At Least $16.7 Billion to Protect Communities from Climate Change through 2040



Confronting Wisconsin's Climate Costs

CENTER FOR CLIMATE INTEGRITY

The Center for Climate Integrity

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Executive Summary

From dangerous heat that forces students out of the classroom to more frequent floods that wreak havoc on residents' homes and wallets, Wisconsin communities are already feeling the effects of climate change — and it's just the beginning.[1] Climate change will have profound impacts on Wisconsin communities in the coming years, increasing the prevalence of pediatric asthma, destabilizing bridges, eroding lake shorelines, and more.

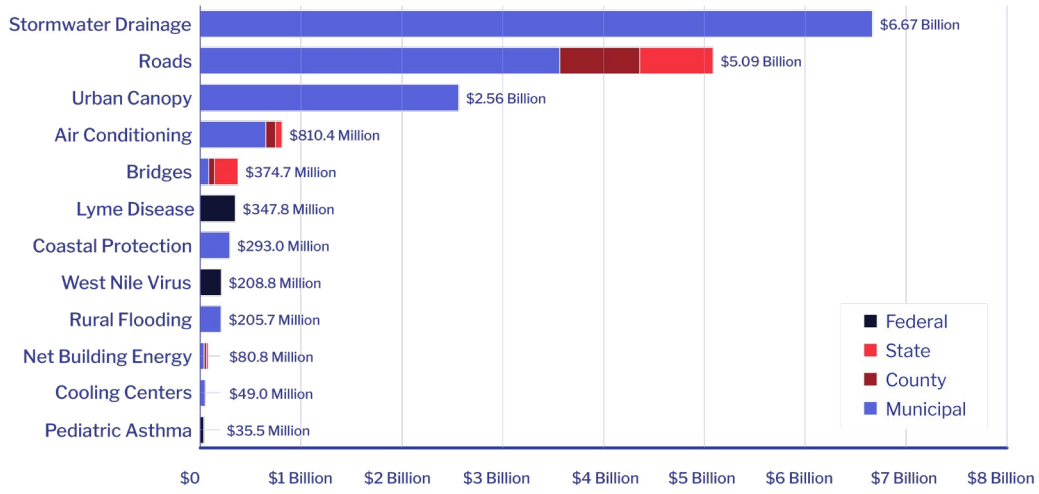
In the face of these mounting threats, it's more important than ever for communities to invest in a growing range of climate adaptation projects to protect residents and infrastructure.

This study is the first-ever attempt to calculate the cost of nine different climate adaptation measures and three climate-induced public health threats for municipal, county, state, and federal governments across Wisconsin.

These numbers represent just a fraction of the challenges Wisconsin communities will face to respond and adapt to the impacts of climate change.

We estimate Wisconsin taxpayers would need to spend at least $16.7 billion through 2040, or nearly $1 billion a year, to protect residents from extreme heat, heavy precipitation, public health threats, and other impacts from climate change.

Figure 1: Total cost for each adaptation strategy and public health threat analyzed in this study from 2024 through 2040 and colored by the government entity responsible for implementation.



1 Jackson Danbeck, "Milwaukee Public Schools Closed Aug. 23 Due to Excessive Heat, Website Says," *WTMK-TV Milwaukee*, August 22, 2023, https://www.tmj4.com/news/local-news/milwaukee-public-schools-closed-aug-23-due-to-excessive-heat-website-says; Elizabeth Dohms-Harter, "Climate Change Is Causing More Flooding. Here's How Wisconsinites Can Protect Themselves.," *Wisconsin Public Radio*, March 11, 2024, https://www.wpr.org/news/flooding-outside-floodplains-flood-insurance-protection.

We calculate taxpayers in Wisconsin will face the following costs to implement nine climate adaptations and treat three public health threats through 2040:

- **$6.67 billion** to improve stormwater management to mitigate flooding
- **$5.09 billion** to increase road maintenance because of heavy rain and heat stress
- **$2.56 billion** to plant and maintain trees to combat urban heat islands
- **$810.4 million** to install air conditioning in public buildings
- **$374.7 million** to reinforce bridges against anticipated climate wear and tear
- **$347.8 million** to respond to an increase in Lyme disease cases
- **$293 million** to build coastal defenses to protect infrastructure from coastal erosion and changing lake levels
- **$208.8 million** to respond to an increase in West Nile Virus cases
- **$205.7 million** to protect rural communities from flooding
- **$80.8 million** to heat and cool public buildings in response to changing temperatures
- **$49 million** to expand and operate cooling centers
- **$35.5 million** to respond to an increase in pediatric asthma cases

Across the country, local governments are paying for the vast majority of climate adaptation and resilience measures. Taxpayers in Wisconsin are no exception, and as the impacts of climate change grow more destructive, the need for these measures will only become more acute. This report looks at only nine adaptation measures and three public health threats, but the total number of adaptation and resilience measures communities face as climate change worsens will be far greater. For example, this report has identified at least 66 additional adaptation measures, not included in this analysis, that are likely to be needed as Wisconsin communities struggle to adapt to coming changes (Table A3).

How We Calculated These Costs

This finding is based on a moderate climate scenario (Shared Socioeconomic Pathway 2-4.5 [SSP2-4.5]), is confined to the costs created by implementing only nine out of many climate adaptations and treating only three climate-induced public health threats that communities will ultimately face (See Appendix A.3, Table A3), and does not account for the costs of recovering from any climate-driven disasters that will almost certainly occur, creating additional damages. 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.

Climate costs will strain municipal budgets and force difficult choices that impact people's daily lives. While each community will ultimately be responsible for deciding what climate adaptation measures to invest in, the impacts of climate change will continue to worsen and costs to adapt to Wisconsin's changing climate will only increase over time. Local leaders could seek additional financial support from the federal government, but there is no source of federal funds for adaptation at this scale — and even then, the funding that is available is still coming from taxpayers.

Dozens of states and communities — including the neighboring State of Minnesota and City of Chicago — have filed lawsuits to recover the costs of climate damages from major oil companies, who have long known their products fuel climate change but waged a decades-long disinformation campaign to deceive the public.[2] Wisconsin 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.



Repairs and highway expansion take place on Highway 23 from Fond du Lac to Sheboygan.

2 Center for Climate Integrity, Cases, accessed May 28, 2024, https://climateintegrity.org/cases.

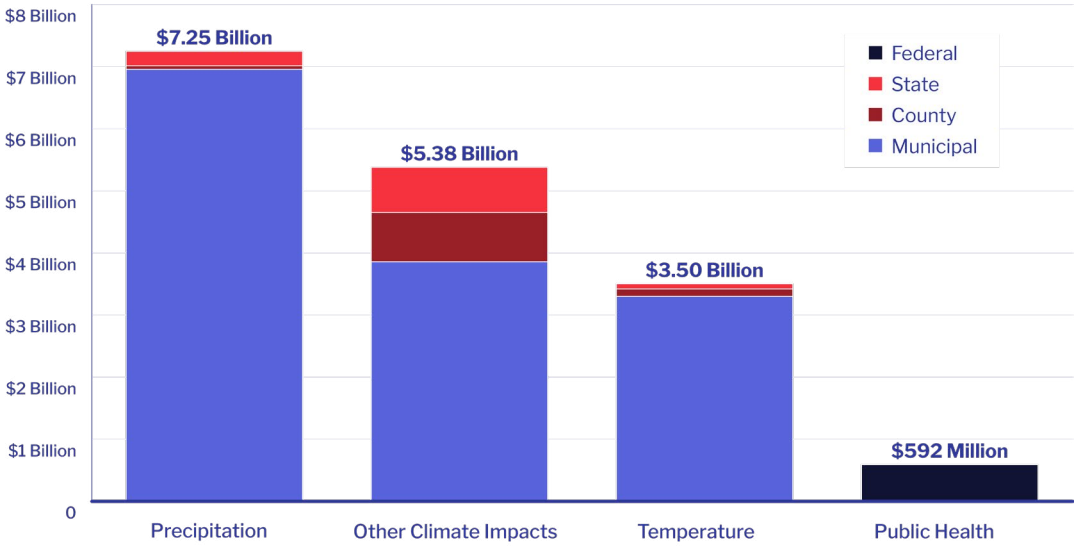
Key Findings

As climate change fuels more powerful storms and floods across Wisconsin, the highest climate cost facing taxpayers would be adapting stormwater and drainage infrastructure, at a cost of $6.67 billion through 2040.

That cost would land inequitably on some communities. Municipalities with "high racial minority areas" — defined as areas where more than 20% of the population are people of color and/or Hispanic white — would face much higher average per capita costs to increase stormwater drainage capacity ($2,464) compared to the statewide municipal average ($1,579).

Rural communities face flood risk from waters surpassing river banks that do not have levees or other protection measures. Protecting rural communities from this kind of flooding involves constructing river bank protection in the urbanized areas of these communities — an adaptation facing 3% of Wisconsin municipalities. The average per capita cost to protect rural communities from flooding is more than five times higher in low education areas ($1,068) than the statewide average ($199).

Figure 2: The total costs local governments face through 2040 to adapt to the worsening impacts of climate change in Wisconsin, by climate impact and by the government entity responsible for implementation.[3]



3 The increased precipitation adaptations are increasing stormwater drainage capacity, protecting rural communities from flooding, and bridge stabilization. The other climate impact adaptations are proactive road maintenance and protecting infrastructure from lake level change. The increased temperature adaptations are protecting residents from heatwaves, net energy costs for heating and cooling public buildings, installing AC in public buildings, and increasing urban canopy. The public health impacts are treating increased cases of pediatric asthma, West Nile Virus, and Lyme disease.

Climate change will also be brutal on Wisconsin's roads, as increased temperature and precipitation are expected to stress and degrade surfaces at a faster rate.

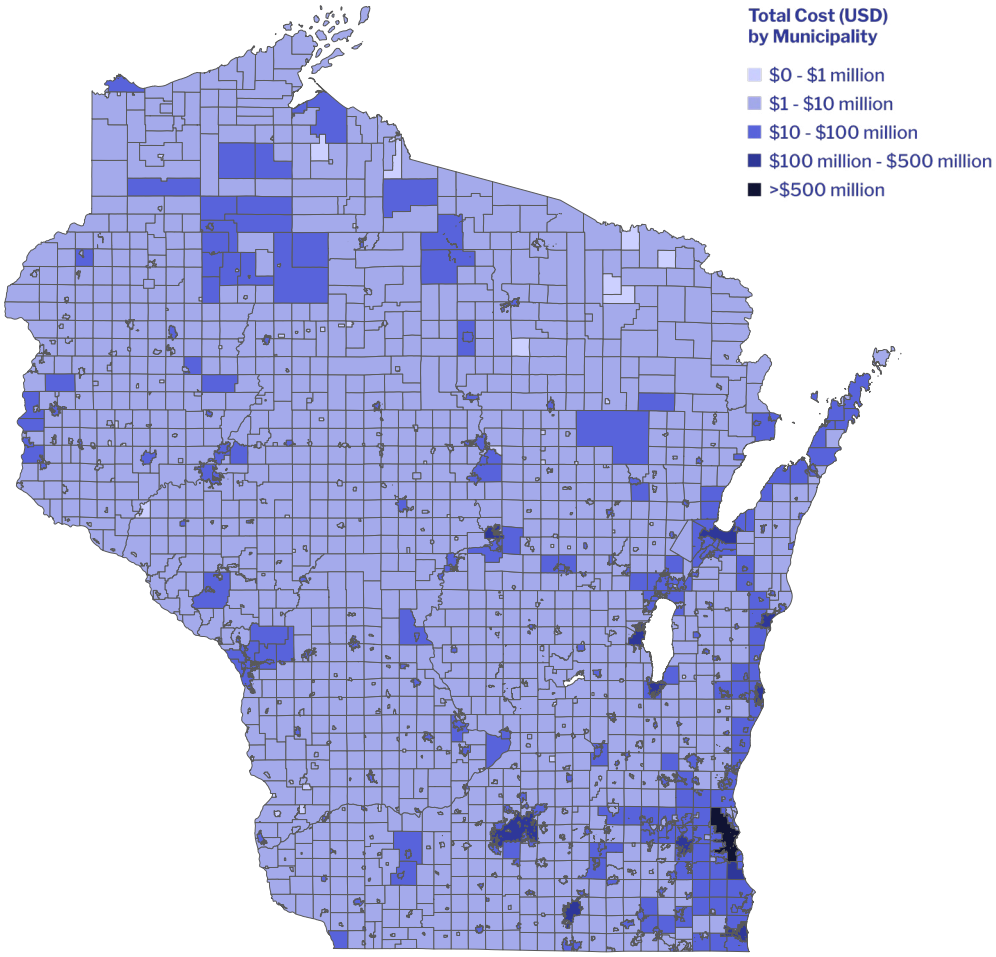
Proactively maintaining roads is the second costliest adaptation facing Wisconsin communities at $5.09 billion through 2040. Proactive road maintenance — which includes repaving roads with more temperature-resilient materials and lessening the effects of increased precipitation by diverting runoff and strengthening the road base — addresses the degradation before it threatens drivers and vehicles and, in the long-term, it can be significantly less expensive than reactive road maintenance. If Wisconsin governments proactively prepare all roads for climate change, they could save taxpayers about $1.55 billion compared to reactively repairing the road surfaces. While many governments may commonly wait for degradation to occur before acting, in many cases it is better — and less costly — to act earlier rather than to wait to react until road degradation occurs.

Adapting to climate impacts would strain, or outright consume, relevant municipal budgets for many communities in Wisconsin. The yearly costs of just seven adaptation measures would account for more than half of the annual Public Works Department budget in communities such as Oshkosh (104%), Kenosha (75%), Milwaukee (72%), and Sheboygan (58%) (Table 9). The seven adaptation costs include increasing stormwater drainage capacity, proactive road maintenance, bridge stabilization, protecting infrastructure from coastal erosion and lake level change, protecting rural communities from flooding, increasing urban canopy, and protecting residents from heatwaves.

Hot days are becoming more common in Wisconsin, revealing the current gaps in communities' existing access to cooling infrastructure. The cost of protecting residents from the dangerous impacts of heatwaves and urban heat islands will fall disproportionately across the state. Municipalities with greater populations of Black, Hispanic, and other non-white residents face higher per capita costs to address tree planting and maintenance, investments in cooling centers, and the changing costs for building heating and cooling than the statewide average per capita costs.

Finally, this report calculates which governments in Wisconsin are most likely responsible for bearing the cost of the adaptation. Costs are either assigned to the municipality where the adaptations are being made or assigned to the government entity that owns the infrastructure in question (see Appendix A.2). For example, stormwater infrastructure improvements are assigned to the municipality where the infrastructure exists, while the state is assigned costs for a state-owned highway. When analyzing the four climate adaptations where municipal, county, and state governments are all responsible for some of the costs — proactive road maintenance, bridge stabilization, cooling system installation, and changes in energy to heat and cool public buildings — municipalities bear the burden, taking on $4.34 billion, or about 70%, of the costs for those adaptations.

Figure 3: Wisconsin's high-population urban cities face the highest costs to implement nine climate adaptations through 2040.[4]



4 The three public health costs are not included, as costs cannot be assigned to municipalities.

Case Studies

Oshkosh, Wisconsin

The City of Oshkosh faces the third-highest climate costs identified in this report. Oshkosh faces $180 million in climate costs through 2040, with the majority of the adaptation costs coming from increasing stormwater drainage capacity and planting trees. That is larger than Oshkosh's 2023 total annual budget of $164 million, meaning the next 17 years of climate costs would cost the city the equivalent of an entire year's budget.[5] On an annual basis, protecting Oshkosh residents from the impacts of climate change would result in more than $10 million in new costs for the city per year if that spending is spread evenly over the next 17 years. This yearly expense is more than double the size of the city's entire 2023 Public Works budget of $4.7 million.[6]

Fond du Lac, Wisconsin

Fond du Lac, a city in Eastern Wisconsin, faces the fourth highest climate costs in the state through 2040. Of the $174 million the city will face in adaptation costs, $121 million stems from increasing the city's stormwater drainage capacity to adapt to worsening rain storms. Annually, Fond du Lac will face $10 million per year in climate adaptation costs through 2040, which is about 17% greater than the city's 2024 Public Works budget of $8.7 million.[7]

Blaine, Wisconsin

Blaine, a town of about 200 residents, will face one of the highest per capita costs for climate adaptation in Wisconsin. To reasonably adapt to the climate impacts assessed, Blaine would need to spend more than $9 million on climate adaptation costs through 2040. This translates to about $540,000 in annual climate costs, a sum that far exceeds the town's entire 2024 proposed annual budget of $420,000.[8] The significant cost of adapting to climate change in Blaine is almost entirely driven by road adaptations, which account for 97% of the town's climate adaptation costs. In 2024, Blaine has allocated $260,000 for road maintenance. In order to proactively protect their roads from the effects of climate change, officials would need to increase their road spending by 200%.

5 "City of Oshkosh: 2023 Proposed Budget," City of Oshkosh, p. 67, October 10, 2022 Accessed February 20, 2024, https://www.oshkoshwi.gov/BudgetFinancials/2023/2023_City_of_Oshkosh_Proposed_Budget.pdf.

6 "City of Oshkosh: 2023 Proposed Budget," City of Oshkosh, p. 75, October 10, 2022 Accessed February 20, 2024, https://www.oshkoshwi.gov/BudgetFinancials/2023/2023_City_of_Oshkosh_Proposed_Budget.pdf.

7 "City of Fond du Lac 2024 Adopted Budget," City of Fond du Lac, Accessed February 20, 2024. https://www.fdl.wi.gov/administration/wp-content/uploads/sites/19/2023/12/0000-2024-Adopted-Budget-Book-pdf.pdf.

8 "Town of Blaine," Town of Blaine. Accessed February 20, 2024, https://townofblainewi.com/.

American Indian Nations in Wisconsin

There are 11 federally recognized American Indian Nations in Wisconsin who live on approximately 650,000 acres of reservation or trust land, which is about 2% of the state's land area. It would cost an estimated $108 million through 2040 to make the nine infrastructure adaptations analyzed in this report within tribal reservations to protect communities from climate change impacts like extreme heat and more severe storms. Proactively maintaining roads is by far the most expensive single cost reservations face at about $98 million through 2040, while installing air conditioning in public buildings is the second highest cost at about $5.4 million through 2040.

To determine the costs to adapt to climate change within the reservation lands across Wisconsin, we used an area-weighted approach. We determined the total costs within the reservation or trust lands by multiplying the total costs by the percentage of tribal land, developed tribal land, or tribal coastline depending on adaptation in the respective municipality.

Table 1: The total cost inside tribal reservations or land trusts to implement nine climate adaptations through 2040.[9]

Climate Adaptation	Total Cost through 2040
Proactively maintaining roads	$97,889,000
Installing air conditioning in public buildings	$5,361,000
Protecting infrastructure from lake level change	$2,302,000
Increasing stormwater drainage capacity	$1,552,000
Increasing urban tree canopy	$610,000
Change in energy costs for public buildings	$267,000
Stabilizing bridges	$196,000
Protecting rural communities from flooding	$156,000
Expanding and operating cooling centers	$38,000

9 The three public health costs are not included, as costs cannot be assigned to municipalities.

Table 2: The total cost each of the 11 federally recognized American Indian Nations faces to implement nine climate adaptations through 2040.[10]

Reservation or Land Trust Name	American Indian Nation	Total Cost through 2040
Menominee Reservation	Menominee Indian Tribe of Wisconsin	$34,861,000
Lac Courte Oreilles Ojibwe Reservation	Lac Courte Oreilles Band of Lake Superior Chippewa	$18,916,000
Lac du Flambeau Ojibwe Reservation	Lac du Flambeau Band of Lake Superior Chippewa	$17,829,000
Oneida Reservation	Oneida Nation	$15,296,000
Bad River Ojibwe Reservation	Bad River Band of Lake Superior Chippewa	$13,050,000
Red Cliff Ojibwe Reservation	Red Cliff Band of Lake Superior Chippewa	$3,282,000
Stockbridge-Munsee Reservation	Stockbridge-Munsee Community Band of Mohican Indians	$2,108,000
Ho-Chunk Trust Lands	Ho-Chunk Nation	$1,265,000
Forest County Potawatomi Trust Lands	Forest County Potawatomi	$1,011,000
St. Croix Ojibwe Reservations	St. Croix Chippewa Indians of Wisconsin	$418,000
Mole Lake Ojibwe Reservation	Sokaogon Chippewa Community (Mole Lake Band)	$281,000
Not Assigned[11]	Not Assigned	$54,000

10 The three public health costs are not included, as costs cannot be assigned to municipalities.

11 We were unable to match four municipalities to a reservation or land trust using the Current Reservations and Tribal Lands map of Wisconsin.

Municipal Costs $14.1 Billion

Municipal governments bear the majority of the costs analyzed in this report, making up $14.1 billion of the $16.7 billion total climate adaptation and public health costs facing Wisconsin through 2040.

Table 3: The 12 municipal governments facing more than $100 million in costs to adapt to nine municipal climate adaptations through 2040.[12]

Rank	Municipality	Type	Municipal Cost
1	Milwaukee	City	$ 554,092,000
2	Madison	City	$ 242,734,000
3	Oshkosh	City	$ 180,192,000
4	Fond du Lac	City	$ 173,565,000
5	Green Bay	City	$ 152,899,000
6	Manitowoc	City	$ 150,629,000
7	Janesville	City	$ 144,432,000
8	Kenosha	City	$ 143,253,000
9	Sheboygan	City	$ 137,707,000
10	Oak Creek	City	$ 123,974,000
11	Waukesha	City	$ 117,835,000
12	Stevens Point	City	$ 112,561,000

Municipal governments are responsible for at least a portion of all nine adaptation projects analyzed in this report: urban tree canopy, cooling centers, building cooling systems, road maintenance, bridge stabilization, coastal protection, stormwater drainage, rural flooding, and changes in building energy usage for heating and cooling.

12 The three public health costs are estimated at the county level and are federally incurred costs, so they are not included in the municipal costs.



Storm surge crashes into a Milwaukee lakefront beach.

Temperature Adaptations: $3.3 Billion

Rising heat is already posing major threats to Wisconsin's residents and environment. In 2022, two Wisconsin residents died from unusually hot June temperatures.[13] In late summer 2023, Wisconsin experienced an unprecedented heatwave, breaking a 76-year-old heat record as temperatures soared to triple digits.[14] By the end of 2040, Wisconsin communities will see an average of 6.1 days above 95°F per year compared to the typical 1.1 days above 95°F they experienced from 1990-2013.

Protecting Wisconsin communities from rising temperatures would cost about $3.3 billion through 2040. The most expensive temperature-related climate adaptation Wisconsin faces is planting and maintaining urban tree canopy at $2.56 billion through 2040. The second most costly would be installing cooling infrastructure in public buildings at roughly $650 million through 2040, assuming that 50% of public buildings already have air conditioning infrastructure. Expanding and staffing cooling centers during increasingly severe temperatures throughout the state would cost $49 million through 2040 and the increased climate-driven cost to heat and cool buildings is estimated to cost $38 million through 2040.

Table 4: Ten municipalities face at least $40 million in costs to adapt to just four temperature-related climate adaptations through 2040.[15]

Rank	Municipality	Type	Municipal Cost
1	Milwaukee	City	$ 115,923,000
2	Oshkosh	City	$ 81,279,000
3	Janesville	City	$ 74,229,000
4	Stevens Point	City	$ 66,555,000
5	Oak Creek	City	$ 62,363,000
6	Wisconsin Rapids	City	$ 57,775,000
7	Fond du Lac	City	$ 48,931,000
8	Tomah	City	$ 42,622,000
9	Manitowoc	City	$ 41,341,000
10	Franklin	City	$ 40,967,000

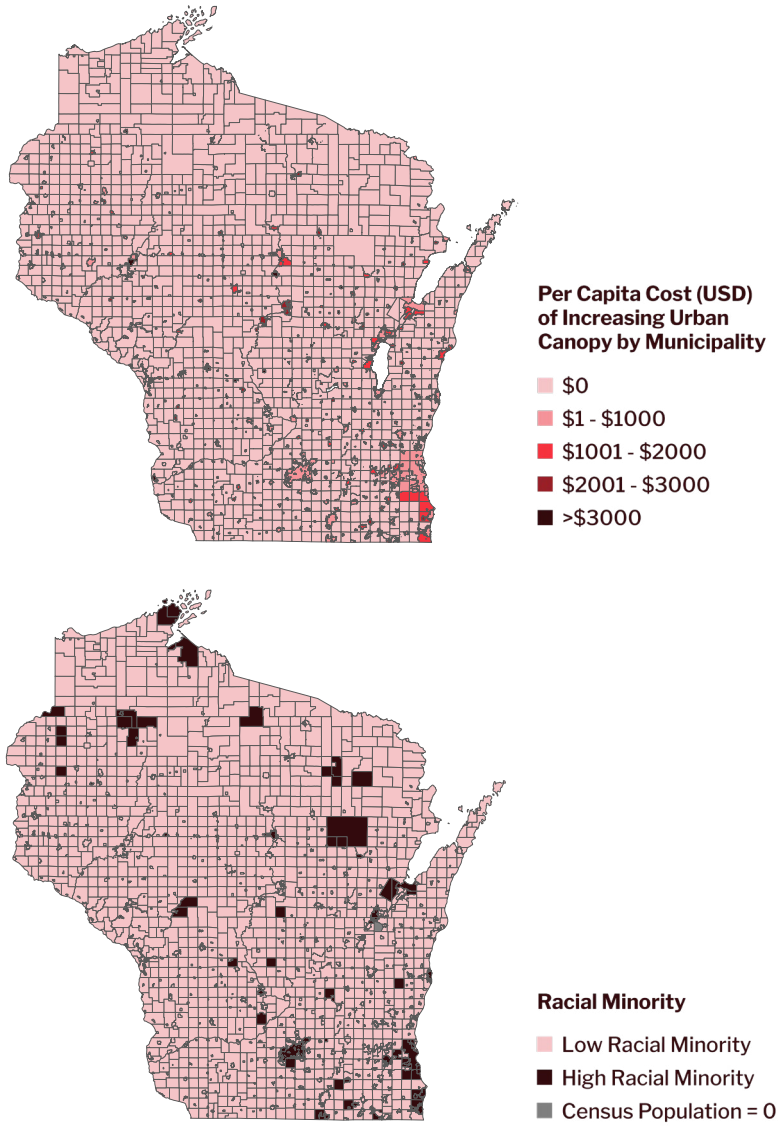
13 Phil Helsel, "Two Dead in Wisconsin as Heat Wave Blankets Large Parts of Nation," *NBC News*, June 16, 2022, https://www.nbcnews.com/news/weather/two-dead-wisconsin-heat-wave-blankets-large-parts-nation-rcna33853.

14 Mariana La Roche, "Excessive Heat Warning in Wisconsin Extended until Thursday," *WISN*, August 23, 2023, sec. News, https://www.wisn.com/article/wisconsin-heat-wave-breaks-76-year-old-record-heat-warning-extended/44890924.

15 The four temperature-related climate adaptations are protecting residents from heatwaves, net building energy usage, installing HVAC systems, and increasing urban canopy.

The burden of life-threatening heat does not fall equally across communities in Wisconsin. Communities of color in Wisconsin disproportionately lack existing cooling measures such as green spaces and cooling infrastructure, meaning these same communities are projected to face higher-than-average per capita costs to combat increasing temperatures.

Figure 4: (a) Per capita cost to increase urban canopy by municipality. (b) Municipalities with high and low racial minority areas in Wisconsin.



16 Jonmaesha Beltran and Rachel Hale, "Milwaukee Public Schools: Half of Buildings Lack Air Conditioning," *Wisconsin Watch*, October 16, 2023, http://wisconsinwatch.org/2023/10/milwaukee-schools-air-conditioning-hot-temperatures/.

17 Danbeck, "Milwaukee Public Schools Closed Aug. 23 Due to Excessive Heat, Website Says."

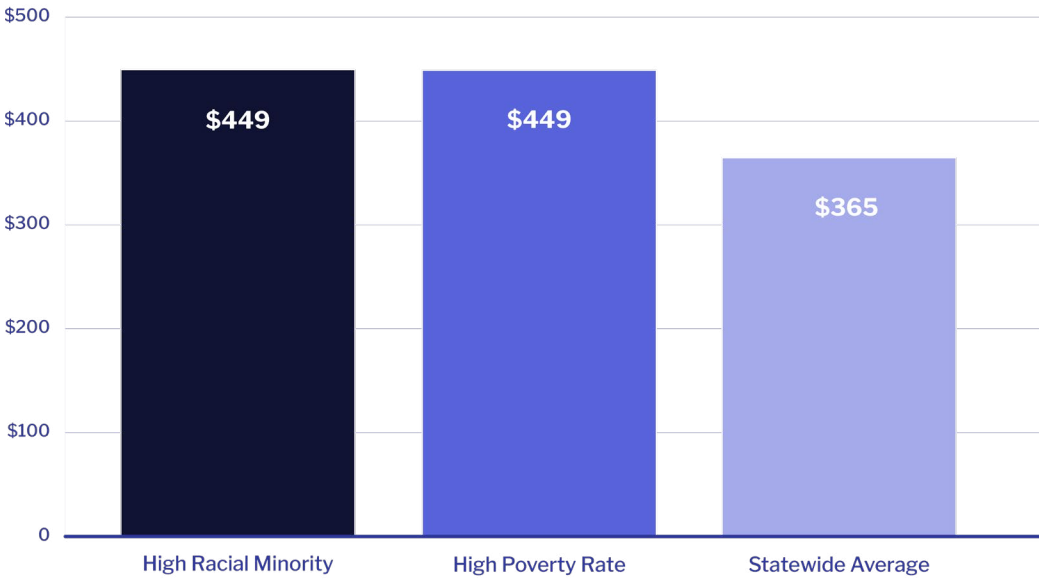
The Cost to Keep Schools at Safe Temperatures

Hotter temperatures are already causing classroom disruptions for Wisconsin students. In August 2023, Milwaukee Public Schools — which lacks air conditioning in half of its schools[16] — canceled classes as temperatures were expected to reach 100°F.[17]

Installing air conditioning in 50% of public schools across Wisconsin would cost $467 million through 2040. Climate-driven increases in energy costs for heating and cooling systems is estimated to reach $2.7 million through 2040.

The per capita costs to combat urban heat islands are also disproportionately higher in high racial minority areas and populations with lower income. In areas of the state where residents experience higher levels of poverty or are considered high racial minority areas, per capita costs to plant and maintain tree canopy to combat urban heat islands are 1.2 times higher than average statewide costs.

Figure 5: The cost to increase urban canopy is disproportionately higher in municipalities in Wisconsin with high racial minority areas and higher poverty rates (1.2 times higher compared to statewide average).



Precipitation Adaptations: $6.96 Billion

Climate change will alter precipitation patterns in Wisconsin, bringing more bouts of heavy rain that will overwhelm the region's stormwater drainage systems, trigger flooding in urban and rural areas, and increase wear and tear on bridges and roads.

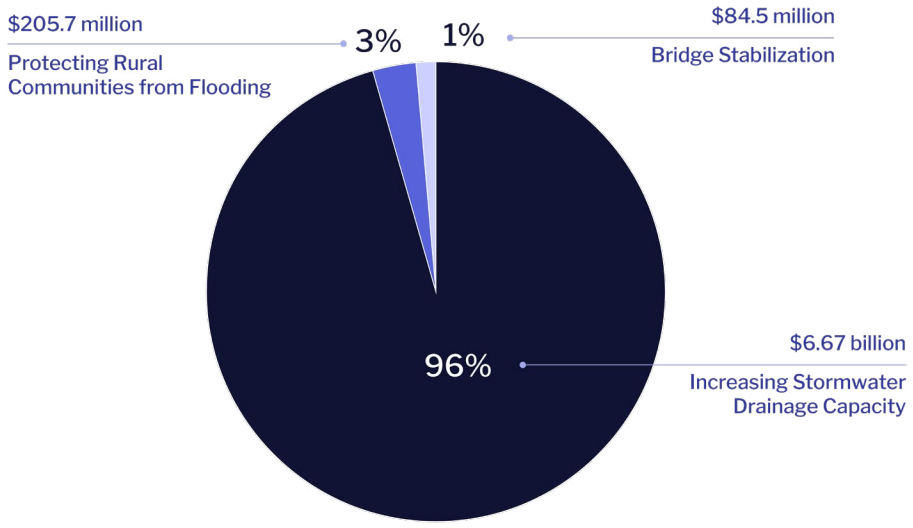
Annual precipitation increased by up to 20% in Wisconsin between 1950 and 2020. In the previous decade (2010-2019), the state saw an increase in the number of days with 1-2 inches of precipitation and the number of extreme precipitation events, with at least 21 rainfall events exceeding the 100-year rain event, which ranges from 4.5 inches in northern Wisconsin to 6.25 inches in southern Wisconsin.[18]

18 Wisconsin Initiative on Climate Change Impacts, "Wisconsin's Changing Climate: Impacts and Solutions for a Warmer Climate" (WisconsinInitiative on Climate Change Impacts. Nelson Institute for Environmental Studies, University of Wisconsin-Madison and the Wisconsin Department of Natural Resources, Madison, Wisconsin., 2021), https://uwmadison.app.box.com/s/qi5evkp4nac87chjmfxoa6kn9840sh35.

Wisconsin communities are already experiencing more frequent floods. It's not unusual for day-long rainstorms to flood local roads, and flooding is becoming more common outside of floodplains.[19] Heavy rains are already overflowing wastewater systems in Milwaukee semi-regularly; in early April 2024, a three-day rainstorm that dropped nearly 2 inches of rain in a 24-hour period led to 357 million gallons of untreated sewer water being discharged into local waterways.[20] Because just 1 inch of rain creates 7.1 billion gallons of water flowing through the Milwaukee Metropolitan Sewerage District's system, even small increases in rain can threaten the system's capacity.[21] By 2060, it is estimated that there will be a 30% increase in 2 inch rainfall events and twice as many 5 inch rainfall events.[22]

Increasing stormwater drainage capacity through infrastructure such as porous pavement, bioswales, and bioinfiltration — the least expensive stormwater infrastructure to manage increased precipitation — would cost Wisconsin taxpayers $6.67 billion through 2040. Stormwater drainage adaptations are the most significant cost municipalities face to protect their communities from changing precipitation, making up 96% of the total municipal precipitation cost.

Figure 6: Percent of the total municipal precipitation cost for each of three precipitation-related adaptation strategies.



19 Drake Bentley, "Heavy Rain Brings Flooding to Milwaukee after Tornado Warnings in Central Wisconsin," *Milwaukee Journal Sentinel*, March 4, 2024, https://www.jsonline.com/story/weather/2024/03/04/heavy-rain-forecasted-following-tornado-warnings-in-milwaukee-area/72845224007/; Beck Andrew Salgado and Drake Bentley, "Flood Watch Issued for Milwaukee Area as 'numerous Roads Flooded' across County," *Milwaukee Journal Sentinel*, August 14, 2023, https://www.jsonline.com/story/weather/2023/08/14/flood-watch-issued-for-portions-of-the-state-rain-expected-all-day/70587054007/; Dohms-Harter, "Climate Change Is Causing More Flooding. Here's How Wisconsinites Can Protect Themselves."

20 Sharon Mertens, "April 2-4, 2024 Combined Sewer Overflow Event Report WPDES Permit No. WI-0036820-04-0," April 8, 2024, https://www.mmsd.com/application/files/7517/1260/7903/April_2-4_2024_5-Day_Report.pdf.

21 MMSD, "MMSD Sewer Overflow Information," MMSD Partners for a Cleaner Environment, October 7, 2016, https://www.mmsd.com/what-we-do/wastewater-treatment/overflows.

22 Wisconsin Department of Natural Resources, "The Science of Climate Change," accessed May 20, 2024, https://dnr.wisconsin.gov/climatechange/science.

Table 5: The nine municipal governments facing more than $90 million in costs to increase stormwater drainage capacity through 2040.

Rank	Municipality	Type	Municipal Cost
1	Milwaukee	City	$ 384,325,000
2	Madison	City	$ 162,229,000
3	Fond du Lac	City	$ 121,084,000
4	Sheboygan	City	$ 105,698,000
5	Kenosha	City	$ 100,549,000
6	Green Bay	City	$ 99,224,000
7	Manitowoc	City	$ 98,073,000
8	Waukesha	City	$ 94,012,000
9	Oshkosh	City	$ 92,979,000

Our analysis reveals that increasing stormwater drainage capacity would cost more for high racial minority communities in Wisconsin.

Figure 7: Municipal per capita costs to increase stormwater drainage capacity.

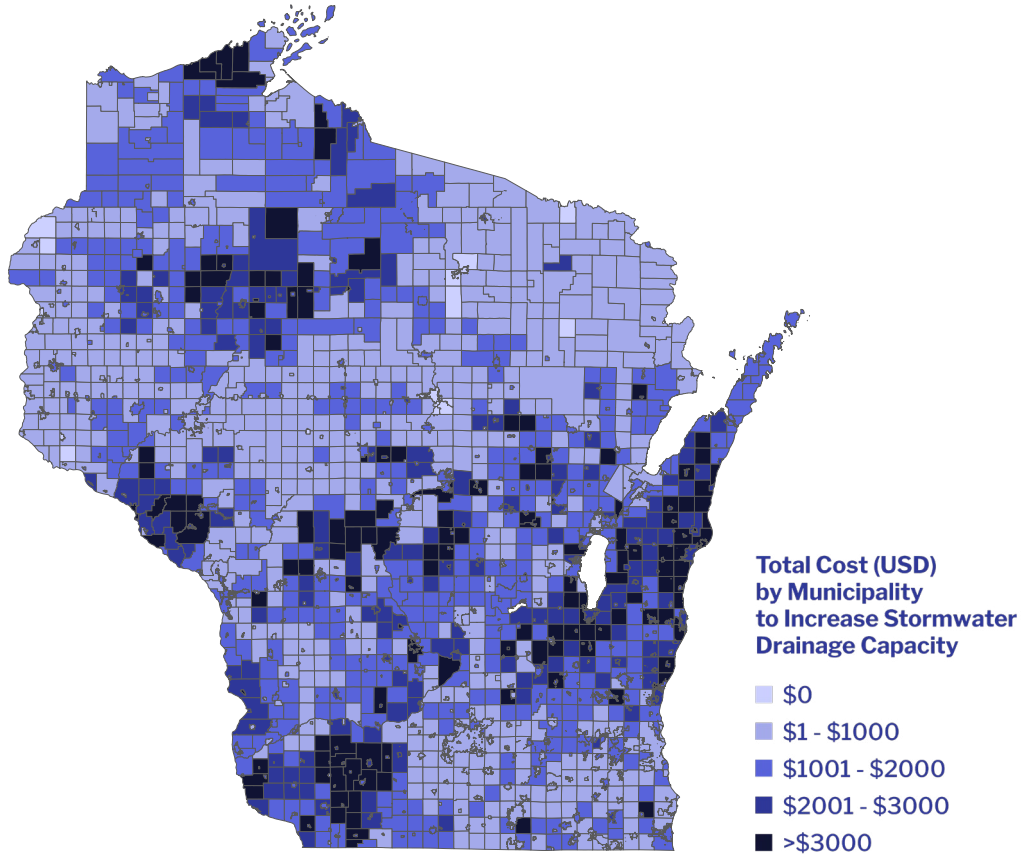
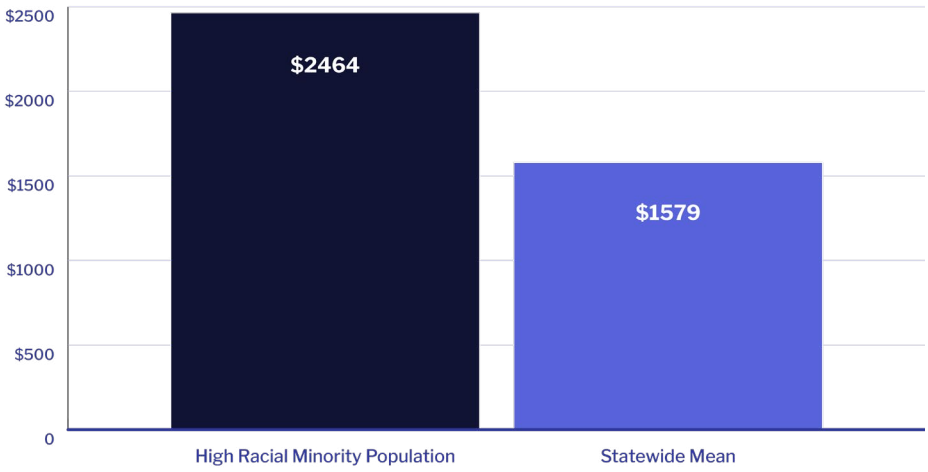


Figure 8: The cost to increase stormwater drainage capacity is disproportionately higher in areas of the state with higher minority populations (1.6 times higher compared to statewide average).



Protecting communities against rural flooding is an expensive adaptation of its own, but it may be especially burdensome on smaller communities with higher per capita adaptation costs. Townships and villages — types of municipalities frequently located in rural areas — are typically smaller in population and have lower municipal budgets. Consequently, any climate adaptation cost, such as rural flooding resilience, would stress those municipal budgets. For example, the 2024 budget for Hamilton Township in Wisconsin is about $15.2 million, of which $3 million is for capital projects. The annual cost to protect residents against flooding is about $622,000, or about 21% of the 2024 capital projects budget.[23]

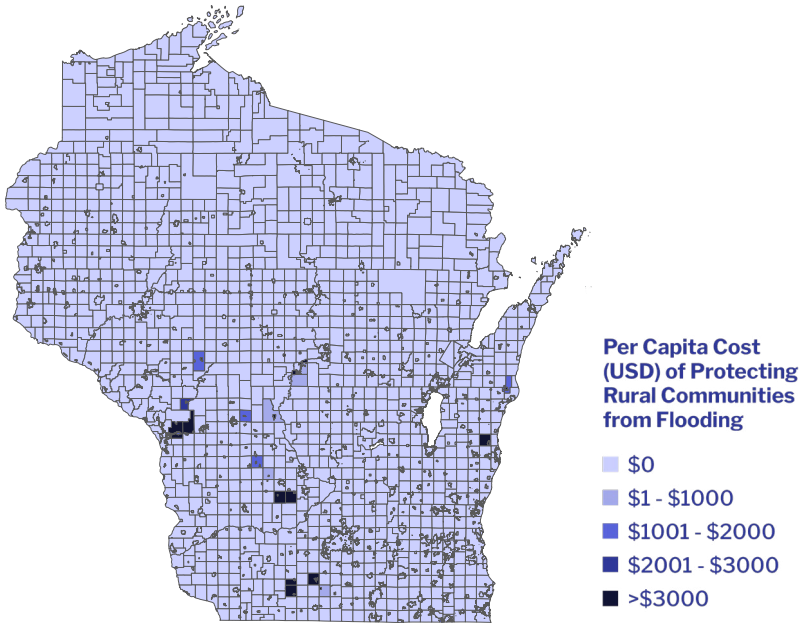
Table 6: The nine municipal governments facing over $7 million to protect their communities from rural flooding through 2040.

Rank	Municipality	Type	Municipal Cost
1	Hamilton	Township	$ 10,567,000
2	Howards Grove	Village	$ 9,976,000
3	Port Edwards	Village	$ 9,224,000
4	West Salem	Village	$ 8,658,000
5	Necedah	Village	$ 8,138,000
6	Mishicot	Village	$ 7,923,000
7	Herman	Township	$ 7,696,000
8	North Freedom	Village	$ 7,608,000
9	Merrillan	Village	$ 7,067,000

23 Sarah Hyatt, "Township of Hamilton Approves $15.2M Budget, with Net Levy Hike at 4.6%," *Northumberland News*, December 22, 2023, https://www.northumberlandnews.com/news/council/township-of-hamilton-approves-15-2m-budget-with-net-levy-hike-at-4-6/article_1752794e-a4b9-5708-a1aa-498661882b67.html.

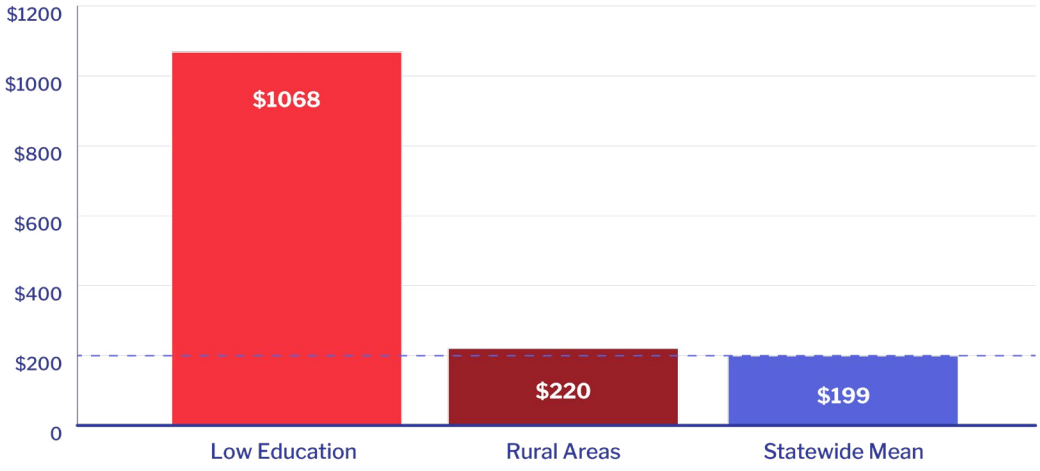
While the vast majority of Wisconsin is considered rural (85% of municipalities), only 49 municipalities (about 3%) face rural flooding costs because of their proximity to rivers in the developed area of rural communities.

Figure 9: Municipal per capita rural flooding costs.



The majority of Wisconsin municipalities do not face rural flooding concerns, but the areas that do happen to have lower levels of education. While the average statewide per capita cost to combat rural flooding is $199, rural areas have a per capita cost of $220, and low education areas of the state have a per capita cost of $1,068.

Figure 10: The per capita cost to protect 3% of Wisconsin municipalities from rural flooding is disproportionately higher in municipalities with lower levels of education (5.4 times higher compared to statewide average). Overall, rural areas do not have significantly higher per capita costs than the statewide average.



Proactive Road Maintenance: $3.57 Billion

Climate change can devastate road conditions. Higher temperatures soften road surfaces and increase degradation rates, making roadways cracked and rutted. Higher precipitation increases erosion, which weakens the road base and creates more maintenance demands in order to keep the infrastructure functioning as designed. A reactive approach involves fixing the roads as they are damaged. Alternatively, a proactive approach entails making the roads resilient to projected increases in temperature and precipitation before damage occurs. Both the proactive and reactive approaches analyzed by this report only consider the cost to adapt to normal road degradation due to climate change and do not account for any potential damage from individual extreme weather events. To proactively keep municipal roads in current conditions, municipalities in Wisconsin face $3.57 billion in climate-driven proactive repair costs through 2040.



Road work in Green Bay, Wisconsin.

Table 7: Five municipalities face at least $20 million in climate-driven proactive road maintenance costs through 2040.

Rank	Municipality	Type	Municipal Cost
1	Madison	City	$ 42,894,000
2	Milwaukee	City	$ 42,688,000
3	Menominee	Township	$ 28,970,000
4	Round Lake	Township	$ 21,088,000
5	Spider Lake	Township	$ 20,306,000

Table 8: The five municipalities that would save the most money implementing proactive road maintenance instead of reactive road maintenance from 2024 through 2040.

Municipality	Type	Reactive Cost	Proactive Cost	Difference in Cost	Percent Increase
Madison	City	$70,200,000	$42,894,000	$27,306,000	64%
Milwaukee	City	$62,090,000	$42,688,000	$19,402,000	45%
Eau Claire	City	$20,322,000	$9,909,000	$10,413,000	105%
Greenfield	City	$20,801,000	$12,221,000	$8,580,000	70%
Waukesha	City	$16,392,000	$8,078,000	$8,314,000	103%

Reactive vs. Proactive Municipal Road Maintenance

Proactive road maintenance would cost municipal governments and their taxpayers approximately $3.57 billion through 2040. If municipal governments choose to repair roads after they have been damaged by climate change, the estimated costs climb to more than $4.46 billion through 2040. While local governments are more accustomed to taking a reactive road maintenance approach, they could save their taxpayers around $900 million by acting proactively.

In the long-term, proactive road maintenance is usually less expensive than reactive costs because it accounts for future temperature and precipitation conditions caused by climate change, which makes the roads more resilient to changing conditions as opposed to reactive road repairs, which spot treat a problem that will continuously occur as conditions change.

In 72% of Wisconsin municipalities (1,369 of 1,913), reactive road costs are more expensive than proactive road costs through 2040. Through 2060, the ratio gets worse: in 83% of municipalities (1,582 of 1,913) reactive road costs are more expensive than proactive road costs. Proactive road maintenance savings become even greater over time as damage increases as climate change worsens. Implementing proactive road maintenance from 2041 through 2060 in Wisconsin would cost an estimated $6.05 billion less than reactive road maintenance in the same time period.

While most municipalities would ultimately save money by proactively adapting roads for changing climate conditions, 534 municipalities face lower reactive than proactive road repair costs through 2040. That number drops to 324 municipalities that would save money by reactively repairing roads through 2060. The municipalities that tend to save money by reactively repairing roads are typically located in northern Wisconsin, where average temperatures and precipitation rates increase the least during this time period.

Table 9: Six municipalities would save more than $6 million by reactively repairing roads from 2024 through 2040.

Municipality	Type	Reactive Cost	Proactive Cost	Difference in Cost	Percent Increase
Wascott	Township	$678,000	$9,121,000	$(8,433,000)	1245%
Drummond	Township	$5,477,000	$12,697,000	$(7,220,000)	132%
Menominee	Township	$22,326,000	$28,970,000	$(6,644,000)	30%
Winter	Township	$8,938,000	$15,574,000	$(6,636,000)	74%
Grand View	Township	$5,877,000	$12,132,000	$(6,255,000)	106%
Lac Du Flambeau	Township	$7,440,000	$13,539,000	$(6,099,000)	82%

Coastal Erosion and Lake Level Change: $293 Million

As temperatures become more volatile and precipitation patterns change, the Great Lakes bordering Wisconsin will experience more significant lake level changes and increased wave energy, causing inundation and erosion of lake banks.[24] This increased erosion will cause instability along the shoreline and coastal bluffs, threatening the stability of infrastructure along the lakes.[25] This report used the NOAA Lake Level Viewer[26] — a tool that predicts future lake level changes that does not take into account coastal protection measures already in place — combined with the NOAA U.S. Great Lakes Hardened Shoreline Classification to determine whether the shoreline is natural or artificial.[27]

24 Miraj B. Kayastha et al., "Future Rise of the Great Lakes Water Levels under Climate Change," *Journal of Hydrology* 612 (September 2022): 128205, https://doi.org/10.1016/j.jhydrol.2022.128205; "Future Rise of the Great Lakes Water Levels Under Climate Change | Great Lakes Research Center | Michigan Tech," Michigan Technological University, accessed September 11, 2023, https://www.mtu.edu/greatlakes/research-highlights/climate-change-great-lakes/.

25 Dea Larsen Converse, "Flooding and Bluff Erosion from Extreme Storms Are Impacting Wisconsin's Great Lakes Coastlines," Wisconsin Initiative on Climate Change Impacts, accessed May 13, 2024, https://wicci.wisc.edu/2021-assessment-report/built-environment/flooding-and-bluff-erosion-from-extreme-storms-are-impacting-wisconsins-great-lakes-coastlines/.

26 National Atmospheric and Oceanic Administration, "Lake Level Viewer: United States Great Lakes," 2023, https://coast.noaa.gov/llv/.

27 National Atmospheric and Oceanic Administration, "U.S. Great Lakes Hardened Shorelines Classification 2019," 2019, https://coast.noaa.gov/digitalcoast/data/hardened-shorelines.html.

The increasingly volatile conditions on the lake shores, including higher water levels and more violent storms, will impact about 5% of municipalities in the state, threatening buildings, residential homes, and other infrastructure. One piece of critical infrastructure threatened by changing lake levels is Milwaukee's sewage treatment plant on Jones Island, which treats approximately 200 million gallons of sewage daily.[28] This facility is uniquely vulnerable to the dual climate threats of heavy precipitation events and lake level changes.

Milwaukee is also currently pursuing funding to replace the breakwater that was built at the turn of the 20th century to protect the harbor.[29] As it stands, the breakwater does not protect against the highest lake levels, like those experienced in 2020 where lake level was four feet higher than normal.[30] Those high lake levels led to millions of dollars in damages across Wisconsin. As future variations in lake levels become more extreme, protecting these communities is projected to cost approximately $293 million through 2040.

This cost represents the financial burden of protecting infrastructure that is within 250 feet of the present-day coastline of the Great Lakes in Wisconsin by restoring natural shorelines or enhancing artificial shorelines. If municipalities were to protect infrastructure within 500 feet of the coastline, the cost would balloon to $432 million through 2040.

Table 10: Eleven local governments face more than $7 million in upgrades to protect their communities from increased coastal erosion and flooding due to lake level change through 2040.

Rank	Municipality	Type	Municipal Cost
1	Sheboygan	City	$14,516,000
2	Baileys Harbor	Township	$12,072,000
3	Liberty Grove	Township	$11,885,000
4	Milwaukee	City	$11,156,000
5	Racine	City	$9,510,000
6	Kenosha	City	$9,417,000
7	Scott	Township	$9,091,000
8	Caledonia	Village	$9,075,000
9	Green Bay	City	$8,648,000
10	Somers	Village	$7,572,000
11	Two Rivers	City	$7,023,000

28 ASCE, "Milwaukee Metropolitan Sewage Treatment Plant," American Society of Civil Engineers, 2024, https://www.asce.org/about-civil-engineering/history-and-heritage/historic-landmarks/milwaukee-metropolitan-sewage-treatment-plant.

29 Graham Kilmer, "MKE County: Supervisors Stall, Inflate Cost of Sea Wall Project," *Urban Milwaukee*, accessed May 28, 2024, https://urbanmilwaukee.com/2023/02/01/mke-county-supervisors-stall-inflate-cost-of-sea-wall-project/.

30 Ricardo Torres, "Milwaukee County Requests Help from State, FEMA for Lakeshore Storm Damage," *Milwaukee Journal Sentinel*, January 17, 2020, https://www.jsonline.com/story/weather/2020/01/17/lakeshore-storm-damage-milwaukee-county-requests-aid-state-fema/4498894002/.

In Baileys Harbor, Wisconsin, the cost to protect communities from the rising lake level is $710,000 per year for 17 years, which is substantially greater than the township's entire proposed 2024 Public Works budget of $593,510.[31]

Municipal Budgets

Generally, municipal budgets operate at or near capacity with little to no unused funds. The costs to respond to climate change impacts, on top of existing municipal costs, present enormous and difficult choices for Wisconsin communities. With finite resources and growing budget demands, investing in climate resilience may mean not spending on other services such as firefighting, police, schools, senior centers, libraries, sanitation, and more. Faced with these trade offs, communities often delay or fail to implement climate adaptation initiatives until after a major disaster, if even then.

Table 11: Municipalities facing the highest annual infrastructure adaptation costs could see an increase of more than 50% in Department of Public Works expenses.[32]

Municipality	Annual Cost	Fiscal Year	Department	Budget	% of Annual Budget
Milwaukee	$28,486,000	2024	Public Works - Infrastructure Services Division[33]	$39,322,000	72%
Madison	$12,711,000	2024	Public Works[34]	$50,112,000	25%
Oshkosh	$10,093,000	2024	Public Works, Transportation, and Parks[35]	$9,736,000	104%
Fond du Lac	$9,763,000	2024	Public Works and Parks, Culture, and Recreation[36]	$8,937,000	109%

31 "Notice of Public Budget Hearing for Town of Baileys Harbor Wisconsin Door County," November 27, 2023, https://baileysharborwi.gov/wp-content/uploads/2023/11/2024-Budget-Public-Hearing-1.pdf.

32 The seven infrastructure costs are increasing stormwater drainage capacity, proactive road maintenance, bridge stabilization, protecting infrastructure from lake level change, protecting rural communities from flooding, increasing urban canopy, and protecting residents from heatwaves.

33 Cavalier Johnson, Preston Cole, and Nik Kovac, "2024 Budget: City of Milwaukee" (Department of Administration, Budget Management Division, 2024), https://city.milwaukee.gov/ImageLibrary/Groups/doaBudgetOffice/2024-Adopted-Budget.pdf.

34 Satya Rhodes-Conway, "2024 Adopted Budget, Operating & Capital Budget, Capital Improvement Plan" (City of Madison, 2024), https://www.cityofmadison.com/finance/documents/budget/2024/operating/adopted/Adopted2024.pdf.

35 Mark A. Rohloff, "2024 Adopted Budget: Oshkosh, WI" (City of Oshkosh, December 29, 2023), https://www.oshkoshwi.gov/BudgetFinancials/2024/2024_Adopted_Budget_Book.pdf.

36 Joseph P. Moore, "2024 Adopted Budget: City of Fond du Lac" (City of Fond du Lac, November 8, 2023), https://www.fdl.wi.gov/administration/wp-content/uploads/sites/19/2023/12/0000-2024-Adopted-Budget-Book-pdf.pdf.

Table 11 cont.

Municipality	Annual Cost	Fiscal Year	Department	Budget	% of Annual Budget
Manitowoc	$8,572,000	2024	Public Works[37]	$10,940,000	78%
Green Bay	$8,256,000	2024	Public Works[38]	$18,357,000	45%
Janesville	$8,072,000	2024	Public Works[39]	$8,626,000	94%
Sheboygan	$7,806,000	2024	Public Works[40]	$13,478,000	58%
Kenosha	$7,556,000	2024	Public Works[41]	$10,134,000	75%
Oak Creek	$6,938,000	2024	Public Works[42]	$5,904,000	118%

Note: Unless otherwise specified, the 2024 Department of Public Works (DPW) Budget is taken from the 2024 adopted budget line item for a given municipality's DPW.

Table 12: The fiscal stress on local budgets for the top 10 municipalities facing the highest proactive road maintenance costs.

Municipality	Annual Cost	Fiscal Year	Department	Budget	% of Annual Budget
Madison	$2,523,000	2024	Public Works - Streets[43]	$2,118,000	119%
Milwaukee	$2,511,000	2024	Street Reconstruction or Resurfacing Program[44]	$18,750,000	13%
Menominee	$1,704,000	2023	Major Street Fund	$1,496,000	114%
Round Lake	$1,240,000	2023	Maintenance of Roads and Road Construction	$156,000	793%
Spider Lake	$1,194,000	2021	Total Expenditures	$957,000	125%
Minocqua	$973,000	2024	Total Budget	$6,491,000	15%
Hayward	$953,000	2024	Public Works	$612,000	156%
Green Bay	$924,000	2023	Street Construction	$1,871,000	49%
Winter	$916,000	2024	Public Works	$917,000	100%
Bass Lake	$857,000	2022	Total Expenditures	$825,000	104%

37 Justin M. Nickels, "2024 Proposed Budget: City of Manitowoc" (City of Manitowoc, October 24, 2023), https://www.manitowoc.org/DocumentCenter/View/34318/2024-Mayor-Proposed-Budget?bidId=.

38 Eric Genrich, "2024 Budget: City of Green Bay" (City of Green Bay, November 9, 2023), https://greenbaywi.gov/ArchiveCenter/ViewFile/Item/614.

39 Kevin M. Lahner, "Annual Budget 2024: City of Janesville" (City of Janesville, 2024), https://www.janesvillewi.gov/home/showpublisheddocument/12073/638382256439170000.

40 "City of Sheboygan Annual Program Budget 2024," October 2, 2023, https://www.sheboyganwi.gov/wp-content/uploads/2024/03/2024-Adopted-Budget-Publication-1.pdf.

41 John M. Antaramian and John W. Morrissey, "Adopted 2024 Operating Budget: The City of Kenosha" (City of Kenosha, November 29, 2023), https://www.kenosha.org/images/finance/2024-adopted-book.pdf.

42 Dan Bukiewicz, "2024 Annual Budget & Capital Improvement Program: Oak Creek Wisconsin" (City of Oak Creek, January 1, 2024), https://www.oakcreekwi.gov/home/showpublisheddocument/18285/638411096653470000.

43 Rhodes-Conway, "2024 Adopted Budget, Operating & Capital Budget, Capital Improvement Plan."

44 Johnson, Cole, and Kovac, "2024 Budget: City of Milwaukee."

County Costs
$968 Million

Of the nine climate adaptations and three public health threats analyzed in this report, counties in Wisconsin are responsible for a portion of the costs associated with four adaptations: changes in building energy usage for heating and cooling, installing air conditioning in public buildings, road maintenance, and bridge stabilization. For a full explanation of each climate adaptation, refer to the Municipal Costs section or Appendix A.1, Table A1.

Of the $968 million in climate adaptation costs facing Wisconsin counties through 2040, the most expensive cost county governments face is proactive road maintenance. Proactively maintaining county-owned roads would cost $792 million through 2040. Installing air conditioning in 50% of county-owned buildings is the second costliest climate adaptation facing counties at $95 million through 2040.

Table 13: Ten county governments face more than $20 million in costs from four climate adaptations through 2040.[45]

Rank	County	County Cost
1	Polk	$ 33,181,000
2	Sawyer	$ 30,210,000
3	Dane	$ 27,534,000
4	St. Croix	$ 27,456,000
5	Marathon	$ 27,171,000
6	Oconto	$ 26,710,000
7	La Crosse	$ 22,682,000
8	Waukesha	$ 21,972,000
9	Chippewa	$ 21,821,000
10	Dunn	$ 20,034,000

45 The four costs incurred by the county are installing air conditioning in public buildings, net building energy usage, proactively maintaining roads, and bridge stabilization.

Temperature Impacts: $119 Million

Changes in energy usage for heating and cooling, as well as installing air conditioning systems in county-owned buildings would cost Wisconsin counties $119 million through 2040. The vast majority of those costs can be attributed to installing air conditioning in an assumed 50% of county-owned buildings, which would cost $95 million.

Table 14: Eight county governments are facing more than $4 million in costs through 2040 to implement just two temperature-related climate adaptations.[46]

Rank	County	County Cost
1	Brown	$ 8,246,000
2	Waukesha	$ 6,348,000
3	Milwaukee	$ 5,881,000
4	Racine	$ 5,628,000
5	Walworth	$ 5,047,000
6	Winnebago	$ 4,570,000
7	Dane	$ 4,435,000
8	Fond du Lac	$ 4,411,000

Bridge Stabilization: $57 Million

County-owned bridges will be subject to extra wear and tear as the climate crisis worsens, eroding their stability. Stabilizing county-owned bridges throughout Wisconsin would cost $57 million through 2040.

Table 15: Eight county governments are facing at least $2 million through 2040 to stabilize county-owned bridges.

Rank	County	County Cost
1	Sheboygan	$ 6,080,000
2	Waukesha	$ 4,580,000
3	Manitowoc	$ 4,399,000
4	La Crosse	$ 4,318,000
5	Clark	$ 3,523,000
6	Green	$ 3,435,000
7	Lafayette	$ 2,861,000
8	Dane	$ 2,402,000

46 The two temperature-related adaptations counties will face are net building energy usage and installing cooling systems in buildings. We are unable to assign costs for the remaining temperature adaptations to the county, but they will likely be incurred.

Proactive Road Maintenance: $792 Million

Proactively maintaining county-owned roads against climate-induced degradation would cost Wisconsin counties about $792 million through 2040.

Table 16: Seven county governments are facing at least $20 million through 2040 to proactively maintain county-owned roads.

Rank	County	County Cost
1	Polk	$ 30,929,000
2	Sawyer	$ 29,055,000
3	St. Croix	$ 25,910,000
4	Oconto	$ 24,930,000
5	Marathon	$ 23,862,000
6	Dane	$ 20,697,000
7	Chippewa	$ 20,198,000

Table 17: Of the 10 counties with the highest proactive road maintenance costs, the annual cost consumed more than 10% of the annual budget for five counties.

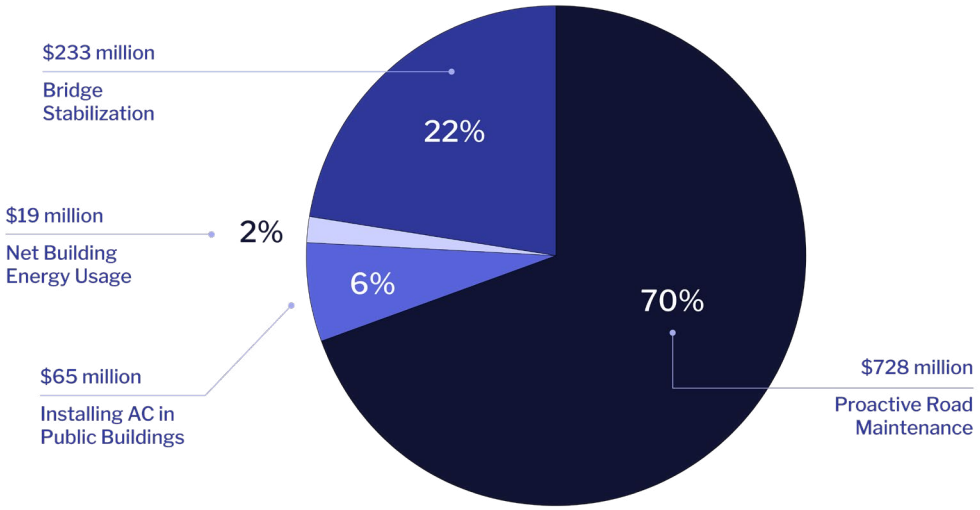
County	Annual Road Cost	Fiscal Year	Department	Budget	% of Annual Budget
Polk	$1,819,000	2024	Road Construction / Repairs	$3,665,000	50%
Sawyer	$1,709,000	2024	Highway Department	$5,360,000	32%
Oconto	$1,466,000	2024	Highway Road and Bridge Fund	$10,621,000	14%
Marathon	$1,404,000	2024	Highway Paving	$5,944,000	24%
Burnett	$1,041,000	2024	Highway	$7,957,000	13%

State Costs
$1 Billion

The State of Wisconsin would be responsible for a portion of the costs for four climate adaptations analyzed by this report: proactive road maintenance, installing air conditioning in public buildings, changes in energy usage because of heating and cooling, and bridge stabilization.

Proactively maintaining state-owned roads in Wisconsin would cost $728 million through 2040, the most expensive cost facing the state government. Stabilizing bridges against climate-induced wear and tear would cost $233 million, installing AC in public state buildings would cost $65 million, and costs to heat and cool public buildings in response to changing temperatures would cost $19 million through 2040. Overall, protecting state infrastructure from climate change would cost Wisconsin more than $1 billion through 2040.

Figure 11: The costs of four climate adaptation measures facing Wisconsin state government.



Federal Costs
$592 Million

The federal government will be responsible for responding to three climate-induced public health threats analyzed in this report and their related increase in Medicaid and Medicare costs.

Public Health: $592 Million

Climate change is contributing to increasing threats to public health, including rising rates of pediatric asthma and certain diseases — the ballooning costs of which will fall heavily on the federal government. As climate change alters temperatures, precipitation rates, and other weather patterns in Wisconsin, ecological conditions that contribute to various insect populations — and the corresponding diseases they carry — will also shift.

Changing temperatures driven by climate change mean that areas of Wisconsin that were once too cold for ticks to thrive are becoming tick hotspots. The expanded range of ticks is now increasing the potential risk of Lyme disease transmission. **Through 2040, Wisconsin is projected to see 85,375 new cases of Lyme disease — a 136% increase in cases compared to 2024.** Of those new cases, we estimate 30,820 would receive treatment through Medicaid or Medicare, costing the federal government $347.8 million through 2040.

Increasing populations of mosquitoes will lead to a significant increase in West Nile Virus cases. **Through 2040, Wisconsin communities are projected to see an estimated 94,712 new cases of West Nile Virus — a 1,944% increase in new cases compared to 2024.** Of those new cases, we estimate 34,191 would receive publicly funded treatment, costing taxpayers about $208.8 million through 2040.

Increased temperatures are also linked to an increase in pollen, leading to higher rates of pediatric asthma. **Wisconsin is expected to see a 69% increase in pediatric asthma cases through 2040, or an estimated 63,514 new cases.** Of those cases, we estimate that 32,202 would receive publicly funded treatment at a cost of $35.5 million.

Figure 12: The total estimated cost to address three public health threats identified in this report.

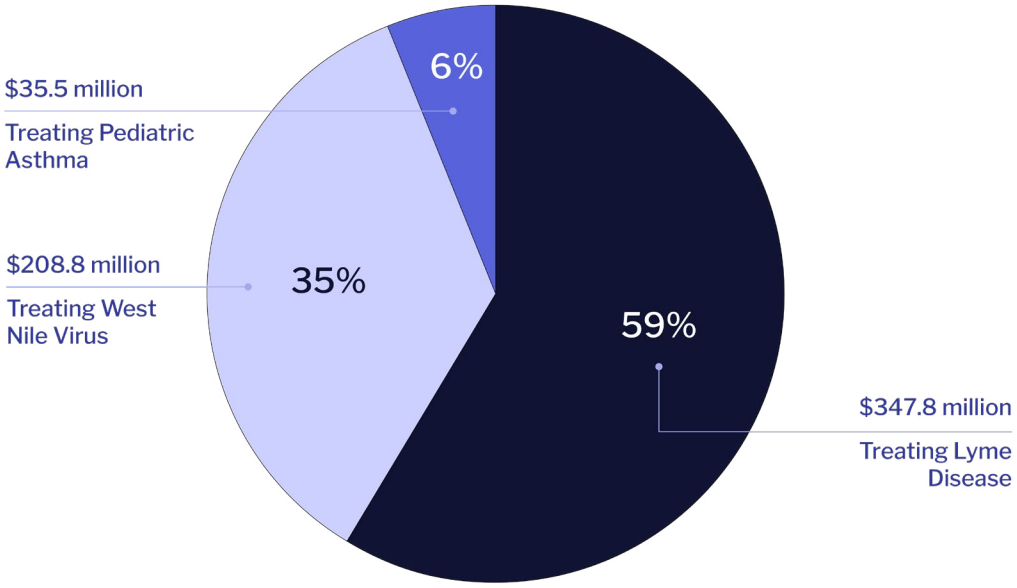


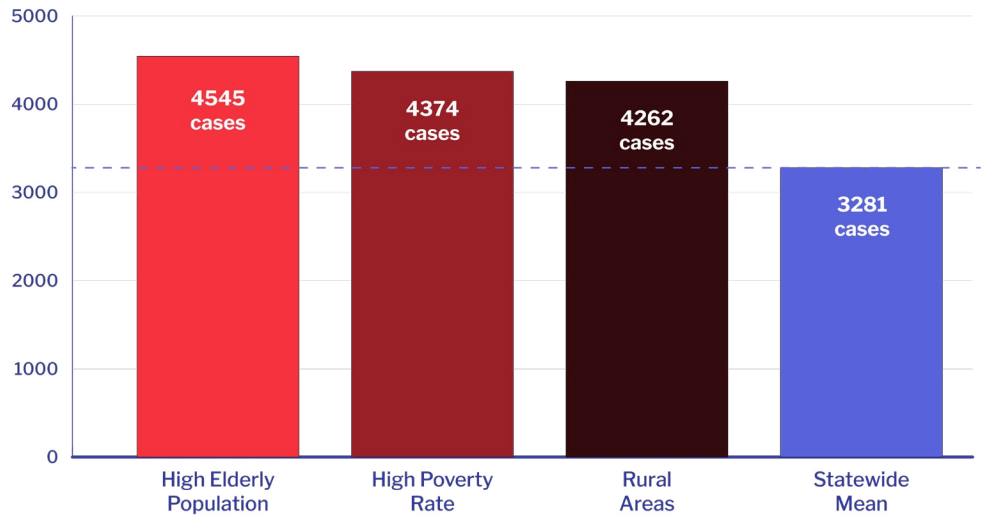
Table 18: Nine counties face at least $12 million in federally-funded healthcare costs to treat an increase in pediatric asthma, West Nile Virus, and Lyme disease through 2040. Bolded costs represent the most expensive public health threat treatment each county faces.

Rank	County	Pediatric Asthma	West Nile Virus	Lyme Disease	Total Cost
1	Waukesha	$ 1,260,000	$ 11,848,000	**$ 36,349,000**	$ 49,457,000
2	Dane	$ 1,822,000	$ 15,796,000	**$ 19,282,000**	$ 36,900,000
3	Milwaukee	**$ 13,773,000**	$ 12,402,000	$ 9,420,000	$ 35,595,000
4	Brown	$ 1,506,000	$ 1,811,000	**$ 12,920,000**	$ 16,237,000
5	Marinette	$ 203,000	$ 1,489,000	**$ 13,714,000**	$ 15,406,000
6	Eau Claire	$ 406,000	$ 2,186,000	**$ 12,556,000**	$ 15,148,000
7	Jefferson	$ 402,000	**$ 8,753,000**	$ 3,746,000	$ 12,901,000
8	Sauk	$ 333,000	$ 2,277,000	**$ 10,136,000**	$ 12,746,000
9	Waupaca	$ 319,000	$ 1,788,000	**$ 10,188,000**	$ 12,295,000

These new public health threats will not fall equally on Wisconsin communities.

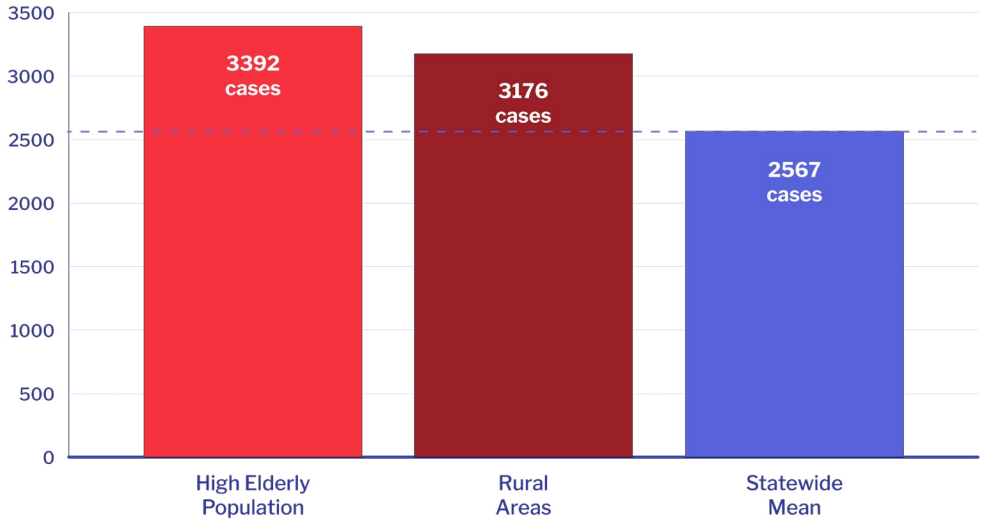
Counties with higher elderly populations, higher rates of poverty, and in rural areas of the state will experience higher per capita rates of West Nile Virus than the statewide average.

Figure 13: The occurrence of West Nile Virus cases is greater in high elderly (1.4 times higher compared to statewide average), high poverty (1.3 times higher compared to statewide average), and high rural counties (1.3 times higher compared to the statewide average).



Lyme disease will also impact elderly and rural communities at higher rates than the statewide average.

Figure 14: The occurrence of Lyme disease cases is greater in high elderly (1.3 times higher compared to statewide average) and high rural counties (1.2 times higher compared to the statewide average).



Public Health Threats Through 2040 vs. Through 2060

While this report details the cost of implementing climate adaptations and treating public health threats in Wisconsin through 2040, the cost of protecting communities from climate change impacts through 2060 is enormous. As climate-induced public health threats continue through 2060, the cost to treat new cases of West Nile Virus, Lyme disease, and pediatric asthma will balloon.

It would cost $208.8 million in public funds to treat residents infected with West Nile Virus from 2024 through 2040, and an additional $10.2 billion to treat cases from 2041 through 2060. The population infected is projected to increase from 2% to 78%, respectively.

We estimate the public-funded cost to treat residents infected with Lyme disease from 2024 through 2040 will be $347.8 million, and an additional $1.8 billion from 2041 through 2060. The population infected is projected to increase from 1% to 5%, respectively.

Treating pediatric asthma cases from 2024 through 2040 would cost $35.5 million in public funds, and $52.9 million to treat cases from 2041 through 2060. The population of children suffering from pediatric asthma is projected to increase from 1% to 2%, respectively.



A projected 1,944% increase in the number of West Nile Virus infections threaten the residents of Wisconsin from 2024 through 2040.

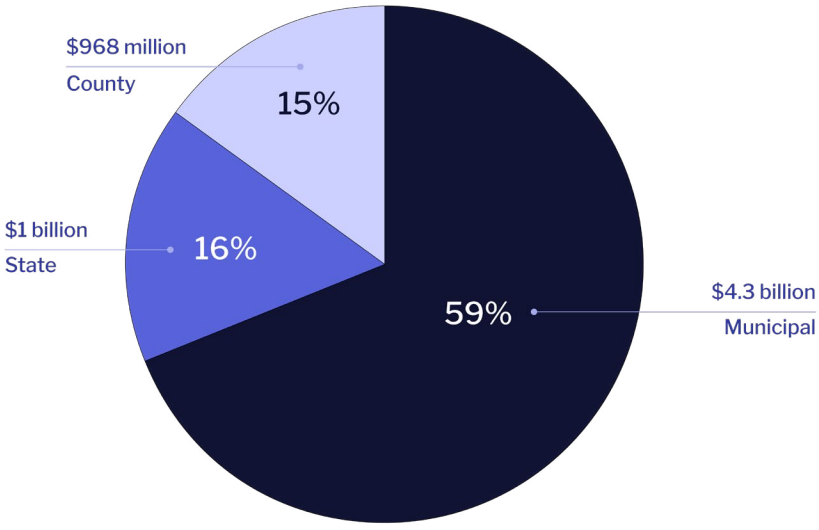
Comparison Across Governments

The majority of the climate adaptation and public health costs analyzed in this report — about $14.1 billion — are expected to fall on Wisconsin's municipal governments, with the remainder falling on state ($1 billion), county ($968 million), and federal ($592 million) governments.

Where possible, this report delegates the costs to the government entity that would be responsible for paying for the costs depending on ownership of structures, land, and/or services. In cases where it is not clear how governments divide responsibility, costs have been assigned to the municipality where the adaptations are being made, and in all other cases, costs are assigned based on the entity that owns the infrastructure in question. (See Appendix A.2).

When comparing the costs of just four climate adaptations that municipal, county, and the state governments have in common — installing air conditioning in public buildings, heating and cooling buildings in response to changing temperatures, proactive road maintenance, and bridge stabilization — municipalities still face the greatest cost burden. Bridge stabilization is the only climate adaptation that would create the largest costs for the state government, while the three other climate adaptations would be the most expensive for municipalities.

Figure 15: The percentage of costs borne by municipal, county, and the state government(s) in Wisconsin for the four climate adaptations that would impact each government.[47]



47 Installing air conditioning in public buildings, net change in heating and cooling cost for public buildings, proactive road maintenance, and bridge stabilization.

Table 19: Estimated costs for each of the four climate adaptations that would be borne by municipal, county, and the state government(s) in Wisconsin. Bolded costs represent which government entity faces the highest costs for each adaptation type.

Adaptation	Municipal	County	State
Installing AC in public buildings	**$650,414,000**	$95,186,000	$64,815,000
Net change in heating and cooling cost for public buildings	**$37,886,000**	$24,101,000	$18,802,000
Proactive road maintenance	**$3,565,513,000**	$792,498,000	$728,014,000
Bridge Stabilization	$84,531,000	$56,705,000	**$233,455,000**
All four adaptations	**$4,338,344,000**	$968,490,000	$1,045,086,000

Conclusion and Recommendations

This report identifies at least $16.7 billion in climate adaptation and climate-induced public health costs facing Wisconsin taxpayers through 2040. These figures capture only a portion of the total bill that major climate polluters have racked up for local taxpayers who are suffering from intense flooding, deadly heat, and threatened infrastructure. In reality, most local governments — and their taxpayers — will simply not be able to afford these costs to protect communities.

Wisconsin residents who are suffering the most from the climate crisis did not create it — fossil fuel companies did. Just 100 companies are responsible for more than 70% of global carbon emissions from 1988 to 2016, with oil giants ExxonMobil, Shell, Chevron, and BP ranking among the most egregious polluters.[48] Even now, just 57 companies are responsible for the vast majority of carbon dioxide emissions since 2015.[49]

Fossil fuel companies knew decades ago that their products were directly contributing to climate change.[50] But instead of sounding the alarm or changing their business models, oil companies notoriously deceived the public and

48 Paul Griffin, "New Report Shows Just 100 Companies Are Source of over 70% of Emissions," *CDP*, July 2017, https://www.cdp.net/en/articles/media/new-report-shows-just-100-companies-are-source-of-over-70-of-emissions.

49 CarbonMajors, "Carbon Majors: 57 Fossil Fuel and Cement Producers Linked to 80% of Global Fossil CO2 Emissions since the Paris Agreement," April 2024, https://carbonmajors.org/site//data/000/027/Carbon_Majors_Press_Release.pdf.

50 Neela Banerjee, Lisa Song, and David Hasemyer, "Exxon's Own Research Confirmed Fossil Fuels' Role in Global Warming Decades Ago," *Inside Climate News*, September 16, 2015, https://insideclimatenews.org/news/16092015/exxons-own-research-confirmed-fossil-fuels-role-in-global-warming/.

policymakers about the science in an effort to protect their massive profits.[51] There is growing evidence that the industry's deception continues today.[52] It's only fair that major polluters that knowingly caused and profited from the climate crisis — and then lied about it — 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 often turn 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 useful model.

Municipalities, counties, and the State of Wisconsin should consider taking legal action to protect their taxpayers from footing the entire bill and make polluters pay their fair share. Across the country, a growing number of state and local governments — including the State of Minnesota and City of Chicago — have filed lawsuits to hold oil majors accountable for their climate deception.[53] Earlier this year, Michigan's attorney general announced plans to take similar legal action against fossil fuel companies.[54]

In Wisconsin, community groups have called on Attorney General Josh Kaul to take Big Oil companies to court for the industry's climate deception and harms.[55] The costs detailed in this report provide a window into the types of damages state and local governments will face and could seek to recover from fossil fuel companies through legal action.

Courts play a key role in our democracy, and Wisconsin leaders have an opportunity to take bold action to ensure their residents aren't left to foot these bills alone. Similar to other local and state governments across the country, Wisconsin can pursue accountability through the courts and demand that polluters pay their fair share of the crisis they imposed on these communities.

51 Katie Jennings, Dino Grandoni, and Susanne Rust, "How Exxon Went from Leader to Skeptic on Climate Change Research," *Los Angeles Times*, October 23, 2015, https://graphics.latimes.com/exxon-research/.

52 House Committee on Oversight and Accountability and Senate Committee on the Budget, "Denial, Disinformation, and Doublespeak: Big Oil's Evolving Efforts to Avoid Accountability for Climate Change," Senate Committee on the Budget, April 2024, https://www.budget.senate.gov/imo/media/doc/fossil_fuel_report1.pdf.

53 Center for Climate Integrity, Cases, accessed May 28, 2024, https://climateintegrity.org/cases.

54 Carol Thompson, "Nessel Plans to Sue Oil and Gas Companies over Michigan's Changing Climate," *The Detroit News*, May 9, 2024, https://www.detroitnews.com/story/news/local/michigan/2024/05/09/fossil-fuel-climate-change-big-oil-and-gas-industry-dana-nessel-michigan-lawsuit-private-law-firms/73624884007/.

55 JT Cestkowski, "'Sue Big Oil': Youth Climate Activists Press State Attorney General to Be More Aggressive on Climate Change," February 14, 2024, https://www.wkow.com/news/environment/sue-big-oil-youth-climate-activists-press-state-attorney-general-to-be-more-aggressive-on/article_c64d4e3c-cace-11ee-9213-c364d034944d.html.

Appendix

Appendix A: Supplemental Information

Appendix A.1: Adaptation Definitions

Table A1: This report estimates the cost of 12 climate change impacts and adaptation strategies that Wisconsin taxpayers will face, defined in the table below. Note that this report is not exhaustive and Wisconsin taxpayers will likely incur further costs as a result of additional climate change adaptation strategies not assessed herein.

Climate Impact	Adaptation	Explanation	Taxpayer Costs	Appendix
Increased temperature	Installing and upgrading heating and cooling infrastructure.	Cost to install AC systems in 50% of public buildings and upgrade AC systems in the remaining 50% of public buildings to cope with the need for increased usage due to climate change.	Municipal, county, state	C.1
Increased temperature	Estimating the change in energy costs to heat and cool public buildings.	Changes in energy costs are estimated based on the number of days below (heating) or above (cooling) a certain threshold as compared to the climate baseline.	Municipal, county, state	C.1
Increased temperature	Expanding and operating cooling centers.	To help residents escape the increasing summer heat, cooling centers will need to be expanded and operated. The cost of opening and operating cooling centers due to increased days with temperatures above 80°F, as compared to the climate baseline are estimated.	Municipal	C.2
Increased temperature	Planting and maintaining urban trees.	Planting trees can help decrease ambient air temperature, as they cool the air through evapotranspiration. The adaptation is planting and maintaining trees in urban areas and accounts for both initial costs and yearly maintenance costs. The initial costs include labor and materials. The maintenance costs include water, fertilizer, pruning, and pest spraying.	Municipal	C.3
Increased temperature and precipitation	Proactively and reactively fixing roads.	When pavement temperature rises above its mixture threshold, increased degradation occurs. In the reactive scenario, this increased cracking requires more maintenance to avoid a decrease in the projected lifespan of the road. In the proactive scenario, adaptation includes installation of roads with pavement rated to projected future temperatures. Excess precipitation above what the road was designed to handle can also increase degradation. A percentage decrease in lifespan based on the level of projected damage, as compared to the climate baseline, informs road maintenance costs. In the proactive road scenario, adaptation requires a strengthening the roadbase to resist the increased potential for erosion. In the reactive road scenario, adaptation is fixing roads after precipitation-induced damage.	Municipal, county, state	C.4

Climate Impact	Adaptation	Explanation	Taxpayer Costs	Appendix
Increased precipitation	Installing drainage & stormwater infrastructure.	To combat increased inflow to the wastewater treatment plants, we estimate the cost to increase drainage & stormwater infrastructure area by implementing drainage & stormwater infrastructure. Drainage & stormwater infrastructure includes bio retention, porous pavement, bioinfiltration, and bioswale construction.	Municipal	D.1
Increased precipitation	Proactively adapting bridges.	As rivers flow faster during extreme precipitation events, bridges will degrade faster due to enhanced scour. To combat enhanced damage to bridges, we estimate the cost to proactively rehabilitate bridges in order to prevent disruption. Rehabilitation consists of applying riprap to stabilize bridges and additional concrete to strengthen piers and abutments.	Municipal, county, state	D.2
Increased precipitation	Constructing flood protection systems in rural areas.	Increased wet weather events, which increase the flow in rivers, threaten rural areas that are not protected from overbank flooding. To combat damage to rural communities, we assess the cost to install flood protection systems.	Municipal	D.3
Increased temperature and increased precipitation	Expanding or constructing natural and artificial coastal protection along Lake Michigan and Lake Superior in vulnerable areas.	Climate change is causing inundation and coastal erosion along the shorelines of Lake Michigan and Lake Superior, which both threaten coastal infrastructure. We determine the cost of constructing both seawalls and implementing natural shorelines to help combat the threat of coastal inundation.	Municipal	E
Public Health: Increased temperature	Increased costs from pediatric asthma hospital visits.	Increased temperatures correlates to increased pollen levels, which lead to more cases of pediatric asthma that require emergency room visits. We estimate the government-incurred cost of increased pediatric asthma visits as compared to the climate baseline.	Federal	F.1
Public Health: Increased temperature and increased precipitation	Initial and long-term costs to treat increased West Nile virus manifestations.	Mosquitoes thrive in warm temperatures and near water, so increased temperatures and precipitation due to climate change will make West Nile virus more prevalent. We estimate the increased government-incurred cost to treat both initial and long-term manifestations of West Nile virus.	Federal	F.2
Public Health: Increased temperature	Initial and long-term cost to treat Lyme disease.	The range of ticks has expanded due to increased temperatures. As the climate continues to warm, increased Lyme disease from Ticks is expected.	Federal	F.3

Appendix A.2: How to read this report.

In the report, we present municipal, county, state, federal, and total costs to adapt to climate change. We break down what each of these costs mean below:

Municipal Costs: Costs we assume will be incurred by the city, township, or village government. When we cannot assign costs to the county, state, or federal government, we assume that municipalities are incurring the entirety of the cost. For example, because the available data limit our ability to assign the proportion of costs for increasing stormwater drainage capacity across government entities, we assume 100% of the cost to increase stormwater drainage capacity will fall on the municipality, even though in some cases, the county, state, or federal government may incur some portion of this cost.

County Costs: Costs we can directly assign to counties in Wisconsin. We assign county costs when the data inventory allows us to assign ownership of structures (roads, bridges, and buildings) to the county.

State Costs: Costs we can assign directly to the State of Wisconsin. We assign state costs when the data inventory allows us to assign ownership of structures (roads, bridges, and buildings) to the state.

Federal Costs: Costs we can assign directly to the Federal government. We assign federal costs for the three public health impacts, as we present the health care costs for each illness that will be covered by Medicare or Medicaid.

Total Costs: The aggregate of municipal, county, state, and federal costs for the 12 impacts included.

Table A2: The 12 climate adaptations and the government entities we assign the costs to.

Climate Impact	Adaptation	Taxpayer Costs
Increased temperature	Upgrading heating and cooling infrastructure.	Municipal, county, state
	Estimating the change in energy costs to heat and cool public buildings.	Municipal, county, state
	Expanding and operating cooling centers.	Municipal
	Planting and maintaining urban trees.	Municipal
Changes in precipitation	Installing drainage & stormwater infrastructure.	Municipal
	Proactively adapting bridges.	Municipal, county, state
	Protecting rural communities from flooding.	Municipal
Increased temperature and increased precipitation	Proactively and reactively fixing roads.	Municipal, county, state
Lake Level Change	Protecting infrastructure from lake level change.	Municipal
Public Health: Increased temperature	Increased costs from pediatric asthma hospital visits.	Federal
	Initial and long-term cost to treat Lyme disease.	Federal
Public Health: Increased temperature and increased precipitation	Initial and long-term costs to treat increased West Nile virus manifestations.	Federal

Appendix A.3: This analysis only examines a fraction of the total costs Wisconsin may incur due to climate change.

Table A3: Climate change impacts and some potential costs associated with these impacts. **Only the costs in bolded text were analyzed in this report.** This list is not exhaustive and other costs may be incurred as a result of additional climate change impacts.

Climate Impact	Category	Potential Costs Incurred in Wisconsin
Increased Precipitation	Structure and Infrastructure Projects	Remove, relocate, acquire, or demolish structures to minimize future flood losses.
		Install, reroute, increase capacity, or implement a routine cleaning plan of the storm drainage system.
		Add extra culverts, increase dimensions of existing culverts, or implement routine cleaning and repairing.
		Install detention or retention basins, relief drains, spillways, drain widening/dredging or rerouting, etc.
		Inspect and maintain drainage systems and flood control structures (dams, levees, etc.).
		Install flood control structures in rural areas.
		Inspect bridges in order to identify and/or implement repairs or retrofits or clean under low bridges.
		Stabilizing bridges against scour by hardening abutments and piers.
		Increased road damage due to increased precipitation.
		Resurface roads with more permeable pavement and concrete.
		Elevate roads and bridges above the base flood elevation (BFE)[1] to maintain dry access.
		Elevate structures above the BFE, or relocate utilities, water heaters, etc. above BFE.
		Floodproof inside of municipal buildings, for example by installing check valves, sump pumps, or backflow prevention devices.
		Floodproof wastewater treatment facilities located in flood hazard areas.
		Floodproof water treatment facilities located in flood hazard areas.
		Protect emergency operations by requiring or moving all emergency operations centers, police stations, and fire department facilities outside of flood-prone areas.
		Protect critical and emergency facilities by requiring all such facilities be built one foot above the 500-year flood elevation (to meet requirements of FEMA Executive Order 11988).[2]
		Protect critical and emergency facilities from floods using any other technique, for example, raising components above BFE, installing pumping systems or back-up generators for pumping, building dikes or stabilizing banks.
		Construct floodwalls, small berms, revetments, bioengineered bank stabilization, or other small structural mitigants.

1 Base flood elevation (BFE), as defined by FEMA, is "the elevation of surface water resulting from a flood that has a 1% chance of equaling or exceeding that level in any given year."

2 Federal Emergency Management Agency, "Executive Order 11988: Floodplain Management," www.fema.gov/executive-order-11988-floodplain-management.

		Implement severe storm strategies for the future like burying utility lines underground.
	Natural Flood Mitigation	Protect and enhance natural floodplain mitigation features (such as wetlands, dunes, and vegetative buffers) to help prevent flooding in other areas.
	Public Health	Protect public water supplies from harmful algal blooms.
		Treat an increase in hospitalizations related to water-borne illness.
	Local Planning and Regulation	Update flood risk maps and flood zones.
		Develop a floodplain management plan.
		Adopt a stormwater management or drainage plan.
		Adopt, apply, and enforce building codes to ensure buildings can withstand flooding.
		Obtain easements to use privately-owned land for temporary water retention and drainage.
		Join or improve compliance with the National Flood Insurance Program (NFIP).3
		Preserve floodplains as open space using any of several land use planning tools: develop a plan that targets hazard areas for acquisition, reuse, and preservation, a land banking program, use of transfer of development rights to keep floodplains vacant, easements to prevent development, or acquiring properties in the floodplain and turning them into open space.
	Education and Awareness Programs	Increase public outreach to encourage flood insurance purchase; educate residents in flood safety, flood mitigation, technical assistance availability, funding sources, and best practices.
		Locate new utilities and critical facilities outside of susceptible areas.
		Increase public outreach to provide awareness of harmful algal blooms and their health impacts.
Lake Level Change	Structure and Infrastructure Projects	Stabilize susceptible coastal slopes, cliffs, and shorelines using grading techniques, planting vegetation, riprap or geotextile fabric, or bioengineering.
		Update piers and other coastal infrastructure to accommodate fluctuating water levels.
		Increased cost of dredging during times of low lake levels.
		Refer to "Structure and infrastructure projects" from "Increased Precipitation," as they also apply here.
	Coastal Protection	Protect critical infrastructure using techniques like **installing seawalls**.
		Restore natural wetland areas.
	Local Planning and Regulation	Identify, map, and track coastal erosion and flood hazards.
		Develop and enforce a coastal zone management plan.
		Develop site and building standards.
	Education and Awareness Programs	Increase awareness by disclosing location of high-risk areas to current and future property owners; offer mitigation technique information.
		Locate new utilities and critical facilities outside of susceptible areas.
		Identify, map, or track erosion hazard areas.

3 U.S. Federal Emergency Management Agency (FEMA), The National Flood Insurance Program (NFIP), at www.fema.gov/national-flood-insurance-program Policy Information by State (https://nfipservices.floodsmart.gov//reports-flood-insurance-data), accessed April 25, 2024; There are over 10,000 policies in place in Wisconsin covering over $2 billion.

Increased Temperature	Structure and Infrastructure Projects	Energy efficiency retrofits in public and private buildings and housing, including costs for the design and development of standards.
		Installing green roofs or cool roofing systems on public buildings.
		Increased cooling costs for all public buildings and new AC installation or upgrade costs for public buildings, including schools.
		Increased road damage due to more frequent extreme heat events.
		Increase road damage due to increased freeze/thaw cycles.
		Plan for and increase capacity for increased energy demands due to both increased daytime and nighttime temperature.
		Increase high-albedo surfaces on buildings, roads, or where feasible.
	Public Health Projects	**Build and manage more cooling centers, including staffing and tracking of high-risk individuals.**
		Increased demand for publicly financed air conditioning targeted to low income families and public housing.
		Control the increase of vector borne illness – education and physical and chemical controls for ticks and mosquitoes.
		Treat victims of vector borne illness.
		Treat an increase in asthma attacks requiring hospitalization (resulting from increased heat and ground level ozone, and the increase in airborne allergens).
		Reduce the urban heat island effect by planting trees.
		Protect drinking water supplies from hazardous algae blooms.
Increasing Drought	Water Management	Protect drinking water supplies from low lake levels.
		Diminished groundwater supply in rural areas.
		Replace old pipelines that have water leak issues.[4]
		Hire a climate scientist to recommend updates to water treatment, wastewater treatment, and other energy chronic health conditions.[5]
		Reinforce roads, bridges, and buildings to withstand prolonged drought.
	Wildfires	Increase fire suppression, including staffing and aviation.
		Rebuild or relocate damaged properties and public infrastructure, such as homes and utility lines.
		Relocate public infrastructure where necessary.
		Update power lines to withstand dust from wildfires.
		Implement fire mitigation strategies for the future like burying utility lines underground.
		Plan for and disburse community aid after wildfires.
		Implement fire detection strategies, like solar-powered sensors.[6]
		Rehabilitate the landscape post-fire to reduce the risk of erosion and invasive species and mitigate future fire risk.

4 "Drought and Infrastructure - A Planning Guide" (Cybersecurity and Infrastructure Security Agency with the National Drought Resilience Partnership, 2021), https://www.cisa.gov/sites/default/files/publications/Drought_and_Infrastructure_A_Planning_Guide_508c.pdf.

5 Ibid.

6 Jennifer L, "Wildfires Cost Over $148B and 30% of Emissions," Carbon Credits, January 30, 2023, https://carboncredits.com/wildfires-cost-emissions/.

		Increased hospitalization costs for asthma attacks and other chronic health conditions (resulting from decreased air quality due to wildfire smoke).
	Education and Awareness Programs	Increase public outreach to encourage wildfire risk management; educate residents in wildfire safety, technical assistance availability, funding sources, and best practices.
Other Extreme Weather	Structure and Infrastructure Projects	Increased costs of storm recovery and clean-up.
		Protect power lines through pruning trees.
		Bury overhead power lines or install systems that allow small sections of power lines to fail rather than the complete system.
	Revenue	Impacts to revenue from agriculture, recreation, and tourism due to warm winters.
Other Costs	Education and Awareness and Treatment	Increased allergen levels, food- and waterborne infections, and zoonotic diseases.[7]
	Climate refugees	Costs to accommodate an influx in climate refugees.

Appendix B: Climate Baselines

The climate projections in this report are derived from the Localized Constructed Analogs (LOCA) statistically downscaled Coupled Model Intercomparison Project Phase 6 (CMIP6) climate projections for North America. We selected different climate variables at 1/16th of a degree (approximately 3.7 mile^2) resolution[8] for 24 global climate models (GCMs) under a moderate greenhouse gas and aerosol emission scenario (Shared Socioeconomic Pathway 2-4.5 [SSP2-4.5]). In the report, the 50th percentile of the 24 model outputs is presented for each of the analyses. The projection time periods used are 20-year averages centered on 2040 (2030-2049). We also make the data available for download. In the data download, the estimated cost through both 2040 and 2060 are presented. The cost estimates for both time periods are also based on the 50th percentile of the 24 model outputs for SSP2-4.5 for each analysis. The projection time periods used for the 2060 estimates are 20-year averages centered on 2060 (2050-2069). The climate baseline for temperature-related analyses in this study is derived from Livneh et al. (2015).[9] The climate baseline for precipitation-related analyses in this study is derived from Pierce et al. (2021).[10] Unless otherwise stated, we use a 20-year baseline time period centered on 2000 (1990-2009) for all analyses presented. A shapefile for Wisconsin cities, towns, and villages is used to determine municipal bounds throughout the study.[11]

Costs for some adaptations are computed as a time series and costs for other adaptations are assessed once in 2040 and then again in 2060.

7 Carmen Milanes et al., "Indicators of Climate Change in California" (Office of Environmental Health Hazard Assessment, 2022), https://oehha.ca.gov/media/downloads/climate-change/document/2022caindicatorsreport.pdf.

8 David W. Pierce, Daniel R. Cayan, and Bridget L. Thrasher, "Statistical Downscaling Using Localized Constructed Analogs (LOCA)," *Journal of Hydrometeorology* 15, no. 6 (December 1, 2014): 2558–85, https://doi.org/10.1175/JHM-D-14-0082.1.

9 Ben Livneh et al., "A Spatially Comprehensive, Hydrometeorological Data Set for Mexico, the U.S., and Southern Canada 1950–2013," Scientific Data 2, no. 1 (August 18, 2015): 150042, https://doi.org/10.1038/sdata.2015.42.

10 David W. Pierce et al., "An Extreme-Preserving Long-Term Gridded Daily Precipitation Dataset for the Conterminous United States," Journal of Hydrometeorology 22, no. 7 (July 1, 2021): 1883–95, https://doi.org/10.1175/JHM-D-20-0212.1.

11 Wisconsin State Legislature, "WI Cities, Towns, and Villages," 2022, https://data-ltsb.opendata.arcgis.com/maps/bdd880e932ed4e6e89206464b961e61e/about.

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

We analyze five different resilience and adaptation measures in this report related to increasing temperatures, as described below. It is important to note that this is a small fraction of the potential resilience and adaptation measures that communities face. In Appendix A.3 we have identified 13 costs related to increased temperatures ranging from infrastructure adaptations to public health impacts.

Appendix C.1: Installing and Upgrading Building Heating and Cooling Infrastructure and Estimating the Change in Energy Cost

Taxpayer costs were analyzed at the municipal, county, and state level.

Buildings Inventory

We create a buildings database that is based on public datasets to inform building location, area, owner, and use type. Building location and footprint are based on the USA Structures data published by the Federal Emergency Management Agency (FEMA).[12] Building height is assumed based on the classification as published within the United States Geological Survey (USGS) national dataset of average building height[13] using the United States Census (Census) block groups.[14] Each block group is sorted into one of four classifications based on the average number of stories per building. These classifications are sourced from a NASA dataset of Census block group data, which is based on LiDAR data collected in 2000 and verified and published in 2016.[15] This data provides a conservative height estimate, as we assume that the building height classification in any given block group has either increased or remains unchanged since the dataset was verified. Total building floor area is calculated by multiplying a given building's footprint by the average number of stories in the block group where the building is located. Building owner is determined based on a text scrape algorithm of the Wisconsin state parcel database for keywords related to each of the local governments of concern.[16] For example, buildings with "State" in their name are filtered into the state-owned category. Lastly, building type is based on the Homeland Security buildings database,[17] the Department of Housing and Urban Development public housing database,[18] and is supplemented by OpenStreetMap.[19] Each building within the inventory is assigned a building type from the Department of Energy (DOE) energy models in order to inform the energy, install, and upgrade calculations. Please note that the buildings inventory may not be an exhaustive representation of all public buildings that exist.

12 FEMA, "USA Structures" (Federal Emergency Management Agency Geospatial Resource Center, 2022), https://gis-fema.hub.arcgis.com/pages/usa-structures.

13 James A. Falcone, "U.S. National Categorical Mapping of Building Heights by Block Group from Shuttle Radar Topography Mission Data" (U.S. Geological Survey, 2016), https://doi.org/10.5066/F7W09416.

14 United States Census Bureau, "Glossary," under "Block Group," (accessed September 27, 2023), https://www.census.gov/glossary/?term=Block+Group+%28BG%29.

15 Falcone, "U.S. National Categorical Mapping of Building Heights by Block Group from Shuttle Radar Topography Mission Data."

16 Wisconsin State Cartographer's Office and Wisconsin Land Information Program, "Wisconsin Statewide Parcel Map Initiative: V9 Statewide Parcel Data," 2023, https://www.sco.wisc.edu/parcels/data/.

17 U.S. Department of Homeland Security, "Homeland Infrastructure Foundation-Level Data (HIFLD)" (Geospatial Management Office, 2021), https://hifld-geoplatform.hub.arcgis.com/pages/hifld-open.

18 Department of Housing and Urban Development, "Public Housing Buildings" (HUD GIS Helpdesk: Office of Policy Development and Research (PD&R), 2023), https://hudgis-hud.opendata.arcgis.com/datasets/HUD::public-housing-buildings-2/explore?location=43.099602,-87.972687,14.56.

19 OpenStreetMap, "Wisconsin" (GEOFABRIK, 2018), http://download.geofabrik.de/north-america/us/wisconsin.html.

Climate Metrics

The number of cooling degree days (CDD)[20] and heating degree days (HDD)[21] for the baseline and projection time periods for each building are computed to determine changes in energy costs. The 20-year average number of annual CDDs and HDDs are reported. A degree day base of 50°F[22] is utilized for each because it demonstrates a better relationship with building cooling capacity and energy usage than other temperature metrics, such as degree days with a base of 65°F.

Degree Day Relationships

The DOE Commercial Reference Building models define the characteristics of a representative building for each climate zone[23] based on nationwide survey data.[24] Models are available for buildings built pre-1980, post-1980, and new. We used only the post-1980 models for the purposes of this study. Cooling system type, heating system type, cooling system capacity, cooling system energy usage, heating system energy usage, and building square footage as defined by the DOE Reference Building Models were used to calculate cooling capacity intensity (ft^2/ton), cooling energy use intensity (kWh/ft^2) and heating energy use intensity (kWh/ft^2 for electricity or MJ/ft^2 for gas) for a representative building in each climate zone.

Each building type within the building inventory is matched with a building type from the DOE representative energy models as outlined in the table below (Table C1).

Table C1: Building types within the building inventory and their corresponding building type within the DOE reference building energy models.

Inventory Building Type	DOE Building Type
Court House	Office
EMS	Office
Fire Station	Office
Hospital	Hospital
Library	Office
Office	Office
Prison	Hotel
Public Health Department	Office
Public Housing	Midrise Apartment
Primary School	Primary School
Secondary School	Secondary School

20 Cooling degree days (CDD) is a daily measure of how much (in degrees) the average outside air temperature is above a specified temperature threshold.

21 Heating degree days (HDD) is a daily measure of how much (in degrees) the average outside air temperature is below a specified temperature threshold.

22 In this context, CDD and HDD with a base of 50°F are used as climate variables. The base temperature does not inform when any given building is in cooling or heating mode (which typically has a threshold of 65°F).

23 There are eight main climate zones that are subdivided into moist, dry, and marine subsets to make 16 total classifications. The zones are determined based on a location's historic weather characteristics, in this case as defined by Briggs et al., (2003), https://www.proquest.com/openview/d1c49b47cddf83d4cb8ffc7b2ec1b075/1?pq-origsite=gscholar&cbl=34619.

24 U.S. Department of Energy, "Commercial Reference Buildings" (Department of Energy: Office of Energy Efficiency & Renewable Energy, 2010), https://www.energy.gov/eere/buildings/existing-commercial-reference-buildings-constructed-or-after-1980.

Cooling Days

A relationship was established between the annual CDDs with base 50°F (CDD50) reported in ASHRAE 90.1 2004[25] and both the cooling capacity intensity and the cooling energy use intensity for each representative building. This relationship was used to calculate cooling system capacity and energy usage for all buildings using inputs of baseline and projected CDD50, building area, and building type.

Heating Days

A relationship was established between the annual HDD50 reported in ASHRAE 90.1 2004[26] and the heating energy use intensity for each representative building. This relationship was used to calculate heating system energy usage for all buildings using inputs of baseline and projected HDD50, building area, and building type.

Cost Estimates: Cooling System Capacity

Cost per ton of cooling is calculated for install and upgrade. System install and upgrade use the same $/ton costs based on RSMeans Assembly costs in the 2021 edition of the RSMeans Square Foot Cost Book.[27] System types in the DOE Commercial Reference Building documentation were matched with the most appropriate assembly type (Table C1) in the RSMeans construction cost estimating data.

Costs are in Q2-2023 dollars and include material, labor, sales tax (6%), general requirements (10%), general contractor overhead (5%) and profit (5%), and an average location factor for the state of Wisconsin based on the national average.[28] No architect fee or contingency was added. Percentages follow RSMeans methodology. Additional costs will vary on a case-by-case basis and are outside of the scope of this study.

Cooling system install costs were calculated for each building in the database based on the projected capacity. The full system capacity was costed. Cooling system upgrade costs were calculated for each building in the database based on the projected capacity increase from baseline. An upgrade was assumed to be necessary if the change in cooling system capacity in a given projection was more than 10% higher than the cooling system capacity for the baseline. Only the change from baseline capacity was costed, rather than the full system capacity, so that only impacts on system size arising from anthropogenic climate change were captured. Costs are presented on a municipality, county, and state basis by summing upgrade and install costs for all buildings within the respective jurisdiction that are owned by the jurisdiction(s) of interest.

Since the prevalence of air conditioning within most building types is unknown, the upgrade and install costs for these building types are presented in a series of bins according to the prevalence of air conditioning across the jurisdiction's building stock. As an example, the 50% bin implies that 50% of a jurisdiction's buildings have existing cooling, and so 50% of the upgrade costs are reported while 50% of the install costs are reported.[29] All hospitals are assumed to have AC and therefore only upgrade costs are reported.

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

26 Ibid.

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

28 Attilio Rivetti, "Turner Building Cost Index: 2023 Second Quarter Forecast" (Turner Construction Company, 2023), https://turnerconstruction.com/uploads/CostIndex2023Qtr2.pdf.

29 Kendall Keys, "'Our Schools Need Air-Conditioning': Extreme Heat Forces School Closures," WISN, August 24, 2023, https://www.wisn.com/article/our-schools-need-air-conditioning-extreme-heat-forces-school-closures/44904783.

Cost Estimates: Cooling and Heating Energy

Cost per kWh of electricity and per MW of natural gas are based on statewide 2022 annual average values as reported by the United States Energy Information Administration (US EIA).[30] Costs presented are based on 2022 average utility costs rather than projected costs. Available energy cost projections include substantial uncertainty and only extend to 2050. Additionally, use of present-day dollar amounts maintains consistency with the other analyses, which do the same. Energy costs assume all buildings have cooling and heating, while the percent change in costs will apply to any prevalence of buildings with both cooling and heating.

Assumptions

System type is as reported in DOE Commercial Reference Building models. Only components[31] that are included in the RSMeans assemblies were included in our estimate. Other items that may incur costs but were not included in analysis include: required code improvements, structural improvements, asbestos abatement, redundant equipment, electrical upgrades, inflation, design fees, permitting, inspections, crane, constructability, demolition, waste and disposal. Costs are based on the average $/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[32] used by the DOE Reference Building models.

Appendix C.2: Protecting Residents during Heatwaves

Taxpayer costs were analyzed at the municipal level.

We quantified how much it will cost Wisconsin to expand and operate cooling centers in order to protect residents from extreme heat in "vulnerable areas." We used 2019 U.S. Census block data and the Wisconsin 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 Census block groups[33] 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 only used areas classified as medium or high intensity developed areas by the National Land Cover Database (NLCD) 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. As such, we determined the quantity of vulnerable areas within each municipality.

We assume that a cooling center within a vulnerable area must be within a 0.5 mile radius walking distance, thus every cooling center covers 0.785 sq. mi. To determine the number of cooling centers required in a given municipality, we divided the vulnerable area of each municipality by 0.785. Based on a report from the Center for Disease Control,[34] we assume that 62% of cooling centers do not incur

30 U.S. Energy Information Administration, "Electricity Data Browser," 2022, https://www.eia.gov/electricity/data/browser/; U.S. Energy Information Administration, "Natural Gas Prices," 2022, https://www.eia.gov/dnav/ng/ng_pri_sum_a_EPG0_PCS_DMcf_a.htm.

31 The RSMeans system costs include the parts typical to cooling systems like the air handling unit, piping, valves, insulation, etc. These costs are for a generalized system and any given installation would likely see variations to meet the specific needs of that system.

32 The DOE reference building models include a 20% safety factor when sizing a cooling system. We remove this safety factor to determine the minimum amount of cooling a building needs.

33 United States Census Bureau, "Glossary," under "Block Group," (accessed September 27, 2023), https://www.census.gov/glossary/?term=Block+Group+%28BG%29.

34 Stasia Widerynski et al., "The Use of Cooling Centers to Prevent Heat-Related Illness: Summary of Evidence and Strategies for Implementation Climate and Health Technical Report Series Climate and Health Program, Centers for Disease Control and Prevention," Climate and Health Technical Report Series (Climate and Health Program: Centers for Disease Control and

additional costs, 15% incur only additional HVAC costs, and 23% incur both additional HVAC and staffing costs when operating for 8-hours. Though 62% of cooling centers did not incur additional costs for the first 8-hours of operation, 54% of all cooling centers operate on a 12-hour schedule and will incur an additional 4-hours of HVAC and staffing costs.[35] For this reason, we separated costs into 8-hours and 4-hours (see example computation below; Table C2). We estimated operational costs by using a report from the City of Los Angeles that details the city's cooling center costs. They report that HVAC costs were $26.86 per hour, and HVAC and staffing costs (HSC) were $292.79 per hour.[36] We approximated HVAC costs for Wisconsin using a conversion ratio of 0.518, which was obtained by dividing the average electricity cost in Wisconsin (12.95 ¢/kWh)[37] by that in Los Angeles (25 ¢/kWh).[38] We found that hourly HVAC in Wisconsin costs $13.91 per hour (HC). We convert labor costs from the City of Los Angeles to Wisconsin based on a cost index ratio of 0.71, calculated by dividing the Wisconsin cost of living index by the California cost of living index.[39] We found that hourly labor in Wisconsin costs $187.83 per hour. Accounting for both changes in cost from Los Angeles to Wisconsin, we estimate that it costs $201.75 per hour to operate a cooling center in Wisconsin (HSC).

Table C2: An example for how to calculate the cost to operate cooling centers in a Wisconsin municipality.

Vulnerable Area **(A)**	**# of Cooling Centers** **(CC)**	**Additional HVAC Costs** **(AHC)**	**Additional HVAC and Staffing Costs** **(AHSC)**	**8 Hour Costs** **(C8)**	**4 Additional Hours Costs** **(C4)**	**Total Daily Costs**
	A/0.785, round up to nearest whole number	CC*0.15*HC*8	CC*0.23*HSC*8	AHC + AHSC	((CC*0.62)* 0.54)*HSC*4	C8 + C4

This method calculates the daily operation cost for cooling centers for each municipality in Wisconsin. 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.

Note that because some areas are vulnerable but will not require cooling centers (rural areas) 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 rural areas with low populations relative to other urban environments.

Appendix C.3: Combating Heat Islands – Urban Trees

Taxpayer costs were analyzed at the municipal level.

We quantified how much it will cost Wisconsin's municipalities 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

Prevention, 2017), https://www.researchgate.net/publication/319112587_The_Use_of_Cooling_Centers_to_Prevent_Heat-Related_Illness_Summary_of_Evidence_and_Strategies_for_Implementation_Climate_and_Health_Technical_Report_Series_Climate_and_Health_Program_Centers_for_Disea.

35 Ibid.

36 C.P. Parks, "Cooling Center Operations in Los Angeles City." (City of Los Angeles Emergency Management Department, 2022), https://clkrep.lacity.org/onlinedocs/2021/21-1277_rpt_07-29-22.pdf.

37 U.S. Energy Information Administration, "Electric Power Monthly," 2023, https://www.eia.gov/electricity/monthly/epm_table_grapher.php.

38 U.S. Energy Information Administration, "Electricity Data Browser," 2022, https://www.eia.gov/electricity/data/browser/.

39 Missouri Economic Research and Information Center, "Cost of Living Data Series," 2023, https://meric.mo.gov/data/cost-living-data-series.

(NLCD). We determine the cost of planting urban trees only in municipalities with less than 500 pop/mi^2 or municipalities with less than 100 people as the total population as these are not "urban" areas and are excluded from the analysis.

Quantifying Canopy Coverage in Wisconsin Urban Environments

We used NLCD 2021 Land Cover data and NLCD 2021 Canopy Coverage to quantify the current canopy coverage in municipalities across Wisconsin.

Cost Data

We used RSMeans to collect cost data.[40] We broke the initial planting data into labor 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 the costs to 2023 values using an inflation rate of 13.84%, per the Turner Building Cost Index.[41] Additionally, we adjusted the national average to Wisconsin specific city cost index data.

Determining Ideal Canopy Numbers

We combined canopy cover from 16 metropolitan areas across the country to serve as representative models for different size municipalities in Wisconsin 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 variable resulted in an adjusted R squared value of 0.73. The output regression formula is below.

The output regression formula is:

Canopy Cover Goal % = -5.4913424 + (-3.74075E-06 * (Pop Density))
+ (1.073584308 * (Initial Canopy Cover))
+ (0.003353585 * (Year Assessed))
+ (-0.000552275*(Target Year))

We used the formula to calculate goals for municipalities for each development level as shown below. We used a target year of 2033 based on a 10-year period for trees to reach their average canopy cover (Table C3).

Table C3: Wisconsin urban canopy model. Note that each municipality has an average current and goal canopy cover. The percentages in this table represent the average of those current and goal canopy covers across all incorporated municipalities.

Cities & Villages		
Population Density	1,292	
Year Assessed	2023	
Target Year	2033	
Developed Area	**Current Canopy Cover (%)**	**Predicted Canopy Cover (%)**
Medium Intensity	5.64	6.21
HighIntensity	0.97	1.20

40 Derrick Hale, "Site Work & Landscape Costs with RSMeans Data" (The Gordian Group, 2021).

41 Rivetti, "Turner Building Cost Index: 2023 Second Quarter Forecast."

Table C4: The needed increase in urban tree canopy coverage to meet the goal canopy cover for Wisconsin. The table also shows how much it will cost to increase canopy coverage and the approximate number of trees to do so.

Developed Area	Needed Increase (sq. ft.)	Cost to Increase	~# of Trees
Medium Intensity	173,638,050	$8,838,874	192,240
High Intensity	23,389,981	$2,429,884	52,848
Total	1997,028,031	$44,620,453	970,466

Cost Estimates

Table C5: Cost model for urban canopy in Wisconsin showing an initial planting cost and then the costs in Year 1 (Y1), Y2, and Y3.

Developed Area	Initial Planting Cost	Y1 (2023)	Y2 (2024)	Y3 (2025)
Medium & High Intensity	$651,850,926	$85,451,992	$85,451,992	$85,452,992
Tree Mortality Cost	-	-	$44,325,863	$44,325,863
Total	$651,850.926	$85,451,992	$129,777,855	$129,777,855

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 combination of large and small street tree species as recommended by the Wisconsin Department of Natural Resources[42] and averaging their canopy size at year 10 determined from a Virginia Tech Urban Forestry database.[43]
- 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 Years 1-5 and Year 6+[44]

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+.[45] 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 and inflation costs can be incorporated based on whatever rate is deemed appropriate. Note that the model does not specify where trees are planted within the municipalities.

42 Wisconsin Department of Natural Resources, "Recommended Small Street Trees," Urban Tree Planting Resources, 2022, https://dnr.wisconsin.gov/topic/urbanforests/treeplantingresources.

43 Virginia Tech Urban Forestry, "Tree Canopy Spread & Coverage in Urban Landscapes," 2010, https://vnla.org/tree-canopy-spread-coverage-in-urban-landscapes/.

44 Deborah R. Hilbert et al., "Urban Tree Mortality: What the Literature Shows Us," *Arborist News*. Oct: 22-26. Oct (2019): 22, https://www.fs.usda.gov/research/treesearch/59819.

45 Ibid.

Appendix C.4: Maintaining Roads

Taxpayer costs were analyzed at the municipal, county, and state level.

To determine the potential future damage to municipal, county, and state roads in Wisconsin, we analyzed both the historic environment and projected future conditions to determine how climate change will affect the as-designed condition of road infrastructure. Increasing temperatures cause more surface degradation[46] and decreases road lifespan.[47] Increasing precipitation levels cause erosion, which weakens the roadbase, causing increases in cracking, potholes, and breakage.[48] We designed distinct stressor-response functions for paved (assumed to be asphalt), gravel, and unpaved roads. Furthermore, within each category we made refinements for primary, secondary, and tertiary roads.[49] We identified local roads using a database containing Wisconsin roads that are owned by municipalities, counties, or states. Ownership is determined for each road segment based on classification from the Census.[50]

Temperature

Pavement temperature determines the required pavement design or the ability for the pavement to withstand temperature-related degradation.[51] We find a relationship between pavement temperature and 7-day maximum ambient air temperature (T-7_{max}), so we use historic and projected T-7_{max} to determine when a projected change in temperature will be significant enough to cause climate-based damage to road infrastructure.

We used guidance from Superpave increments of pavement temperature to determine the exceedance parameters.[52] When pavement temperature rose above the mixture threshold, we calculated the increased degradation based on published material studies.[53] In the reactive scenario, this increased cracking requires more maintenance to avoid a decrease in the projected lifespan of the road.[54] In the proactive scenario, adaptation includes installation of roads with pavement rated to projected future temperatures.

Precipitation

We used historic and projected maximum monthly precipitation amounts to determine if excessive erosion will increase damage to the roadbase. We compared the historic maximum monthly precipitation to the projected change in maximum monthly precipitation rates at the time-slice of interest. We used a threshold based on the type of road surface to determine whether 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. In the proactive road scenario, adaptation for this scenario requires a strengthening of the roadbase to resist the increased potential for erosion. In the reactive road scenario, adaptation is fixing roads after precipitation-induced damage.

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

47 Transportation Research Board, "Superpave: Performance by Design," 2005, https://www.trb.org/publications/sp/superpave.pdf.

48 James E. Neumann et al., "Climate Change Risks to US Infrastructure: Impacts on Roads, Bridges, Coastal Development, and Urban Drainage," Climatic Change 131, no. 1 (July 1, 2015): 97–109, https://doi.org/10.1007/s10584-013-1037-4.

49 Paul Chinowsky and Channing Arndt, "Climate Change and Roads: A Dynamic Stressor–Response Model," Review of Development Economics 16, no. 3 (2012): 448–62, https://doi.org/10.1111/j.1467-9361.2012.00673.x.

50 U.S. Census Bureau, "TIGER/Line Shapefiles," 2022, https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.html.

51 Patrick Lavin, Asphalt Pavements: A Practical Guide to Design, Production and Maintenance for Engineers and Architects (London: CRC Press, 2003), https://doi.org/10.1201/9781482267716.

52 Transportation Research Board, "Superpave: Performance by Design."

53 M Miradi, "Artificial Neural Network (ANN) Models for Prediction and Analysis of Ravelling Severity and Material Composition Properties," ed. M. Mohammadian, CIMCA 2004, 2004, 892–903.

54 Ibid.

Cost Estimates

We conducted this analysis with the goal of retaining the original design life and service level of the roadways. We present costs for both a proactive and reactive adaptation approach.

Proactive: The proactive scenario 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. First, we generated stressor-response values for infrastructure elements. Next, we designed infrastructure to a level that protects against the future changes in climate conditions and the accompanying changes in material or design requirements. Last, we subjected any new or rehabilitated structures to material changes when it was anticipated that a significant climate change stressor would occur during the lifespan.

Reactive: Reactive adaptation costs were calculated to understand the cost-benefit of proactive adaptation. Reactive adaptation involves fixing roads as problems arise and is usually more expensive than a proactive approach. Damage threshold exceedance data from each grid within the climate model data is used to determine the level of additional maintenance and repair required for any given segment of road on an annual basis. This is then fed into the cost module where a per-mile maintenance cost is applied to each mile of road segment within each affected grid. Lastly, road maintenance costs are aggregated from a grid-level to a municipality-level using an area-based weighted average approach.

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

We analyze three different resilience and adaptation measures in this report related to extreme precipitation, as described below. It is important to note that this is a small fraction of the potential resilience and adaptation measures that communities face. In Appendix A.3 we have identified over 30 costs related to extreme precipitation events ranging from infrastructure adaptations to education and awareness plans.

Appendix D.1: Drainage Infrastructure: Mitigating Urban Flooding and Inflow to Water Treatment Plants

Taxpayer costs were analyzed at the municipal level.

We assessed the impact of increases in extreme wet weather events to wastewater conveyance systems and wastewater treatment plants and processes. 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 corroded manholes.[55]

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 wastewater 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 (TSS) of the wastewater remains the same, resulting in a dilution of the influent to the wastewater treatment plant, which can affect biological treatment processes.[56] During 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.[57]

55 James Hughes et al., "Impacts and Implications of Climate Change on Wastewater Systems: A New Zealand Perspective," Climate Risk Management 31 (January 1, 2021): 100262, https://doi.org/10.1016/j.crm.2020.100262.

56 Benedek Gy Plósz, Helge Liltved, and Harsha Ratnaweera, "Climate Change Impacts on Activated Sludge Wastewater Treatment: A Case Study from Norway," Water Science and Technology: A Journal of the International Association on Water Pollution Research 60, no. 2 (2009): 533–41, https://doi.org/10.2166/wst.2009.386.

57 J. G. Langeveld, R. P. S. Schilperoort, and S. R. Weijers, "Climate Change and Urban Wastewater Infrastructure: There Is More to Explore," Journal of Hydrology 476 (January 7, 2013): 112–19, https://doi.org/10.1016/j.jhydrol.2012.10.021.

To combat increased inflow to wastewater treatment plants, we estimate how much it will cost to install drainage & stormwater infrastructure (referred to as green infrastructure in the engineering literature).[58] Drainage & stormwater infrastructure includes bio retention, porous pavement, bioinfiltration, and bioswale construction. By increasing pervious surfaces with drainage & stormwater infrastructure, flooding during wet weather events decreases, offsetting what would have been increased inflows to wastewater treatment plants from climate change. We choose this adaptation, as opposed to expanding or adding culverts and storm drains, as it is generally low-impact and less expensive.

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 seven 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 rainfall depth (inches) for a certain percentile between the two distributions (baseline distribution and the projected distribution). 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 additional runoff (thus infiltration and inflow) into the wastewater treatment plant. We assume the offset is proportional to the change in wet weather events. For example, if the wet weather events are increasing by 10%, then 10% of the developed impervious area needs to be offset by drainage infrastructure.
We calculate the developed impervious area using the NLCD.[59]

We derived the per-unit cost for green stormwater infrastructure from the following equation:[60]

- Cost = A * ΔWWE * 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)

GSI unit costs are sourced from a green stormwater infrastructure report.[61] The unit costs are adjusted to Wisconsin using an RSMeans location multiplier. Finally, the costs are adjusted to 2023 dollars.

58 S.E Gill et al., "Adapting Cities for Climate Change: The Role of the Green Infrastructure," Built Environment 33, no. 1 (March 13, 2007): 115–33, https://doi.org/10.2148/benv.33.1.115.

59 Earth Resources Observation and Science (EROS) Center, "National Land Cover Database" (U.S. Geological Survey, 2021), https://www.usgs.gov/centers/eros/science/national-land-cover-database.

60 Allegheny County Sanitary Authority, "Staring at the Source: How Our Region Can Work Together for Clean Water - Appendix E-3: GIS Cost Literature Review," 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.

61 Ibid.

Appendix D.2: Stabilizing Bridges

Taxpayer costs were analyzed at the municipal, county, and state level.

Climate-driven changes in precipitation will increase the flow rates of waterways, thereby increasing the rate of wear and tear on the bridges that span them. 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. We classify bridges into municipal, county, and state owned using the National Bridge Inventory ownership identifiers.

Methods based on the United States Department of Agriculture's Natural Resources Conservation Service (NRCS) TR-20 model were used to translate 24-hour rainfall "design-storm" depths to peak discharge.[62] This model is based on empirical runoff relationships referred to as the Soil Conservation Service Curve Number Method.[63] The bridge data is from the National Bridge Inventory,[64] from which we selected only inland bridges that spanned bodies of water. Changes in runoff were determined based on a study of the watersheds feeding the waterways. The location and details of the rivers was derived from the United States Geological Survey (USGS) Hydrologic Unit Code 8 (HUC 8) database for Wisconsin.[65] We determine the increase in peak discharge based on a study of the watersheds at the HUC8 level feeding the local waterways. We utilize daily runoff data, which covers the state of Wisconsin. The LOCA Global Climate Model (GCM) projections provide daily precipitation outputs from the Coupled Model Intercomparison Project Phase 6 (CMIP6) as inputs.

Cost Estimates

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. We stabilize bridges only if projected runoff increases by 20% compared to the baseline. We strengthen piers and abutments only when runoff increases by 60% compared to the baseline for bridges on non-sandy soils and by 100% compared to the baseline for bridges on sandy soils. The percent increase in runoff for the different soil types are based on federal guidelines and were also utilized in Wright et al. (2012).[66] This method may underestimate potential damages because proactive costs are likely far lower than repairing or rebuilding a failed bridge.[67] Notably, our analysis does not estimate damages associated with delays/disruptions from the bridge being closed.

Appendix D.3: Protecting Rural Communities from Flooding

Taxpayer costs were analyzed at the municipal level.

The rural flooding analysis utilizes the Federal Emergency Management Agency (FEMA) 100-year floodplain maps from the National Flood Hazard Layer (NFHL),[68] National Land Cover Database (NLCD),

62 Len Wright et al., "Estimated Effects of Climate Change on Flood Vulnerability of U.S. Bridges," Mitigation and Adaptation Strategies for Global Change 17, no. 8 (December 1, 2012): 939–55, https://doi.org/10.1007/s11027-011-9354-2.

63 Surendra Kumar Mishra and Vijay P. Singh, Soil Conservation Service Curve Number (SCS-CN) Methodology, vol. 42, Water Science and Technology Library (Dordrecht: Springer Netherlands, 2003), https://doi.org/10.1007/978-94-017-0147-1.

64 Federal Highway Administration, "National Bridge Inventory," 2023, https://www.fhwa.dot.gov/bridge/nbi/ascii.cfm.

65 "Hydrologic Unit Maps," United States Geological Survey, accessed December 13, 2023, https://water.usgs.gov/GIS/huc.html.

66 Wright et al., "Estimated Effects of Climate Change on Flood Vulnerability of U.S. Bridges."

67 Neumann et al., "Climate Change Risks to US Infrastructure."

68 Federal Emergency Management Agency, "National Flood Hazard Layer," August 26, 2021, https://www.fema.gov/flood-maps/national-flood-hazard-layer.

Wisconsin Department of Natural Resource's "24k hydro" database,[69] and calculated changes in peak discharge to quantify the risk of projected rural flooding.[70]

Change in Runoff

The 24-hour rainfall "design storm"[71] depths are translated to peak discharge using the USDA's Natural Resources Conservation Service TR-20 model.[72] This model is based on empirical runoff relationships referred to as the Soil Conservation Service Curve Number Method. We then determine the increase in runoff using a study of the watersheds feeding the local waterways at the 8-digit Hydrologic Unit Code (HUC8) level.[73]

We use daily runoff outputs from simulations with the Variable Infiltration Capacity (VIC) model from Livneh et al. (2015).[74] The LOCA Global Climate Model (GCM) projections[75] provide daily runoff outputs from the Coupled Model Intercomparison Project Phase 6 (CMIP6) as inputs. Using the separate HUC8 shapefiles, the maximum 7-day totals of runoff for each year and for each HUC8 were calculated. The projected changes from the historical baseline were calculated including absolute, percent, and ratio percent changes of 100-year return period values from the historical and future period for all HUC8 basins.

Cost Quantification

The flood protection adaptation strategy is constructing a setback levee. Adaptation costs are $2.58 million per mile of protection and are based on a U.S. Army Corps of Engineers analysis.[76] The construction of the setback levee is determined to be either in 2040 or 2060 depending on the vulnerability of a given flooded area. Once a protection levee is in place, there is not a need to repeat the protection cost. In other words, a municipality only incurs the cost in one of the timeframes. We determine the municipalities that must invest in rural flood protection adaptation following these rules:

- The municipality must be rural[77] and;
- The municipality must contain a developed area that is within the FEMA 100-year floodplain and;
- The waterway must have a stream order of 4 or greater (eliminates small creeks and streams) and;
- The 100-year peak discharge values are projected to increase by at least 20%.

Appendix E: Protecting Infrastructure from Coastal Erosion and Lake Level Change

Taxpayer costs were analyzed at the municipal level.

We analyze one resilience and adaptation measure in this report related to lake level change, as described

69 Wisconsin Department of Natural Resources, "24k Hydro Full File Geodatabase," October 26, 2022, https://data-wi-dnr.opendata.arcgis.com/datasets/cb1c7f75d14f42ee819a46894fd2e771.

70 Wright et al., "Estimated Effects of Climate Change on Flood Vulnerability of U.S. Bridges."

71 Adaptation necessity and size is determined based on cumulative 24-hour precipitation amounts. The 24-hour precipitation total informs the flow rates in the rivers and streams, which allows us to size and design the flood protection accordingly.

72 Mishra and Singh, Soil Conservation Service Curve Number (SCS-CN) Methodology.

73 U.S. Geological Survey, "USGS HUC8 Watersheds," December 11, 2022, https://www.arcgis.com/home/item.html?id=1cb304e085cb46f9b8e2127f9e0bd921.

74 Livneh et al., "A Spatially Comprehensive, Hydrometeorological Data Set for Mexico, the U.S., and Southern Canada 1950–2013."

75 Joseph J. Hamman et al., "The Variable Infiltration Capacity Model Version 5 (VIC-5): Infrastructure Improvements for New Applications and Reproducibility," Geoscientific Model Development 11, no. 8 (August 30, 2018): 3481–96, https://doi.org/10.5194/gmd-11-3481-2018.

76 John I Remus, "Assessment of Conceptual Nonstructural Alternative Levee Setbacks along the Missouri River (Lower L-575 / Upper L-550 and Lower L-550)," Missouri River Flood Task Force Meeting (U.S. Army Corps of Engineers, 2012).

77 Rural is defined as a developed area within the flood zone in a village that is not bordering a city.

below. It is important to note that this is a small fraction of the potential resilience and adaptation measures that communities face. In Appendix A.3 we have identified 12 costs related to lake level change.
We estimated the costs of constructing seawalls or utilizing natural shoreline protection strategies needed to protect Wisconsin's public infrastructure from increased coastal erosion and lake levels in medium- and high-intensity developed areas (referred to as developed areas hereafter). Research regarding the potential rise in water levels in the Great Lakes due to climate change is in the early stages. However, initial modeling indicates that lake levels could reach historic highs with an increase of two feet by 2040.[78]

Data

The National Oceanic and Atmospheric Administration (NOAA) has developed a Lake Level Viewer to visualize locations where increased lake levels will result in new inundation areas along the lakefronts of the Great Lakes.[79] We obtained a GIS shapefile from the Lake Level Viewer that provided inundation zones for a two-foot rise in the Lake Superior water level and a three-foot rise in Lake Michigan water level. This dataset was further refined using only areas deemed "High Confidence" of inundation according to NOAA.

Determine quantity of vulnerable coastline in areas where infrastructure protection is required

We define vulnerable coastline as an area where projected lake level increase will result in inundation to areas containing infrastructure assets. We intersect projected lake level rise with a coastline shapefile for each municipality to gain a baseline of where projected rises may occur. We then filter these areas to only include areas that were within 250 feet of a developed area (defined as medium to high intensity according to the NLCD). We then total the resulting inundated coastlines by municipality to render a total length of inundated coastline, both artificial and natural. An artificial shoreline has existing protection strategies already in place, whereas natural shorelines do not. We determine the shoreline type using data from NOAA (see following section for more information).

Establish type of protection required

Coastal protection is only adapted in developed areas along the lakefront. The type of protection required for a length of developed coastal area is then determined based on the type of current protection that exists and the current type of shoreline (artificial or natural) based on the NOAA U.S. Great Lakes Hardened Shoreline Classification.[80] We then have areas where projected lake level rises overlap developed areas and have classified those areas as either "natural" or "artificial" coastlines based on the NOAA's hardened classification.

Cost Estimates

For natural shoreline areas, we cost out the price of improving their natural status to "Marsh + Sill/Breakwater" using an average median cost of construction of $246 per foot. After adjusting from 2019 to 2023 Q2 costs based on the Turner Cost Index,[81] the cost of construction is $290.48 per foot. For artificial shoreline areas, we estimate the cost of improving the shorelines to "Revetments" using an average median cost of construction of $569 per foot. After adjusting from 2019 to 2023 Q2 costs based on the Turner Cost Index, the cost of construction is $671.87 per foot. For areas that do not have a current protection status, we estimate the cost of improving the natural status to "Marsh + Sill/Breakwater," as described above. The costs of using these two shoreline improvement techniques were determined based on a study conducted by the Federal Highway Administration.[82]

78 Miraj B. Kayastha et al., "Future Rise of the Great Lakes Water Levels under Climate Change," Journal of Hydrology 612 (September 2022): 128205, https://doi.org/10.1016/j.jhydrol.2022.128205.

79 National Atmospheric and Oceanic Administration, "Lake Level Viewer: United States Great Lakes," 2023, https://coast.noaa.gov/llv/.

80 National Atmospheric and Oceanic Administration, "U.S. Great Lakes Hardened Shorelines Classification 2019," 2019, https://coast.noaa.gov/digitalcoast/data/hardened-shorelines.html.

81 Rivetti, "Turner Building Cost Index: 2023 Second Quarter Forecast."

82 Bret M. Webb et al., "Nature-Based Solutions for Coastal Highway Resilience: An Implementation Guide," August 1, 2019,

Based on the type of protection determined as appropriate for an individual segment, a per-foot cost is applied for the eventual cost of the segment.

Appendix F: Methodologies for estimating the cost to treat climate-induced illnesses

In all public health analyses, a baseline year of 2010 was used to determine increased costs of hospitalizations due to climate change.

We analyze three different climate change induced public health concerns in this report, as described below. It is important to note that this is a small fraction of the potential public health concerns that communities face.

Appendix F.1: Treating Respiratory Illness

Taxpayer costs for respiratory illness were analyzed at the federal level.

Pediatric asthma-related emergency room visits are directly correlated to pollen levels, and therefore to climatic conditions that are projected to change in the coming decades. We quantify the cost of treatment for climate-induced respiratory illness for both the baseline and projected time periods.

We define the asthma baseline as the average number of hospital visits for asthma for each county in Wisconsin per year from 2002 to 2019, which are documented in the National Environmental Public Health Tracking Network.[83] The baseline does not use data from 2020 onward because COVID-19 significantly reduced the number of pediatric asthma emergency department visits.[84] We use a distribution curve relating the number of asthma cases to pollen levels[85] to determine weekly asthma cases, since the National Environmental Public Health Tracking Network only reports asthma cases annually and ages are not included in the data. We use the documented pollen counts for trees, weeds, and grasses (pollen types) from 2018-2021 to set an average weekly level.[86] Average pollen load is determined by adding all pollen counts together and then dividing by the time period to smooth peaks that occur in some of the years.

The annual minimum temperature is used to calculate pollen counts for the asthma baseline and projection time periods to see a general trend in case counts.

Asthma Cases

We determine the impact of climate change on pollen loads by using the relationship between pollen load and annual cumulative minimum temperature.[87] The relationship used to determine pollen counts based on temperature comes from the slope of the best fit line in Figure F1. Using this relationship, we calculate the percent change in pollen load for each type of pollen (tree, grass, weed) through time compared to the baseline year (2010).

https://rosap.ntl.bts.gov/view/dot/43591.

83 Centers for Disease Control and Prevention, "National Environmental Public Health Tracking Network," n.d., https://ephtracking.cdc.gov/DataExplorer/.

84 Tregony Simoneau et al., "Impact of the COVID-19 Pandemic on Pediatric Emergency Department Use for Asthma," Annals of the American Thoracic Society 18, no. 4 (April 2021): 717–19, https://doi.org/10.1513/AnnalsATS.202007-765RL.

85 Paul J Villeneuve et al., "Outdoor Air Pollution and Emergency Department Visits for Asthma among Children and Adults: A Case-Crossover Study in Northern Alberta, Canada," Environmental Health 6 (December 24, 2007): 40, https://doi.org/10.1186/1476-069X-6-40.

86 Allergy, Asthma, & Sinus Center, S.C., "Pollen Explorer," 2023, https://myaasc.com/pollen-explorer.

87 Lewis H. Ziska et al., "Temperature-Related Changes in Airborne Allergenic Pollen Abundance and Seasonality across the Northern Hemisphere: A Retrospective Data Analysis," The Lancet. Planetary Health 3, no. 3 (March 2019): e124–31, https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196(19)30015-4/fulltext.

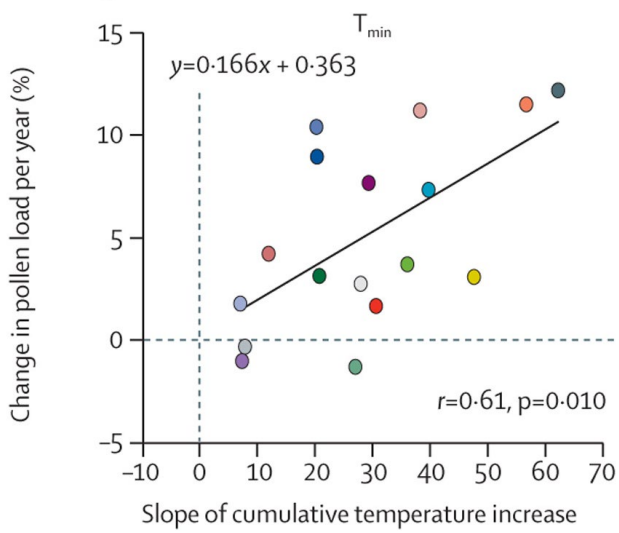


Figure F1: Slope of cumulative temperature increase (-) versus the change in pollen load per year (%) taken from Ziska et al. (2019).

Research has shown that pediatric emergency room visits increase in proportion to pollen loads.[88] Based on this research, we assume the increase in cases from increase in pollen levels for each pollen type (Table F1).

Table F1: The 5-day average unit increase[89] for different pollen types and the corresponding increase in emergency room visits for pediatric asthma.

Pollen Type	5-day Average Pollen Concentration	5-day Average Pediatric Emergency Department Visits
Tree	664 unit increase	23% increase in visits
Grass	10 unit increase	2% increase in visits
Weed	10 unit increase	13% increase in visits

Cost Estimates

The yearly cost increase of the emergency room visits was established based on insurance type and what the individual scenarios cover.[90] The percent of patients with each insurance coverage and the corresponding cost per visit for that scenario (Table F2).

Table F2: The average breakdown of pediatric asthma visits in the United States.

Type of Insurance	Patient Count	Cost per Asthma Visit	Government Funded?
Uninsured	11.9%	$1,120	No
Medicaid	50.2%	$1,108	Yes – Federal
Medicare	0.5%	$414	Yes – Federal
Private	40.2%	$1,263	No

88 Jessie A. Gleason, Leonard Bielory, and Jerald A. Fagliano, "Associations between Ozone, PM2.5, and Four Pollen Types on Emergency Department Pediatric Asthma Events during the Warm Season in New Jersey: A Case-Crossover Study," Environmental Research 132 (July 2014): 421–29, https://doi.org/10.1016/j.envres.2014.03.035.

89 1 unit increase is 1 grain per cubic meter. Since each source contains a different amount of pollen, unit increases are different for each source.

90 Tiffany Wang et al., "Emergency Department Charges for Asthma-Related Outpatient Visits by Insurance Status," Journal of Health Care for the Poor and Underserved 25, no. 1 (February 2014): 396–405, https://doi.org/10.1353/hpu.2014.0051.

Appendix F.2: Treating Increasing Incidence of West Nile Virus

Taxpayer costs were analyzed at the federal level.

West Nile virus (WNV) is carried and transmitted by a genus of mosquitoes that thrive in warmer climates.[91] WNV was first detected in mosquitoes in Wisconsin in 2001, and the first case in a human was reported the year after. Studies have shown that warmer temperatures are linked to accelerated mosquito breeding, bite rates, and the incubation of WNV within mosquitoes.[92] Increased rainfall can also contribute to expanding the suitable breeding grounds for mosquitoes.[93] While most people infected with WNV experience no symptoms, a small percentage develop life-threatening illness.[94]

We modeled the increasing number of cases of West Nile virus in Wisconsin and the associated health costs as a result of rising temperatures. We established a current West Nile virus-infection rate for each Wisconsin county using data provided by the CDC.[95] While West Nile virus exists in all counties in Wisconsin, 14 counties do not have human case data. For those counties, we determined the first year of incidence using the relationship between temperature and West Nile virus by peer-reviewed research.[96] We used both mean weekly maximum temperature and daily maximum precipitation to model the future West Nile virus incidence rate for each Wisconsin county. We distribute cases by week by using the weekly incidence curve[97] to distribute cases by week since the county data is reported annually.

If the week's mean weekly maximum temperature is at least 5°C higher than the climate baseline (1991-2010), we assume the incidence increases by 40% that week and the following three weeks.[98] If the following three weeks also meet the same criteria, we do not increase the incidence by 40% again (i.e. the incidence will increase by 40% only once, even if all four weeks meet the temperature criteria).

If the week does not have increased incidences because of temperature, we then look at daily maximum precipitation per week.99 If one or more days in a week have more than 50mm of precipitation, then we assume the incidence increases by 33% that week and the following two weeks. If the following two weeks also meet that criteria, we do not increase the incidence by 33% again.

Because people cannot get WNV more than once, when the total case count reaches the county's population, we stop counting incidences.[100] Most of those infected with WNV experience no symptoms, while

91 Pien Huang, "The U.S. Is Unprepared for the Growing Threat of Mosquito- and Tick-Borne Viruses," NPR, December 15, 2023, sec. Public Health, https://www.npr.org/sections/health-shots/2023/12/15/1219478835/arboviruses-mosquito-tick-borne-viruses-tropical-disease.

92 David M. Hartley et al., "Effects of Temperature on Emergence and Seasonality of West Nile Virus in California," The American Journal of Tropical Medicine and Hygiene 86, no. 5 (May 1, 2012): 884–94, https://doi.org/10.4269/ajtmh.2012.11-0342; Shlomit Paz, "Climate Change Impacts on West Nile Virus Transmission in a Global Context," Philosophical Transactions of the Royal Society B: Biological Sciences 370, no. 1665 (April 5, 2015): 20130561, https://doi.org/10.1098/rstb.2013.0561; Nooshin Mojahed, Mohammad Ali Mohammadkhani, and Ashraf Mohamadkhani, "Climate Crises and Developing Vector-Borne Diseases: A Narrative Review," Iranian Journal of Public Health 51, no. 12 (December 2022): 2664–73, https://doi.org/10.18502/ijph.v51i12.11457.

93 C. B. Beard et al., "Ch. 5: Vectorborne Diseases," The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (U.S. Global Change Research Program, Washington, DC, April 4, 2016), https://health2016.globalchange.gov/vectorborne-diseases.

94 Centers for Disease Control and Prevention, "West Nile Virus," August 23, 2023, https://www.cdc.gov/westnile/index.html.

95 Centers for Disease Control and Prevention, "West Nile Virus Historic Data (1999-2022)," June 13, 2023, https://www.cdc.gov/west-nile-virus/data-maps/historic-data.html?CDC_AAref_Val=https://www.cdc.gov/westnile/statsmaps/historic-data.html.

96 Marta S Shocket et al., "Transmission of West Nile and Five Other Temperate Mosquito-Borne Viruses Peaks at Temperatures between 23°C and 26°C," ed. Eduardo Franco, Talía Malagón, and Alyssa Gehman, eLife 9 (September 15, 2020): e58511, https://doi.org/10.7554/eLife.58511.

97 Jonathan E. Soverow et al., "Infectious Disease in a Warming World: How Weather Influenced West Nile Virus in the United States (2001–2005)," Environmental Health Perspective 117, no. 7 (2009): 1049–52, https://doi.org/10.1289/ehp.0800487.

98 Ibid.

99 Ibid.

100 Centers for Disease Control and Prevention, "West Nile Virus."

those that do get sick can have wide ranging symptoms. Using CDC data, we distributed the yearly incidences by manifestation (Table F3).[101]

Table F3: Initial and long-term cost to treat manifestations of West Nile Virus. Non-neuroinvasive manifestations only have an initial cost, and neuroinvasive manifestations have both an initial and long-term cost.

Manifestation Type	Initial Cost	Long-term Cost	Percent of Cases
Non-neuroinvasive	$5,873.07	$0	96.7%
Neuroinvasive			
Meningitis	$9,546.53	$181.44 per year	2.65%
Encephalitis	$19,900.34	$3,233,02 per year	0.35%
Acute Flaccid Paralysis	$27,313.00	$6,998.51 per year	0.15%

To account for death of a WNV patient due to the neuroinvasive WNV,[102] only 93.56% of the neuroinvasive cases are included in the long-term costs. This is because 6.44% of people with neuroinvasive WNV die within 90 days of symptom onset. To account for death for WNV patients that survive the first 90 days, 50% of the remaining 93.56% neuroinvasive WNV cases from 3 years prior starting in 2023 are removed. In other words, in 2023, 50% of the remaining 93.56% of neuroinvasive WNV cases are removed from 2020, in 2024, 50% of the remaining 93.56% of neuroinvasive WNV cases are removed from 2021, etc. This is because the median time between symptom onset and death is 3 years for people with neuroinvasive WNV if they did not die within the first 90 days. Thus, every year has an initial cost, a long-term cost, and a total yearly cost.[103]

Appendix F.3: Treating Increasing Incidence of Lyme Disease

Taxpayer costs were analyzed at the federal level.

Climate change has contributed to the expanded range of ticks, increasing the potential risk for Lyme disease transmission.[104] Temperature strongly influences the life cycle and prevalence of ticks; as temperatures increase, areas that were previously too cold for ticks to thrive are becoming tick hot-spots.

To establish the baseline number of Lyme disease infections in Wisconsin, we used the 2019 county-level Lyme disease incidence data from the CDC.[105] While more recent data exists, the COVID-19 pandemic disrupted data collection, making more recent datasets incomplete.[106] We relied on peer-reviewed research that explores how temperature impacts tick incidence. We used two temperature-related variables to model the potential changes in tick population. We looked at spring daily minimum temperature and counted the number of days per year that have a minimum temperature between 40-50°F. If the sum of the counted days that year and the previous year is greater than the counted days from the baseline year (2010), we assume a 6% increase in incidence.[107]

101 Emily McDonald et al., "Surveillance for West Nile Virus Disease — United States, 2009–2018," MMWR. Surveillance Summaries 70 (2021), https://doi.org/10.15585/mmwr.ss7001a1.

102 David C.E. Philpott et al., "Acute and Delayed Deaths after West Nile Virus Infection, Texas, USA, 2002–2012," *Emerging Infectious Diseases* 25, no. 2 (February 2019): 256–64, https://doi.org/10.3201/eid2502.181250.

103 J. Erin Staples et al., "Initial and Long-Term Costs of Patients Hospitalized with West Nile Virus Disease," *The American Journal of Tropical Medicine and Hygiene* 90, no. 3 (March 5, 2014): 402–9, https://doi.org/10.4269/ajtmh.13-0206.

104 Beard et al., "Ch. 5."

105 Centers for Disease Control and Prevention, "Lyme Disease Surveillance and Data," May 15, 2024, https://www.cdc.gov/lyme/data-research/facts-stats/index.html.

106 Centers for Disease Control and Prevention, "Lyme Disease Surveillance Data," May 15, 2024, https://www.cdc.gov/lyme/data-research/facts-stats/surveillance-data-1.html?CDC_AAref_Val=https://www.cdc.gov/lyme/datasurveillance/surveillance-data.html.

107 Shao Lin et al., "The Effects of Multiyear and Seasonal Weather Factors on Incidence of Lyme Disease and Its Vector in New York State," Science of The Total Environment 665 (May 15, 2019): 1182–88, https://doi.org/10.1016/j.scitotenv.2019.02.123.

We also took into account summer daily maximum temperature, and tallied the number of days with a maximum temperature over 75°F. If the total number of counted days that year is greater than the counted days from the baseline year, we assume incidence increases by 2%.[108] As such, the maximum increase in Lyme disease is 8%.

Lyme disease can have lifelong negative health impacts. In our cost assessment, we account for the annual distribution of Lyme disease as well as the post-treatment symptom incidence using data from the CDC (Table F4).

Table F4: The cost to treat initial manifestation of Lyme disease (LD) and post-treatment Lyme disease symptoms (PTLDS).[109]

Manifestation Type	Treatment Cost	Percent of Cases
Lyme Disease	$3,790	87.5%
Post-Treatment Lyme Disease Symptoms	$8,630	12.5%

While Lyme disease does not shorten lifespan, the average lifespan in the U.S. is 78.8 years, and 52.2% of Lyme cases are people between the ages of 40 and 79, making the average age 59.5 years. Therefore, we must account for the mortality of patients with PTLDS who reach the end of the average U.S. lifespan during the analysis time frame. To do this, we removed 52.2% of PTLDS cases from 2020 and 2021 from the total number of PTLDS cases in 2039 and 2040, respectively (i.e., we assume 60 year-old patients with PTLDS in 2020 were no longer alive 19 years later in 2039).[110]

Appendix G: Technical Documentation for Equity and Budget Analysis

Appendix G.1: Equity Analysis

All demographic data used in this study comes from the 2022 U.S. Census Bureau 5-year American Community Survey (ACS-5 2022). [111]

Categorizing Municipalities

We use nine demographic characteristics from the United States Census Bureau to conduct equity analysis of climate adaptation costs in Wisconsin. For the nine structure & infrastructure impacts, we conduct a municipal-level equity analysis on per capita costs. For the three public health impacts, we conduct a county-level equity analysis on case counts.

Municipal Equity Thresholds: Structure & Infrastructure Impacts

We define municipalities in Wisconsin as "high poverty," "high racial minority," "high disability," "high non-English speaking," "high foreign born," "high elderly," "high youth," and "low education" using thresholds that limit the number of Wisconsin municipalities in each category to about 10%. For rural municipalities, we use the definition provided by the Wisconsin Department of Health Services (Table G1).[112] To do this, we first collect municipal-level data for each of the nine demographic characteristics using

108 Ibid.

109 Emily R. Adrion et al., "Health Care Costs, Utilization and Patterns of Care Following Lyme Disease," PLOS ONE 10, no. 2 (February 4, 2015): e0116767, https://doi.org/10.1371/journal.pone.0116767.

110 Amy M. Schwartz et al., "Surveillance for Lyme Disease — United States, 2008–2015," MMWR. Surveillance Summaries 66 (2017), https://doi.org/10.15585/mmwr.ss6622a1.

111 US Census Bureau, "American Community Survey 5-Year Data (2009-2022)," Census.gov, accessed January 29, 2024, https://www.census.gov/data/developers/data-sets/acs-5year.html.

112 "WISH: Urban and Rural Counties," Wisconsin Department of Health Services, October, 2022, https://www.dhs.wisconsin.gov/wish/urban-rural.htm.

the "tidycensus"[113] package in the R programming language.[114] To get municipal level data, we use the "county subdivision" geographic level. Although this designation is not exactly one-to-one (there are some county subdivisions that do not contain a municipality), it includes every city, village, and town in Wisconsin.[115]

For the demographic characteristics indicating the categories of high poverty, high disability, high non-English speaking, and low education, greater than 20% of a given municipality's population must meet the description to fall under the "high" risk equity category. This roughly equates to less than 10% of Wisconsin municipalities falling in each category.

For the demographic characteristics indicating the categories of high elderly and high youth, greater than 30% of a municipality's residents must either be at least 65 years of age or younger than 18 years of age, respectively. Both categories contain about 10% of Wisconsin municipalities.

For the demographic characteristic indicating the high foreign-born category, greater than 10% of residents must have been born outside of the United States. This equates to about 3% of Wisconsin municipalities.

For the demographic characteristic indicating a rural municipality, greater than 50% of residents must live in areas classified as rural by the Census Bureau. This equates to about 85% of Wisconsin municipalities.

Table G1: Thresholds for defining municipalities that fall in each of the nine equity categories.

Equity Category	Threshold	Number (Percent) of Municipalities	Census Table[116]
High poverty	>20% in poverty	113 (6.0%)	S1701
High racial minority	>20% non-white and Hispanic white	118 (6.2%)	P9
High disability	>20% disability	168 (8.8%)	S1810
High non-English speaking	>20% speaking language other than English at home	64 (3.4%)	S1601
High foreign-born	>10% foreign-born	51 (2.7%)	B05002
High elderly	> 30% population age 65+	208 (11.0%)	S0101
High youth	>30% population age <18	163 (8.6%)	
Low education	> 20% adults without a highschool diploma	65 (3.4%)	S1501
Rural	>50% of population living in a rural area	1,640 (85.3%)	P2

113 Kyle Walker and Matt Herman, "Tidycensus: Load US Census Boundary and Attribute Data as Tidyverse and Sf-Ready Data Frames," 2023, https://walker-data.com/tidycensus/.

114 R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

115 Wisconsin State Legislature, "WI Cities, Towns, and Villages."

116 This column lists American Community Survey Table IDs produced by the U.S. Census Bureau that we use for determining demographic characteristics for Wisconsin municipalities. Each unique ID refers to a specific set of questions asked in the survey. For example, table S0101 contains all of the questions asking about age and sex. For more information, you can read the full explanation here: https://www.census.gov/programs-surveys/acs/data/data-tables/table-ids-explained.html.

Below we summarize previous research used to inform the municipal thresholds defined in this study:

- *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%.[117] We find that 6.0% of municipalities in Wisconsin are considered "high poverty" under this threshold.
- *High racial minority:* 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."[118] The Washington Post analysts set this threshold based on their finding that the 20% threshold is "a tipping point that's often followed by steady diversification." This study is not explicit about whether Hispanic whites are or are not included in their definition of "non-white," though the definition implies they would be excluded since The Census Bureau designates Hispanic as an "ethnicity" rather than a "race," meaning many people who designate themselves as "Hispanic" in the American Community Survey can also designate themselves as "white." We find that 6.2% of Wisconsin municipalities are considered "high racial minority" under this threshold.
- *High disability:* A recent study on the geography of disability and food insecurity defined a high disability county as one with a "share of people with disabilities at or above the 75th percentile of the nation."[119] Another study found that disability prevalence among veterans in geographic areas is based on quintiles of disability prevalence.[120] Quintiles have been used as a cutoff for "high disability" since the 1990s.[121] We define "high disability" municipalities as greater than 20% of residents are disabled and we find that 8.8% of Wisconsin municipalities are considered "high disability" under this threshold.
- *High non-English speaking*: While a recent report by the Census Bureau includes a map of U.S. states organized by prevalence of languages other than English spoken at home, the report does not define a threshold for "high non-English speaking" areas.[122] As such, we define our own threshold for this category. We find that 3.4% of Wisconsin municipalities have more than 20% of residents speaking a language other than English at home and define this as the threshold for "high non-English speaking" municipalities in Wisconsin.
- *High foreign-born:* Similarly, there is not much research defining a threshold for "high foreign-born" areas in the United States, aside from one study by the Hoover Institute, a conservative think tank.[123] This study looked at cities with over 20% foreign-born population. This definition only comprised 17 cities across the country, none of which were in Wisconsin. As such, we lowered the threshold to include cities with at least 10% of the population having been born outside of the United States. We find that 2.7% of Wisconsin municipalities are considered "high foreign-born" under this threshold.
- *High elderly:* In most contexts, "elderly" is a descriptor reserved for people 65 and older.[124] In the State of Wisconsin's aging plan, they focus on the population of people aged 60 and older.

117 U.S. Census Bureau, "Poverty Areas: Statistical Brief," June 1995, https://www2.census.gov/library/publications/1995/demographics/sb95-13.pdf.

118 Ted Mellnik and Andrew Van Dam, "How Mixed-Race Neighborhoods Quietly Became the Norm in the U.S.," Washington Post, November 4, 2022, sec. Business, https://www.washingtonpost.com/business/2022/11/04/mixed-race-neighborhoods/.

119 Barbara Butrica, Stipica Mudrazija, and Jonathan Schwabish, "The Geography of Disability and Food Insecurity" (Urban Institute, March 31, 2022), https://www.urban.org/research/publication/geography-disability-and-food-insecurity.

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

121 J. L. McCoy, M. Davis, and R. E. Hudson, "Geographic Patterns of Disability in the United States," Social Security Bulletin 57, no. 1 (1994): 25–26.

122 Sandy Dietrich and Erik Hernandez, "Language Use in the United States: 2019" (U.S. Census Bureau, September 1, 2022), https://www.census.gov/library/publications/2022/acs/acs-50.html.

123 Steven Moore, "Immigration and the Rise and Decline of American Cities" (Hoover Institution, August 1997), https://www.hoover.org/research/immigration-and-rise-and-decline-american-cities.

124 Hajime Orimo et al., "Reviewing the Definition of 'Elderly,'" Geriatrics & Gerontology International 6, no. 3 (2006): 149–58, https://doi.org/10.1111/j.1447-0594.2006.00341.x.

We choose to define "elderly" municipalities as those where at least 30% of the population is above the age of 65, as this is the most common definition of the term in most contexts. We find that 11% of Wisconsin municipalities are considered "high elderly" under this threshold.

- *High youth:* Additionally, we explore how impacts differ for municipalities that have large populations under the age of 18. As with elderly municipalities, we define a high youth municipality as one where at least 30% of the population is under the age of 18. We find that 8.3% of Wisconsin municipalities are considered "high youth" under this threshold.
- *Low education:* Low levels of education are correlated with decreased earnings, and as a result decreased resources to adapt to climate change.[125] We measure the percentage of adults age 25 and older without a highschool diploma or equivalent. Following most of the other categories we previously defined, we set the threshold for municipalities that have large populations of adults without high school diplomas as those where more than 20% of adults meet that criteria. We find that 3.4% of Wisconsin municipalities are considered "low education" under this threshold.
- *Rural:* To classify a municipality as rural or urban, we look at the number of residents in that municipality that live in rural places according to the Census Bureau. If the majority of a municipality's residents live in a rural setting, then the entire municipality is designated as rural. Using this method, 85.3% of Wisconsin municipalities are considered rural.

County Equity Thresholds: Structure & Infrastructure and Public Health Impacts

We define counties in Wisconsin as "high poverty," "high racial minority," "high disability," "high non-English speaking," "high foreign-born," "high elderly," "high youth," and "low education." For rural counties, we use the definition provided by the Wisconsin Department of Health Services.[126] To do this, we collect county-level data for each of the nine demographic characteristics using the "tidycensus"[127] package in the R programming language.[128] Due to higher levels of homogeneity among Wisconsin counties and a smaller number of counties that fit into the municipal thresholds defined above, we define a threshold to designate high equity categories as counties that have demographic characteristics that are above the statewide average (Table G2). For example, we designated "high poverty" counties, as those whose poverty rates are above the statewide poverty rate.

125 Jacob Mincer, "Education, Experience, and the Distribution of Earnings and Employment: An Overview," NBER Chapters, 1975, 71–94, https://ideas.repec.org//h/nbr/nberch/3693.html.

126 "WISH: Urban and Rural Counties," Wisconsin Department of Health Services, October, 2022, https://www.dhs.wisconsin.gov/wish/urban-rural.htm.

127 Walker and Herman, "Tidycensus: Load US Census Boundary and Attribute Data as Tidyverse and Sf-Ready Data Frames."

128 R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, https://www.R-project.org/.

Table G2: Thresholds for designating counties that fall in each of the nine equity categories. The threshold is defined by the statewide average demographic characteristic that corresponds to each of the equity categories.

Equity Category	Threshold	Number (Percent) of Counties	Census Table[129]
High poverty	>10.7% in poverty	31 (43%)	S1701
High racial minority	>21.4% non-white and Hispanic white	13 (16%)	P9
High disability	>12.5% with a disability	50 (69%)	S1810
High non-English speaking	>8.7% speaking a language other than English at home	9 (13%)	S1601
High foreign-born	>5% foreign born	8 (11%)	B05002
High elderly	>16.5% age 65+	34 (47%)	S0101
High youth	>22.1% age <18	37 (51%)	
Low education	>6.5% of adults without a highschool diploma or equivalent	46 (63%)	S1501
Rural	>50% of population living in a rural area	46 (63%)	P2

Method

For all nine structure & infrastructure climate adaptation costs estimated in this study (Table A1, rows 1-9), we calculate the per capita costs for each municipality. We then compare the municipal per capita costs to the statewide average per capita costs to see if municipalities with equity designations experience higher or lower per capita costs than the statewide average. We exclude municipalities under 100 residents from the final analysis to remove per capita costs that are so large they skew the analysis.

For four of the structure & infrastructure climate adaptation costs (net building energy costs, installing air conditioning, bridge maintenance, and road maintenance; Table A1; rows 1, 2, 5, and 7), we also have county-level cost estimates. We perform the same equity assessment described above to determine whether counties that meet the equity thresholds defined in this section will face higher or lower per capita costs as compared to the statewide average.

For the three public health costs estimated in this study (Table A1, rows 10-12), we center our equity analysis on the estimated number of cases predicted to occur during the study period (2024 through 2040), as opposed to the estimated costs. We compute the increase in per capita cases for counties that meet the equity thresholds defined above. We then compare the county-level per capita case counts to the statewide increase in per capita case counts to determine which counties will experience more or less case counts than the statewide average for a given equity category.

129 This column lists American Community Survey Table IDs produced by the U.S. Census Bureau that we use for determining demographic characteristics for Wisconsin municipalities. Each unique ID refers to a specific set of questions asked in the survey. For example, table S0101 contains all of the questions asking about age and sex. For more information, you can read the full explanation here: https://www.census.gov/programs-surveys/acs/data/data-tables/table-ids-explained.html.

Appendix G.2: Budget Analysis

Survey of State and Local Government Finance

The budget analysis for the state of Wisconsin is conducted using the most recent data available of state and local government finances, a 2017 survey reported by the U.S. Census Bureau.[130] In Wisconsin, 99.5% of all local governments responded to the survey, with the other 0.5% of results supplied by the U.S. Census Bureau. The survey aggregates municipal spending to the county level 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 Wisconsin is calculated by adding up all of the spending within the categories labeled as direct expenditures for city, township, and village governments. It is assumed that large capital expenditures (e.g., drainage & stormwater infrastructure, coastal protection, etc.) are debt financed with a conservative 0% interest rate to be paid over the course of the 17 years between 2024 and 2041, so they are completely paid off by the year 2041.

All cost estimates are adjusted to 2023 dollars using the Bureau of Labor Statistics producer price index adjustment for total government purchases.[131] To determine a conservative and reliable estimate of climate adaptation costs throughout Wisconsin, communities with populations fewer than 100 were excluded from all per capita costs analysis. While some of these smaller communities will experience devastating climate impacts, applying cost models to small populations can create outlying cost estimates and uncertainty in the overall data.

Local Government Expenditures and Fiscal Stress

Over two thirds of the counties in Wisconsin will see their local government budgets increase by 5% or more due to the costs associated with the 12 climate adaptations analyzed in this report. Total statewide local spending will increase by about 4%.

Local governments in Wisconsin will shoulder climate adaptation costs that will stress local revenue sources. Fiscal stress is analyzed at the municipal level by comparing per capita climate adaptation costs to historical growth in local government revenues. The annual Survey of State and Local Governments shows that local general revenue in Wisconsin increased from $18 billion to $33 billion from 2000 to 2020.[132] Adjusted for inflation to 2020 dollars, this represents a 25% increase in per capita revenue generated by local governments in the form of taxes.[133] Per capita local government revenue was $5,600 in 2020, which means that if annual municipal spending increased by 25% ($1,400 per capita), it would amount to the entirety of municipal revenue growth over the 20-year period from 2000 to 2020, driven solely by climate change. This would constitute a severe fiscal stress for local governments as they would have to find new sources of revenue to cover these costs.

130 U.S. Census Bureau, "2017 State & Local Government Finance Tables," 2017, https://www.census.gov/data/tables/2017/econ/gov-finances/summary-tables.html.

131 U.S. Bureau of Labor Statistics, "Producer Price Index Home," 2024, https://www.bls.gov/ppi/.

132 U.S. Census Bureau, 2000 Annual Surveys of State and Local Government Finances, https://www2.census.gov/programs-surveys/gov-finances/tables/2000/summary-tables/00slss2.xls; https://www2.census.gov/programs-surveys/gov-finances/tables/2020/20slsstab1b.xlsx, Accessed February 23, 2023.

133 U.S. Bureau of Labor Statistics, "CPI Inflation Calculator," 2024, https://www.bls.gov/data/inflation_calculator.htm; U.S. Census Bureau, "Total Population in Wisconsin," 2020, https://data.census.gov/all?q=population%20of%20wisconsin%20in%202020.

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