category are higher or lower. We then provide some descriptive statistics that show how the communities that incur these costs compare demographically to the state as a whole.