Transportation Resilience Improvement Plan

Risk-based Vulnerability Assessment

Chicago Metropolitan Agency for Planning

ICF

Executive summary

Building resilience for northeastern Illinois' transportation system

Northeastern Illinois is feeling the effects of climate change. More intense storms are worsening flooding, making roads impassable, causing transit service delays, and damaging critical infrastructure. Temperatures are also on the rise, resulting in more frequent and intense heatwaves that can harm travelers and disrupt transit. In the future, these impacts are projected to become more frequent and intense across the region.

As the federally designated metropolitan planning organization for northeastern Illinois, the Chicago Metropolitan Agency for Planning (CMAP) seeks to improve the transportation network's resilience to extreme weather and climate change. To do this, CMAP is developing a Transportation Resilience Improvement Plan (TRIP) that will identify transportation assets vulnerable to climate change and prioritize them for equitable resilience investments.

TRIP will inform transportation planning and decision making at CMAP and throughout the region. It will also meet the Federal Highway Administration's Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Program requirements — and position northeastern Illinois to compete for PROTECT funds as well as other resilience funds.

Risk-based vulnerability assessment

The first phase in developing TRIP is to assess climate risks to and vulnerabilities of the transportation system by:

- Evaluating recent trends and latest projections to understand future climate change
- Identifying which components of the transportation system are most likely to be impacted by climate-related events
- Determining clusters of transportation assets and climate risk across the region
- Assessing where extreme heat poses the most risk to transit riders

Key findings

Flooding poses the biggest threat, impacting all transportation infrastructure, service operations, and users:

- 34 percent of road miles studied have high or very high risk, meaning they could experience up to two or more feet of flooding during a 500-year flood event by mid-century.
- 64 percent of CTA bus stops and 47 percent of Pace bus stops are exposed to flooding.
- 36 percent of CTA stations and 31 percent of Metra stations are at risk of flooding.
- 28 percent of regional trails have high flood risks and 33 percent have very high flood risk. Many trails follow waterways and are particularly vulnerable to flooding.

Extreme heat and severe storms impact service operations and active transportation users. These hazards also threaten rail infrastructure, electrical service, and backup power.

However, not all transit riders are equally affected by heat:

- Heat vulnerability is influenced by extreme temperatures, social and health factors, and transit stop conditions.

- When accounting for these risk factors, more than half of bus stops and rail stations have high or very high transit rider vulnerability. Urban areas demonstrate higher vulnerability than non-urban areas, with higher concentrations in Chicago's south and west sides.

What's next

Following this vulnerability assessment, the next phase is to develop a regional Transportation Resilience Improvement Plan by late 2025. The vulnerability assessment supports regional transportation resilience planning by identifying and prioritizing resilience projects that will, in turn, be eligible for increased federal funding. CMAP and regional partners can also use the assessment data, which is available on CMAP's Data Hub, to inform more immediate transportation planning and programming activities that increase climate resilience throughout northeastern Illinois.

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1 Introduction

Northeastern Illinois is feeling the effects of climate change. More intense storms are worsening flooding, making roads impassable, causing service delays, and damaging critical infrastructure. Temperatures are also rising in the region, resulting in more frequent and intense heatwaves that can pose a health risk to travelers and disrupt transit operations. The Chicago Metropolitan Agency for Planning (CMAP) seeks to improve the resilience of the region's transportation network to extreme weather and climate change. CMAP is the federally designated metropolitan planning organization for northeastern Illinois — covering Cook, DuPage, Kane, Kendall, Lake, McHenry, and Will counties — and plays a key role in providing a reliable and safe transportation system that works for everyone.

1.1 Project purpose

CMAP and transportation agencies must understand current and future climate risks to advance the resilience of the transportation network in northeastern Illinois. The risk-based vulnerability assessment evaluates climate risks to the region's transportation network and identifies priority areas for resilience investments. This work represents a significant milestone in CMAP's overarching focus on resilience and implements a priority action from ON TO 2050, the region's comprehensive plan.

The assessment will also inform CMAP's Transportation Resilience Improvement Plan (TRIP). Through this plan, CMAP will identify and prioritize major vulnerable transportation assets and the investments needed to build resilience equitably. TRIP is intended to inform transportation planning and decision making; it will also position northeastern Illinois to be competitive for federal investment opportunities, including the Federal Highway Administration's (FHWA) Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Discretionary Grant Program, which provides a unique funding opportunity for increasing transportation resilience to natural hazards.[1]

1.2 Overview of approach

CMAP used current best practices as outlined in the FHWA's Vulnerability Assessment and Adaptation Framework and lessons learned from other transportation agencies to develop the risk-based vulnerability assessment approach.[2] In order to ensure the assessment provides a comprehensive understanding of climate risks to the region's transportation network, CMAP included the four key components described in Table 1.

[1] (FHWA 2022)
[2] (FHWA 2017)

Table 1. Components of CMAP's risk-based vulnerability assessment

Analysis	Description	Purpose
Climate analysis	Conducted a preliminary evaluation of recent trends and future projections for key climate hazards included in the assessment.	Provides the foundation for understanding future climate change (e.g., increased rainfall).
Vulnerability assessment part 1: System-level analysis	Screened priority asset categories for risk across the transportation system, assessing the sensitivity of various transportation system components to specific climate hazards.	Identifies the asset categories that are most likely to be at risk or impacted by climate-related events. Project resources will be focused on evaluating these categories.
Vulnerability assessment part 2: Asset-level analysis	Assessed the priority asset/hazard pairs identified in the system-level analysis to identify specific geographic areas, as well as individual assets (e.g., a road, rail segment, or bus stop) with particularly high risk to climate hazards. The asset-level analysis results will help CMAP and regional stakeholders prioritize resilience investments and identify the types of investments that may be most effective for reducing risk.	Determines the assets and asset clusters that are most at risk to climate hazards across the region.
Transit rider vulnerability analysis	Assessed factors that lead to increased vulnerability at transit points and identified potential resilience improvements to help reduce extreme heat risk to transit riders.	Provides an understanding of how increased heat will impact transit riders across the region.

Combined, these four components provide a comprehensive analysis of the most at-risk regional transportation assets and the locations where transit riders are the most likely to be impacted by heat events. The risk-based vulnerability assessment generates a risk score for each asset/hazard pair analyzed, and the transit rider vulnerability analysis creates heat risk scores for transit facilities throughout the region. This information will provide the foundation for TRIP, in which CMAP and its stakeholders will identify strategies that increase transportation infrastructure and transit rider resilience.

1.2.1 Stakeholder engagement

Effective transportation planning requires collaboration and communication with regional stakeholders. As such, CMAP conducted extensive stakeholder engagement throughout the risk-based vulnerability assessment to ground-truth findings and ensure that assessment outputs are useful to regional decision makers and stakeholders alike.

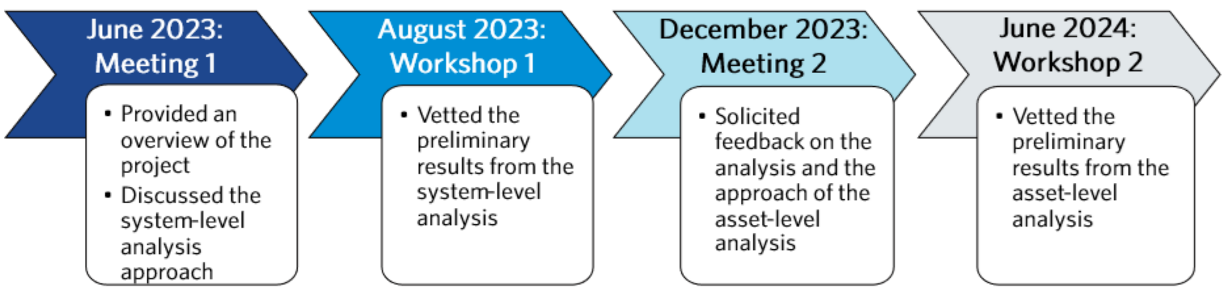
CMAP created a steering committee of individuals with expertise in transportation, emergency management, stormwater, climate resilience, equity, and mobility justice, who represent the seven counties in the CMAP region (see Table 2). CMAP also solicited input from steering committee members and other regional stakeholders through workshops, focus groups, interviews, and CMAP's public bodies.

Table 2. List of steering committee members

Steering committee members	
• American Association of Retired Persons (AARP) • Argonne National Laboratory • Chicago Department of Transportation • Chicago Transit Authority • Cook County Department of Transportation and Highways • DuPage County Division of Transportation • Equiticity • Illinois Department of Transportation, District 1 • Kane County Division of Transportation	• Kendall County • Lake County Division of Transportation • McHenry County Division of Transportation • Metra • Metropolitan Water Reclamation District of Greater Chicago • Pace Suburban Bus • Will County Emergency Management Agency • Will County Department of Transportation

Figure 1 summarizes stakeholder engagement activities conducted throughout the development of the risk-based vulnerability assessment.

Figure 1. Stakeholder engagement activities



2 Risk-based vulnerability assessment

This section summarizes the four key components of the risk-based vulnerability assessment: climate analysis, system-level analysis, asset-level analysis, and transit rider vulnerability analysis. Together, these components provide a comprehensive understanding of climate risks to the region's transportation network.

2.1 Climate analysis

To better understand how climate hazards have and will continue to change in the region, CMAP evaluated historical climate conditions and future climate projections for select climate hazards. The findings from this analysis informed the scoring approach used in the asset-level analysis (see the asset-level analysis section for more details).

2.1.1 Methodology

The following hazards were included in the climate analysis:

- Extreme heat
- Extreme cold
- Precipitation and flooding (urban, riverine, coastal)
- Severe storms (rain, snow, ice, wind)
- Compounding hazards (severe storm followed by high heat and ice storm followed by a cold snap)

These hazards were identified as the greatest risks to the region's transportation network and the expectation is that they will worsen under future climate change.

CMAP analyzed extreme heat, extreme cold, and flooding quantitatively using projections from an ensemble of climate models. Changes in freeze-thaw cycling were evaluated as part of the extreme cold analysis. Severe storms and compounding hazards are more difficult to simulate using standard climate models, so CMAP analyzed these hazards qualitatively through a literature review.

Quantitative analysis: Heat, cold, precipitation, and flooding

CMAP used an ensemble of climate models and current best practices for estimating future climate conditions for the quantitative analysis.[3] CMAP analyzed climate projections for the following hazards, time periods, and emission scenarios:

- **Hazards:** Extreme heat, extreme cold (including freeze-thaw cycling), precipitation, and flooding (using precipitation data)
- **Time periods:** Observed (1985-2014), mid-century (2035-2064), late-century (2065-2094)
- **Emission scenarios:** Shared Socioeconomic Pathways (SSPs) 2-4.5 (medium emissions) and 5-8.5 (high emissions)

Flood modeling

Given that flooding is the primary regional concern and is expected to worsen over time, CMAP performed additional modeling and analysis on future flood events for all seven counties in the region. The analysis used an innovative two-dimensional Hydrologic Engineering Center River Analysis System (HEC-RAS 2D) framework with the direct rainfall method, integrating hydrology and

[3] (Eyring, et al. 2016)

hydraulics into a single model. HEC-RAS 2D includes the ability to directly represent precipitation on a grid within the model, streamlining the hydrologic modeling effort. The approach also allowed the model to account for spatial variability in the rainfall across the landscape and simulate runoff-routing physics based on high-resolution LiDAR topography.

The HEC-RAS 2D model creates flood depth rasters based on the model results. Four scenarios were run through the model, with six sets of flood depth rasters developed. All the modeling domains used the same rainfall depths for the four analyzed scenarios. These scenarios include:

- **Existing 100-year event** (1 percent annual chance): [4] a depth of 8.57 inches (based on Bulletin 75 rainfall)
- **Forecasted 100-year event**: a depth of 9.10 inches (based on projected one-day rainfall results for the mid-century high emissions scenario)
- **100-year change in depth raster** (i.e., the difference between the existing and forecasted)
- **Existing 500-year event** (0.2 percent annual chance): [5] a depth of 11.24 inches (based on Bulletin 75 rainfall)
- **Forecasted 500-year event:** a depth of 11.93 inches (based on the projected one-day rainfall results for the mid-century high emissions scenario)
- **500-year change in depth raster** (i.e., the difference between the existing and forecasted)

The results from the developed model provide planning-level estimates where future flood risk will likely increase. Note that this method does not account for storm sewer details or drainage. The focus was to identify more significant flood concerns, and therefore a more conservative approach was selected (e.g., this approach is similar to assuming storm sewers are operating at or above capacity).

Qualitative analysis: Severe storms and compounding hazards

Extreme events such as wind gusts and thunderstorms occur over small space and time scales, making them difficult to project with standard climate models. Therefore, CMAP conducted a literature review of more specialized modeling studies to understand how climate change may impact these types of extreme hazards in northeastern Illinois. The literature review included established and peer-reviewed scientific literature on severe storms and associated events such as heavy precipitation and wind gusts within the region.

2.1.2 Key Findings

Table 3 provides the high-level findings from the climate analysis, which include:

- Temperatures are expected to continue increasing in the future.
- Flooding events are expected to worsen as extreme precipitation events become more frequent and intense. The detailed findings from the climate analysis are included in Appendix A: Climate analysis findings.

[4] A 1 percent annual chance of occurrence means that it occurs on average once in every 100 years.
[5] A 0.2 percent annual chance of occurrence means that it occurs on average once in every 500 years.

Table 3. Climate hazard summary for northeastern Illinois

Hazard	Future conditions (high emissions scenario, SSP5-8.5)
Extreme heat	• Both average and extreme high temperatures are **expected to increase** in the future. • Average monthly temperature is **expected to increase** for all months of the year and the monthly average could increase by up to 7°F by mid-century and 11°F by late-century. • The number of days with extreme high temperatures and the frequency of heatwaves is **expected to increase**, with the annual average number of days with maximum temperature over 95°F increasing from 2 days historically to 18 days by mid-century and more than 45 days by late-century.
Extreme cold	• Extreme cold temperatures are **expected to occur less frequently** in the future. • The annual average number of days under 15°F is **expected to decrease** from about 5 days historically to 1 day by mid-century and 0 days by late-century. • Similarly, the annual average number of days with maximum temperature under 32°F is **expected to decrease** from 43 days historically to 23 days by mid-century and just 14 days by late-century. • **Freeze-thaw cycles are projected to decrease** approximately 7-9 percent by mid-century and 12-29 percent late-century.
Precipitation & flooding	• Flooding is **expected to worsen** in the future. • Total monthly precipitation is expected to decrease slightly in summer months and increase in the fall, winter, and spring. • The frequency and intensity of extreme precipitation events is **expected to increase**, with the amount of precipitation falling during the maximum 1-day precipitation event (e.g., event with the most precipitation falling in a 24-hour period) increasing by 8 percent by mid-century and 21 percent by late-century. • Two-dimensional modeling (HEC-RAS 2D) of future flooding indicates that the 100- and 500-year flood event is **expected to increase in severity** by 5-10 percent by mid-century.
Severe storms (rain, snow, ice, wind)	• There is consensus in the literature that climate change is **expected to drive an increase** in the frequency and severity of storms in northeastern Illinois. • Projected increases in severe storms will **drive an increase** in the risk of flooding, heavy precipitation, and extreme wind associated with these storms.
Compounding hazards	• Scenario 1: **Severe storm followed by high heat** — based on historical trends, climate projections, and a review of the existing literature, such a scenario is **more likely to occur, in terms of frequency and severity**. • Scenario 2: **Ice storm followed by a cold snap** — based on historical trends, climate projections, and a review of the existing literature, such a scenario is **more likely to occur, in terms of frequency and severity**.

2.2 System-level analysis

The system-level analysis allowed CMAP to conduct a preliminary screening of climate risks for multiple transportation asset categories. CMAP used the results of this analysis to identify priority asset/hazard pairs to assess in the more detailed asset-level analysis.

2.2.1 Methodology

CMAP reviewed asset categories that are major components of the regional transportation system and identified those likely to be impacted by climate events. The transportation asset categories were selected based on previously published work, expert knowledge, and past hazard impacts.

Table 4. Assets and hazards included in the system-level analysis

Focus transportation asset categories	
Roadways	CTA and Pace bus service and stops
Bridges (road and rail) and culverts	CTA and Pace bus facilities
Roadway facilities	Electrical services and backup power
CTA and Metra rail lines and stations	Bicycle and pedestrian facilities
CTA and Metra rail facilities	
Focus climate hazards	
Extreme heat	Freeze-thaw cycling
Extreme cold	Severe storms (rain, snow, ice, wind)
Precipitation & flooding (urban, riverine, coastal)	

CMAP analyzed the sensitivity of each of these asset-hazard pairs on a low, medium, and high scale across two dimensions:

- The sensitivity of the **physical infrastructure**
- The sensitivity of **service operations and user experience**

Table 5 and Table 6 show the rating scales used for physical infrastructure and service operations/user experience, respectively.

Table 5. Physical infrastructure sensitivity rating scale

Low	When exposed to the hazard, the infrastructure suffers minor to no damage and maintains functionality.
Medium	When exposed to the hazard, the infrastructure suffers damage requiring repairs to resume full functionality.
High	When exposed to the hazard, the infrastructure is severely damaged or destroyed and cannot resume normal function until extensive repairs or replacement are made.

Table 6. Service operations and user experience sensitivity rating scale

Low	When exposed to the hazard, there is minimal to no impact to service or no discomfort to users/workers/operators.
Medium	When exposed to the hazard, service is disrupted or suspended for up to a day. Or, hazard exposure causes discomfort for users/workers/operators, but minimal threat to safety.
High	When exposed to the hazard, service is suspended for more than 24 hours and disruptions may continue for days to weeks after the event as infrastructure repairs are made. Or, hazard poses risk of illness, injury, or death to users/workers/operators.

2.2.2 Key findings

The sensitivity ratings for each asset category and hazard pair are summarized in Table 7, which include:

- Both physical transportation infrastructure and service operations and users tend to be most sensitive to flooding.
- Service operations and users are also highly sensitive to extreme heat and severe storms.
- Multiple asset categories have a high sensitivity to flooding, indicating that this hazard is of particular concern for northeastern Illinois.
- CTA and Metra rail lines and stations, and CTA and Pace bus service and stops, have high sensitivity to multiple hazards. However, certain individual assets will be more affected than others.

For the details underlying these sensitivity scores, please see Appendix B: System-level analysis sensitivity for details.

Table 7. Summary system-level analysis results for northeastern Illinois

	Extreme heat		Extreme cold		Flooding (urban, riverine, coastal)		Freeze-thaw cycling		Severe storms (rain, snow, ice, wind)	
	I	S	I	S	I	S	I	S	I	S
Roadways	M	M	L	M	H	H	M	L	M	M
Bridges and culverts	M	L	L	M	H	H	M	L	M	M
Roadway facilities[6]	L	M	L	M	L	L	N/A	N/A	L	M
CTA & Metra rail lines and stations	H	H	H	H	H	H	M	L	M	H
CTA & Metra rail facilities[7]	M	M	L	M	M	M	L	N/A	M	M
CTA & Pace bus service and stops[8]	M	H	M	H	M	H	N/A	L	L	H
CTA & Pace bus facilities[9]	M	M	M	M	M	L	L	N/A	M	M
Electrical services and backup power	H	H	M	M	H	M	N/A	N/A	H	H
Bicycle and pedestrian facilities	M	H	M	H	H	H	L	L	M	H

I = Physical infrastructure sensitivity rating
S = Service operations and user experience sensitivity rating
N/A = Asset category/operation is unaffected by the hazard

Low = Low sensitivity
Medium = Medium sensitivity
High = High sensitivity

2.2.3 Recommendations for the asset-level analysis

CMAP used the following criteria to determine which asset/hazard pairs should be assessed in the asset-level analysis:

- Physical infrastructure sensitivity: All pairs that received a high rating were assessed

[6] Roadway facilities include any buildings, vehicles, and equipment that are used to maintain and repair roadways. Service impacts to roadway facilities include impacts to roadway facility workers.
[7] CTA and Metra rail facilities include any buildings, vehicles, and equipment that are used to maintain the CTA and Metra rail trains, lines, and stations. This includes switch yards. Service impacts for this category include impacts to rail facility workers.
[8] CTA and Pace bus service and stops include the Pace ADA paratransit service. Impacts to bus routes that are a result of damage or disruption to the road are considered under the roadways category. Service impacts to CTA bus service and stops include impacts to workers/operators as well as passengers.
[9] CTA and Pace bus facilities include any buildings, vehicles, and equipment that are used to maintain the CTA and Pace buses, routes, and stops. Service impacts to this category include impacts to bus facility workers.

- Service operations and user experience sensitivity: With discretion, pairs that received a high rating were assessed
- Data availability: e.g., severe storms and electrical services and backup power were not assessed due to data limitations)

Based on the system-level analysis findings, the following asset/hazard pairs were assessed in the asset-level analysis:

- Extreme heat
    - CTA and Metra rail lines and stations
    - CTA and Pace bus service and stops
- Extreme cold
    - CTA and Metra rail lines and stations
    - CTA and Pace bus service and stops
- Flooding
    - Roads
    - Bridges and culverts
    - CTA and Metra rail lines and stations
    - CTA and Pace bus service and stops
    - Bicycle and pedestrian facilities

2.3 Asset-level analysis

Whereas the system-level analysis assessed the general sensitivity of asset categories and services to various climate hazards, the asset-level analysis assessed extreme heat, extreme cold, and flooding risks to individual assets (e.g., a road, rail segment, or bus stop). This analysis helped identify high-risk assets that could be prioritized for resilience investments. Additionally, the asset-level analysis helped target the factors driving high risk scores which can, in turn, help shed light on the types of investments that may be most effective for reducing climate risks to transportation infrastructure.

2.3.1 Methodology

CMAP calculated the total risk score for each asset based on exposure and criticality using the equation below.

$$\text{Risk Score} = (\text{Exposure Score})(60\%) + (\text{Criticality Score})(40\%)$$

In this analysis, risk is defined as the weighted combination of asset exposure and criticality. Assets with high exposure and criticality are considered highly vulnerable to climate hazards. Exposure is weighted higher than criticality because it is the main driver of climate-related impacts. Additionally, the exposure indicators used in the analysis are adjusted to consider future climate conditions, while the criticality indicators are based solely on historical data.

See the glossary for more detailed definitions of exposure, criticality, and vulnerability. For more details on the methodology used for this analysis, see Appendix C: Asset-level analysis methodology details.

As noted in Table 8, asset categories where all of the assets were deemed critical were only scored on exposure (e.g., a section of a rail line is needed for the full line to function). In those cases, exposure made up 100 percent of the risk score (see Appendix C: Asset-level analysis methodology details). The scoring approaches used for each asset/hazard pair analyzed in the asset-level analysis are summarized in the right two columns of Table 8.

Table 8. Risk scoring approaches used for asset/hazard pairs in the asset-level analysis

Hazard	Assets	Risk scoring approach	
		Exposure	Criticality
Flooding	Roads	✓	✓
	Bridges (roadway only)/culverts	✓	✓
	CTA and Metra rail stations	✓	✓
	CTA and Metra rail lines	✓	
	CTA and Metra rail yards	✓	
	CTA and Pace bus stops and Pace ADA transfer points	✓	✓
	CTA and Pace bus routes	✓	✓
	CTA and Pace bus garages	✓	
	Regional trails[10]	✓	✓
Extreme heat	CTA and Metra rail stations	✓	✓
	CTA and Metra rail lines	✓	
Extreme cold	CTA and Metra rail stations	✓	✓
	CTA and Metra rail lines	✓	

Table 9 shows the breakdown of risk scoring and the associated risk ranges.

Table 9. Final risk score thresholds

Final risk rating	Risk score value
Not exposed	0
Low	1.0 – 1.49
Medium	1.5 – 1.99
High	2.0 – 2.49
Very high	2.5 – 3.00

Extreme cold temperatures are expected to occur less frequently in the future, and the asset-level analysis found that neither rail stations nor rail lines are at risk of new extreme cold impacts. The results for the extreme cold analysis are therefore not included in the key findings below. The extreme cold analysis methodology and results are summarized in Appendix D: Extreme cold analysis.

2.3.2 Key findings

The following sections provide a summary of the results by hazard and asset types. Note that the flood depth thresholds discussed in this section were determined based on the level of safe driving conditions for passenger vehicles. See Appendix C: Asset-level analysis methodology details for more information.

[10] A subset of bicycle and pedestrian facilities were assessed in the asset-level analysis, as the data indicated that on-road bike infrastructure and sideways are largely covered by the roads analysis. Regional trails are defined as existing regional bikeways and multi-use trails in the Northeastern Illinois Regional Greenways and Trails Plan, https://cmap.illinois.gov/focus-areas/transportation/walking-and-biking/greenways-and-trails

Flooding: Roads

- Of the approximately 8,400 miles of road in northeastern Illinois, 5,931 miles (70 percent) could experience at least 0.5 feet of flooding during a 500-year flood event by mid-century.[11, 12]
- 2,471 miles of road (29 percent) have high flood risk and 393 miles of road (5 percent) have very high flood risk (see Figure 2).
- Table 10 shows the county-level results for total road miles scored with high and very high flood risk and respective percentages compared to the total road miles in each county.
- Most high- and very high-scoring roadways have experienced past flooding and/or could experience two feet or more of flooding during a 500-year flood event by mid-century.
- Figure 3 shows the high and very high flood risk results for the entire region. Very high-scoring road segments are concentrated in Cook County but occur throughout the region. There are also clusters of very high-scoring road segments in Waukegan, Joliet, and Elgin. All counties except Kendall County have at least some very high-scoring segments.

Figure 2. Breakdown of flood risk scores for roads in miles

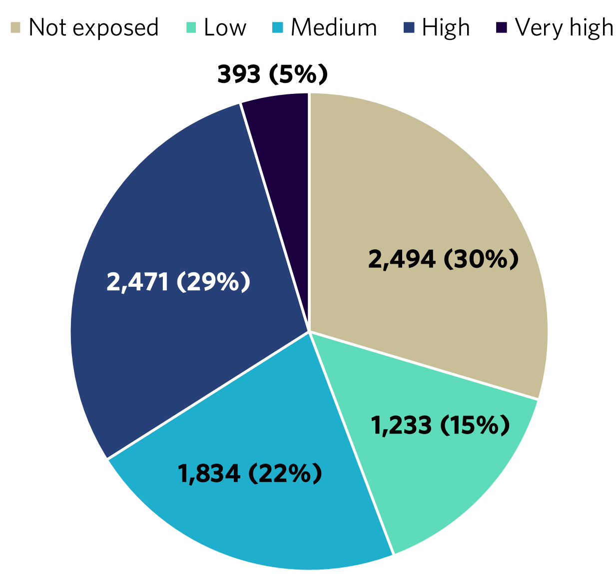


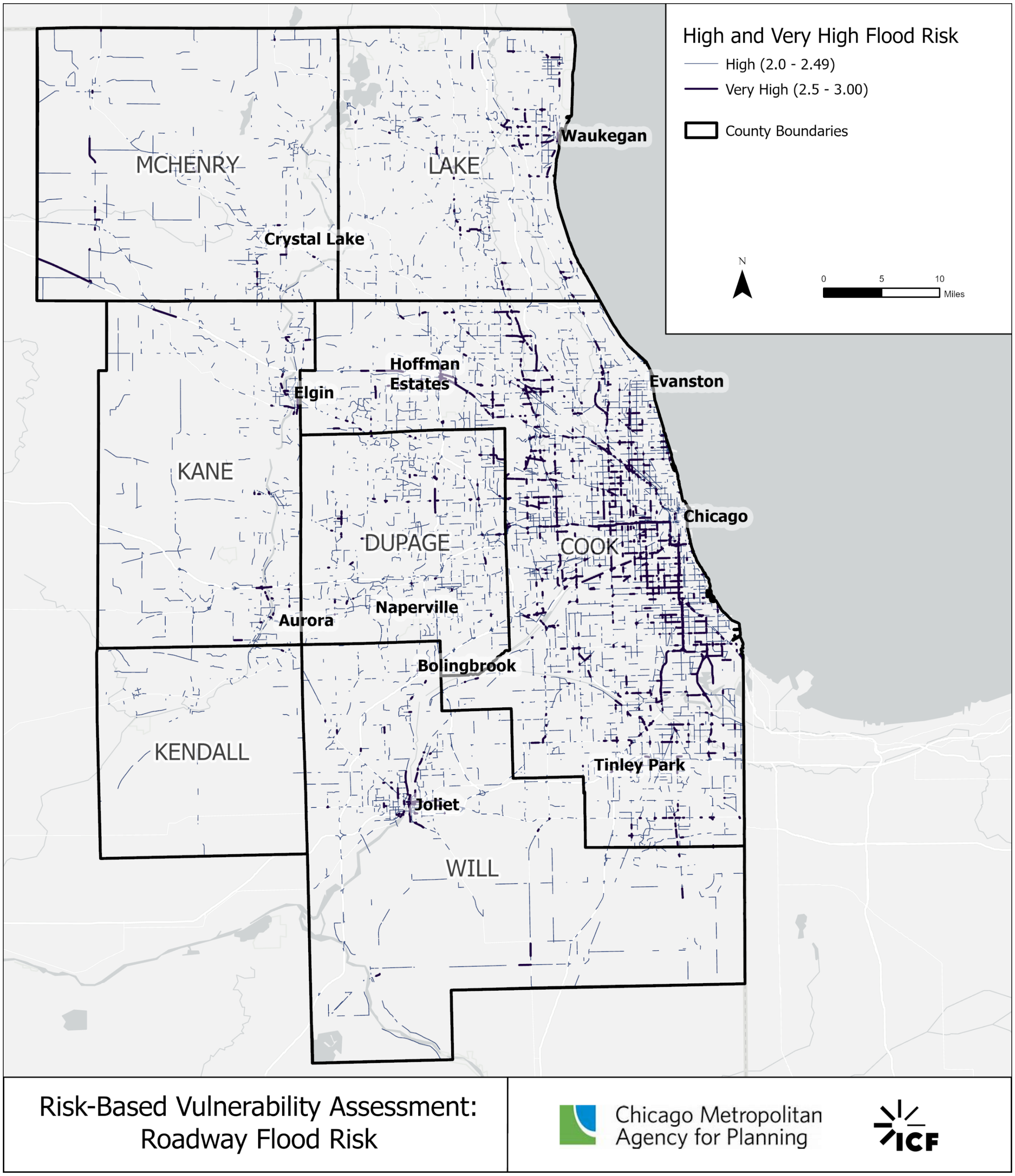
Table 10. County-level breakdown of high and very high flood risk scores for roads in miles

County	Score	Miles	Percent of county miles
Cook	High	1,215	35%
	Very high	312	9%
DuPage	High	278	28%
	Very high	13	1%
Kane	High	198	23%
	Very high	13	2%
Kendall	High	47	15%
	Very high	0	0%

[11] The analysis for roads excludes the local road functional classification.
[12] The 500-year flood event has a 0.2 percent annual chance of occurring. The current 500-year flood event corresponds to 11.24 inches of rain falling in a 24-hour period, and the projected 500-year event for mid-century corresponds to 11.93 inches of rain falling in a 24-hour period. This represents an increase of 0.69 inches

Lake	High	238	24%
	Very high	20	2%
McHenry	High	216	31%
	Very high	12	2%
Will	High	280	26%
	Very high	22	2%

Figure 3. Map of roads with high and very high flood risk scores



Flooding: Bridges (roadway only) and culverts

- Bridges and culverts are designed to withstand flooding to a certain extent. However, culverts tend to be more vulnerable as they are designed to carry lower flows and require more frequent maintenance. Of the 3,038 bridges and 1,329 culverts in the region, 467 (15 percent) of bridges and 524 (39 percent) of culverts are exposed to flooding (Figure 4).
- 216 (7 percent) bridges and 234 (18 percent) culverts have high flood risk, while 17 (1 percent) bridges and 19 (1 percent) of culverts have very high flood risk.
- Table 11 shows county-level results for bridges and culverts with high and very high flood risk and respective percentages of the total assets in each county. All the very high-scoring assets have previously experienced flooding and/or could experience two feet or more of flooding during a 500-year flood event by mid-century.
- Figure 5 shows the high and very high flood risk results for the entire region. Most very high-scoring bridges/culverts are in Cook County, especially in the south and west suburbs. There are also clusters of very high-scoring bridges/culverts in Aurora, Elgin, Joliet, Naperville, and Waukegan. While Cook County has the greatest number, all counties except Lake have a higher percentage of high-scoring bridges.

Figure 4. Breakdown of flood risk scores for bridges and culverts

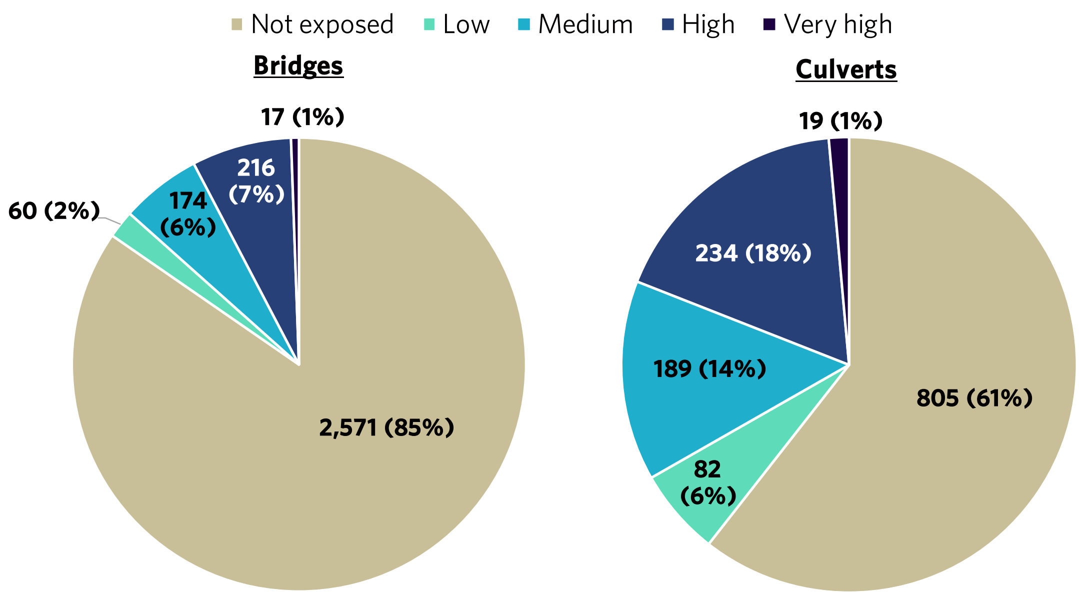
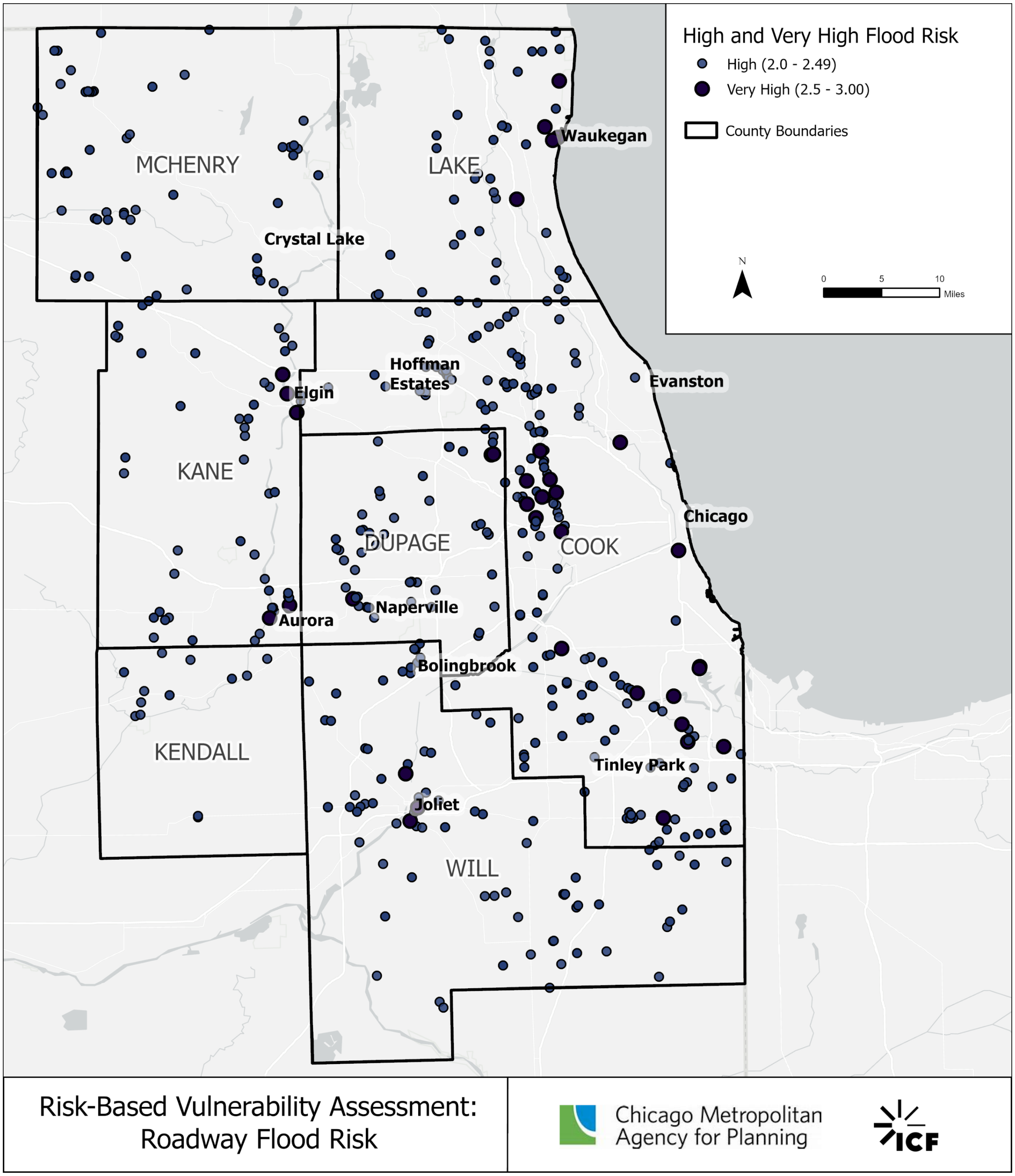


Table 11. County-level breakdown of high and very high flood risk scores for bridges and culverts

County	Score	Bridges		Culverts	
		Count	Percent	Count	Percent
Cook	High	76	5%	91	23%
	Very high	9	1%	11	3%
DuPage	High	27	10%	19	16%
	Very high	1	0%	2	2%
Kane	High	29	12%	19	14%
	Very high	5	2%	0	0%
Kendall	High	8	8%	5	6%
	Very high	0	0%	0	0%
Lake	High	11	5%	28	18%
	Very high	1	0%	4	3%
McHenry	High	24	15%	31	20%
	Very high	0	0%	0	0%
Will	High	41	8%	41	15%
	Very high	1	0%	2	1%

Figure 5. Map of bridges and culverts with high and very high flood risk scores

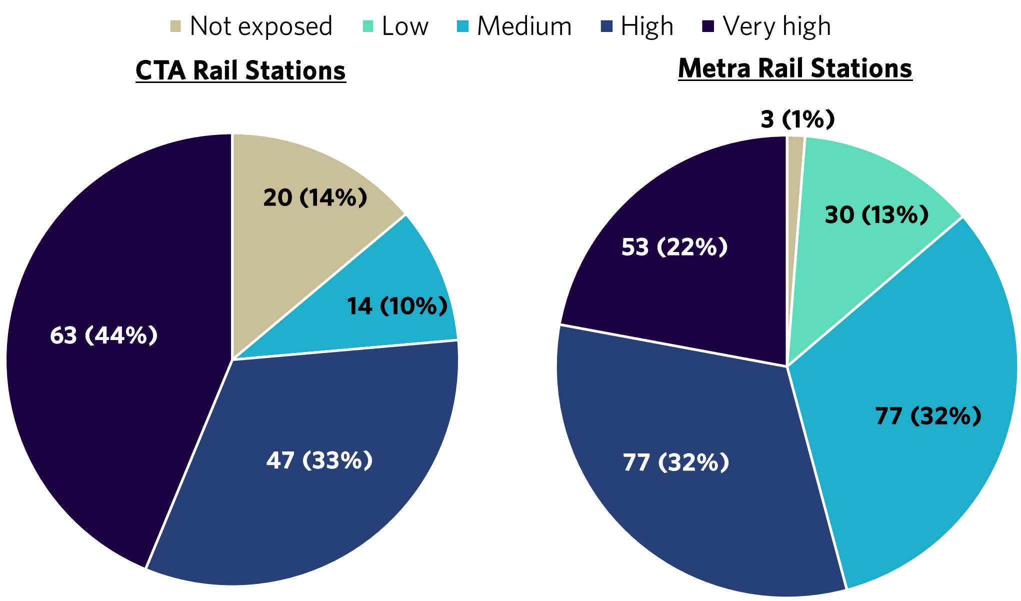


Extreme Heat: CTA and Metra rail lines and stations

Rail stations[13]

- Figure 6 compares the breakdown of extreme heat risk results for CTA rail stations to Metra rail stations. Not exposed stations are located underground.
- About 77 percent of CTA's rail stations have high (33 percent) or very high (44 percent) extreme heat risk, and over half of Metra's rail stations have high (32 percent) or very high (22 percent) extreme heat risk.
- All CTA and Metra stations with very high risk scores are located in areas that are projected to experience over 20 days per year with maximum temperatures over 95°F by mid-century.
- The number of stations with very high extreme heat risk is similar for both agencies (63 for CTA and 53 for Metra), but the CTA has a higher percentage basis. This difference is primarily driven by the criticality scores for the two agencies — CTA has a higher percentage of stations with high social vulnerability scores and more of CTA's stations are located in regional freight or employment clusters.

Figure 6. Breakdown of extreme heat risk scores for CTA and Metra rail stations



Rail lines[14]

- The extreme heat risk scores for rail line segments are solely determined by the level of heat exposure for the segment (i.e., the number of days with maximum temperature above 95°F by mid-century). Rail line segments that are not exposed to extreme heat are located underground. For the purposes of this analysis, rail lines were split into segments at rail stations and where elevation status changes (i.e., subway to ground level).
- Most (89 percent) of CTA's rail lines and over half (55 percent) of Metra's rail lines have high extreme heat risk. Three miles (3 percent) of CTA's rail lines and 80 miles (16 percent) of Metra's rail lines have very high extreme heat risk (see Figure 7).

[13] This analysis does not consider whether stations have air conditioning, which could reduce their level of risk.
[14] This analysis only considers temperature and not track condition, which is an important risk factor.

- All of CTA's exposed rail lines score high or very high. This is because CTA's lines are concentrated in downtown Chicago, where the number of days with maximum temperatures over 95°F are expected to be highest by mid-century, ranging from almost 18 days to over 22 days.

Figure 7. Breakdown of extreme heat risk scores for CTA and Metra rail lines in miles

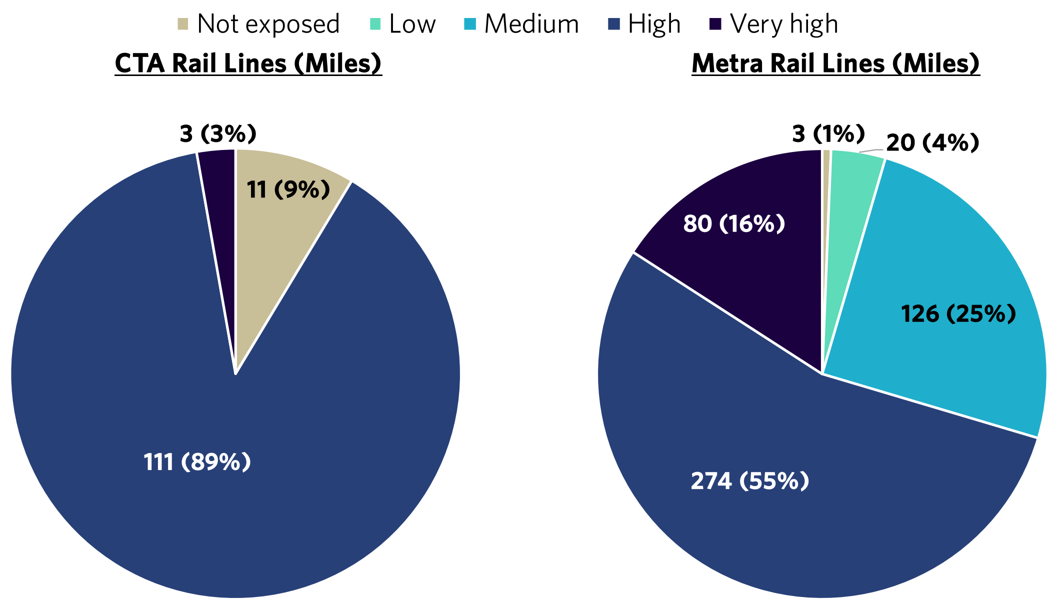


Figure 8 and Figure 9 show the extreme heat risk scores for rail lines and stations for CTA and Metra, respectively. For CTA, almost all exposed assets received high and very high scores and are therefore evenly distributed throughout the region. For Metra, most high and very high-scoring assets are in Chicago and the south/southwest suburbs. There are clusters of very high-scoring Metra rail stations in Chicago and south of Chicago. For Metra rail lines, two very high-scoring lines converge north of Tinley Park (the SouthWest Service and Rock Island lines) and one very high-scoring line goes out to Aurora (the BNSF line).

Figure 8. Map of extreme heat scores for CTA rail lines and stations

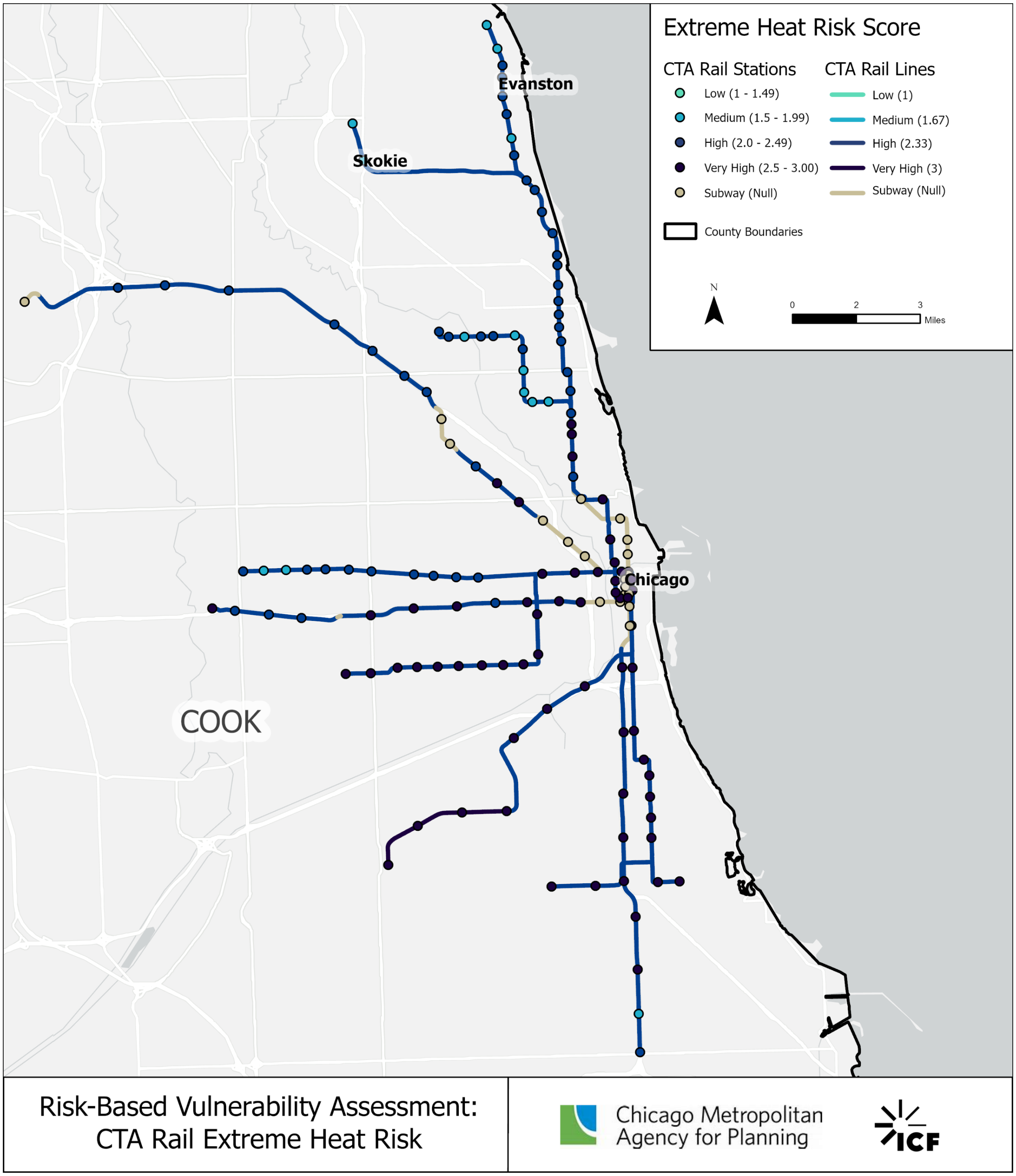
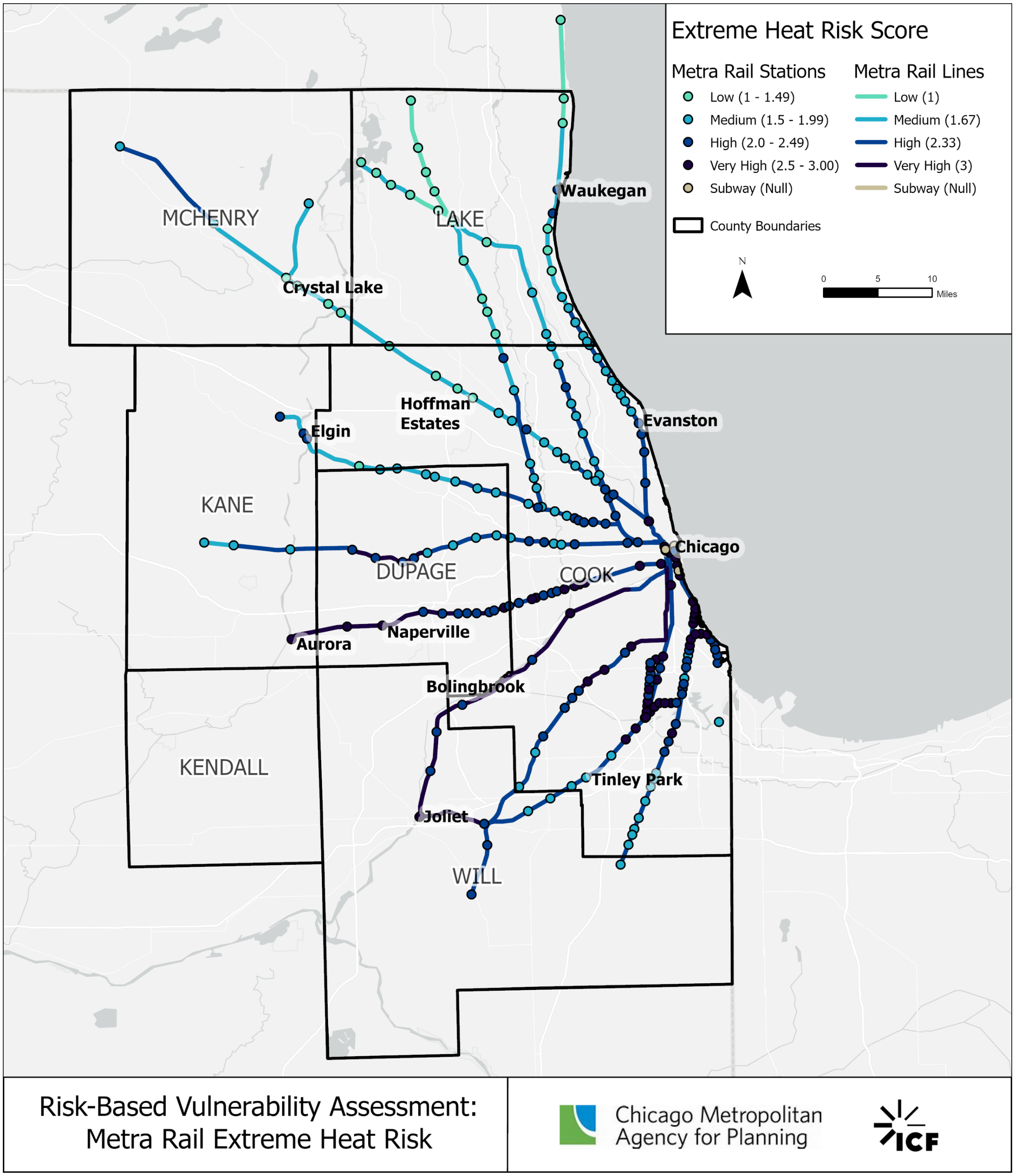


Figure 9. Map of extreme heat scores for Metra rail lines and stations

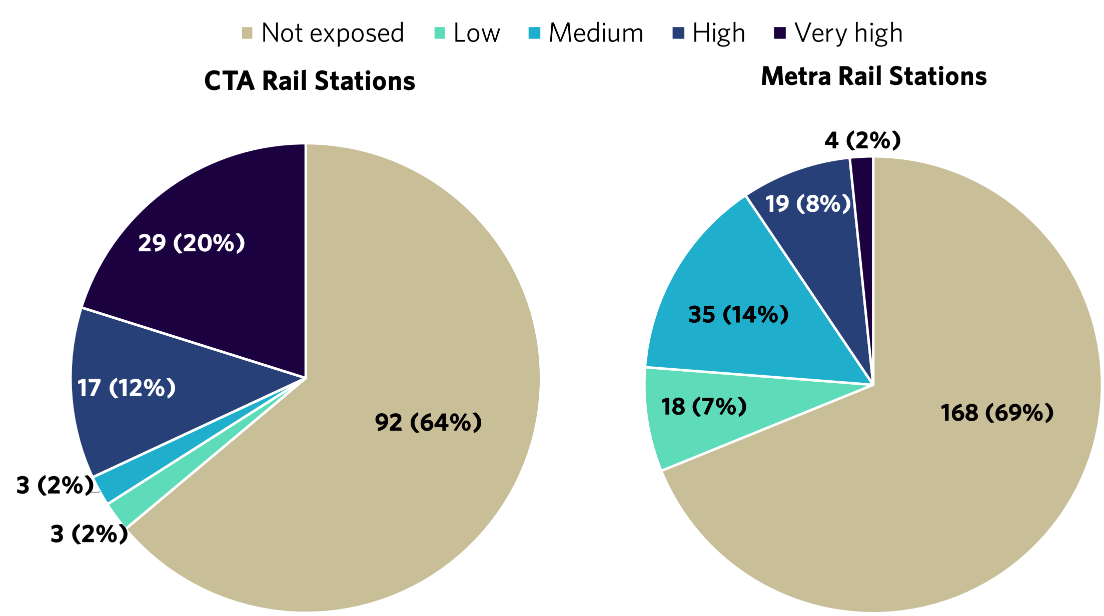


Flooding: CTA and Metra rail lines, stations, and yards

Rail stations

- Figure 10 shows the breakdown of flood risk results for CTA rail stations and Metra rail stations. 52 (36 percent) of CTA's rail stations and 76 (31 percent) of Metra's rail stations are exposed to flooding.
- For CTA rail stations, 17 (12 percent) have high flood risk and 29 (20 percent) have very high flood risk. For Metra rail stations, 19 (8 percent) have high flood risk and 4 (2 percent) have very high flood risk.
- All CTA and Metra stations with very high flood risk scores are in areas that could experience at least 1.2 feet of flooding during a 500-year flood event by mid-century. Additionally, most very high-scoring stations for both agencies are located in regional freight or employment clusters. The extent to which these areas rely upon transit riders is ripe for future exploration.
- CTA has more very high-scoring stations than Metra because it has more of both subway stations (20, while Metra has 4 below grade stations) and rail stations with high social vulnerability scores.

Figure 10. Breakdown of flood risk scores for CTA and Metra rail stations

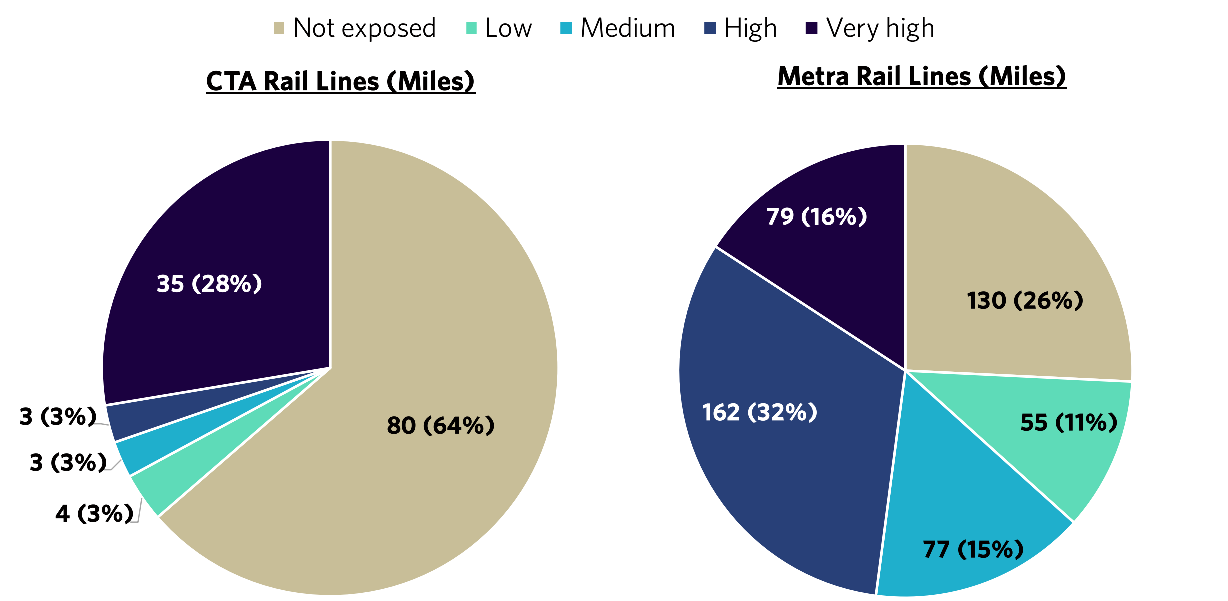


Rail lines

- The flood risk scores for rail line segments are solely determined by the level of flood exposure for the segment. Exposed rail segments either have past flood experience or are expected to be inundated during a 500-year flood event by mid-century. Rail line segments that are not exposed to flooding are elevated/above grade. For the purposes of this analysis, rail lines were split into segments between at-grade rail stations. 45 miles (37 percent) of CTA's rail lines and 373 miles (74 percent) of Metra's rail lines are exposed to flooding.
- Three miles (3 percent) of CTA's rail lines have high flood risk and 35 miles (28 percent) of CTA's rail lines have very high flood risk (see Figure 11).
- 162 (32 percent) of Metra's rail lines have high flood risk and 79 miles (16 percent) of Metra's rail lines have very high flood risk.

- Metra has more miles of rail lines with high flood risk, meaning that more of Metra's rail lines are expected to experience approximately 3.5 feet or more of flooding during the 500-year flood event by mid-century.
- Although Metra has a greater number of very high-scoring rail line miles than CTA, on a percentage basis, very high-scoring rail lines miles are higher for CTA. Very high-scoring rail line segments are expected to experience approximately 9.5 feet or more of flooding during the 500-year flood event by mid-century.

Figure 11. Breakdown of flood risk scores for CTA and Metra Rail Lines in Miles



Rail yards

- The flood risk scores for rail yards are solely determined by the percent of flooded area at the yard. Exposed rail yards either have past flood experience or part of the yard is expected to be inundated during a 500-year flood event by mid-century. All 11 of CTA's rail yards and 24 (96 percent) of Metra's rail yards are exposed to some level of flooding.
- Five (45 percent) of CTA's rail yards and nine (36 percent) of Metra's rail yards have very high flood risk (see Figure 12).
- Although Metra has a greater number of yards with very high flood risk, on a percentage basis, CTA has more very high-scoring yards. These results reflect that a higher percentage of CTA's rail yards either have past flood experience or at least 37 percent of the yard is expected to be inundated during the 500-year flood event by mid-century.

Figure 12. Breakdown of flood risk scores for CTA and Metra rail yards

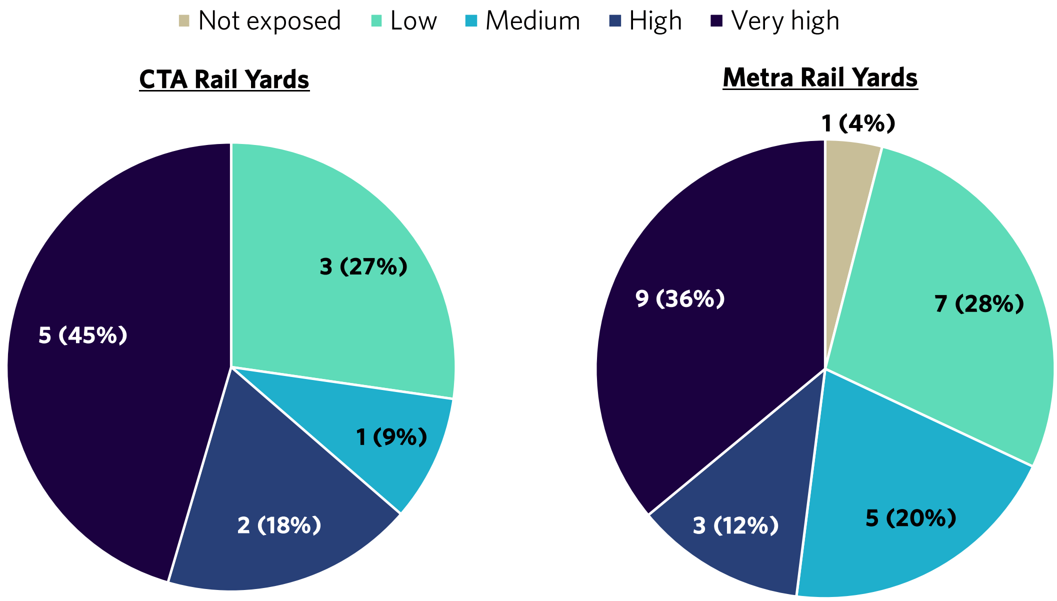


Figure 13 and Figure 14 show the flood risk scores for rail lines, stations, and yards for CTA and Metra, respectively. For CTA, very high-scoring rail stations are located in the Loop and on both the west and south sides of Chicago. Very high-scoring rail yards and lines are also located on the south side (Red Line Dan Ryan branch) and west/southwest sides of Chicago (Blue Line Forest Park branch and Pink Line). Very high-scoring CTA rail yards are relatively evenly distributed throughout the region. For Metra, very high-scoring rail stations and yards are relatively evenly distributed throughout the region.

Figure 13. Map of flood scores for CTA rail lines, stations, and yards

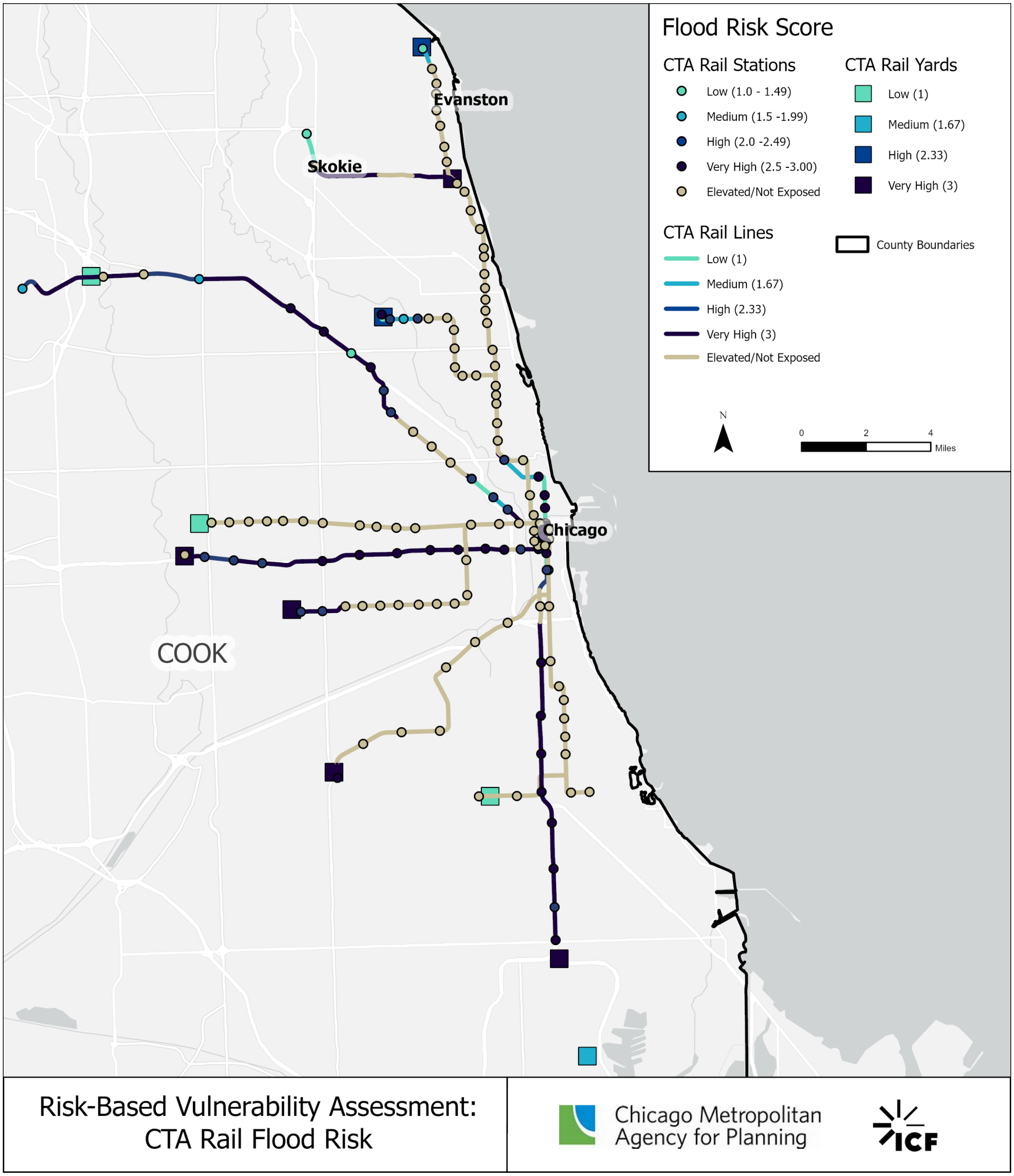
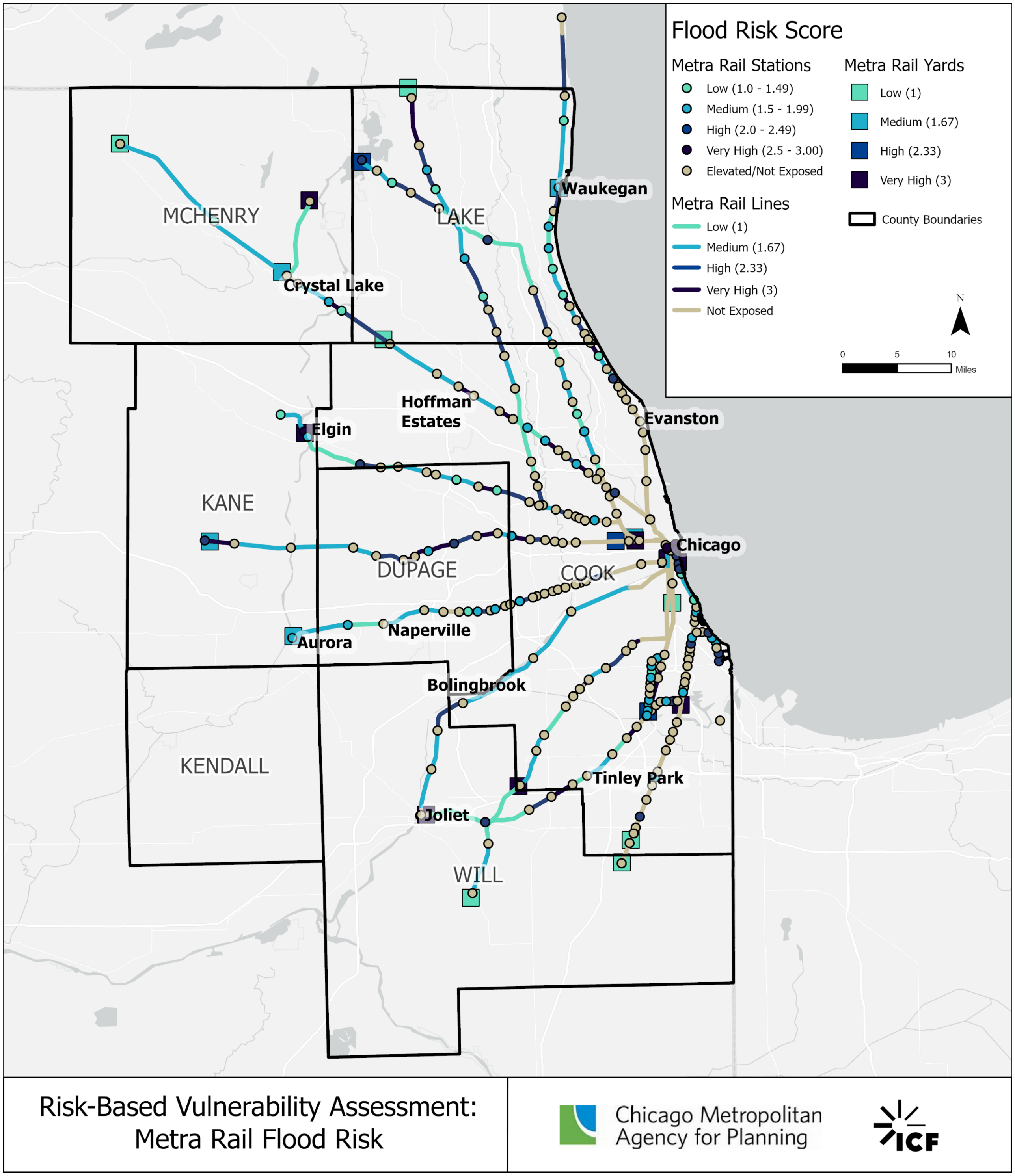


Figure 14. Map of flood scores for Metra rail lines, stations, and yards



Flooding: CTA and Pace bus stops, routes, and garages

Bus stops

- Figure 15 shows the breakdown of flood risk results for CTA and Pace bus stops. 6,826 (64 percent) of CTA's bus stops and 6,687 (47 percent) of Pace's bus stops are exposed to flooding. Pace bus stops include 58 ADA transfer points, of which 25 (43 percent) are exposed to flooding.
- For CTA bus stops, 2,736 (25 percent) have high flood risk and 432 (4 percent) have very high flood risk. For Pace bus stops, 2,079 (15 percent) have high flood risk and 116 (1 percent) have very high flood risk. Twelve of the high-scoring Pace bus stops and eight of the very high-scoring Pace bus stops are ADA transfer points.
- All bus stops with very high flood risk scores either have past flood experience and/or are expected to experience at least 1.8 feet of flooding during the 500-year flood event by mid-century. Additionally, almost all very high-scoring bus stops have high social vulnerability scores and are located in regional freight or employment clusters. The extent to which these areas rely upon transit riders is ripe for future exploration.
- CTA has more very high risk bus stops than Pace, driven primarily by flood exposure scores. CTA bus stops are expected to experience greater flood depths in the future and/or have experienced past flooding.

Figure 15. Breakdown of flood risk scores for CTA and Pace bus stops

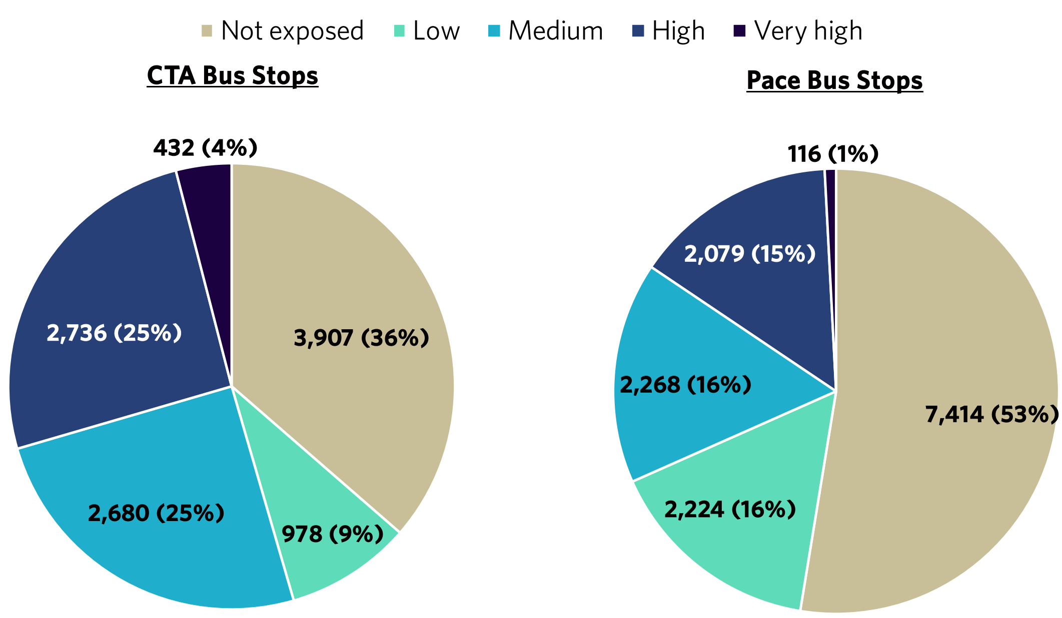


Figure 16 and Figure 17 show the flood risk results for bus stops for CTA and Pace, respectively. There are clusters of very high-scoring CTA bus stops throughout the CTA bus system. The very high risk Pace bus stops tend to be concentrated around the Des Plaines River in west Cook, the south Cook suburbs, and other urban centers (e.g., Aurora, Elgin, Joliet, and Waukegan). However, they also occur throughout the Pace bus system.

Figure 16. Map of flood scores for CTA bus stops

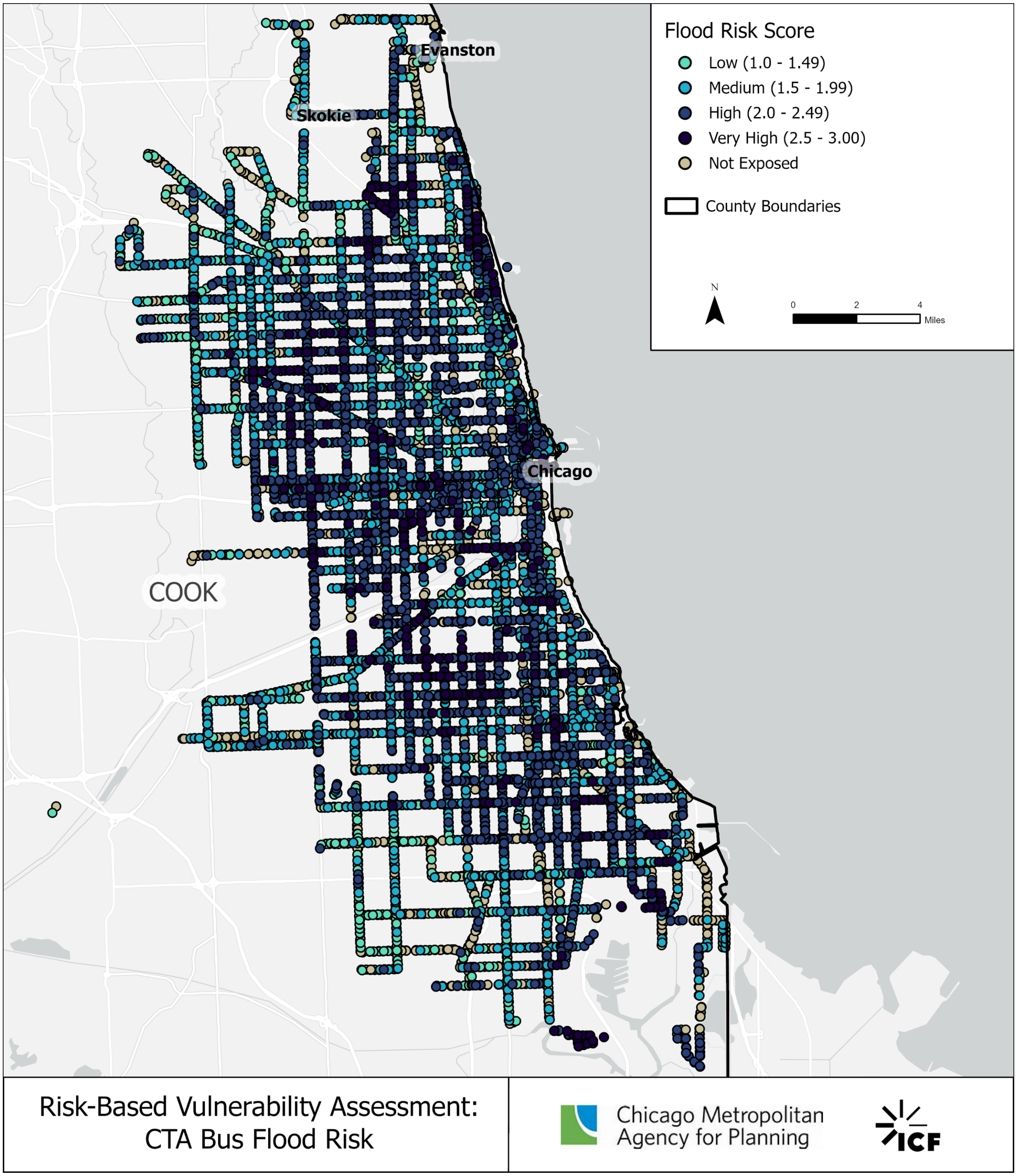
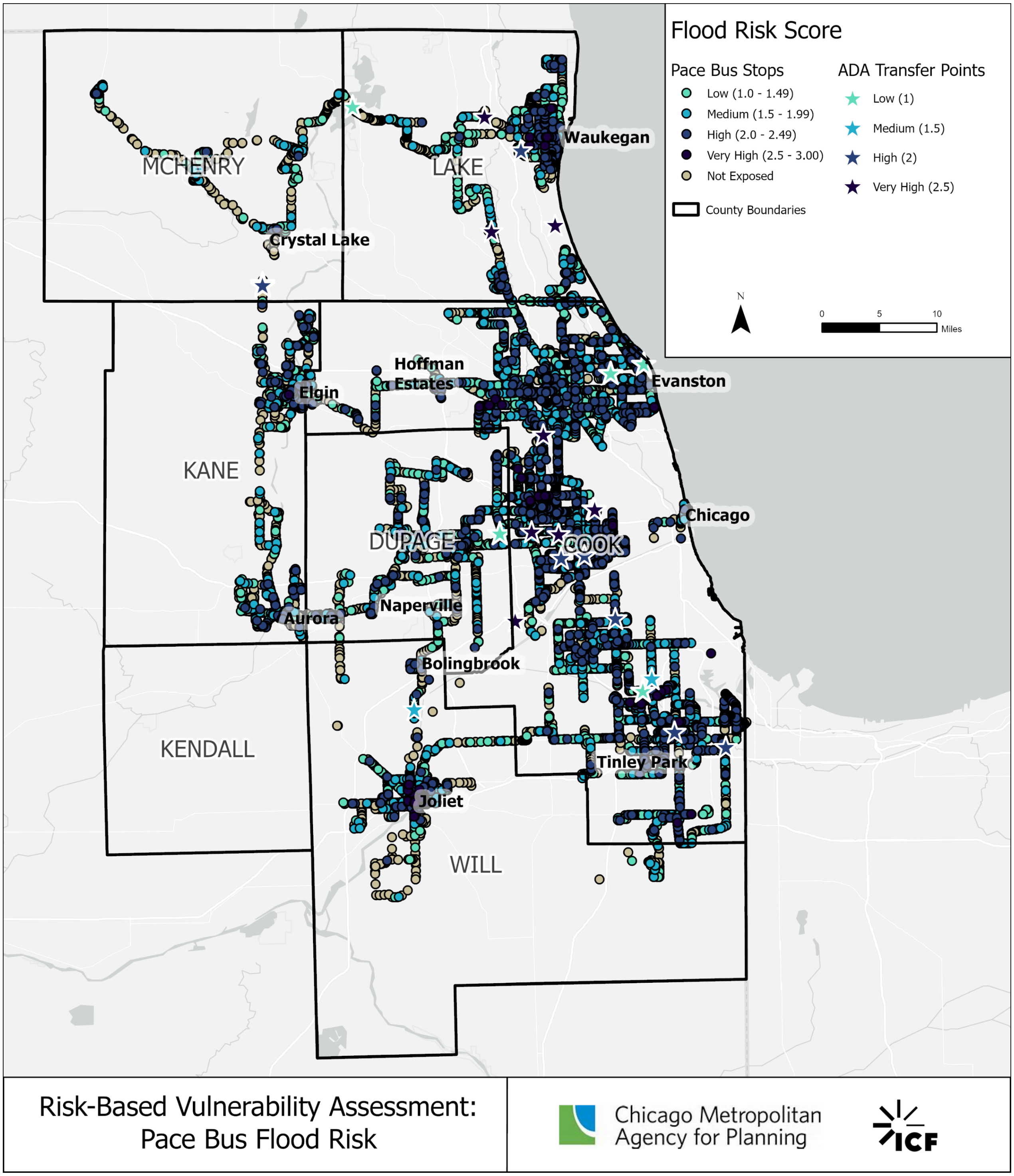


Figure 17. Map of flood scores for Pace bus stops, including ADA transfer points



Bus routes

- Figure 18 and Figure 19 show the flood risk results for bus routes for CTA and Pace, respectively, as determined by road flood risk scores. Exposed bus routes either run on roads that are exposed to flooding and/or were identified as important routes within the Regional Transportation Authority's (RTA) 2018 Flooding Resilience Plan for Bus Operations. Bus routes were not segmented. Rather, they were analyzed for the extent of flooding exposure along the entire route since flooding at one location could impact service along the entire route. See Appendix C: Asset-level analysis methodology details for more details on the methodology.
- Very high flood risk for CTA bus routes is evenly distributed across the service area. Pace bus routes have a concentration of very high-scoring routes in west and northwest Cook County. McHenry County has lower-scoring routes overall.

Figure 18. Map of flood scores for CTA bus routes and garages

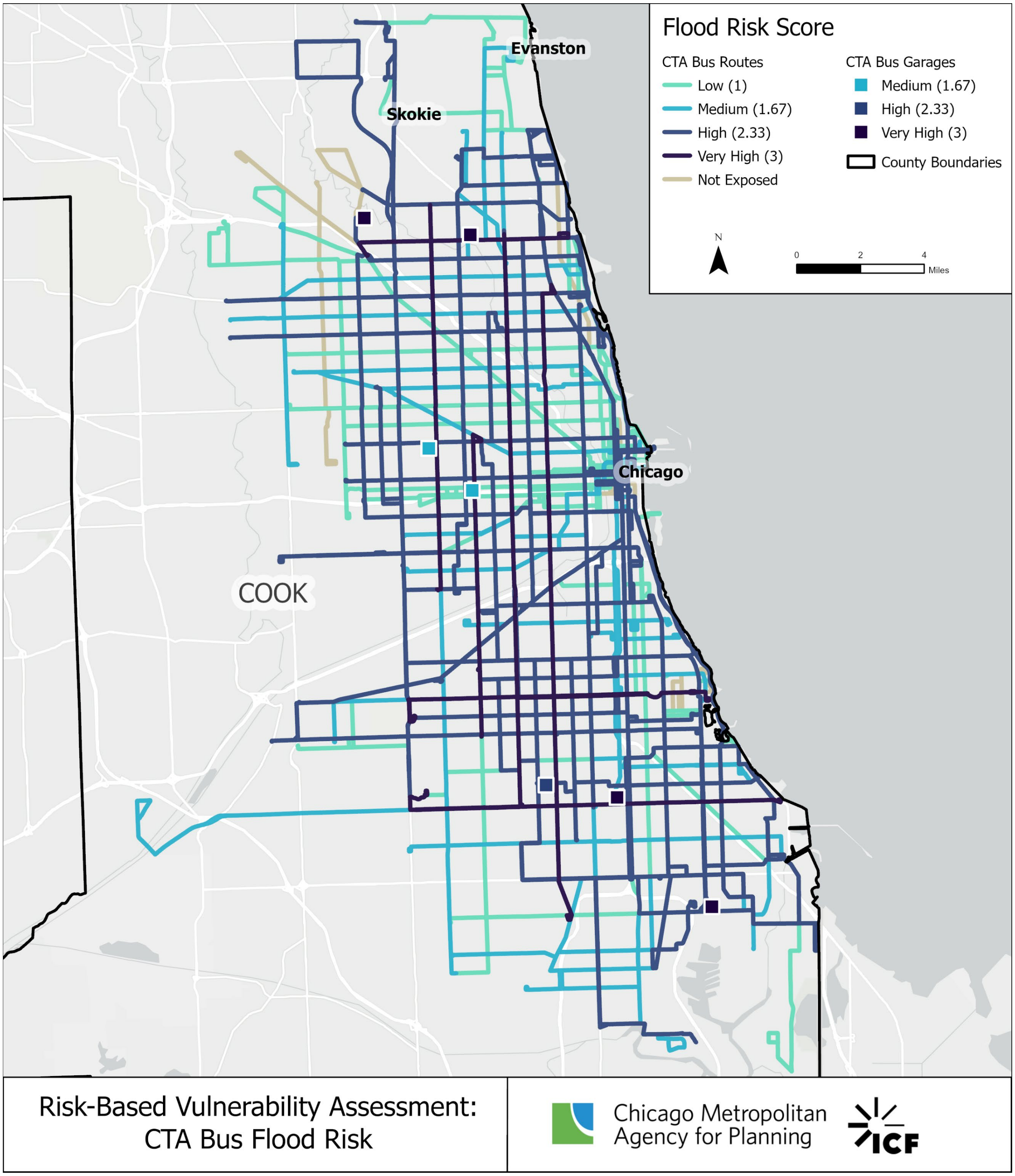
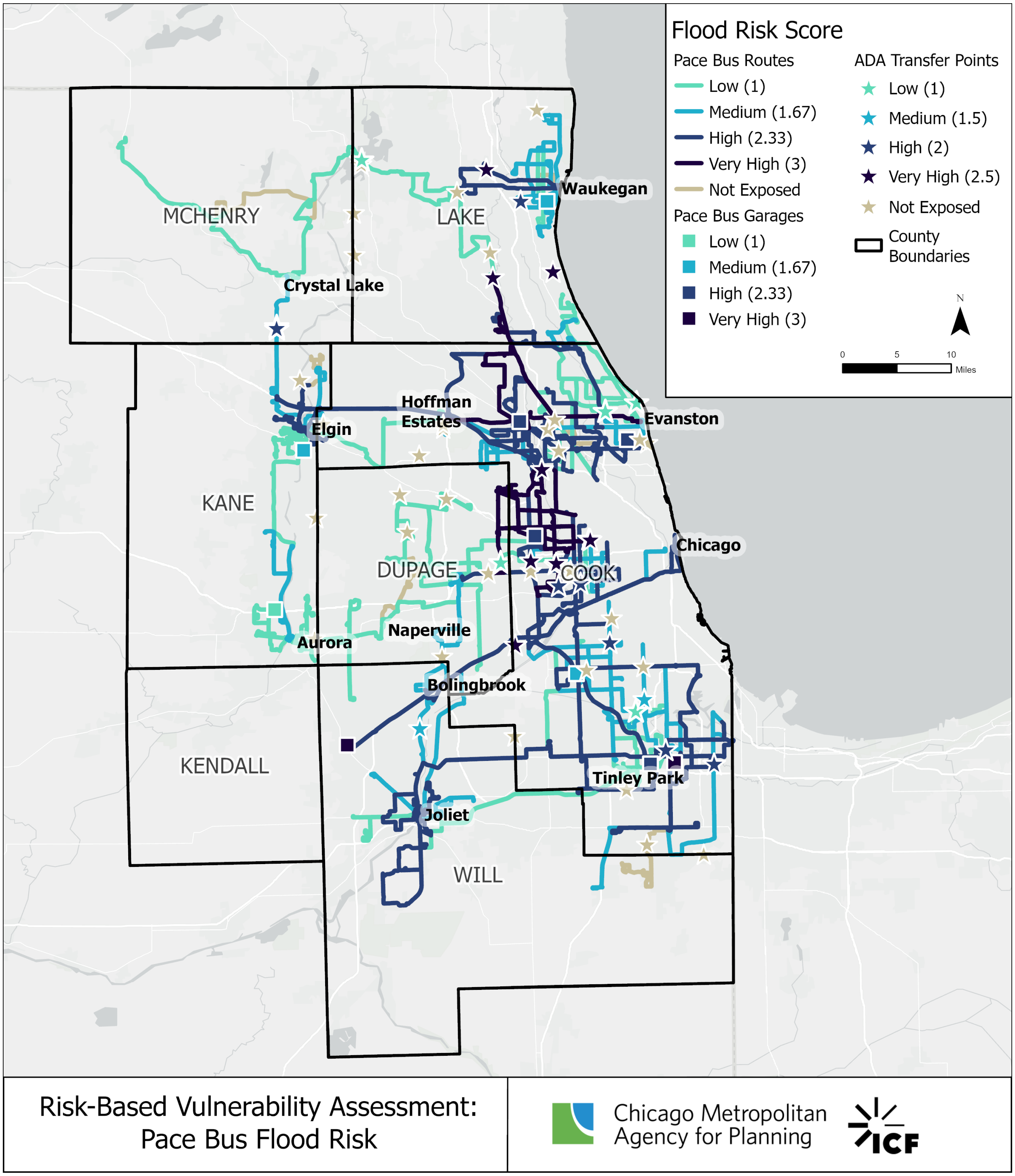


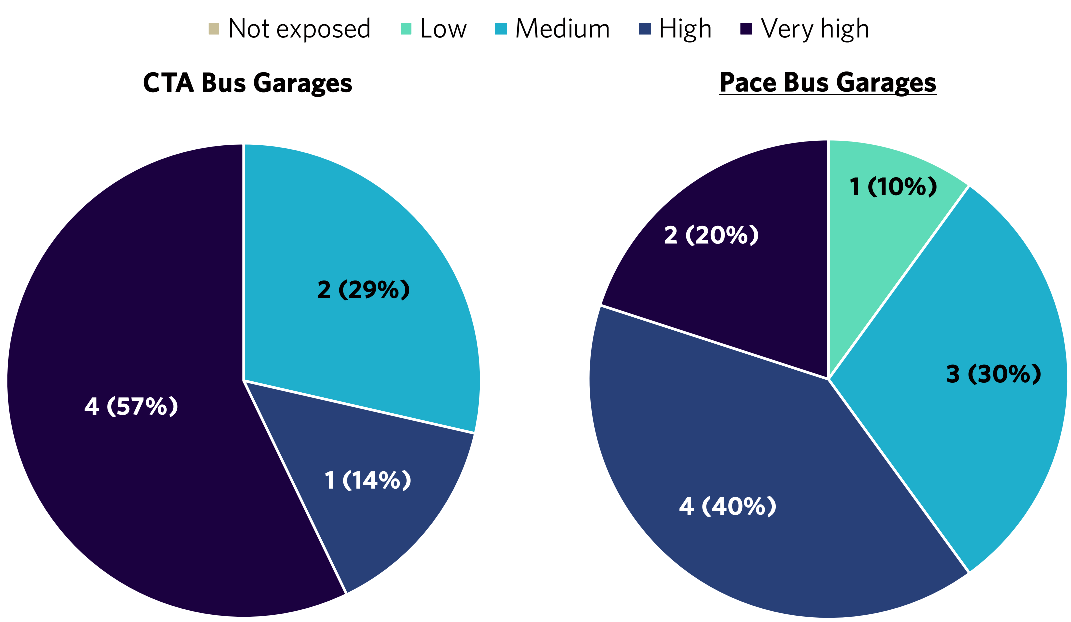
Figure 19. Map of flood scores for Pace bus routes, garages, and ADA transfer points



Bus garages

- The flood risk scores for bus garages are solely determined by the percent of flooded area at the garage. Exposed bus garages either have past flood experience or at least part of the garage is expected to be inundated during a 500-year flood event by mid-century. All of CTA's and Pace's bus garages are exposed to some degree of flooding.
- Four (57 percent) of CTA's bus garages and two (20 percent) of Pace's bus garages have very high flood risk (see Figure 20).
- These results reflect that more of CTA's bus garages either have past flood experience or at least 37 percent of the garage is expected to be inundated during the 500-year flood event by mid-century.

Figure 20. Breakdown of flood risk scores for CTA and Pace bus garages



As shown in Figure 18 and Figure 19, CTA and Pace bus garages are spread throughout the region, with the most high-risk locations on Chicago's south side, south Cook County, and northwest Will County.

Flooding: Regional trails

Regional trails were identified through the Northeastern Illinois Greenways and Trails Plan and reflect existing trails and pathways that are accessible to bikes and may also be used by pedestrians. Many trails throughout the region are prone to flooding, especially the Chicago Lakefront Trail along Lake Michigan and others that run along rivers and streams. A common flooding problem occurs when trails pass under railroad or road viaducts. Due to data limitations, the flood exposure analysis does not take known flood locations into account. These results are intended to serve as a first step toward examining flood risk of regional trails and to ensure their inclusion in TRIP.

- Of the approximately 1,400 miles of trails in the region, 1,376 miles (97 percent) could experience at least 0.5 feet of flooding during a 500-year flood event by mid-century.
- 402 miles of trail (28 percent) have high flood risk and 468 miles of trail (33 percent) have very high flood risk (see Figure 21).
- Table 12 shows the county-level risk results for high and very high-risk trail miles.
- Figure 22 shows the flood risk results for the entire region. Very high-scoring trail miles are relatively evenly distributed throughout the region. Cook County has the largest number of very high-scoring trail miles, whereas Kane County has the highest percentage (48 percent). For all counties, over half of trails score high or very high.

Figure 21. Breakdown of flood risk scores for regional trails in miles

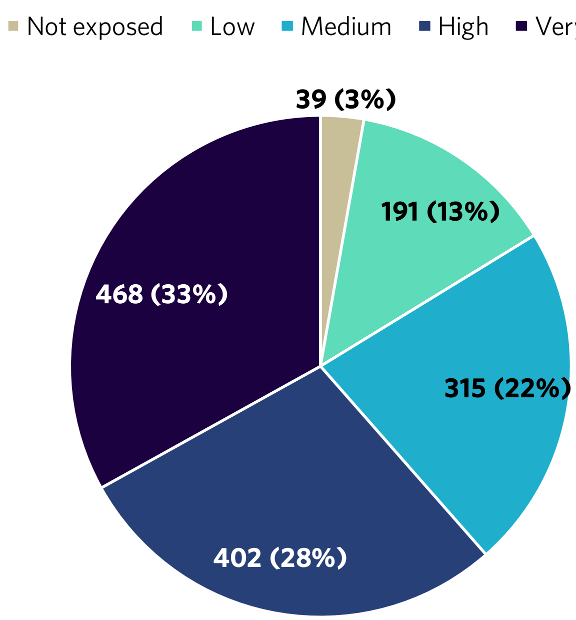
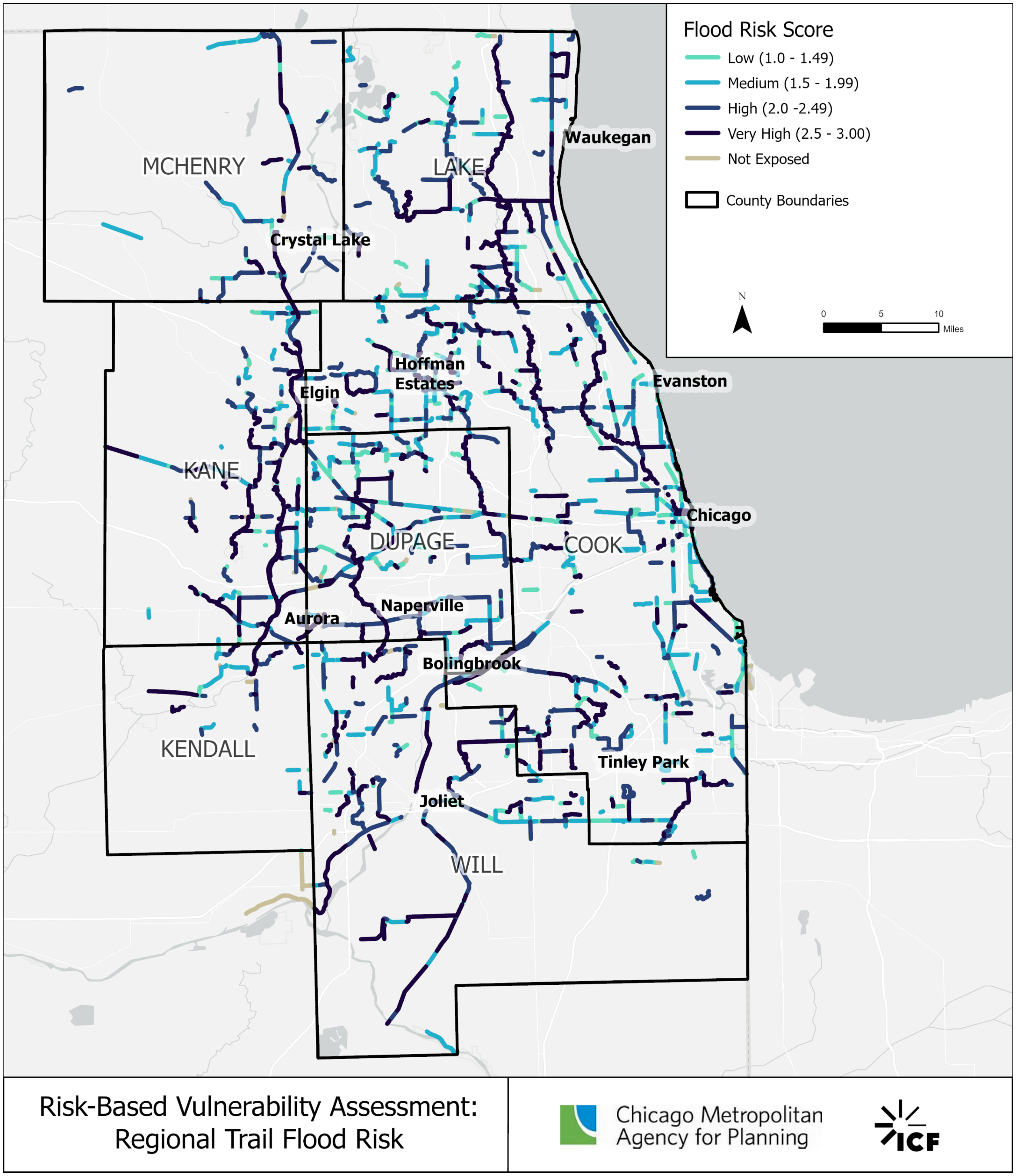


Table 12. County-level breakdown of high and very high flood risk scores for regional trails in miles

County	Score	Miles	Percent of county miles	County	Score	Miles	Percent of county miles
Cook	High	139	28%	**Lake**	High	57	26%
	Very high	134	27%		Very high	83	38%
DuPage	High	65	30%	**McHenry**	High	28	37%
	Very high	63	28%		Very high	20	26%
Kane	High	43	25%	**Will**	High	61	31%
	Very high	83	48%		Very high	73	37%
Kendall	High	8	23%				
	Very high	13	36%				

Figure 22. Map of flood scores for regional trails



2.4 Transit rider vulnerability analysis for extreme heat

Not all transportation users are affected equally by extreme heat. During heat events, some people may experience mild inconveniences, while others may face serious health and socioeconomic consequences. Transit users are particularly vulnerable as they are directly exposed to impacts from extreme weather, and some riders may not have access to alternate modes to get to where they need to go.

CMAP conducted the transit rider vulnerability analysis to understand the impact of extreme heat on the health and wellbeing of transit riders (including bus and rail riders), assess factors that lead to increased vulnerability at some transit points (bus stops and rail stations), and identify potential transit asset- or service-related resilience improvements that can help reduce vulnerabilities for transit users.

2.4.1 Methodology

CMAP calculated a transit rider vulnerability score at each transit point in northeastern Illinois. In this analysis, vulnerability is represented as the weighted combination of exposure,[15] sensitivity, and adaptive capacity of a transit rider at a transit point (bus stops and rail stations), as shown in the equation below:

$$\text{Transit Rider Vulnerability Score} = (\text{Exposure Score})(33.3\%) + (\text{Sensitivity Score})(33.3\%) + (\text{Adaptive Capacity Score})\ (33.3\%)$$

Key terms used in transit rider vulnerability analysis

Exposure is a measure for the extent to which transit users are physically exposed to extreme heat. All other things equal, transit riders in locations with high heat exposure are more likely to be affected by extreme heat impacts than those with low exposure.

Sensitivity represents the degree to which a transit rider is prone to being adversely affected or harmed by exposure to extreme heat. Certain population groups (e.g., older adults, infants and young children, those with pre-existing health conditions) tend to be more sensitive to adverse extreme heat impacts.

Adaptive capacity indicates the ability of transit riders to potentially adjust to, cope with, or respond to increased exposure to extreme heat. Factors such as service frequency, proximity to transit stops, and the availability of tree shade can influence conditions experienced by transit users.

Vulnerability represents the overall susceptibility of transit users to experiencing adverse impacts from extreme heat. Exposure, sensitivity, and adaptive capacity are contributing factors. In general, higher exposure, higher sensitivity, and lower adaptive capacity can contribute to higher levels of vulnerability.

All three components were weighted equally in the analysis to assign equal importance to exposure, sensitivity, and adaptive capacity indicators in determining the overall vulnerability. See the Key Terms box for definitions of exposure, sensitivity, adaptive capacity, and vulnerability.

[15] The exposure indicator used in the analysis is adjusted to consider future climate conditions, whereas the sensitivity and adaptive capacity indicators are based only on historical data.

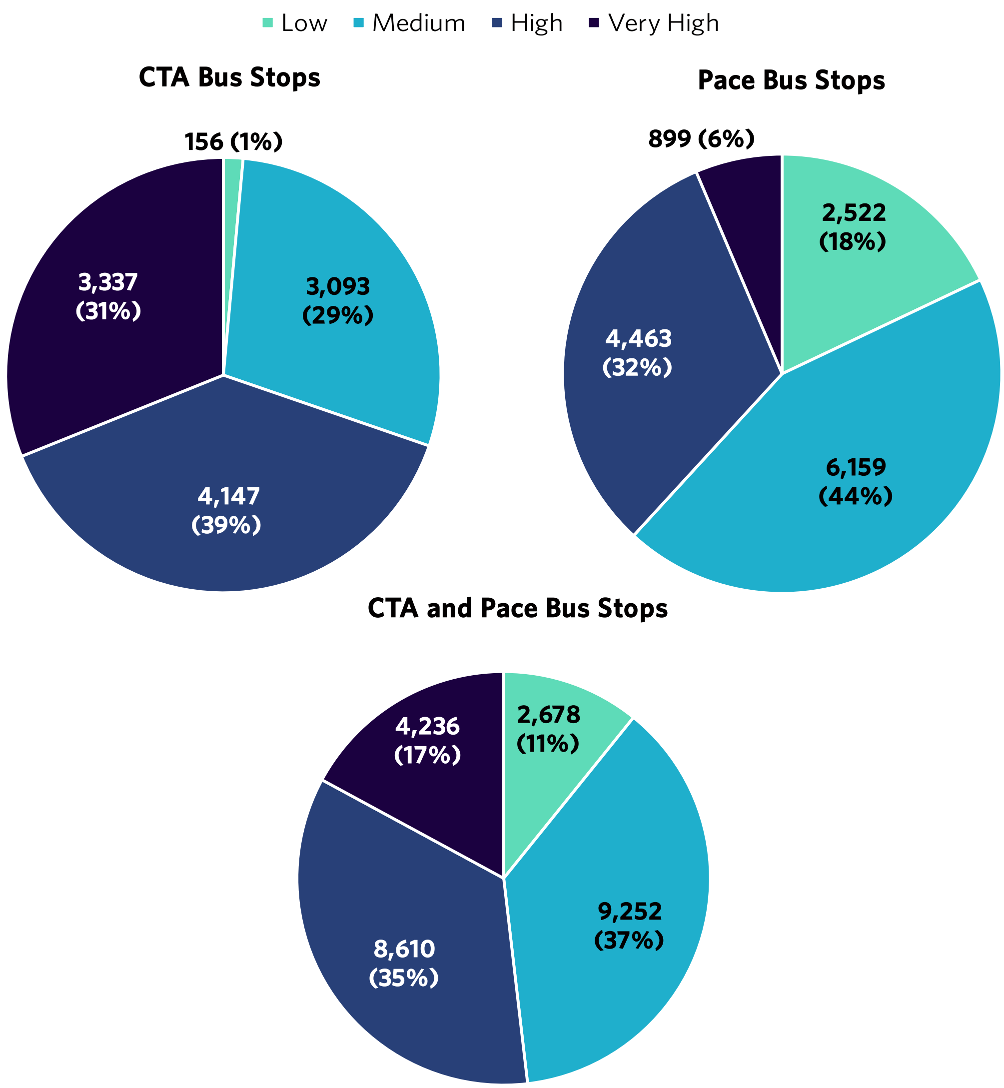
For more details on the methodology used for this analysis, see [Appendix E: Transit Rider Vulnerability Analysis Methodology Details](#).

2.4.2 Key findings

Transit rider vulnerability for bus stops

As shown in Figure 23, more than half of bus stops in northeastern Illinois (52 percent) were scored as having high or very high vulnerability. At a service agency level, 70 percent of CTA bus stops and 38 percent of Pace bus stops were scored as having high or very high vulnerability ratings. Compared to Pace bus stops, CTA stops are more frequently scored with a high or very high rating due to their concentration in areas having higher social and health vulnerability scores. They also tend to be in areas with the highest projected number of days above 95°F which leads to high exposure scores.

Figure 23. Breakdown of transit rider vulnerability ratings for CTA and Pace bus stops

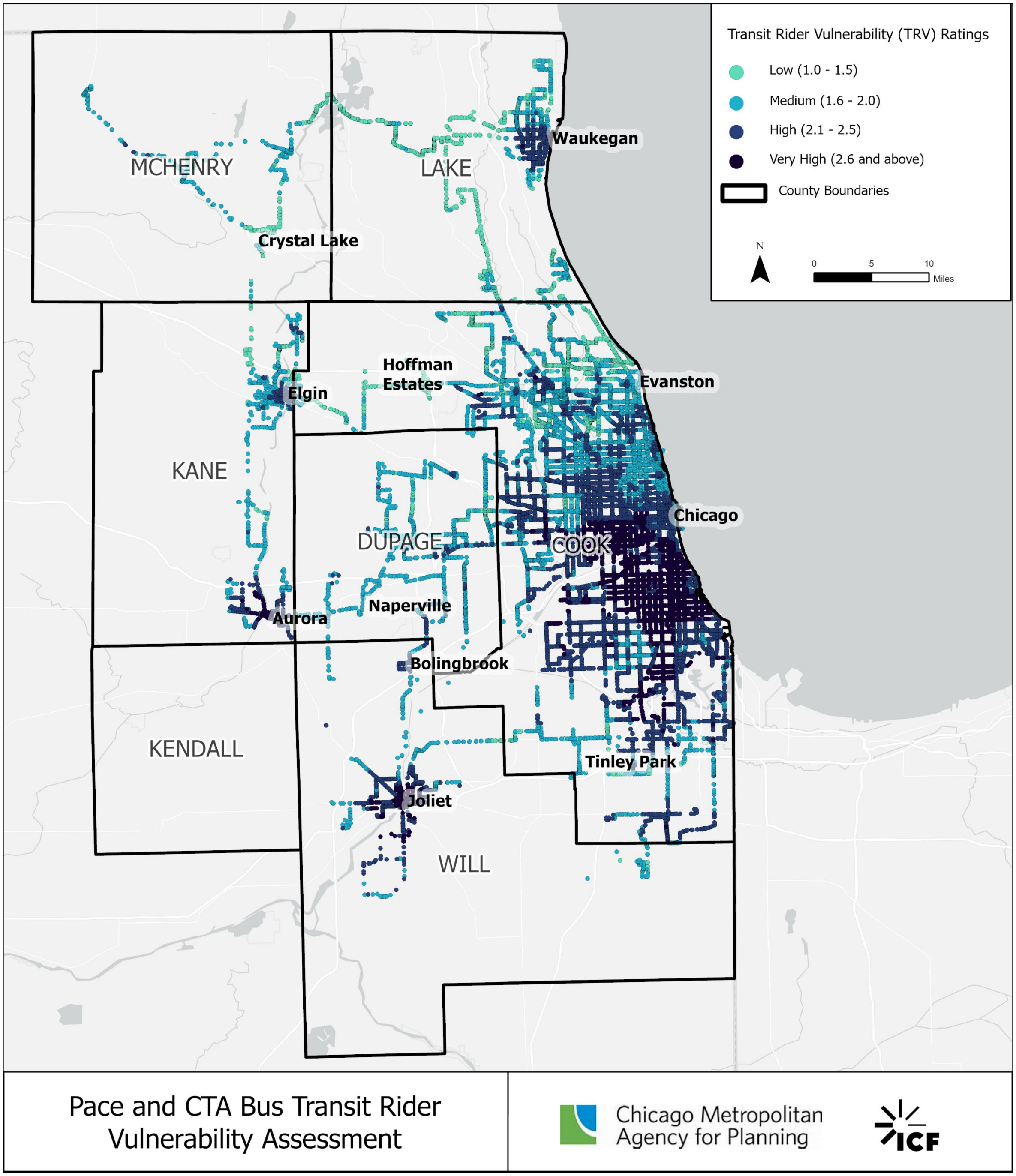


In terms of geographic distributions (as shown in Figure 24):

- Aurora, Elgin, Joliet, and Waukegan as well as the south and west sides of Chicago have large clusters of bus stops with high and very high ratings.

- A majority of stops along the Chicago Department of Transportation and CTA's Better Streets for Buses network also have high and very high ratings.

Figure 24. Map of transit rider vulnerability ratings for CTA and Pace bus stops



Since some stops are used more heavily by transit riders than others, CMAP also considered the ridership at bus stops with the ratings.[16] Considering ridership provides more insight into the overall vulnerability of the transit users, not just the transit stops themselves. As shown in Table 13:

- In September 2023, more than half (57 percent) of CTA ridership was linked to a stop scored with a high or very high rating, which accounts for 70 percent of all CTA stops.
- In 2023, approximately 42 percent of Pace ridership was linked to a bus stop with a high or very high rating, which accounts for 38 percent of all Pace stops.

These findings indicate that, although relatively fewer Pace stops score highly for transit rider vulnerability, they tend to be highly used, thus affecting relatively more riders. Meanwhile, the higher scoring CTA stops represent over half of all rides.

Table 13. Bus ridership by transit rider vulnerability ratings

Rating	Ridership	
	CTA	Pace
Low	237,894 (43%)	611,346 (14%)
Medium	1,505 (1%)	1,898,206 (44%)
High	166,181 (30%)	1,500,663 (35%)
Very high	153,347 (27%)	280,077 (7%)
Total	558,927	4,290,292

In addition to tree shade, bus shelters can shade waiting passengers, which can help alleviate some of the health and comfort-related impacts of high heat. However, the vast majority of the region's bus stops (79 percent% of CTA bus stops and 92 percent of Pace bus stops) are unsheltered, meaning riders must wait in conditions exposed to the elements.[17] As shown in Table 14, most of the unsheltered CTA bus stops (69 percent) received high and very high ratings. Comparatively, the percentage is lower, but still significant, for unsheltered Pace stops, of which 37 percent received a high or very high rating. Notable clusters of highly vulnerable, unsheltered stops are as follows:

- A vast majority of unsheltered CTA stops (80 percent) in the central and south side areas of Chicago were scored with very high ratings.
- A large cluster of unsheltered Pace stops, between Berwyn and Cicero, was scored very high. This cluster follows Pace Route 349 between West 119th Street and West 147th Street.

[16] CTA bus ridership is measured as average weekday ridership during September 2023 per stop. Pace bus ridership is measured as average daily (weekday and weekend) ridership for 2023 per route. The analysis assumes that average ridership for a route applies to each stop situated along that route. Please note, ridership metrics between service providers are not to be compared to each other. Ridership data was provided by CTA and Pace.

[17] Availability of shelters can influence conditions experienced by transit riders while waiting at bus stops. Riders waiting at unsheltered stops can be relatively more directly exposed to extreme heat effects than those at sheltered stops. Since only a small percentage of CTA and Pace bus stops have shelters available, this indicator was not included in the calculation of the transit rider vulnerability rating. However, bus stops which are unsheltered and have a high or very high rating can be prioritized for shelter improvement projects which can reduce vulnerability for transit users at these locations.

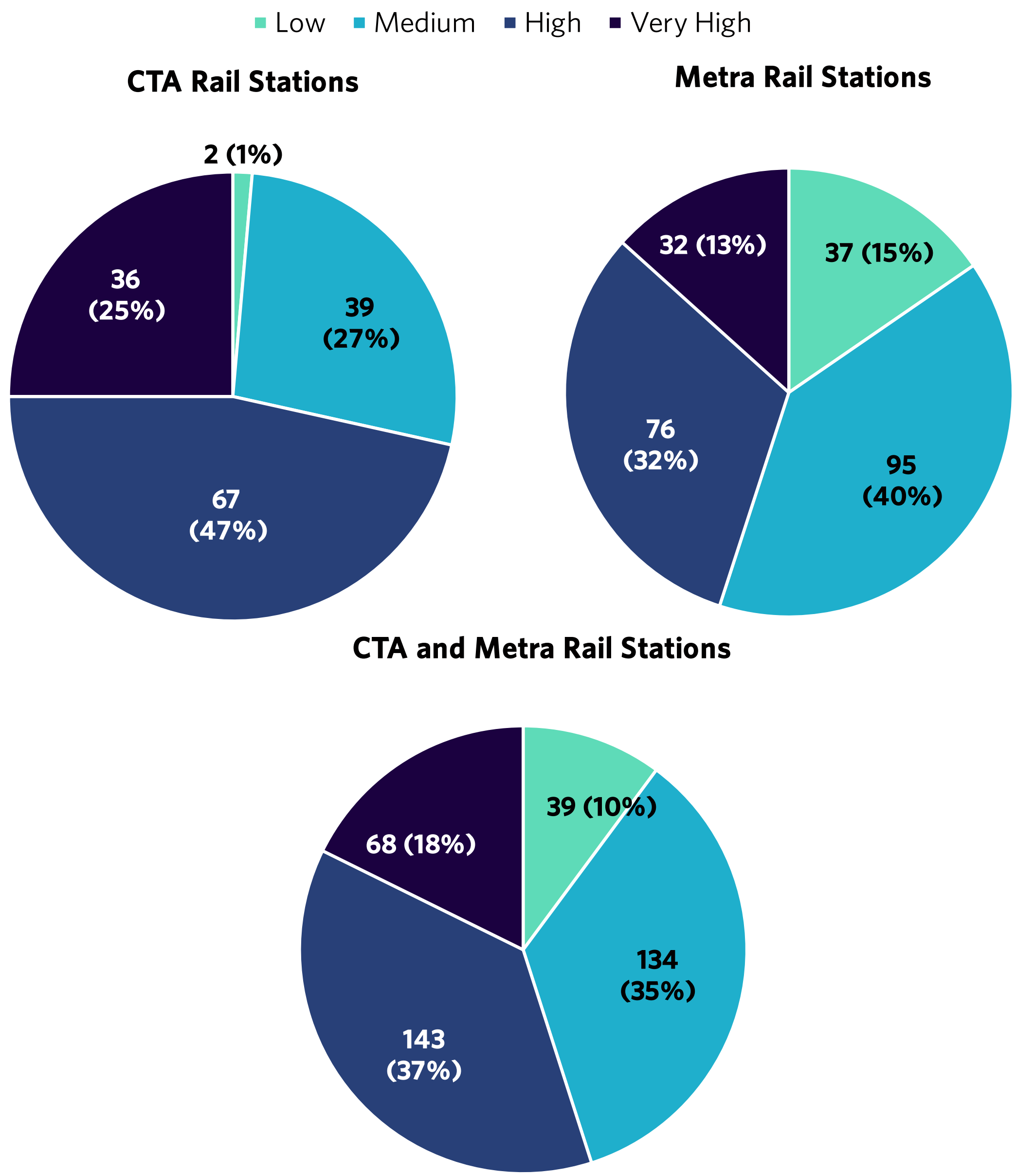
Table 14. Breakdown of transit rider vulnerability scores for unsheltered bus stops

Rating	Number (and %) of unsheltered bus stops	
	CTA	Pace
Low	134 (2%)	2,402 (19%)
Medium	2,443 (29%)	5,682 (44%)
High	3,250 (38%)	4,014 (31%)
Very high	2,682 (31%)	828 (6%)
Total	8,509	12,926

Transit rider vulnerability for rail stations

As shown in Figure 25, more than half (55 percent) of rail stations in the CMAP region were scored with a high or very high rating. At a service agency level, 72 percent of CTA rail stations, and 45 percent of Metra rail stations were scored high or very high. These percentages are roughly similar to the statistics for bus stops described in the previous section (70 percent of CTA bus stops and 38 percent of Pace bus stops, per Figure 23). CTA stations are more frequently scored with a high or very high rating compared to Metra stations due to their concentration in areas having higher sensitivity scores (composed of social and health vulnerability). They also tend to be in areas that have high exposure scores which are projected to experience a larger number of days above 95°F.

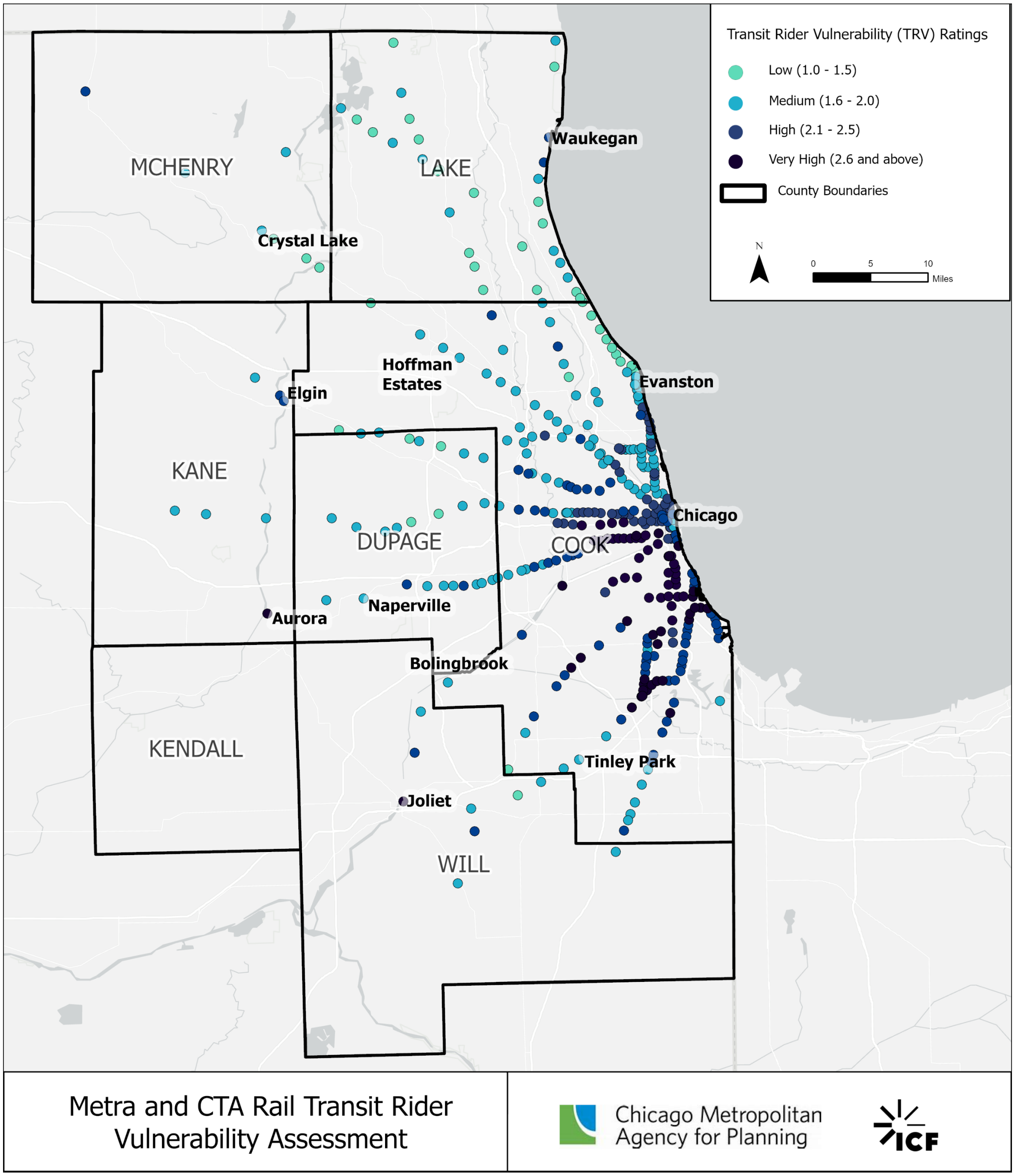
Figure 25. Breakdown of transit rider vulnerability ratings for CTA and Metra rail stations



In terms of geographic distributions (as shown in Figure 26):

- Rail stations in urban areas generally have higher ratings than suburban and rural areas as urban areas are projected to have high exposure to extreme temperature (indicated by days above 95°F) and also have concentrations of people with higher socioeconomic and health vulnerabilities.
- The CTA Pink Line stations from 18th to 54th/Cermak all have very high vulnerability. This means they are located in areas expected to experience a high number of days above 95°F degrees and are surrounded by populations that tend to both have higher social and health vulnerability index scores and be more transit dependent.
- All stations on the CTA Orange, Red, and Green lines south of the Loop have high and very high vulnerability ratings for the reasons as described for the Pink Line above.

Figure 26. Map of transit rider vulnerability ratings for CTA and Metra rail stations



Since some stations are used more heavily by transit riders than others, CMAP also considered the number of rides that originate or end at stations with high ratings. [18] Doing so provides additional insight into the overall vulnerability of the transit users, not just the stations themselves. As shown in Table 15:

[18] CTA rail ridership is measured as annual (November 2022 to October 2023) average daily ridership per station. Metra rail ridership is measured as the annual (2018) average of boardings and dismounts per station. Please note, ridership metrics between service providers are not to be compared to each other. Ridership data was provided by CTA and Metra.

- From November 2022 to October 2023, 69 percent of CTA ridership was linked to stations scored with either a high or very high rating, which account for 72 percent of all CTA stops (see Figure 25).
- In 2018, 58 percent of Metra ridership was linked to stations with either a high or very high rating, which accounts for 45 percent of all Metra stops (see Figure 25).

Table 15. Rail ridership by transit rider vulnerability ratings

Rating	Ridership	
	CTA	Metra
Low	691 (1%)	22,996 (9%)
Medium	68,777 (30%)	87,327 (33%)
High	129,925 (57%)	148,121 (55%)
Very high	28,068 (12%)	8,190 (3%)
Total	227,461	266,632

Some rail stations are located underground, which helps reduce direct exposure to high temperatures while transit riders wait for trains. Therefore, CMAP specifically looked at non-subway stations (at-grade or elevated; considered "non-subway" or "unsheltered" in this analysis) since riders at those stations are likely more exposed while waiting for trains. Within northeastern Illinois, 86 percent of CTA rail stations and 99 percent of Metra rail stations are at-grade or elevated. [19]

As shown in Table 16, 69 percent of non-subway CTA rail stations and 44 percent of non-subway Metra rail stations were scored with a high and very high rating. Specific geographic areas to note are:

- All CTA stations south and southwest of the Loop are scored with a high or very high rating. These stations are located on the Pink, Orange, Red, and Green lines. More than half of the stations on the CTA Pink and Orange lines are at-grade or elevated stations and have a very high rating.
- At-grade and elevated Metra stations that were scored with very high ratings include the Joliet and Aurora stations, as well as a cluster south of the Loop, following a similar pattern as CTA.

[19] This analysis considers subway or below-grade stations as sheltered, and elevated and at-grade stations as unsheltered. Availability of shelter can influence conditions experienced by transit riders while waiting at rail stations. Riders waiting at unsheltered (elevated/at-grade) stations can be relatively more directly exposed to extreme heat effects than those at sheltered (subway) stations. Since only a small percentage of CTA and Metra rail stations are subway stations, this indicator was not included in the calculation of the transit rider vulnerability rating. However, rail stations which are unsheltered (elevated/at-grade) and have a high or very high transit rider vulnerability rating can be prioritized for shelter construction/improvement projects which can reduce vulnerability for transit users at these locations. Even though below-grade stations may be more sheltered from high heat, riders that need to travel to and from stations will still experience the effects of high heat exposure. Due to unavailability of data for this subset of riders, this aspect is not accounted for in the transit rider vulnerability analysis. However, CMAP does recognize that using a below-grade or subway station does not eliminate all factors that influence vulnerability to extreme heat impacts.

Table 16. Breakdown of transit rider vulnerability ratings for unsheltered (at-grade or elevated) rail stations

Rating	Number (and %) of unsheltered rail stations	
	CTA	Metra
Low	2 (2%)	37 (16%)
Medium	36 (29%)	95 (40%)
High	50 (40%)	73 (31%)
Very high	36 (29%)	32 (13%)
Total	124	237

3 Application of the risk-based vulnerability assessment results

The risk-based climate vulnerability assessment systemically analyzed climate risks in northeastern Illinois and provided CMAP and its partners with a better understanding of how climate hazards are expected to impact the region's transportation network in the future. The assessment also identified the asset types and geographic areas most at risk of extreme heat and flooding impacts. Finally, the assessment provided more insights into where and how transit riders are vulnerable to extreme heat.

This information will be used to identify, justify, and prioritize potential investments to improve the resiliency of the region's transportation system.

3.1 Transportation Resilience Improvement Plan

In the second part of this project, CMAP will develop TRIP, a regional resilience plan for the transportation system. This risk-based vulnerability assessment will serve as a key component of the plan and will support regional transportation resilience planning by informing the identification and prioritization of resilience projects.

CMAP serves a key role in transportation planning for northeastern Illinois but ultimately relies on its partners to identify and implement transportation resilience projects. **CMAP will compile a list of priority resilience projects, in collaboration with its partners, to include in the plan's priority project list.** The inclusion of the project list in the plan will also support implementers interested in applying for PROTECT discretionary grants for resilience improvement projects. **If a project is listed in the CMAP TRIP priority project list, the grant applicant will get the following benefits:**

- Preference during the awards process [20]
- Exclusion from benefit-cost analysis requirement
- 7 to 10 percent reduction in the non-federal cost-share for awarded projects

CMAP used a systemic approach when developing the risk-based vulnerability assessment by covering a range of climate hazards and asset categories. CMAP will continue to use a systemic approach when developing TRIP by considering all submitted projects in the plan's priority project list, including projects for assets/locations that did not receive a high risk score in the assessment. By considering all submitted projects, CMAP will also help maximize the opportunities for its key partners to receive match reductions. As appropriate, the transit rider vulnerability analysis results may be used to inform which transit stop and station projects should be included in the TRIP priority project list.

3.2 CMAP's long-range planning and transportation programming

CMAP will use the assessment results to inform the Regional Transportation Plan and its transportation programs. In the near-term, CMAP will incorporate the asset-level results into the scoring methodology for regionally significant projects as part of the next Regional Transportation Plan and the Surface Transportation Program Shared Fund. CMAP will seek other opportunities to incorporate the assessment results into its planning and programming activities, relying on recommendations outlined in the forthcoming TRIP.

[20] (FHWA 2023)

3.3 Regional partners

Regional partners can use the assessment results to site resilience projects and determine the most effective project for reducing risk based on the exposure and criticality scores. For example, assets that have high risk due to flooding exposure may benefit from infrastructure improvements, such as raised elevation, green infrastructure, or floodproofing. Alternatively, highly critical assets that support large volumes of passengers may benefit from redundancy enhancements, such as additional transit stops nearby or the establishment of default detour routes. The transit rider vulnerability results can inform improvements and drive discussions around resilience needed to address the impacts of extreme heat on transit riders.

3.4 Future updates to the assessment

CMAP is dedicated to the continuous improvement of its risk-based vulnerability assessment to support both CMAP and regional partners' understanding of climate risks and how to advance regional transportation resilience. CMAP is committed to maintaining and updating its risk-based vulnerability assessment periodically, which may include improvements to the assessment methodology to further refine the results. Potential future improvements to the CMAP risk-based vulnerability assessment include:

- Incorporating new and/or better asset data (e.g., bridge polygon vs. point location, county culvert assessments, socioeconomic demographics of transit riders) or climate data (e.g., updated precipitation projections).
- Standardization and improved collection of key datasets across the agencies within the CMAP region (e.g., tracking of flooded roadways, severity, associated damage, length of closure).
- Incorporating more local information on climate impacts to better ground-truth the assessment results. For example, CMAP could distribute a survey to municipalities or conduct more targeted outreach with partner agencies to expand on the information already included.
- Enhancing equity considerations by analyzing who the actual users of transportation assets are, rather than relying on US Census Bureau data to analyze assets based on their proximity to disadvantaged communities.
- Updating the flood model used to screen assets to include newer datasets and additional features (e.g., run with stormwater drainage infrastructure, if available).
- Considering interdependencies across different sectors (e.g., communications, energy, healthcare) and potential cascading impacts associated with certain climate hazard events (e.g., extreme rain followed by extended power outage).

4 Glossary

The following definitions are consistent with the Intergovernmental Panel on Climate Change's (IPCC) most recent glossary of terms and have been customized to be more relevant to this project.[21]

- **Adaptation:** Measures to reduce the impacts of climate change, including but not limited to hardening of infrastructure and operational changes to improve the ability of the transportation system to recover from damage and disruptions. *Adaptation* and *resilience* are often used interchangeably but have slightly different meanings. *Adaptation* refers to specific measures that can reduce climate-related impacts, while *resilience* is used more broadly to describe the ability of the transportation system to anticipate, prepare for, or adapt to impacts and/or disruptions from climate hazards. For the purposes of this assessment, CMAP primarily uses the term *resilience*.
- **Climate hazard:** A climate-related event or condition that may cause physical damage to infrastructure, disrupt operations, or injure people. For this vulnerability assessment, CMAP investigated the following hazards: extreme heat, extreme cold, flooding, freeze-thaw cycling, and severe storms, including rain, snow, ice, and wind.
- **Climate projections:** Modeled future climate conditions that are based on assumptions about changes in greenhouse gas concentrations. For example, the number of additional days over 95°F estimated for mid-century under a medium global emissions scenario.
- **Criticality:** The level of importance of an asset to the transportation system. For example, roads with higher volumes and/or fewer alternative routes are considered highly critical. The consequence to the transportation system is significant for highly critical assets. Criticality also considers social vulnerability indicators, such as transportation access.
- **Emission scenarios (sometimes referred to as SSPs):** Emission scenarios are applied to a climate model or a suite of models to project future climate conditions based on that scenario. Shared socioeconomic pathways (SSPs) are scenarios of projected socioeconomic global changes that, together with representative concentration pathways (RCPs), can be used to determine how greenhouse gas emissions and concentrations may change with different climate policies. These combined SSP/RCP scenarios are the current global standard for discussing future climate scenarios. The high emissions scenario (SSP5/RCP 8.5) assumes greenhouse gas concentrations continue to rise throughout the twenty-first century, while the medium emissions scenario (SSP2/RCP 4.5) assumes significant greenhouse gas emission mitigation prior to mid-century. These are referred to as SSP5-8.5 and SSP2-4.5 respectively.
- **Exposure:** Indicates whether an asset is in an area that is affected by climate hazards. All other things equal, assets with high exposure are more likely to be affected by climate hazards than those with low exposure.
- **Greenhouse gases (GHGs):** Gases such as carbon dioxide, methane, and nitrous oxide that absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into space.
- **Resilience:** The ability of a transportation system to anticipate, prepare for, respond to, and recover from climate hazards. *Adaptation* and *resilience* are often used interchangeably but mean have slightly different meanings. *Adaptation* refers to specific measures that can reduce

[21] (IPCC 2019)

climate-related impacts, while *resilience* is used more broadly to describe the ability of the transportation system to anticipate, prepare for, or adapt to impacts and/or disruptions from climate hazards. For the purposes of this assessment, CMAP primarily uses the term *resilience*.

- **Risk:** Potential threats to the transportation system due to climate hazards. These can include physical impacts to infrastructure and disruptions to services and operations. *Risk* is often used interchangeably with *vulnerability*, although some studies make distinctions between the terms; for example, *risk* may be a representation of the potential harm caused by vulnerabilities if an event happens.
- **Risk-based vulnerability assessment:** An analysis of the degree to which a system may be adversely affected by impacts of climate change. For this project, risk-based vulnerability assessment refers to the process of identifying and evaluating the level of exposure to and impact of climate change on the transportation system and its assets.
- **Sensitivity:** The degree to which a system is affected by exposure to a climate hazard.
- **Transit rider vulnerability analysis:** An assessment of factors that lead to increased vulnerability at transit points and identification of potential resilience improvements to help reduce extreme heat risk to transit riders.
- **Uncertainty:** An expression of the degree to which future climate conditions are unknown. Climate uncertainty is caused by the complexity of the climate system, the ability of models to represent it, and the unpredictable nature of future societal changes.
- **Vulnerability:** The susceptibility of the transportation system or its riders to adverse impacts from climate hazards. Exposure and sensitivity can be used to determine how vulnerable a transportation asset or its riders are to climate hazards.

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5 References

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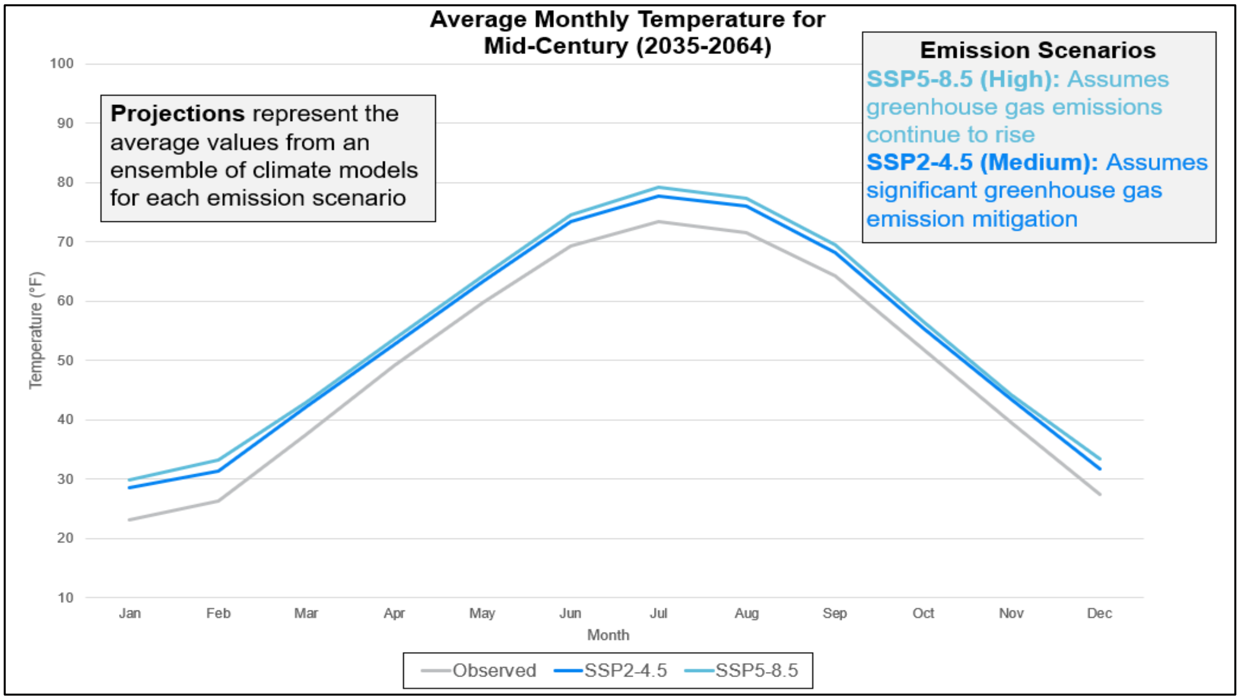
6 Appendix A: Climate analysis findings

This appendix provides more details on the findings from the climate analysis.

Included below are graphs and tables showing observed historical data and future climate projections (see Figure 27 for an example). These graphs show how climate conditions are expected to change in the future. While average conditions will change gradually, northeastern Illinois will still experience year-to-year variability in the future. [22]

Figure 27. Example climate variable graph



In order to derive future climate variable values, ICF first calculated the difference (or delta) between the modeled future value and the modeled baseline for each variable and scenario/time period. The delta was then subtracted from the observed baseline to derive the future climate projection values. We subtract the delta from the observed baseline rather than using the future modeled values because it decreases model biases and makes sure projections are aligned relative to local climate conditions. In some cases, the delta is larger than the observed baseline, resulting in a negative future value, which is impossible. In these instances, ICF rounded the value to 0.

6.1 Extreme heat

6.1.1 Historical information

Northeastern Illinois is prone to extreme high heat. In July 1995, the Midwest experienced a historic heat wave, with Chicago suffering the brunt of its impact. [23] This stretch of days claimed over 500 lives in the city alone and saw record-breaking temperatures, including the highest ever recorded at

[22] There is some degree of uncertainty in all climate projections. However, there are differences in the level of uncertainty for different hazards. For example, we are typically confident about temperature projections, but there is more uncertainty around precipitation projections due to the complexity of this hazard and the many factors that contribute to precipitation events.

[23] (NWS n.d.)

Midway Airport (106°F). The combination of extreme heat and humidity made conditions even more dangerous, with peak heat indices reaching 124-125°F. This event serves as a stark reminder of the dangers of recent heat waves, especially as Chicago has seen five of its ten hottest years on record occur in the past decade.[24] While not quite reaching the peak heat index of 1995, Chicago experienced similar challenges in August 2023, with readings hitting 118°F.[25] Additionally, a separate heat wave with a heat index of 106°F combined with a tornado outbreak in late July 2023,[26] further highlighting the increasing frequency and intensity of extreme weather events.

6.1.2 Future projections

Climate projections show the potential for a significant increase in extreme temperatures and heat wave frequency and intensity in the Midwest over the next century.[27] The most recent CMIP6 GCM projections show more warming than the previous CMIP5 climate projections, particularly for high emissions scenarios.[28] Similarly, new research from First Street Foundation all CMAP counties are expected to experience at least one day above 125°F by 2053.[29] The Environmental Protection Agency (EPA) estimates that higher temperatures due to unmitigated climate change could result in $6 billion annually in road maintenance costs in the Midwest by 2090.[30]

Figure 28 shows the observed and projected average monthly temperature for mid-century for northeastern Illinois. The average temperature is expected to increase for all months of the year, with temperatures increasing by 3.5-5.5°F under a medium emissions scenario (SSP2-4.5) and 4-7°F under a high emissions scenario (SSP 5-8.5) by mid-century. By late-century, monthly average temperatures are expected to increase by 5-7.5°F under a medium emissions scenario and 8-11°F under a high emissions scenario.

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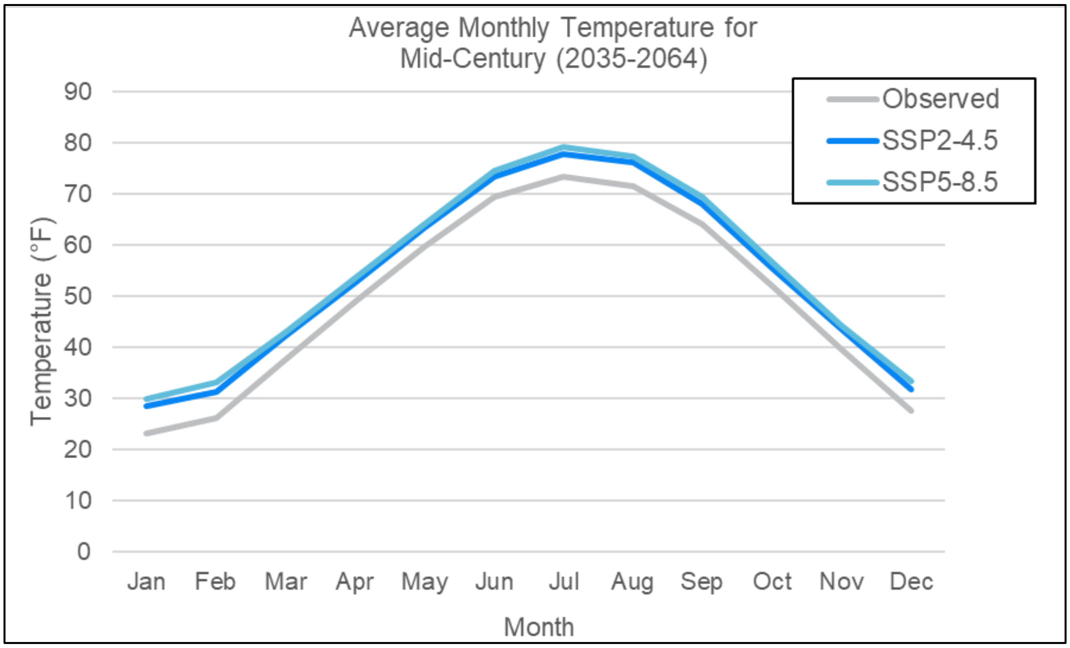
[24] (NWS 2022b)
[25] (NWS 2023a)
[26] (NWS 2023b)
[27] (Winkler, Arritt and Pryor 2012, Vose, et al. 2017, Li, et al. 2021)
[28] (Martel, et al. 2022)
[29] (First Street Foundaton 2022)
[30] (USGCRP 2018)

Figure 28. Observed and projected average monthly temperature for mid-century



As shown in Figure 28, monthly average temperatures are expected to change similarly under both SSPs. Additionally, monthly average temperatures are expected to change relatively uniformly across all months. However, summer months are expected to experience slightly more significant increases.

Extreme high temperatures are also expected to increase in the future. Table 17 and Figure 29 show the observed and projected annual average number of days with maximum temperature over 95°F. By mid-century, this is expected to increase by 12-16 days under a medium emissions scenario and 16-22 days under a high emissions scenario. By late-century, this is expected to increase by 19-27 days under a medium emissions scenario and 43-56 days under a high emissions scenario.

Table 17. Annual average number of days with max temperature over 95°F [31]

	Observed (1985-2014)	Mid-century (2035-2064)				Late-century (2065-2094)			
		SSP2-4.5		SSP5-8.5		SSP2-4.5		SSP5-8.5	
	Days	Days	Change	Days	Change	Days	Change	Days	Change
Mean	2	13.5	11.5 (575%)	18.1	16.1 (805%)	20.9	18.9 (945%)	45.4	43.4 (2170%)
Min	0.6	4	3.4 (567%)	6.2	5.6 (933%)	6.9	6.3 (1050%)	19.5	18.9 (3150%)
Max	4.1	19.9	15.8 (385%)	25.7	21.6 (527%)	29.5	25.4 (620%)	58.8	54.7 (1334%)

[31] The tables throughout this section show the mean, min, and max values. These refer to the mean, minimum, and maximum of the grid cells in the CMAP region. Each grid cell over the CMAP region, spanning a ~6 km by ~6 km area, yields one value for each variable. Taking the mean, minimum, and maximum of all grid cells across the CMAP region better represents the spatial variation across the region.

Figure 29. Observed and projected annual average number of days with max temperature over 95°F (projections are shown for mid-century under a high emissions scenario)

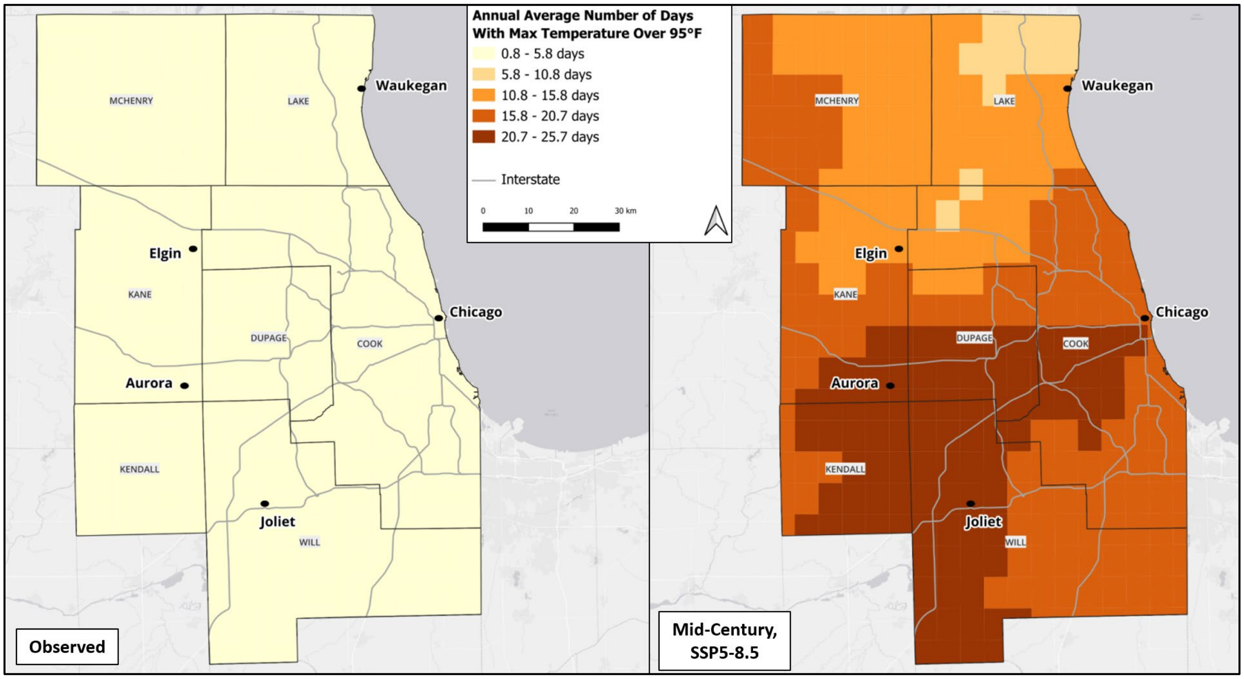


Table 18 shows the observed and projected annual average number of heatwaves (3-day periods with maximum temperatures over 90°F).[32] Heatwave frequency is expected to increase from approximately 1.7 heatwaves per year on average to almost 8 heatwaves per year on average by late-century under a high emissions scenario.

Table 18. Annual average number of heatwaves (3-day period with max temperature over 90°F)

	Observed (1985-2014)	Mid-century (2035-2064)				Late-century (2065-2094)			
		SSP2-4.5		SSP5-8.5		SSP2-4.5		SSP5-8.5	
	Heat-waves	Heat-waves	Change	Heat-waves	Change	Heat-waves	Change	Heat-waves	Change
Mean	1.7	5.1	3.4 (200%)	5.9	4.2 (247%)	6.5	4.8 (282%)	7.8	6.1 (359%)
Min	0.5	2.0	1.5 (300%)	2.9	2.4 (480%)	3.2	2.7 (540%)	6.3	5.8 (1160%)
Max	2.6	6.4	3.8 (146%)	7.1	4.5 (173%)	7.4	4.8 (185%)	8.7	6.1 (235%)

Projected changes in extreme high temperatures present a significant concern for northeastern Illinois. Whereas summer average temperatures typically reach up to 80°F, the region could experience an additional two weeks of temperatures above 95°F by mid-century and over a month of temperatures above 95°F by late-century under a high emissions scenario. The region could also experience almost eight heatwaves, which is significant. Extreme high temperatures are a major public health concern and can adversely impact transportation infrastructure, services, and users. For example, sustained

[32] ICF calculated all climate variables using a 30-year time period surrounding the year of interest to account for interannual variability and to capture larger climate trends. As such, variables that reflect the annual frequency of a climate event, for example, heatwaves, may be presented as decimal numbers (e.g., 1.5 heatwaves per year). These data do not reflect partial events, rather, indicate the event may occur, for example, three times in two years - or "1.5 times" per year.

high temperatures can cause physical damage to roads, increase stress on bridges, and cause mechanical failures in railroad locomotives and equipment. Extreme high temperatures can also cause service disruptions by increasing closures on roads and bridges due to repairs and causing reduced operating speeds on rail lines. Metra trains, for example, reduce speeds when temperatures reach 95°F (Neveau 2023). Additionally, extreme high temperatures present health and safety concerns for transportation workers, operators, and passengers.

6.2 Extreme cold

6.2.1 Historical information

Historically, the Midwest has always faced extreme cold events (also known as cold snaps). While these events are not necessarily very frequent, they can be quite intense when they do occur, causing power outages and posing a threat to human health and safety. In January 1985, Chicago O'Hare International Airport recorded a temperature of -27 F.[33] More recently, there was an extreme cold event that descended on the Midwest in January 2019, bringing bitterly cold temperatures which caused more than 20 fatalities and resulted in economic impacts that exceeded $1 billion.[34] Moreover, in mid-January 2024, a disruption of the polar vortex brought frigid Arctic air down into mid-latitudes, including in and around Chicago. Wind chills during this event were as low as -20 to -30°F in some places.[35]

6.2.2 Future projections

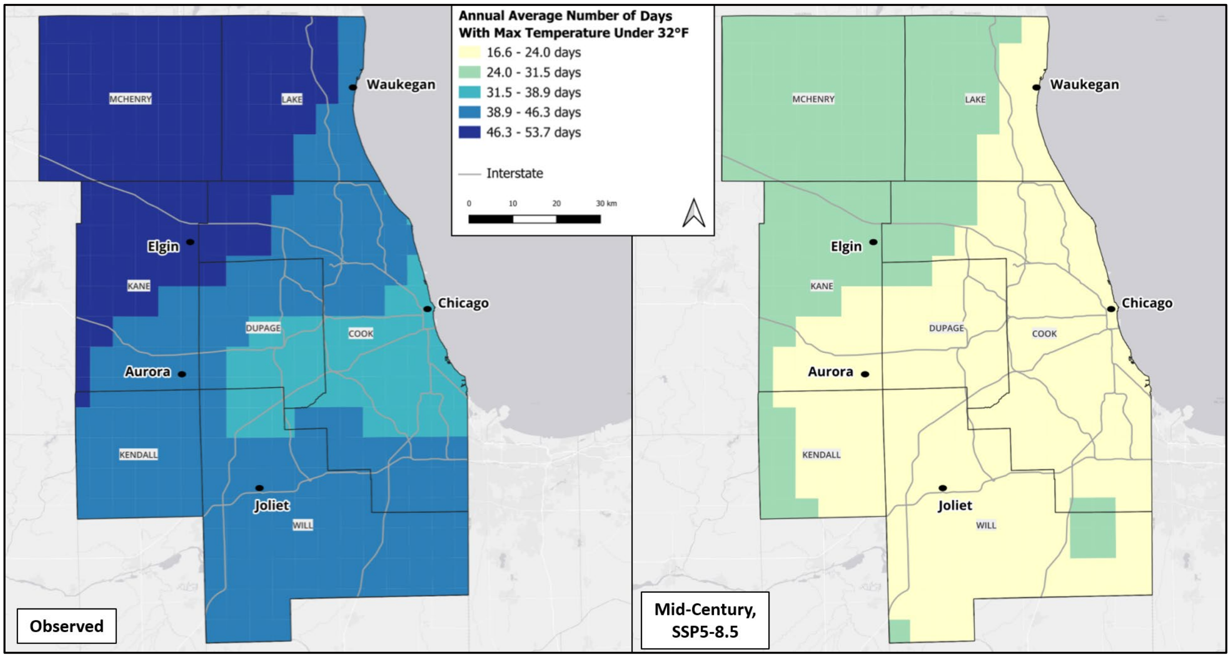
Extreme cold temperatures are expected to occur less frequently in the future. By mid-century the average year is expected to have only 1 day below 15°F, an 80 percent decrease from the observed average of approximately 5 days. Table 19 and Figure 30 show the observed and projected annual average number of days with maximum temperature below 32°F. While 32°F is not typically considered extremely cold, it helps provide a clear trend of how cold temperatures are shifting. By mid-century, this is expected to decrease by 16-21 days under a medium emissions scenario and 20-25 days under a high emissions scenario. By late-century, this is expected to decrease by 22-28 days under a medium emissions scenario and 29-37 days under a high emissions scenario. Freeze-thaw cycles are also projected to decrease approximately 7-9 percent by mid-century and 12-29 percent late-century.

Table 19. Annual average number of days with max temperature under 32°F

	Observed (1985-2014)	Mid-century (2035-2064)				Late-century (2065-2094)			
		SSP2-4.5		SSP5-8.5		SSP2-4.5		SSP5-8.5	
	Days	Days	Change	Days	Change	Days	Change	Days	Change
Mean	43.4	26.9	-16.5 (-38%)	23.4	-20.0 (-46%)	21.4	-22.0 (-51%)	14.0	-29.4 (-68%)
Min	36.8	19.9	-16.9 (-46%)	16.6	-20.2 (-55%)	14.8	-22.0 (-60%)	8.0	-28.8 (-78%)
Max	57.1	36.0	-21.1 (-37%)	32.5	-24.6 (-43%)	29.6	-27.5 (-48%)	19.8	-37.3 (-65%)

[33] (NBC 5 Chicago 2023a)
[34] (Arguez 2019)
[35] (NWS 2024)

Figure 30. Observed and projected annual average number of days with max temperature under 32°F (projections are shown for mid-century under a high emissions scenario)



Although the average number of extreme cold days is expected to decrease in the future, the Midwest may still experience extreme cold events, and there is uncertainty regarding how the intensity of these events may change in the future. One study suggests that climate change will cause an intensification of thermal extremes in the Midwest by mid-century, meaning that heat events get hotter and cold events get colder.[36] This aligns with other findings that suggest climate change is making cold snap events more extreme.[37] Other studies suggest that climate change could drive an increase in the frequency of extreme cold waves in the upper Midwest.[38]

While some scientists argue that climate change will increase the frequency and intensity of extreme cold events in the Midwest in the near- to mid-term, other scientists argue that climate change will actually decrease the duration and intensity of cold spells in the Midwest due to the general warming trend.[39] One study found a decrease in the severity and frequency of cold waves across northern mid-latitudes in the US and suggest that this trend will continue in the future.[40] Even as the Midwest experiences a decrease in the number of days below freezing, the future of isolated extreme cold events remains uncertain.[41]

Extreme cold temperatures can adversely impact transportation infrastructure, services, and users. For example, extreme cold temperatures can cause rail bending and cracking, which can lead to service shutdowns for repairs. Extreme cold conditions can also present health risks to transit passengers waiting outside, and infrastructure damage from cold temperatures can cause service disruptions due to increased repairs/maintenance. However, given that extreme cold temperatures are expected to occur less frequently in the future, these risks will likely be reduced in the future.

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[36] (Pryor, Barthelmie and Schoof 2013)
[37] (Barcikowska, et al. 2019)
[38] (Xie, Black and Deng 2017)
[39] (Wuebbles and Hayhoe 2004)
[40] (van Oldenborgh, et al. 2019)
[41] (USGCRP 2018)

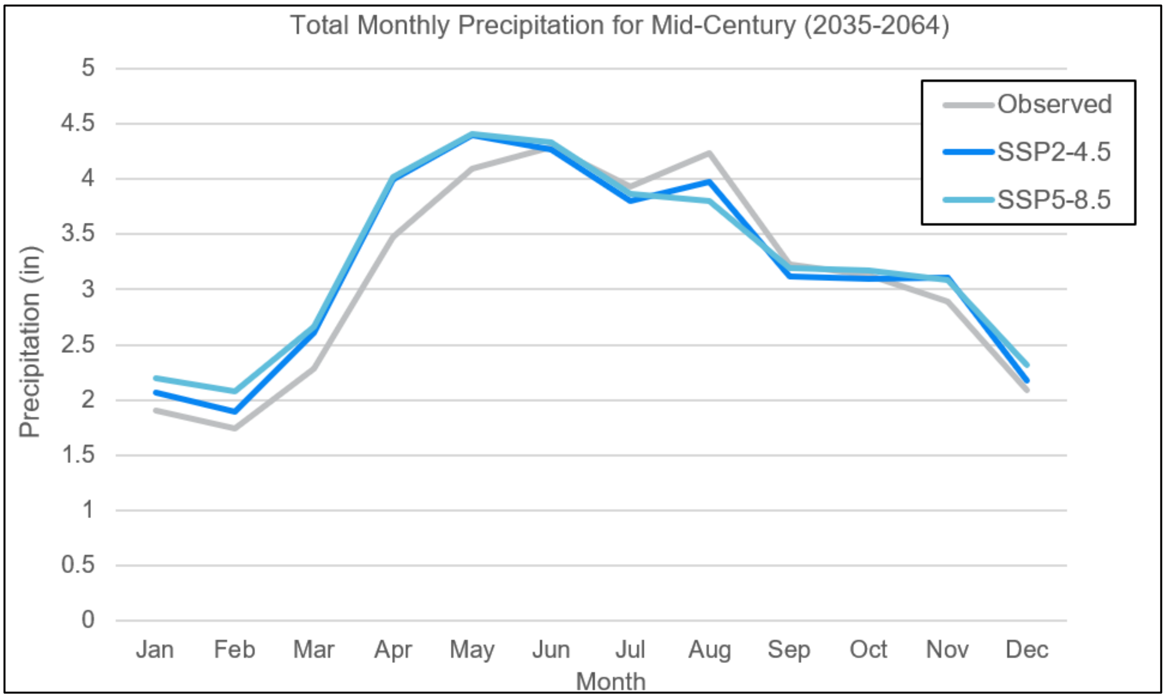
6.3 Precipitation and flooding

Precipitation events and flooding are expected to worsen in the future. ICF included both precipitation variables and detailed modeling of future flood events in the quantitative analysis to understand projected changes in flooding in northeastern Illinois.

6.3.1 Precipitation projections

Figure 31 shows the observed and projected total monthly precipitation for mid-century for northeastern Illinois. **Total monthly precipitation is expected to change by 0.5 inches or less, with the results indicating a shift towards wetter winters and springs and drier summers.**

Figure 31. Observed and projected total monthly precipitation for mid-century



However, the severity and frequency of extreme precipitation events are expected to increase in the future. Table 20 and Figure 32 show the observed and projected annual average number of days with over 1 inch of precipitation. The number of days is not expected to increase significantly under both scenarios.[42] Under a high emissions scenario, the increase is projected to be just 1 day by mid-century and by up to 2 days by late-century.

Maximum 1-day precipitation is also expected to increase in the future (see Table 21). Under a high emissions scenario, the amount of precipitation falling during the maximum 1-day precipitation event is expected to increase by 8 percent by mid-century and 21 percent by late-century. It should be noted that precipitation is not the only contributor to flooding, and subsequent flooding after a precipitation event depends on a number of other hydrological factors. For this reason, we also conducted a more detailed flood analysis. The results from this analysis are included in the next section.

Table 20. Annual average number of days with over 1 inch of precipitation

[42] While temperature projections are more precise, precipitation projections are complex: they point towards increased variability overall, with more intense and extreme weather events.

	Observed (1985-2014)	Mid-century (2035-2064)				Late-century (2065-2094)			
		SSP2-4.5		SSP5-8.5		SSP2-4.5		SSP5-8.5	
	Days	Days	Change	Days	Change	Days	Change	Days	Change
Mean	6.6	7.4	0.8 (12%)	7.6	1.0 (15%)	7.7	1.1 (17%)	8.3	1.7 (26%)
Min	3.9	4.6	0.7 (18%)	4.6	0.7 (18%)	5.1	1.2 (31%)	5.5	1.6 (41%)
Max	9.5	10.2	0.7 (7%)	10.5	1.0 (11%)	10.7	1.2 (13%)	10.7	1.2 (13%)

Figure 32. Observed and projected annual average number of days with over 1 inch of precipitation (projections are shown for mid-century under a high emissions scenario)

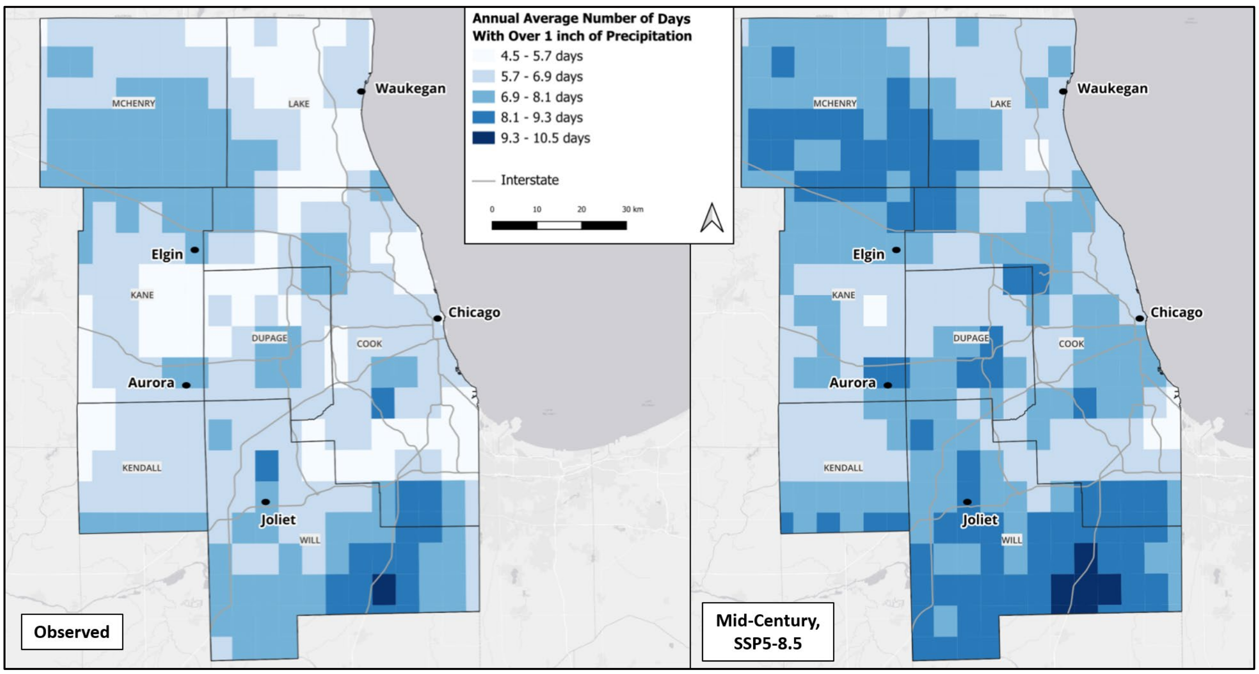


Table 21. Annual average maximum 1-day precipitation (inches)

	Observed (1985-2014)	Mid-century (2035-2064)				Late-century (2065-2094)			
		SSP2-4.5		SSP5-8.5		SSP2-4.5		SSP5-8.5	
	Inches	Inches	Change	Inches	Change	Inches	Change	Inches	Change
Mean	2.4	2.6	0.2 (8%)	2.6	0.2 (8%)	2.7	0.3 (12.5%)	2.9	0.5 (21%)
Min	1.8	1.9	0.1 (6%)	1.9	0.1 (6%)	1.9	0.1 (6%)	2.1	0.3 (17%)
Max	3.0	3.2	0.2 (7%)	3.2	0.2 (7%)	3.5	0.5 (17%)	3.7	0.7 (23%)

6.3.2 Future flooding

Flooding can severely disrupt transportation infrastructure, services, and impact users. For example, flooding can cause erosion of paved surfaces and around bridges, damage stations and trains/vehicles, inundate/damage pump stations, which can cause secondary and tertiary impacts on other transportation assets. Flooding can also cause severe and long-lasting closures and service disruptions in addition to increasing safety hazards for pedestrians and transit riders.

To further understand how the projected increase in precipitation will impact the region's infrastructure, subcontractor Geosyntec created a detailed analysis of the change in land surface flood depth between existing and forecasted 100- and 500-year flood events. The analysis resulted in flood depths across the seven counties for the following six scenarios:

- Flood depths for the existing 100-year flood event
- Flood depths for the forecasted 100-year flood event
- The change in flooding between the existing and forecasted 100-year flood event
- Flood depths for the existing 500-year flood event
- Flood depths for the forecasted 500-year flood event
- The change in flooding between the existing and forecast 500-year event

Table 22 shows the analysis results for the 100-year flood event by county. The increased area (shown in acres) is the mid-century, 100-year flood inundation compared to the existing 100-year flood inundation. The total increase is shown, as well as the increase in areas flooded at or above 0.5, 1, and 2 feet.

Table 22. Increase in 100-year flood inundation area by mid-century by county

County information		Total area with increase in ponding		Increase in areas flooded, at or above 2 ft.		Increase in areas flooded, at or above 1 ft.		Increase in areas flooded, at or above 0.5 ft.	
Name	Area (ac)	Area (ac)	Percent	Area (ac)	Percent	Area (ac)	Percent	Area (ac)	Percent
Cook	612,746	358,255	58.47%	156	0.025%	795	0.13%	7,818	1.28%
DuPage	215,283	88,484	41.10%	42	0.020%	146	0.07%	2,568	1.19%
Kane	335,394	158,519	47.26%	1	0.000%	63	0.02%	4,045	1.21%
Kendall	206,277	99,752	48.36%	0	0.000%	365	0.18%	3,509	1.70%
Lake	301,307	140,700	46.70%	19	0.006%	79	0.03%	2,572	0.85%
McHenry	390,902	190,227	48.66%	22	0.006%	64	0.02%	1,414	0.36%
Will	543,377	255,053	46.94%	219	0.040%	732	0.13%	7,641	1.41%

The maps in Figure 33 and Figure 34 are a sample of the analysis results for a small portion of the region. As a full map of the results would not be legible within the report, they were studied and presented to CMAP staff using an online ArcGIS map. These examples show the modeled change in flood depth between the existing and forecast 100-year flood event for a portion of McHenry County (Figure 33) and between the existing and forecast 500-year flood event for a portion of Kane County (Figure 34). They demonstrate the level of change anticipated, with some locations experiencing an increase of almost 4 feet of floodwater.

Figure 33. Map of increased flooding during 100-year flood event for western portion of McHenry County

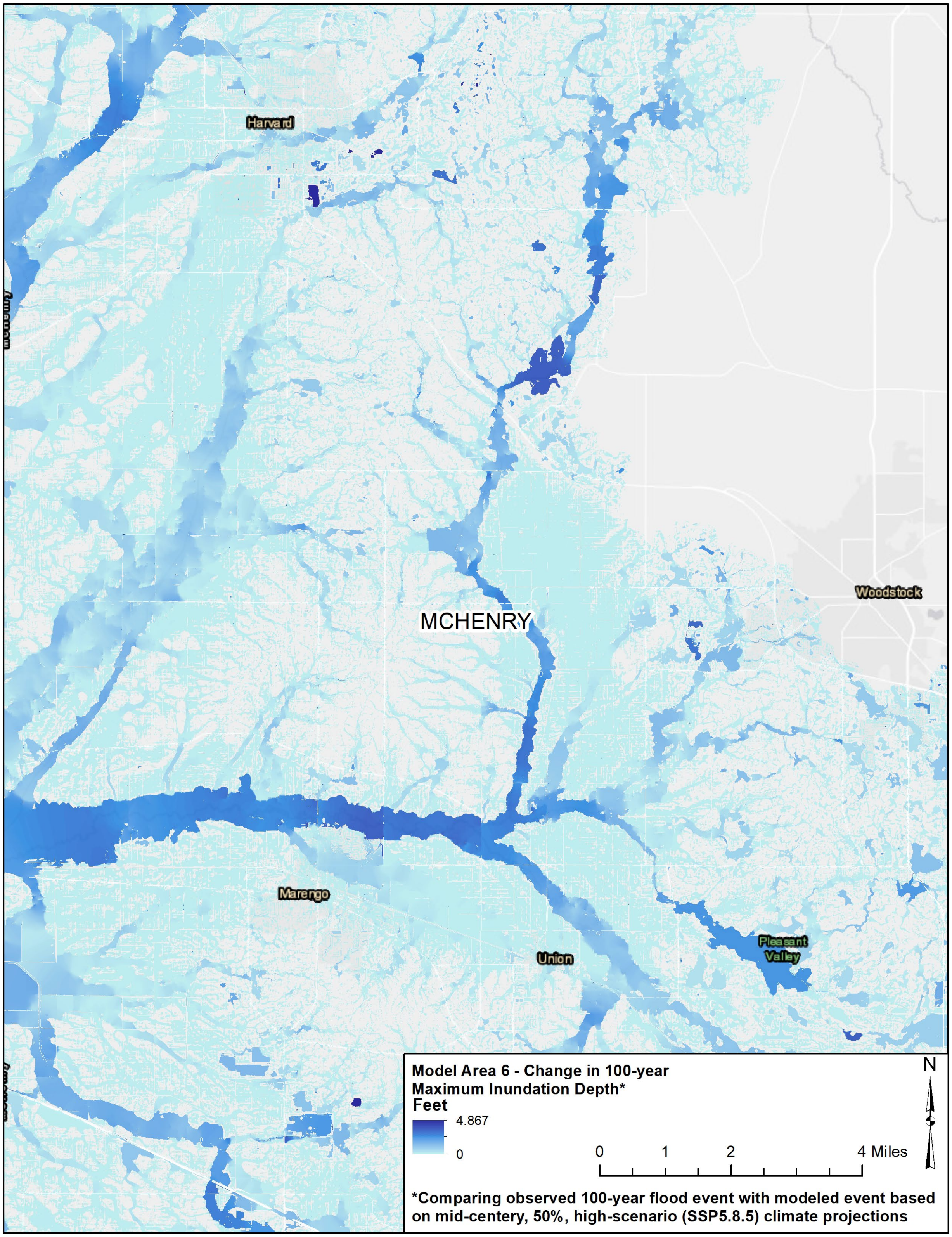
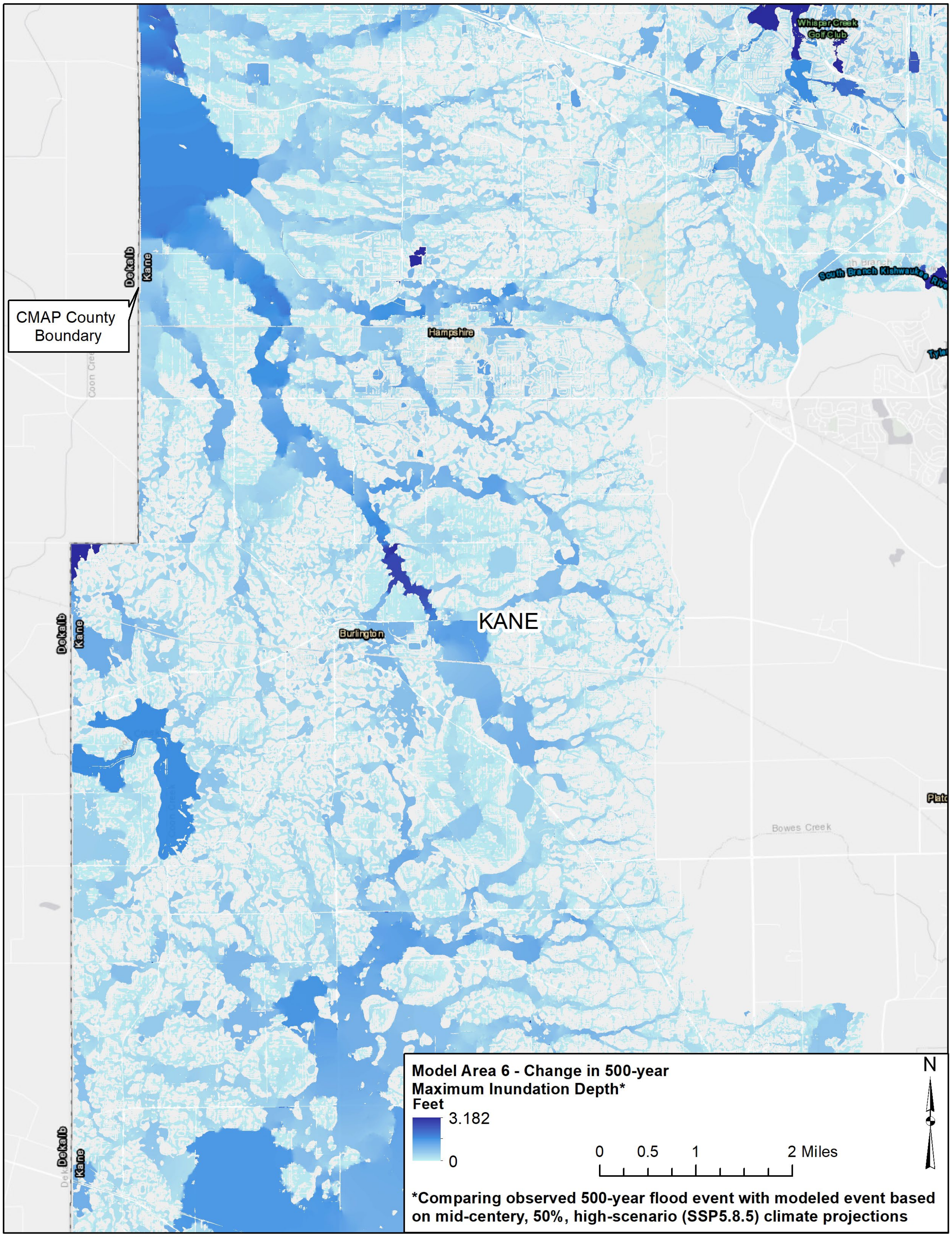


Figure 34. Map of increased flooding during 500-year flood event for western portion of Kane County



6.4 Severe storms

Historically, the Great Lakes region has experienced a variety of severe storms, including thunderstorms and derechos. In 1966, severe thunderstorms hit Aurora, IL, with 16.9 inches of rain falling in 24 hours and continuous lightning and waves of thunderstorms. This event led to widespread flooding and shut down parts of Interstate 55 and a section of Interstate 88. [43] In recent years, several severe storms have hit the Midwest region leading to widespread damage from heavy precipitation, extreme wind, and flooding. For example, in August 2020, a derecho event moved across the Midwest and through northeastern Illinois, flipping cars, knocking down trees, and leading to widespread power outages. [44] Though these storms are already present in the region, research suggests that they may increase in both frequency and intensity in the future.

Severe storms can adversely impact transportation infrastructure and users/services. For example, heavy precipitation events can cause pavement damage, increase erosion and scouring of bridges and culverts and wash out rail lines and stations. Severe storms can also cause severe and long-lasting closures and service disruptions in addition to increasing safety hazards for pedestrians and transit riders.

Potential rainfall totals and windspeeds are exceptional in northeastern Illinois. The area sees several types of severe storms, including hail, thunderstorms, tornadoes, straight-line wind events, and more. Table 23 outlines notable recent historical severe storms. While the list is not comprehensive, these storms serve as exceptional examples of severe storms. Severe storms in the region are capable of bringing nearly 7 inches of precipitation in just 3 hours, such as the July 2011 storm, and up to 9 inches in a single day, as in the case of the July 2023 storm. Chicago experienced wind gusts of a record 87 mph [45] in 1894 and the region experienced gusts of up to 90 mph in a more recent March 2023 tornado outbreak.

[43] (NOAA 2023b)
[44] (Rice and Schoolman 2020)
[45] (NWS 2023a)

Table 23. Notable historical analogs for recent severe storms in the CMAP area[46]

Date	Rainfall	Winds	Impacts and notes
September 17, 2023[47]	Up to 6 inches of rain	No notable wind gusts	Slow-moving storm produced pockets of locally heavy rainfall in south Cook County. Radar estimates that up to 9 inches fell in Calumet City. Flooding resulted in a federal disaster declaration.
July 2, 2023[48]	Up to 9 inches of rain in Cook County	No notable wind gusts	Peak rainfall intensity of up to 2 inches an hour, concentrated on the west side of Chicago and west Cook County; total property damages estimated at over half of $1B. Flooding resulted in a federal disaster declaration.
May 7, 2023[49]	Up to 5 inches of rain	Wind gusts up to 62 mph	Localized flash flooding and reduced transportation visibility due to dust storm.
March 31, 2023[50]	Flooding and hail of up to 1 inch diameter	Wind gusts of up to 90 mph	22 confirmed tornadoes in the Chicago National Weather Service forecast area associated with the event, with 146 nationally — tied for the most tornadoes in a single day in Chicago-area history. Impacts near Chicago included: flipped 18-wheeler on Interstate 88, damage to roofs power lines, and snapped trees.
August 29, 2022[51]	Two-day rainfall totals of nearly 3.5 inches	Wind gusts of up to 60 mph in Chicago and 80 mph more broadly	A severe thunderstorm slammed the broader Chicago area, leaving a trail of wind damage, flooding, and hail in its wake. Fallen trees and snapped powerline poles caused widespread disruption to transportation and traffic flow. Airline delays were also reported, and roofs were ripped from buildings by the strong winds.
April 15-22, 2013[52]	Upwards of 3.5 inches in one day and 5.5 inches over two days	Minimal notable wind gusts	Record two-day rain total in Chicago for April; River crests on the Des Plaines, Vermilion, Chicago, DuPage, Fox, and Illinois rivers reached record heights. Flooding resulted in a federal emergency declaration, allowing for nearly $170 million of aid from the Federal Emergency Management Agency and about $120 million dollars of relief from Housing and Urban Development.[53]
July 23, 2011[54]	Over 6.8 inches of rain in one day, 8.2 inches in	Minimal notable wind gusts	Nearly all precipitation fell in a 3-hour window from 1:00 to 4:00 a.m., setting the record for calendar-day precipitation, and the second-most precipitation for a 24-hour period. The event flooded roadways

[46] Analogs are illustrative and not a comprehensive set of historical extreme events.
[47] (NWS 2023e)
[48] (NCEI 2023)
[49] (NWS 2023d)
[50] (NWS 2023c)
[51] (NWS 2022a)
[52] (NWS n.d.)
[53] (ASCE 2017)
[54] (NWS 2011)

	a 24-hour period		throughout the area including highways and ramps. Flights at airports were delayed and canceled, and around 90,000 Commonwealth Edison customers lost power.[55]

There is consensus in the literature that climate change is expected to drive an increase in the frequency and severity of storms in northeastern Illinois. Additionally, projected increases in severe storms will drive an increase in the risk of flooding, heavy precipitation, and extreme wind associated with these storms. Because the term "storms" encompasses a range of specific types of weather events, the subsections below summarize key components of a storm. Based on the literature review future storm trends can better be synthesized using the findings for:

- Thunderstorms, tornadoes, and derechos
- Storms and heavy precipitation
- Extreme windspeeds and wind gusts

6.4.1 Thunderstorms, tornadoes, and derechos

Thunderstorms are severe local storms often characterized by thunder, lightning, heavy rain, hail, or extreme wind gusts.[56] Thunderstorms can also drive the formation of tornadoes and/or derechos, widespread, long-lived, and straight-line windstorms associated with a band of rapidly moving showers or thunderstorms. There is agreement in the literature that climate change will increase thunderstorm activity in northeastern Illinois.

One metric for measuring thunderstorm activity is convective available potential energy (CAPE), which can be analyzed for future climates based on climate projections. CAPE refers to the amount of energy available to a developing thunderstorm and is used to quantify unstable atmospheric conditions. Larger CAPE values create environments more favorable for severe thunderstorm formation.

The literature indicates that CAPE values will increase through the end of the twenty-first century. These studies include Del Genio, Yao, & Jonas 2007 and Brooks 2012. Similarly, the IPCC's Sixth Assessment Report suggests that there is high confidence for CAPE values to increase and medium confidence for the frequency of severe spring thunderstorms in the United States to increase, leading to a lengthening of the severe thunderstorm season.[57]

The increases in CAPE values are projected to be particularly pronounced in the central, midwestern, and eastern United States.[58] In the Chicago area specifically, one study projects that CAPE values will drive an increase in the frequency and severity of storms.[59]

It is unclear how tornado activity will increase in the future. Although CAPE is projected to increase, another severe weather variable, wind shear, is projected to decrease.[60] Wind shear describes sharp shifts in wind speed and direction, occurring either vertically or horizontally throughout the atmosphere. Both CAPE and wind shear are important factors in tornado formation. Wind shear is a more significant contributor than CAPE for the development of tornadoes and hail. As the conditions

[55] (Rodriguez 2011)
[56] (Royal Meteorological Society 2020)
[57] (Seneviratne 2021)
[58] (Van Klooster and Roebber 2009)
[59] (Richmond and Rodriguez 2023)
[60] (Brooks 2012)

that form tornadoes are complex and two factors that can help predict the future potential of severe storms are in competition, the future of tornadic activity is highly uncertain. While wind shear is projected to decrease under future climate change scenarios, a majority of low wind shear days are correlated with low CAPE days, and therefore do not decrease the total occurrence of days with conditions for severe storms. [61] Wind shear may decrease due to the reduction of temperature gradients between the poles and the equator. [62] A separate study also used CMIP5 climate models to project a decrease in wind shear through the end of the century in the Midwest.

6.4.2 Storms and heavy precipitation

An increase in the frequency and intensity of storms is projected to bring more precipitation. Over the past several decades, northeastern Illinois has experienced an increase in precipitation intensity. Individual storm events are characterized by increasingly large precipitation totals. [63] Furthermore, an analysis of heavy precipitation events in Chicago revealed that the 24-hour 100-year storm (a 1 percent annual chance) has already occurred five times since a notably severe 1987 storm with a 24-hour total of 9.35 inches. [64] These findings are consistent with the results of ICF's modeling in the Precipitation and Flooding section.

While there are many ways to define heavy precipitation, climate change is projected to increase heavy precipitation under all definitions in the reviewed literature. For example:

- One study projects an increase in thunderstorm frequency in the region by end-of-century. [65]
- Another study suggests that the number of days with greater than one inch of precipitation may increase significantly by end-of-century in the northern portion of the Midwest, similar to what is modeled for this report. [66]
- One study projects that Chicago will experience more days with greater than 2.5 inches of precipitation per day, [67] and another study projects that the events characterized by **more than 1.5 inches of precipitation per day may increase by 25 percent** under a low emissions scenario and as much as 60 percent under a high emissions scenario by the end of the century. [68]

Though these studies used different models and assumptions, the findings are generally consistent and align with those developed for this report.

As higher precipitation days become more common, the risk of flooding is also likely to increase. One study projects that flooding will be an increasing problem in northeastern Illinois region in the coming decades. [69] Outside of the region, precipitation across the northeastern Midwest is expected to increase and drive an increased risk of flooding. [70]

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[61] (Diffenbaugh, Scherer and Trapp 2013)
[62] (Trapp 2007, Van Klooster and Roebber 2009, Brooks 2012)
[63] (CMAP 2013)
[64] (CMAP 2013, NOAA 2023b)
[65] (Trapp 2007)
[66] (Kunkel, Steven and Stevens 2012)
[67] (Hayhoe 2010)
[68] (Vavrus and Van Dorn 2010)
[69] (Markus, et al. 2012)
[70] (EPA n.d.)

6.4.3 Extreme windspeeds and wind gusts

Severe storms can also be associated with extreme wind speeds and wind gusts which have the potential to cause significant damage and disrupt the transportation system (e.g., downed trees knocking out rail lines). In 1984, the highest wind gust in Chicago was recorded at 87 mph. [71] The second highest wind gust was recorded in June 2022 when Chicago O'Hare International Airport measured an 84-mph wind gust during a bout of severe thunderstorms in the region. [72]

While *average* wind speeds in the Northern Hemisphere show the potential for no change or a decrease through the twenty-first century, [73] the increase in more frequent and intense storms more correspond with more extreme wind events and wind gusts. The research supporting this conclusion includes the following:

- In their sixth assessment report, the IPCC suggests that peak wind speeds associated with extreme events, such as tropical cyclones, may increase in this century due to warming. [74]
- A study of wind gusts across Canada found that future daily wind gusts greater than 43 mph could increase by as much as 20 percent. [75] Furthermore, their research projects that the magnitude of increase in the frequency of future hourly and daily wind gusts events will be greater for more severe wind gust events. In other words, more extreme wind gust events will see greater increases than more moderate wind gusts events.
- In the central United States specifically, a recent study published in *Nature Climate Change* found that straight-line winds (i.e., non-tornadic thunderstorm winds) have intensified over the past 40 years and are expected to continue to intensify under a changing climate. [76]

6.4.4 Ice storms: historical and future

Historical information

Ice storms are not uncommon in the Midwest, and Illinois specifically, and can result in severe damage across the region. [77] Ice storms can lead to widespread outages, physical damage, and can pose significant problems for transportation systems. [78] Damage from ice storms is often due to ice coating highway surfaces as well as electrical wires (i.e., transmission and distribution line wires). Ice can also coat tree branches and lead to trees falling over, which causes further damage. [79]

Early January 1998 brought one of the worst storms in US history. Parts of upstate New York and Ontario, northeast of the Chicago region, received almost 4 inches of freezing rain and the storm caused more than $3 billion in damages. [80] The greater Chicago area has experienced more localized ice storms as well. As recently as February 2023, an ice storm led to widespread power outages in and around Chicago and some areas experienced more than 0.3 inches of ice accumulation. [81]

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[71] (NWS 2023a)
[72] (NOAA 2023a).
[73] (Zha 2021)
[74] (Seneviratne 2021).
[75] (Cheng, et al. 2014)
[76] (Prein 2023)
[77] (Call 2010, Changnon 1969)
[78] (Andresen, Hilberg and Kunkel 2012)
[79] (Changnon 1969)
[80] (Manges 2021)
[81] (NBC 5 Chicago 2023b)

Future projections

Generally, climate change is leading to warming temperatures and more frequent and intense precipitation in the Midwest.[82] Competition between increasing temperatures and greater rates of precipitation makes the future of ice storms in the Midwest uncertain and hard to model. Furthermore, while some weather patterns that cause ice storms are decreasing in the Great Lakes region, other events are increasing, particularly those that lead to longer-lasting icing events.[83] This means that while the frequency of ice storms may decrease, the duration and intensity of discrete ice storm events may increase. Across the entire United States, however, studies suggest that there will be an increase in the frequency of winter ice storms.[84]

The future of ice storms will likely be highly variable and depend on the rate at which temperature warms in the Midwest, specifically. For example, in New York, one study predicts that ice storms may increase by mid-century.[85] However, temperatures may get high enough in the second half of the century that there is a decrease in the frequency of ice storms over the longer time period.

6.5 Compounding hazards

This section summarizes two compounding hazard scenarios for northeastern Illinois. It provides information from historical analog events and future climate projections to generate plausible worst-case scenarios for:

- Severe storm followed by high heat
- Ice storm followed by a cold snap

These compounding events were selected as they have previously occurred, pose a significant risk to the region, and are not already covered by the single-hazard analysis.

This information is intended to supplement the quantitative climate projections that ICF developed earlier in the project for temperature and precipitation. The projections already developed help illustrate how temperature or precipitation events may change in the future. Those datasets look at each climate hazard in isolation and focus on hazards that can be quantitatively projected into the future. However, some of the most damaging weather events are ones where a combination of hazards occurs at the same time or within short succession. For example, an extreme storm can cause power outages, which can cause various disruptions to normal life. However, if that extreme storm is then followed by an extreme heat wave, and air conditioning is not available for vulnerable populations due to power outages, then there is a greater risk to human safety. Moreover, some of the most damaging weather events include hazards — such as high winds — that cannot be projected quantitatively.

Unlike for temperature and precipitation projections, scientific understanding of these compound events is not sufficient to allow quantification of expected changes in frequency or severity of the events in the future. Therefore, ICF took a scenarios-based approach to help illustrate plausible events that could occur in the future. ICF developed scenarios that are considered “extreme but plausible” to illustrate particularly severe events that could conceivably occur in mid-to-late twenty-first century. These scenarios help illustrate a broader set of potential impacts and vulnerabilities across the transportation system.

[82] (EPA n.d.)
[83] (GLISA n.d.)
[84] (Klima and Morgan 2015)
[85] (Horton, et al. 2010)

Each scenario is supported by a suite of underlying climate information including recent historical "analogs" for each event — that is, observed events that occurred in the past and that could shed light potential future impacts to the region. The information also includes a review of recent scientific research related to each event, and climate model projections, as appropriate. Analogs help constrain a historical baseline for each event type, while forward-looking climate research and projections characterize potential future change. The subsections below provide an overview of this information and the corresponding scenario for the two compounding events of interest.

This information will be used to inform the general trends in how the climate is changing, and to better understand the likelihood of these compounding events to occur. Additional discussion may be included within the CMAP TRIP on how the projected changes for these compounding events may impact the transportation system and its assets. Particular attention will be on any new impacts from these compounding events that are not otherwise captured within the single-hazard vulnerability assessment.

Figure 35. Photo of historic flooding in Chicago on Grand Avenue, April 15-22, 2013 [86]

6.5.1 Scenario 1: Severe storm followed by high heat

During warmer months, northeastern Illinois experiences a variety of extreme weather including drought, severe storms with the possibility of tornadoes, and high temperatures. While these events typically occur independently, the region has witnessed instances where both severe storms and heat waves have happened concurrently.

86 (NWS n.d.)

Historical information

Northeastern Illinois has experienced several instances where extreme weather events combined to create dangerous situations. In July 2016, several days of severe thunderstorms brought damaging winds, up to 5 inches of rain, and heat index values exceeding 115°F. [87] Similar events occurred in July 2019 with heavy rain and heat indexes reaching 110°F [88], and in August 2021 with powerful wind gusts of up to 70 mph, flooding, power outages impacting over 100,000 customers, and heat indexes of 105°F. [89] Most recently, June 2022 saw another severe storm followed by a heatwave. [90] These examples highlight the increasing frequency and intensity of combined extreme weather events in the region.

Future scenario

This section describes a scenario for mid-century in which a severe storm followed by a heat wave occurs in northeastern Illinois. As noted previously, the frequency of both severe storms and heat waves are expected to increase in the future. And thus, the frequency of this compounding scenario is also expected to increase. The purpose of this scenario is to explore a potential future extreme event that could help inform potential resilience investments. This scenario uses historical information in combination with the literature review of future projections to highlight an unlikely but plausible extreme scenario that may become more likely by mid-century.

In this scenario, a low-pressure system with ample moisture from the Gulf of Mexico forms off the Rocky Mountains in Colorado and moves northeastward through Kansas and Missouri. The system brings a warm, moist air mass northward from the Gulf of Mexico up through southern Wisconsin. This warm air, in combination with a cold front stretching from southwestern Illinois to Arkansas, sets the stage for severe weather. The Chicago area is hit with significant precipitation (localized totals of 8 inches in less than 24 hours), flooding, and high winds, including multiple tornadoes. Gusts in Chicago reach 85 mph and as high as 100 mph in the broader region. As the low pressure continues eastward, a strong, slow-moving high pressure begins to move southeastward from North Dakota into the Chicago area. This system produces 12 consecutive days above 90°F with a maximum temperature of 100°F. Heat index values climb over 125°F.

A weather system of this magnitude could have severe consequences across the region, including but not limited to the following impacts:

- **Infrastructure:** Widespread impacts to infrastructure throughout the region due to high winds, tornadoes, and localized flooding. Impacts could include damaged housing, damaged bridges and disruptions to the transportation system, and large-scale power outages due to knocked down trees and power lines.
- **Transportation system:** High winds could knock down trees and signage, blocking traffic flow. Loss of power would disrupt traffic signals and the transit system, resulting in significant travel delays. Extended high heat increases the likelihood of transportation infrastructure impacts such as concrete buckling and asphalt rutting on roadways and bending and kinking of rail lines, that may decrease health and safety for the operators and users of transportation. High heat would make it unsafe to use active transportation (e.g., walking, bike) for much of the population. Combined with disruptions to the transit system, community members may have

[87] (NWS n.d.)
[88] (Freund 2019)
[89] (Sun-Times Wire 2021)
[90] (NBC 5 Chicago 2022)

difficulty accessing critical services (e.g., hospitals). Loss of power could further exacerbate the situation (e.g., air conditioning systems do not work).

- Community health: The high winds put active transportation users at risk and could limit access to transit services. The ensuing heat wave poses significant health risks throughout the community, especially for vulnerable populations (e.g., older adults, infants and children, outdoor workers, people with chronic illness, and people experiencing unsheltered homelessness) and users of transit and active transportation. Disruptions to the transportation system could isolate community members, limiting their ability to access critical services (e.g., cooling centers, hospitals).

6.5.2 Scenario 2: Ice storm followed by a cold snap

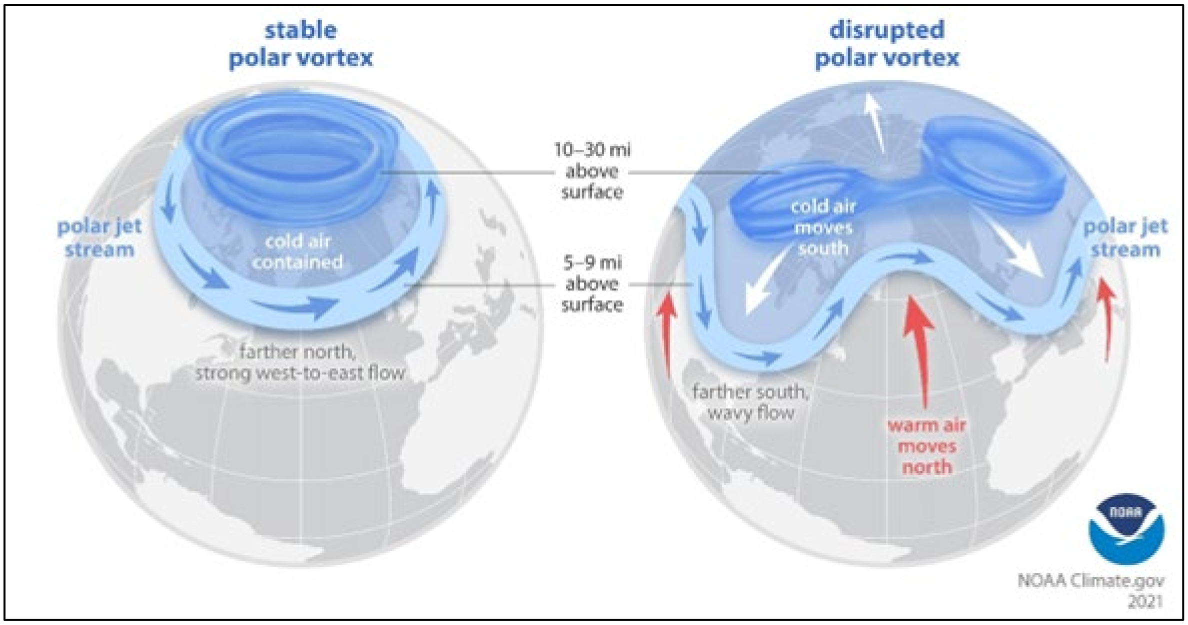
Ice storms, also known as "freezing rain events," occur when specific atmospheric conditions create a specific vertical temperature profile conducive to the formation of freezing rain. Typically, freezing rain, the primary precipitation type during ice storms, occurs during temperature inversions where warm air moves over colder air. Under these conditions, precipitation falls as a liquid and then freezes on or near the surface (in the form of ice). In cases where there is a high atmospheric moisture content and a strong temperature inversion, ice accumulation can be quite significant.

Historical information

Extreme cold events are another winter weather hazard that is often connected to a phenomenon known as Arctic amplification. Arctic amplification describes the trend by which the Arctic is warming more quickly than lower latitudes. [91] Enhanced Arctic warming reduces the temperature gradient between high and mid-latitudes and increases the likelihood of a disrupted polar vortex during the winter months (Figure 36). This can lead to periods where cold, Arctic air penetrates into lower latitudes, creating extreme cold events in places like the Midwest. [92] There is reason to believe that Arctic amplification will become more frequent in the future as sea ice melts. [93]

Figure 36. Illustration of disrupted polar vortex [94]

[91] (Rantanen, et al. 2022)
[92] (Francis and Vavrus 2012)
[93] (Linke, Feldl and Quaas 2023)
[94] (NOAA 2021)



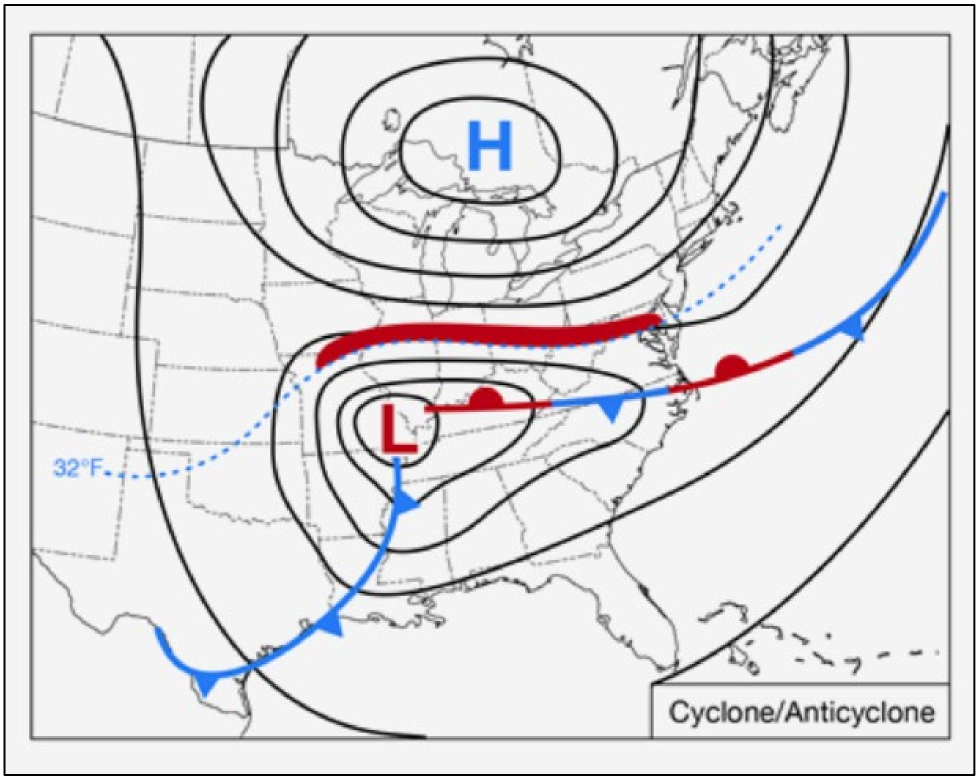
Future scenario

The following sections describes a plausible "worst-case scenario" for mid-century in which a severe ice storm followed by a cold snap occurs in northeastern Illinois.

In this scenario, a high-pressure system from the north collides with a low-pressure system from the south over the Great Lakes region (see Figure 37). This setup maintains a strong flow of cold air near the surface and prevents warmer air from moving farther north. At the same time, strong southerly winds bring moist air northward across the frontal boundary, which forces air up to form clouds and precipitation. The precipitation tends to fall over a long duration and in the form of freezing rain due the pressure different between the high and low systems and below freezing surface temperatures. [95] This storm brings heavy precipitation to northeastern Illinois in the form of freezing rain. Over the course of a day, some areas receive close to half an inch of ice accumulation. The storm is accompanied by frigid temperatures and parts of the region experience temperatures below 0°F. The extreme cold lingers for up to a week after freezing rain has fallen.

Figure 37. Image of the weather system setup described in this scenario[96]

[95] (Midwestern Regional Climate Center n.d.)
[96] (Midwestern Regional Climate Center n.d.)



A weather system of this magnitude could have severe consequences across northeastern Illinois, including but not limited to the following impacts.

- **Infrastructure:** Freezing rain causes ice accumulation ranging from small amounts to at least half an inch across large portions of the region. This causes impacts to the transportation system and utility infrastructure from downed trees and power lines, leading to lengthy transportation delays and widespread power outages. With temperatures reaching below 0°F, and in some places much lower due to wind chill, surfaces and structures remain frozen for long periods, limiting the recovery of utility and transit services, further isolating large portions of the population.
- **Transportation system:** Freezing rain causes ice accumulation across the region leading to major crashes and significant disruptions to the transportation system. Transit lines and services are suspended or delayed. Loss of power due to downed trees would further amplify these disruptions, with traffic signals and rail lines unavailable. An extended period of extreme cold further inhibits the region's ability to recover from these disruptions and may decrease health and safety for the operators and users of. The extreme cold would also be unsafe to use active transportation (e.g., walking, bike) for much of the population. Combined with disruptions to the transit system, community members may have difficulty accessing critical services (e.g., warming centers, hospitals).
- **Community health:** The freezing rain and resulting ice put active transportation users at risk and could limit access to transit services. Residents with limited mobility and users of active transportation are severely affected as sidewalks, bike routes, bus stops, and train stations have dangerous conditions. The ensuing extreme cold snap poses significant health risks throughout the community, especially for vulnerable populations (e.g., older adults, infants, and people experiencing unsheltered homelessness) and users of transit and active

transportation. Disruptions to the transportation system could isolate community members, limiting their ability to access critical services (e.g., warming centers, hospitals).

7 Appendix B: System-level analysis sensitivity details

This appendix provides the detailed evidence base for each sensitivity rating in the system-level analysis.

7.1 Roadways

Roadways have high sensitivity to flooding. Table 24 summarizes expected impacts to physical infrastructure and users and services for roadways. Although most of the impacts described in this section focus on drivers and vehicle passengers, other users also rely on roadway infrastructure. These include people riding buses, walking, rolling, and riding bicycles. Impacts related to these users are covered in the CTA & Pace bus service and stops section and the bicycle and pedestrian facilities sections.

Table 24. Sensitivities of roadways to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium** • Sustained high temperatures can result in softening of the asphalt binder, leading to rutting and shoving. • High temperatures can cause heaving of concrete joints as concrete contracts and expands. • Sustained periods of high heat preceded by cooler temperatures can cause concrete roadways to buckle as pavement expands. • Higher temperatures can reduce the operational lifespan of pavement leading to more frequent surface treatments and material/labor costs. • Different binders and/or asphalt types may be used under future higher temperatures but may increase operations and maintenance costs. *Expected future conditions would cause moderate damage that may impact functionality.*	**Sensitivity: Medium** • Road repairs can cause lane closures and delays. ○ For example, pavement heaving can take days to fix and may result in multiple lane closures, causing additional service disruptions and delays. • Extreme heat can increase the risk of tire blow-outs, especially on heavy vehicles. • Extreme heat can heighten the risk of heat stress for drivers and passengers in vehicles without air conditioning, especially populations that are highly vulnerable to heat-related health risks like the young and the elderly. • Extreme heat can cause long-term health impacts for workers. *Expected future conditions would cause moderate impact to service and users.*
Extreme cold	**Sensitivity: Low** • Extreme cold can cause asphalt to contract and shrink, which can lead to cracks and other road damage. • Extreme cold can cause heaving and cracking of concrete roads.	**Sensitivity: Medium** • Road repairs can cause lane closures and delays. ○ Additionally, maintenance operations to de-ice roadways can be affected as temperatures

	• Extreme cold can cause various issues in vehicles, including reduced battery capacity and deflated tires. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	drop, leading to additional service disruptions or delays. • Extreme cold can heighten safety risks for drivers and passengers if vehicles malfunction or break down. *Expected future conditions would cause moderate impact to service and users.*
Flooding (urban, riverine, coastal)	**Sensitivity: High**	**Sensitivity: High**
	• Flooding can cause erosion of paved surfaces, worsening of existing pavement damage, and structural integrity degradation. • Pavement and embankment failure can result from overtopping and erosion when roadways parallel streams and rivers. • The pavement subgrade can take a very long time to dry out after a flooding event, making the pavement weaker. This can lead to additional damage to the pavement subgrade as vehicles travel over the road. *Expected future conditions would cause significant damage that may impact functionality.*	• Roadway drainage and stormwater systems may be undersized for current and future flooding events. Insufficient drainage capacity or blockage may worsen local flooding and cause standing water on driving surfaces. Similarly, if pump stations are overwhelmed or damaged, local flooding could worsen. • Flooding can lead to severe and long-lasting road closures and delays as well as safety hazards. ○ The 2013 DuPage River flood caused multiple road closures that lasted for days. • Short-term nuisance or flash flooding can lead to congestion, detours and rerouting, and safety hazards on roadways, causing delays. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*
Freeze-thaw cycling	**Sensitivity: Medium**	**Sensitivity: Low**
	• Freeze-thaw cycling can cause potholes, surface cracks, and deformations in concrete and asphalt roads. Increased freeze-thaw cycling can over time accelerate the degradation of pavements, thereby increasing cost and frequency of maintenance. *Expected future conditions would cause moderate damage and would have minimal impact on functionality.*	• More frequent road repairs due to increased freeze-thaw cycling can cause service delays, • Vehicles may require additional maintenance due to hitting potholes more frequently. *Expected future conditions would cause minimal impact to service and users.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: Medium**
	• During heavy precipitation events, pavement can be completely submerged, and water may reach the	• Heavy rain events can reduce visibility (difficulty seeing street signs and other vehicles) and heighten safety

	pavement subgrade. This can lead to pavement damage as the subgrade is sensitive to moisture levels. Moisture damage to roadways includes surface defects, surface deformations, and cracking. • Ice formation and snow removal can deteriorate pavement, causing potholes and cracking. Extreme cold can also make road salt ineffective, preventing ice removal on roadways. • Heavy winds can create and move debris and down power lines, potentially damaging or blocking roads. • Strong winds can blow over highways, street and road signs, and damage traffic signals. *Expected future conditions would cause moderate damage that may impact functionality.*	risks (slippery roads, moving or standing water over roads). • Roadways may require additional maintenance and repair following severe storms, which could lead to delays or closures. • Snow or ice can pose a safety risk to drivers, which can also contribute to reduced speeds and longer travel times. • Winter storms can reduce visibility, creating additional safety hazards. • Winter storms may require additional maintenance and repair, which could cause road delays/closures. ○ For example, during the blizzard in February of 2011, 2 feet of snow caused the interstate and DuSable Lake Shore Drive to close for a day and other roads were closed for multiple days. During this event, more than 500 motorists were stranded and McHenry County Department of Transportation housed crews on site. • Road closures or delays may occur due to downed power lines and debris blocking roadways following heavy winds. • High winds can reduce visibility and cause safety risks. *Expected future conditions would cause moderate disruptions to service.*

7.2 Bridges (road and rail) and culverts

Bridges (road and rail) and culverts have high sensitivity to flooding. Table 25 summarizes the expected impacts to physical infrastructure and users and services for bridges and culverts.

Table 25. Sensitivities of bridges (road and rail) and culverts to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium**	**Sensitivity: Low**
	• High temperatures can increase stress on the bridge structure. • Sustained high temperatures can result in softening of the asphalt binder, leading to rutting and shoving in bridge decks. • High temperatures can cause heaving of concrete joints as concrete contracts and expands. • Joint clogging in simple steel girder bridges prevents steel from naturally expanding when temperatures rise. *Expected future conditions would cause moderate damage that may impact functionality.*	• Bridge repairs can cause lane closures and delays. *Expected future conditions would cause minimal impact to service and users.*
Extreme cold	**Sensitivity: Low**	**Sensitivity: Medium**
	• Extreme cold can cause asphalt to contract and shrink, which can lead to cracks and other road damage. • Cold temperatures can stress metal bridge structures. • Extreme cold can cause ice jams, which can damage bridges. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• Bridges freeze faster than roads, and ice formation on bridges can pose a safety risk to drivers. • Bridge repairs can cause lane closures and delays. ○ Additionally, maintenance operations to de-ice bridges can be affected as temperatures drop, leading to additional service disruptions or delays. *Expected future conditions would cause moderate impact to service and users.*
Flooding (urban, riverine, coastal)	**Sensitivity: High**	**Sensitivity: High**
	• Heavier water flows may increase scour and erosion around bridge foundation areas, making them more susceptible to damage.	• Flooding can lead to more severe and longer-lasting service disruptions. For example, bridge overtopping as well as unsafe conditions and /or failure can cause long-term bridge closures and travel delays.

	Impacts to physical infrastructure	Impacts to users and services
	• Insufficient drainage capacity or blockage may cause standing water on driving surfaces. • Debris flows during flood events can damage bridge foundations. • Debris and sediment accumulation due to flooding can block culverts and worsen flood impacts by bringing more floodwater to other culverts. • Floodwater can overwhelm culverts, causing them to fail. • Culverts can collapse due to flood damage of surrounding soil and vegetation. *Expected future conditions would cause significant damage that may impact functionality.*	Additionally, culverts can get clogged or backed up with debris, worsening local flooding. • More frequent or severe flooding may necessitate more frequent cleaning and repair of culverts, potentially causing service delays. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*
Freeze-thaw cycling	**Sensitivity: Medium**	**Sensitivity: Low**
	• Freeze-thaw cycling can cause potholes, surface cracks, and deformations in concrete and asphalt roads. • Earlier spring thaw can cause ice jam flooding, which can damage bridges over water. • Freeze-thaw cycles can cause bridge scour and heaving or rutting. *Expected future conditions would cause moderate damage that may impact functionality.*	• More frequent road and bridge repairs due to increased freeze-thaw cycling can cause service delays. *Expected future conditions would cause minimal impact to service and users.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: Medium**
	• Heavy precipitation can increase the flow velocity and depth of streams, lakes, and rivers, which in turn can increase erosion and scouring of bridge supports. Heavy precipitation can also cause debris accumulation, sedimentation, erosion, scour, and structural damage to culverts. • Sudden, high-volume runoff can lead to increased score and degradation of culverts.	• Heavy rain events can reduce visibility and heighten safety risks. • Bridges may require additional maintenance and repair following severe storms, which could lead to bridge delays or closures. • Bridges freeze faster than roads, and ice formation on bridges can pose a safety risk to drivers. • Winter storms can reduce visibility, creating additional safety hazards.

	Impacts to physical infrastructure	Impacts to users and services
	• Ice formation and snow removal can deteriorate pavement, causing potholes and cracking. • Ice accumulation can completely block culverts. • Damage can occur from salting to prevent icing. • Snow melt runoff after heavy snowfall can overwhelm culverts and other stormwater infrastructure. • Wind can cause additional stress on the bridge superstructure and substructure, leading to increased degradation. Wind damage can also cause debris to build up in culverts. If extreme wind events are followed by flooding, this debris build-up can then clog culverts and other stormwater management infrastructure. • High wind speeds can lead to stronger flows and water force, which can cause bridges to scour. *Expected future conditions would cause moderate damage that may impact functionality.*	• Winter storms may require additional maintenance and repair, which could cause bridge delays or closures. • Travel restrictions may be put in place on bridges exposed to high winds. For example, vehicle traffic is typically restricted at sustained wind speeds of around 30-40 mph. Once wind speeds reach 40-50 mph, the bridge may be closed. High wind speeds are especially concerning for trucks and other high-profile vehicles. *Expected future conditions would cause moderate disruptions to service.*

7.3 Roadway facilities

Roadway facilities do not have high sensitivity to any climate hazards. Table 26 summarizes expected impacts to physical infrastructure and users and services for roadway facilities. This asset category includes any buildings, vehicles, and equipment that are used to maintain and repair roadways. This includes locations where maintenance equipment is stored. Service impacts to roadway facilities include impacts to roadway facility workers, such as maintenance and construction workers.

Table 26. Sensitivities of roadway facilities to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Low**	**Sensitivity: Medium**
	• High temperatures can increase engine and equipment heat stress for road maintenance. • Extreme heat coupled with drought conditions can reduce water availability, which has the potential to affect maintenance operations. • Higher temperatures can reduce the operational lifespan of equipment, leading to more frequent repairs and material/labor costs. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• High temperatures can increase health and safety risks for workers in addition to reducing worker productivity and slowing roadway projects. • During periods of high temperatures, there may be restrictions in place to limit the number of hours that road crew can work. This can affect maintenance and construction operations. • Extreme heat impacts on roadways and maintenance operations can cause service disruptions and delays. *Expected future conditions would cause moderate disruptions to service.*
Extreme cold	**Sensitivity: Low**	**Sensitivity: Medium**
	• Maintenance equipment and vehicles may have reduced operating capacity during periods of extreme cold. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• Extreme cold impacts on roadways and maintenance operations can cause service disruptions and delays. • During periods of cold temperatures, there may be restrictions in place for outdoor workers. This can affect maintenance operations. *Expected future conditions would cause moderate disruptions to service.*
Flooding (urban, riverine, coastal)	**Sensitivity: Low**	**Sensitivity: Low**
	• Floodwater and moving debris can damage roadway facilities and equipment.	• Roadways and roadway facilities may become inaccessible during flood events, causing maintenance and service disruptions or delays.

	Impacts to physical infrastructure	Impacts to users and services
	Expected future conditions would cause minor damage and would have minimal impact on functionality.	• Floods can create safety risks for drivers who attempt to drive through them. *Expected future conditions would cause minimal impact to service and users.*
Freeze-thaw cycling	**Sensitivity: N/A**	**Sensitivity: N/A**
	• No major infrastructure impacts.	• No service impacts.
Severe storms (rain, snow, ice, wind)	**Sensitivity: Low**	**Sensitivity: Medium**
	• Equipment and machinery can be damaged if exposed to heavy rainfall. • Equipment can be damaged by increased icing. • High wind speeds can create and move debris, potentially damaging roadway facilities and equipment. • High wind speeds can damage structures, including roofs. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• Snow or ice can pose a safety risk to outdoor maintenance workers. • Increased maintenance and repairs due to snow/ice damage can cause service delays and disruptions. • Outdoor work may temporarily stop during a storm event, slowing down projects and potentially increasing roadway delays/closures. ○ During the blizzard in February of 2011, 2 feet of snow caused the interstate and DuSable Lake Shore Drive to close for a day and other roads were closed for multiple days. During this event, more than 500 motorists were stranded and MCDOT housed crews on site. *Expected future conditions would cause moderate disruptions to service.*

7.4 CTA and Metra rail lines and stations

CTA and Metra rail lines and stations have high sensitivity to extreme heat, extreme cold, flooding, and severe storms. Table 27 summarizes expected impacts to physical infrastructure and users and services for CTA and Metra rail lines and stations. This asset category also includes CTA and Metra trains, signals, and switches. Service impacts to CTA and Metra rail lines and stations include impacts to rail passengers and workers, such as train conductors.

Table 27. Sensitivities of CTA and Metra rail lines and stations to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: High**	**Sensitivity: High**
	• Expanding, weakening, and bending/kinking of rail can cause line stretch damaging tracks and even leading to derailment. A heat kink may require the replacement of a section of the rail. • Extreme heat can cause mechanical failures in railroad locomotives and equipment, especially when temperatures are above 110°F. • Exposure to heat can also reduce the operational lifespan of rail assets, leading to more frequent maintenance and material/labor costs. • Increased air conditioning demand due to high temperatures can cause stress on the cooling system on trains and in rail stations, in addition to raising operating costs. • *Expected future conditions would cause significant damage that may impact functionality.*	• Many Metra and CTA stations do not have adequate climate-controlled waiting areas. Passengers waiting on train platforms in high temperatures are at higher risk of heat stress, especially populations that are highly vulnerable to heat-related health risks like the young and older adults. Similarly, if cooling is inadequate at rail stations, passengers are at risk of discomfort and heat-related illness. ○ For example, while many passengers may choose alternate modes of transportation, low-income passengers and people with disabilities may not have other transportation options. • Services can be disrupted if a passenger has a medical emergency. • Service delays or closure can result from buckled tracks. • Extreme heat can occasionally impact CTA signals and rail cars. • Reducing operating speeds to limit the potential for damage or derailments may increase passenger travel time and cause delays. • Derailments can cause injury and death to passengers and train operators. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*

	Impacts to physical infrastructure	Impacts to users and services
Extreme cold	**Sensitivity: High** • Extreme cold temperatures can cause continuous welded rail to contract, which can cause fractures that result in rail separations. ○ CTA has frequently experienced rail bending and cracking due to extreme cold, which can lead to service shutdowns for repairs. • Cold temperatures can make tracks more brittle, increasing the risk of track breakage and separation. • Extreme cold can affect catenary systems. • Extreme cold can also affect locomotive engines. *Expected future conditions would cause significant damage that may impact functionality.*	**Sensitivity: High** • Many Metra stations do not have adequate climate-controlled waiting areas. • Severe cold conditions can present health risks to transit passengers waiting on exposed platforms. • Gaining heat systems can go down during extreme cold events. • Service delays or closure can result from track breakage and separation, as well as freezing switches. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*
Flooding (urban, riverine, coastal)	**Sensitivity: High** • Floodwater and moving debris can damage stations, rails, and trains. • Inundation of equipment can lead to electrical damage, which would close the line. • Flooding can weaken wooden ties and erode track supporting systems, causing washouts. This can threaten track stability. • Underground rail tunnels can be inundated by floodwater, especially if pump stations are overwhelmed or damaged. *Expected future conditions would cause significant damage that may impact functionality.*	**Sensitivity: High** • Flooding can lead to more severe and longer-lasting service disruptions. ○ Metra and CTA halted service due to flooding in July of this year. • Since trains are not designed to run on tracks that are flooded, passengers may experience travel delays during flood events. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*
Freeze-thaw cycling	**Sensitivity: Medium** • Earlier spring thaw can cause ice jam flooding, which in turn can damage rail bridges. • Freeze-thaw cycles can affect elevated steel tracks, especially older ones in the Loop.	**Sensitivity: Low** • Rail seat deterioration due to freeze-thaw cycling can compromise safety by increasing rail displacement. • Increased maintenance and repairs due to freeze-thaw damage can cause service delays and disruptions.

	Impacts to physical infrastructure	Impacts to users and services
	• Freeze-thaw cycles can cause rail seat deterioration or the loss of concrete in the rail seat area of concrete ties. This can increase rail displacement. • Freeze-thaw cycles can affect catenary systems. *Expected future conditions would cause moderate damage that may impact functionality.*	*Expected future conditions would cause minimal impact to service and users.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: High**
	• During severe rainstorms, rail lines and stations can be washed out. When a washout occurs, the roadbed is eroded away, which can cause physical damage to both rail lines and stations. • Heavy rainfall can erode track supporting systems, which can threaten track stability. • Tracks and overhead power cables can ice over during severe storms, which can prevent trains from running if they cannot draw power from the electrified third rail and power cables. • Snow and ice conditions can make rail yards impassable. • Catenary systems and equipment can be damaged by increased icing. • High winds can create and move debris, potentially damaging or blocking rail lines. • High winds can damage platforms, stations, and other structures. *Expected future conditions would cause moderate damage that may impact functionality.*	• Service delays or shutdowns may occur due to track washouts following heavy rainfall, snow build-up on rail lines, or ice formation on aboveground rails. • Severe storm weather can pose a risk to passengers waiting on outdoor platforms. • Icy conditions from snow melting and then freezing again can present safety risks to transit passengers waiting on exposed platforms. • Severe winter storms can cause wind damage and electricity outages, leading to service disruptions. • High winds can knock over signals, which can lead to additional service disruptions. • High winds can cause trains to operate at slower speeds, leading to service disruptions. • Reduced train speed during high precipitation events may cause service delays. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*

7.5 CTA and Metra rail facilities

CTA and Metra rail facilities do not have high sensitivity to any climate hazards. Table 28 summarizes expected impacts to physical infrastructure and users and services. This asset category includes any buildings, vehicles, and equipment that are used to maintain the CTA and Metra rail trains, lines, and stations. This includes switch yards. Service impacts to CTA and Metra rail facilities include impacts to rail facility workers.

Table 28. Sensitivities of CTA and Metra rail facilities to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium**	**Sensitivity: Medium**
	• Extreme heat could cause pavement buckling at and around rail facilities. • Extreme heat can cause mechanical failures in equipment, especially when temperatures are above 110°F. • Extreme heat coupled with drought conditions can reduce water availability, which has the potential to affect maintenance operations. • Higher temperatures can reduce the operational lifespan of equipment, leading to more frequent repairs and material/labor costs. *Expected future conditions would cause moderate damage that may impact functionality.*	• Extreme heat impacts on maintenance facilities and equipment can cause service disruptions and delays. • Extreme heat impacts around rail facilities can impede access to the facilities. • During periods of high temperatures, there may be restrictions in place for outdoor workers. This can affect maintenance operations. *Expected future conditions would cause moderate disruptions to service.*
Extreme cold	**Sensitivity: Low**	**Sensitivity: Medium**
	• Maintenance equipment and vehicles may have reduced operating capacity during periods of extreme cold. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• Extreme cold impacts on rail facilities and maintenance operations can cause service disruptions and delays. • During periods of cold temperatures, there may be restrictions in place for outdoor workers. This can affect maintenance operations. *Expected future conditions would cause moderate disruptions to service.*
	Sensitivity: Medium	**Sensitivity: Medium**

	Impacts to physical infrastructure	Impacts to users and services
Flooding (urban, riverine, coastal)	• Floodwater can inundate or wash out rail yards. • Floodwater and moving debris can damage maintenance buildings, vehicles, and equipment. *Expected future conditions would cause moderate damage that may impact functionality.*	• Rail facilities may become inaccessible during flood events, causing maintenance and service disruptions or delays. • The 2013 DuPage River flood caused multiple road closures that lasted for days. *Expected future conditions would cause moderate disruptions to service.*
Freeze-thaw cycling	**Sensitivity: N/A**	**Sensitivity: Low**
	• No major infrastructure impacts.	• Freeze-thaw cycling can affect track stability, leading to service disruptions or delays. *Expected future conditions would cause minimal disruptions to service.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: Medium**
	• During severe rainstorms, rail facilities can be washed out. • Equipment and machinery can be damaged if exposed to heavy rainfall. • Equipment can be damaged by increased icing. • High wind speeds can create and move debris, potentially damaging rail facilities and equipment. • During a widespread snow event, clearing facility entrances and parking areas may require additional resources and staff. *Expected future conditions would cause moderate damage that may impact functionality.*	• Severe storm weather can pose a risk to outdoor workers. • During high winds, delays could occur from physical damage, unsafe conditions, or power outages. *Expected future conditions would cause moderate disruptions to service.*

7.6 CTA and Pace bus service and stops

CTA and Pace bus service and stops have high sensitivity to extreme heat, flooding, and severe storms. Table 29 summarizes expected impacts to physical infrastructure and users and services for CTA and Pace bus service and stops. This asset category also includes CTA and Pace buses and Pace ADA paratransit service. Impacts to bus routes that are a result of damage or disruption to the road are considered under the roadways category. Service impacts to CTA and Pace bus service and stops include impacts to bus passengers and workers, such as bus drivers.

Table 29. Sensitivities of CTA and Pace bus service and stops to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium**	**Sensitivity: High**
	• Extreme heat can contribute to overheated engines and result in engine failure. • Increased demand for cooling will put stress on air conditioning and energy supply in addition to raising operating costs. This may also reduce the battery life for electric buses. • Heat stress can increase the frequency of tire shredding. *Expected future conditions would cause moderate damage that may impact functionality.*	• Passengers waiting at bus stops and paratransit transfer points in high temperatures are at higher risk of heat stress, especially populations that are highly vulnerable to heat-related health risks like the young and older adults. ○ For example, while many passengers may choose alternate modes of transportation, low-income passengers and people with disabilities may not have other transportation options. • Services can be disrupted if a passenger has a medical emergency. • Bus engine failure can cause travel delays for passengers. • Road delays and closures due to increased roadwork following sustained high temperatures may lead to service delays for passengers. • As CTA and Pace move to more electric vehicles, power outages due to extreme heat can impact bus charging and lead to service disruptions. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*

<table>
<tr><th></th><th>Impacts to physical infrastructure</th><th>Impacts to users and services</th></tr>
<tr><td rowspan="2">Extreme cold</td><td>Sensitivity: Medium</td><td>Sensitivity: High</td></tr>
<tr><td>Bus engines may have difficulty starting in cold temperatures.
Many Pace facilities are undersized, and vehicles are stored outside, making them more vulnerable to the elements.
CTA has two bus garages with outdoor storage, putting equipment at higher risk of cold-related damage.
Aging heating, ventilation, and air conditioning (HVAC) systems have increasingly affected garage facilities and operator comfort.
Extreme cold reduces the effectiveness and efficiency of storage and vehicle batteries, potentially reducing the service life of electric vehicles.
Expected future conditions would cause moderate damage and may impact functionality.</td><td>Severe cold conditions can present safety and health risks to transit passengers waiting at stops and traveling to and from transit stops, especially passengers that are more vulnerable to health risks like the young and older adults.
Extreme cold impacts on buses, including electric ones, may cause service delays.
Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.</td></tr>
<tr><td rowspan="2">Flooding (urban, riverine, coastal)</td><td>Sensitivity: Medium</td><td>Sensitivity: High</td></tr>
<tr><td>Floodwater and moving debris can damage vehicles, bus stop shelters, and signage.
Many Pace facilities are undersized, and vehicles are stored outside, making them more vulnerable to the elements.
CTA has two bus garages with outdoor storage, putting equipment at higher risk of flood-related damage.
Expected future conditions would cause moderate damage and may impact functionality.</td><td>Flooding can lead to more severe and longer-lasting service disruptions. For example, bus service can be suspended for multiple days.
Road delays or closures for repairs may cause service delays for passengers.
There are safety risks for drivers and passengers aboard buses that get caught in floods or drive through them. Standing water around bus stops can also make it more difficult for passengers to board, especially for passengers with disabilities.
Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.</td></tr>
</table>

	Impacts to physical infrastructure	Impacts to users and services
Freeze-thaw cycling	**Sensitivity: N/A** • No major infrastructure impacts.	**Sensitivity: Low** • Increased road maintenance and repairs due to freeze-thaw damage can cause service delays and disruptions. *Expected future conditions would cause minimal impact to service and users.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Low** • Heavy snow can cause damage to bus stop infrastructure (e.g., signage, shelters). • High winds can create and move debris. • High winds can damage bus stop infrastructure. *Expected future conditions would cause minor damage with minimal impact to functionality.*	**Sensitivity: High** • Heavy rain events can cause moderate service disruptions or delays for up to a day. Buses may be rerouted to avoid flooded or blocked roads, leading to service delays and longer travel times. o For example, during extreme wind events, DuSable Lake Shore Drive express buses sometimes must run on surface streets. Additionally, paratransit services have been canceled due to severe storm conditions. • Storm events can result in reduced visibility (difficulty seeing street signs and other vehicles) and slippery roads. • Severe storm weather can pose a risk to passengers waiting at bus stops. • Bus service delays and rerouting may occur, especially for bus lines that run on steep slopes or plow routes. • During severe snow events, buses may only run on major streets, reducing service in remote locations. • Severe cold and icy conditions from snow melting then freezing again can present safety risks to transit passengers waiting at bus stops. • Bus stops can become more difficult to access due to snow pile-up following plowing. • Severe winter storms can cause wind damage and electricity outages, leading to service disruptions.

	Impacts to physical infrastructure	Impacts to users and services
		• Ice formation and snow removal can deteriorate pavement, causing potholes and cracking. Road delays or closures for repairs may cause service delays for passengers. • Road closures or delays due to downed power lines and debris blocking roadways can lead to service delays. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*

7.7 CTA and Pace bus facilities

CTA and Pace bus facilities do not have high sensitivity to any climate hazards. Table 30 summarizes expected impacts to physical infrastructure and users and services for CTA and Pace bus facilities. This asset category includes any buildings, vehicles, and equipment that are used to maintain the CTA and Pace buses, routes, and stops. Service impacts to CTA and Pace bus service and stops also includes impacts to bus facility workers.

Table 30. Sensitivities of CTA and Pace bus facilities to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium**	**Sensitivity: Medium**
	• Extreme heat could cause stress on the cooling system in bus stations/transit centers. • Extreme heat could cause pavement buckling at and around bus facilities. • Extreme heat can cause mechanical failures in equipment, especially when temperatures are above 110°F. • Extreme heat coupled with drought conditions can reduce water availability, which has the potential to affect maintenance operations. • Many Pace facilities are undersized, and vehicles are stored outside, making them more vulnerable to the elements. • CTA has two bus garages with outdoor storage, putting equipment at higher risk of heat-related damage. • Extreme heat can impact outdoor chargers, causing them to overheat and fail. • Higher temperatures can reduce the operational lifespan of equipment, leading to more frequent repairs and material/labor costs. *Expected future conditions would cause moderate damage and may impact functionality.*	• If cooling is not adequate in buildings used for bus maintenance, workers are at risk of discomfort and heat-related illness. • Extreme heat impacts on buses and maintenance operations can cause service disruptions and delays. • During periods of high temperatures, there may be restrictions in place for outdoor workers. This can affect maintenance operations. *Expected future conditions would cause moderate disruptions to service.*
Extreme cold	**Sensitivity: Medium**	**Sensitivity: Medium**

	Impacts to physical infrastructure	Impacts to users and services
	• Maintenance equipment and vehicles may have reduced operating capacity during periods of extreme cold. • Many Pace facilities are undersized, and vehicles are stored outside, making them more vulnerable to the elements. • CTA has two bus garages with outdoor storage, putting equipment at higher risk of cold-related damage. • Aging heat and HVAC systems have increasingly affected garage facilities and operator comfort. • Extreme cold reduces the effectiveness and efficiency of storage and vehicle batteries, potentially delaying routes with electric vehicles (buses, etc.). *Expected future conditions would cause moderate damage and may impact functionality.*	• Extreme cold impacts on bus facilities and maintenance operations can cause service disruptions and delays. • During periods of cold temperatures, there may be restrictions in place for outdoor workers. This can affect maintenance operations. *Expected future conditions would cause moderate disruptions to service.*
Flooding (urban, riverine, coastal)	**Sensitivity: Medium**	**Sensitivity: Low**
	• Floodwater and moving debris can damage buses, stations, and equipment. • Many Pace facilities are undersized, and vehicles are stored outside, making them more vulnerable to the elements. • CTA has two bus garages with outdoor storage, putting equipment at higher risk of flood-related damage. *Expected future conditions would cause moderate damage and may impact functionality.*	• Bus stations may become inaccessible during flood events, causing maintenance and service disruptions or delays. *Expected future conditions would cause minimal impact to service and users.*
Freeze-thaw cycling	**Sensitivity: Low**	**Sensitivity: N/A**
	• Freeze-thaw cycling can cause pavement damage at both stops and facilities (transfer stations, etc.), especially where heavy buses stop or park. *Expected future conditions would cause minor damage with minimal impact to functionality.*	• No service impacts.

	Impacts to physical infrastructure	Impacts to users and services
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: Medium**
	• Equipment and machinery can be damaged if exposed to heavy rainfall. • Equipment can be damaged by increased icing. • High wind speeds can create and move debris, potentially damaging rail facilities and equipment. • During a widespread snow event, clearing station entrances and parking areas may require additional resources and staff. *Expected future conditions would cause moderate damage that may impact functionality.*	• Dangerous storm conditions can cause travel cancelations. • Severe storm weather can pose a risk to outdoor workers. • During high winds, delays could occur from physical damage, unsafe conditions, or power outages. *Expected future conditions would cause moderate disruptions to service.*

7.8 Electrical services and backup power

Electrical services and backup power have high sensitivity to extreme heat. Table 31 summarizes expected impacts to physical infrastructure and users and services for electrical services and backup power.

Table 31. Sensitivities of electrical services and backup power to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: High**	**Sensitivity: High**
	• High temperatures can cause power lines to sag. • Extreme heat can damage electrical wires and equipment. • Periods of extreme heat can increase electricity demand, putting significant pressure on power grids and causing outages. *Expected future conditions would cause significant damage that may impact functionality.*	• Power outages due to extreme heat can increase the risk of heat stress, especially for populations that are highly vulnerable to heat-related health risks like the young and older adults. • Extreme heat can cause power outages, which can subsequently lead to service disruptions and delays for most of the other asset categories. For example, power outages can impact traffic lights, causing congestion and safety hazards on roadways, which can also lead to bus service delays. Power outages may result in rail service suspensions as well as disrupted Tollway operations. This is increasingly disruptive as the transit system further electrifies. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*
Extreme cold	**Sensitivity: Medium**	**Sensitivity: Medium**
	• Periods of extreme cold can increase electricity demand, putting significant pressure on power grids and causing outages. *Expected future conditions would cause moderate damage that may impact functionality.*	• Power outages due to extreme cold can increase health and safety risks, especially for populations that are highly vulnerable to cold-related health risks like the young and elderly. • Extreme cold can cause power outages, which can subsequently lead to service disruptions and delays for most of the other asset categories. For example, power outages can affect bus and rail service. *Expected future conditions would cause moderate disruptions to service.*

	Impacts to physical infrastructure	Impacts to users and services
Flooding (urban, riverine, coastal)	**Sensitivity: High**	**Sensitivity: High**

	• Electrical equipment and infrastructure can be damaged or destroyed by floodwater.
	• Flooding can adversely impact pump stations, which can cause secondary and tertiary impacts on other transportation asset categories.
	  ○ For example, CTA substations have been damaged by floodwater in the past.
	Expected future conditions would cause significant damage and that may impact functionality.
		• Flooding can cause power outages, which can subsequently lead to service disruptions and delays for most of the other asset categories. For example, power outages can affect traffic lights, which can lead to bus service delays and unsafe conditions on roadways.
		• Damage to pump stations can cause service disruptions and suspensions.
		  ○ CTA substations have been damaged by floodwater in the past, causing service disruptions and suspensions.
		Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.

Freeze-thaw cycling	**Sensitivity: N/A**	**Sensitivity: N/A**
	• No major infrastructure impacts.	• No service impacts.
Severe storms (rain, snow, ice, wind)	**Sensitivity: High**	**Sensitivity: High**
	• Heavy rainfall, snow, ice, or high winds can down power lines. • Ice storms can bring down electrical wires or cause them to snap. • Snow and ice can cause power lines and other electrical equipment to freeze. *Expected future conditions would cause significant damage that may impact functionality.*	• Severe storms can cause power outages, which can lead to service disruptions and delays for most of the other asset categories. For example, power outages can lead to delays or suspensions for both bus and rail service. This is increasingly important as the transit system becomes more electrified. ○ In 2010, a derecho caused a power outage that lasted for a week. Without power, signalized intersections became a safety concern. • The heavy weight of snow or ice on power lines can lead to outages. • Backup for traffic signals only lasts for several hours during outages. *Expected future conditions would cause significant disruptions to service and may cause discomfort/risk for users.*

7.9 Bicycle and pedestrian facilities

Bicycle and pedestrian facilities have high sensitivity to severe storms. Table 32 summarizes expected impacts to physical infrastructure and users and services for bicycle and pedestrian facilities. This asset category includes on- and off-road bike lanes, sidewalks, multi-use paths, and other infrastructure that is used for active transportation. Service impacts to bicycle and pedestrian facilities include the impact on users of this infrastructure, such as pedestrians and bicyclists.

Table 32. Sensitivities of bicycle and pedestrian facilities to climate hazards

	Impacts to physical infrastructure	Impacts to users and services
Extreme heat	**Sensitivity: Medium**	**Sensitivity: High**

	• Sustained extreme temperatures could cause concrete to expand and eventually buckle, leading to cracks and lifts on sidewalks and bikeways.
	• For on-road bikeways, sustained high temperatures can result in softening of the asphalt binder, leading to rutting and shoving.
	    ○ High temperatures can also cause heaving of concrete joints as concrete contracts and expands.
	    ○ Extreme heat can also reduce the operational lifespan of pavement, leading to more frequent surface treatments and material/labor costs.
	
	Expected future conditions would cause moderate damage that may impact functionality.
		• Only some segments of sidewalks and bikeways have street trees or other shading features that help mitigate heat impact for people using them.
		• Pedestrians/cyclists experience discomfort during extreme heat events and consequently limit sidewalk and bike lane use.
		• If exposed to extreme heat, concrete buckling can pose safety risks for pedestrians and bicyclists. This can also create trip hazards or render the sidewalk unusable for people with physical disabilities.
		• Road closures due to increased roadwork following sustained high temperatures may disrupt access to on-road bikeways.
		
		Expected future conditions would cause significant disruptions and may pose risks to pedestrians and bicyclists.

Extreme cold	**Sensitivity: Medium**	**Sensitivity: High**
	• Extreme cold can cause cracks and other damage on sidewalks and bikeways. • For on-road bikeways, extreme cold can cause asphalt to contract and shrink, leading to cracks and other road damage. Extreme cold can also cause heaving and cracking of concrete roads. *Expected future conditions would cause moderate damage and may impact functionality.*	• Pedestrians experience discomfort during extreme cold events and consequently limit sidewalk use. • It can be difficult to keep bike lanes clear during extreme cold events. • Periods of extreme cold can make walking and biking dangerous for users. *Expected future conditions would cause significant disruptions and may pose risks to pedestrians and bicyclists.*

	Impacts to physical infrastructure	Impacts to users and services
Flooding (urban, riverine, coastal)	**Sensitivity: High**	**Sensitivity: High**
	• Flooding events may cause damage to sidewalks and bikeways through erosion and possible embankment failure, especially if there is existing damage. • Sidewalks and bikeways along Lake Michigan or near waterways may experience washouts during significant flooding events, causing damage to sidewalks and bikeways. • Insufficient drainage system capacity may lead to standing or flowing water on sidewalks and bikeways. • Flooding can cause erosion of paved surfaces, worsening of existing pavement damage, and structural integrity degradation. *Expected future conditions would cause significant damage that may impact functionality.*	• Flooding events can cause sections of sidewalks and bikeways to become flooded, rendering them unpassable and dangerous for pedestrians (though sidewalks and bikeways usually do not require significant cleanup to resume functionality once flood waters recede). • Flooding can lead to severe and long-lasting road closures and delays as well as safety hazards. • Road delays or closures for repairs may disrupt access to on-road bikeways. *Expected future conditions would cause significant disruptions to service and may pose risks to pedestrians and bicyclists.*
Freeze-thaw cycling	**Sensitivity: Low**	**Sensitivity: Low**
	• Freeze-thaw cycling can cause cracking on sidewalks and bikeways if snow melt is absorbed and then refrozen. *Expected future conditions would cause minor damage and would have minimal impact on functionality.*	• Increased road maintenance and repairs due to freeze-thaw damage can cause service disruptions for on-road bikeways. *Expected future conditions would cause minor impact to pedestrians and bicyclists.*
Severe storms (rain, snow, ice, wind)	**Sensitivity: Medium**	**Sensitivity: High**
	• Severe rainstorms can inundate sidewalks and bikeways, causing damage. • Wind can cause overhead structures (utility lines, trees, etc.) to fall onto sidewalks and bikeways, potentially causing damage. • Clearing sidewalks of snow and ice may require additional resources and staff. *Expected future conditions would cause moderate damage that may impact functionality.*	• Severe rain and snowstorm events can result in reduced visibility and heightened safety risks for pedestrians and cyclists. • Portions of the sidewalk may be closed if trees or structures topple over and restrict pedestrians from using the sidewalk. • Heavy snow can make it difficult to walk on sidewalks. • Sidewalks and bike lanes are often last to be cleared of snow or debris from storms. As a result, sidewalk and

	Impacts to physical infrastructure	Impacts to users and services
		bike lane closures may be more long-lasting than road closures. • Bike lanes may become inaccessible due to snow pile-up from plowing. • Snow melting and then freezing again creates slick surfaces on sidewalks and bikeways. This can pose a safety risk to pedestrians and bicyclists. *Expected future conditions would cause significant disruptions and may pose risks to pedestrians and bicyclists.*

8 Appendix C: Asset-level analysis methodology details

This appendix provides more details on the methodology used for the asset-level analysis.

8.1 Overview

Whereas the system-level analysis assessed the general sensitivity of asset categories and services to various climate hazards, the asset-level analysis assesses the vulnerability of individual assets to extreme heat, extreme cold, and flooding.[97] CMAP calculated the total risk score for each asset based on exposure and criticality using the equation below.

$$\text{Risk Score} = (\text{Exposure Score})(60\%) + (\text{Criticality Score})(40\%)$$

Exposure is weighted higher than criticality because it is the main driver of climate-related impacts. Additionally, the exposure indicators used in the analysis are adjusted to consider future climate conditions, whereas the criticality indicators are based solely on historical data. In this assessment, risk is defined as the weighted combination of asset exposure and criticality. Assets with high exposure and criticality are considered highly vulnerable to climate hazards.

For each asset/hazard pair, the exposure and criticality of each asset were scored on a scale of 0 to 3.[98] These scores were then weighted and added together to determine the risk score, with 3 being the highest possible score.

Table 33 shows the risk score thresholds that correspond to low, medium, high, and very high risk ratings for each asset/hazard pair.

Table 33. Final risk score thresholds

Final Risk Rating	Risk Score Value
Not exposed	0
Low	1.0 - 1.49
Medium	1.5 - 1.99
High	2.0 - 2.49
Very high	2.5 - 3.00

Table 34 lists the data sources used in this assessment and indicates whether they were used to determine extreme heat, extreme cold, or flooding exposure or criticality.

[97] The methodology used for extreme cold is excluded from this appendix as extreme cold is not expected to present a significant risk in the future.

[98] An exposure score of 0 indicates that the asset is not exposed to the climate hazard. Assets that scored a 0 for exposure therefore also received a vulnerability score of 0, even though they may have a high criticality score.

Table 34. Data indicators

Data indicators	Extreme heat exposure	Extreme cold exposure	Flooding exposure	Criticality
ICF ClimateSight Projections	✓	✓		
Geosyntec Flood Modeling Results			✓	
Known flood locations[99]			✓	
US Department of Transportation Equitable Transportation Community Social Vulnerability Subindex				✓
CMAP Transit Availability Index				✓
Transportation access (zero-car households)				✓
Transit ridership				✓
RTA Flooding Resilience Plan for Bus Operations (priority bus routes for flood resilience)				✓
Annual average daily traffic				✓
Functional class				✓
Bus/truck route				✓
Access to freight/employment clusters				✓
Access to emergency facilities				✓

All asset/hazard pairs were scored on exposure in this analysis. Many of the asset/hazard pairs were also scored on criticality (e.g., social vulnerability, ridership, access to employment clusters, emergency facilities). However, not all the asset categories were scored on criticality, as these are inherently spatial indicators, and the scores would not have varied meaningfully across the asset categories. For example, rail lines were not scored on criticality, as nearly all the lines service high social vulnerability census tracks and therefore it would not help distinguish priority locations in the final results. In some cases, all the locations are considered critical to the operation of the system or for users, and therefore only exposure was analyzed (e.g., ADA transfer points).

8.2 Criticality datasets

CMAP used four categories of indicators to score criticality for the remaining asset/hazard pairs: social/equity, usage and operational importance, socioeconomic importance, and health and safety importance. These indicators are helpful for assessing the relative importance of the asset to the transportation system and the potential impact to the transportation system if the asset were affected by the climate hazard. Many of these datasets are used as a proxy for those who use and depend on the transportation system. The datasets used for these indicators are described below.

[99] Known flood locations were collected and, in some cases, digitized from various sources, including transportation and stormwater agencies as well as local planning efforts.

8.2.1 Social/Equity

- **U.S. Department of Transportation (USDOT) Equitable Transportation Community (ETC) Social Vulnerability Subindex**
  - The USDOT ETC Explorer uses 2020 census tracts and data to help users understand how specific communities or areas experience transportation disadvantage compared to all other Census Tracts. The ETC Explorer is designed to complement the Climate & Economic Justice Screening Tool (CEJST) and visualizes transportation disadvantage across five components: transportation insecurity, climate and disaster risk burden, environmental burden, health vulnerability, and social vulnerability. The Social Vulnerability Subindex is a measure of socioeconomic indicators that have a direct impact on quality of life. These include unemployment, poverty, educational attainment, and housing cost burden. CMAP used the subindex as a proxy for understanding which communities would be most significantly impacted by loss of a transportation option.
- **Transportation access (zero-car households)**
  - Zero-car households are assumed to rely heavily on public transportation. Therefore, the number of zero-car households in a geographic area is a useful indicator for evaluating transportation access. 2020 census tract data on percentage of households with no car from the Transportation Insecurity Subindex of the USDOT ETC Explorer database was used as a separate criticality indicator to evaluate transportation access, as zero car households are not included in the ETC Social Vulnerability Subindex.

8.2.2 Usage and operational importance

- **Ridership**
  - Ridership is based on data provided to CMAP by Metra, CTA, and Pace or accessed through the Regional Transportation Authority Mapping and Statistics website. This metric was used for rail stations and bus stops to understand which stations and stops are used by more riders. Stations and stops with higher ridership volumes are considered more critical to the transportation system and are therefore prioritized higher for investment. Details on the ridership data used for CTA and Metra rail stations and CTA and Pace bus stops are:
    - **CTA rail stations:** Data from November 2022 to October 2023 was used. The daily average number of rides was averaged over the entire year.
    - **Metra rail stations:** Data from the 2018 Boarding and Alighting survey was used. Average annual number of boardings and alightings was calculated for each station.
    - **CTA bus stops:** Data on average weekday ridership from September 2023 was used. The average combined number of boardings was calculated at each stop.
    - **Pace bus stops:** Data from January to December 2023 was used. The Pace route-level ridership per month was averaged over the entire year.
- **Annual average daily traffic (AADT)**
  - AADT is the average number of daily vehicle trips on a segment of road derived from annual estimates. AADT is useful for understanding traffic volume on different road segments. Roads with higher traffic volumes are more critical to the transportation system and should therefore be prioritized for investment. AADT from the 2022 Illinois Roadway

Information System was used as an indicator for usage and operational importance for roads, bridges, and culverts in this assessment.

- **Functional classification**
  - Functional classification is a FHWA designation for roads that describes their degree of mobility (e.g., where the road goes and the speed limit) and how easy it is to access them. For example, interstates, principal roads, and local roads are types of functional classifications with decreasing levels of speed and use. Roads that are highly utilized are considered more critical to the transportation system. Functional classification came from the 2022 Illinois Roadway Information System.
- **Bus/truck route**
  - Road segments that also serve as bus or truck routes receive a higher prioritization for investment since they are more critical to the transportation system. These routes and the roadways they use frequently change (e.g., construction detours) and therefore received a lower weighting. Truck routes were defined as road segments on the National Highway System or segments identified as a port intermodal connector or rail-truck intermodal connector in the 2022 Illinois Roadway Information System.
- **CMAP Transit Availability Index**
  - CMAP's Transit Availability Index is a metric that can be used to measure access to transit. The index is made up of four indicators: transit frequency, transit connectivity, sidewalk density, and transit proximity. The index was developed to understand how the transit system as a whole serves the region and measure how the transit level of service changes over time. For this assessment, CMAP used the 2019 Transit Availability Index for bus stops to understand the relative importance of each bus stop to the surrounding community.

8.2.3 Socioeconomic importance

- **Access to freight clusters or employment clusters**
  - Freight clusters[100] are areas within the seven-county region that have a disproportionate amount of the region's freight-intensive land uses. These areas were developed by CMAP using land use and building data to describe the density of either land area encompassed by freight-related activities or building stock of freight-related activities. There are six clusters within the region, and roadway/bridge assets located within these clusters received a higher score as it is anticipated that freight relies on these assets more.
  - Employment clusters[101] are geographies developed by CMAP within the seven-county region that contain the top 10 percent of employment density based on Illinois Department of Employment Security data. Transportation assets within these geographies are crucial for residents to reach major employment assets located within these geographies received a higher score as it is assumed that they are important for job access and economic growth destinations.

[100] Freight-supportive land use clusters, https://datahub.cmap.illinois.gov/maps/CMAPGIS::freight-clusters-and-truck-bottlenecks/about.

[101] CMAP developed these geographies, as part of the mobility recovery project, to understand employment patterns and how the COVID-19 pandemic impacted travel across the region, https://www.cmap.illinois.gov/programs/mobility-recovery.

8.2.4 Health and safety importance

- **Access to emergency facilities**
  - Emergency facilities include hospitals and medical centers (e.g., urgent care facilities) and cooling/warming centers. During extreme weather events and natural disasters, transportation assets near emergency facilities are crucial for providing public safety services. Assets near these locations should be prioritized for resilience investments. CMAP used 2015 medical facility data from the Illinois Department of Public Health.
  - Cooling centers are included within this dataset, as access to safe place during heat waves and extreme heat events are essential. This will be increasingly important in the coming decades based on the region's climate projections. Regional cooling center data was compiled by CMAP in August 2023.

8.3 Roads

Flooding exposure scores for roads were determined using the maximum flood depth for the 500-year flood event by mid-century from Geosyntec's flood modeling analysis, as well as data on past flood experience. Flood depth thresholds for roads were determined based on the level of safe driving conditions for passenger vehicles. Roads become dangerous at flood depths of 0.5 feet, and at 1-2 feet, vehicles may begin to float. Once flood depths reach 2-3 feet, vehicles may be swept away. Criticality for roads was scored using the social vulnerability score (USDOT ETC Subindex only), AADT, functional class, bus/truck route, access to freight/employment clusters, and access to emergency facilities. Table 35 and Table 36 show the scoring scales used for exposure and criticality, respectively.

Table 35. Exposure scoring scale for flooding and roads

Indicator	Weight	Indicator value	Score
Flood depth	**60%**	Above 2ft exposure depth AND past flood experience	3
		Past flood experience, but not above 2 ft	2.5
		Exposure depth above 2 ft	2.5
		Exposure depth 1.5-2.0 ft	2
		Exposure depth 1.0-1.5 ft	1.5
		Exposure depth 0.5-1 ft	1
		Not exposed to flooding OR Elevated	0

Table 36. Criticality Scoring Scale for Flooding and Roads

Indicator	Weight	Indicator value	Score
Social vulnerability score *(USDOT ETC Subindex only)*	20%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of assets based on rescaled index value	1
AADT	5%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of assets based on AADT + all null entries for traffic counts	1
Functional class	5%	Interstate/freeway/expressway	3
		Other principal arterial	2.33
		Minor arterial	1.67
		Collector (major/minor), local	1
Bus route	2.5%	Bus route(s)	3
		Not a bus route	1
Truck route	2.5%	Truck Route(s)	3
		Not a truck route	1
Access to freight or employment clusters	2.5%	Yes	3
		No	1
Access to emergency facilities	2.5%	Within 1/2 mile of 3+ destinations	3
		Within 1/2 mile of 1or 2 destinations	2
		Within 1/2 mile of 0 destination	1

8.4 Bridges and culverts

Flooding exposure scores for bridges (roadway only) and culverts were determined using the same approach used for roads. Criticality for bridges and culverts was scored using the social vulnerability score (USDOT ETC Subindex only), AADT, bus/truck route, access to freight/employment clusters, and access to emergency facilities. Table 37 and Table 38 show the scoring scales used for exposure and criticality, respectively.

Table 37. Exposure scoring scale for flooding and bridges and culverts

Indicator	Weight	Indicator value	Score
Flood depth	60%	Above 2 ft exposure depth AND past flood experience	3
		Past flood experience, but not above 2 ft	2.5
		Exposure depth above 2 ft	2.5
		Exposure depth 1.5-2.0 ft	2
		Exposure depth 1.0-1.5 ft	1.5
		Exposure depth 0.5-1 ft	1
		Not exposed to flooding OR Elevated	0

Table 38. Criticality scoring scale for flooding and bridges and culverts

Indicator	Weight	Indicator value	Score
Social vulnerability score *(USDOT ETC Subindex only)*	20%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of assets based on rescaled index value	1
AADT	4%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of assets based on AADT + all null entries for traffic counts	1
Bus route	4%	Bus routes	3
		Not a bus route	1
Truck route	4%	Truck routes	3
		Not a truck route	1
Access to freight or employment clusters	4%	Yes	3
		No	1
Access to emergency facilities	4%	Within 1/2 mile of 3+ destinations	3
		Within 1/2 mile of 1 or 2 destinations	2
		Within 1/2 mile of 0 destination	1

8.5 CTA and Metra rail stations, lines, and yards

8.5.1 Extreme heat

Rail stations

Exposure scores for extreme heat were determined by calculating the number of days with maximum temperature above 95°F by mid-century. The extreme heat results for rail stations were divided into thirds to determine the score thresholds. Criticality was scored using the social vulnerability score (combined USDOT ETC Subindex and zero car households scores), ridership, access to freight/

employment clusters, and access to emergency facilities. Table 39 and Table 40 show the scoring scales used for exposure and criticality, respectively.

Table 39. Exposure scoring scale for extreme heat and CTA/Metra rail stations

Indicator	Weight	Indicator value	Score
Days with maximum temperature above 95°F by mid-century	60%	Top 1/3 future heat	3
		Middle 1/3 future heat	2
		Bottom 1/3 future heat	1
		Subways	0

Table 40. Criticality scoring scale for extreme heat and CTA/Metra rail stations

Indicator	Weight	Indicator value	Score
Social vulnerability score *(USDOT ETC Subindex + zero-car households)*	20%	Top 1/3 (after rescaled and combined)	3
		Middle 1/3 (after rescaled and combined)	2
		Bottom 1/3 (after rescaled and combined)	1
Ridership	7.5%	Top 1/3	3
		Middle 1/3	2
		Bottom 1/3	1
Access to freight or employment clusters	7.5%	Yes	3
		No	1
Access to emergency facilities	5%	Within 1/2 mile of 3+ destinations	3
		Within 1/2 mile of 1 or 2 destinations	2
		Within 1/2 mile of 0 destination	1

Rail lines

Exposure scores for rail lines and extreme heat were determined using the same method described above for rail stations but with a different scoring scale (see Table 41). For rail lines, exposure made up 100 percent of the score.

Table 41. Exposure scoring scale for extreme heat and CTA/Metra rail lines

Indicator	Weight	Indicator value	Score
Days with maximum temperature above 95°F by mid-century	100%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%)	1
		Subways	0

8.5.2 Flooding

Rail stations

Flooding exposure scores for CTA and Metra rail stations were determined using the maximum flood depth for the 500-year flood event by mid-century from Geosyntec's flood modeling analysis. The flood depth results for rail stations were divided into quartiles to determine the score thresholds. Criticality for CTA and Metra rail stations was scored using the same approach used for rail stations and extreme heat (see Table 40). Table 42 shows the scoring scale used for exposure.

Table 42. Exposure scoring scale for flooding and CTA/Metra rail stations

Indicator	Weight	Indicator value	Score
Flood depth	**60%**	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%)	1
		Not exposed OR elevated	0

Rail lines

Exposure scores for flooding were determined using the same method described above for rail stations (see Table 42). For rail lines, exposure made up 100 percent of the score.

Rail yards

Flooding exposure scores for CTA and Metra rail yards were determined using the percentage of the rail yard inundated by the 500-year flood event by mid-century, as well as past flooding data. For rail yards, exposure made up 100 percent% of the risk score. Table 43 shows the scoring scale used for exposure.

Table 43. Exposure scoring scale for flooding and CTA/Metra rail yards

Indicator	Weight	Indicator value	Score
Flood area	**100%**	Top 1/4 of flood area by % OR identified as having a flood issue	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of road exposure	1
		Not exposed to flooded roads	0

8.6 CTA and Pace bus stops, routes, and garages

8.6.1 Bus stops

Flooding exposure scores for CTA and Pace bus stops were determined using the same method described above for roads. The flood depth results for bus stops were divided into quartiles to determine the score thresholds. Criticality for CTA and Pace bus stops was scored using the social vulnerability score (combined USDOT ETC Subindex and zero-car households scores), ridership, the CMAP Transit Availability Index, access to freight/employment clusters, and access to emergency facilities. Table 44 and Table 45 show the scoring scales used for exposure and criticality, respectively.

Table 44. Exposure scoring scale for flooding and CTA/Pace bus stops[102]

Indicator	Weight	Indicator value	Score
Flood depth	**60%**	Top quartile AND past flood experience	3
		Past flood experience, but not in top quartile	2.5
		Top quartile with NO past flood experience	2.5
		Third quartile (50-75%)	2

[102] Pace bus stops include ADA transfer points. However, for ADA transfer points, exposure made up 100 percent of the risk score.

		Second quartile (25-50%)	1.5
		Bottom quartile (0-25%) of all assets in terms of modeled flooding depths	1
		Not exposed to flooding OR Elevated	0

Table 45. Criticality scoring scale for flooding and CTA/Pace bus stops

Indicator	Weight	Indicator value	Score
Social Vulnerability Score *(USDOT ETC Subindex + zero-car households)*	**20%**	Top 1/3 (after rescaled and combined)	3
		Middle 1/3 (after rescaled and combined)	2
		Bottom 1/3 (after rescaled and combined)	1
Ridership	**5%**	Top 1/3	3
		Middle 1/3	2
		Bottom 1/3	1
CMAP Transit Availability Index	**5%**	2	3
		3	2.33
		4	1.67
		5	1
Access to freight or employment clusters	**5%**	Yes	3
		No	1
Access to emergency facilities	**5%**	Within 1/2 mile of 3+ destinations	3
		Within 1/2 mile of 1 or 2 destinations	2
		Within 1/2 mile of 0 destination	1

8.6.2 Bus routes

Flooding exposure scores for CTA and Pace bus routes were determined using the road flood risk results, as well as inclusion in the RTA 2018 Flooding Resilience Plan for Bus Operations. For bus routes, exposure made up 100 percent of the risk score. Table 46 shows the scoring scale used for exposure.

Table 46. Exposure scoring scale for flooding and CTA/Pace bus routes

Indicator	Weight	Indicator value	Score
Road flood risk score	**100%**	Top 1/3 AND the route is identified in RTA Plan	3
		Top 1/3 not in plan OR the route is identified in RTA Plan but not in top 1/3	2.33
		Middle 1/3 (after rescaled and combined)	1.67
		Bottom 1/3 of road flood vulnerability	1
		Not exposed to flooded roads	0

8.6.3 Bus garages

Flooding exposure scores for CTA and Pace bus garages were determined using the same method described above for flooding and rail yards. For bus garages, exposure made up 100% of the risk score. Table 47 shows the scoring scale used for exposure.

Table 47. Exposure scoring scale for flooding and CTA/Pace bus garages

Indicator	Weight	Indicator value	Score

Flood area	**100%**	Top 1/4 of flood area by % OR identified as having a flood issue	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%) of road exposure	1
		Not exposed to flooded roads	0

8.7 Regional trails

Flooding exposure scores for regional trails were determined using the same method used for roads and bus routes. The flood depth results for regional trails were divided into quartiles to determine the score thresholds. Criticality for regional trails was scored using the social vulnerability score (USDOT ETC Subindex only). Table 48 and Table 49 show the scoring scales used for exposure and criticality, respectively.

Table 48. Exposure scoring scale for flooding and regional trails

Indicator	Weight	Indicator value	Score
Flood depth	**80%**	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%)	1
		Not exposed to flood	0

Table 49. Criticality scoring scale for flooding and regional trails

Indicator	Weight	Indicator value	Score
Social Vulnerability Score *(USDOT ETC Subindex only)*	**20%**	Top third	3
		Middle third	2
		Bottom third	1

9 Appendix D: Extreme cold analysis

This appendix provides more detail on the extreme cold component of the asset-level analysis. Extreme cold was only evaluated for rail stations and rail lines.

9.1 Methodology

9.1.1 Rail stations

Exposure scores for extreme cold were determined by calculating the number of days with maximum temperature below 15°F by mid-century. The extreme cold results for rail stations were divided into thirds to determine the score thresholds. Criticality was scored using the social vulnerability score (combined USDOT ETC Subindex and zero car households scores), ridership, access to freight/employment clusters, and access to emergency facilities. Table 50 and Table 51 show the scoring scales used for exposure and criticality, respectively.

Table 50. Exposure scoring scale for extreme cold and CTA/Metra rail stations

Indicator	Weight	Indicator value	Score
Days with maximum temperature below 15°F by mid-century	60%	Top 1/3 future heat	3
		Middle 1/3 future heat	2
		Bottom 1/3 future heat	1

Table 51. Criticality scoring scale for extreme cold and CTA/Metra rail stations

Indicator	Weight	Indicator value	Score
Social Vulnerability Score *(USDOT ETC Subindex + zero-car households)*	20%	Top 1/3 (after rescaled and combined)	3
		Middle 1/3 (after rescaled and combined)	2
		Bottom 1/3 (after rescaled and combined)	1
Ridership	7.5%	Top 1/3	3
		Middle 1/3	2
		Bottom 1/3	1
Access to freight or employment clusters	7.5%	Yes	3
		No	1
Access to emergency facilities	5%	Within 1/2 mile of 3+ destinations	3
		Within 1/2 mile of 1 or 2 destinations	2
		Within 1/2 mile of 0 destination	1

9.1.2 Rail lines

Exposure scores for rail lines and extreme cold were determined using the same method described above for rail stations but with a different scoring scale (see Table 52). For rail lines, exposure made up 100 percent of the score.

Table 52. Exposure scoring scale for extreme cold and CTA/Metra rail lines

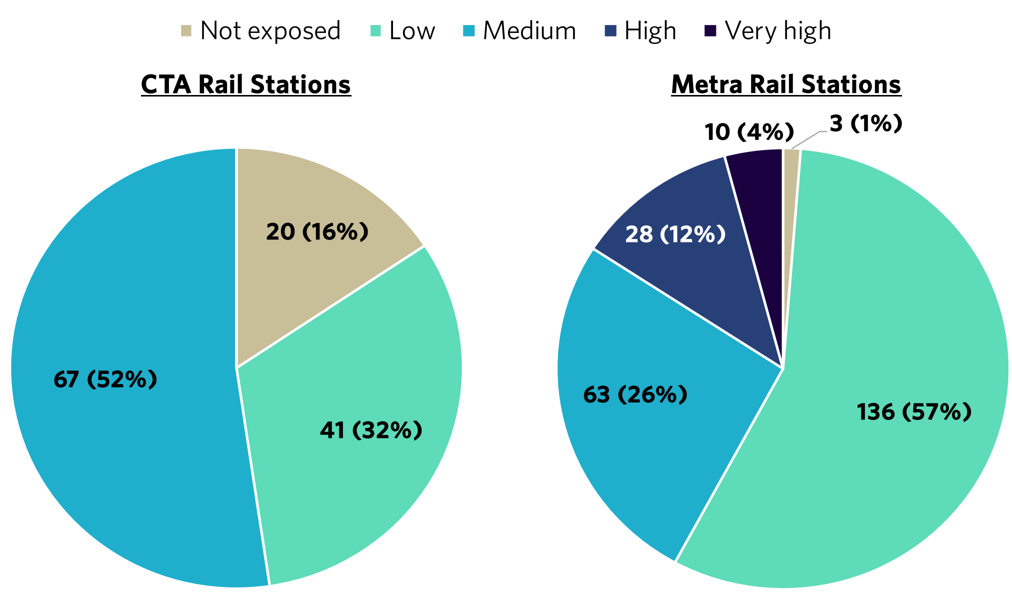
Indicator	Weight	Indicator value	Score
Days with maximum temperature below 15°F by mid-century	100%	Top quartile (75-100%)	3
		Third quartile (50-75%)	2.33
		Second quartile (25-50%)	1.67
		Bottom quartile (0-25%)	1
		Subways	0

9.2 Key findings

9.2.1 Rail stations

- Figure 38 shows the breakdown of extreme cold risk results for CTA rail stations compared to Metra rail stations. Stations that are not exposed to extreme cold are located underground. In general, very few rail stations have high or very high extreme cold risk scores because temperatures are expected to increase in the future, and therefore the number of days with maximum temperatures below 15°F is expected to decrease by mid-century.
- None of CTA's rail stations have high or very high extreme cold risk. Twelve percent of Metra's rail stations have high extreme cold risk and 4 percent of Metra's rail stations have very high extreme cold risk.
- Metra stations with very high risk scores are located in areas that are projected to see more than 1 day per year with maximum temperatures below 15°F by mid-century.

Figure 38. Breakdown of extreme cold risk scores for CTA and Metra rail stations



9.2.2 Rail lines[103]

- The extreme cold risk scores for rail line segments are solely determined by the level of cold exposure for the segment (i.e., the number of days with minimum temperature below 15°F by

[103] This analysis only considers temperature and not track condition, which is an important risk factor.

mid-century). Rail line segments that are not exposed to extreme cold are located underground. For the purposes of this analysis, rail lines were split into segments at rail stations and where elevation status changes (i.e., subway to ground level).

- None of CTA's rail lines have high or very high extreme cold risk. Sixty-eight miles (14 percent) of Metra's rail lines have high extreme cold risk and 58 miles (12 percent) of Metra's rail lines have very high extreme cold risk.
- These results reflect that a higher percentage of Metra's rail line segments are in areas projected to experience at least 1.5 days per year below 15°F by mid-century.

Figure 39. Breakdown of extreme cold risk scores for CTA and Metra rail lines in miles

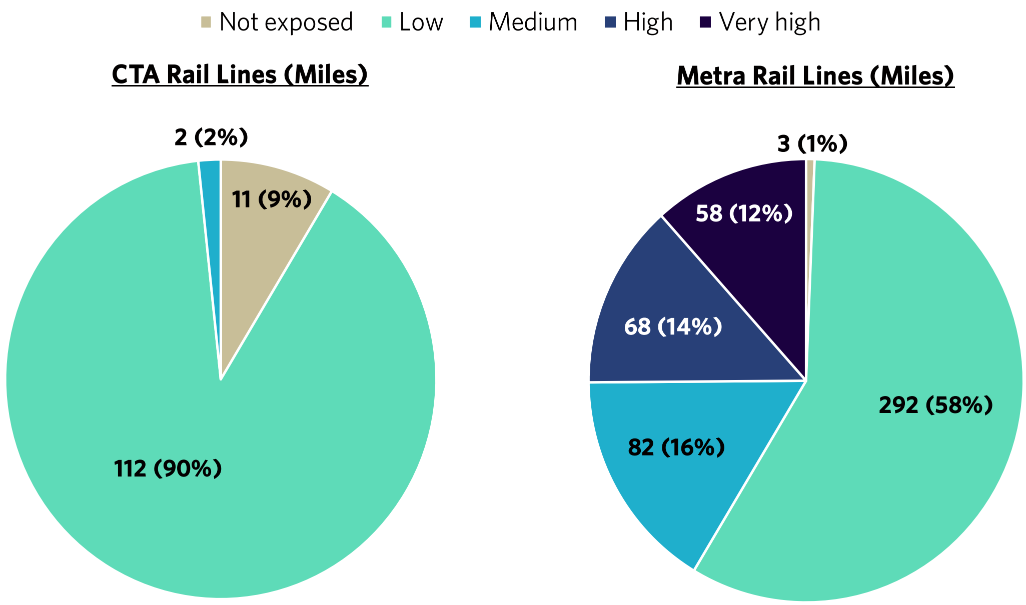


Figure 40 and Figure 41 show the extreme cold risk scores for rail lines and stations for CTA and Metra, respectively. CTA does not have any high or very high scoring stations or lines. For Metra, most high and very high-scoring assets are located in McHenry County and northwest Lake County.

Figure 40. Map of extreme cold scores for CTA rail lines and stations

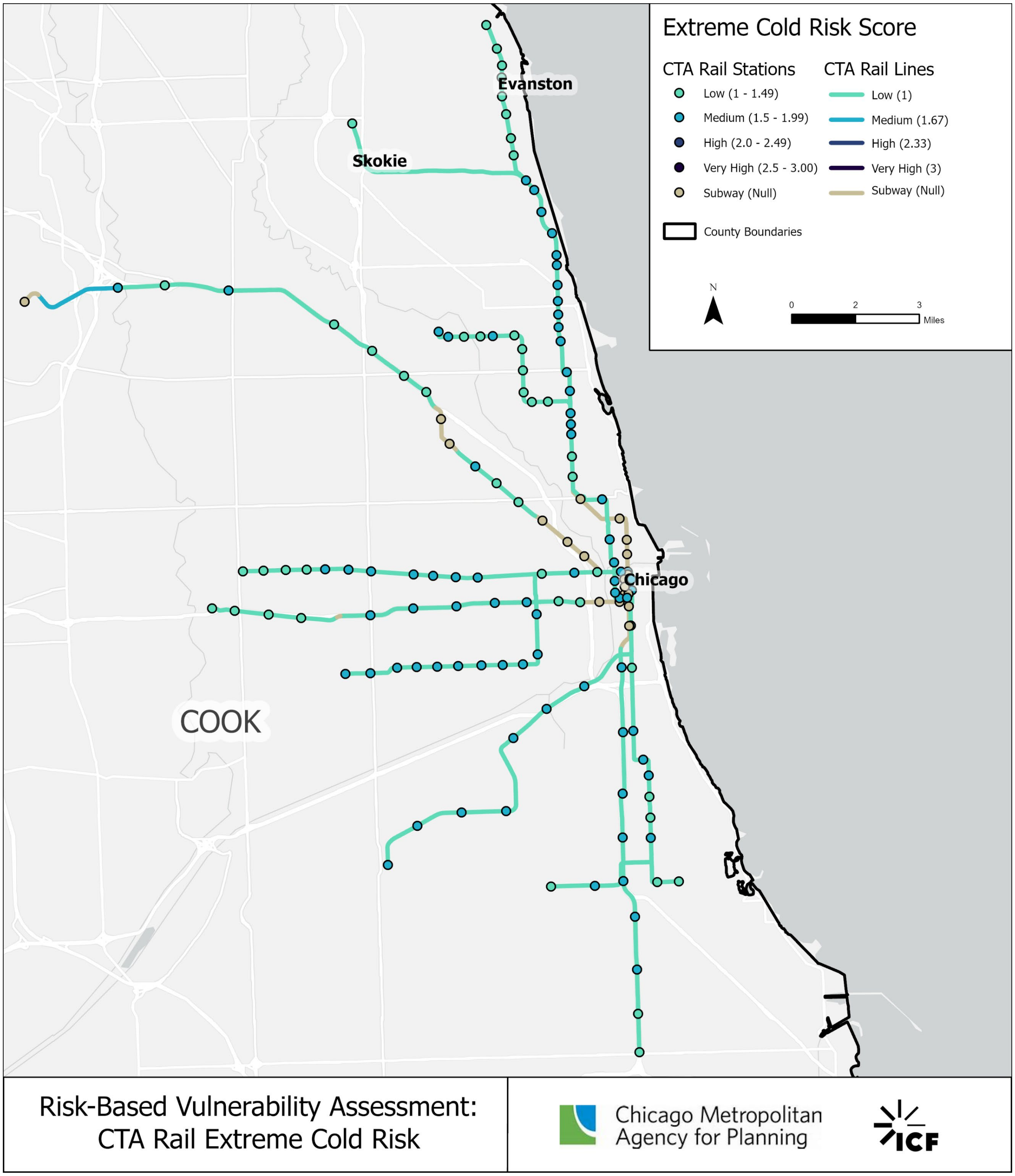
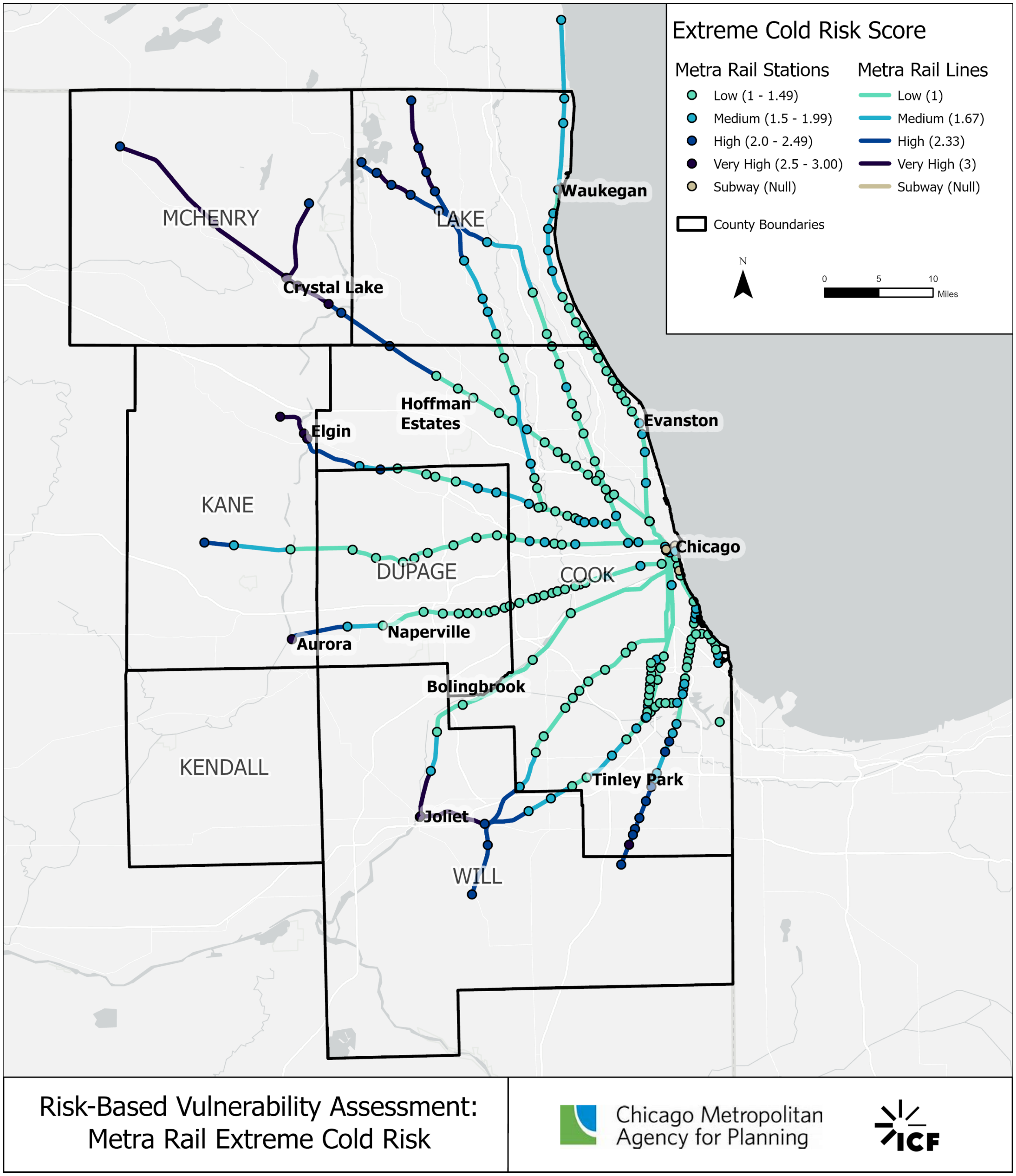


Figure 41. Map of extreme cold scores for Metra rail lines and stations



10 Appendix E: Transit rider vulnerability analysis methodology details

This appendix provides more details on the methodology used for the transit rider vulnerability analysis.

10.1 Overview

CMAP calculated a vulnerability score at each transit point in the northeastern Illinois region. In this analysis, vulnerability[104] is represented as the weighted combination of exposure, sensitivity, and adaptive capacity of a transit rider at a transit point (bus stops and rail stations), as shown in the equation[105] below:

$$\textbf{Transit Rider Vulnerability Score} = (\text{Exposure Score})\ (33.3\%) + (\text{Sensitivity Score})\ (33.3\%) + (\text{Adaptive Capacity Score})\ (33.3\%)$$

For each transit point, exposure, sensitivity, and adaptive capacity indicators were scored on a scale of 1 to 3 (for more details, see Table 54). These scores were then weighted and added together to determine the total vulnerability score, with 3 being the highest possible score. A higher transit rider vulnerability score represents higher vulnerability of transit riders to extreme heat effects. Table 53 shows the vulnerability score ranges that correspond to low, medium, high, and very high vulnerability ratings at any given individual transit point.

Table 53. Transit rider vulnerability ratings and corresponding ranges of vulnerability scores

Vulnerability Rating	Vulnerability score ranges
Low	1.0 - 1.5
Medium	1.6 - 2.0
High	2.1 - 2.5
Very high	2.6 - 3.0

10.2 Indicators and datasets

CMAP used the following indicators for exposure, sensitivity, and adaptive capacity in the calculation of the transit rider vulnerability scores:

Exposure: Exposure indicator for extreme heat was determined by calculating the number of days with maximum temperature above 95°F by mid-century. An exposure score was assigned to each bus stop and rail station based on their location and used as a proxy for the magnitude to which transit riders using a given bus stop or station may be exposed to extreme heat.

Sensitivity: The sensitivity indicator combines two sub-indices from the USDOT ETC Explorer database. This dataset uses 2020 census tract data to help users understand how specific communities or areas experience transportation disadvantage compared to all other census tracts. The ETC Explorer is designed to complement the CEJST and visualizes transportation disadvantage across

[104] Add reference for to the IPCC 2007 Fourth Assessment Report.
[105] The exposure indicator used in the analysis is adjusted to consider future climate conditions, whereas the sensitivity and adaptive capacity indicators are based only on historical data.

five components: transportation insecurity, climate and disaster risk burden, environmental burden, health vulnerability, and social vulnerability. Of these, the following two sub-indices were combined into the transit rider vulnerability sensitivity indicator:

- **Social Vulnerability Subindex:** This subindex blends a number of socioeconomic and demographic indicators, such as age, disability, income, etc. that can directly impact the quality of life. In the transit rider vulnerability analysis, CMAP used this subindex as a proxy for understanding which communities may be more dependent on using transit services and more sensitive to experiencing adverse effects. Certain population groups, such as the elderly, young, and those who are socially or economically disadvantaged have been shown to be more sensitive to experiencing adverse health impacts from extreme heat exposure.
- **Health Vulnerability Subindex:** This subindex measures the prevalence of certain health conditions that may result from exposure to environmental pollution and/or lifestyle factors, such as poor walkability and long commute times. In the transit rider vulnerability analysis, CMAP used this subindex as a proxy for understanding which communities may have high prevalence of conditions like asthma, high blood pressure, and diabetes. Transit riders who suffer from these pre-existing health conditions are known to show a higher sensitivity to adverse effects, such as heat stress and heat stroke.

Adaptive capacity: Adaptive capacity indicator combines the following three sub-indicators, which are inversely related to the transit rider vulnerability:

- **Households with no car:** Households without a private vehicle are assumed to rely heavily on public transportation. In the transit rider vulnerability analysis, CMAP used 2020 census tract data on percentage of households with no car from the Transportation Insecurity Subindex of the USDOT ETC Explorer database as an indicator for transit dependence. A high level of dependence on public transit indicates a lower adaptive capacity as it influences whether a transit rider would be able to reduce or completely avoid exposure to extreme heat by using a personal vehicle to fully or partially cover their commute.
- **Transit Availability Index:** CMAP's Transit Availability Index is a metric that measures how the transit system as a whole serves a location. It is composed of four sub-indicators: transit frequency, transit connectivity, sidewalk density, and transit proximity. In the transit rider vulnerability analysis, the Transit Availability Index score is used to evaluate factors which can influence the time required by transit users to walk or bike to transit stops/stations, as well as the time spent waiting at transit stops/stations.
- **Tree canopy coverage:** Percentage of tree canopy coverage from 2021 Ecopia landcover data was used as a proxy for the availability of tree shade at or near a transit point. Tree cover may modulate the local temperature or micro-climate and therefore influence conditions experienced by transit riders while walking to or from transit stops/stations or while waiting at these locations.

The scoring rubric for each of the exposure, sensitivity, and adaptive capacity indicators is shown in Table 54.

Table 54. Scoring rubric for transit rider vulnerability indicators

<table>
<tr><th>Indicator</th><th>Data source</th><th>Weight[106]</th><th>Ranges[107]</th><th>Range values – bus stops</th><th>Range values – rail stations</th><th>Score</th></tr>
<tr><td colspan="7">Exposure</td></tr>
<tr><td rowspan="3">Days with maximum temperature above 95°F by mid-century[108]</td><td rowspan="3">ICF ClimateSight Projections</td><td rowspan="3">33%</td><td>Highest 1/3 extreme heat days</td><td colspan="2">20 - 26 days</td><td>3</td></tr>
<tr><td>Middle 1/3 extreme heat days</td><td colspan="2">14 - 20 days</td><td>2</td></tr>
<tr><td>Lowest 1/3 extreme heat days</td><td colspan="2">7-14 days</td><td>1</td></tr>
<tr><td colspan="7">Sensitivity</td></tr>
<tr><td rowspan="3">Combined Social and Health Vulnerability Score[109] (using USDOT ETC Social Vulnerability Subindex + Health Vulnerability Subindex)</td><td rowspan="3">USDOT Equitable Transportation Community (ETC) Explorer</td><td rowspan="3">33%</td><td>Highest 1/3 combined social and health vulnerability score</td><td>0.5 - 0.8</td><td>0.4- 0.8</td><td>3</td></tr>
<tr><td>Middle 1/3 combined social and health vulnerability score</td><td>0.3 - 0.5</td><td>0.3 - 0.4</td><td>2</td></tr>
<tr><td>Lowest 1/3 combined social and health vulnerability score</td><td>0.0 - 0.3</td><td>0.0 - 0.3</td><td>1</td></tr>
</table>

[106] Combined weight does not equal to 100 percent due to rounding.
[107] For bus transit rider vulnerability indicators, data was extracted for area that falls within a 0.25-mile radius of the bus stop, assuming bus riders residing or working within that buffer zone are primary users of that bus stop. Similarly, for rail transit rider vulnerability indicators, data was extracted for area that falls within 0.5-mile radius of the rail station, assuming train riders residing or working within that buffer zone are the primary users of that rail station. For some indicators like US DOT Social and Health vulnerability subindex score, this included averaging values for census derived datasets, if multiple census tracts were in the defined proximity, i.e., 0.25-mile buffer of a bus stop or 0.5-mile buffer of a rail station.
[108] For subways, exposure was scored the same as other rail stations (elevated and at-grade), despite being underground, as riders would still be exposed to heat as they walk to/from the station or wait at modal transfer points or to be picked up by a vehicle.
[109] To calculate the combined sensitivity score, a higher weight was assigned to the USDOT ETC Social Vulnerability sub-index (70 percent) due the diversity and larger number of relevant socioeconomic and demographic indicators that were included in that sub-index, compared to the USDOT ETC Health Vulnerability sub-index (30 percent weight).

Indicator	Data source	Weight[106]	Ranges[107]	Range values – bus stops	Range values – rail stations	Score
Adaptive capacity						
Percentage of households with no car *(using USDOT ETC Transportation Insecurity Subindex)*	USDOT ETC Explorer	11%	Highest 1/3 percentage of households with no car	0.1 - 0.8	0.1 - 0.6	3
			Middle 1/3 percentage of households with no car	0.0 - 0.1	0.0 - 0.1	2
			Lowest 1/3 percentage of households with no car	0.0	0.0	1
Transit Availability Index	CMAP, Transit Availability Index, 2019	11%	Lowest 1/3 index score	0.0	0.0	3
			Middle 1/3 index score	0.0-0.7	0.500	2
			Highest 1/3 index score	0.7-1.0	1.000	1
Tree Canopy Coverage	Ecopia AI, 2021[110]	11%	Lowest 1/3 percentage of tree canopy coverage	0.0 - 0.1	0.0 - 0.2	3
			Middle 1/3 percentage of tree canopy coverage	0.1 - 0.2	0.2 - 0.3	2
			Highest 1/3 percentage of tree canopy coverage	0.2 - 0.8	0.3 - 0.6	1

[110] Tree canopy coverage in northeastern Illinois. Retrieved from CMAP, more info at https://www.ecopiatech.com/, accessed on October 13, 2023.

FY25-0013

The Chicago Metropolitan Agency for Planning (CMAP) is the region's comprehensive planning organization. The agency and its partners developed and are now implementing ON TO 2050, a long-range plan to help the seven counties and 284 communities of northeastern Illinois implement strategies that address transportation, housing, economic development, open space, the environment, and other quality-of-life issues.

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