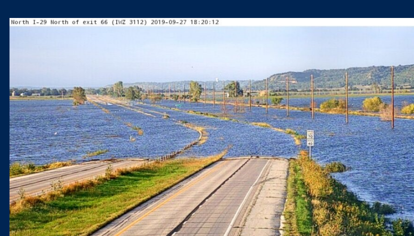
All-Hazards Assessments of Major Freight Corridors in the MAASTO Region

MID-AMERICA FREIGHT COALITION



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About the Mid-America Freight Coalition (MAFC)

The industries and farms of the Mid-America region can compete in the marketplace only if their products can move reliably, safely and at reasonable cost to market.

State Departments of Transportation play an important role in providing the infrastructure that facilitates movement of the growing amount of freight. The Mid-America Freight Coalition was created to support the 10 states of the Mid America Association of State Transportation Officials (MAASTO) region in their freight planning, freight research needs and in support of multi-state collaboration across the region.

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Photo credits
Top: Iowa State Patrol, I-29 closure
Bottom (middle): Iowa Public Radio, 2019 I-29 floods
(right): Milwaukee Journal Sentinel, I-94 in Waukesha County

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This project provides an all-hazards assessment for nominated major corridors within the MAASTO region. The report provides a summary of resources available for hazard analysis on regional corridors and documents and maps historic hazards on a selection of five multistate corridors: I-90, I-94, I-70, I-65, and I-29. The report further proposes hazard ranking systems to reflect potential impact of hazards to multistate freight movement.		
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1. INTRODUCTION

Project Objectives

To better understand and mitigate freight transportation resiliency issues, transportation agencies have adopted “all-hazards resiliency assessments” for transportation assets within many states. Such an analysis typically evaluates how the hazard may impact (or sometimes halt) operations along the transportation system. According to the Federal Emergency Management Administration (FEMA), an “all-hazards” assessment includes natural, technological, or human-caused incidents that warrant action to protect life, property, environment, and public health or safety [1]. The state-by-state approach utilized for all-hazards resiliency assessments does not account for the freight movements on major multistate freight corridors nor the impacts that travel hazards in any one state can have on a multistate trip. To understand and address multistate freight operations and management of critical economic freight corridors, an all-hazards and resiliency assessment based on a multistate freight corridor approach is necessary.

Planning for multistate freight movement on major freight corridors challenges the resilience efforts of any individual state unless the efforts are coordinated with adjacent states sharing the same corridors. As an example, if a portion of a multistate freight corridor is reconstructed to prevent road closures due to flooding in one state, but no improvements are made on the same corridor in a neighboring state, in the event of severe flooding, the entire corridor may become unavailable. These closures result in delays, detours, economic impacts, and far-reaching supply chain disruptions.

The benefits of collaboratively managing a multistate freight corridor include uniform and harmonized operational management, consistent policies, and construction/repair that focuses on the entire corridor, rather than just facilities and policies in one state. With coordinated planning and management informed by a corridor based all-hazards assessment, the overall risk of hazard delay on a multistate corridor is minimized. Furthermore, construction and maintenance activities can be coordinated to reduce delays along the corridor.

Scope of Work

The intent of the project is to identify sources for historic information on hazards and impacts to multistate corridors in the MAASTO region, to generate mapping of hazards of significant impact, and to develop a hazard ranking system based on severity of event and impact to the freight transportation network.

The study was carried out through two main tasks.

<u>Task 1</u>

In Task 1, the project team first reviewed data sources for hazard assessment of freight corridors. An assessment of data sources is critical to identifying gaps in information sources and for developing strategic plans to compile data that could be useful for future multistate freight corridor hazard assessments. The team coordinated with the Mid America Freight Coalition (MAFC) technical representatives to identify five MAASTO freight corridors for development of a multistate all-hazards corridor inventory and assessment. The corridors were selected with consideration to the importance of the corridor to freight movement in the MAASTO region, known susceptibility to resiliency issues during severe weather events, and importance of the corridor across multiple states. An all-hazards assessment was performed, and historical hazards were mapped to illustrate the location, date, type, and duration of each event impacting each selected corridor.

Task 2

In Task 2, a hazard ranking system was developed to reflect the potential impacts of hazards on multistate freight movement. Due to gaps in data available for historic hazards, a simplified hazard ranking system was also developed to demonstrate how a ranking system could be applied using historic hazards as mapped in Task 1.

Organization of the Report

The report is organized as follows:

- Chapter 2 presents an overview of the candidate corridor selection process for the study.
- Chapter 3 provides an outline of data sources used for all-hazard analysis.
- Chapter 4 presents a hazard ranking system.
- Chapter 5 presents hazards assessment for the study corridors.
- Chapter 6 provides a summary discussion and concluding comments.

2. CORRIDOR SELECTION

This section outlines the process used to identify study corridors for historic hazard and impact mapping. The corridor selection was completed with input from each MAASTO state through MAFC state representatives.

Candidate Corridors

An initial list of 10 candidate corridors was generated based on estimated value of goods moved, and the importance of the corridor to the states and to the region. A previous MAFC report (Identification and Characterization of the MAASTO Region's Multimodal Freight Network, 2019, [2]) identified the most significant freight corridors in the MAASTO region by ranking corridors by value of goods moved. This report was used as the basis for generating the initial list of candidate corridors.

Figure 1 displays major freight corridors in MAASTO by estimated value of freight moved through each section. Figure 2 ranks the top 10 corridors in the region by value along with overall share of relative value moved on the corridor compared to all major corridors in the region (percentage of value of goods moved on corridor to value of all goods moved on major freight corridors in the region).

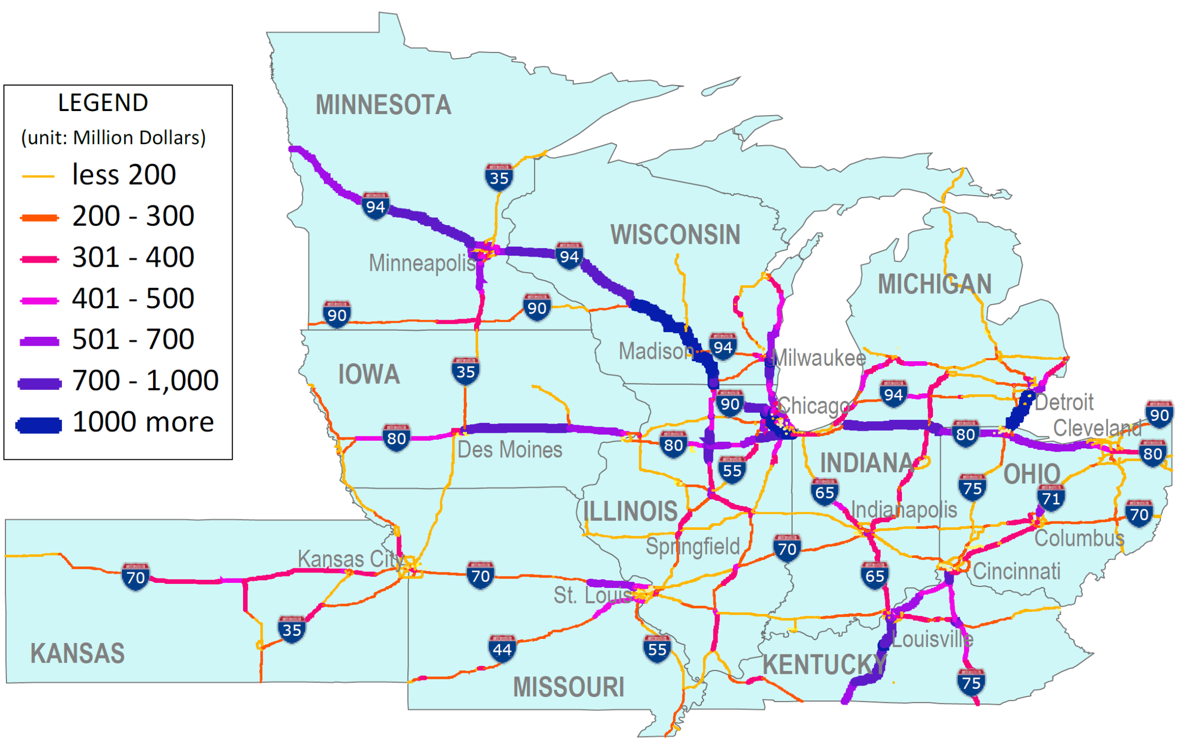

Figure 1: Value of freight moved by corridor through MAASTO region (Source: MAFC Report #18 [2], estimated average annual daily value).

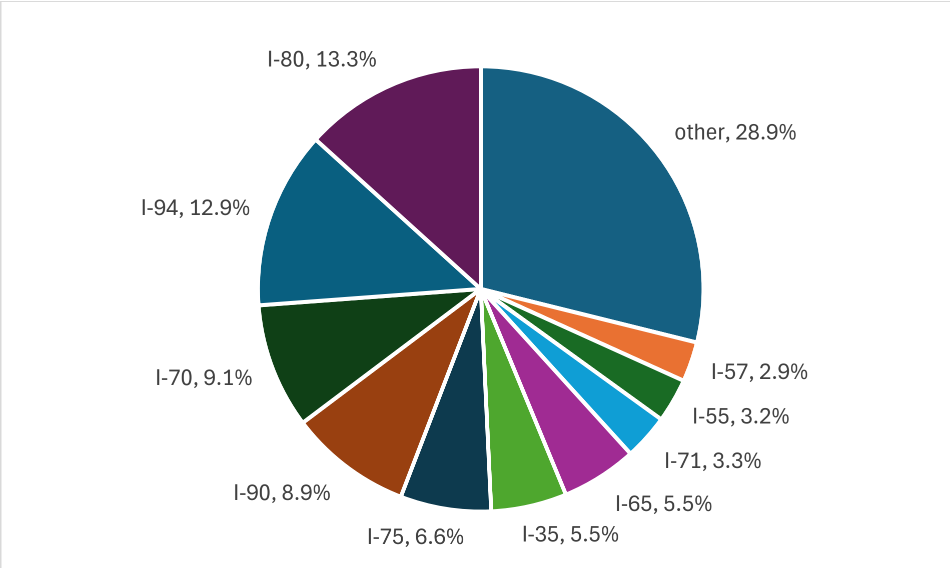

Figure 2: Top 10 freight corridors in MAASTO region by share of value of goods moved (Source: MAFC Report #18 [2], estimated average annual daily value).

Based on the work in MAFC 18 [2], a list of 10 candidate corridors was generated. Since the focus of the present study is to assess only MAASTO multistate corridors, I-57, which ranked in the top 10 corridors in the region by value was not considered, and I-69 was substituted in its place. Table 1 summarizes the candidate corridors along with the estimated value of freight moved in each state. This table is only used as an approximate assessment of the relative value of corridors by freight moved in each state. Note that the estimated values are only listed for a state if the corridor ranks among the top five corridors by freight value moved for the state and thus this table should only be seen as approximate representation of value of corridors by state. For example, I-94 and I-70 are corridors of importance through Illinois, but do not rank among the top five corridors by freight value moved in the state (the top five are I-57, I-80, I-55, I-39 and I-90), and thus do not have a listed value in the table. Further note that the estimated freight value is assigned to only one of multiple concurrent corridors (such as I-80 in Indiana where it runs concurrent with I-90, i.e. section of corridor that is part of both I-80 and I-90, but value is only assigned to the primary corridor). Similarly, most of I-57 is concurrent with I-55 in Missouri and thus does not separately function as a multistate corridor of value in the region. The calculations presented later in the report (Section 5) use more accurate measures for value by corridor segment where all major corridors (and not just the top 5 for each state) are represented.

		Estimated Value by State (billion dollar-miles annually)										Total Value
C #	**Corr.**	**IL**	**IN**	**IA**	**KS**	**KY**	**MI**	**MN**	**MO**	**OH**	**WI**	**(billion dollar-miles / %)**
1	**I-80**	93.5	93.9	162.1						111.5		**461.0 / 13.3**
2	**I-94**						79.9	164.4			182.3	**426.6 / 12.3**
3	**I-70**		36.4		127.9				77.9	49		**291.2 / 8.4**
4	**I-90**	57.9						67.3			164.9	**290.1 / 8.4**
5	**I-75**					72.8	109.6			45.5		**227.9 / 6.6**
6	**I-35**			41.4	62			73.6	15.7			**192.7 / 5.6**
7	**I-65**		85			106.9						**191.9 / 5.5**
8	**I-71**					52				62.5		**114.5 / 3.3**
9	**I-55**	79.2							31.6			**110.8 / 3.2**
-	**I-57**	96.2										**96.2 / 2.8**
10	**I-69**		50.6				38					**88.6 / 2.6**

Table 1: Top 10 corridors by estimated value (Source: MAFC #18 [2]).

State Voting

The list of candidate corridors was presented to the MAFC representatives committee, and each state was asked to vote for their preferred five corridors for selection. In addition to the candidate corridors generated earlier, I-29 was included in the list of candidate corridors based on recommendation from Missouri as a special candidate because of its history of operational issues due to flooding. Table 2 shows the results from the first round of state voting. The votes were solicited in the form of rank order voting, and corridors were assigned points decreasing from 5 for a state's top pick to 1 for their fifth pick. Note that Illinois and Michigan approved the corridors as ranked at this stage and thus the table does not show ranked scores for corridors for these two states. However, these states' ranked preference was incorporated during subsequent voting stages.

	Vote Scores											
Corr	IL	IN	IA	KS	KY	MI	MN	MO	OH	WI	Total	Rank
I-80		5	5	5			2	2	4	3	26	1
I-90		1		2			3		5	4	15	2
I-94				4			5			5	14	3
I-70		3		3				5	3		14	4
I-35			4	1			4	4			13	5
I-65		4			5					2	11	6
I-29			3				1	3			7	7

Table 2: Initial corridor voting results. Corridors that received votes from fewer than two states are not shown. (Source: MAFC)

Final Corridor Selection

Based on discussions with the MAFC representatives and the ranking results, the project team developed three proposed corridor sets. The proposed corridor sets were generated to include a range of corridors of highest value to the region, corridors representing freight movement in major directions in the region, and corridors with a known history of vulnerability issues.

Set 1: I-80, I-94, I-70, I-90, I-35

Set 1 was generated to represent the top five voted corridors from initial state voting.

Set 2: I-80, I-94, I-70, I-35, I-29

Set 2 was generated to include the top three voted corridors, the highest voted N-S spanning corridor (I-35), and I-29 as a special corridor with high relevance to resiliency assessment. I-35 is also a good representation of a corridor of high importance to international freight movement as it connects with Canada in the north and Mexico in the south.

Set 3: I-80, I-94, I-70, I-35, I-65

Set 3 was generated to include the top 3 voted E-W spanning corridors and the top 2 voted N-S spanning corridors (I-35 and I-65).

The proposed corridor sets were presented once again to the MAFC representatives for discussion and voting. An initial voting and discussion revealed that there was a demand for selecting a combination of corridors that included I-29 as a special case due to its history of flooding related resiliency issues, as well as having at least one corridor of high importance to each member state. A suggestion to exclude I-80 (the busiest corridor for the region) and I-35 in favor of picking I-90, I-94, I-70, I-65 and I-29 was made and was supported by all states. I-80 spans through Iowa, Illinois, Indiana and Ohio. In Indiana and Ohio I-80 runs concurrent with I-94 and I-90 for a large portion, and thus most of I-80 is covered through those corridors for the study. For Iowa, I-80 and I-35 are the most important corridors, but Iowa supported dropping I-80 if it was a trade-off for retaining I-29 as a candidate corridor, and with consideration in the study that findings and suggestions presented for the studied corridors may be informational for similar corridors (such as similarities between I-80 and I-90). After discussions, the set of corridors was unanimously approved by all state representatives. This final set included three major E-W corridors in the region (I-94, I-70, and I-90) and two N-S corridors including one with high relevancy to resiliency assessment (I-65 and I-29).

Table 3 illustrates corridor sets presented to the committee as well as the final set approved for study. Table 4 further lists the approximate length of each selected corridor spanning through each MAASTO state. The miles reported are based on Federal Highway Administration's (FHWA) Route Log and Finder List and includes total miles reported including overlap miles. For I-29 this includes roughly 5.5 miles overlapped with I-35, 3 miles with I-80 and 9.91 miles with I-880. For I-65 this includes 2.13 miles overlapped with I-70. For I-70 this includes 1 mile overlapped with I-35, 5.59 miles with I-57, 16 miles with I-55, 2.13 miles with I-65, and 1.74 miles with I-71. For I-90, miles reported include 107 miles overlapped with I-94, 16.6 miles with I-39 and nearly 280 miles with I-80 through Indiana and Ohio. For I-94, overlaps with I-41 (28 miles) and I-80 (18.5 miles) are included in addition to the overlap with I-90.

Corr	Set 1	Set 2	Set 3	Final
I-80	✓	✓	✓	
I-94	✓	✓	✓	✓
I-70	✓	✓	✓	✓
I-90	✓			✓
I-35	✓	✓	✓	
I-65			✓	✓
I-29		✓		✓

Table 3: Candidate corridor sets, and final set of corridors selected. (Source: MAFC)

Corr	IA	IN	IL	KS	KY	MI	MN	MO	OH	WI
I-70		155	156	424				250	226	
I-90		156	124				276		245	187
I-94		46	62			275	259			341
I-65		261			137					
I-29	152							129		

Table 4: Selected corridors and their run-length (miles) through each state. (Source: MAFC, based on FHWA Route Log and Finder List [3])

3. HAZARD REPORTING – DATA SOURCES

Federal Emergency Management Agency and State Hazard Mitigation Offices

FEMA is the federal agency (under the Department of Homeland Security) responsible for coordinating response to disasters that overwhelm state and local authorities. FEMA's mission is to help people and communities prepare for, respond to, and recover from disasters. As part of its efforts, FEMA keeps records of major disasters declared as national emergencies, impacts and damages due to the disaster, and mitigation and relief efforts undertaken. MAFC Report #26 [4] provides a summary review of FEMA's repository of major disaster data. Figure 3 shows a sample of information available through FEMA's website for declared major disasters.

Table 5 lists State Hazard Mitigation Offices for each MAASTO state along with a link to the corresponding offices' websites. These agencies provide valuable resources for a wide range of information including weather event advisories, state policies and plans for disaster preparedness, past resiliency reports, and state emergency response guides. In our research, however, the state offices unfortunately do not provide a reliable source for detailed lists of historic hazards and disasters, their impacts, and mitigation and relief efforts that were undertaken.

Figure 3: FEMA major disaster information (sample case). (Source: FEMA [5])

State Hazard Mitigation Offices [6]	
Illinois Illinois Emergency Management Agency	**Indiana** Indiana Department of Homeland Security
Iowa Iowa Homeland Security & Emergency Management Department	**Kansas** Homeland Security Emergency Operations
Kentucky Kentucky Division of Emergency Management	**Michigan** Michigan State Police Department / Emergency Management & Homeland Security Division
Minnesota Minnesota Department of Public Safety, Division of Homeland Security & Emergency Management	**Missouri** Missouri Office of Homeland Security / Department of Public Safety
Ohio Ohio Emergency Management Agency	**Wisconsin** Wisconsin Emergency Management – Department of Military Affairs

Table 5: List of State Hazard Mitigation Offices for MAASTO States (Source: FEMA [6]).

Hazards Risks (FEMA)

FEMA maintains data on a total of 18 hazards across the country through the National Risk Index (NRI) [7]. The database includes Annualized Frequency (AF), which is a direct measure of likelihood of a hazard occurring in the region and is based on historic record of such events.

Figure 4 through Figure 9 below show the FEMA AFs for 6 hazards of high relevance to the region:

- River flooding
- Severe Winter Weather
- Strong Winds
- Tornadoes
- Landslides
- Earthquakes

One should note that the AF maps illustrate the frequency, and thus an estimate of likelihood of a hazard occurrence, but do not represent the severity of hazard, nor the potential impact to population and structures.

FEMA also maintains a National Risk Index (NRI) dataset [7] to illustrate risk indices for communities across the US for natural hazards. The annualized hazard frequency as described earlier is multiplied by an exposure factor representing value of population, buildings, and goods exposed to occurrence of hazards, and by a historic loss ratio representing the estimated percentage of exposed value expected to be lost due to a hazard occurrence based on historic data, to generate the Expected Annual Loss (EAL) for each hazard type [8]. Thus, the EAL incorporates aspects such as population density and urbanization levels (through the exposure factor metric). The NRI is then calculated as the product of the EAL and a Community Risk Factor (CRF). CRF is a scaling factor incorporating social vulnerability and community resilience measures to represent how vulnerable a community is to damage. The CRF accounts for social considerations such as population demographics, employment rates, economic status, housing cost burdens, disabilities, and racial and ethnic minorities. The NRI maps for the 6 hazards of high relevance to the region (riverine flooding, severe winter weather, strong winds, tornadoes, earthquakes, and landslides) are included in Appendix A –. Note that unlike the AF maps, these NRI maps do not show risk of occurrence of disaster, which can therefore skew the risk to look higher for more densely populated urbanized areas as well as areas with socially vulnerable communities (a geographic score measured through factors such as rate of unemployment, economic status, housing cost burden, age demographics, disabilities, racial and ethnic minorities, etc.).

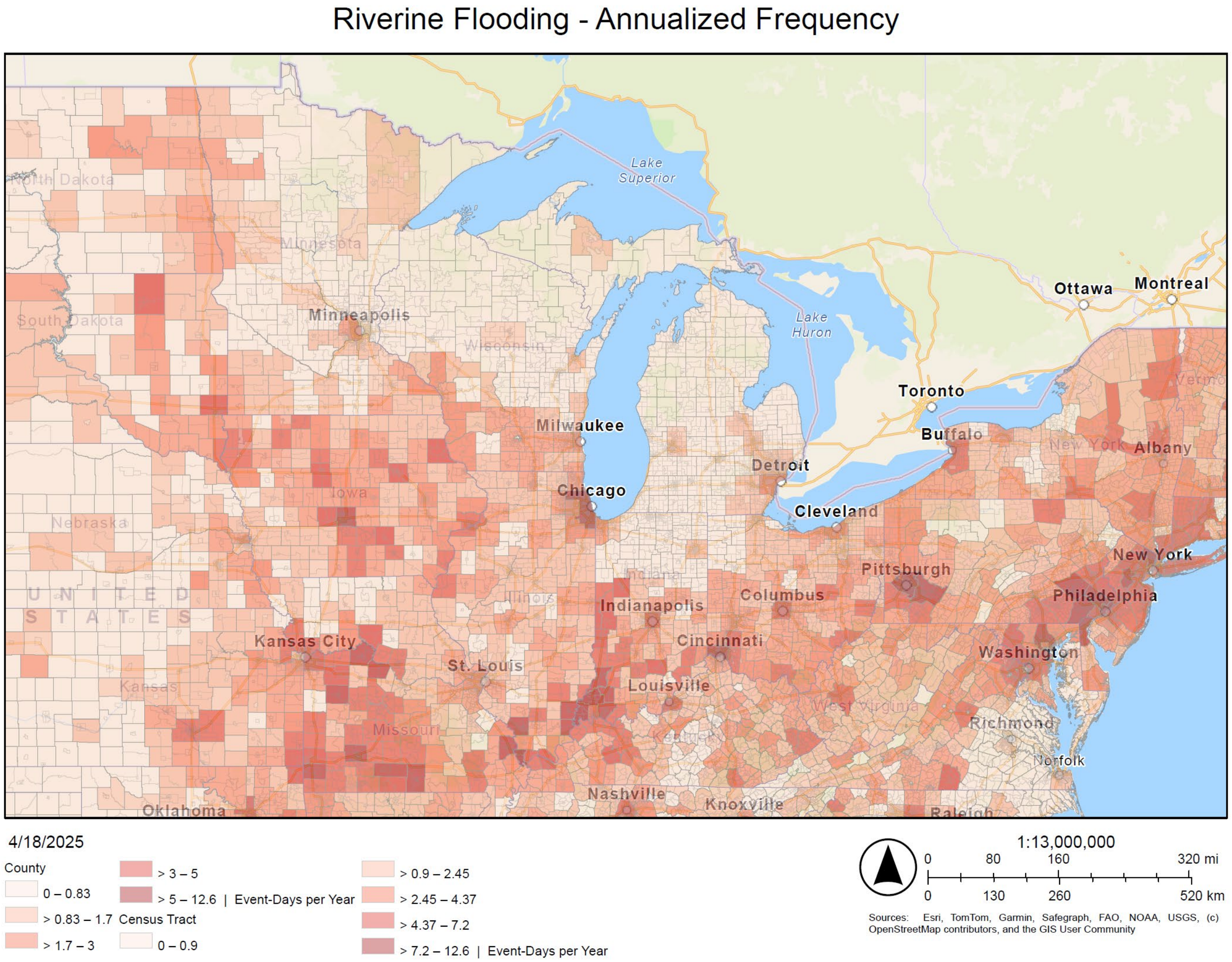

Figure 4: Annualized frequency of riverine flooding (Source: FEMA/Esri)

Riverine flooding is the most impactful weather hazard for freight movement in the region. Flooding is relatively frequent through most of the region but is especially frequent along the Missouri-Platte floodplains (western Iowa and Missouri), and along the Mississippi and Ohio rivers.

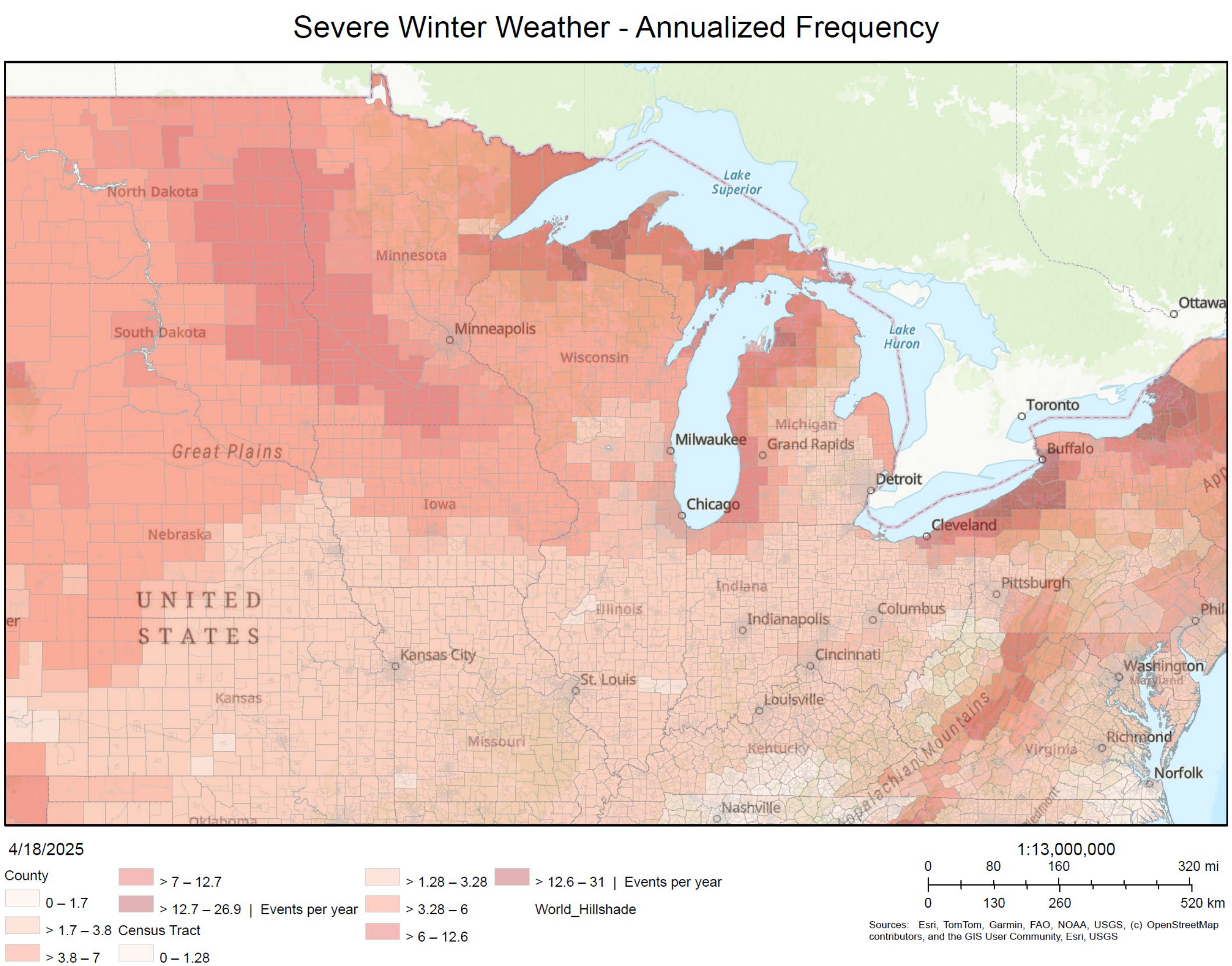

Figure 5: Annualized frequency of severe winter weather (Source: FEMA/Esri).

Severe winter weather is a common occurrence in the region, with northern parts of Minnesota, Wisconsin and Michigan experiencing high frequency conditions.

Strong Wind - Annualized Frequency

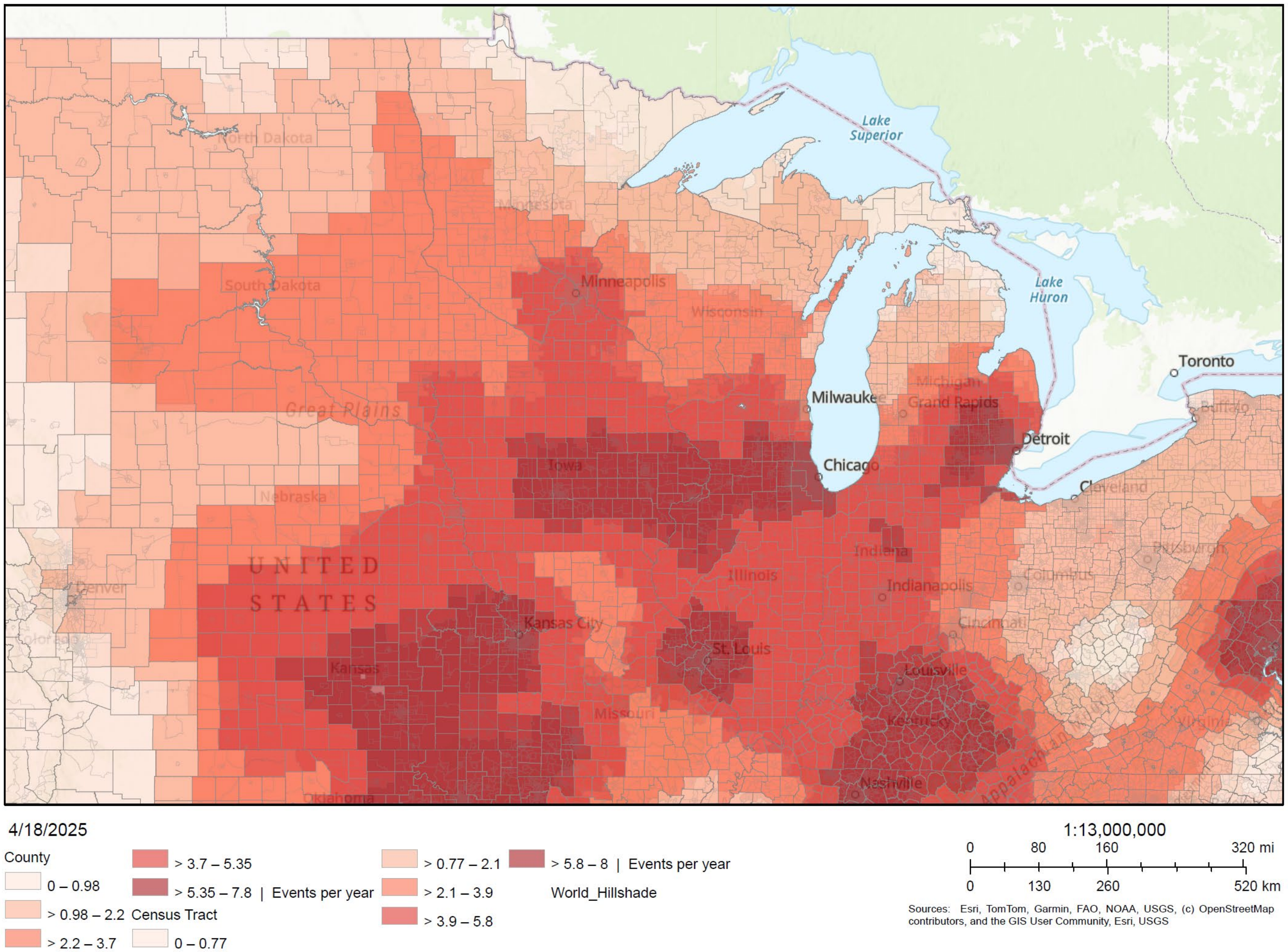

Figure 6: Annualized frequency of strong wind events (Source: FEMA/Esri).

The region also sees a high frequency of strong wind hazards. The hotspots for strong winds are across the Iowa and northern Illinois, western Missouri and across Kansas, around St. Louis, central Kentucky, and southeastern Michigan.

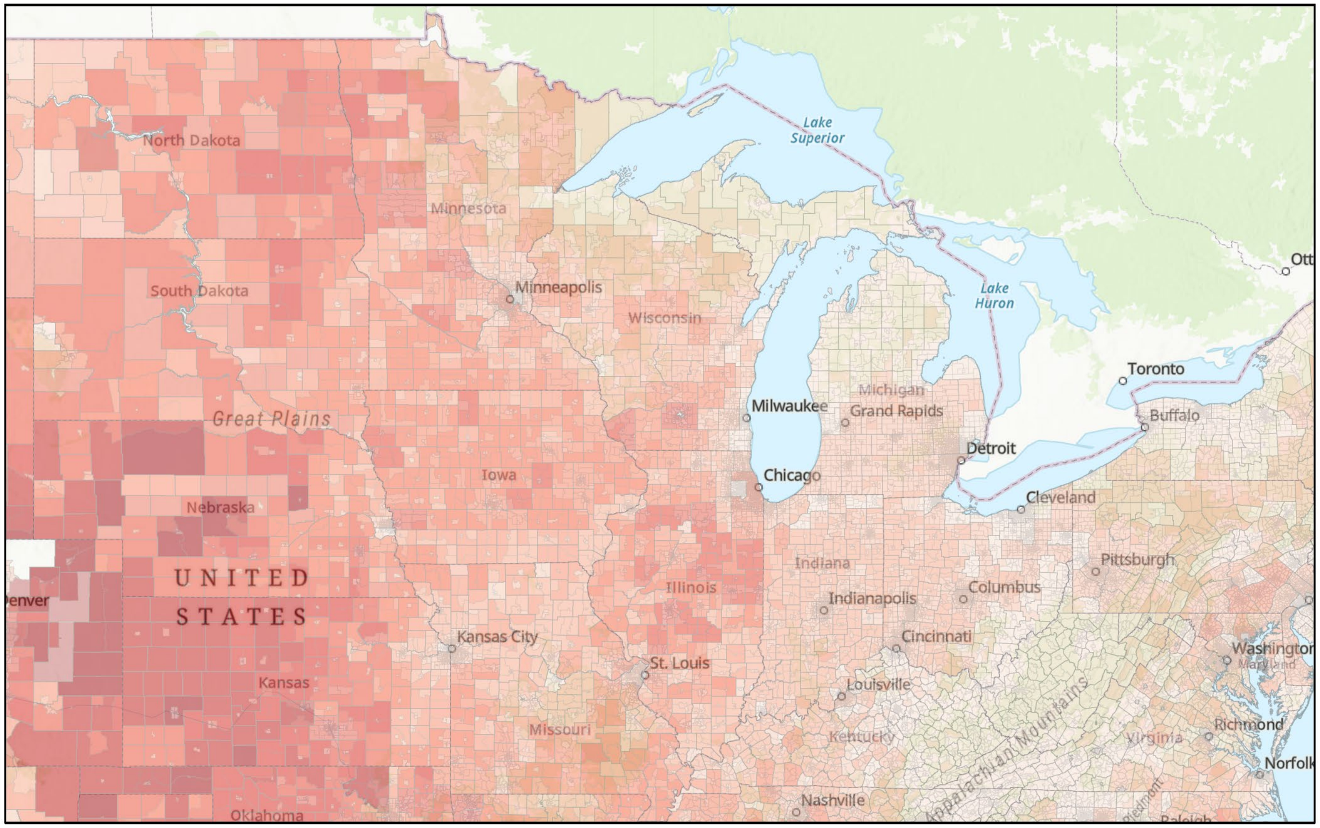

Figure 7: Annualized frequency of tornadoes (Source: FEMA/Esri).

Tornadoes are frequent in western part of the region, with notable frequency of occurance across Kansas, but also through Iowa, Illinois, and Minnesota.

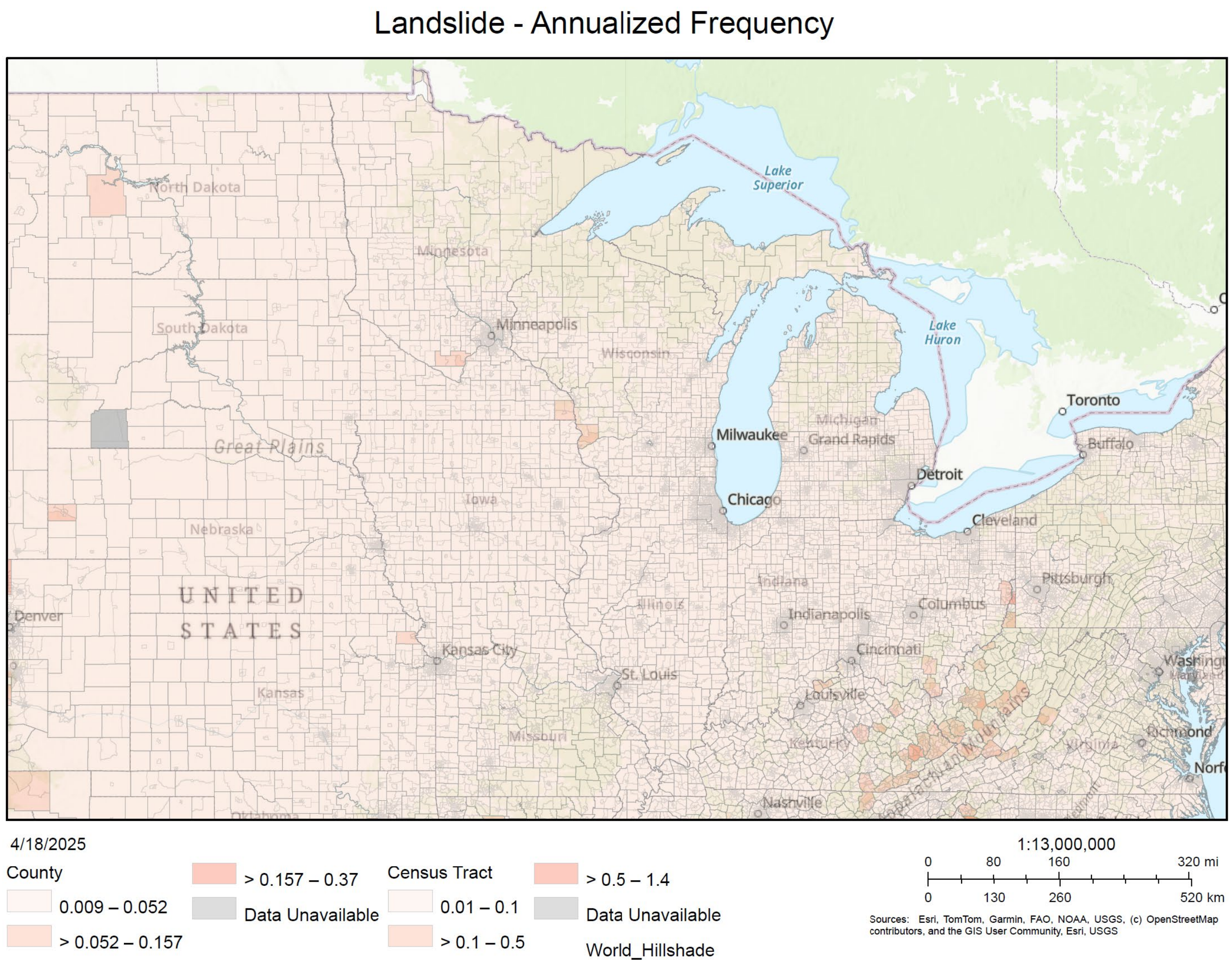

Figure 8: Annualized frequency of landslides (Source: FEMA/Esri).

In general, landslides are not very common in the region, except along the eastern borders of Kentucky and Ohio due to the Appalachian Mountains.

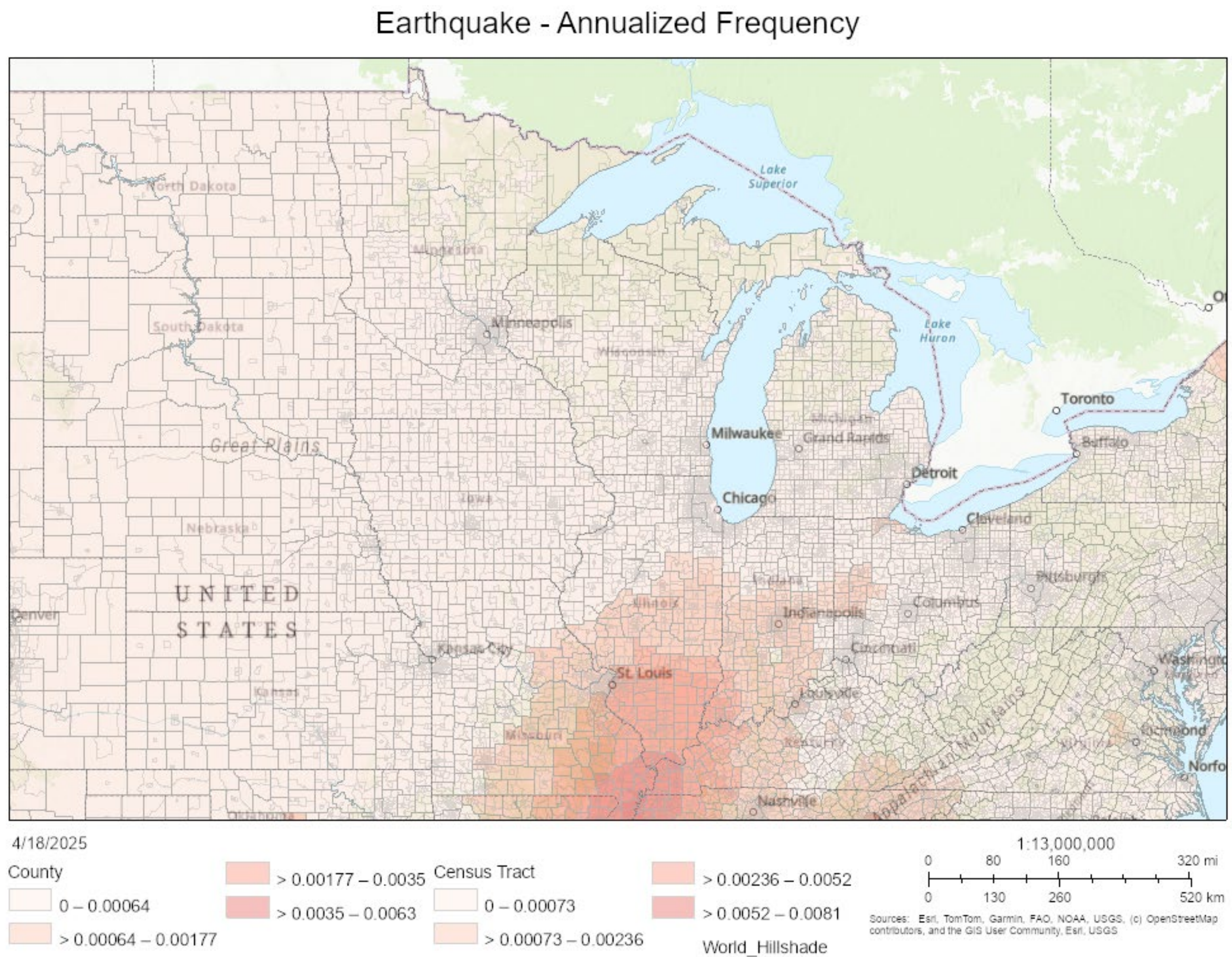

Figure 9: Annualized frequency of earthquakes (Source: FEMA/Esri).

Earthquakes occur with high frequency along the New Madrid fault line in southern Illinois, southwestern Indiana, western Kentucky, and southeastern Missouri.

National Center for Environmental Information

National Oceanic and Atmospheric Administration (NOAA)'s National Center for Environment Information documents major weather and climate disasters in the US that result in estimated damages of over $1 billion [9]. Termed 'billion-dollar' weather and climate disasters, these are events that resulted in total estimated damages/costs reaching or exceeding $1 billion each (CPI adjusted to 2024) in the United States. These include events such as the flooding in June 2024 of the Upper Midwest region with an estimated damage of $1.1 billion, as well as hurricane Katrina in 2005 that resulted in estimated damages exceeding $200 billion. According to recorded statistics, since 1980, the U.S. has sustained a total of 403 'billion-dollar' events to date, with a combined damage of $2.915 trillion (CPI adjusted). Figure 10 and Figure 11 show the number of "billion-dollar weather disaster" events seen in each state in the U.S. between 2008 and 2024 (the timeline used for historic hazard assessment in this report), and the estimated total cost associated with all events. Figure 12 shows a year-by-year timeline representation of recorded billion-dollar weather events across the entire US.

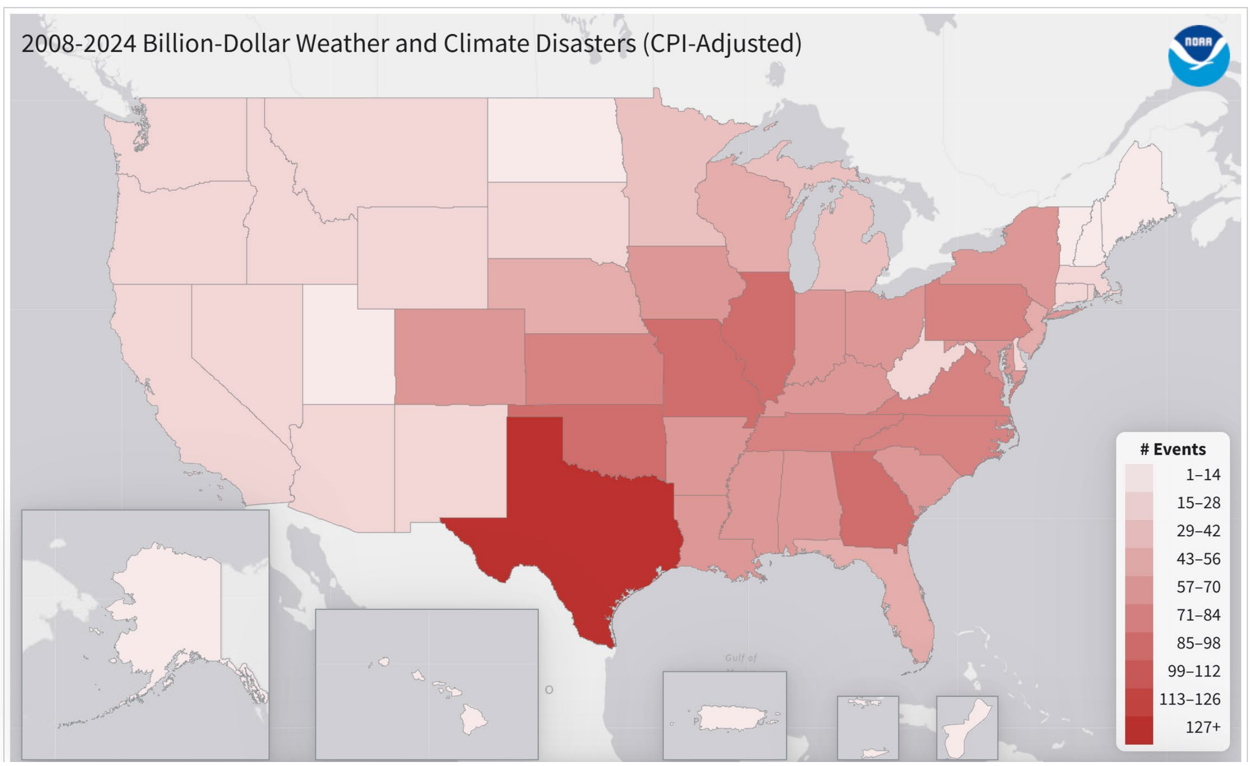

Figure 10: Number of billion-dollar weather disasters in US by state (Source: NOAA)

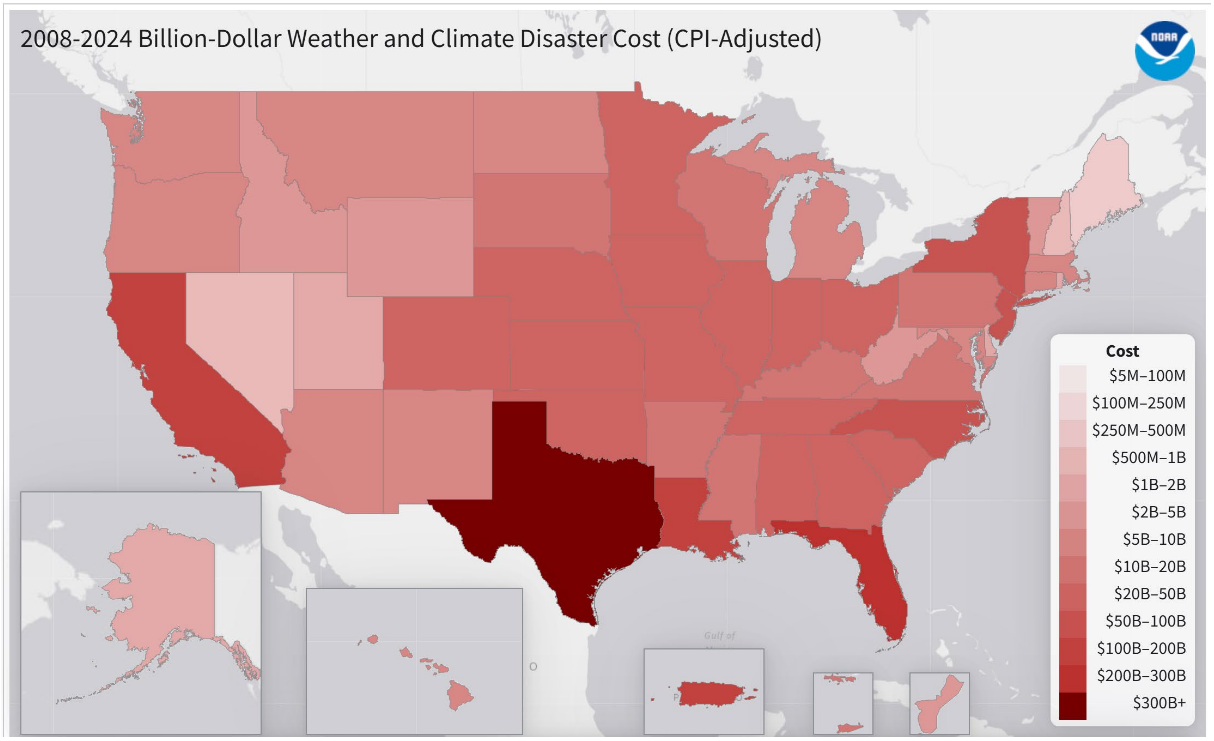

Figure 11: Total cost estimate for billion-dollar weather disasters in US by state (Source: NOAA)

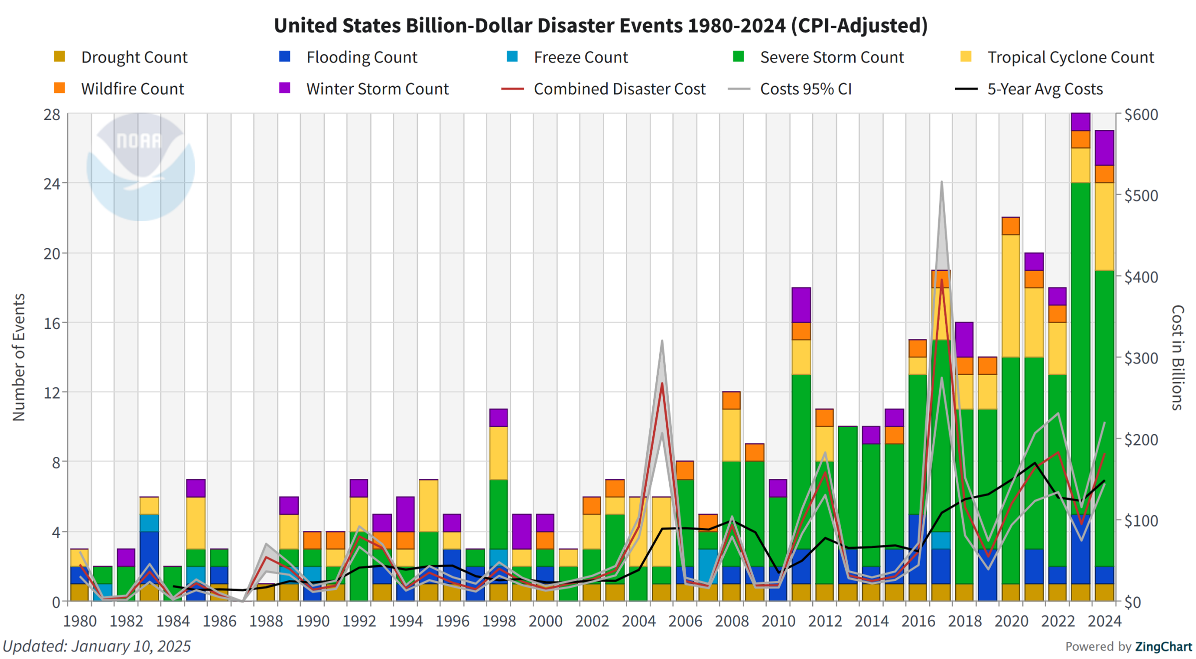

Figure 12: Year-to-year trend of billion-dollar weather disasters in the US (Source: NOAA)

State Agency Press Releases and News Agencies

State DOT press releases and a variety of news agency report archives provided a source of historic weather events that affected major freight corridors in the MAASTO region. All states in the region have news and press releases issued by the DOT accessible through their websites. Press releases and DOT updates corresponding to severe weather events typically mention geographical extent of impacts when an event makes a major corridor inaccessible. While news releases and updates are available for the current and last year through all state DOTs' websites, accessing archived items from past years is not possible for all states. Public access to archived press releases is available back to 2018 for Illinois and Kentucky, back to 2009 for Missouri, to 2008 for Iowa, and to 2006 for Kansas. In addition to state DOT press releases, news agency (local and state) reports were also searched for reporting of weather events that impacted the transportation network in each state. This was done through a combination of specific event searches for known major weather events in the region, searching for corridor specific keywords, and browsing major news outlet websites.

Assessment of Resources

An in-depth review of the data sources explored reveals the strengths and weaknesses of each source. FEMA has a comprehensive database of national disasters and other emergency declarations, providing a reliable source for disaster events, dates, regions affected, and mitigation efforts undertaken. While the database usually covers maps of geographical areas affected by the disaster, it does not typically cover information on transportation networks affected by the disaster. Further, since FEMA's role is to monitor national emergencies and declarations, it does not cover all weather event incidents that affect transportation corridors. For example, a flooding event that makes a bridge or a section of an interstate inaccessible would not result in a disaster declaration as the impact is localized and controlled and thus would not be archived by FEMA. State disaster management agencies also do not consistently carry records of historical hazard events in the state.

For the current study, state DOT press releases and news agency articles were found to be the most reliable sources for information on historic weather events and their impact on the freight transportation network. However, neither source consistently delivered all associated information in detail (such as exact dates for which the roadway was shut down, precise geographical coordinates for roadway shutdown extent, quantification of resulting damage to infrastructure, or delays/losses to freight movement due to re-routing required). Further, the data is scattered across multiple agencies, and with a lack of a singular comprehensive repository, there are possibilities of historic events being missed if they were not widely reported by major news outlets. These gaps in the data illustrate a need for systematically and consistently collecting hazard data when events impact transportation networks across the region.

4. HAZARD RANKING FRAMEWORK

Summary

This section presents hazard ranking framework developed to score and rank hazards on freight corridors based on severity and impact to freight movement. The presented ranking system is designed with a focus on freight movement on major multistate corridors, however it could be extended to state and local roadways where applicable as well. We present the ranking framework at two levels of detail: 1) a comprehensive model that accounts for all relevant factors to measure impact; and 2) a data-light model that can be used when information on impact measures are not reliably available. For historic hazard events, such as those collected for this study (presented in Section 5), the data-light model would be used. The intent and the vision, however, is that with improved uniform and systematic data archiving for hazards and their impacts on the freight transportation network, the comprehensive model can be used to score and rank hazard events and corridors going forward.

Factors

A corridor hazard ranking system should provide for scoring and ranking hazards relative to one another, as well as possibly ranking corridors based on historic impact from hazards that disrupt operation of the corridor. Such a system should reflect the impact of a hazard based on measures of severity and spatial and temporal extent of disruption to freight movement. For the ranking system presented, the following factors were considered.

Duration of Closure

The temporal extent of disruption to a corridor due to a hazard can be measured accurately through the duration (in number of days) for which the section of corridor impacted remained closed / inaccessible due to the hazard. This is a key factor for measuring the impact of any hazard event. For simplicity, the duration of impact is measured in number of days rounded up, where events that resulted in disruptions that lasted shorter than 24 hours being rounded to be a single day disruption. We use $t_{closure}$ to define the duration of closure in days.

Degree of Closure

Weather events, major crashes, and other hazards can disrupt roadway operation either due to completely shutting down sections of the corridor, or by causing partial closures (such as some but not all lanes needing to be closed). The degree of closure, $f_{closure}$, is also a key factor in measuring the impact of an event and is used as a scaling factor in our model. A factor (multiplier) value of 1 is used for complete closures and a factor of 0.5 is used for partial closures.

Average Delay Incurred

In addition to the duration of closure, average delays incurred, r_{delay}, due to rerouting, as a ratio of average trip time, should be estimated to arrive at accurate measures of impact on the value of freight movement. This measure reflects additional costs incurred due to delays in goods movement, as well as due to additional cost of travel (such as crew wages, and fuel).

Value of Freight Impacted

A key factor in determining the impact of a hazard event on freight movement in the region is measuring the value of freight impacted. Ideally, the impact should be measured in the form of added dollar-hours of freight movement due to detours / delays. However, due to the sensitivity of commercial data, such information is not readily available for public use. Instead, estimated average freight movement value for sections of the roadway (for example, using extrapolation of Freight Analysis Framework (FAF) data to quantify value of freight moved on freight corridors by GIS mapping origin-destination movement pairs to freight corridor the freight movement is likely to occur on; process described in [2]) can be used as a representative of impacted value of freight. $V_{freight}$ will represent the value of freight moving daily on the impacted corridor segment. The total impact can then be estimated as the product of duration of closure, estimated value of goods moved, and delays incurred.

Average Delay Incurred

In addition, average delays incurred due to rerouting of freight should be estimated to arrive at accurate measures of impact on value of freight movement. The total impact can then be estimated as the product of duration of closure, estimated value of goods moved, and delays incurred.

Average Number of Trucks Affected

In the absence of a reliable measure of average value of freight movement on the corridor segment, an alternative measure can be employed using the average number of trucks moving on the corridor instead. The product of delays due to detours, number of days of impact, and number of trucks affected each day would provide an estimate of total delay (in truck-minutes) incurred due to the hazard. This can then be converted to an estimated loss due to delays using industry cost of delay numbers. This measure can further be refined if expected extra distance travelled due to detour is known and is factored into the calculation. However, such a measure would not consider the type, volume, and value of freight being moved.

Damage to and Improvement of Infrastructure

In addition to the economic impact on freight movement caused due to disruptions to the freight transportation network, a severe weather event can also lead to substantial costs through repairs / replacement of transportation infrastructure damaged, as well as costs of improvements planned for mitigation efforts towards future hazards resiliency. The impacted infrastructure typically includes repairs / improvements to bridges, levees and other structures impacted, addition of new structures, repair / replacement required for roadway pavement, and costs for clearing debris / accumulated snow etc. as a direct result of a hazard. When accurate costs for repair and planned improvements are known, these might be used. When accurate costs are not known, an estimated approximate cost can be computed for the cost of repairs using an average cost of replacing a bridge structure. FHWA maintains estimates for cost per square foot for bridge replacements derived from average moneys spent in previous years for replacing structurally deficient bridges [10]. For a 2-lane roadway bridge over a 4-lane interstate, the average expected cost of bridge replacement using the FHWA averages amounts to roughly $3 million (based on 10,000 sq. ft. of replacement area). The estimated costs for repair, C_{repair}, and for improvement, $C_{improvement}$, can thus be computed as:

$$C_{repair} = \begin{cases} C_{repair}, & if\ cost\ is\ known \\ N_{struct} * C_{avg_{repair}} * d_f, & if\ cost\ is\ estimated \end{cases}$$

$$C_{improvement} = \begin{cases} C_{improvement}, & if\ known \\ 0, & if\ unknown \end{cases}$$

where,

N_{struct} is the number of structures damaged, $C_{avg_{repair}} = \$3\ million$ is the average estimated cost of replacing one bridge structure, and d_f is a damage severity factor to determine the fraction of the cost of replacing being attributed to damage due to the hazard event and can be assumed to be 1 when no other information is available.

Comprehensive Scoring Framework

Using quantified representation of impact factors discussed above, a hazard impact score can be developed for each hazard event. This score reflects the estimated cost of a hazard event on the corridor. The hazard impact score, I_{hazz}, can be calculated as:

$$I_{hazz} = (t_{closure} * f_{closure} * r_{delay} * V_{freight}) + C_{repair} + C_{improvement}$$

The hazard scores for all hazard events impacting a corridor over a five-year period can be aggregated to generate a corridor hazard impact score. This score reflects the estimated cost of all hazard events on a corridor over the period considered. The corridor hazard impact score, I_{corr}, can be calculated as:

$$I_{corr} = \sum I_{hazz}$$

Data-Light Scoring Framework

As stated earlier, scoring and ranking hazards / corridors for hazard resiliency is challenging for historic hazards due to data limitations in this study. Data on the delays caused due to corridor closures was not available for any recorded historic event, data on the damage to structures and pavements was only available in some cases and the estimated value of freight moved are available for only a single year and does not scale with time. Due to these limitations, a simplified data-light version of hazard and corridor impact scores formulation was also developed and used. The data-light hazard impact score, I'_{hazz}, is computed as:

$$I'_{hazz} = (t_{closure} * f_{closure} * V'_{freight}) + C'_{repair}$$

where, $V'_{freight}$ is the estimate value of freight on corridor section based on the FAF data compiled in [2] (MAFC #18 quantifies value of freight moved by corridor sections), and C'_{repair} is the cost of repair estimated for only those events where information was available.

Similarly, the data-light corridor impact score is calculated as:

$$I'_{corr} = \sum I'_{hazz}$$

It is important to stress that these calculations should be taken in context of data availability issues and with the understanding that there could be discrepancies in impact comparisons between events where structural damage information was or was not available.

Corridor	Year	State	Counties	Impact Score
I-29	2019	IA	Mills, Pottawattamie, Fremont	180
I-29	2019	MO	Atchinson, Andrew	126
I-70	2020	IN	Hendricks	60
I-65	2015	IN	Boone	56
I-94	2021	MI	Wayne	49
I-90	2008	WI	Sauk	30

Table 6: Hazards with the highest impact score (with corridor, year and county). (Source: MAFC)

Based on the data light methodology, impact scores were computed for each historic road closure event studied (see Section 5 of the report). Scenarios where a single event caused closures across multiple states were treated on a per state basis to account for differences in repair expenditures. Scenarios where multiple non-contiguous sections of a roadway were closed in a single state due to the same hazard event were combined as impact of a single hazard event.

Table 6 shows the top five ranked hazard events on the study corridor during the study period. The 2019 flooding of the Missouri-Platte Rivers that closed I-29 in Iowa and Missouri scored highest and second highest respectively on impact score. In Iowa, a larger section of I-29 was flooded, and the reported repair costs were more than $30 million [11]. The cost of damages in Missouri due to the flooding was also estimated to be over $29 million across the state; however, this was distributed across multiple highways and the best available estimate for repairs on I-29 was $6 million [12]. 5 of the 6 highest impact score hazards were direct results of flooding events. The I-70 closure was due to extensive bridge repair undertakings.

5. HAZARD ASSESSMENT FOR STUDY CORRIDORS

Summary of Hazards on Study Corridors

A total of 78 hazard-impacted locations were identified along study corridors, covering the period from 2008 to 2024. This covers incidents that resulted in closure of a portion of the freeway for at least 1 day. If a single weather event (such as flooding of a river) resulted in multiple closures along a corridor, each closure was recorded independently and thus the number of hazardous weather events would be smaller than the number of reported impact locations.

Figure 13 through Figure 16 identify the recorded historic events that affected the study corridors. The data includes the number of closures, cause of corridor closure, duration of impact on the corridor, and extent of closure caused respectively. I-70, which spans across Kansas, Illinois, Missouri, Indiana, and Ohio, has seen the highest number of recorded events. These closures resulted from a mix of causes, including flooding and snow / winter weather. More than two-thirds of all events impacting the study corridors were flooding events. Storms, heavy snowfall, and tornadoes made up the rest of weather event related disruptions. 11 percent of closure incidents were attributed to major crashes; these were often caused by severe weather conditions.

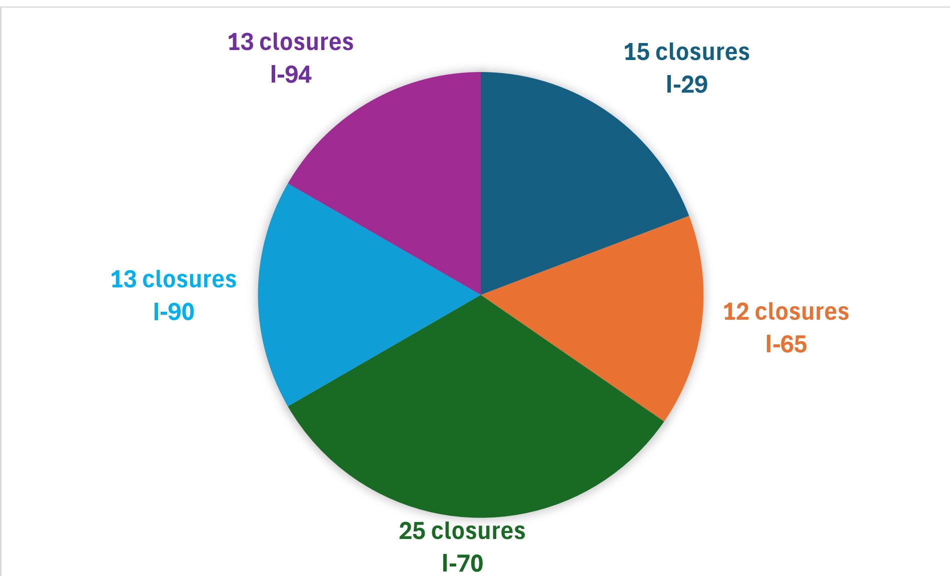

Figure 13: Number of closures by corridor. (Source: MAFC)

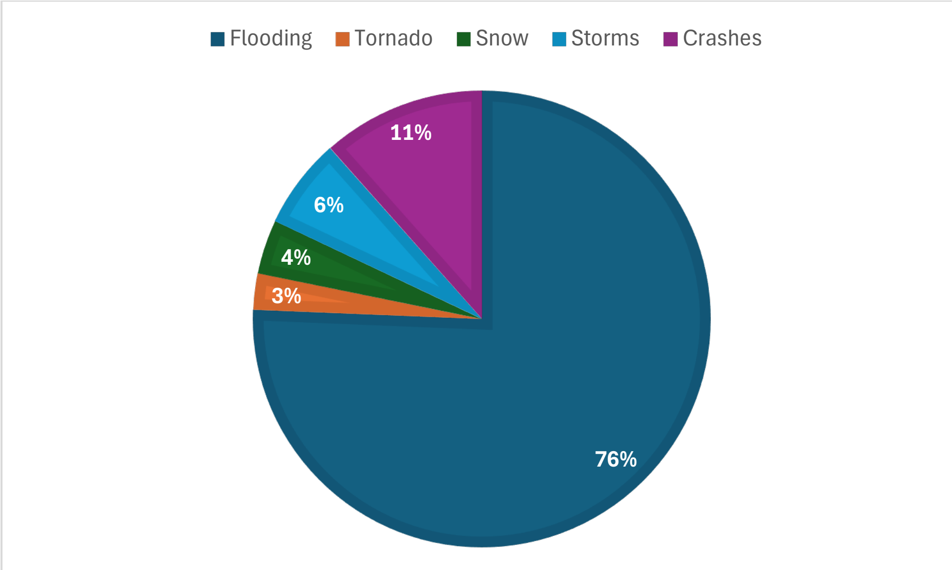

Figure 14: Split of closure events by cause. (Source: MAFC)

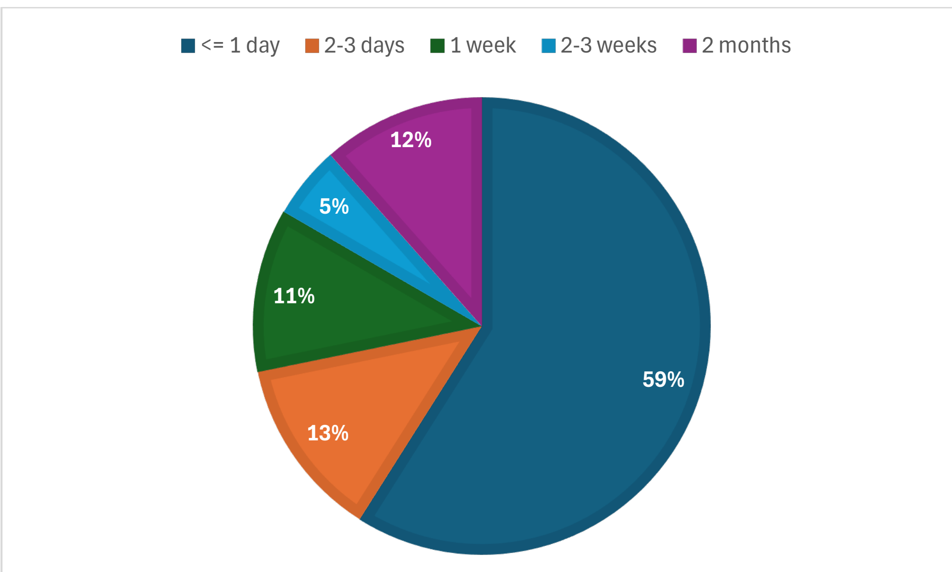

Figure 15: Distribution of closure events by duration of impact on corridors. (Source: MAFC)

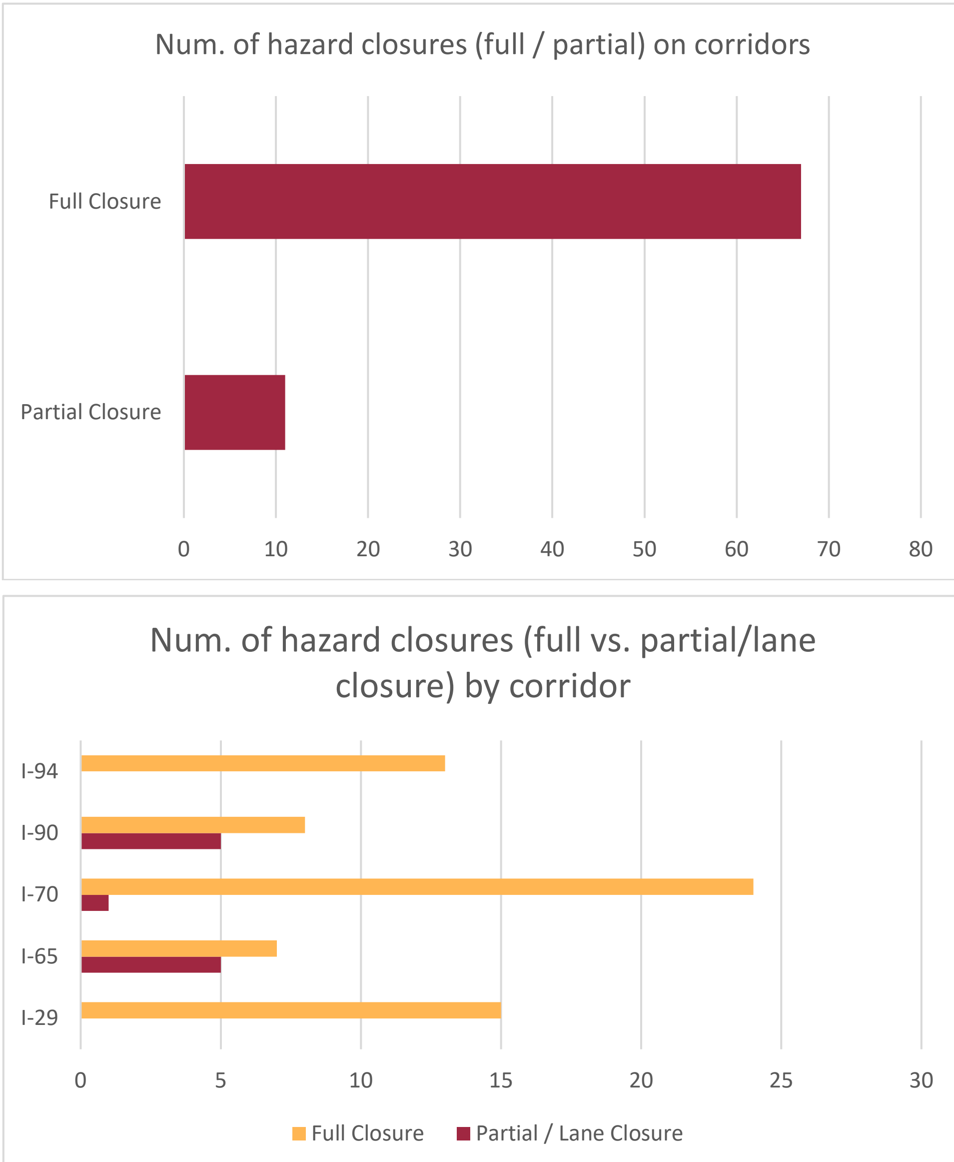

Figure 16: Number of hazard closures, either full or partial / lane closure. Top: across all 5 corridors; and Bottom: by corridor. (Source: MAFC)

Maps

This section presents GIS mapping for hazards that led to road closures on the studied corridors in the last 15 years. In addition to showing timeline / recency of hazards (Figure 17), the duration of impact of weather event is also explored (Figure 18). Each marker on the map represents a key access point (entry or exit ramp) to the freeway that was affected due to a weather event. Point markers instead of line markers were used to map the events due to gaps in for accurate spatial information for a large portion of the events set, where only an entry ramp or a town / region was reported.

As can be seen from Figure 18, I-29 is the most severly impacted corridor studied. The two major flooding events on I-29 each resulted in large portions of the highway staying inoperational for multiple months. Interestingly, this is not obvious from looking at the flood risk map in Figure 21. Outside of floods on I-29, there were other flooding related roadway closures as well (including flash floods). These were typically cleared out in a day. There were some instances where bridge/structure damage led to longer shutdowns.

Figure 19 below illustrates how many of the mapped events were related to flooding incidents (riverfloods and levee failures as well as flash floods). All other instances (including those due to blizzards, storms, tornadoes, snowstorms and crashes resulting from such events) are marked in red in the map.

Figure 17: Road closures by timeline of occurrence. (Source: MAFC)

Figure 18: Road closures by duration of impact. (Source: MAFC)

Figure 19: Road closures by cause. (flooding vs. other) (Source: MAFC)

Study Corridor Assessments

The following sections further discuss the major hazards recorded on each corridor. An analysis of the impact of hazards on I-29 is further presented. This detailed analysis was possible due to the availability of detailed data for the 2019 flooding of I-29, details that were not available for the remaining corridors studied.

As noted in Section 4, hazard impact can be quantified if data is available for delays incurred due to roadway closure, duration of closure, and volume / value of freight impacted. While durations of closures were available for all events studied, and value of freight was estimated through a previous MAFC study, data on delays due to detours was not readily available, except in the case of the 2019 floodings affecting I-29. Thus, the estimated impacts for major events presented will differ from the analysis for I-29.

In the case of the 2019 flooding, the analysis presented uses estimates for delays due to known official detours, average truck volumes on affected portions of I-29 (AADT), and duration of closure, to calculate the estimated total hours of truck delays incurred. This total delay is multiplied by industry accepted national average cost of delay for trucks to estimate the total cost of delays due to the closure (details of the analysis are presented under I-29 analysis below).

For the other corridors (I-65, I-70, I-90, and I-94), a more rudimentary analysis of the event with highest impact (see Table 6) is presented in each case. This analysis uses the value of freight moved daily on the corridor (Figure 1), and duration of closure to estimate total value of freight affected due to the hazard, and scales it by a delay impact multiplier (representing likely costs due to delays) to obtain an overall hazard impact score. A similar analysis as that for I-29 could be performed using AADT and delays due to detours if such data was available for these 4 corridors.

For this analysis, we use delay impact multiplier as a range from 0.03 to 0.1 (additional cost due to delays as between 0.3% and 1% of value of freight moved). Due to lack of better data on the subject, this range is obtained from estimated overall costs due to congestion across US as a ratio of value of goods moved. The total value of freight moved on trucks in the US in 2022 was estimated to be $13.6 trillion [13]. The corresponding estimated trucking annual congestion cost for 2022 was $108.8 billion [14]. Using these numbers, the delay due to congestion across all truck freight in the country was a factor of 0.008 with respect to value of goods moved. This provides a starting basis for estimating the delay impact multiplier. Note that the national congestion cost factor (0.008) computed accounts for all congestion delays through entire truck trips and can include multiple bottlenecks along a single trip. Furthermore, the cost due to delays should not only include the cost to the trucking industry, but also additional costs for warehousing, storage times for goods, spoilage when applicable etc. Therefore, the delay impact multiplier used in this study should be taken as a rudimentary estimate and not with a high degree of confidence, and efforts should be undertaken to study this factor in further detail.

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I-29

States impacted and approximate length of highway in each state (in miles):
MO 129, IA 152

I-29 runs N-S connecting the US-Canada border in North Dakota to Kansas City, traversing through Iowa and Missouri in the MAASTO region. With a majority of the interstate running through large floodplains of the Missouri and Platte Rivers, I-29 has seen frequent closures due to flooding over the past years. Additionally, the interstate has also undergone multiple scheduled closures for repair of damages, especially to bridges and structures, from flooding incidents.

A major flooding closure of I-29 occurred in early 2019 with nearly 200 miles of highway being shut down in both directions in Iowa and Missouri for over two months. The 2023 Iowa Statewide Levee Assessment Annual Report estimates that the 2019 I-29 closure resulted in $700 million in lost economic impact to the state. Prior to this, a large portion of I-29 in Iowa and parts of the highway in Missouri were closed for multiple months due to the Missouri River flooding of 2011.

I-29 is the most severly impacted corridor of this study. However, because this corridor is predominantly located within a large floodplain area, it is important to note that this corridor is considered to be an outlier for this reason. Additionally, due to the magnitude of flooding, there was considerably more data available for analysis of this corridor than the other routes. While this route is distinguishable from the other routes selected, this analysis offers key insights into the overarching costs that states can face for such multistate corridors.

The 2019 midwestern U.S. floods were major weather events in 2019. Regions along the Missouri River and its tributary system were flooded in Iowa, Missouri, Nebraska, South Dakota and Kansas, and impacts of the floods were also felt in Illinois and North Dakota. According to NOAA, the Missouri River flooding resulted in over $13 billion worth of damages (adjusted to 2024 dollars), and loss of three lives, making it one of the costliest U.S. inland flooding events on record [9]. Figure 24 shows the extent of the flooding captured through the Landsat satellite by U.S. Geological Survey (USGS) [15]. The flood events in spring 2019 were followed by further flooding in May and in September of 2019, and with flooding of the Mississippi and Ohio rivers as well.

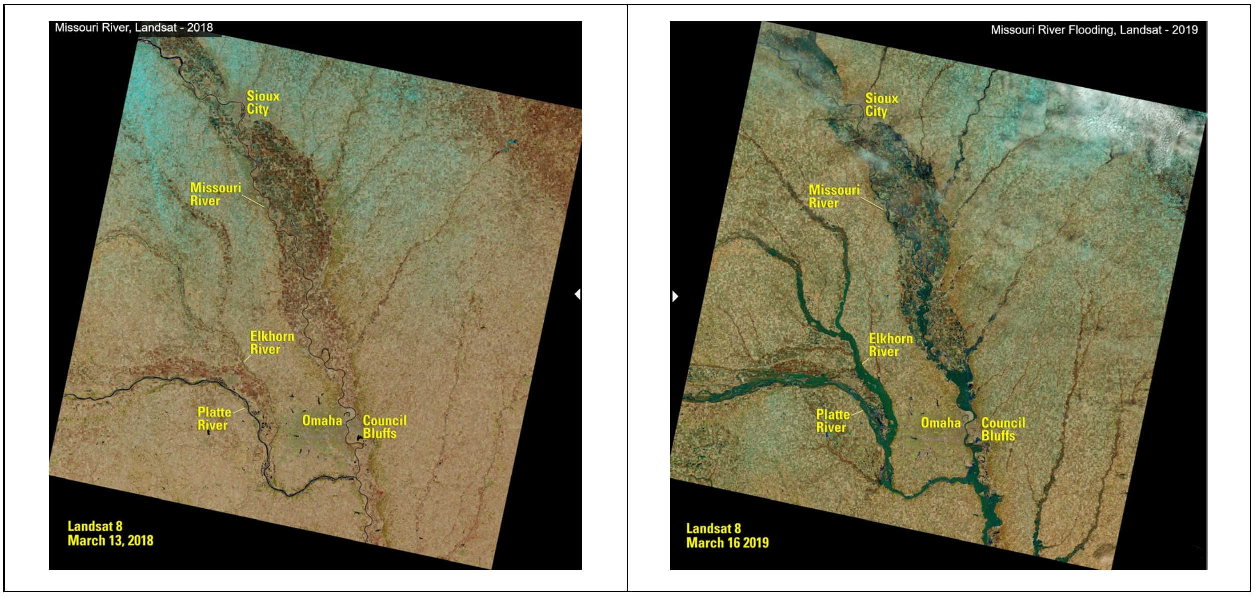

Figure 20: Landsat satellite images of the Missouri River between Sioux City and Omaha before, and after the 2019 flood (Source: USGS [15]).

The floodings had a severe impact on operations along I-29 in Iowa and Missouri (as well as in North and South Dakota). Nearly 200 miles of the I-29 roadway was affected for a period starting on March 14, 2019, and spanning into October of 2019. In Iowa, major parts of the highway remained closed for over 100 days.

Detours for I-29

Official closures and detours used for I-29 in Iowa during the flooding period were requested from and provided by Iowa DOT. The following summarizes the detour information obtained:

North of Omaha-Council Bluffs metro - I-29 from Exit 61 (I-680) to Exit 71 (I-880)

This section closed on four separate occasions for a total of 100 days. During closure, traffic was directed to I-80 and I-880 instead. Due to I-680 also getting affected by the flooding, traffic on I-29 coming from/heading towards I-680 was also diverted through US-30 and US-75.

The periods of closure for the section were:

1. 65 days from March 14 to May 18, 2019.
2. 20 days from May 28 to June 17, 2019.
3. 14 days from September 20 to October 4, 2019.
4. 1 day from October 6 to October 7, 2019.

South of Omaha-Council Bluffs metro - I-29 from Exit 35 (US-34) to the Iowa-Missouri border.

This section was closed for a total of 74 days between March and June of 2019. During this period, a combination of various roadways acted as detour for this section of I-29 depending on flooding closure status of these alternate routes. Detours included use of US-34, US-275, US-59, US-71, US-136, IA-2, and US-75. The two periods of closure for the section were:

1. 54 days from March 15 to May 8, 2019
2. 20 days from May 29 to June 18, 2019.

The primary detour for I-29 south was through US-34 and US-275 while IA-2 was open, through US-24, US-59, and US-136 when IA-2 was closed, and through US-34 and US-71 when US-136 was closed. US-75 was also used by many operators as an unofficial detour.

Delay and Cost of Delay Estimation

Due to lack of detailed data, there were several assumptions made while estimating the additional travel time (delay) and travel distance incurred due to the flooding on I-29 for the affected periods. First, the estimation assumes current free flow travel times (based on posted speed limits on roadways involved) to estimate additional delays. The detouring traffic would have impacted congestion at the interchanges, ramps, and roadways involved due to additional volumes being services on these facilities, but the impact is not known. Further, AADT volumes on I-29 in 2019 are used to estimate the number of freight vehicles impacted by the I-29 closures. The AADT data was also provided by Iowa DOT. However, because AADT volumes are annual average daily volumes, variations such as seasonality, day-of-week, and time-of-day are not captured accurately, and neither are any changes in traffic demand due to the flooding itself. Additionally, the weight and value of commodity transported, type of commodity transported, configuration of truck, which are other factors that may affect the costs associated with the delay incurred, are not included in this analysis.

Acknowledging and incorporating the aforementioned data limitations, the cost of delay used in this analysis is estimated to be $64.68 per vehicle hour (based on the 2023 Urban Mobility Report [16]). The estimated average delay incurred by a truck (additional time due to detour) is multiplied by AADT to estimate daily truck delay for a closure. This is then multiplied by the number of days of closure to obtain the estimated total delay incurred over the period of closure. This estimated total delay over the period of closure (in vehicle-hours) is multiplied by the industry average cost of delay per vehicle per hour to obtain the estimated cost of delay due to the closure. The total additional truck miles traveled is also calculated as a product of the estimated additional miles due to detour, the AADT, and the duration of closure.

North of Omaha-Council Bluffs

The detour through I-80 – I-880 required northbound vehicles to exit at Exit 51 (just south of Council Bluffs) on to I-80 E, switch to I-880 W and merge back into I-29 N, with an equivalent detour in the opposite direction for southbound vehicles. The detour resulted in traffic bypassing a roughly 23-mile flood affected section of I-29 and taking a 40-mile detour through a combination of I-80 and I-880, adding 17 miles of travelled distance. The detour adds an additional 14 mins of travel time (36-40 mins compared to 22-26 mins).

Table 7 provides a summary of the estimated delay incurred, additional vehicle-miles and the cost of delay for the section of I-29 north of Council Bluffs. Closure of this section resulted in an estimated cost of $9.60 million for freight movement during the affected period due to additional delays incurred. This corresponds to roughly 148 thousand additional vehicle hours and 10.17 million additional vehicle-miles travelled.

Detour	I-80 and I-880
Estimated Average Delay (per truck)	14 minutes
Estimated Additional Distance (per truck)	16 miles
Average No. of trucks affected per day (AADT)	3200 N, 3160 S
Estimated Total Delay (vehicle-hours)	148,400
Estimated total additional truck-miles traveled (vehicle-miles)	10.17 million
Estimated Cost of Delay ($)	$9.60 million

Table 7: Summary of estimated delay and cost of delay for I-29 north of Council Bluffs (Source: MAFC).

South of Omaha-Council Bluffs

The initial detour posted on March 15th for I-20 south of Council Bluffs was through I-35 from Kansas City, MO to I-80 in Des Moines, and merging back onto I-29. This would have been a nearly 100-mile detour (301 miles total compared to 206 miles on I-29), with an additional travel time of 70 minutes. However, the detours were updated to US-34 to either US-275, US-59 and US-136, or US-71 depending on the extent of flooding and impact on other roadways. The shorter detour, Exit 35 on to US-34, transfer to US-275 and merge back onto I-29 was available when IA-2 and US-275 were not affected. When IA-2 was shut down, the detour changed from using US-275, to US-59 further to the east. This detour required vehicles to take US-34 to US-59 to US-136 and back on to I-29. When US-136 was also affected by the flood, a longer detour was used that routed through US-34 to US-71 and merged back to I-29 in Missouri.

Detour	US-34, US-275	US-34, US-59, US-136	US-34, US-71
Estimated Average Delay (per truck)	22 mins	30 mins	42 mins
Estimated Additional Distance (per truck)	9.7 miles	15.0 miles	23.1 miles
Average No. of trucks affected per day (AADT)		3800 NB, 3850 SB	
Estimated Total Delay (vehicle-hours)		305,235	
Estimated total additional truck-miles traveled (vehicle-miles)		8.37 million	
Estimated Cost of Delay ($)		$19.74 million	

Table 8: Summary of estimated delay and cost of delay for I-29 south of Council Bluffs (Source: MAFC).

Table 8 provides a summary of the estimated delay incurred, additional vehicle-miles and the cost of delay for the section of I-29 south of Council Bluffs. The closure of this section resulted in an estimated cost of $19.74 million for freight movement during the affected period due to additional delays incurred. This corresponds to over 305 thousand additional vehicle hours and 8.37 million additional vehicle-miles travelled.

This analysis using AADT and average cost of delay to trucking puts the cost of delays near the Omaha-Council Bluffs metro at a total of $29.34 million. This does not include delays due to closures on other parts of I-29, and does not include costs due to warehousing, spoilage etc., nor does it include costs for damages to structures.

In contrast, using value of goods moved on corridor as the approach to quantify impact of closure, we arrive at a conservative estimate of impact score ranging from 45 to 150 (delay impact multiplier 0.003 to 0.01) without accounting for cost of repairs, or 75 to 180 including cost of repairs. This translates to a conservative estimated cost of $45 million on the low end not including cost of repairs, up to a total estimated cost of $180 million with repair costs included and with higher delay impact multiplier.

I-65

States impacted and approximate length of highway in each state (in miles):
KY 137, IN 261

I-65 is a major N-S interstate and of special interest to freight as it connects the Great Lakes to the Gulf of Mexico. In the MAASTO region, it is a major N-S corridor for Indiana and Kentucky.

I-65 has had some shutdowns due to crashes as well as flash flooding. In each instance, the impact was typically contained within a few miles and was cleared relatively quickly (within a day). Flooding events that led to closure of the interstate have been primarily localized to the segment of I-65 between Indianapolis, Indiana and Louisville, Kentucky.

One exception was a flooding event in 2015 near Lebanon, in Boone County, northwest of Indianapolis that resulted in parts of I-65 being inaccessible for nearly two weeks. This was the weather event of highest estimated impact to freight movement on the corridor for the study period (Table 6). Freight movement on the section of I-65 impacted is estimated to be nearly $400 million in value. This freight was impacted for 14 days of full closure on I-65. Using a delay impact multiplier range of 0.003 to 0.01, the impact score for the event is estimated to be between 16.8 and 56. This translates to a conservative estimated cost of $16.8 million, up to $56 million in impact to freight movement due to the closure.

I-70

States impacted and approximate length of highway in each state (in miles):
KS 424, MO 250, IL 156, IN 157, OH 226

Another major E-W interstate, I-70, runs from Utah to I-695 in Maryland. In the MAASTO region, I-70 runs across the state of Kansas, continuing through Missouri, Illinois, Indiana, and Ohio. It is a critical freight corridor for multiple states in the region.

Most I-70 shutdowns in Kansas in the past 15 years were due to winter storms and blizzards (especially in 2019), either due to deteriorating conditions or due to an accident resulting from inclement weather. In Missouri and Illinois, I-70 has been shut down multiple times near St. Louis due to flooding events. There were also similar localized shutdowns in Indiana (Putnam and Clay Counties in 2008; near Indianapolis in 2024), near Hebron (Licking County), Ohio (2017), and around Columbus, Ohio (2024). The 2017 closure in Indiana lasted for nearly a full week while the interstate was re-opened within a day in all other cases.

The closure event of highest estimated impact to freight movement on I-70 for the study period (Table 6) was a closure in 2020 in Indiana for extensive bridge repair and maintenance work. Freight movement on the I-70 section impacted is estimated to be $300 million in value. With a closure duration of roughly 20 days and using a delay impact multiplier of 0.003 to 0.01, the impact score for the event was estimated to be between 18 and 60. This translates to a conservative estimated cost of $18 million up to $60 million in impact to freight movement due to the closure.

I-90

States impacted and approximate length of highway in each state (in miles):
MN 276, WI 187, IL 124, IN 156, OH 245

I-90 is a major E-W Interstate Highway that runs through the states of Minnesota, Wisconsin, Illinois, Indiana, and Ohio. In Wisconsin, I-90 shares a large portion of its length with I-94. I-90 and I-94 are also concurrent for a portion in Illinois near Chicago. For the length where I-90 and I-94 are concurrent, the report will not repeat hazard instances under I-94 to avoid duplication.

I-90 has seen flooding related closures multiple times in the past fifteen years. In 2008 and in 2018, the Baraboo River (Sauk and Columbia Counties) near Portage and the Lemonweir River (Monroe County) near New Lisbon and Mauston flooded, causing closures (partial and full) in Wisconsin. The flooding in 2008 resulted in closure for three days while the one in 2018 was cleared within two days. In 2024, parts of I-90 were closed due to flooding in southern Minnesota for a day. While I-90 has not been closed due to flooding in Illinois in recent years, it has been affected by access roads getting flooded leading to exits and entries being inaccessible. Flooding related delays have also been seen across I-90 through other states in the MAASTO region as well.

The 2008 flooding related closure on I-90 in Sauk county registered the highest impact score in the study for the corridor (Table 6). The section of I-90 impacted is of high importance for freight movement with an estimated value of freight at $1 trillion. While the closure only lasted for 3 days, the impact score was estimated to be between 9 and 30, due to the high value of the corridor to freight. This translates to a conservative estimated cost of $9 million, up to $30 million in impact to freight movement due to the closure.

I-94

States impacted and approximate length of highway in each state (in miles):
MN 259, WI 341, IL 62, IN 46, MI 275

I-94 is another E-W interstate that runs through the states of Minnesota, Wisconsin, Illinois, Indiana, and Michigan in the region. In Wisconsin, I-94 runs concurrent with I-90 for a large fraction of its length, between Madison and Tomah. I-94 also merges with I-90 in Chicago and in Lake Station, Indiana. On the west, I-94 connects into I-90 at its terminus in Montana, through North Dakota, and on the east, I-94 connects Michigan to Canada (Ontario highway 402) after converging with I-69.

I-94 saw occasional flooding near Detroit, Michigan (in June of 2021 and August of 2024), and Jefferson County, Wisconsin along the Rock River near Johnson Creek (2008), and in Waukesha County, Wisconsin near Pewaukee Lake (2022). The flooding near Detroit has closed parts of the Interstate for long periods (two weeks in 2021; one week in 2024), while the 2008 closure in Wisconsin lasted for three days. The flooding in 2022 only affected operations on the highway for a day. As noted earlier, where it connects with I-90, the roadway is more susceptible to flooding near Portage, WI.

The flooding in 2021 near Detroit which resulted in parts of I-94 being shut down for two weeks, was the event with the highest impact to freight based on this study for the corridor (Table 6). This section of I-94 is estimated to be valued at nearly $400 million value of goods moved. The impact score, using a delay impact multiplier range of 0.003 to 0.01, was estimated to be between 14.7 and 49. This translates to an estimated cost of between $14.7 million and $49 million to freight movement due to the closure.

6. CONCLUDING REMARKS

This project provides an all-hazards assessment for a selection of major multistate corridors within the MAASTO region. The report provides a summary of resources available for hazard analysis on regional corridors and documents and maps historic hazards on a selection of five multistate corridors: I-90, I-94, I-70, I-65, and I-29. An analysis of estimated costs incurred due to a major closure on each corridor is also presented, with a detailed analysis for the I-29 closure in 2019 where more data was collected due to the magnitude of the flooding event. The report further proposes hazard scoring and ranking systems to reflect potential impact of hazards to multistate freight movement.

Apart from a few events, and with the exception of I-29, the study corridors currently show relatively high resilience to adverse weather events, with only three weather events over the past 25 years causing a section of roadway to be rendered inaccessible for longer than a week. It should be highlighted here that the corridors selected were chosen due to their status as Interstate Highways and as major freight corridors in the region in terms of tonnage and value of goods moved, and thus, in terms of contribution to economy for the region. This would usually translate to more infrastructure investments and maintenance services and thus contribute to high resiliency.

It is noteworthy that even though the corridors have not had frequent closures due to hazards, any closure of significant duration (>1 day) on these corridors can result in substantial costs of delay within the context of freight movement. In the case of the I-29 closure due to the 2019 floods, due to the long duration of impact, conservative estimates of costs incurred to freight movement was as high as $45 million, with an additional $30 million spent in repairs to structures. It is also important to note that the volume and value of freight moved on the corridor plays an integral role in the overall cost of delay calculation, as illustrated by the I-90 event in 2008 where a mere three days saw a conservative estimated cost of delay of $9 million that nearly approached the two week (14 days) cost of delay on I-94, which was conservatively estimated to be $14.7 million.

This study finds that there is a need for collecting, tracking, and evaluating consistent and detailed hazard impact data for multistate corridors. For a better all-hazards assessment on multistate corridors, the MAASTO states should advocate for improved monitoring and record keeping at state and regional levels. These efforts should capture impacts due to severe adverse weather events, damage caused, delays incurred due to corridors being closed, as well as costs for improvements planned to mitigate future impacts. States should consider maintaining a repository of weather events and accidents that result in closures on major corridors. For each event, a listing of corridors impacted (corridor or lane closures), date and durations for when each affected roadway section was closed and reopened (with complete geolocation information), and corresponding detours posted could be maintained. For corridors where sections are affected across state borders, a collaborative effort could be made to make detour and closure information within the state as well as across the border available. In addition, where possible, estimates for peak and non-peak traffic volumes and delays due to closures and detours linked to closure events would be very helpful for an all-hazards impact analysis. All states consistently tagging DOT press releases with keywords for hazards (such as flooding, or snow closure etc.) and allowing filtering of results by tags could also prove to be useful for such a study in future.

While only 5 corridors were used for mapping historic hazards in the region, based on a variety of selection criteria, we would note that the findings should be considered as applicable to other corridors of similar value in the region when they share similar susceptibility to hazard events. For example, findings from I-90/I-94 may be applicable to a majority of I-80 as well with the two roadways carrying comparable freight traffic and similar infrastructure. Sections of I-80 (and I-680/I-880) have similar susceptibility (though for a shorter stretch) to flooding as I-29, and a detailed analysis of flooding impact in the region would benefit from inclusion of I-80. Similarly, findings from I-65 could be used towards understanding hazard impact on I-75 as well. Also of note is that the number of historic hazards with significant closure (more than half a day) recorded on all candidate corridors was relatively similar, suggesting similar level of susceptibility to failure due to hazards.

The study also illustrates the need for future advanced hazard analysis efforts for corridors especially prone to disruptions due to extreme weather events. I-29 is a great example of such a corridor, which may benefit from a more in-depth investigation of the highway's resiliency to a future flooding event. The lessons learned and infrastructure improvements implemented as a result of the 2019 flooding could provide valuable guidance as a case study for other regions across U.S. that reside in major floodplain regions as well. Resiliency studies along multistate corridors should further include analysis of alternate routes that can be used to divert important freight movement on local roads that are able to accommodate freight when major corridors are impacted due to hazards.

The MAASTO Operations Committee, Subcommittee on Highway Transport (SCOHT), and the Motor Carrier Committee (MCC) should consider increased multistate communication during disasters to ensure continuity of major multistate freight corridors. State resiliency plans should also consider the addition of multistate corridor hazard assessments for major corridors shared with other states.

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8. APPENDIX A – NATIONAL RISK INDEX (NRI) MAPS

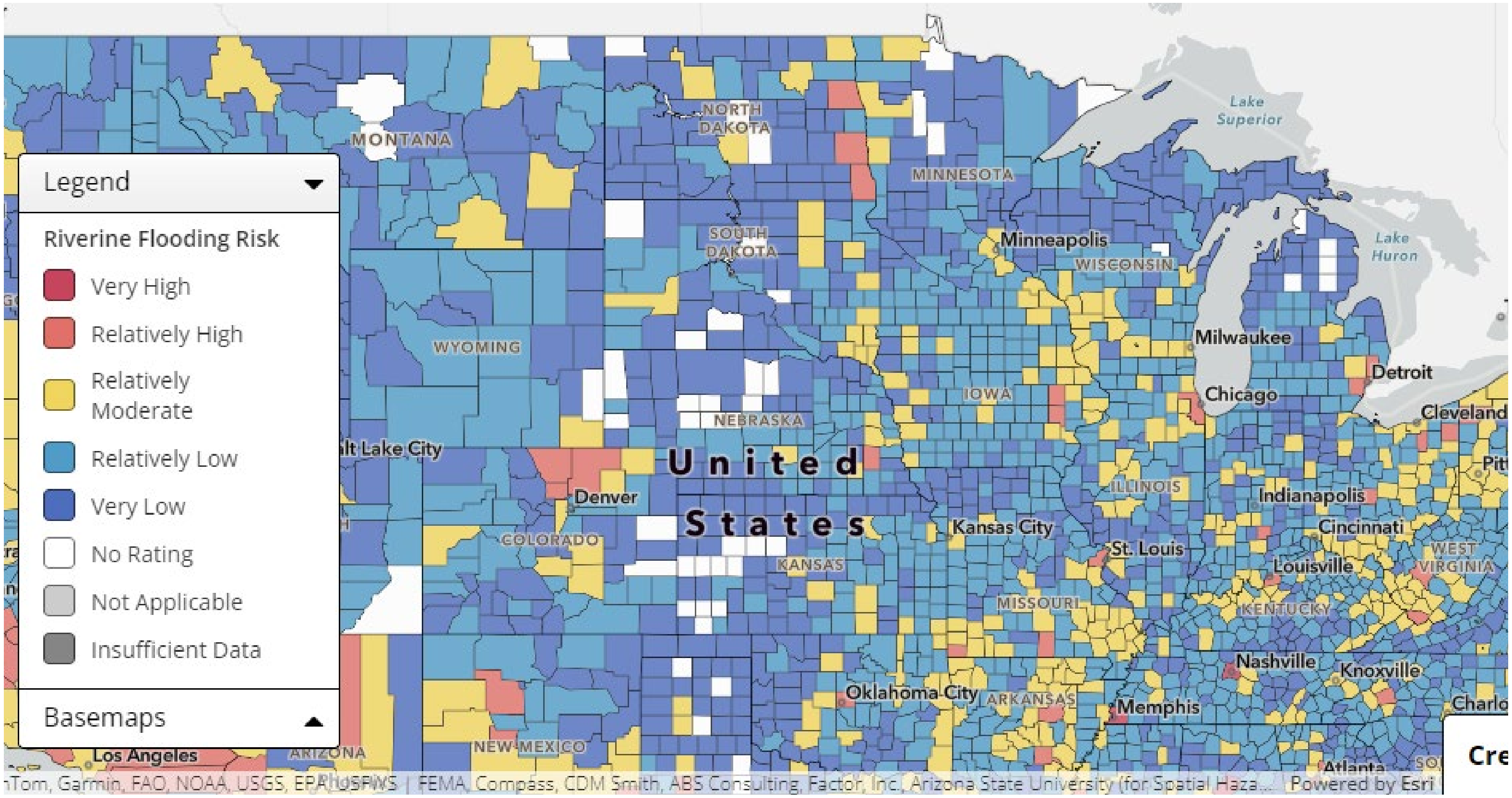

Figure 21: National Risk Index for river flooding risk (Source: FEMA)

For river flooding risk, the elevated NRI is seen along the Mississippi river basin along the Minnesota and Iowa borders with Wisconsin and Illinois, along the Missouri-Platte floodplains in the western parts of Iowa and Missouri, along the Ohio river basin, and in southeastern Missouri near the confluence of the Missouri, Mississippi and Ohio rivers. The Missouri-Platte floodplains, shown at relatively moderate risk here, have been the site of the 2 most severe weather-based closures (I-29 and multiple other neighboring roadways) in the past 15 years as noted in the report.

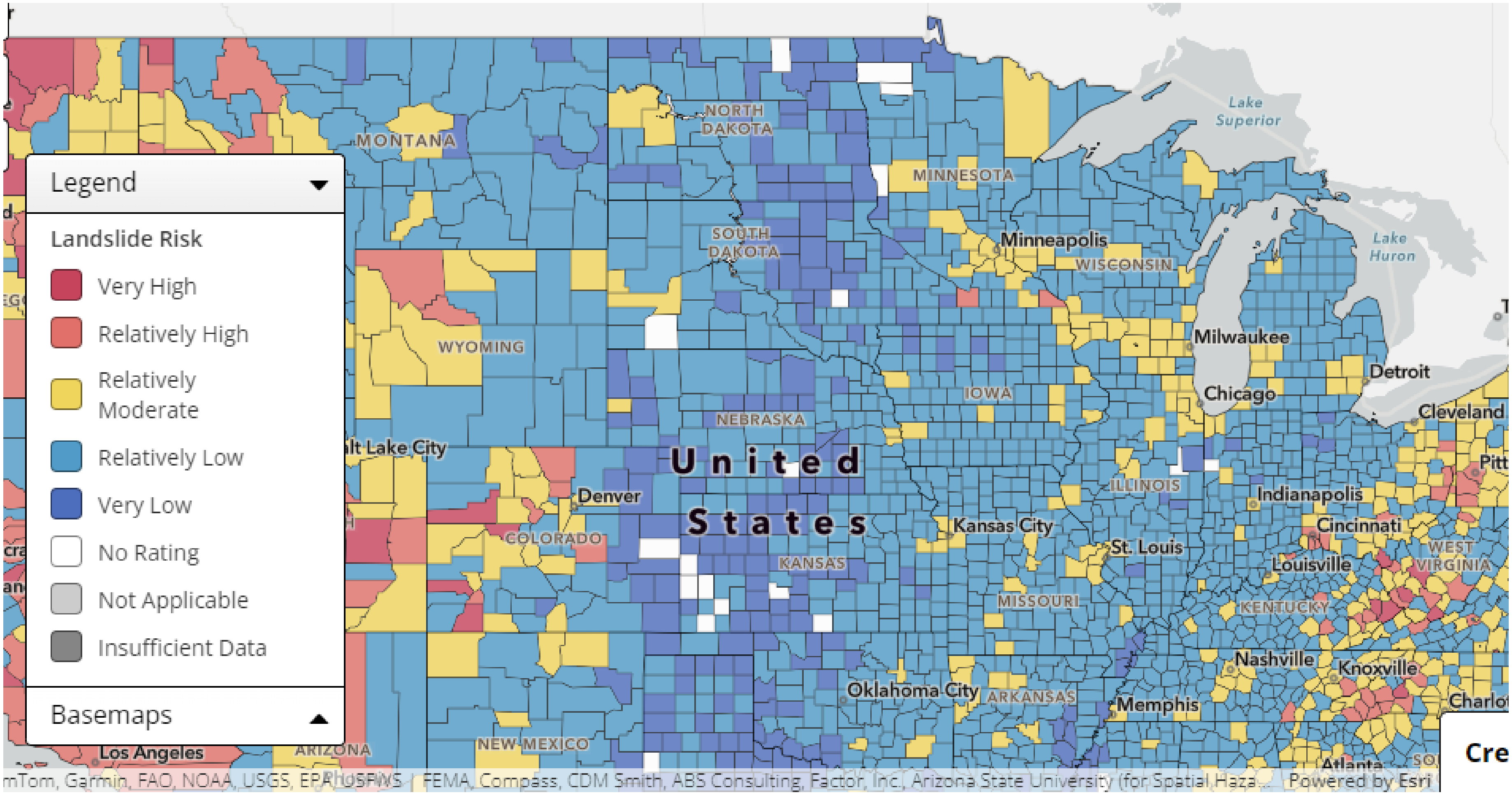

Figure 22: National Risk Index for landslide risk (Source: FEMA)

For landslide risk, a higher NRI is observed in eastern Ohio and eastern Kentucky due to the steeper terrain of the Appalachian Mountains. A higher NRI is also seen in south central Minnesota and southern Wisconsin. These regions, while not associated with mountainous terrain, are susceptible to landslides due to a combination of geological factors such as the presence of loose soil and rainfalls, along with steep hillsides along river valleys.

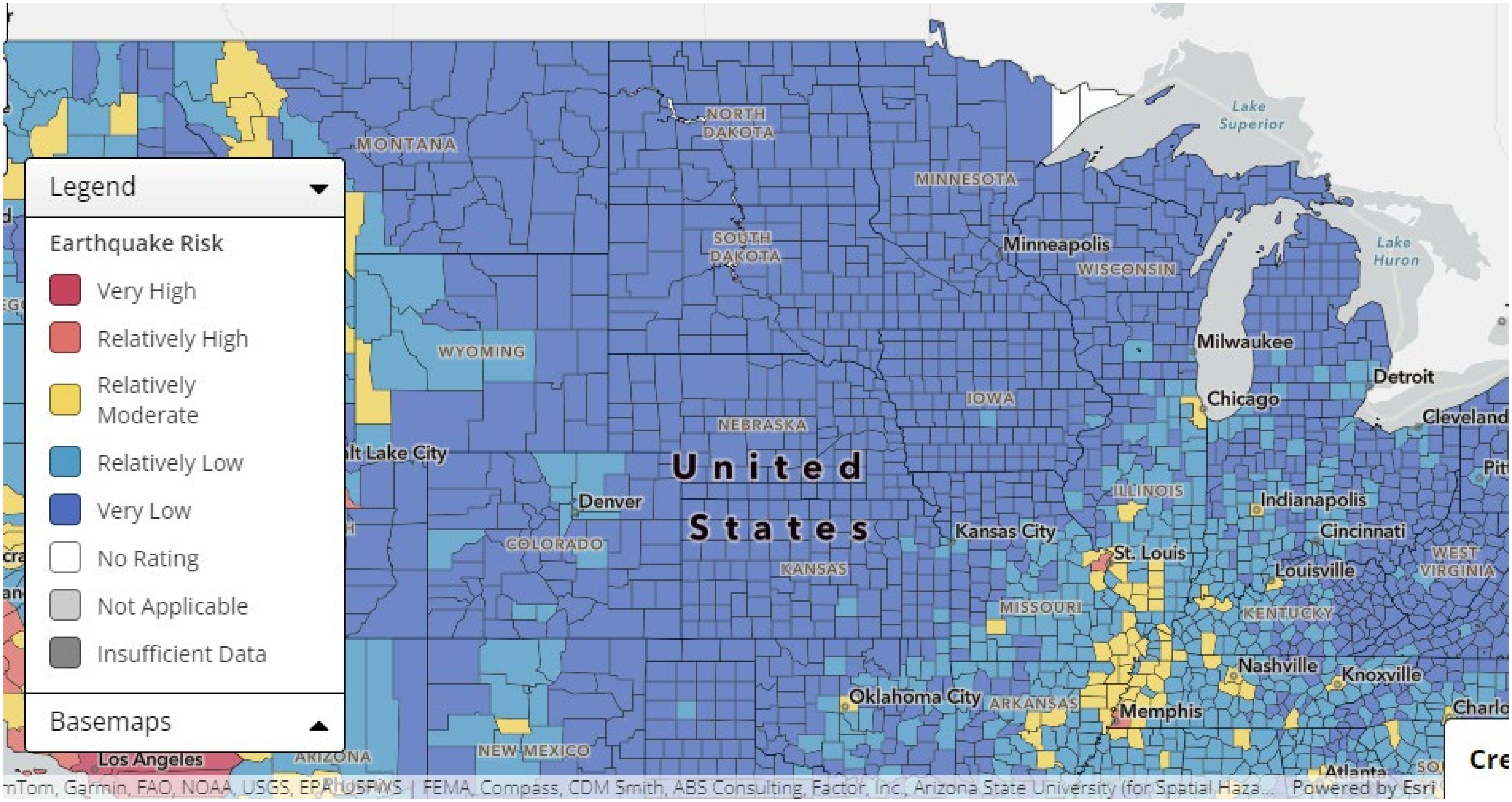

Figure 23: National Risk Index for Earthquake risk (Source: FEMA)

The NRI for earthquakes is relatively low for most of the MAASTO region apart from SE Missouri, southern Illinois, western Kentucky, and St. Louis due to the New Madrid Fault.

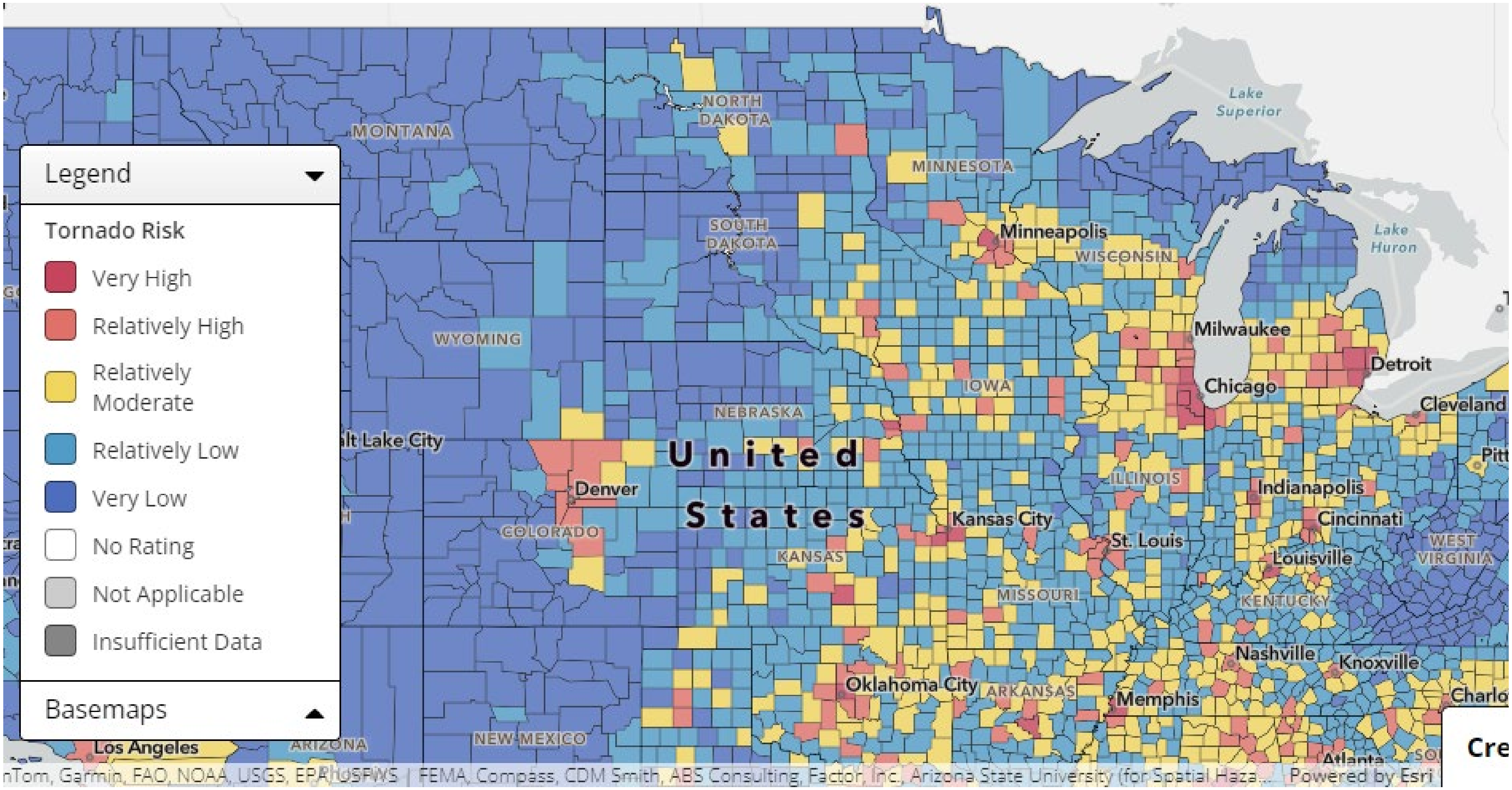

Figure 24: National Risk Index for Tornado risk (Source: FEMA)

With most of the MAASTO region being vulnerable to tornadoes, the tornado risk NRI expectedly runs high across the region near major urban areas with higher population density (such as Chicago, Detroit, Kansas City, St Louis, Indianapolis, Cincinnati and Minneapolis).

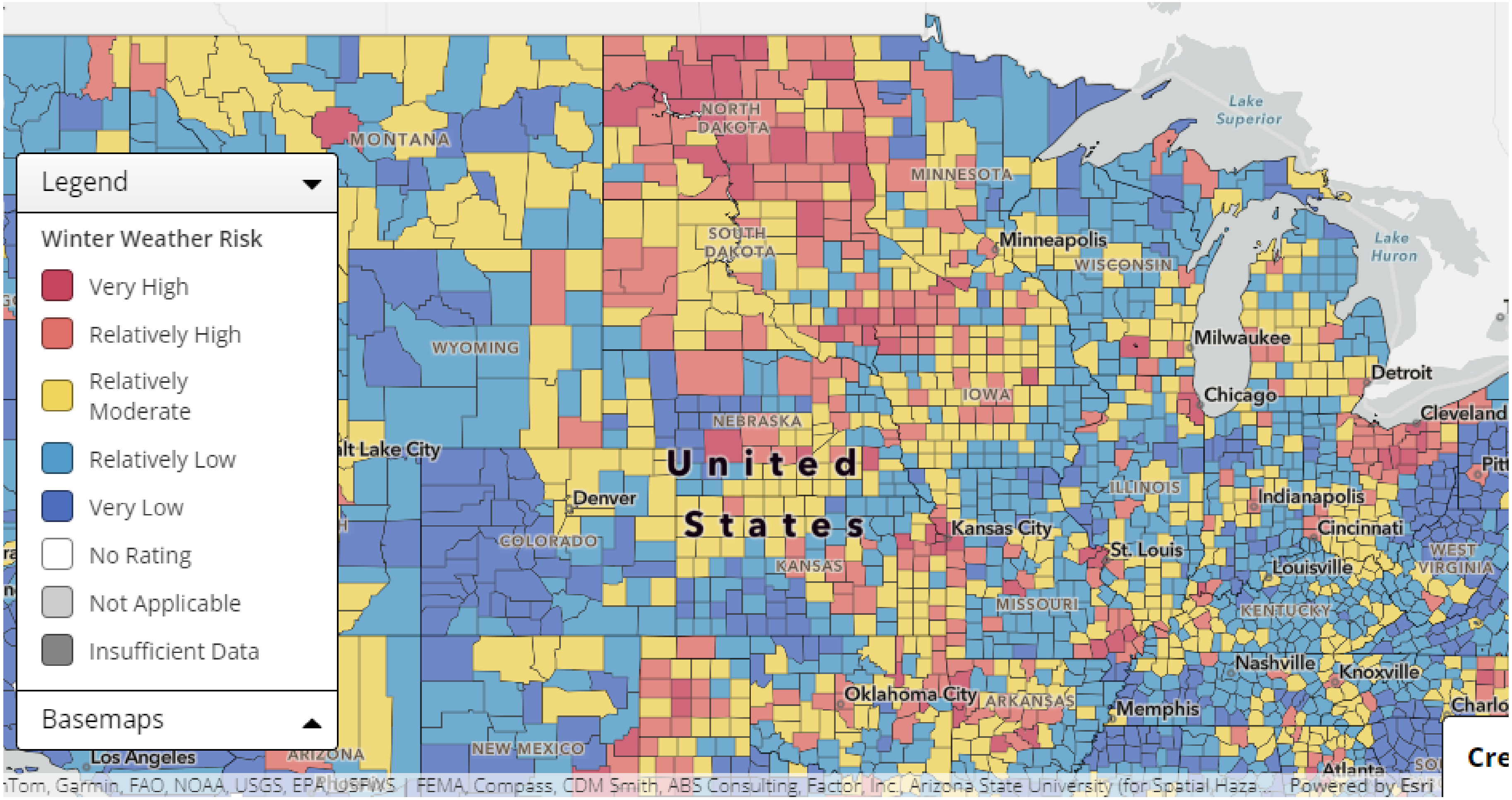

Figure 25: National Risk Index for Severe Winter Weather risk (Source: FEMA)

As can be expected, most of the MAASTO region is also succeptible to severe winter weather conditions and thus registers high NRI for severe winter weather. The northern part of the region has moderate to high NRI throughout the region with the exception of very sparsely populated areas. With the southern states, the risk is moderate-high through most urbanized regions.

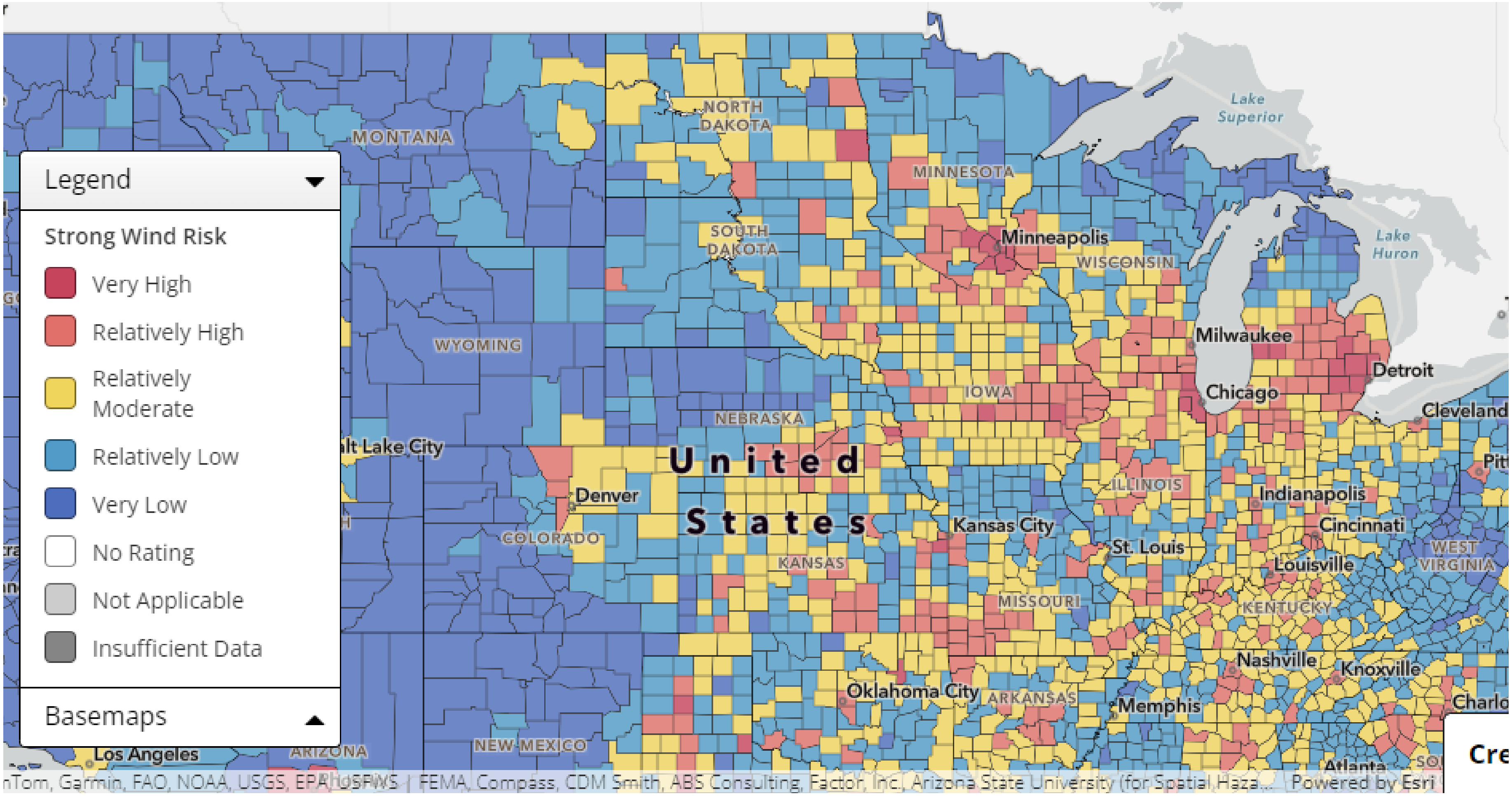

Figure 26: National Risk Index for Strong Wind risk (Source: FEMA)

The NRI for strong winds in the region is relatively high, being highest near Detroit, Chicago, and Minneapolis, but remaining moderate or above throughout most of the region. Eastern parts of Ohio and Kentucky, and northern parts of Missouri, Wisconsin, Michigan, and Minnesota are the only regions with low NRI for strong winds with the latter being low due to low population density.

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