Figure 1. Image from VISIT Milwaukee.

Milwaukee County Climate Action 2050 Plan

Vulnerability Assessment

Achieving Net Zero Carbon Emissions While Advancing Equity, Justice, and Community Resilience

CORRECTED REPORT (received July 31, 2023)

MILWAUKEE COUNTY

Climate Change Impacts and Hazards in Milwaukee County

Executive Summary

Climate Change Impacts and Hazards in Milwaukee County

This executive summary provides an overview of the climate change impacts in Milwaukee County based on a comprehensive vulnerability assessment. The assessment examines climate hazard projections under low-emissions constraints (RCP4.5) and high-emissions constraints (RCP8.5) in the early, mid, and late 21st century. The assessment identifies key climate change impacts, including temperature and heat wave impacts, precipitation impacts, flooding and erosional impacts, and highlights high priority vulnerabilities across the County.

In a high-emissions scenario, average temperatures are expected to increase by approximately 10°F by the end of the century compared to the beginning. Currently, the county experiences a small temperature gradient, with slightly higher temperatures inland and lower temperatures near the lake shore. This pattern is anticipated to continue in the future. Historically, the average temperature in Milwaukee County has ranged from 57°F to 59°F near the lake shore to West Allis. In recent years, this range has slightly increased to 58°F to 61°F. However, by midcentury, under the high-emissions scenario (RCP8.5), projected temperature increases could reach 61°F to 63°F. By the end of the century, the high-emissions scenario suggests average temperatures of 67°F to 69°F. On the other hand, if emissions are constrained under the low-emissions scenario (RCP4.5), similar increases of 62°F to 64°F can be expected by midcentury, stabilizing to 62°F to 65°F by the end of the century.

Heat waves, characterized by high temperatures, are projected to become more intense in Milwaukee County. By the mid-century, average heat wave temperatures are expected to range from 92°F to 98°F in a constrained emissions scenario (RCP4.5) and 94°F to 100°F in a non-constrained emissions scenario (RCP8.5). These projections indicate an increase of 2-4°F compared to historical heat wave temperatures. By the end of the century, heat waves could become even more severe, with projected average temperatures ranging from 94°F to 100°F in a constrained emissions scenario and 98°F to 102°F in a non-constrained emissions scenario. It is worth noting that the western border of the county is projected to experience warmer temperatures during heat waves than the lake shore in all predicted periods and scenarios.

Precipitation patterns are also expected to shift in Milwaukee County. While changes in annual precipitation are relatively small, seasonal changes are anticipated. Winters are projected to become wetter, with slight increases in average precipitation, while summers are expected to become drier. This shift may impact the region's water resources and necessitate adjustments in water management strategies. Additionally, changing precipitation patterns are likely to have significant effects on flooding in Milwaukee County.

Flooding is another key vulnerability identified in this assessment. Changing precipitation patterns and increased frequency of extreme weather events can lead to a higher risk of flooding in vulnerable areas. Specifically, this assessment identifies the Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek corridors as areas prone to flooding. The potential impacts of flooding include property damage, infrastructure disruptions, and threats to public safety. Addressing this vulnerability requires proactive measures such as improved stormwater management, enhanced floodplain mapping, and the implementation of resilient infrastructure designs.

The findings of this vulnerability assessment will provide crucial insights to inform the development of Milwaukee County's Climate Action 2050 Plan (CA50). The CA50 Plan aims to achieve net-zero carbon emissions from county operations while advancing equity, justice, and community resilience. By integrating this assessment's identified climate change impacts into the CA50 Plan, Milwaukee County can develop targeted strategies and policies to mitigate risks, enhance resilience, and foster sustainable development. This assessment serves as a foundation for informed decision-making and will guide the County's efforts in building a climate-resilient and environmentally responsible future.

High Priority Vulnerabilities:

1. **Heat Waves and Human Health:** Milwaukee County faces an increasing threat from extreme heat events, particularly during severe heatwaves. The acute risk to human health, including the potential for mass-casualty events due to acute heat stress, is a pressing concern. Heat stress is a cumulative risk, and populations exposed to multiple days of continuously hot, humid conditions will experience greater heat stress. The projected increase in extreme heat, combined with the urban heat island effect, exacerbates the impact on vulnerable communities. Factors such as old buildings, lack of air conditioning, high concentrations of impermeable surfaces, and limited tree canopy intensify the urban heat island effect, leading to higher temperatures in urban areas. Social vulnerability factors, including poverty, disability, and age, further contribute to the susceptibility of certain populations to heat-related health issues. Targeted measures, such as improving access to cooling centers, enhancing public awareness, and implementing heat resilience strategies are essential to protect human health and ensure community resilience in the face of heat waves.
2. **Flooding in Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek Corridors:** Milwaukee County is confronted with significant flood vulnerabilities in key watersheds, namely the Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek corridors. These areas are home to critical facilities, communities, and infrastructure that are exposed to risk of flood-related damage and/or service disruption. Using FEMA FIRMs 100-year and 500-year floodplain maps, several high-priority flood hazards have been identified, intensifying the urgency of addressing this issue. Specifically, critical facilities such as parking enforcement, fleet services/repair garages, healthcare facilities, and transportation infrastructure, including rail yards and rail lines, are exposed to substantial flood risks. Residential neighborhoods and commercial districts situated near these waterways are also susceptible to flooding, particularly during extreme precipitation events. Notable locations affected include the Piggsville residential neighborhood, State St. industrial/commercial corridor, Glendale and River Hills residential neighborhoods along the Milwaukee River, Brown Deer neighborhoods surrounding Highway 57 and W. Joleno Drive, and Brown Deer commercial districts near N 51st St., Highway 57, and W Schroeder Dr. It is imperative to implement comprehensive flood mitigation strategies, including improved stormwater management, infrastructure updates, and community resilience initiatives to safeguard these vulnerable areas and protect the well-being of Milwaukee County residents.
3. **Acute Air Quality Hazards:** Milwaukee County is highly susceptible to acute air quality hazards, specifically focusing on the risks associated with ground-level ozone and fine particulate matter (PM2.5), which pose significant health implications, particularly for vulnerable populations. The impact of climate change exacerbates these hazards by increasing the occurrence of conditions that contribute to compromised air quality, such as elevated ozone levels and heightened exposure to allergens. The communities most affected by the urban heat island effect, characterized by elevated temperatures, limited tree coverage, and inadequate access to open spaces, tend to harbor the highest concentrations of vulnerable populations. Moreover, their proximity to major pollution sources, including highways and interstates, further compounds their vulnerability. Effectively addressing these air quality challenges necessitates the implementation of comprehensive strategies that focus on reducing pollution, promoting clean transportation alternatives, and enhancing the availability of green spaces.

Table of Contents

Glossary

100-Year Flood: In the context of Federal Emergency Management Agency (FEMA) flood insurance rate maps (FIRMs), the 100-year flood is a theoretical flood stage with a 1-in-100 chance of occurring each year (also called a 1% flood). Because FEMA FIRMs are the most ubiquitous flood hazard mapping product available, many planning decisions are made around the regulatory 100-year floodplain. However, the 100-year floodplain is both derived from historical data and thus does not account for changes to future precipitation under climate change. Because floodplains are modeled, the hazard area contains significant uncertainty.

500-Year Flood: The 500-year flood (also called a 0.2% flood) is a flood with a probabilistic return period of 500 years, or a 0.2% annual chance of occurring. The 500-year floodplain is the area expected to be inundated in a 500-year flood. As with the 100-year floodplain, the 500-year floodplain is derived from historical data and does not reflect projected changes to future precipitation from climate change. For resilience planning purposes, locating a facility or asset outside of the 500-year floodplain is one approach to mitigating flood hazard when detailed flood hazard analyses are unavailable.

Adaptation: The term "adaptation," in the context of climate change, refers to the process of adjusting and preparing for the impacts and risks associated with changing climatic conditions. It involves developing strategies, policies, and actions to reduce vulnerability and increase resilience to the challenges posed by climate change.

Climate Change: The term "climate" refers to the general weather conditions in an area over a long period of time. Typically, climate averages are measured over a 30-year period. Climate change refers to significant changes in the typical or average weather of a region over several decades or longer.

Coastal Flooding: Flooding along the shoreline of an ocean, bay, lake, sea, or other body of water that does not flow.

Erosion: The process during which the earth's surface is gradually worn down, removed, and carried away by natural forces such as rain and wind.

Extreme Precipitation: Precipitation whose intensity exceeds a threshold typical for a region can be considered to be extreme precipitation. In this assessment, extreme precipitation is evaluated by comparing historical precipitation extremes to projected precipitation extremes for 100-year and 500-year precipitation events.

Extreme Weather Event: Weather events that are unexpected or unusual for a place or season. Extreme weather can refer to weather events (including temperature or precipitation extremes, storms, winds, drought, floods, or fires) that cause significant damage to human or natural systems. These can also be defined as weather events that are statistically unlikely to occur when compared to historical climate for a place and time of year.

Freeze-thaw Cycle: A freeze-thaw cycle (FTC) occurs when the temperature decreases to a point that it freezes water (32 °F) then increases, causing the water to thaw. Since water expands when it freezes, the expansion caused by repeated freeze-thaw cycles can result in significant damage to infrastructure.

Heat Wave: For the purposes of this assessment, heat waves are defined by the hottest consecutive seven-day period per year, per simulation, as defined by the daily high temperature.

Nuisance Flooding: Flooding of low-lying areas caused by high tide events. Nuisance flooding is also referred to as "sunny day flooding" because it does not necessarily occur with rain.

Reduced Emissions Scenario (RCP4.5): The reduced emissions scenario assumes that global greenhouse gas emissions peak in 2040 and decline afterwards, resulting in an elevated but stable amount of warming by 2100. The scenario is defined by the amount of radiative forcing (i.e., solar energy) trapped by the atmosphere in 2100 in units of watts per square meter. Thus, the Representative Concentration Pathways (RCP) scenario corresponding to an emissions pathway that produces 4.5 W/m2 of radiative forcing in 2100 is referred to as RCP4.5.

This scenario is considered very unlikely given current international emissions outlooks, but serves as an illustrative 'minimum' in terms of projected change. Both the RCP4.5 and RCP8.5 scenarios were created as part of the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report (AR5), published in 2014.4 These scenarios have become the industry standard for anticipating potential outcomes of climate change.

Riparian Flooding: Flooding that occurs along the edges of rivers, streams, and other moving water bodies.

Unconstrained Emissions Scenario (RCP8.5): This assessment uses two emissions scenarios which incorporate divergent assumptions about the future. The unconstrained emissions scenario corresponds to a world where global greenhouse gas emissions continue to rise throughout the century, leading to rapid and escalating warming by 2100. The scenario is defined by the amount of radiative forcing (i.e., solar energy) trapped by the atmosphere in 2100 in units of watts per square meter. The RCP8.5 scenario corresponds to an emissions pathway that produces 8.5 W/m2 of radiative forcing in 2100.

This scenario is considered a 'worst case' scenario, but one that reflects current global trends in emissions and assumes no change in trajectory. Both the RCP4.5 and RCP8.5 scenarios were created as part of the IPCC's fifth assessment report, published in 2014.5 These scenarios have become the industry standard for anticipating potential outcomes of climate change.

Urban Heat Island: An urban area that experiences significantly higher temperatures than surrounding environments with more vegetation. This occurs when natural surfaces are replaced with unshaded roads and buildings which reflect heat instead of absorbing it.

Introduction

Climate change is imposing escalating costs on governments, infrastructure owners and operators, and on the civilians and businesses who rely on them. Milwaukee County has embarked on a project to develop a Climate Action 2050 Plan (CA50 Plan) which would see County emissions achieve net zero by 2050. A strong emphasis on community engagement throughout the project's lifespan has provided valuable feedback on various project activities, including the development of this vulnerability assessment and the subsequent formulation of climate action goals and strategies. As part of this initiative, the County has prepared a comprehensive vulnerability assessment that describes, explains, and evaluates its exposure to climate change hazards, while identifying key vulnerabilities in the region. This assessment focuses on the effects climate change may have on both County operations and residents' well-being.

Methods

Climate Change Projections

Climate change projections in this assessment are based on the outputs of four downscaled global climate models (GCMs) produced as a part of the United Nations-backed Intergovernmental Panel on Climate Change (IPCC) Climate Model Intercomparison Project round five (CMIP5) experiment.[1] The IPCC-sponsored CMIP efforts represent the global gold standard climate change projections, and are the basis of analysis supporting the IPCC's Fifth Assessment Report (AR5).[2] GCM outputs were further downscaled to 4km x 4km resolution by Abatzoglou et al. & Livneh et al. using the Multivariate Adaptive Constructed Analogs (MACA) method to enable greater insight into local distribution of projected climate change within the geography of Milwaukee County.[3,4]

Downscaled climate change projections include daily values for the following climate parameters: maximum and minimum daily temperatures, precipitation, wind speed, and relative humidity. Each climate metric is derived from a statistical abstract of these projected parameters.

Scenarios

This assessment uses two emissions scenarios which incorporate divergent assumptions about the future. These scenarios are referred to as Representative Concentration Pathways (RCP) scenario, and each incorporates a timeline of GHG emissions with the number in the scenario name corresponding to the resulting amount of solar radiative forcing created by GHGs in the year 2100 (in W/m^2).

- Reduced Emissions scenario (RCP4.5): This scenario represents a future that approximates a 'global best-case scenario' with respect to emissions and warming. This scenario describes a world where GHG emissions peak in 2040 and decline afterwards, resulting in an elevated but stable amount of warming by 2100.

[1] Taylor, K.E., R.J. Stouffer, G.A. Meehl: An Overview of CMIP5 and the experiment design. MS-D-11-00094.1, 2012.

[2] More recent projections are available from the CMIP6 exercise, however at the time of production of this analysis, no high-resolution, downscaled datasets were available using the CMIP6 projections. Energetics conducted an analysis comparing CMIP6 and CMIP5 climate projections in the Milwaukee County region and found very little deviation between the two experiments for future periods on key metrics of precipitation and temperature. Therefore, downscaled CMIP5 projections are used.

[3] Abatzoglou J.T. and Brown T.J. "A comparison of statistical downscaling methods suited for wildfire applications " International Journal of Climatology (2012),doi: 10.1002/joc.2312.;

[4] Livneh B, E.A. Rosenberg, C. Lin, V. Mishra, K. Andreadis, E.P. Maurer, and D.P. Lettenmaier. " A Long-Term Hydrologically Based Dataset of Land Surface Fluxes and States for the Conterminous United States: Update and Extensions. J. Climate, 26, 9384–9392.(2013)

- Unconstrained emissions scenario (RCP8.5): This scenario approximates a 'global worst-case scenario' – a world where countries fail to cut emissions and global carbon concentrations continue to increase through 2100. This scenario is associated with catastrophic warming across the world.

Time Periods

Four time periods are used in this analysis, each reflecting a 30-year 'window' of climate outcomes. These 30-year periods are used to highlight climatic changes rather than the noise introduced by year-to-year variations in weather. Time periods in this analysis include:

- **Historical Period** (1985 – 2014)
- **2020** (2005 – 2034)
- **2050** (2035 – 2064)
- **2085** (2070 – 2099)

Temperature and Heat Waves

- Average annual and seasonal temperature projections are based on the average daily high temperature for a season or year, averaged over the 30 years within each timeframe (e.g., 2070 – 2099). Projections for each of the four GCMs used are then averaged together to generate a single average projection for each scenario (historical period, RCP4.5, and RCP8.5).
- Diurnal freeze-thaw cycles are calculated based on the annual number of day-night pairs featuring high temperatures of 32 degrees or higher, and low temperatures below 32 degrees. These annual totals are averaged over the 30-year timeframe. Projections for each of the four GCMs used are then averaged together to generate a single average projection for each scenario (historical period, RCP4.5, and RCP8.5).
- Heat waves projections are calculated by finding the average temperature of the hottest 7-day period (based on daily high temperatures) in each simulation year. This 'heat wave temperature' is then averaged across all years in the climate period and across all four GCMs.

Precipitation Impacts

- Average annual and seasonal precipitation projections are based on the daily precipitation value, aggregated over either a year or season, and averaged over the 30 years within each timeframe. Summer season precipitation reflects the months of June, July, and August; winter season precipitation reflects the months of December, January, and February. Projections for each of the four GCMs used are then averaged together to generate a single average projection for each scenario (historical period, RCP4.5, and RCP8.5).
- Extreme precipitation projections are evaluated by fitting a Weilbull distribution to the daily precipitation totals across each time period and scenario. This best fit line is used to estimate daily extreme precipitation totals corresponding to a 1% probability per year (i.e., a 100-year precipitation event).

Storms and Extreme Weather Impacts

- Storm and extreme weather impacts are based on a synthesis of relevant assessment literature, including scientific and government reports, as well as qualified case studies. Storm impacts involve no additional quantitative analysis as hazards related to convective storms (including wind speed, frequency, severity) are not explicitly simulated in GCMs.

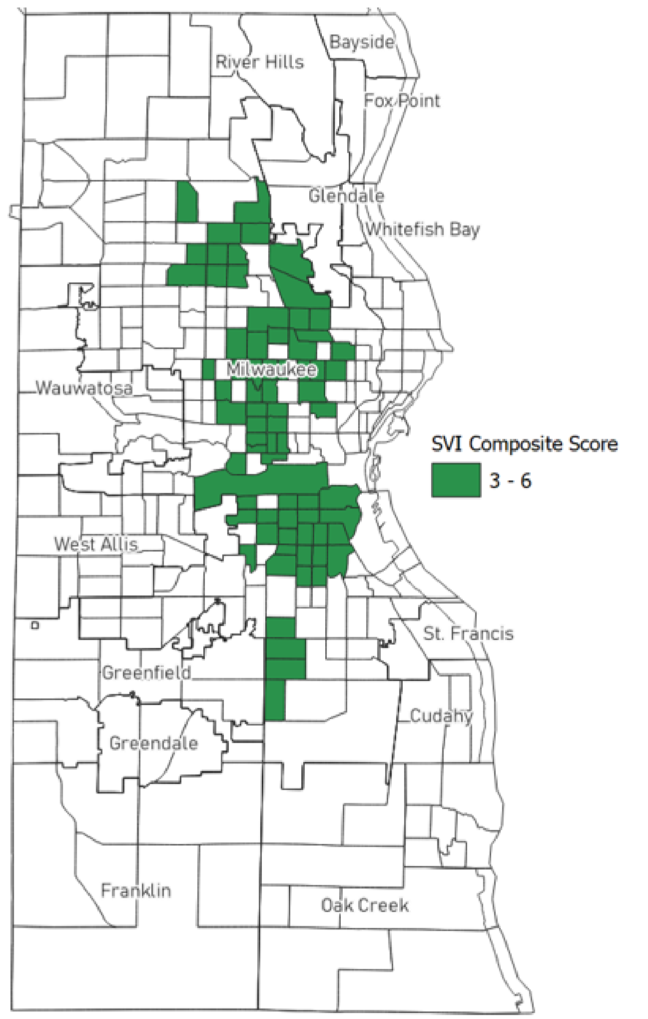
- Flooding hazards are evaluated using FEMA FIRMs accessed via the FEMA National Flood Hazard Layer (NFHL).[5] Flood hazards in both the 100-year floodplain (FIRM Zone A & Zone AE) and the 500-year floodplain (Zone X, excluding areas indicated as "zone of minimal flood hazard") are included in this analysis.

Community Contributions

In January 2023, Milwaukee County published and distributed an online survey on climate change and extreme weather impacts in Milwaukee County. The survey was conducted to understand residents' experiences with extreme weather events and their concerns about the impacts of climate change on the county's infrastructure, economy, and public health.

The survey received a substantial number of responses, with over 755 people participating. The respondents represented a good age distribution and near-equal gender representation. However, it's important to note that the survey respondents are not fully representative of Milwaukee County's population. The survey respondents predominantly identified as White/Caucasian (90%) and from zip codes with higher average levels of income and educational attainment. Geographically, though the survey received responses from all but one zip code, most respondents lived in zip codes closer to the lakefront. The overrepresentation of respondents from these areas and underrepresentation of respondents from communities which experience systemic racism and classism is crucial to bear in mind; nonetheless, the survey responses provide some valuable insights into how many residents perceive climate change and the impacts of extreme weather events on their lives and communities. Throughout this assessment, survey results are discussed in tandem with supplemental research to ensure a robust analysis of climate hazards posed to Milwaukee County residents.

Figure 2. SVI composite map, displaying Milwaukee County census tracts with compounding social vulnerabilities. U.S. Census Bureau; American Community Survey, 2021 American Community Survey 5-Year Estimates, Tables DP02 DP03 DP04 DP05; Generated by Energetics; using QGIS3.26.1.



The County also organized a series of community workshops in May 2023, providing a platform for meaningful community engagement and dialogue. These workshops brought together a diverse group of twelve county residents who generously shared their first-hand experiences, vividly illustrating the tangible impacts of climate change within their homes and neighborhoods. Their personal narratives shed light on the immediate challenges faced, including rising temperatures, increased flooding, and other climate-related disruptions. These community gatherings served as valuable forums for fostering a deeper understanding of the local impacts of climate change and the unique

[5] U.S. Federal Emergency Management Administration (FEMA). 2023. "National Flood Hazard Layer." Washington, DC: U.S. Federal Emergency Management Administration. Accessed online, April 24. https://www.fema.gov/flood-maps/national-flood-hazard-layer.

vulnerabilities faced by different communities within Milwaukee County. The insights gained from these shared experiences will play a crucial role in informing and shaping the County's climate adaptation strategies, ensuring that the voices and needs of the residents are central in the development of effective and equitable solutions.

Social Vulnerability Index

Milwaukee County is dedicated to fostering environmental equity and justice, striving to ensure that all residents have equitable access to the resources necessary for their well-being and prosperity within their communities. However, many communities, especially those consisting of low-income residents and people of color, may face systemic challenges in accessing resources that are necessary for a high quality of life. These challenges can manifest in many forms, including limited access to healthcare, transit, healthy food, and green spaces, which can negatively impact health outcomes and exacerbate vulnerability to climate hazards.

To ensure that the needs of all residents are considered equitably when assessing climate hazards, this study makes use of geospatial data on Milwaukee County communities, including multiple measures of social vulnerability at the community scale. These include eight Census-derived metrics that describe different facets of vulnerability to climate change impacts, including age, disability, education, language, people whose rent is over 35% of their income, poverty, race/ethnicity, and unemployment. These eight metrics are descriptive of community exposure to relevant climate hazards and are used to highlight concentrations of vulnerability to specific hazards. For example, a neighborhood with a high concentration households that speak a language other than English may be more vulnerable to acute climate hazards that require the County to rapidly notify and inform residents to protect their health and safety.

Additionally, this study uses a modified social vulnerability index (SVI) based on a similar product from the U.S. Centers for Disease Control (CDC) and Agency for Toxic Substances and Disease Registry (ATSDR).[6] The modified composite SVI is shown in **Figure 2**. The SVI utilizes data from the United States Census Bureau 2021 American Community Survey to identify percentile thresholds for each variable of vulnerability. Based on these thresholds, census tracts were assigned a composite score that indicates the level of vulnerability. For this vulnerability assessment, census tracts with a score of three or higher may be considered vulnerable. By utilizing the SVI, Milwaukee County can identify regions and neighborhoods that may need additional support to adapt to the impacts of climate change. This information is crucial in contextualizing the projected impacts of climate change and ensuring that vulnerable populations receive the necessary support to build resilience and thrive.

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[6] U.S. Centers for Disease Control (CDC). 2022a. "CDC/ATSDR SVI 2020 Documentation." Atlanta, GA: U.S. Centers for Disease Control. August 5.
https://www.atsdr.cdc.gov/placeandhealth/svi/documentation/pdf/SVI2020Documentation_08.05.22.pdf

Climate Change Impacts in Milwaukee County

This assessment includes climate hazard projections under low-emissions constraints (RCP4.5) and high-emissions constraints (RCP8.5) in the early, mid, and late 21st century (approximately 2020, 2050, and 2085, respectively). Climate change impacts include temperature and heat wave impacts, precipitation impacts, flooding & erosional impacts, and impacts related to interconnected systems. General trends across Milwaukee County see temperature increases into the end of the century, with the higher temperatures tending to be concentrated more on the western side of the County and cooler temperatures near the lakeshore. Though overall trends in precipitation show wetter winters and dryer summers into 2085, the most significant impact of changing patterns in precipitation may be effects associated with flooding and erosion. This assessment delves thoroughly into each climate change impact to assess its relationship to Milwaukee County's infrastructure and communities such that the County may take action to improve resilience and mitigate harmful climate hazards.

Temperature & Heat Wave Impacts

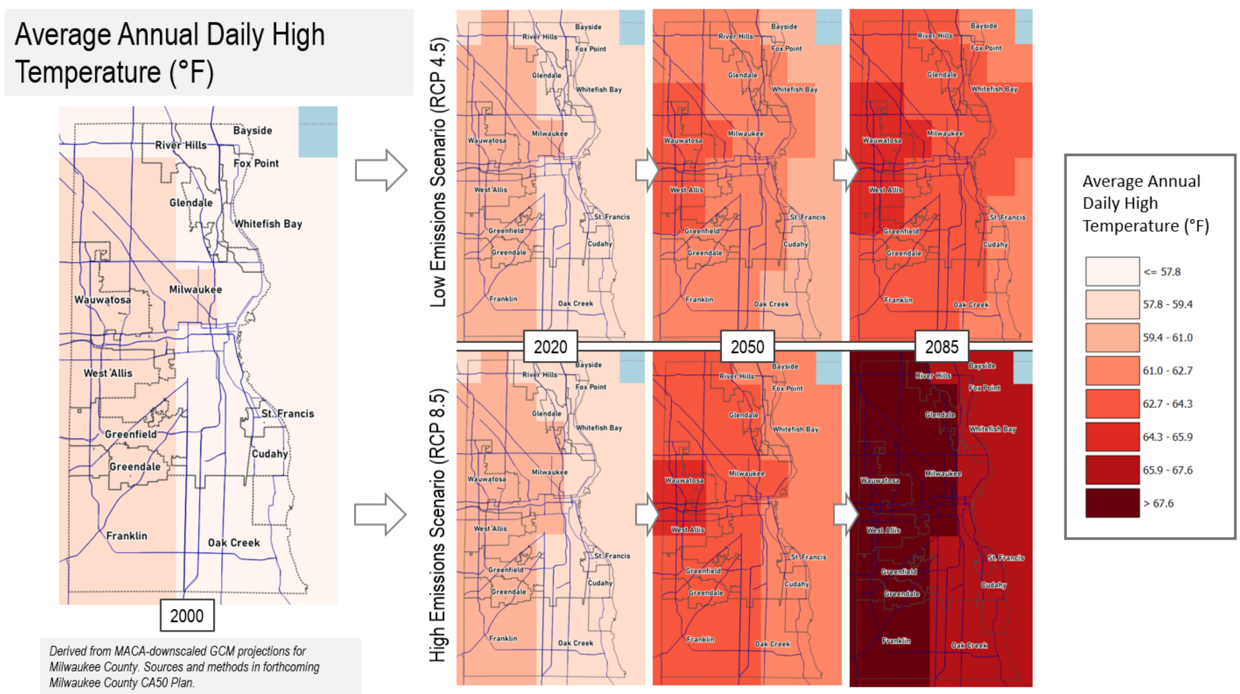

Figure 3. Historical and projected future average annual daily high temperatures across Milwaukee County.

Average and Seasonal Temperature Projections

On average, temperatures in Milwaukee County are expected to increase by about 10°F by the end of this century, as compared to the beginning under a high-emissions scenario. Without taking heat islands into account, the county typically sees a small temperature gradient with higher temperatures farther inland, and lower temperatures towards the lake shore. This pattern holds in projected future periods with the county's western border seeing higher temperatures than the lake shore in all periods and scenarios. **Figure 3** shows the historical and projected average annual temperatures across Milwaukee County through 2085. Historically, the county's average temperature has ranged from 57° - 59°F from the lake shore to West Allis. In recent years, this range has increased slightly to 58° - 61°F. But by midcentury, projected increases could reach 61° – 63°F, and 67° - 69°F by the end of the century in a high-emissions scenario (RCP8.5). If emissions are constrained (RCP4.5), similar increases of 62° - 64°F by midcentury can be expected, stabilizing to 62° – 65° by end of century.

Infrastructure Vulnerabilities to Increasing Average Temperatures

Projections of annual and seasonal daily average temperatures depend on scenario but indicate a trend towards a hotter future. While a matter of a few degrees may not seem concerning, average temperatures in Milwaukee County are on track to match the weather of a city like St. Louis, Missouri – and infrastructure and ecosystems must adapt.[7] The implications of hotter summers and warmer winters for Milwaukee County's residents and infrastructure can be significant. Elevated temperatures can lead to significant changes in the operation, maintenance, and ownership costs of infrastructure systems. Subtle but sustained changes in temperature also affect ecosystems, with knock-on effects for the populations and infrastructure systems that depend on them.

Accelerated Wear & Tear: Elevated temperatures accelerate the wear and tear on moving parts like wheels, bearings, and belts; and on load-bearing materials like concrete and asphalt. However, some of this physical damage may be offset by reduced exposure to severe winter temperatures and winter-related antagonists like salt and plowing during the cold season.

Energy Infrastructure: Increasing temperatures pose challenges for energy infrastructure, particularly power generation and transmission systems.[8] Higher ambient temperatures can reduce the efficiency of thermal power plants, such as natural gas and coal-fired plants, leading to decreased power output. Buildings, vehicles, and any space that accommodates people will face greater demands for cooling energy, including spaces/vehicles which may not have air conditioning. Additionally, higher temperatures can affect the transmission and distribution of electricity, leading to equipment failures and reliability issues.

Ecosystem Shift: Climate change may also impair waste/water treatment and handling, as surface water bodies see higher temperatures and associated growth of fouling algae or dangerous pathogens, and/or eutrophication. These challenges could impose significant costs on the county's water treatment facilities as added treatment capacity becomes necessary.[9] Green infrastructure like urban tree canopy may face challenges from new pests or pathogens, or accelerated tree death during hot weather.

Transportation Infrastructure: Rising average temperatures can lead to pavement degradation, increased maintenance costs, and reduced service life of transportation infrastructure. Heat-related expansion of rail tracks may cause misalignments or derailments.

Water Infrastructure: Water-related infrastructure, including dams, reservoirs, and water supply systems, is susceptible to the impacts of increasing temperatures.[10] Higher temperatures can exacerbate water scarcity by accelerating

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[7] U.S. National Weather Service (NWS). 2023. "Climate Report: The St. Louis Climate Summary for the Year of 2022." https://forecast.weather.gov/product.php?site=LSX&product=CLA&issuedby=STL.

[8] Clarke, L., Wei, Y.-M., Navarro, A. de la V., Garg, A., Hahmann, A. N., Khennas, S., Azevedo, I. M. L., Löschel, A., Singh, A. K., Steg, L., Strbac, G., Wada, K., Ameli, H., de La Beaumelle, N. A., Bistline, J., Byers, E., Calvin, K., Chawla, K., Cui, Y. (Ryna), … Veldstra, J. (2022). Energy Systems. *Climate Change 2022: Mitigation of Climate Change. Working Group III Contribution to the IPCC Sixth Assessment Report*, 613–746. https://doi.org/10.1017/9781009157926.008

[9] U.S. Environmental Protection Agency (EPA). 2022. "Climate Change Adaptation Resource Center: Climate Impacts on Water Utilities." August 15. https://www.epa.gov/arc-x/climate-impacts-water-utilities.

[10] *Water—Climate Action Pathway | UNFCCC*. (2021). https://unfccc.int/climate-action/marrakech-partnership/reporting-tracking/pathways/water-climate-action-pathway#Climate-Action-Pathway-2021

evaporation rates and reducing water availability in reservoirs and rivers. It can also affect the performance of water treatment plants by altering water quality and increasing risk of algal blooms.

Table 1. Infrastructure vulnerabilities associated with increasing average annual and seasonal temperatures.

Increasing Average & Summer Temperatures		
Transportation	Pedestrian & Human-powered transportation	• Greater discomfort on hot days; reduced share of non-motorized transportation
	Streetscape, Parks, & Trails	• Tree death & vegetation loss, intensifying UHI and shade loss • Increased management costs for green infrastructure
	Transit	• Reduced ridership, especially where bus stops are not sheltered/shaded • Accelerated wear on rolling stock during hot season
	Roads & Bridges	• Changing binder regimes and accelerated damage
	Rails	• Rail warping in extreme temperatures (i.e., "sun-kinking")
	Airports	• Increased cooling costs in indoor spaces • Increased asphalt damage on runways and tarmac
Energy	Electricity	• Increased demand for cooling energy; higher average and peak demand; increased risk of demand-related disruptions • Costs associated with capacity expansion • Increased risk of transmission line overheating and curtailment • Increased risk of electricity generator curtailments due to temperature restrictions
Water	Water supply systems[11]	• Accelerated water-borne pathogen growth; increased risk of water-borne diseases • Algal blooms; water quality impairment • Extended mosquito season • Increased demand for water, particularly pertaining to County zoo and park operations
	Wastewater treatment & sewers	• Reduced treatment efficiency resulting in higher levels of pollutants in the effluent • Higher demand for volume of wastewater in need of treatment on hot days
Communications	Internet, Phone, wired services	• Increased demand for equipment cooling • Signal loss and slower speeds due to heat-expanded fiber optic cables
	Cellular & wireless	• Increased demand for equipment cooling • Overheated equipment malfunctions, causing equipment failures and service disruptions

[11] US EPA, O. (2016, May 10). Climate Impacts on Water Utilities [Overviews and Factsheets]. https://www.epa.gov/arc-x/climate-impacts-water-utilities

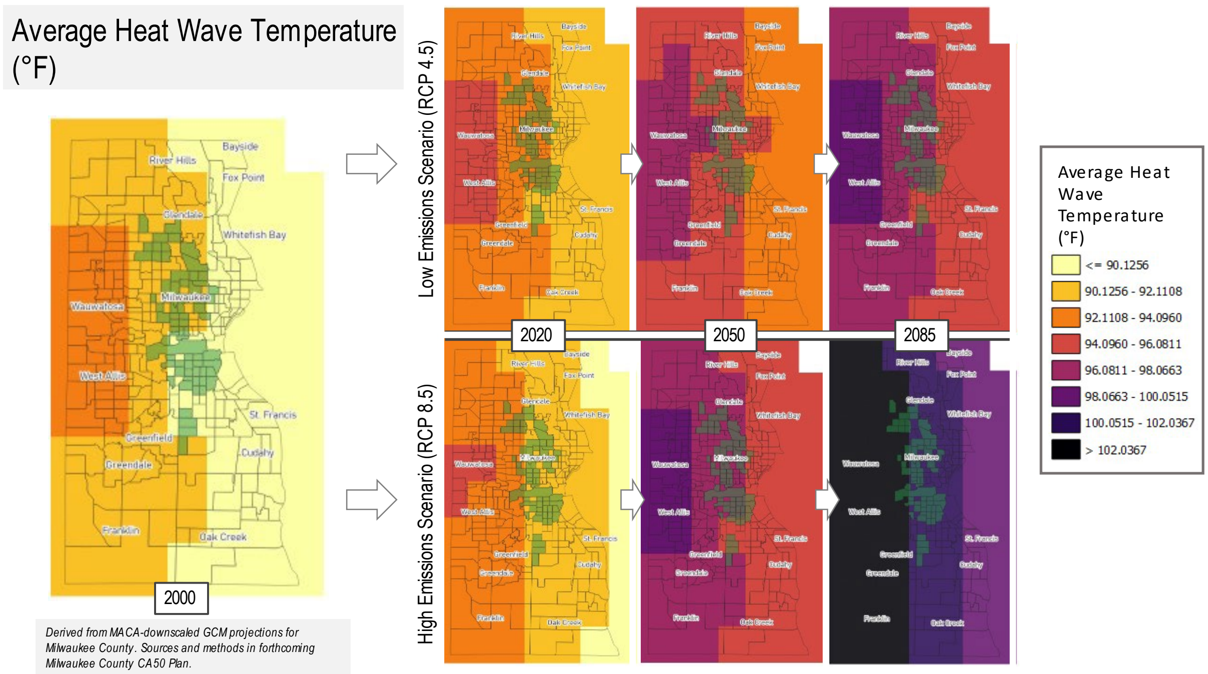

Figure 4. SVI composite score overlaid with future projected average annual daily high temperatures across Milwaukee County.

Social Vulnerabilities to Increasing Average Temperatures

As the effects of climate change become increasingly pronounced, Milwaukee County is projected to see significant changes in its temperature patterns. According to climate models in **Figure 4**, temperatures are expected to rise by an average of 10°F by the end of the century, as compared to the beginning. This change in temperature will have a range of impacts on the county's social fabric. While the county has historically seen a small temperature gradient with higher temperatures inland and lower temperatures towards the lake shore, projections suggest that the western border of the county will see higher temperatures than the lake shore in all future scenarios.

When the SVI is overlaid with annual average daily temperature projections [**Figure 4**], we can determine which regions of Milwaukee County may be most vulnerable to climate change impacts. High-emissions end-of-century scenarios project nearly every census tract identified as vulnerable to hit average daily temperatures of 69.21°F. Increasing daily temperatures impact diverse communities in diverse ways; for example, communities whose infrastructure has experienced historic underinvestment might feel heat impacts more substantially than neighborhoods which have access to high-quality energy efficient homes, or residents living with a disability may find their mobility, and by extension livelihood, affected by drastic temperature increases. Neighborhoods with majority non-native English speakers may struggle to access crucial emergency, public health, and safety resources during extreme heat waves. Many Milwaukee County residents may experience a variety of vulnerability factors, with the SVI indicating these effects intersect most densely near central and northwest Milwaukee County. Models projecting low-emissions scenarios, on the other hand, indicate temperature increases peaking at approximately 67.57°F, with the most severe increases happening largely outside of vulnerable communities.

As the temperature continues to increase, Milwaukee residents may face a variety of social vulnerabilities related to:

Community Health: Community health is a critical aspect of public well-being that encompasses a range of factors, including access to healthcare, air and water quality, and exposure to environmental hazards.[12] [13] In particular, vulnerable populations may experience disproportionate impacts due to a lack of resources and increased exposure to environmental hazards, such as:

Extreme Heat and Heat-Related Illnesses: Rising temperatures can lead to more frequent and severe heat waves, which can increase the risk of heat-related illnesses such as heat exhaustion and heatstroke. This risk is particularly high for vulnerable populations, such as the elderly, people with pre-existing medical conditions, and those living in urban areas with few green spaces. Additionally, extreme heat can exacerbate chronic health conditions such as asthma and heart disease, leading to hospitalizations and premature deaths.

Poor Air Quality: Rising temperatures can worsen air quality, particularly in urban areas with high levels of traffic and industrial activity. Hotter temperatures can accelerate the formation of ground-level ozone, a harmful air pollutant that can trigger respiratory problems such as asthma and increase the risk of heart disease. According to the American Lung Association's State of the Air report, Milwaukee County received a failing grade for ozone pollution in 2020.[14] Projections from the National Climate Assessment also indicate that the Midwest is likely to see a large number of premature deaths from intensified ground-level ozone, with the region comprising half of all ozone-related premature deaths in both 2050 and 2090 projections (Figure 5).[15] Low-income communities and communities of color are often disproportionately impacted by poor air quality, due to factors like residential segregation and the inequitable placement of polluting industries.

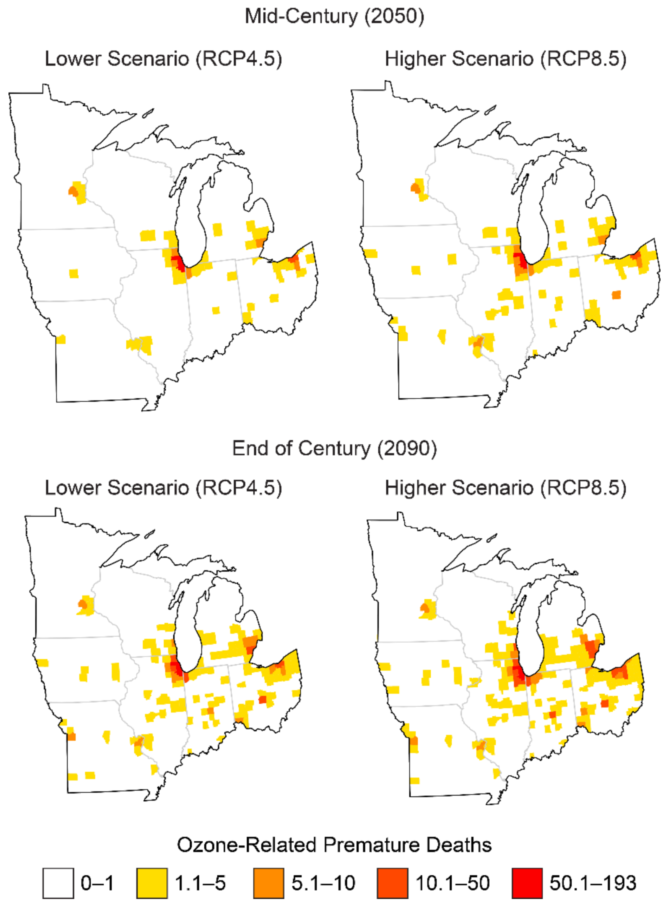

Figure 5. Ground-level ozone is a dangerous air pollutant created by vehicles, power plants, boilers, and other sources of combustion emissions. Ozone concentrations are increased during warm, sunny weather, so projected changes to temperature and precipitation are expected to enhance this impact in the Midwest. *Source: 4th National Climate Assessment, Ch. 21*

[12] Climate Effects on Health | CDC. (2022, May 3). https://www.cdc.gov/climateandhealth/effects/default.htm

[13] USGCRP. (2016). The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment (pp. 1–312). U.S. Global Change Research Program, Washington, DC. https://health2016.globalchange.gov/executive-summary.html

[14] Milwaukee. (n.d.). Retrieved May 3, 2023, from https://www.lung.org/research/sota/city-rankings/states/wisconsin/milwaukee

[15] US EPA, O. (2021, March 24). *Multi-Model Framework for Quantitative Sectoral Impacts Analysis*: [Reports and Assessments]. https://www.epa.gov/cira/multi-model-framework-quantitative-sectoral-impacts-analysis

Another climate-related threat to air quality involves the ways that warming temperatures affect terrestrial ecosystems and natural processes like wildfire. Warming temperatures lead to longer growing seasons, shifting allergy season to earlier in the year and encouraging the northward migration of plant species.[16] In northern forests, warmer temperatures and dryer summers can also contribute to increased risks of wildfire, especially in the vast boreal forests of Canada.[17] While wildfire is a natural process of forest ecosystems, accelerating climate change and decades of fire suppression are contributing to much larger and more frequent wildfires across North America. These fires can create severe air pollution, and in recent months, dozens of wildfires have ignited across Canada, leading to extended periods of air pollution that threatens sensitive groups in Milwaukee County.[18]

Vector-borne Diseases: Rising temperatures can also increase the risk of vector-borne diseases such as West Nile virus and Lyme disease, which are transmitted by mosquitoes and ticks, respectively. Warmer temperatures can lengthen the breeding season of these disease-carrying insects, allowing them to reproduce more frequently and in larger numbers[19]. In addition, rising temperatures can shift the geographic range of these insects farther north, potentially increasing residents' risk of infection. As temperatures continue to rise, it is important to invest in mosquito and tick control measures and public health campaigns that can help prevent the spread of vector-borne diseases. Additionally, addressing the underlying factors that contribute to the spread of these diseases, such as habitat destruction and urbanization, can help reduce the risk of infection for all residents.

Housing Affordability: Rising temperatures can also have a significant impact on housing affordability. According to a report by the National Low Income Housing Coalition, Milwaukee County already has a shortage of affordable and available rental homes, with only 27 affordable and available rental homes for every 100 extremely low-income renters.[20] As demand for air conditioning and other cooling measures increases, housing units with air conditioning may become more valuable and command higher rents. This can be particularly problematic for low-income households, who may not be able to afford the increased costs associated with air conditioning. In addition, rising temperatures can also increase the cost of construction and maintenance for housing units, potentially leading to higher rents and home prices. As temperatures continue to rise, it is crucial to invest in affordable housing options that are energy-efficient and resilient to the impacts of climate change.

Displacement and Gentrification: Rising temperatures can also exacerbate existing housing disparities and lead to displacement and gentrification in vulnerable communities. As the demand for housing in cooler and more comfortable areas increases, vulnerable populations such as low-income households and communities of color may be forced to leave their neighborhoods due to rising costs and lack of affordable housing. As temperatures continue to rise, it is important to invest in affordable housing solutions that can protect vulnerable populations from displacement and gentrification. This can include measures such as rent control, community land trusts, and inclusionary zoning policies that require developers to provide affordable housing units.

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[16] USGCRP. (2016).

[17] USGCRP. (2016).

[18] Kuhagen, C. (2023). "The air you breathe is being threatened this summer in Wisconsin by wildfires. Here's where they're happening." *Milwaukee Journal Sentinel.* June 9. https://www.jsonline.com/story/news/local/wisconsin/2023/06/07/air-quality-wildfire-weather-maps-wisconsin/70297334007/.

[19] Petersen, L. R., Holcomb, K., & Beard, C. B. (2022). Climate change and vector-borne disease in North America and Europe. https://doi.org/10.25646/10393

[20] Wisconsin. (n.d.). National Low Income Housing Coalition. Retrieved May 3, 2023, from https://nlihc.org/housing-needs-by-state/wisconsin

Urban Heat Island Effect

"Urban Heat Islands," or UHIs, occur in cities and dense urban areas when unshaded roads and buildings surfaces replace cooler natural surfaces. Natural surfaces contribute to the cooling of their environments in multiple ways: trees and plants provide shade while grass, soil, and water cool nearby air through evaporative cooling. By contrast, built surfaces (such as asphalt and concrete) absorb and retain heat during the day, then continue slowly emitting that heat over the course of the afternoon and evening. Thus, dense urban landscapes experience significantly higher temperatures (up to 15°F to 20°F) than surrounding environments with more vegetation (NIHHIS, EPA, Gregory, J. & Azarijafari).

The primary impact of UHIs is intensifying heat waves, especially in more dense urban areas. Excessive heat can lead to heat exhaustion, heat stroke, heart and lung stressors, asthma, and geriatric health impacts. The urban surroundings which create UHIs also trap pollution, which adds a layer of adverse health impacts for residents. Neighborhoods whose residents experience systemic socioeconomic inequities may be more susceptible to heat waves, UHIs, and higher rates of pollution. This is often due to inequitable resource allocation across a region, with a disproportionate lack of funding in solutions such as green spaces, heat shelters, and other public cooling systems. Low-income communities are likely to feel additional strain during heat waves through insufficient or unaffordable air conditioning systems.

Milwaukee is already experiencing the impacts of urban heat islands. As part of an ongoing effort by NOAA to record heat waves in urban areas around the U.S., the Wisconsin Department of Natural Resources recently studied temperature differences across Milwaukee in the summertime. During two hot days in July 2022, forty-three participants drove vehicles with car-mounted heat sensors around predetermined routes to capture heat and humidity readings in different neighborhoods. The mapping campaign found that hotter parts of the city could be up to 10 degrees warmer in the evenings. The more densely urban the neighborhood, the hotter the temperature (**Figure 6**; WI DNR).

The impacts of hotter temperatures in urban areas are exacerbated by the fact that Milwaukee, a historically cooler area, is a region without widespread air conditioning or other methods of coping with hotter temperatures. This is especially the case for older buildings and homes, public housing, and rental homes, which disproportionately affects vulnerable populations; vulnerable residents are more likely to live in densely urban areas with older buildings, lower ownership rates (restricting the ability to make changes to your building), fewer green spaces, and less access to cooling centers and adequate healthcare – creating the perfect storm for more severe health impacts among these populations.

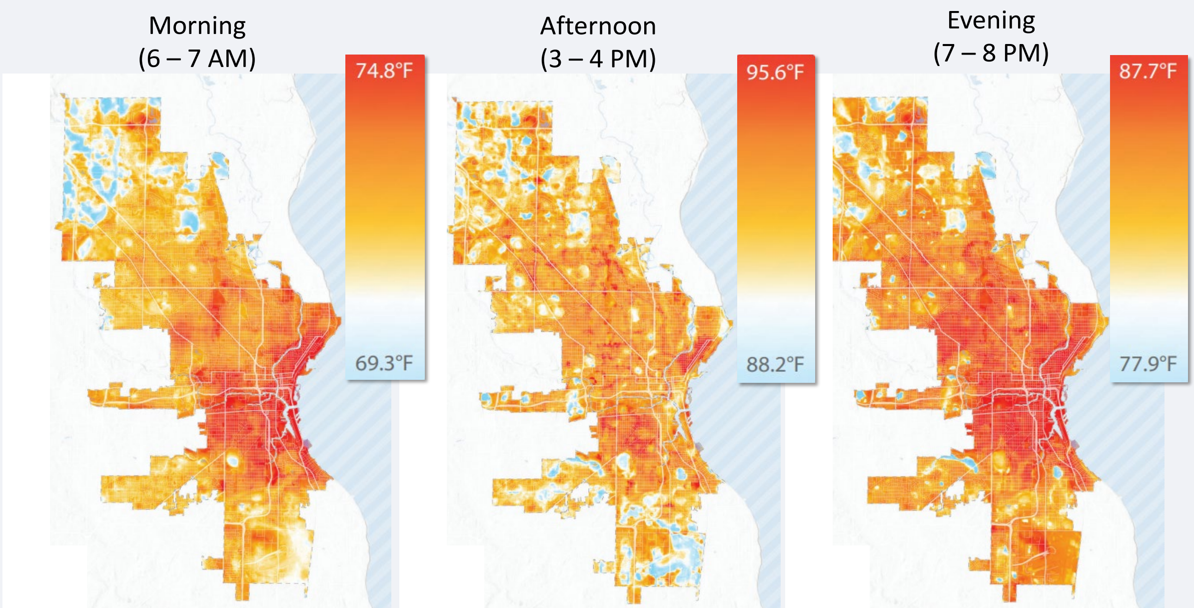

Figure 6. Predicted distribution of temperature distributions across Milwaukee due to summer UHI at three different times throughout a day. Note different temperature scales are used in each time period; afternoon temperatures are hottest, and morning temperatures are coolest. Source: Wisconsin Department of Natural Resources (DNR). 2022.

Mobility & Access: As temperatures continue to rise, extreme heat events are expected to become more frequent and intense, which will have significant impacts on vulnerable populations in terms of community transportation and mobility. Public transit systems, such as buses and trains, may experience heat-related delays or malfunctions, which could disproportionately affect those who rely on these systems as their primary mode of transportation. This could cause disruptions in service and inconvenience for commuters, especially for those who need to access essential services like medical appointments, grocery stores, and pharmacies. Additionally, walking or biking as an alternative to public transportation may become less feasible due to extreme heat, particularly for vulnerable populations such as the elderly, young children, and those with disabilities. This could result in decreased mobility and access to resources for these groups, which could lead to further social isolation and health disparities.

Increased Demand for Emergency Medical Services (EMS): As temperatures rise, the incidence of heat-related illnesses and conditions such as dehydration, heat exhaustion, and heatstroke are likely to increase, particularly among vulnerable populations such as the elderly and those with preexisting medical conditions.[21] This could lead to a surge in demand for emergency medical services, straining resources and potentially causing delays in response times.

Increase in Crime: Rising temperatures may increase the incidence of crime and violence in Milwaukee, as research suggests that higher temperatures are associated with higher rates of certain types of crime, including assault and domestic violence.[22]

Parks: The increased heat and extreme weather events caused by climate change can lead to damage and destruction of parks resources, making them less accessible and enjoyable for residents. For example, extreme heat and drought conditions can damage parkland and green spaces, leading to decreased access to outdoor spaces for vulnerable populations like children, the elderly, and those with disabilities. This can result in decreased physical activity and social isolation, which can have negative impacts on health and well-being.[23]

Cultural Resources: Rising temperatures can discourage people from visiting outdoor cultural events and festivals, leading to decreased attendance and potential economic impacts for local businesses. Vulnerable populations may also face barriers to accessing cultural resources due to transportation challenges, such as unreliable public transportation or lack of personal vehicles. This can result in decreased access to cultural events, recreational facilities, and parks, further exacerbating social inequities.[24]

[21] Sorensen, C. J., et al. (2020). Clinical Implications of Climate Change on US Emergency Medicine: Challenges and Opportunities. Annals of Emergency Medicine, 76(2), 168–178. https://doi.org/10.1016/j.annemergmed.2020.03.010

[22] Lynch, M. J., Stretesky, P. B., Long, M. A., & Barrett, K. L. (2022). The Climate Change-Temperature-Crime Hypothesis: Evidence from a Sample of 15 Large US Cities, 2002 to 2015. International Journal of Offender Therapy and Comparative Criminology, 66(4), 430–450. https://doi.org/10.1177/0306624X20969934

[23] Climate_health_equity.pdf. (n.d.). Retrieved May 3, 2023, from https://www.apha.org/-/media/files/pdf/topics/climate/climate_health_equity.ashx

[24] Sesana, E., Gagnon, A. S., Ciantelli, C., Cassar, J., & Hughes, J. J. (2021). Climate change impacts on cultural heritage: A literature review. WIREs Climate Change, 12(4), e710. https://doi.org/10.1002/wcc.710

Table 2. Social vulnerabilities associated with increasing average annual and seasonal temperatures.

Social Impacts	Increasing Average & Summer Temperatures
Health	• Higher concentrations of ozone and particulate matter (PM), which can be damaging to inhale • Negative impacts on those managing chronic illness • Lengthened duration of the pollen season, worsening respiratory health
Mobility & Access	• Roads may warp or buckle, rail tracks may expand/contract, restricting access to essential services
Parks, Recreation, Arts, Cultural Resources	• Increased pressure on parks and outdoor venues with shade structures as demand for cooling and shade intensifies • Changes in animal behavior, such as increased aggression, lethargy, or even heatstroke, can impact the safety of both animals and visitors at the zoo • Reduced attendance for parks and outdoor recreation facilities
Housing, Education, Food Security	• Old housing stock may expose residents to unhealthy conditions due to insufficient cooling • Increased energy costs for cooling buildings could put a strain on household budgets, particularly for low-income families
Public Safety	• Hotter temperatures associated with increased risk of crime, violent behaviors • Hotter temperatures associated with increase in vehicle crashes; warmer winters may offset
Local Economy	• Lost labor due to elevated temperatures making outdoor labor more strenuous • Reduced tourism in outdoor tourism sectors

Freeze-Thaw Cycles

The diurnal cycle of above-freezing days and freezing nights is called a freeze-thaw cycle (FTC) and the number of FTCs experienced in a region per year can have significant impacts on the costs of infrastructure maintenance. In Milwaukee County, the number of annual FTCs are projected to fall by 13% – 24% by 2050 and 21% - 45% by 2085. These steep reductions in freezing nights will likely ease maintenance costs for built infrastructure systems, especially transportation systems. In almost all infrastructure sectors, falling FTCs reduces costs. Therefore, impacts are not explored in depth. On the other hand, some concerns about falling FTCs may be impacts to local ecology, including species of trees and plants that require high numbers of annual FTCs for healthy growth. For example, Sugar Maple trees require FTCs to be productive, increasing sugar content and flow with greater FTCs.[25]

Table 3. Projected changes to average annual freeze-thaw cycles for select sites in Milwaukee County. Percent difference as compared to historical period (1985-2014).

Location	2020		2050		2085	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Bayside	-4.9%	-4.9%	-14.8%	-19.8%	-23.5%	-43.2%
Greenfield	-5.1%	-6.3%	-15.2%	-20.3%	-24.1%	-41.8%
SE Oak Creek	-4.0%	-5.3%	-14.7%	-20.0%	-24.0%	-42.7%
Milwaukee (Mitchell Park)	-5.1%	-7.7%	-17.9%	-24.4%	-26.9%	-44.9%
Milwaukee (Timmerman)	-4.8%	-4.8%	-13.1%	-17.9%	-21.4%	-40.5%

[25] Duchesne, L., & Houle, D. (2014). Interannual and spatial variability of maple syrup yield as related to climatic factors. *PeerJ*, *2*, e428. https://doi.org/10.7717/peerj.428

Extreme Temperatures and Heat Waves Projections

According to projections in **Figure 7**, heat wave temperatures in Milwaukee County are expected to increase significantly in the coming decades. Historically, the county has experienced average temperatures of 90-94°F during heat waves. In recent years, this range has increased slightly to 90-96°F. By midcentury, projected temperature increases could result in average heat wave temperatures of 92-98°F in a constrained emissions scenario (RCP4.5), or 94-100°F in a non-constrained emissions scenario (RCP8.5). By the end of the century, heat waves could become even more intense, with projected average temperatures of 94-100°F in a constrained emissions scenario, or 98-102°F in a non-constrained emissions scenario. Similar to annual average temperature projections, heat wave temperatures in Milwaukee County generally exhibit a slight temperature variation with elevated temperatures in the inland areas and relatively lower temperatures towards the lake shore. This temperature trend is expected to continue in the future, with the western border of the county experiencing warmer temperatures than the lake shore in all predicted periods and situations. These increases in heat wave temperatures will have significant impacts on human health, as well as on the local economy and infrastructure.

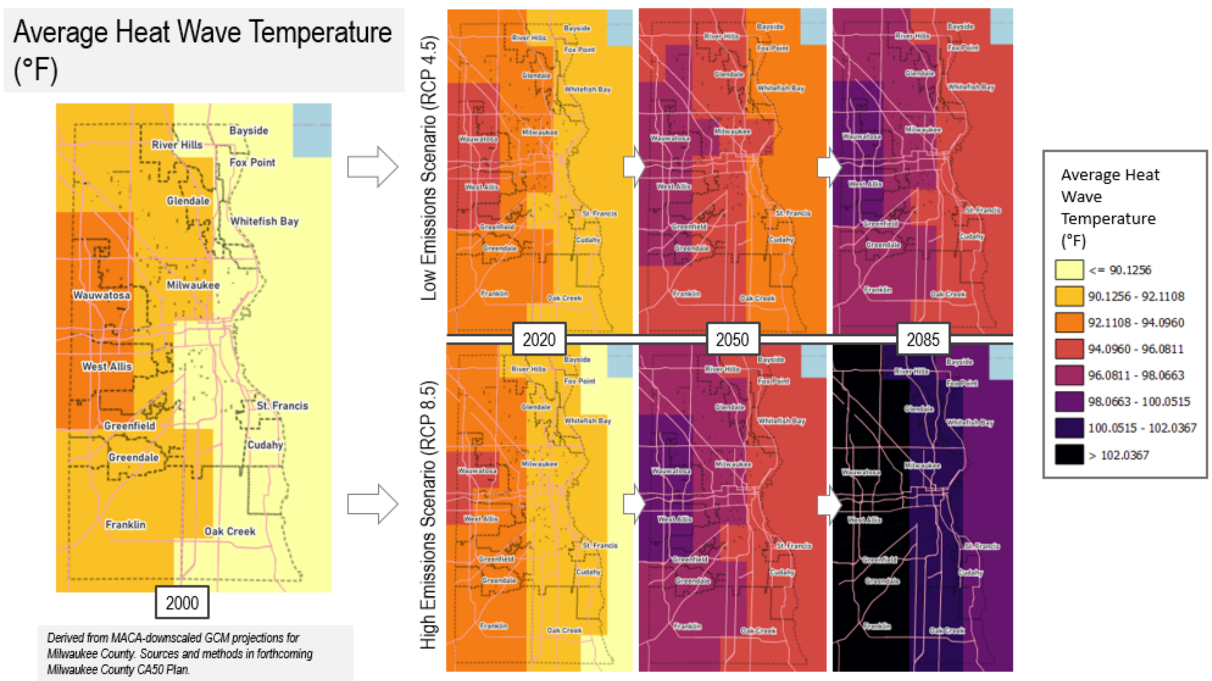

Figure 7. Historical and projected future average heat wave temperatures across Milwaukee County.

Infrastructure Vulnerabilities to Extreme Heat & Heat Waves

Extreme temperatures are primarily a hazard for human health, with the most important infrastructure vulnerabilities related to those that increase the risk of human health impacts due to system disruptions. While extreme temperatures impair the built environment, the greatest threats are associated with the combination of increased electricity demand for cooling combined with impairments to both the ability of generators to produce electricity and the power grid to reliably deliver it. A power outage during a severe heat wave could produce a 'perfect storm' of dangerous conditions, combining unhealthy heat exposure with vulnerable populations living in under-insulated buildings.

Heat Waves and Electricity Supply

Wisconsin's peak power demand occurs during the afternoon in summer months – this is like many other regions in the country where the greatest electrical loads occur during periods where demand for cooling energy is the greatest.[26] Climate change-driven increases in temperatures are expected to strain power grids across the country, and Milwaukee County's infrastructure is likely to face similar challenges. In addition to increased demand, hot temperatures can strain grid infrastructure: transmission lines stretch as they operate closer to their peak capacity, which increases the risk that a high-voltage line could contact a nearby tree or structure, shutting down the line; power transformers that are the backbone of substations must be shut down if they overheat, or risk rapid and expensive damage; and thermoelectric power plants can face physical or environmental restrictions on access to cooling water as water surface temperatures increase. When these effects are combined, a heat wave that pushes the grid to its breaking point could result in a rapid breakdown in power service, exposing large populations to severe heat stress without access to air conditioning.

Building Stock and Green Infrastructure Affect Exposure to Heat

During a heat wave, most people adapt using home air conditioning. However, due to Milwaukee's historically mild summer season, the region has many buildings built before the widespread adoption of air conditioning. This is especially true among the county's most vulnerable residents, including residents of older buildings, as well as lower-income and socially isolated communities. Additionally, the type and age of a residential building can affect the severity of heat exposure impacts, with older, poorly insulated buildings exposing their residents to much greater temperature rises than new buildings with greater insulation and tighter building envelopes. Milwaukee County has an above-average share of older buildings, with the median structure built in 1956, compared to 1974 for Wisconsin, and 1979 for the United States.[27]

Another facet of infrastructure systems that can affect the vulnerability of communities to extreme heat is green infrastructure – including parks, urban trees, and green spaces – that can mitigate heat waves through shading and convective cooling.[28]

Additional infrastructure vulnerabilities to extreme heat are associated with accelerated damage to physical infrastructure (e.g., softening asphalt binders, increased wear in moving parts, accelerated degradation of transformer insulation, batteries, etc.) and high-water temperatures/water shortfalls. **Table 4** identifies the infrastructure system vulnerabilities associated with extreme temperatures and heat waves.

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[26] Wisconsin Public Service Commission (PSC). (2021). *Wisconsin Peak Period Analysis*. http://archive.focusonenergy.com/sites/default/files/inline-files/Potential_Study-Research-Peak_Period.pdf.

[27] *DP04: SELECTED HOUSING CHARACTERISTICS - Census Bureau Table*. (n.d.). Retrieved May 24, 2023, from https://data.census.gov/table?g=040XX00US55_050XX00US55079&tid=ACSDP5Y2021.DP04

[28] NCA4 Ch. 2

Table 4. Infrastructure impacts associated with extreme temperatures and heat waves.

		Extreme Temperatures & Heat Waves
Transportation[29]	Pedestrian & Human-powered transportation	• Accelerated road/trail surface damage
	Streetscape, Parks, & Trails	• Tree death & vegetation loss, intensifying UHI and shade loss • Increased management costs for green infrastructure
	Transit	• Increased wear on heat-sensitive components • Risk of heat-related breakdowns
	Rails	• Increased metal fatigue and accelerated wear and tear
	Airports	• Softened asphalt surfaces, damaging planes and creating safety hazards
Energy[30][31]	Electricity	• Acute risk of power disruptions due to parallel increases in demand and threats to supply • Increased peak energy demand, especially relating to energy for cooling and water supply • Threats to power electronics and transformers which can be damaged or fail due to extreme heat; costly damage with long repair times • Increased risk of transmission line overheating and curtailment • Increased risk of electricity generator curtailments due to temperature restrictions
Water[32]	Water supply systems	• Increased risk of water availability and draught
	Wastewater treatment & sewers	• Higher temperatures can cause water systems to be overwhelmed, leading to backups and overflows that can contaminate local water sources
Communications[33]	Internet, Phone, wired services	• Extreme temperatures can cause damage to fiber optic cables • Increased outages disrupt wired services relying on electricity
	Cellular & wireless	• High temperatures can cause batteries to fail or degrade faster, leading to reduced battery life for mobile devices • Extreme temperatures can cause service disruptions or reduced network performance due to equipment failures or power outages

[29] Boosting Pavement Resilience | FHWA. (n.d.). Retrieved May 3, 2023, from https://highways.dot.gov/public-roads/autumn-2018/boosting-pavement-resilience

[30] Extreme Heat | CISA. (n.d.). Retrieved May 3, 2023, from https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/extreme-weather-and-climate-change/extreme-heat

[31] Singh, D., & Rogers, C. (2022). Assessing the risk of temperature extremes across North America's energy grid regions and associated renewable energy potential. 2022, NH53A-06. https://ui.adsabs.harvard.edu/abs/2022AGUFMNH53A..06S

[32] Extreme Heat | CISA. (n.d.). Retrieved May 3, 2023, from https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/extreme-weather-and-climate-change/extreme-heat

[33] Extreme Heat | CISA. (n.d.). Retrieved May 3, 2023, from https://www.cisa.gov/topics/critical-infrastructure-security-and-resilience/extreme-weather-and-climate-change/extreme-heat

Social Vulnerabilities to Extreme Temperatures and Heat Waves

As a part of Climate Action 2050 Plan, Milwaukee County asked residents about their perspectives on climate vulnerabilities, including extreme temperatures. Community survey respondents display a significant lack of confidence in Milwaukee County's ability to protect its vulnerable populations in the face of extreme weather. As climate change continues to affect Milwaukee County, it is important to understand the ways in which extreme heat events can impact various aspects of daily life, especially for the vulnerable. For example, many community survey respondents shared experiences of their children's schools closing due to insufficient heating and cooling systems. Through community workshop discussion, it became evident that insufficient air conditioning systems across the County have impacted residents, largely in schools and in their homes. From education to public health to parks and recreation, heat waves and extreme temperatures can lead to a range of challenges and potential risks for local communities.

Deadly Milwaukee Heatwave

In the summer of 1995, Milwaukee experienced a severe heat wave that had significant impacts on the community. An estimated 91 deaths were attributed to the heat-wave, with many more residents experiencing heat-related health issues. Similar to other cities, the elderly and low-income individuals residing in neighborhoods with limited access to air conditioning and transportation were particularly vulnerable. The heat wave strained emergency response systems, and healthcare facilities faced challenges in managing the increased number of patients suffering from heat-related illnesses. The event underscored the importance of enhancing emergency preparedness, response capabilities, and implementing measures to mitigate heat-related risks for vulnerable populations in Milwaukee County.

Extreme heat is a significant threat to human health, with both direct and indirect impacts on physical and mental well-being. Extreme heat hazards can cause acute increases in mortality and morbidity, and are particularly dangerous for sensitive populations, including those concentrated in vulnerable communities. Nationally, heat health is becoming a major focus of climate preparedness, and the threat of extreme heat events are not unique to Milwaukee County. Based on historical heat exposure deaths and projected changes to temperatures, an EPA analysis of 49 major urban areas in the United States found that by 2050, extreme heat events could lead to an additional 2,300 – 3,400 deaths per year, depending on emissions scenario. By 2090, the projections are even higher, with 9,300 additional deaths/year in a high emissions scenario.[34] Heat waves can become especially deadly when the right combination of extreme heat and humidity, cumulative exposure, deficient infrastructure, and vulnerable populations converge. The elderly and those with preexisting medical conditions are naturally more vulnerable to heat waves and extreme temperatures, however communities who have experienced historic structural and social underinvestment may face their own unique sets of challenges during extreme weather due to systemic inequities relating to the built environment, health and healthcare, and economic resource accessibility.

Mass-casualty heat waves are not just a projection for the distant future. While heat deaths occur in some limited numbers every year, many examples exist of heat waves that have led to thousands of deaths in the space of just a few days or weeks. Prominent examples of such deadly heat waves include the 1987 Athens heat wave that killed more

[34] US EPA, O. (2021, March 24). *Multi-Model Framework for Quantitative Sectoral Impacts Analysis:* [Reports and Assessments]. https://www.epa.gov/cira/multi-model-framework-quantitative-sectoral-impacts-analysis

than 1,000 residents,[35] the 1995 Chicago heat wave that killed more than 700 (see sidebar),[36] and the 2003 European heat wave that led to at least 30,000 premature deaths, including more than 14,000 in France, especially in Paris.[37]

Heatwave-induced Illness: Prolonged exposure to high temperatures can lead to a range of heat-related illnesses, such as heat exhaustion, heat stroke, dehydration, heat rash and cramps, and heat syncope. These illnesses can range in severity, with heat stroke being the most serious and potentially life-threatening. Vulnerable populations, such as those with little access to cooling systems, are at increased risk of experiencing heat-related illnesses.

Exacerbated Existing Health Conditions: Those with respiratory or cardiovascular diseases may experience worsened symptoms in hot and humid conditions. The air quality can also decrease during heat waves, as stagnant air can trap pollutants close to the ground. Additionally, those who rely on medical devices that require electricity, such as ventilators or oxygen concentrators, may be at risk if power outages occur during heat waves.

Mental Health: Heatwaves can have significant effects on behavioral and mental health. With high temperatures lasting for days or even weeks, people may become more irritable, anxious, or depressed. Disrupted sleep patterns can also occur, which can further exacerbate mental health issues. Communities with limited access to mental health resources may feel disproportionate effects of heat waves on their wellbeing. Additionally, high temperatures can limit people's ability to engage in outdoor activities and socialize, which can also impact mental well-being.

Parks: Higher temperatures and increased humidity levels can make outdoor activities uncomfortable and even dangerous for people, leading to a decrease in park usage during heat waves. The quality of green spaces and natural habitats may also be negatively affected by extreme heat, causing damage to vegetation and wildlife, and impacting the cultural and ecological value of Milwaukee County parks.

Emergency Services: Extreme heat events, which are expected to become more frequent and intense as temperatures rise, can have significant impacts on emergency services. For example, heat waves can cause an increase in emergency medical calls related to heat exhaustion and heat stroke. These calls can place a strain on emergency medical services, especially if there are multiple heat waves occurring in a short period of time. Additionally, first responders may also experience heat-related illnesses and fatigue, which can impact their ability to provide effective care. Vulnerable populations, such as the elderly and those with preexisting medical conditions, are particularly at risk during extreme heat events, and may require additional support from emergency services.

Additional social impacts associated with extreme temperatures and heat waves are identified in **Table 5.**

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[35] Matzarakis, A., & Mayer, H. (1991). The extreme heat wave in Athens in July 1987 from the point of view of human biometeorology. *Atmospheric Environment. Part B. Urban Atmosphere*, *25*(2), 203–211. https://doi.org/10.1016/0957-1272(91)90055-J
[36] Klinenberg, E. (2015). Heat Wave: A Social Autopsy of Disaster in Chicago (W. a N. Preface, Ed.). University of Chicago Press. https://press.uchicago.edu/ucp/books/book/chicago/H/bo20809880.html.
[37] *European heat wave of 2003 | Britannica*. (n.d.). Retrieved May 23, 2023, from https://www.britannica.com/event/European-heat-wave-of-2003

Table 5. Social impacts associated with extreme temperatures and heat waves.

Social Impacts	Extreme Temperatures & Heat Waves
Health	• Hotter than average days can cause illness and death by compromising the body's ability to regulate temperature, inducing health complications • Prolonged exposure to extreme temperatures is associated with increased hospital admissions for cardiovascular, kidney, and respiratory disorders • Extreme heat increases the risk for those with mental health conditions
Mobility & Access	• During heat waves, people may avoid going outside or using public transportation due to the risk of heat-related illness • Extreme temperatures can disproportionately affect vulnerable populations with limited access to air conditioning, essential services, and poor transit infrastructure
Parks, Recreation, Arts, Cultural Resources	• Heat waves can make outdoor spaces uncomfortable or dangerous, reducing visitors to parks, zoos, and cultural events • Heat-induced harm to natural resources impacts the aesthetic and cultural value of parks, historic landscapes, and recreational areas
Housing, Education, Food Security	• Exacerbated indoor air quality issues, impacting residents' health • Disrupted classroom learning, reduced academic performance of students • Increased food spoilage and waste, particularly in regions already experiencing food insecurity
Public Safety	• Heat waves can overwhelm emergency services and disrupt critical infrastructure, exacerbating the impacts of extreme events on public safety • During heat waves, emergency responders face added physical stress and equipment operation challenges, compromising critical services like evacuations, rescues, and medical emergencies

Precipitation Impacts

Average and Seasonal Precipitation

Milwaukee County is expected to experience seasonal shifts in precipitation patterns, including dryer summers and wetter winters. Projected changes to average annual precipitation are small and positive, with seasonal changes mostly canceling out. Summer is historically the region's wet season, with the average summer month seeing about double the average winter month, although the difference is expected to shrink with a warming climate. Distribution of annual precipitation totals generally exhibits a north-south split, with the northern half of the county dryer than the southern half. This north-south pattern is mirrored in winter precipitation, however in the summer season proximity to the lake dominates, with more precipitation inland and less along the lakeshore. Projected changes to annual and seasonal precipitation do not significantly affect these patterns. **Tables 6, 7, and 8** show the current and projected changes to seasonal and annual precipitation across Milwaukee County through 2085.

Milwaukee County Projections

Average annual precipitation is projected to increase by single-digit percentages over the coming century. Mid-century projections are higher for the constrained emissions scenario than in the unconstrained emissions scenario, but by the end of the century, this pattern is reversed. **Table 6** shows expected changes in five locations across the county.

Table 6. Projected changes to average annual precipitation for select sites in Milwaukee County. Percent difference as compared to historical period (1985-2014).

Location	2020		2050		2085	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Bayside	0.9%	2.7%	7.1%	3.1%	4.9%	5.8%
Greenfield	0.4%	2.5%	6.6%	2.5%	4.6%	5.8%
SE Oak Creek	0.4%	2.9%	6.7%	2.9%	5.0%	6.7%
Milwaukee (Mitchell Park)	0.4%	2.5%	6.7%	2.5%	4.6%	5.9%
Milwaukee (Timmerman)	0.4%	2.2%	6.5%	2.2%	3.9%	4.8%

While small, changes to average annual precipitation mask much larger projected changes in seasonal precipitation. In the future, Milwaukee will see a greater share of its annual precipitation during the winter season, and a smaller share during the summer season. **Tables 7 and 8** show these projected changes.

Table 7. Projected changes to summer season precipitation (June, July, and August) for select sites in Milwaukee County. Percent difference as compared to historical period (1985-2014).

Location	2020		2050		2085	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Bayside	-5.8%	1.0%	-3.8%	-13.0%	-8.9%	-18.1%
Greenfield	-5.5%	1.0%	-4.5%	-12.9%	-8.4%	-17.7%
SE Oak Creek	-5.7%	1.4%	-4.4%	-13.5%	-8.1%	-17.2%
Milwaukee (Mitchell Park)	-5.9%	1.0%	-5.0%	-13.2%	-8.6%	-18.2%
Milwaukee (Timmerman)	-5.5%	1.0%	-3.9%	-12.4%	-8.8%	-17.9%

Table 8. Projected changes to winter season precipitation (December, January, February) for select sites in Milwaukee County. Percent difference as compared to historical period (1985-2014).

Location	2020		2050		2085	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Bayside	5.0%	5.7%	13.6%	10.7%	13.6%	22.1%
Greenfield	4.6%	5.3%	12.5%	9.9%	13.2%	21.7%
SE Oak Creek	4.4%	5.1%	12.7%	10.1%	13.3%	21.5%
Milwaukee (Mitchell Park)	4.5%	5.2%	13.0%	9.7%	13.0%	21.4%
Milwaukee (Timmerman)	4.3%	5.8%	12.9%	10.1%	12.9%	20.9%

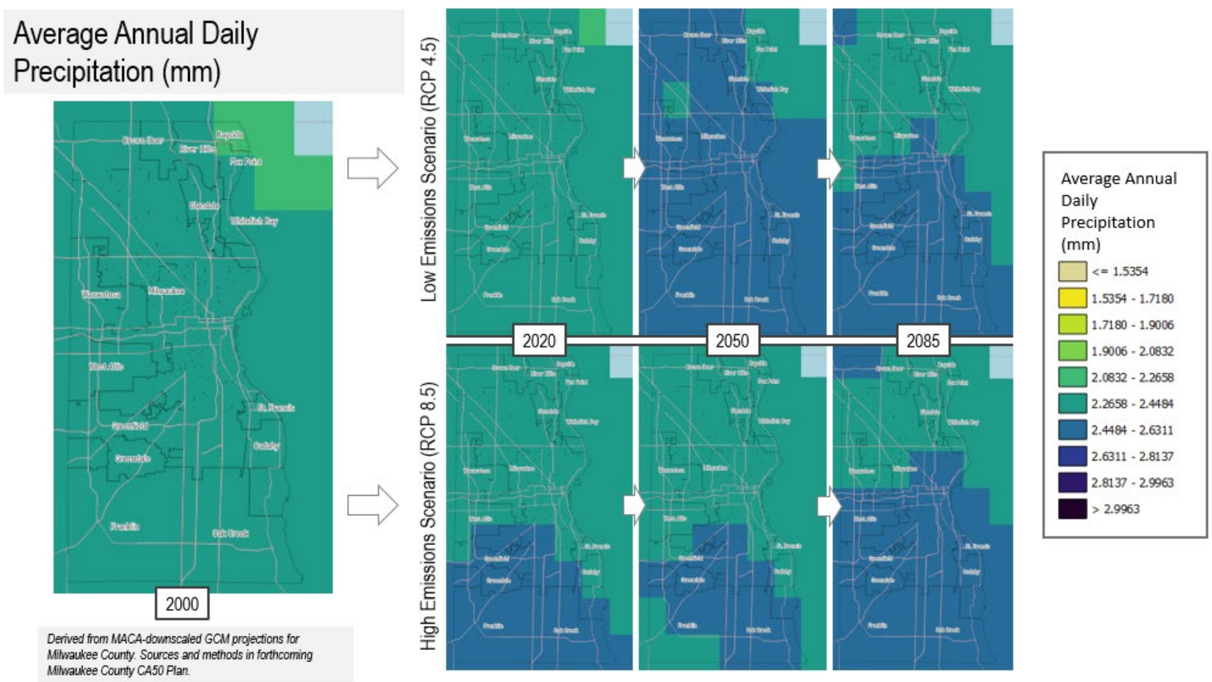

Figure 8. Historical and projected future average annual daily precipitation across Milwaukee County,

Infrastructure Vulnerabilities to Changes in Average Precipitation

Changes to annual and seasonal precipitation can have large but slow-moving implications for infrastructure systems and environments designed or adapted to historical conditions. Dryer summers may increase the risks of drought, including associated harms to important urban ecosystems that Milwaukee County residents have access to such as the urban forest. And wetter winters will invariably be associated with larger volumes of snow, including associated management costs – shoveling, deicing, etc. While adaptation efforts typically focus on mitigating the effects of severe weather events like large storms and natural disasters like floods, slow drifts in climate averages are also relevant to long-term climate planning. Infrastructure and community impacts associated with dryer summers and wetter winters are identified in **Table 9.**

Table 9. Infrastructure and community vulnerabilities associated with dryer summers and wetter winters.

		Dryer Summers	Wetter Winters
Transportation	Pedestrian & Human-powered transportation	• Greater discomfort walking and biking, decreasing human-powered transportation • Soil becomes more compact, impeding walking/cycling abilities	• Accelerated road & trail surface degradation from potholes
	Transit	• Increased dust and debris on roads and tracks, causing transit delays	• Wear and tear on rolling stock from potholes
	Roads & Bridges	• Intensified heat-related issues like pavement cracking & expansion	• Accelerated asphalt & concrete wear and tear
	Rails	• Soil subsidence may cause tracks to shift or buckle	• Accelerated concrete failure
	Airports	• Droughts may impact water availability for airport operations (firefighting, runway cleaning)	• Accelerated asphalt & concrete wear and tear
Energy	Electricity	• Increased risk of ground movement from drier soil, potentially damaging power lines	• Buildup on power lines can lead to outages
Water	Water supply systems	• Reduced availability of intake water • Pathogen growth • Extended mosquito season • Algal blooms/water quality	• Increased risk of erosion and landslides, damaging water supply infrastructure • Increased runoff degrades water quality, impacting reliability of water systems
	Wastewater treatment & sewers	• Subsidence and pipe settlement caused by drier soil damages stability of sewer lines • Reduced dilution capacity of wastewater treatment plants	• Higher stormwater flows for combined sewer systems • Heavy rain and snowmelt can cause sewer backups and overflows • Increased risk of sinkholes, damaging sewer infrastructure
Communications	Internet, Phone, wired services	• Ground movement from drier soil may damage underground fiber optic cables and other infrastructure	• Heavy rain can cause damage to underground and aboveground infrastructure (cell towers, utility poles)
	Cellular & wireless	• Increased strain on power grids heightens the risk of outages disrupting wireless services	• Ice buildup and heavy snowfall on equipment can cause service outages

Social Vulnerabilities to Changes in Average Precipitation

Changes in annual and seasonal precipitation can also have significant impacts on social vulnerabilities. Dryer summers can increase the risk of drought, which can have severe consequences for vulnerable communities who struggle with mobility and resource accessibility.[38] In addition, dryer summers can also have detrimental impacts on urban ecosystems, including the loss of green spaces and urban forests that provide important benefits to local communities. This can have adverse effects on the physical and mental health of residents, particularly those living in areas with limited access to green spaces.

[38] Filosa, G., Plovnick, A., Stahl, L., Miller, R., Pickrell, D. H., & John A. Volpe National Transportation Systems Center (U.S.). (2017). Vulnerability Assessment and Adaptation Framework, Third Edition (DOT-VNTSC-FHWA-18-04). https://rosap.ntl.bts.gov/view/dot/36188

On the other hand, wetter winters can result in larger volumes of snow, which can increase the cost and burden of snow removal and management for communities. This can have disproportionate impacts on low-income communities, who may have limited resources to deal with the increased costs. It is important to recognize that slow changes in climate patterns and averages can also have long-term impacts on vulnerable communities. Efforts to adapt to these changes should consider social vulnerabilities and their impacts on communities, in addition to infrastructure and environmental concerns. In addition to **Table 10**, some community impacts associated with dryer summers and wetter winters include:

Health: In terms of health, dryer summers may increase cases of dehydration, heat exhaustion, and heat stroke, while wetter winters may lead to an increase in respiratory illnesses due to poor air quality from insufficient heating and ventilation systems.[39] Additionally, dryer summers may lead to an increased risk of waterborne illnesses due to lower water levels in lakes and rivers, while wetter winters may pose a risk of hypothermia, frostbite, and other cold-related injuries/illness.[40]

Mobility & Access: Transportation and essential services access may also be impacted by wetter winters and dryer summers. For example, dryer summers may result in increased traffic congestion and longer travel times due to road closures or diversions, as well as reduced transit reliability on hot days. Wetter winters may make roads icy and slippery, leading to increases in traffic accidents and commute times. Additionally, power plants may struggle to cool equipment during hot summers, resulting in outages that place strain on emergency services, while heavy snowfall during wetter winters can make it difficult for emergency vehicles to reach people in need, delaying critical care.

Parks & Recreation: Wetter winters and dryer summers may also impact parks, recreation, cultural resources, housing, and education. Drought conditions resulting from dryer summers may impact park wildlife, affecting recreation opportunities and biodiversity, as well as cultural practices relying on water sources, such as fishing and spiritual activity. Wetter winters may lead to increased erosion and sedimentation in natural areas, damaging habitats and reducing the aesthetic and ecological value of parks and green spaces.

[39] US EPA, O. (2016, July 1). Climate Change Indicators: Heat-Related Deaths [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-heat-related-deaths

[40] [40] Hypothermia | Winter Weather. (n.d.). Retrieved May 3, 2023, from https://www.cdc.gov/disasters/winter/staysafe/hypothermia.html

Table 10. Social impacts associated with dryer summers and wetter winters.

Social Impacts	Dryer Summers[41]	Wetter Winters[42]
Health	• Increase in cases of dehydration, heat exhaustion, and heat stroke • Increased risk of waterborne illnesses due to lower water levels in lakes and rivers	• Increased respiratory illnesses due to poor air quality from insufficient heating and ventilation systems • Risk of hypothermia, frostbite, and other cold-related injuries/illness
Mobility & Access	• Increased traffic congestion and longer travel times due to road closures or diversions • Reduced transit reliability on hot days	• Roads may become icy and slippery, leading to increases in traffic accidents and commute times
Parks, Recreation, Arts, Cultural Resources	• Decreased availability of water for recreation • Lower water levels in lakes and rivers can impact cultural practices relying on water sources (fishing, spiritual activity, etc.) • Drought conditions impact park wildlife, affecting recreation opportunities and biodiversity	• Increased erosion and sedimentation in natural areas, damaging habitats and reducing aesthetic and ecological value of parks and green spaces • Winter storms can damage park facilities such as trails, campgrounds, and visitor centers, reducing access to recreational activities
Housing, Education, Food Security	• Increased demand for water can lead to higher water bills, straining household finances • Reduced precipitation exacerbates existing housing challenges for vulnerable populations	• Intensified winter conditions can cause disruptions to the food supply chain, impacting food security & nutrition
Public Safety	• Power plants may struggle to cool equipment, resulting in outages that place strain on emergency services	• Heavy snowfall can make it difficult for emergency vehicles to reach people in need, delaying critical care

[41] USGCRP. (n.d.). Climate Science Special Report (pp. 1–470). U.S. Global Change Research Program, Washington, DC. Retrieved May 3, 2023, from https://science2017.globalchange.gov/

[42] Flood Waters or Standing Waters | Water, Sanitation, & Hygiene-related Emergencies & and Outbreaks | Healthy Water | CDC. (2022, November 30). https://www.cdc.gov/healthywater/emergency/extreme-weather/floods-standingwater.html

Extreme Precipitation Projections

Extreme precipitation events are periods of intense rainfall that can threaten a large variety of infrastructure systems and social sectors. Such events are made dangerous when they lead to excessive runoff, or when they exceed the carrying capacity of soils, natural waterways, and built infrastructure for handling water (also called hydraulic infrastructure).

Table 11. Projected changes to the intensity of a single-day extreme precipitation event, compared to historical period.

Location	2020		2050		2085	
	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Bayside	-5.3%	1.0%	4.2%	1.6%	5.5%	9.5%
Greenfield	-5.5%	0.6%	5.1%	2.5%	6.4%	10.6%
SE Oak Creek	-6.2%	-0.8%	7.0%	3.7%	13.1%	16.3%
Milwaukee (Mitchell Park)	-3.2%	-2.0%	5.7%	1.5%	7.2%	11.6%
Milwaukee (Timmerman)	-3.1%	-0.7%	5.4%	2.1%	5.9%	9.2%

Infrastructure Vulnerabilities to Extreme Precipitation

Extreme precipitation events produce rainfall rates that exceed the carrying capacity of built hydraulic infrastructure and natural drainages. Resultant localized flooding and erosion is difficult to model but can create widespread damage and disruptions to the built environment, often with extended, costly recovery periods. A wide variety of infrastructure systems are vulnerable to extreme precipitation impacts, and these are summarized in **Table 12**.

Extreme precipitation events are often linked to flooding, but not all extreme precipitation events, may cause riparian flooding (i.e., flooding of a stream or river channel). However, in most cases, extreme precipitation can cause localized flooding that is extremely difficult to model independent of on-the-ground data collection from public works agencies. Localized flooding (also called nuisance flooding or ponding) can take the form of flooding of a local road, intersection, park, or even as little as a sidewalk or curb cut.

A significant, but often underappreciated threat to vulnerable populations from localized flooding is disruptions to transportation and mobility, especially for transit users and populations with limited mobility. Ponding on a single sidewalk or ADA curb cut can force people with limited mobility to take extensive diversions which may add delays or stress that's difficult to appreciate at a systemic level. Similarly, transit users are often affected by route diversions, delays, or suspensions that can disrupt mobility for sensitive populations living without access to vehicles or under the federal poverty line. While localized flooding does not necessarily correlate with riparian flooding, the most transit-dependent neighborhoods – those with the highest concentration of residents living without access to vehicles – are also concentrated around one of the key clusters of low-lying flood risks around the Menomonee River. For more information on the impacts of flooding across Milwaukee County, see section: Riparian & Nuisance Flooding.

Table 12. Infrastructure impacts associated with extreme precipitation,

Extreme Precipitation		
Transportation	Pedestrian & Human-powered transportation	• Heavy rainfall can erode soil and cause sinkholes, leading to the collapse of pedestrian infrastructure • Localized flooding of sidewalks and bike lanes may create unsafe travel conditions/encourage pedestrians to walk in roadways • Ponding can obstruct poorly drained curb cuts, creating mobility barriers for people who use wheelchairs and other mobility challenges
	Transit	• Localized flooding and erosion can cause damage to track beds • Extreme precipitation and localized flooding can cause water infiltration in unprotected equipment boxes including power electronics, signaling equipment, and electromechanical systems • Reduced visibility for drivers, increasing risk of collisions involving transit vehicles • Delays and service disruptions for buses and trains
	Roads & Bridges	• Accelerated deterioration of road and bridge surfaces, increasing maintenance costs and reducing their lifespan • Increased risk of scour of bridge abutments and piers, culverts, and other road hydraulic infrastructure • Increased stopping distances on slick roads and impaired visibility heighten risk of collisions
	Rails	• Reduced visibility for train operators increases risk of rail incidents and collisions • Localized flooding can force rail operators to cancel service, disrupting supply chains and interrupting travel • Localized erosion can damage or wash-out track beds, causing disruptions to service
	Airports	• Damage to essential equipment and infrastructure (navigation systems, runways and taxis, baggage handling equipment) can lead to flight delays, cancellations, and costly repairs • Thunderstorms can cause flight delays and cancellations due to risk of lightning strikes damaging planes and airport equipment
Energy	Electricity	• Damage to transformers, substations, and other crucial components of energy grid due to heavy rainfall, water infiltration, and flooding • Increasing frequency of extreme precipitation events can increase costs for maintaining and upgrading electricity infrastructure • Damage to power lines may cause widespread outages and service disruptions
Water	Water supply systems	• Debris, sediment, and pollutants may wash into water sources, leading to water quality concerns and increased treatment costs • Increased precipitation may lead to overabundance of water in supply systems, overwhelming treatment facilities • Increased precipitation can lead to greater debris and sediment buildup in reservoirs, diminishing their storage capacity
	Wastewater treatment & sewers	• Changes in wastewater flows and treatments due to extreme precipitation can impact cost and reliability of wastewater treatment systems • Aging wastewater infrastructure may be more susceptible to damage from extreme precipitation events, impeding wastewater management

		• Increased runoff can overwhelm sewage systems, increasing public health risk and damaging homes and businesses, especially in areas with combined stormwater/wastewater sewer systems • Increase of untreated runoff into Lake Michigan
Communications	Internet, Phone, wired services	• Damage to underground conduit systems (like fiber optic cables) can cause service disruptions or outages • High winds associated with extreme precipitation may cause trees and branches to fall, damaging aboveground infrastructure (telephone poles, transmission towers, etc.), causing outages
	Cellular & wireless	• Flooded roads and power outages can prevent technicians from accessing and repairing cellular infrastructure, leading to prolonged outages • Strong winds may cause towers to sway, leading to structural damage and service outages

Social Vulnerabilities to Extreme Precipitation

Extreme precipitation events have been found to have disproportionate impacts on vulnerable communities, with low-income communities and communities of color bearing the brunt of these consequences. These communities often face greater challenges in terms of infrastructure, resources, and social support systems due to long histories of inequity, which can amplify the impacts of extreme precipitation. The increased frequency and intensity of heavy rainfall events can lead to a range of adverse effects, including flash floods, property damage, and disruptions in essential services such as transportation, water, and electricity. Furthermore, inadequate urban infrastructure and limited access to resources can hinder the ability of these communities to effectively prepare for and recover from extreme precipitation events. Consequently, addressing the social vulnerabilities associated with extreme precipitation is crucial for building resilience and ensuring equitable outcomes in the face of climate change.

When Milwaukee County residents were asked about their personal experiences with extreme precipitation and severe weather in a survey, respondents most frequently mentioned transportation disruptions and property damage. Respondents reported road closures, ruined vehicles, sewerage overflows, and repeatedly flooded basements during heavy rainfall events. They also shared experiences with downed trees, burst pipes from extreme cold, and power outages, which often resulted in increased costs for respondents, such as for replacing damaged infrastructure or food lost during a power outage. Community workshop discussion corroborated these experiences, with residents confirming flooding in residential areas to be of high concern in regards to its impact on their daily lives.

Figure 9. The City of Milwaukee maintains a large combined sewer system (purple), which can lead to sewerage mixing with stormwater runoff during extreme precipitation events. Source: Reflo 2023.

Health: One of the primary health concerns associated with extreme precipitation is the increased risk of waterborne pathogens and diseases due to contaminated water sources and inadequate sanitation systems. During extreme precipitation events, stormwater runoff can overwhelm the capacity of wastewater systems, resulting in overflows. In parts of Milwaukee, the use of a combined sewer system means that such overflows can result in raw sewerage mixing with stormwater runoff and flowing into surface water bodies. These outflows carry significant risk of pathogens and are serious public health hazards. Additionally, ponding resulting from extreme precipitation can contribute to the spread of infectious diseases, as standing water provides a breeding ground for mosquitoes and other vectors.[43] The heightened moisture levels can also facilitate the growth of mold and fungi, which can trigger respiratory issues and allergies. Moreover, the mental health of communities may be affected, as prolonged periods of inclement weather and associated disruptions, such as damage to infrastructure and displacement, can lead to stress, anxiety, and emotional distress. To safeguard community health, it is crucial to implement strategies that enhance resilience to extreme precipitation events, including effective urban planning, improved green water infrastructure to reduce sewerage overflows into surface water, and public health measures to mitigate and manage the health risks associated with these events.

Housing: Low-income housing is often disproportionately located in flood-prone areas, which can have detrimental effects on the health of residents. Floods can lead to water damage and moisture accumulation, creating an ideal environment for mold growth. Exposure to mold can trigger respiratory problems, such as asthma and allergies, and exacerbate existing respiratory conditions. The presence of mold in homes can have long-term health consequences and contribute to chronic health issues among vulnerable populations. These housing conditions further emphasize the urgent need for equitable access to safe, healthy, and affordable housing for all individuals and communities, ensuring that everyone can live in environments that promote well-being and protect against environmental hazards.

Mobility & Access: Mobility and access also present equity and justice concerns during extreme precipitation events. Low-income communities and communities of color are often located in areas with limited access to public transportation, making it even more difficult to access essential services during and after extreme precipitation events. In addition, these communities may lack the resources and infrastructure necessary to prepare for and respond to flooding events, making them more vulnerable to the impacts of extreme precipitation. This highlights the need for equitable and just investment in public transportation infrastructure, emergency management, and disaster preparedness planning in vulnerable communities.

Cultural Resources: Extreme precipitation can have significant impacts on the cultural and community resources that are essential to the social fabric of low-income communities and communities of color. Damage to community centers, parks, and cultural institutions can exacerbate existing social and economic inequalities, particularly if these resources are not equitably distributed across neighborhoods. In addition, flooding can damage historic buildings and monuments, further erasing the cultural heritage of marginalized communities.

[43] Flood Waters or Standing Waters | Water, Sanitation, & Hygiene-related Emergencies & and Outbreaks | Healthy Water | CDC. (2022, November 30). https://www.cdc.gov/healthywater/emergency/extreme-weather/floods-standingwater.html

Table 13. Social impacts associated with extreme precipitation.

Social Impacts	Extreme Precipitation [44]
Health[45]	• Overwhelmed stormwater infrastructure can lead to localized flooding and mixing of wastewater with stormwater in communities with combined sewer systems • Extreme precipitation can lead to an increase in waterborne diseases, such as cholera and salmonella, due to the contamination of water sources • Increased precipitation can also lead to an increase in mold growth, which can trigger respiratory problems such as asthma and allergies[46]
Mobility & Access	• Flooding disrupts public transportation systems, preventing people from accessing essential services[47] • Heavy rainfall can cause stormwater runoff to overwhelm drainage systems and flood low-lying areas, possibly forcing home evacuations and restricting access to essential services
Parks, Recreation, Arts, Cultural Resources	• Extreme precipitation events can damage park infrastructure, including trails and buildings, making it difficult or unsafe for people to access those resources • Heavy rainfall can cause flooding in zoos, risking animal and habitat safety • Cultural institutions may have to cancel events, negatively impacting both institutions and local community • Heavy rainfall can destroy historic buildings and monuments which hold cultural value
Housing, Education, Food Security	• Damage to schools and educational institutions impacts community wellbeing and security • Infrastructure damage from heavy rainfall can limit access to grocery stores and other essential services, exacerbating food insecurity in affected areas
Public Safety	• Extreme precipitation events may cause emergency services to be stretched thin, making it more difficult for residents to receive emergency care and assistance • Power outages caused by extreme precipitation can disrupt emergency communication systems, impacting community access to critical emergency services

[44] US EPA, O. (2016, June 27). Climate Change Indicators: Heavy Precipitation [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-heavy-precipitation

[45] USGCRP. (2018). Fourth National Climate Assessment (pp. 1–470). U.S. Global Change Research Program, Washington, DC. https://nca2018.globalchange.govhttps://nca2018.globalchange.gov/chapter/14

[46] Floodwater After a Disaster or Emergency | CDC. (2022, October 4). https://www.cdc.gov/disasters/floods/floodsafety.html

[47] Sturm, T. W., Garrow, L. A., Stoesser, T., Harris, T., & Georgia Institute of Technology. (2016). Implementation of an Improved Bridge Scour Prediction Procedure (FHWA-GA-RPXX). https://rosap.ntl.bts.gov/view/dot/39808

Storms and Extreme Weather Impacts

Convective storms – a category which includes thunderstorms, tornadoes, and storm-related extreme precipitation such as hailstorms – represent an area of potential vulnerability, albeit without sufficient scientific confidence to make positive connections to climate change projections. For example, models suggest that the warmer conditions created by climate change should increase the likelihood and intensity of convective storm events, especially in the Midwest and Great Plains regions, however at present confidence in these projections is too low to identify these risks as vulnerabilities.[48] Similarly, while historical records suggest that convective storms have been increasing in intensity and frequency, these records are not complete and do not cover enough years of history to support a finding of a vulnerability.[49]

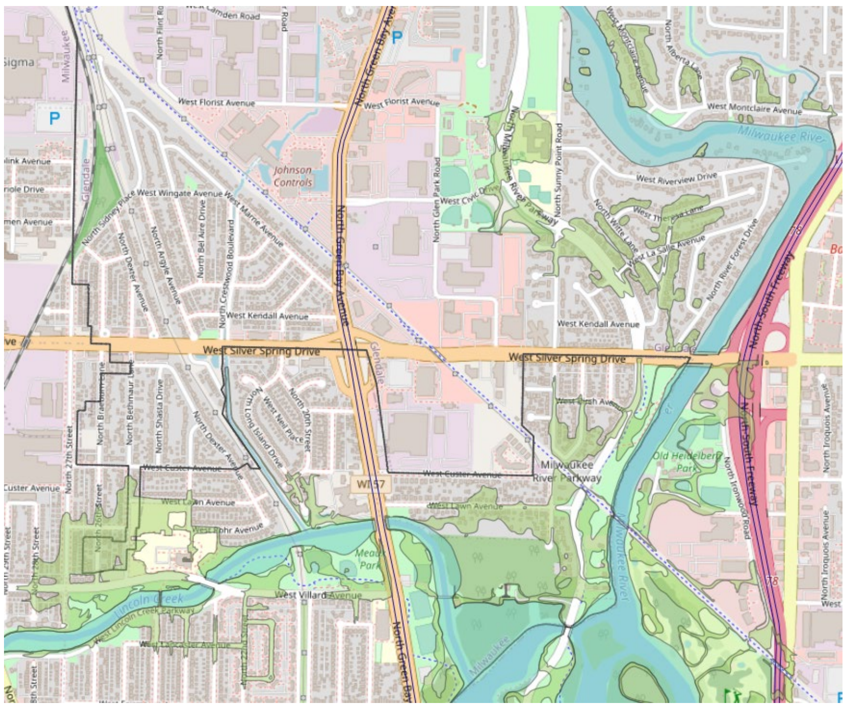

Figure 10. Flooding on Lincoln Creek and Milwaukee River indicated by 100-year and 500-year flood zones.

Riparian & Nuisance Flooding

Floodplain maps rendered using FEMA FIRMs data identify 100-year and 500-year floodplains across Milwaukee County. Areas within the 100-year floodplain maintain a 1% annual risk of shallow flooding, with an average depth hanging from 1 to 3 feet. Regions within the 500-year floodplains stand a 0.2% annual chance of flooding. Milwaukee County generally sees very few hazards within 100-year floodplains, however there is a concentration of communities and important infrastructure facilities which are found across 500-year floodplains. A robust examination of these specific vulnerabilities can be found under Vulnerability #2: Flooding in Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek Corridors, as well as in **Table 14**.

One key factor contributing to the increased occurrence of nuisance flooding is the expansion of impermeable surfaces in urban areas. Urbanization and the proliferation of impervious surfaces such as concrete and asphalt prevent rainwater from infiltrating into the ground, leading to increased surface runoff. As a result, rainfall is more likely to

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48 NCA4 Ch. 2
49 NCA4 Ch. 2

accumulate in low-lying areas, causing ponding and inundation. The combination of urbanization and climate change-induced heavy rainfall amplifies the vulnerability of communities to small-scale flooding events.

A shifting hydrological cycle may alter patterns in precipitation levels and intensifying rainfall. In addition, warmer air can hold more moisture, leading to increased atmospheric water vapor content. This elevated moisture, coupled with changing atmospheric circulation patterns, contributes to more intense rainfall events. The increased volume of rainfall overwhelms drainage systems, especially in urban areas with limited capacity, leading to recurrent flooding.

Infrastructure Vulnerabilities to Riparian & Nuisance Flooding

Flooding can have significant impacts on county infrastructure, leading to various challenges and consequences for the county government and the community. From transportation networks and building structures to utility systems and ecological environments, the impacts of flooding are far-reaching. These challenges can disrupt travel, compromise the integrity of buildings, disrupt critical utility services, and disturb natural ecosystems. Some specific vulnerable infrastructures across Milwaukee County include:

Critical Facilities: Buildings in flood-prone areas are particularly vulnerable to the impacts of small-scale ponding and recurrent flooding.[50] Water infiltration into basements and foundations can lead to structural damage, compromising the stability of the entire structure. Moisture intrusion can also result in mold growth, which poses health risks and requires costly remediation efforts. Additionally, flooding can damage electrical systems, posing safety hazards. The Menomonee River drainage 500-year floodplain encompasses many critical facilities which could be impacted, including parking enforcement facilities, fleet services/repair garages, park maintenance facilities, and the City deforestation building. There are a number of schools that fall into the 100- and 500-year floodplains as well: Thoreau Elementary School, College Park Elementary, Parkway Elementary School, Country Dale Elementary School, and Oak Creek East Middle School. For more details on critical facilities impacted by floods, see Vulnerability #2: Flooding in Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek Corridors.

Transportation: Flooding can have significant impacts on transportation networks. It can cause road closures due to water accumulation, making certain routes impassable. Floodwaters can damage bridges and culverts, compromising their structural integrity and potentially rendering them unsafe for use. Railway tracks can also be affected, leading to disruptions in train services. The accumulation of water on roads reduces visibility and increases the risk of accidents. Across Milwaukee County, several public transit routes may be affected by both 100-year and 500-year floodplains including: Bus Routes 31, 76, and 88.

Utility Systems: Flooding can severely disrupt critical utility services. Water supply systems can be contaminated as floodwaters infiltrate water sources, leading to potential health hazards. Wastewater treatment plants and sewage systems can become overwhelmed by the excess water, causing backups and potential discharges of untreated sewage into the environment. Electrical infrastructure, such as power substations and transformers, can be damaged by flooding, resulting in service disruptions and extended power outages. Within the Menomonee River drainage in particular, the Potawatami Gas Plant lies among the 500-year floodplain.

Ecological Environments: Small-scale ponding and recurrent flooding have adverse effects on natural ecosystems. The prolonged presence of water can alter soil composition and nutrient availability, impacting the growth and survival of plants. Floods can disrupt habitats and displace wildlife, affecting their ability to find food and shelter. Aquatic

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[50] Doocy, S., Daniels, A., Murray, S., & Kirsch, T. D. (2013). The Human Impact of Floods: A Historical Review of Events 1980-2009 and Systematic Literature Review. PLoS Currents, 5, ecurrents.dis.f4deb457904936b07c09daa98ee8171a. https://doi.org/10.1371/currents.dis.f4deb457904936b07c09daa98ee8171a

ecosystems can experience changes in water quality, temperature, and oxygen levels, impacting the health of fish and other aquatic organisms. The National Wildlife Federation emphasizes the ecological impacts of flooding and stresses the importance of floodplain management in preserving biodiversity and maintaining healthy ecosystems.[51] Milwaukee County sees several ecologies potentially affected by both 100-year and 500-year floodplains, including: Hart Park, Kletszch Park, Lincoln Park, Brown Deer Village Park.

Table 14. Infrastructure impacts associated with riparian and coastal flooding and erosion.

Riparian and Coastal Flooding		
Transportation	Pedestrian & Human-powered transportation	• Coastal erosion may cause shorelines to collapse, risking safety of hikers and walkers • High water levels can undermine the foundations of pedestrian bridges, making them unstable or unsafe for use • Flooding may cause damage to pedestrian and bicycle paths, making them inaccessible and unsafe for use
	Transit	• Flooding can damage infrastructure (tracks, tunnels) as well as equipment (signals, switches, communication equipment), causing delays and disrupting service • Transit stations and hubs in flood-prone areas can be damaged/destroyed by extreme rainfall
	Roads & Bridges	• Flooding can cause erosion and scouring around bridge supports and abutments, leading to structural failure of bridges & road and rail embankments • Washed out roads and bridges may become impassable, disrupting travel and commerce • Erosion can affect the integrity of road shoulders, guardrails, and culverts, compromising safety
	Rails	• Floodwaters can weaken foundation of rail bridges and cause erosion around bridge piers, leading to rail bridge failures • Flooding can cause debris to accumulate on tracks, obstructing the rail line and damaging trains • Damaged rail facilities, equipment, and communication systems due to intensive floods can disrupt rail service, causing economic losses
	Airports	• Storm surges and flood conditions may damage coastal navigation aids (beacons, buoys), impeding safe aircraft navigation • Damage to airport terminals, runways, and taxiways prevent safe takeoffs and landings, disrupting services
Energy	Electricity	• Floodwaters can damage electrical transformers and substations, leading to outages and service disruptions • Soil erosion around electrical transmission towers may lead to instability and potential tower collapse • Damage to underground electrical conduits may lead to costly repairs and service disruptions
Water	Water supply systems	• Erosion of stream banks may cause increases in turbidity, impeding water treatment abilities • Damaged water distribution systems (pipelines, pumps, etc.) due to flooding may cause service disruptions and possible water contamination • Infiltration of floodwater into underground water pipes may lead to contamination of the water supply

[51] Environmental Threats. (n.d.). National Wildlife Federation. Retrieved May 23, 2023, from https://www.nwf.org/Home/Our-Work/Environmental-Threats

	Wastewater treatment & sewers	• Overflowing sewage systems lead to the release of untreated sewage into nearby waterways, causing public health risks • Wastewater treatment plants are often located in low-lying areas close to rivers/coastlines, making them more vulnerable to flooding and erosion damage • Erosion can damage sewage pipes, leading to leaks and breaks which release sewage into the environment
Communications	Internet, Phone, wired services	• Destabilized telephone poles due to soil erosion may disrupt services • Damaged telephone exchange buildings and switching centers may disrupt wired phone and internet services • Storm surges can damage underground utility vaults that house internet and phone cables, disrupting services
	Cellular & wireless	• Damage to cell towers, antennas, and related equipment located in flood-prone areas can disrupt cellular and wireless infrastructure & services • Power disruptions caused by intensive flooding and heavy rainfall can impact networks, potentially rendering backup generators inoperable • Erosion can lead to destabilization and collapse of cellular and wireless infrastructure in flood-prone areas (including cell towers)

Social Vulnerabilities to Riparian and Coastal Flooding

Riparian flooding can have significant consequences on social vulnerabilities and exacerbate existing disparities within communities. When asked about their extreme weather concerns, community survey respondents reported road closures, damaged vehicles, sewage overflows, and flooded basements to be most impactful in their communities. When FEMA FIRMs floodplains are overlaid with SVI data, it is evident that there are four waterways (accompanied by relevant affected zip code areas) which may disproportionately impact vulnerable communities in the event of a flooding emergency: Wilson Park Creek (53221), Menominee River (53214, 53208, 53233), Lincoln Creek (53218, 53209), and Milwaukee River (53209, 53204). These communities in particular face strenuous economic challenges in comparison to communities living in floodplains along the Lake Michigan shoreline, exacerbating the risks associated with extreme flooding and posing threats to community resilience. Flood risks can impact various aspects of community life outside of economic wellbeing, in:

Health: Riparian flooding can also have significant impacts on public health. Floodwaters can become contaminated with sewage and other hazardous materials, leading to waterborne illnesses such as diarrhea, cholera, and typhoid fever. In addition, flooding can increase the risk of vector-borne diseases such as West Nile virus, malaria, and dengue fever, as standing water provides a breeding ground for mosquitoes and other insects. Floods can also disrupt health services, making it difficult for individuals to access necessary medical care.

Public Safety: Public safety and emergency services can also be impacted by riparian flooding. Floods can damage critical infrastructure such as roads, bridges, and utilities, making it difficult for emergency responders to reach affected communities. Floods can also cause power outages, which can further disrupt emergency services. In addition, flooding can lead to a higher demand for emergency services, such as search and rescue operations, evacuations, and medical care.

Housing: Floods can damage homes and other buildings, leading to displacement and homelessness. In addition, flooding can damage critical infrastructure such as water and sewage systems, making it difficult for individuals to access basic amenities such as clean water and sanitation. Vulnerable populations, such as low-income communities, are often disproportionately impacted by flooding and may struggle to recover from the damages.

Mobility & Access: Riparian flooding can impact transportation and essential services access in various ways. Floods can damage roads and bridges, making it difficult for individuals to access essential services such as grocery stores, medical facilities, and schools. In addition, floods can disrupt public transportation, making it difficult for individuals to reach work or school. Milwaukee County bus routes may be particularly susceptible to flooding in the following areas:

- Milwaukee River Drainage: North Port Washington Road (500-year)
- Lincoln Creek Drainage: West Villard Avenue (500-year), North 60th Street (500-year), West Hampton Avenue (500-year)
- Beaver Creek Drainage: North Green Bay Road (100- and 500-year), North 51st Street (500-year)
- Menomonee River: West State Street (100- and 500-year), South 35th Street (100-year)
- Root River Drainage: West Oklahoma Avenue (500-year)

Table 15. Social impacts associated with riparian and nuisance flooding.

Social Impacts	Riparian & Nuisance Flooding
Health	• Increased spread of waterborne diseases (cholera, typhoid fever, dysentery) which can cause diarrhea or dehydration • Exposure to flood waters and sewage can increase the risk of skin infections • Increased mold growth in homes, causing respiratory problems and illnesses • Psychological stress of dealing with repeated flooding events may lead to anxiety, depression, and other mental health challenges
Mobility & Access	• Damage to public transportation systems (buses, trains) impedes the ability to commute to work or school • Infrastructure damage can lead to increased traffic congestion and longer commute times, negatively impacting air quality and public health
Parks, Recreation, Arts, Cultural Resources	• Flooding damage to cultural resources can affect tourism, which may negatively impact the local economy • Closures of public facilities (libraries, community centers, museums) limits access to important community resources, impeding resilience of vulnerable communities • Loss of cultural heritage as archaeological sites, historic buildings, and natural cultural sights may be irreparably altered • Loss of wildlife habitats and ecosystems, which can have negative impacts on biodiversity and ecosystem services
Housing, Education, Food Security	• Increase in contaminated food and water sources may lead to food insecurity/malnutrition • Repetitive flooding may make it difficult for homeowners to obtain insurance, potentially leading to mortgage default or foreclosure • Damage to homes and properties can lead to costly repairs and diminished home value • Damage to schools and transit routes make it difficult for children to access education and school resources
Public Safety	• Closure of transportation infrastructure can affect emergency response times, making it harder for first responders to reach people in need • Significant risks of drowning, electrocution, and injuries from debris jeopardize community safety and strain emergency response systems • Swift-moving or contaminated floodwaters place first responders at risk when managing flood-related emergencies, slowing response times • Flooded roads and sidewalks can increase the risk of slip and fall accidents, which can lead to serious injury or death • Emergency vehicles may have difficulty navigating through affected areas, potentially delaying response times and putting lives at risk

Coastal Erosion

As the climate changes, coastal erosion may pose an increasing threat to Milwaukee County. Intensifying storms and changing precipitation patterns can contribute to the acceleration of erosion processes along the Lake Michigan shoreline. These environmental shifts heighten the risk of land loss, shoreline retreat, and ultimately cause damage and disruptions to key county resources. Critical assets becoming more susceptible to erosion-induced hazards can jeopardize the safety, accessibility, and economic stability of the community.

Infrastructure Vulnerabilities to Coastal Erosion

As a coastal community along Lake Michigan, the county faces the ongoing threat of erosion-induced land loss, shoreline retreat, and the potential degradation of critical infrastructure assets. The combination of natural forces, such as wave action, storm surges, and changing weather patterns, exacerbates the vulnerability of infrastructure (including roads, bridges, ports, and utilities that are essential for transportation, commerce, and the well-being of the community). In addition to impacts detailed in **Table 16**, infrastructure hazards associated with coastal erosion include:

Coastal Protection Infrastructure: Coastal erosion poses a significant threat to coastal protection infrastructure, including seawalls, revetments, and breakwaters. Erosion can undermine the stability of these structures, leading to structural failure, reduced effectiveness in protecting coastal areas from erosion and flooding, and increased vulnerability to storm surges. Proper design, monitoring, and maintenance of coastal protection infrastructure are crucial to adapt to changing erosion patterns.

Transportation Infrastructure: Erosion-induced coastal retreat can result in the loss or relocation of coastal roads and highways, disrupt transportation networks, and limit access to coastal areas. In some cases, erosion can cause the undermining or collapse of road embankments due to the erosion of supporting soils. This highlights the need for regular monitoring, maintenance, and adaptive planning of coastal roads to mitigate erosion risks and ensure safe and reliable transportation routes.

Utilities Infrastructure: Coastal erosion may affect utilities infrastructure such as power transmission lines, water and wastewater pipelines, and communication networks. The integrity of underground utility lines can be compromised by erosion-induced coastal retreat, leading to disruptions in power supply, water services, and communication systems. Sustainable coastal planning, setback requirements, and adaptive practices can be essential in mitigating the impacts of erosion on utilities.

Coastal Development and Buildings: Coastal erosion poses risks to buildings and infrastructure in developed coastal areas, including residential, commercial, and tourist facilities. Coastal retreat can threaten the stability of buildings, leading to structural damage and potentially even collapse. It can also impact coastal development by reducing available land for construction and limiting expansion opportunities.

Coastal Recreation and Tourism Infrastructure: Erosion-induced loss of sandy beaches can diminish the attractiveness and recreational value of coastal areas, affecting tourism revenues and local economies. It can also disrupt recreational facilities, such as beachfront parks, marinas, and tourist accommodations. Proper beach nourishment, coastal management, and restoration strategies are important for preserving recreational and tourism infrastructure.

Table 16. Infrastructure impacts associated with coastal erosion.

Coastal Erosion		
Transportation	Pedestrian & Human-powered transportation	• Land loss can limit pedestrian access to coastal properties and resources • Lakebeds steepened by erosion allow waves to travel deeper into the coast and can throw debris onto trails utilized by pedestrians, cyclists, etc.
	Transit	• Lakebeds steepened by erosion allow waves to travel deeper into the coast and can throw debris onto transit paths[52] • Significant erosion caused by extreme weather can require evacuations that disrupt and strain transit systems
	Roads & Bridges	• Increasing coastal property loss can lead to more damage to key structures including roads and bridges • Lakebeds steepened by erosion allow waves to travel deeper into the coast and can throw debris onto roads, resulting in travel interruptions
	Rails	• Coastal rail lines, especially those connecting to Port Milwaukee, may experience interrupted service due to high water levels that put infrastructure at further risk of erosion
	Airports	• Erosion-induced coastal retreat can disrupt transportation networks, including those that rely on and are relied upon by airports
Energy	Electricity	• Underground utility lines can be compromised by erosion-induced coastal retreat, leading to disruptions in power supply
Water	Water supply systems	• Surface water quality can be negatively impacted by sediment displacement into coastal waters • integrity of underground utility lines can be compromised by erosion-induced coastal retreat, leading to disruptions in power supply, water services, and communication systems • Stormwater infrastructure is susceptible to damage as result of high-water levels in the Lake which can flood an outfall and cause debris to enter stormwater infrastructure[53]
	Wastewater treatment & sewers	• Sewer mains in the Lake and other water bodies may become more exposed and vulnerable due to eroding coastlines
Communications	Internet, Phone, wired services	• Integrity of underground utility lines can be compromised by erosion-induced coastal retreat, leading to disruptions in power supply and communication systems
	Cellular & wireless	• Damage to above ground transmission infrastructure, such as radio masts or wireless towers, can disrupt service

Social Vulnerabilities to Coastal Erosion

Addressing the impacts of coastal erosion on community health and resources is essential in building a comprehensive approach to improving community resilience, developing adaptation strategies, and the preservation of natural and cultural assets. In addition to those outlined in **Table 17,** Some community-wide hazards associated with coastal erosion include:

Health: Erosion-induced loss of protective features, such as dunes and wetlands, can leave communities more vulnerable to the impacts of storms, including increased risk of flooding and property damage. Coastal erosion can also

[52] *WICCI 2021 Assessment Report.pdf | Powered by Box*. (2021). Retrieved May 24, 2023, from https://uwmadison.app.box.com/s/lob4igia3b55u1q6kead7l91p14odoqu.
[53] Bostrom, S., Nelson, A., et al. (2021). SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION. https://www.sewrpc.org/SEWRPCFiles/Publications/mr/mr-248-milw-co-coastline-mgmt-guide.pdf.

impact water quality and introduce pollutants into coastal ecosystems, potentially affecting human health through contaminated water sources and compromised fisheries. Strategies for managing the health impacts of coastal erosion include disaster preparedness, public health outreach, and water quality monitoring.

Transportation & Accessibility: Loss of land and damage to coastal roads and highways can disrupt transportation networks, limiting access to residential communities, economic centers, and essential services along the coast. This can result in increased travel distances, longer commute times, and challenges in accessing schools, healthcare facilities, and places of employment.

Parks & Recreation: Coastal erosion may impact community members' access to natural spaces and recreational activities. Loss of sandy beaches, coastal dunes, and vegetation can diminish the aesthetic appeal, recreational value, and biodiversity of coastal parks, reducing healthy opportunities for outdoor engagement.

Table 17. Infrastructure impacts associated with coastal erosion.

Social Impacts	Coastal Erosion
Health	• Loss of natural protective barriers increases vulnerability to storm surges & coastal flooding, posing risks to safety & health
Mobility & Access	• Damage or destruction of coastal roads, bridges, and other transit infrastructure limits access to coastal areas and hinders connectivity within communities • Reduced accessibility to coastal areas can have economic implications, impacting tourism, fisheries, and coastal-dependent industries that contribute to community livelihoods
Parks, Recreation, Arts, Cultural Resources	• Loss of coastal landscapes and iconic landmarks due to erosion can diminish the aesthetic value and sense of place, affecting community pride and cultural tourism • Damaged or eroded coastal parks and recreational infrastructure can reduce the availability and accessibility of amenities such as picnic areas, trails, and sports facilities. • Declining coastal biodiversity and ecosystem health due to erosion can affect recreational opportunities such as birdwatching, wildlife viewing, and fishing
Housing, Education, Food Security	• Erosion-induced coastal retreat can devalue coastal properties and impact housing markets, affecting homeowners' financial stability and investments • Increased vulnerability to storm surges and flooding can compromise the safety and habitability of coastal homes
Public Safety	• Coastal erosion can compromise public safety by undermining the stability of coastal infrastructure, which can lead to accidents and hazards • Erosion-related coastal retreat can limit access routes for first responders

High Priority Vulnerabilities

Climate hazards present a complex challenge for local planners who wish to minimize the impact on their communities. This report utilizes a projection-informed Risk Based Prioritization Framework (RBPF) to analyze and prioritize the most important hazards facing Milwaukee County. The framework uses infrastructure and demographic data, climate change projections, and inferences gleaned from experiences in other communities across the country to rank individual factors contributing to climate vulnerability. The RBPF is intended to be flexible and inclusive, with each component of risk evaluation distributed to expert groups who individually rank risk factors before aggregating results to find average risk scores. This approach ensures that multiple perspectives are reflected in the final prioritization. The low-cost of the approach also allows to it be repeated in future evaluations to update prioritization schemes as new data and changing community responses develop.

Risk-Based Prioritization Framework

In order to rank the priority of identified vulnerabilities, a subjective scoring matrix is completed for the various components of climate risk. Risk is a composite of two concepts: probability and consequence. Probability reflects the likelihood of a climate hazard to result in an impact to a specific system (facility, site, asset, community, etc.), whereas consequence describes the cost if an impact affects the system (including costs resulting from damage and disruption, as well as non-monetized costs such as injury, death, emotional suffering, or loss of cultural heritage).

This report includes both subjective probability and subjective consequence scores. Probability scores are based on both quantitative and qualitative climate change projections and current population characteristics in Milwaukee County but represent a hybrid metric based on expert judgement. **Table 18** provides illustrative examples of benchmark scores for probability. Consequence scores reflect the cost of a damaging event, as well as the extent and duration of disruption to systems. Unlike probability scores, consequence scores are generated using expert elicitation from Milwaukee County's Sustainability Task Force (STF) members. **Table 19** provides illustrative examples of consequence benchmarks.

Table 18. Illustrative examples of scoring benchmarks for Risk-Based Prioritization Framework probability scoring.

Subjective Probability Scoring Matrix: Illustrative Examples of Probability Benchmarks	
Geospatial Exposure	-: Hazard is not relevant to this system 0: No exposure 1: Small areas of exposure or uncertain exposure 2: Multiple small, discontinuous areas of exposure or moderate area 3: Extensive areas of exposure central to system
Frequency of Exposure	-: Hazard is not relevant to this system 0: Never 1: 1-in-100 event (e.g., 100-year storm) 2: More frequent than 1-in-100 (e.g., 100-year floodplain combined with increasing precipitation proj.) 3: Much more frequent than 1-in-100 (e.g., explicit projections)
Vulnerability of Exposed System	-: Hazard is not relevant to this system 0: No indication of increased vulnerability 1: Exposure applies to all areas equally, or to a single site of increased vulnerability 2: Exposure of multiple small areas of increased vulnerability or single large site 3: Exposure of multiple sites of increased vulnerability

Table 19. Illustrative examples of scoring benchmarks for Risk-Based Prioritization Framework consequence scoring.

Subjective Consequence Scoring Matrix: Illustrative Examples of Score Benchmarks

Cost of Damage	-: Hazard is not relevant to this system 0: No damage/marginal damage 1: Light damage; resulting in <10% of replacement cost 2: Heavy damage; resulting in less than full replacement cost 3: Total damage; costs equal to or greater than replacement
Cost of Disruption	-: Hazard is not relevant to this system 0: No disruption/marginal disruption 1: Small/low-cost disruption 2: Heavy disruption or moderate-cost disruption 3: Complete system disruption
Duration of Disruption	-: Hazard is not relevant to this system 0: No disruption 1: Brief disruption (<1 day) 2: Heavy disruption (<1 week) 3: Extended disruption (>1 week)

Vulnerability #1: Heat Waves and Human Health

Milwaukee County's exposure to extreme heat has historically been low relative to most of the rest of the United States, and the region's buildings and infrastructure reflect this history. The growing threat of climate change-driven extreme heat can affect many facets of life in Milwaukee County, but the most urgent concern is the acute threat to human health during severe heat waves, and specifically the risk of mass-casualty events due to acute heat stress.

Human health impacts are exacerbated by a number of coincident environmental factors, infrastructure factors, and existing vulnerabilities in Milwaukee County's communities. Heat stress is a cumulative risk, and populations exposed to multiple days of continuously hot, humid days will experience greater heat stress than those exposed to single extreme heat day. Especially taxing are periods with warm, humid nights which don't allow stressed bodies to rest overnight. When combined with contemporary UHI effects, projections for increases to extreme heat make these types of hazardous events much more likely in the future.

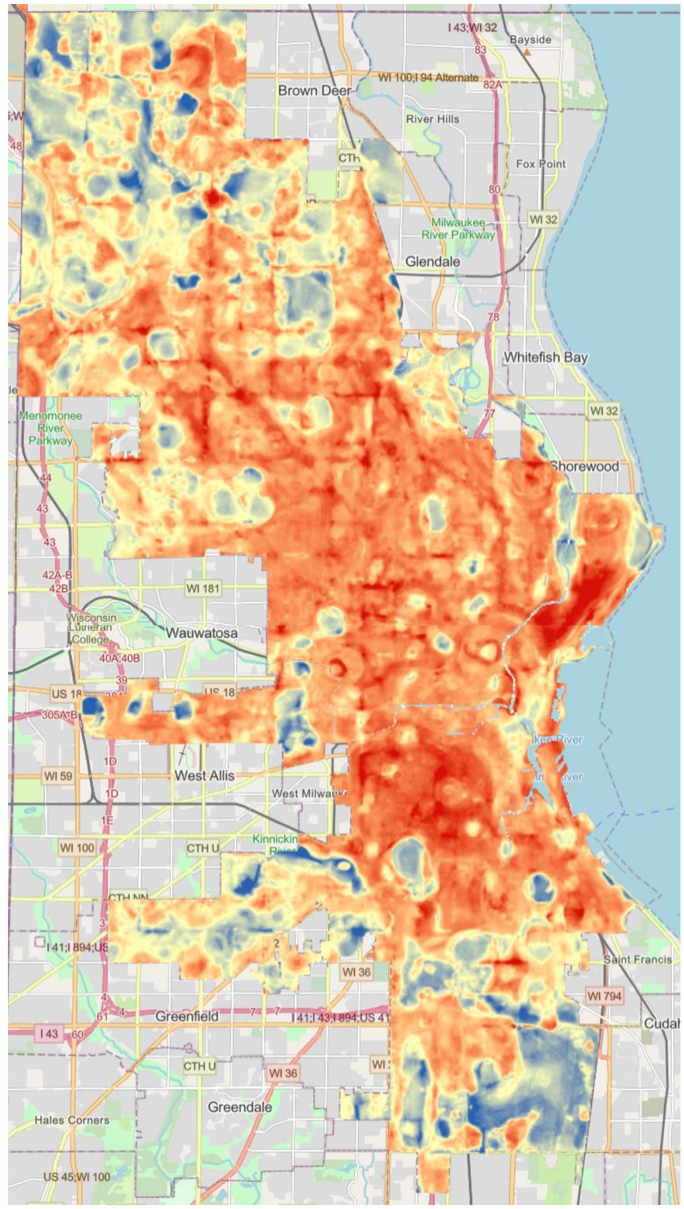

Figure 11. Map showing real-world temperature differences across selected areas in Milwaukee on July 21 - 22, 2022. Afternoon temperatures shown (3-4pm). Data produced by WI DNR as part of a UHI mapping exercise.

Exposed Infrastructure & Communities

While some geographic variation in projected heat wave temperature increases exists across the county, the most meaningful geographically-correlated contributing factors to vulnerability are infrastructure and social vulnerability factors that can either mitigate or intensify extreme heat hazards. Vulnerable infrastructure, including old buildings and lack of air conditioning can impair adaptive responses, and high concentrations of impermeable surfaces (including buildings, paved roads, and parking lots), and a deficit of tree canopy and open space intensify UHI (**Figure 11**). In a recent study, UHI impacts in Milwaukee County were studied by the Wisconsin DNR and three key takeaways were identified:[54]

- Neighborhoods with high percent tree canopy retain less heat throughout the day

[54] Wisconsin Department of Natural Resources (DNR). 2022. "Milwaukee Wisconsin Heat Watch Report." Madison, WI: Wisconsin Department of Natural Resources. Summer. https://dnr.wisconsin.gov/sites/default/files/topic/UrbanForests/summaryReport_heatWatchMilwaukee.pdf.

- Parks create spillover cooling effect for some surrounding blocks
- Large paved areas such as commercial districts can create spillover hot spots

Social vulnerability factors including poverty, disability, and age are correlated with worse outcomes during extreme heat events. Additionally, neighborhoods with diverse lived experiences and access to resources, such as those who speak languages other than English or areas with low concentration of vehicle ownership, can impair the effectiveness of adaptive responses like emergency cooling centers. For example, if residents cannot access cooling centers, or aren't sufficiently notified about heat risks using appropriate translations, protective actions may not be taken that otherwise could have. Unfortunately, many indicators of social vulnerability are compounded in the county's urban core, alongside the most intense UHI effects and the least resilient infrastructure (**Figure 12**).

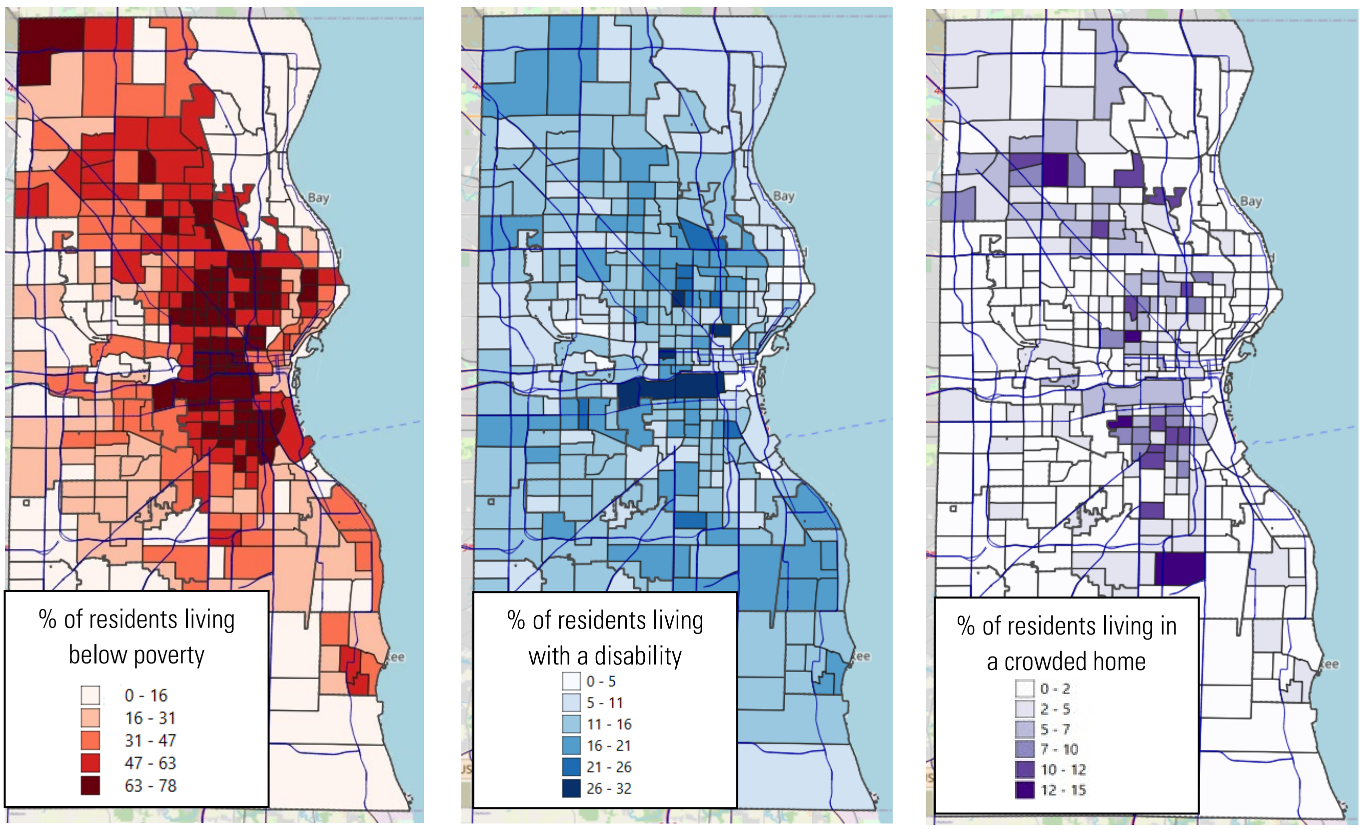

Figure 12. Three indicators of social vulnerability to heat waves show several concentrations of exposure within the inner urban neighborhoods that also experience the greatest UHI impacts. Neighborhoods in central, north, and south Milwaukee City show some of the highest concentrations of exposure. Source: CDC. 2022b

Risk Ranking

Subjective Probability Score Matrix – Heat Waves & Human Health

Table 20. Subjective Probability Score Matrix - Heat Waves & Human Health. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	2	2	3
Worst-Case Scenario (RCP 8.5)		3	3

Subjective Consequence Score Matrix – Heat Waves & Human Health

Table 21. Subjective Consequence Score Matrix - Heat Waves & Human Health. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	-	-	-
Worst-Case Scenario (RCP 8.5)		-	-

Vulnerability #2: Flooding in Menomonee River, Milwaukee River, Beaver Creek, and Lincoln Creek Corridors

A concentration of infrastructure, communities, and important facilities within the 100-year and expected 500-year floodplains. With projected increases to extreme precipitation events, Milwaukee County's exposure to riparian flooding must be evaluated accounting for future weather conditions rather than backward-looking historical data.

Major flood hazards in Milwaukee County are concentrated in four key watersheds: the Menomonee and Milwaukee Rivers and Beaver and Lincoln Creeks (see **Appendix B: Milwaukee County Flood Zones**). While most of the severe high-priority flood hazard areas are indicated in the FEMA FIRM Zone X (i.e., 500-year floodplain, or areas with a 0.2% annual risk of flooding), these probabilities are based on historical precipitation and runoff. Concerningly, several high-priority flood risks are indicated within the FEMA FIRM Zone A or AE (i.e., 100-year floodplain, or areas with 1% annual risk of flooding), which are much more likely to flood during an extreme precipitation event. Additional flooding hazards can be found in **Table 22**.

Table 22. Vulnerable facilities, sites, systems, and communities subject to 100-year and 500-year flood hazards in the Menomonee and Milwaukee River and Beaver and Lincoln Creek watersheds.

Watershed		Vulnerable Sites
Menomonee River	100-yr	• Park – Hart Park • Transit – Route 31 Bus (High SVI for NoVEH)
	500-yr	• Critical Facilities: Parking enforcement, fleet services/repair garage, park maintenance facilities, city forestry division building • Healthcare: Senior living facility • Energy: Potawatami Gas Plant • Transportation: Muskego Rail Yard, Watertown Subdivision rail • Industry: Miller Coors facilities and various other commercial and industrial sites • Piggsville residential neighborhood, State St. industrial/commercial corridor
Milwaukee River	100-yr	• Parks: Kletszch Park, Lincoln Park
	500-yr	• Residential neighborhoods in Glendale and River Hills
Beaver Creek	100-yr	• Parks: Brown Deer Village Park
	500-yr	• Critical Facilities: Brown Deer Village Hall • Transit: Bus Routes 76 and 88 • Residential neighborhoods in Brown Deer, especially around Highway 57 and W. Joleno Drive • Commercial districts in Brown Deer around N 51st St., Highway 57, and W Schroeder Dr.
Lincoln Creek	100-yr	• N/A
	500-yr	• Critical facilities: Ascension Family Health Center

		• Residential neighborhoods including West Villard Avenue, Harriet Tubman Park, 60th St and Custer, West Mills Rd. Crossing

Risk Ranking

Subjective Probability Score Matrix – Riparian Flooding

Table 23. Subjective Probability Score Matrix – Riparian Flooding. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	0	1	2
Worst-Case Scenario (RCP 8.5)		0	2

Subjective Consequence Score Matrix – Riparian Flooding

Table 24. Subjective Consequence Score Matrix – Riparian Flooding. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	-	-	-
Worst-Case Scenario (RCP 8.5)		-	-

Vulnerability #3: Acute Air Quality Hazards

Acute air quality impairment can be a serious hazard, especially for vulnerable populations. Milwaukee County residents have expressed concern, via community survey and workshop discussions, over respiratory conditions becoming exacerbated by impending effects of climate change. Many also voiced worries for their vulnerable family members, particularly their children, many of whom are developing severe seasonal allergies due to increased concentration of pollen and lengthened allergy seasons. These are a few brief examples of how climate change is increasing the risk of acute air quality hazards by increasing the frequency of conditions that can create dangerous air quality days. The greatest air quality hazard is ground-level ozone, with the Midwest-region expected to experience significant increases in annual premature deaths from ozone exposure.[55] Additionally, longer growing seasons and the northward expansion in range of many types of plants and pests increases the risks of allergen exposure, which can exacerbate underlying health conditions.

While ozone concentrations are affected by both day-to-day changes in weather as well as shifts in sources of pollution like the number of vehicles on the road and the operation of stationary combustion boilers and industrial facilities, the primary driver of increased exposure is increased heat and increased frequency of sunny days. Thus, without predicting specific occurrences, the correlation of impaired air quality with additional hot, sunny days is expected to enhance this risk.

Milwaukee County's most vulnerable populations (including residents living with disabilities and residents under the federal poverty line) are concentrated in neighborhoods that experience the greatest UHI-driven increases in local temperature. These are neighborhoods with the least access to open space, least tree canopy, and highest concentrations of impermeable surfaces). Thus, the exposure is correlated with two major indicators of vulnerability (another vulnerable group – residents 65 years of age or older – is not as strongly correlated with the most UHI impacted neighborhoods, however many elderly residents reside in these neighborhoods). A further indicator of vulnerability is proximity to major sources of vehicle-borne pollution, such as highways and interstates. For example, some of the county's highest concentrations of poverty are in neighborhoods bound on two sides by Interstates 43 and 94/794, and on a third side by US-18/WI-57/West Highland Blvd.

Risk Ranking

Subjective Probability Score Matrix – Acute Air Quality Hazards

Table 25. Subjective Probability Score Matrix – Acute Air Quality Hazards. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	1	2	2
Worst-Case Scenario (RCP 8.5)		2	3

Subjective Consequence Score Matrix – Acute Air Quality Hazards

Table 26. Subjective Consequence Score Matrix – Acute Air Quality Hazards. See scoring guidelines for benchmarking.

	2020	2050	2085
Best-Case Scenario (RCP 4.5)	-	-	-
Worst-Case Scenario (RCP 8.5)		-	-

[55] CIRA Report

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Appendix B: Milwaukee County Flood Zones

Figure 13. Flooding along West State Street corridor, indicated by 100-year and 500-year flood zones.

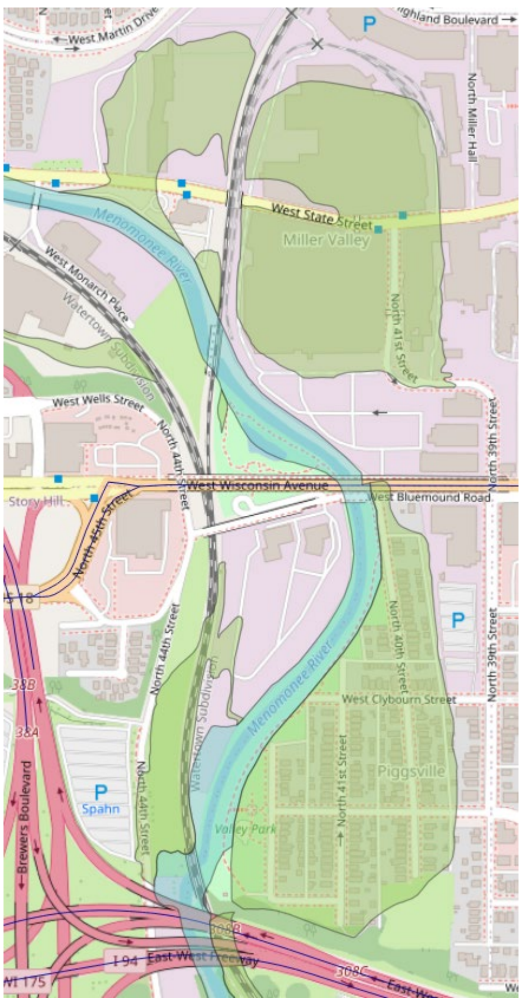

Figure14. Flooding in Piggsville neighborhood, indicated by 500-year flood zone.

Figure 15. Flooding in central Milwaukee, including multiple critical facilities indicated by 500-year flood zone.

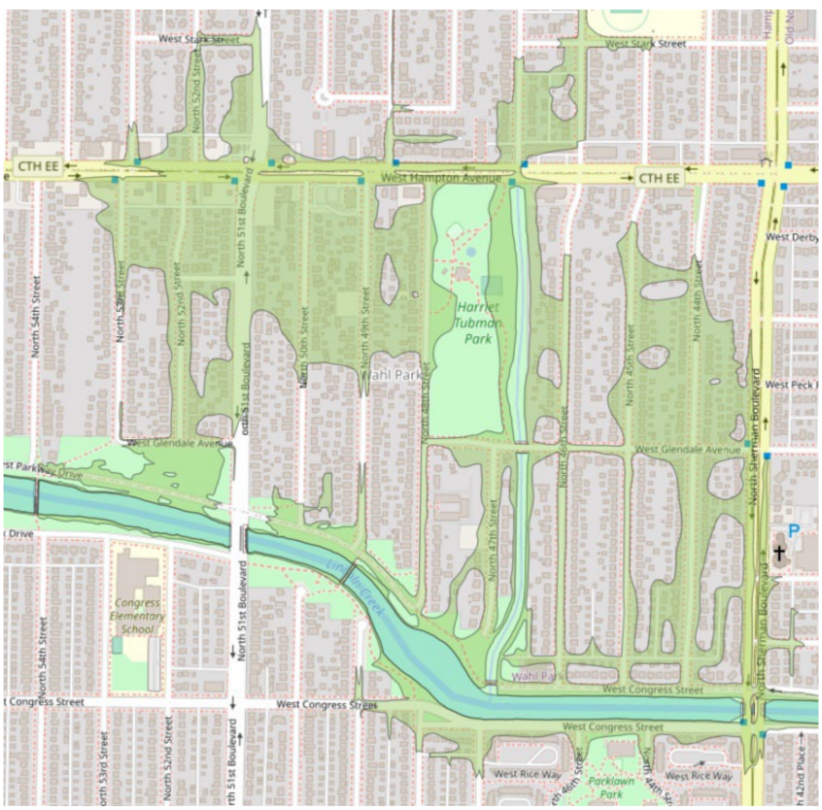

Figure 16. Flooding in and around Harriet Tubman Park indicated as 500-year flood zone.

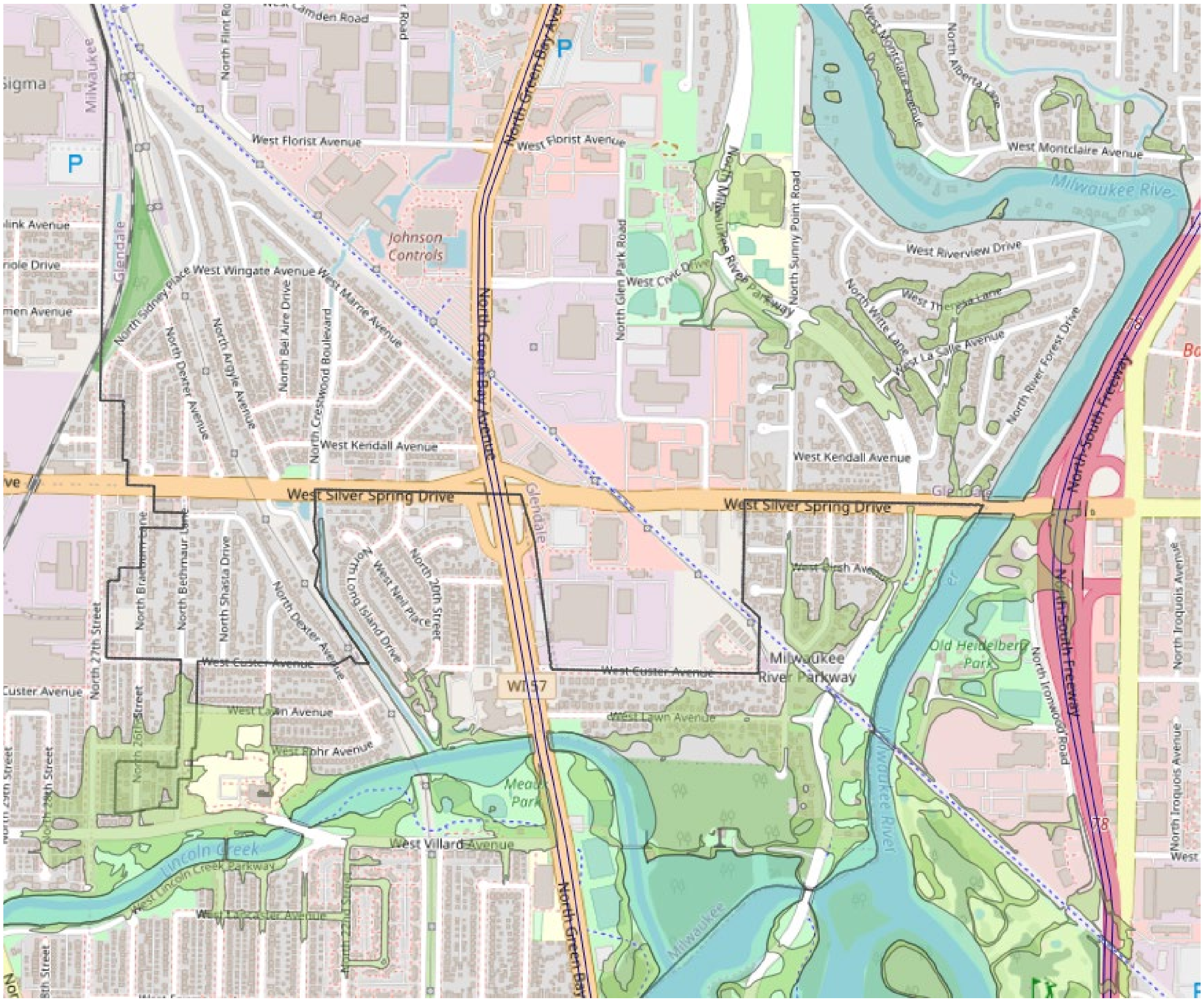

Figure 17. Flooding on Lincoln Creek and Milwaukee River indicated by 100-year and 500-year flood zones.

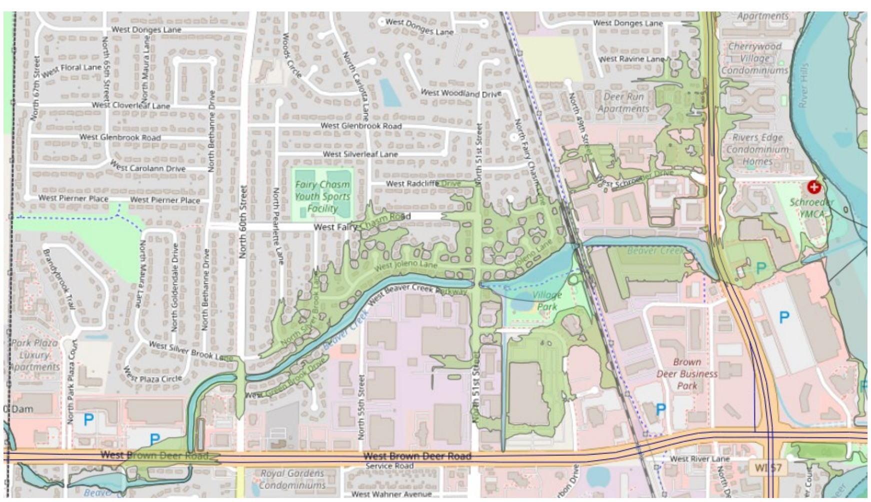

Figure 18. Flooding in Brown Deer indicated as 100-year and 500-year flood zones.

Appendix C: Climate Hazard Projections

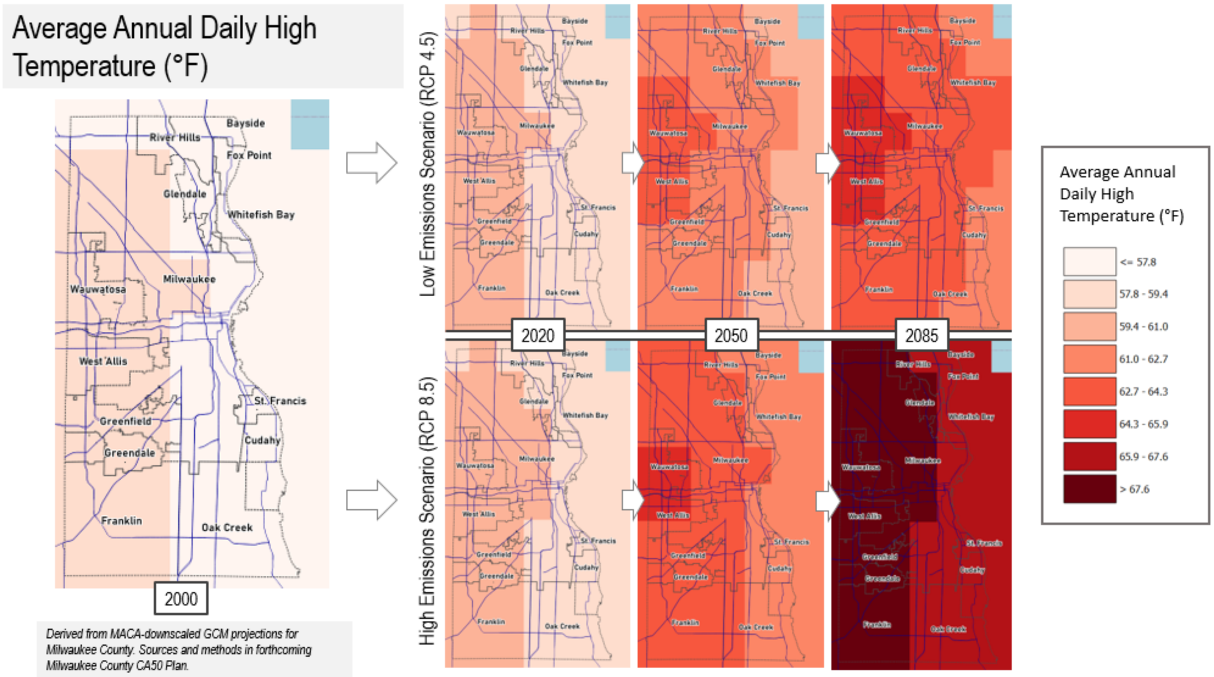

Figure 19. Historical and projected future average annual daily high temperatures across Milwaukee County.

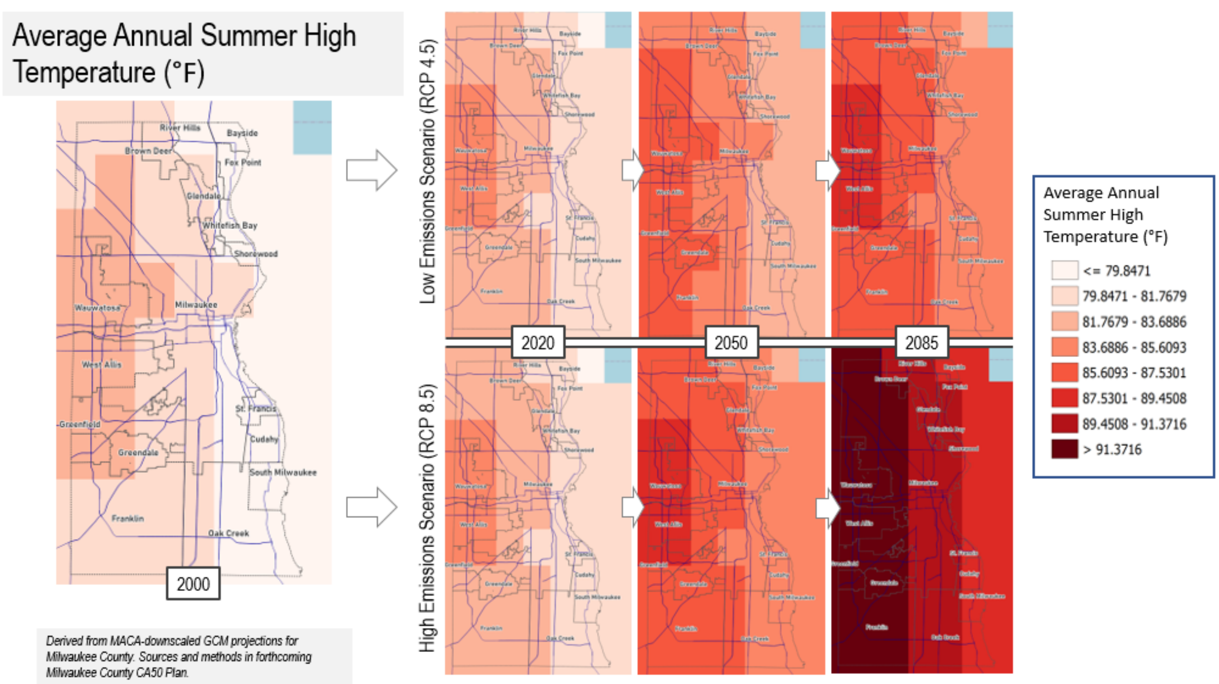

Figure 20. Historical and projected futured daily average annual summer high temperatures across Milwaukee County.

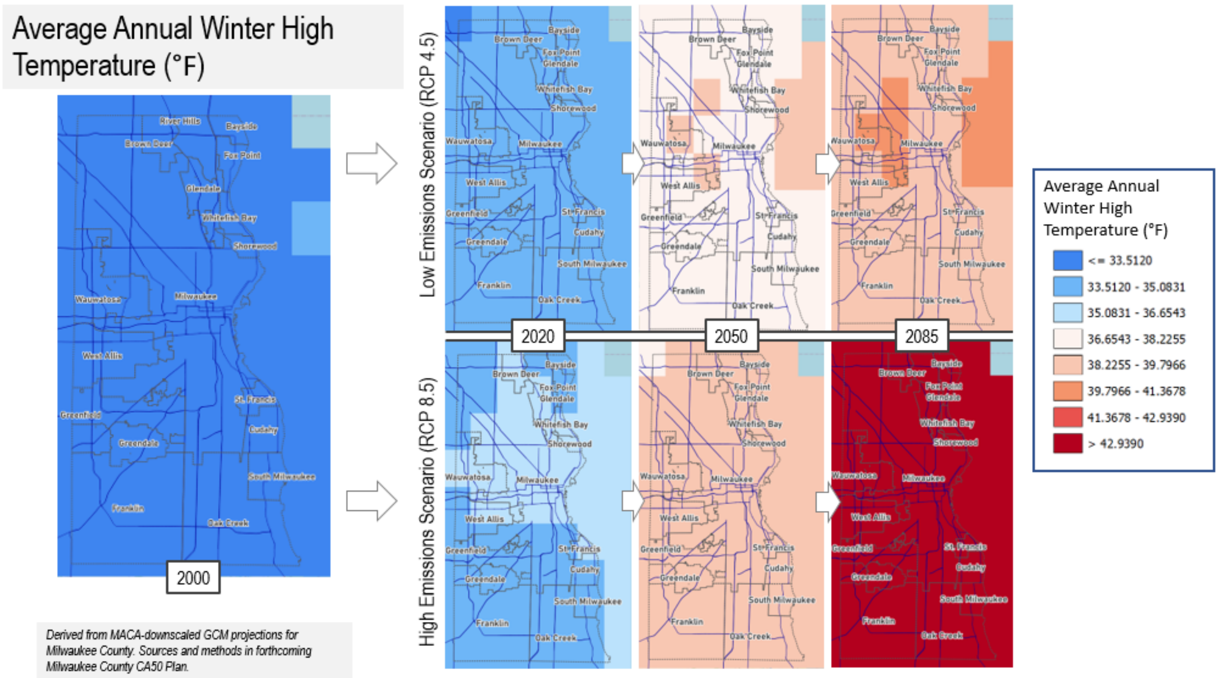

Figure 21. Historical and projected future daily high average winter temperatures across Milwaukee County.

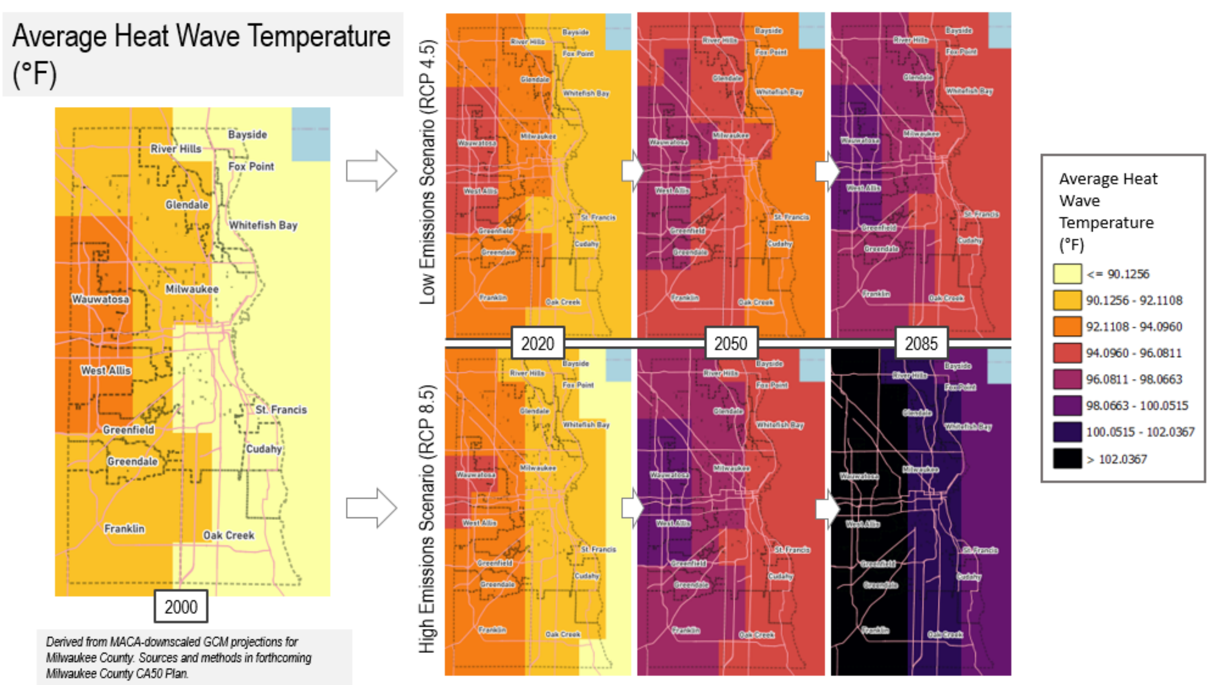

Figure 22. Historical and projected future average heat wave temperatures across Milwaukee County.

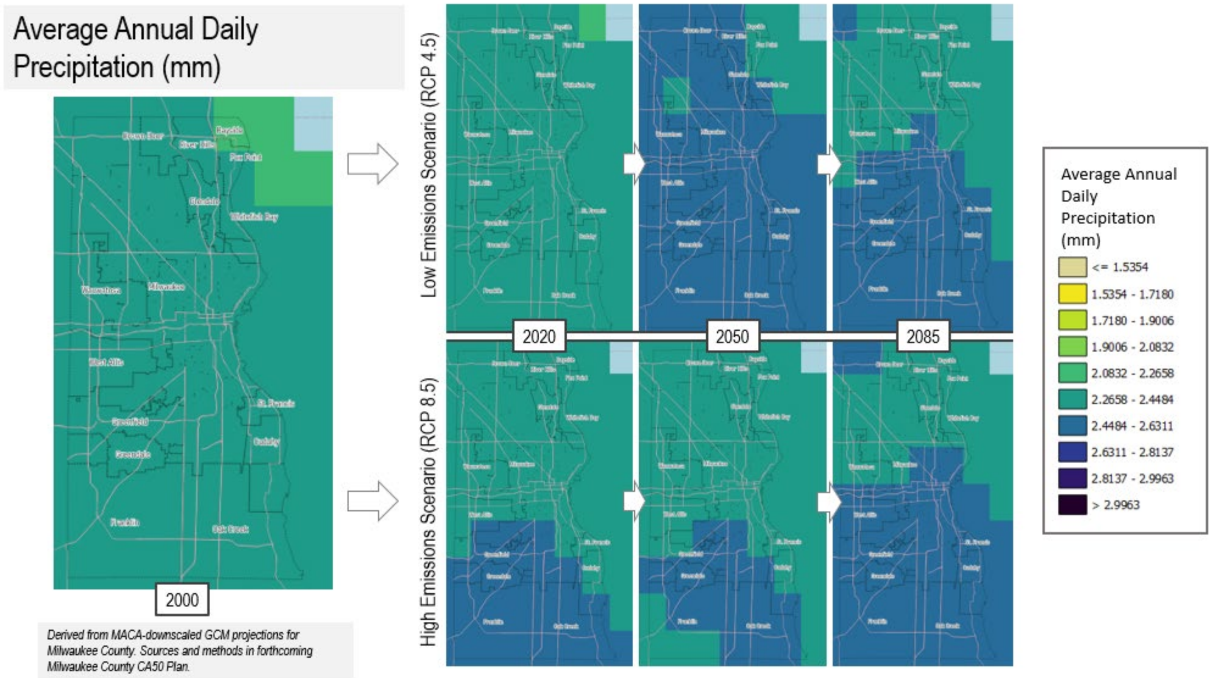

Figure 23. Historical and projected future average annual daily precipitation across Milwaukee County.

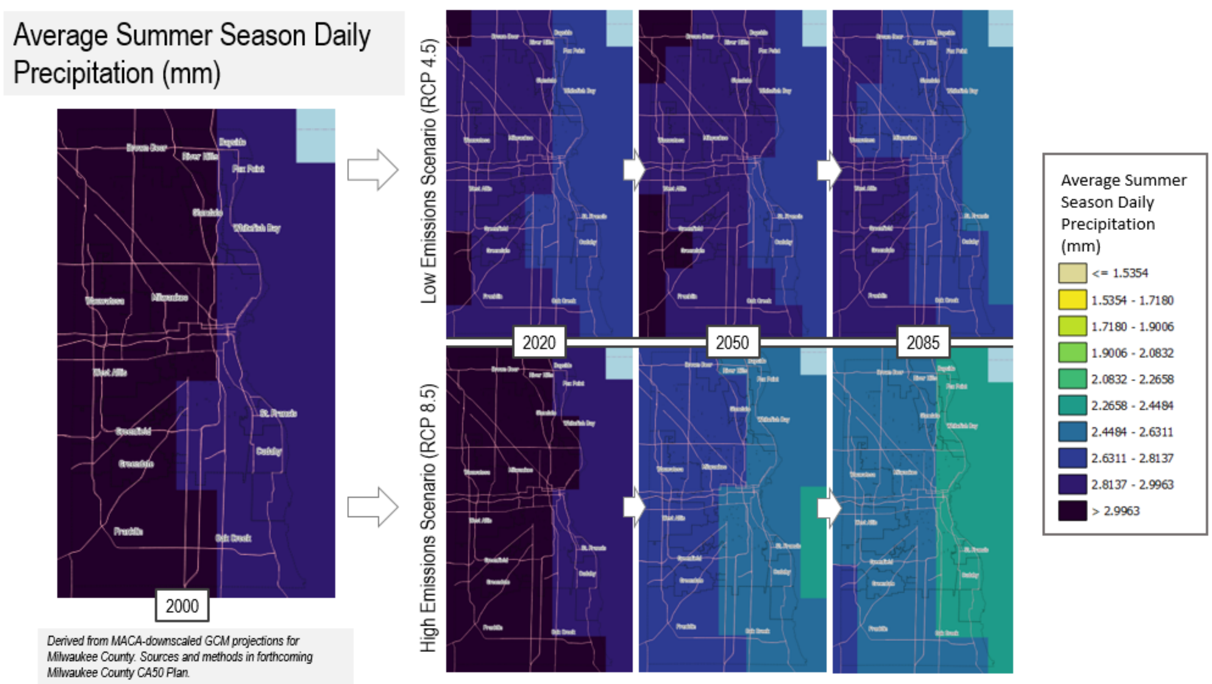

Figure 24. Historical and projected future average daily annual summer precipitation across Milwaukee County.

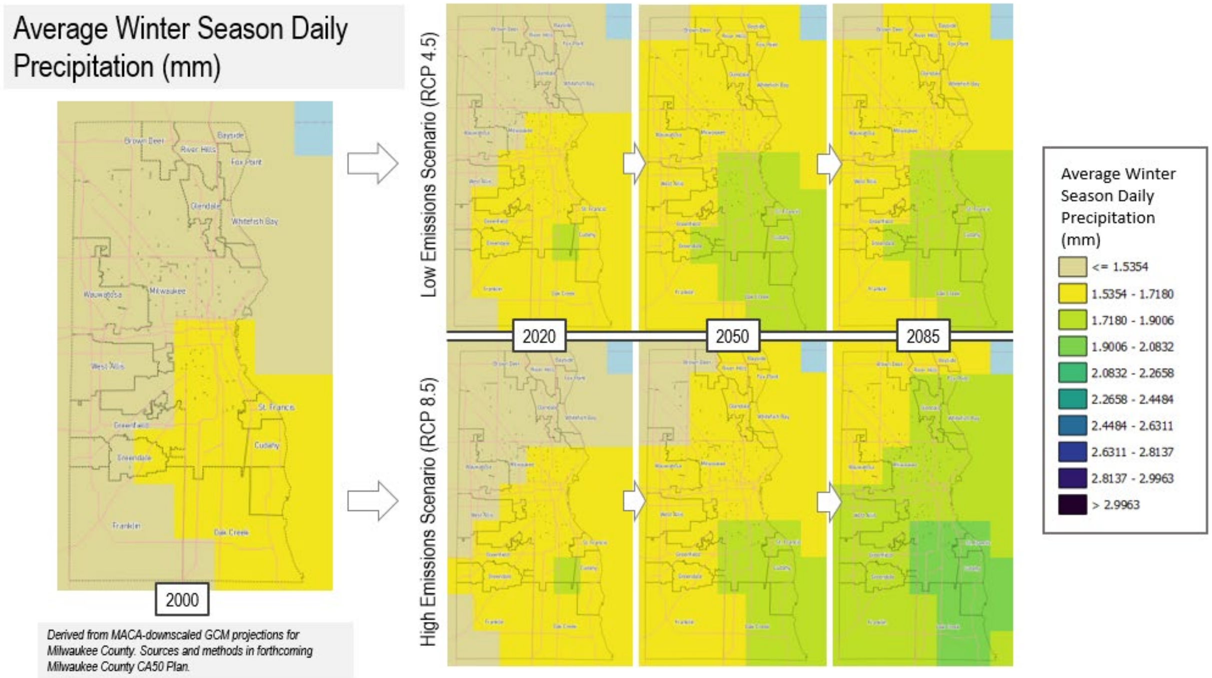

Figure 25. Historical and projected future average daily winter precipitation across Milwaukee County.

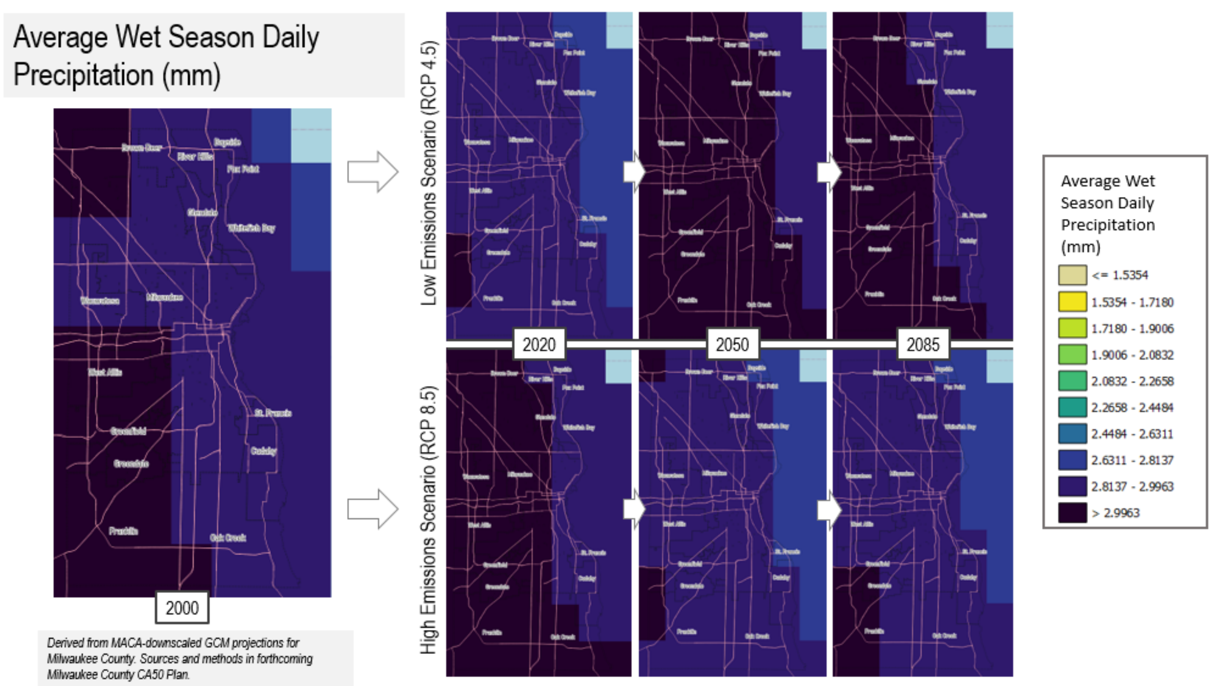

Figure 26. Historical and projected future average daily wet season precipitation across Milwaukee County.

Appendix D: SVI and Temperature Projections

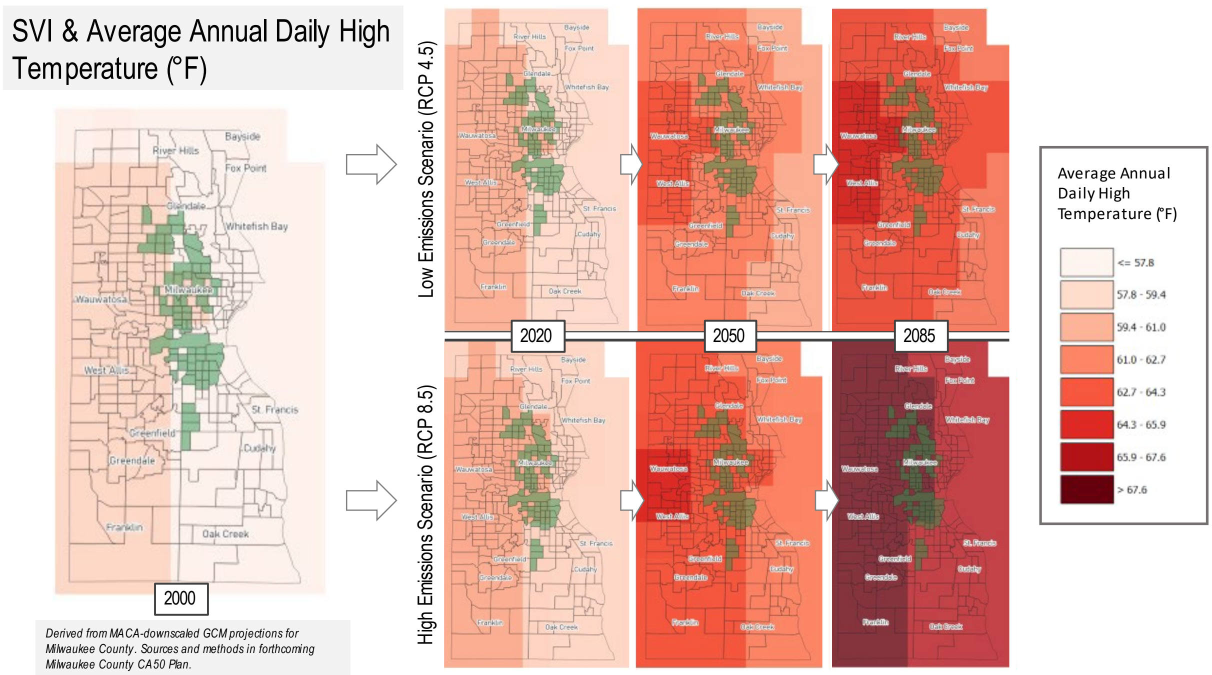

Figure 27. SVI overlaid with historical and projected future average annual daily high temperatures across Milwaukee County.

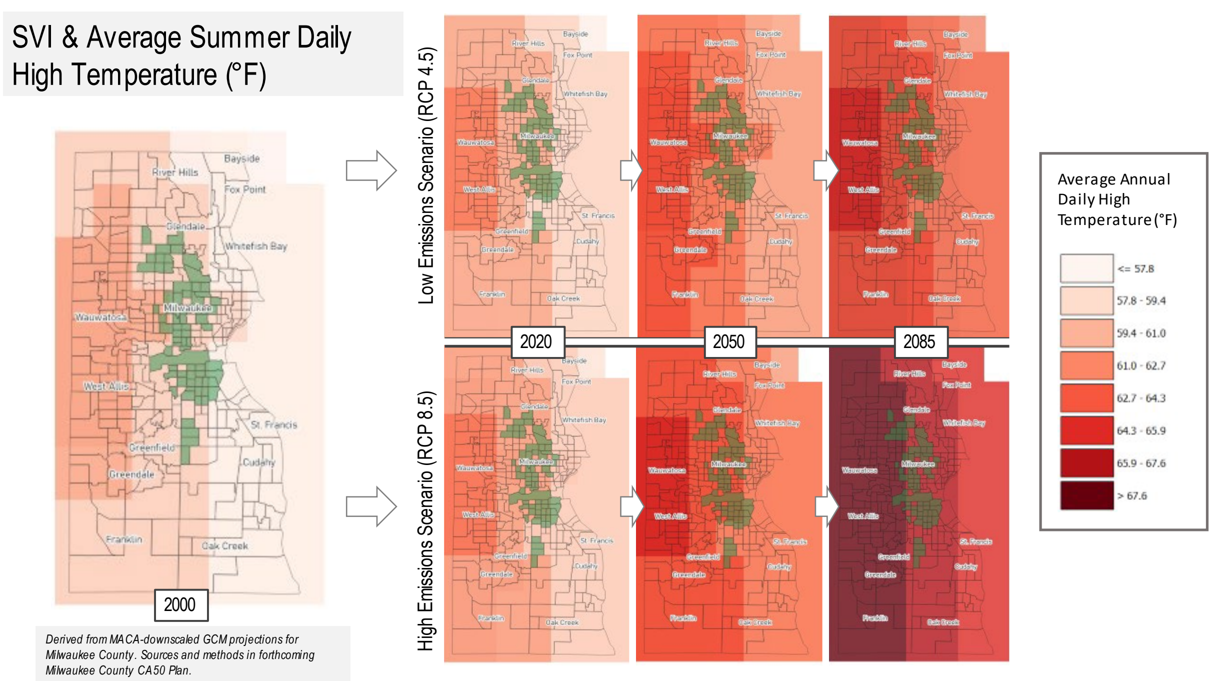

Figure 28. SVI overlaid with historical and projected future average annual daily summer high temperatures across Milwaukee County.

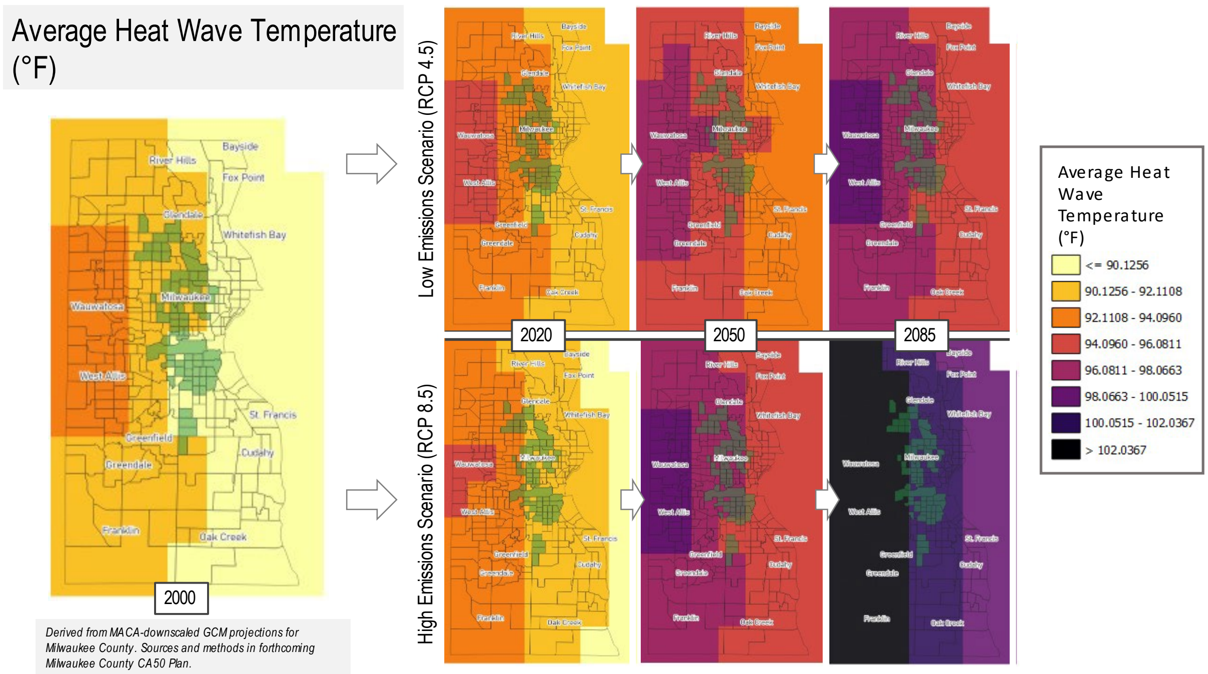

Figure 29. SVI overlaid with historical and projected future average annual heat wave temperatures across Milwaukee County.

Appendix E: Interconnected Systems

Cascading Impacts: Grid Resilience

Milwaukee's primary climate concerns over the coming decades are increased heat waves and high temperatures and increased extreme precipitation and flooding. In addition to direct primary impacts, these events can cause cascading secondary and cross-cutting impacts across multiple sectors and communities.

Heat waves can quickly cause increased energy and electricity demand as residents and building owners try to cool their homes and businesses. Heat can also reduce capacity for electricity transmission lines; coupled with high demand, this can lead to outages and diminished capacity. Power outages in the electricity sector can have cascading impacts for other energy sectors, including fuel production, delivery, and consumption, as well as power plant safety. Power outages during peak demand can also result in heat-related health concerns for residents, especially vulnerable residents who cannot pay high energy costs or whose buildings do not have AC (public housing, older buildings, etc.). This can be compounded by the fact that vulnerable communities do not have the same access to adequate healthcare, transportation, or cooling centers.

Hurricane Sandy

In 2012, Hurricane Sandy caused widespread damage and disruptions across the Northeast, which carried cascading impacts for many weeks to come, in regions well beyond NY and NJ. Storm surge and high winds damaged power lines, substations, and distribution systems, while also shutting down ports and power plants across the Northeast. 8 million people in 21 states lost power, including residents as far west as Illinois and Tennessee. For some, the power outages lasted up to two weeks. The disruptions rippled through other sectors, causing interruptions in transportation networks, communication towers, wastewater treatment facilities, and healthcare services. Residents' lives and access to key services were upended, due mostly to large-scale disruptions to the power grid and the interconnected nature of the region's energy systems to all other sectors.

The key issue was that each of these sectors relied heavily on electricity and energy operations, which were ill-prepared to handle such widespread damage to their production and delivery networks. Power losses meant that fuel pumps couldn't operate, even when stocked with fuel. Electrical equipment failures affected fuel delivery to other areas, resulting in continued outages. In some cases, substantive effort was made to get fuel pumps and other power plants back online, only to be kept waiting by damaged ports or terminals. Several major tunnels into New York City flooded for the first time, causing substantial disruptions in fuel transportation and other crucial transportation for over two weeks. In the end, Hurricane Sandy exposed the region's deep vulnerability to interconnected damages from a major climate event, costing an estimated $50 billion dollars and directly resulting in the deaths of nearly 150 people.

Increased precipitation can cause increased wear on infrastructure over time, disrupting fuel delivery routes and resulting in delays and price increases. However, extreme precipitation and flooding will carry a high risk of disruptions in the energy sector, which can have far-reaching impacts into residents' lives. Flooding can result in the inundation of energy facilities, damage ports and fuel delivery networks, cause power outages that disrupt energy production and transmission, and damage critical roadways and infrastructure.